FINAL REPORT

ENVIRONMENTAL RESOURCES MANAGEMENT STUDIES OF THE KISSIMMEE RIVER BASIN

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ABSTRACT

Environmental Resources Management Studies of the Kissimmee River Basin

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The 2,300 square mile Kissimmee River Basin (KRB) in central Florida is undergoing pressure for rapid expansion due to both urbanization and agricultural activities. The Central and Southern Florida Flood Control District (FCD) and other regulatory agencies are faced with the need for management decisions from the standpoint of environmental control as well as flood control and water use. The river is also the major tributary to Lake Okeechobee; hence, basin activities affect the integrity of this vital resource for South Florida.

This study first describes the transition of the KRB from a status typified by natural vegetation with low intensity agriculture to one increasingly characterized by intensive agriculture and urbanization with associated water quantity and quality problems caused primarily by drainage practices. The ramifications of channelization of the lower Kissimmee River (Canal C-38) and other flood control and water management projects of the 1960's are discussed.

Management alternatives are considered in three phases: (1) land use analysis, (2) hydrologic and water quality analysis, and (3) analysis of storage/treatment capabilities of natural systems. The land use analysis utilizes a linear programming model for apportionment of land among different uses and over different soil types on the basis of agricultural demands, costs and constraints. A

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runoff constraint is also provided. Reliance is placed on Soil Conservation Service (SCS) and other USDA sources for projections and production data. Results are presented for possible 1980 and 2020 conditions, although these are recognized simply as possibilities. Present (1972) and 1958 land use apportionment is also presented.

Hydrologic analysis for the lower basin is performed by generation of surface and subsurface runoff in the model HLAND, which is then coupled to a Muskingum routing model for the Kissimmee River. HLAND generates runoff from the depressional watersheds characteristic of the KRB via the technique of Thornthwaite and Mather, modified to produce base flow as well. Verification of the model is illustrated and direct correlation with drainage density is shown. Natural and present drainage densities for the lower KRB are about 1.6 and 5.1 miles/square mile, respectively. Details of drainage density measurements are given.

Water quality, as illustrated by concentrations of total phosphorus, is shown to decrease as drainage density increases. Increased surface loadings due to fertilization and cattle are also a factor.

Lakes, swamps, marshes and reservoirs act as storage/treatment devices because of attenuation of both flood peaks and pollutant concentrations. The latter effect may be characterized through the detention time, T, during which uptake of pollutants may occur via biological, chemical or physical processes. The magnitude of this effect is illustrated in a detailed simulation of flow and quality attenuation through Chandler Slough in the lower basin. Significant peak flow attenuation is accomplished when at least 15 percent of the surface area remains as lakes or marshes. The percent of treatment of runoff decreases with increasing drainage area/treatment area rates. Upper basin lakes illustrate the same pollutant concentration reduction as flow travels through them. A detailed examination of Lake Tohopekaliga is presented in which the importance of maintaining the natural hydroperiod (stage fluctuations) is emphasized.

Detention times for surface and subsurface runoff are derived for the lower basin in connection with analysis of the effects of C-38. The most significant reduction in these times appears to be caused by upland drainage, since average travel times in C-38 are not reduced from the pre-channelized condition.

Management for environmental quality focuses upon maintaining high proportions of subsurface flow, high detention times and natural hydroperiod, and upon utilization of natural marshes and swamps for water quantity and quality control. A logical area for first application of such strategies is in the lower basin south of structure S65-C since this area is intensively drained and shows high pollutant loadings.

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This study was financed by the Central and Southern Florida Flood Control District. The close cooperation of professional personnel from the FCD was of vital importance to its successful completion. Professor Barry Baldwin of the Department of Agricultural Engineering at the University of Florida provided much insight into problems associated with agricultural activities. The efforts of Mr. Steve Gatewood and Mr. Ron Fuller, formerly of the University of Florida, were significant in measurement of drainage densities, land use analysis and figure preparation.

The first draft of this publication was produced in July 1975. Reviews by personnel from the FCD, Department of Administration, Department of Environmental Regulation and Corps of Engineers were invaluable in reducing errors and encouraging adequate explanations of the work performed. The content of this final draft is, of course, the responsibility of the writers alone.

I. INTRODUCTION

The competition for water among various users has reached new levels as growth rates continue to accelerate. Agricultural and urban demands for increased water use have far-reaching effects from economic, social, and environmental standpoints. The problem of determining an acceptable distribution of water quantity for all competing users is difficult in itself, but add to that the immense complexity of maintaining high levels of water quality at the same time, and the problems seem insurmountable.

Environmental resource planners are being asked to solve these very problems in a way that maintains economic productivity along with environmental quality. In addition, solutions should not favor any one group at the expense of another. There is hope that waste treatment and recycling will allow users of water, e.g., municipal, industrial, agricultural, recreational, and ecological, to exist harmoniously within the same region. The reality of the trade-offs which exist between continued economic productivity and environmental quality should indicate to what extent harmonious conditions are possible. There is no doubt that sacrifices will have to be made in one or both of these goals.

The problem to be investigated here revolves around the question of balancing agricultural and urban expansion with environmental quality, measured as hydrologic and water quality responses in a river basin. It is therefore necessary to define parameters which describe past, present, and projected rates of expansion. Measured changes in land use and drainage patterns in a river basin provide a useful starting point for estimating the impact of alternative future levels of development.

The prediction of associated hydrologic and water quality responses which exist under present land use regimes, and which may result under some future condition presents a more complex problem. Such cause-effect relationships are only now being addressed by environmental resource planners. It is first necessary to define indices of environmental quality which can be measured or predicted. Secondly, the environmental responses must be related to land use and drainage patterns so that a variety of interactions can be evaluated. Finally, the question of controls or constraints on these indices must be addressed so that trade-offs between economic expansion and environmental quality can be quantified. The above concepts are introduced here and extended and quantified in later sections.

During the past two years, intensive studies by several agencies, university groups, and consultants have been underway to examine problems associated with Lake Okeechobee and its drainage basin which includes the Kissimmee River Basin. This report deals with a water resources investigation of the Kissimmee River Basin. Included in this analysis is an evaluation of the extent to which the channelization of the lower Kissimmee River has caused water quality problems in Lake Okeechobee. The remainder of this report summarizes the findings.

II. ENVIRONMENTAL RESOURCES IN THE KISSIMMEE RIVER BASIN

DESCRIPTION OF THE BASIN

Introduction

The Kissimmee River Basin is located in the central portion of peninsular Florida between the Peace River Basin to the west and the St. Johns River Basin to the east. The river originates near Orlando and passes through a series of shallow lakes in the upper reaches before emerging south of Lake Kissimmee as a channelized (early 1960's) river. It then flows south to Lake Okeechobee through a relatively narrow flood plain (see Figure 2.1).

The basin can be conveniently divided at the outlet of Lake Kissimmee into upper and lower sections. The upper lake system includes 881,000 acres of land and 130,400 acres of surface water while the lower river system includes 472,900 acres of land and 1,900 acres of surface water.

Parts of seven counties are within the boundaries of the basin as shown in Figure 2.1. The area has been partitioned into 18 sub-areas based on the Soil Conservation Service divisions. Planning units in the upper basin are designated as lake units and those in the lower basin as river units. Much of the following discussion is summarized from a report on the Kissimmee-Everglades area by the Soil Conservation Service (1973).

Climate and Rainfall

The climate of the basin is subtropical with a mean annual temperature of 72.5 degrees at Orlando. The temperature is fairly uniform over the basin during the summer months, while many winters pass without the frost or freezing temperatures. The average growing season, or period between killing frosts, varies from 300 days around Orlando to 365 days south of Lake Okeechobee.

Rainfall over the basin varies seasonally and by location, although the area has a fairly uniform average annual rainfall of approximately 52 inches with over 60 percent falling between June and October. The distribution of average monthly rainfall and temperature in the northern and southern part of the basin is shown in Figure 2.2.

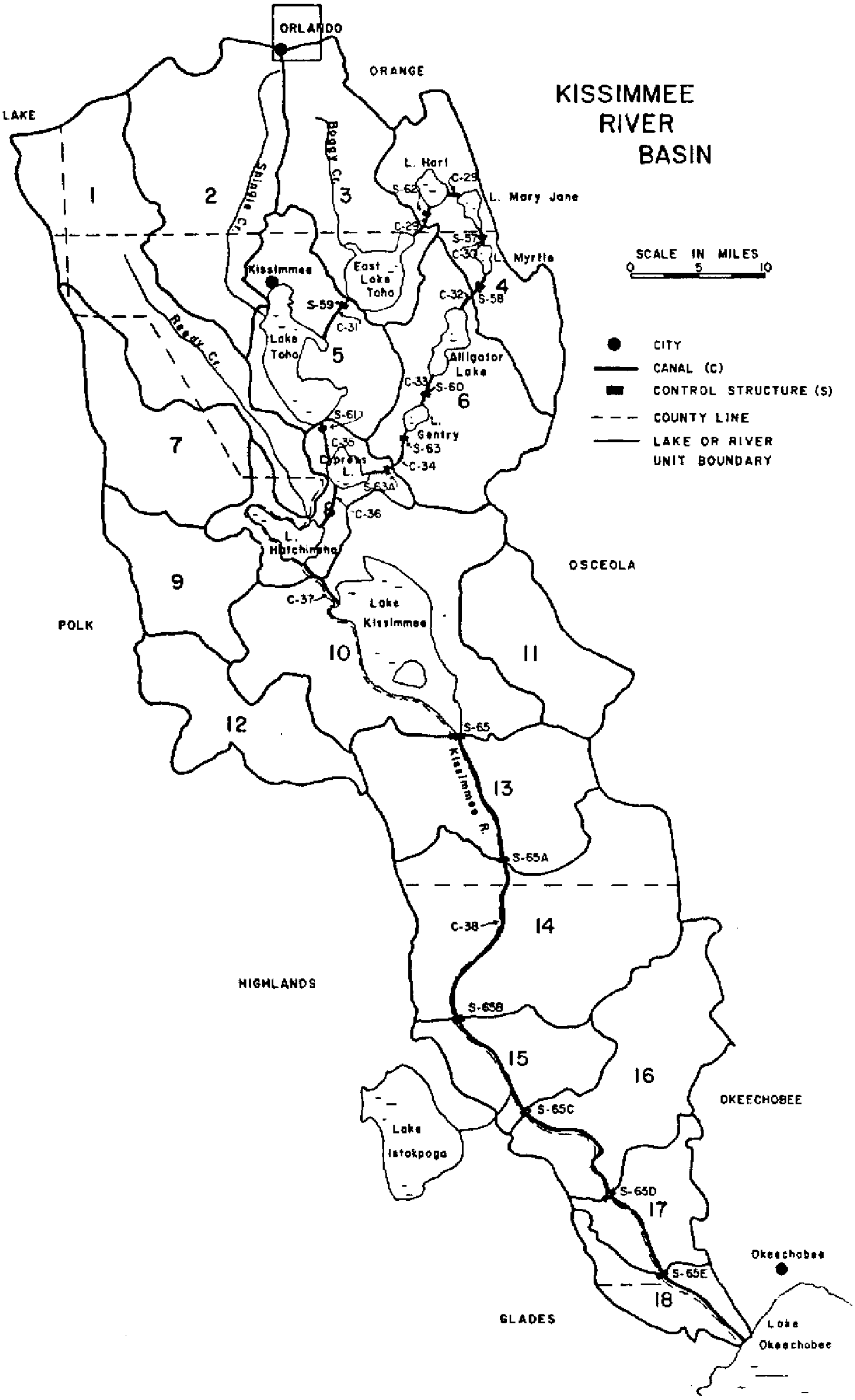

Figure 2.1. Location Map of the Kissimmee River Basin

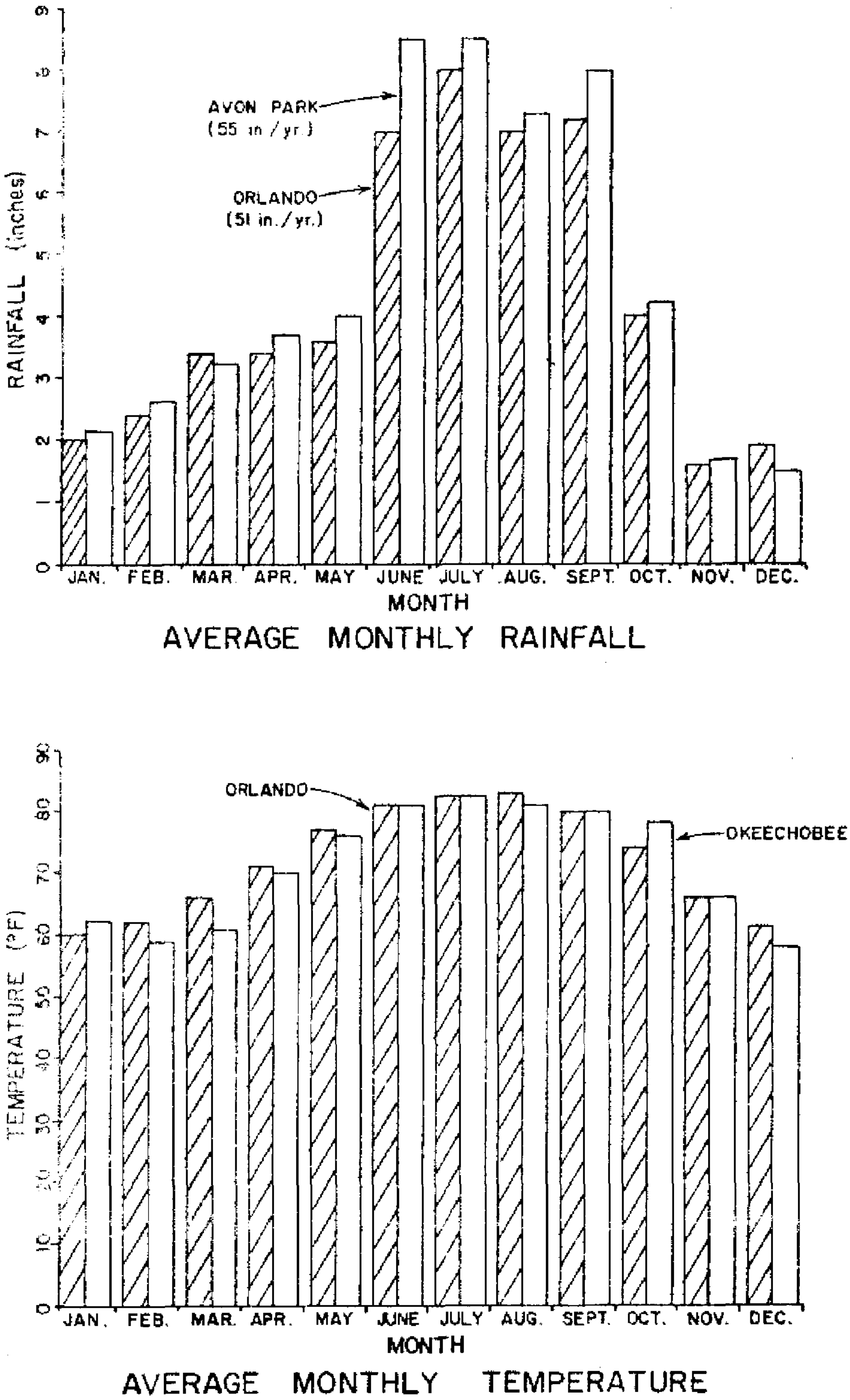

Figure 2.2. Monthly Rainfall and Temperature in the Kissimmee River Basin (SCS, 1973)

Physical Geography and Geology

The topography of the basin is dominated by the central ridge of rolling hills along the western edge with elevations exceeding 100 feet above mean sea level (Figure 2.3). Drainage is principally into the thick, sandy soils. The area east of the ridge consists of a large, flat, swampy, pine forest interspersed with many shallow lakes with elevations between 50 and 100 feet mean sea level. The lowest elevations in the basin occur along the Kissimmee River flood-plain marsh south to Lake Okeechobee. Numerous sloughs and small lakes drain the wet prairie adjacent to the narrow flood plain and ground water is near the surface over much of the area.

The geologic formations of the basin are entirely sedimentary. The uppermost stratum is the Ocala limestone which serves as the principal artesian aquifer for ground water in the basin. The Hawthorne formation is relatively impervious in most locations and forms a seal over the underlying limestone. The primary recharge area for the artesian Floridan aquifer is in Polk County, west of the Kissimmee River Basin.

A shallow aquifer system exists in the Pleistocene deposits in the basin within 100 feet of the surface. Recharge of nonartesian ground water is mostly from local rainfall. The groundwater table generally follows the topography of the land in flat areas, and may fluctuate up to five feet in elevation between wet and dry seasons of the year.

Water Resources

The Kissimmee River Basin contains vast quantities of fresh water available as ground water and as surface water in lakes and streams. The upper basin consists of many shallow lakes and several major streams draining both urban and agricultural areas. Reedy, Shingle, and Boggy are the more important creeks south of Orlando and Disney World (Figure 2.1). Recent studies indicate that Shingle Creek has the most severe water quality problems due to nutrient loading from several sewage treatment plants (Orange County, 1973).

The lakes of the upper basin provide more than 150 square miles of surface water area as shown in Table 2.1. Numerous smaller lakes scattered throughout the Kissimmee Valley provide additional storage capacity. Water quality problems are most noticeable in Lake Tohopekaliga which receives heavy nutrient loads from sewage plants in the area. A recent drawdown of the lake to improve fish and wild-life habitat and water quality resulted in partial success (Florida Game and Fresh Water Fish Commission, 1972). As one proceeds south through Lakes Cypress, Hatchineha, and Kissimmee, the quality of water generally improves.

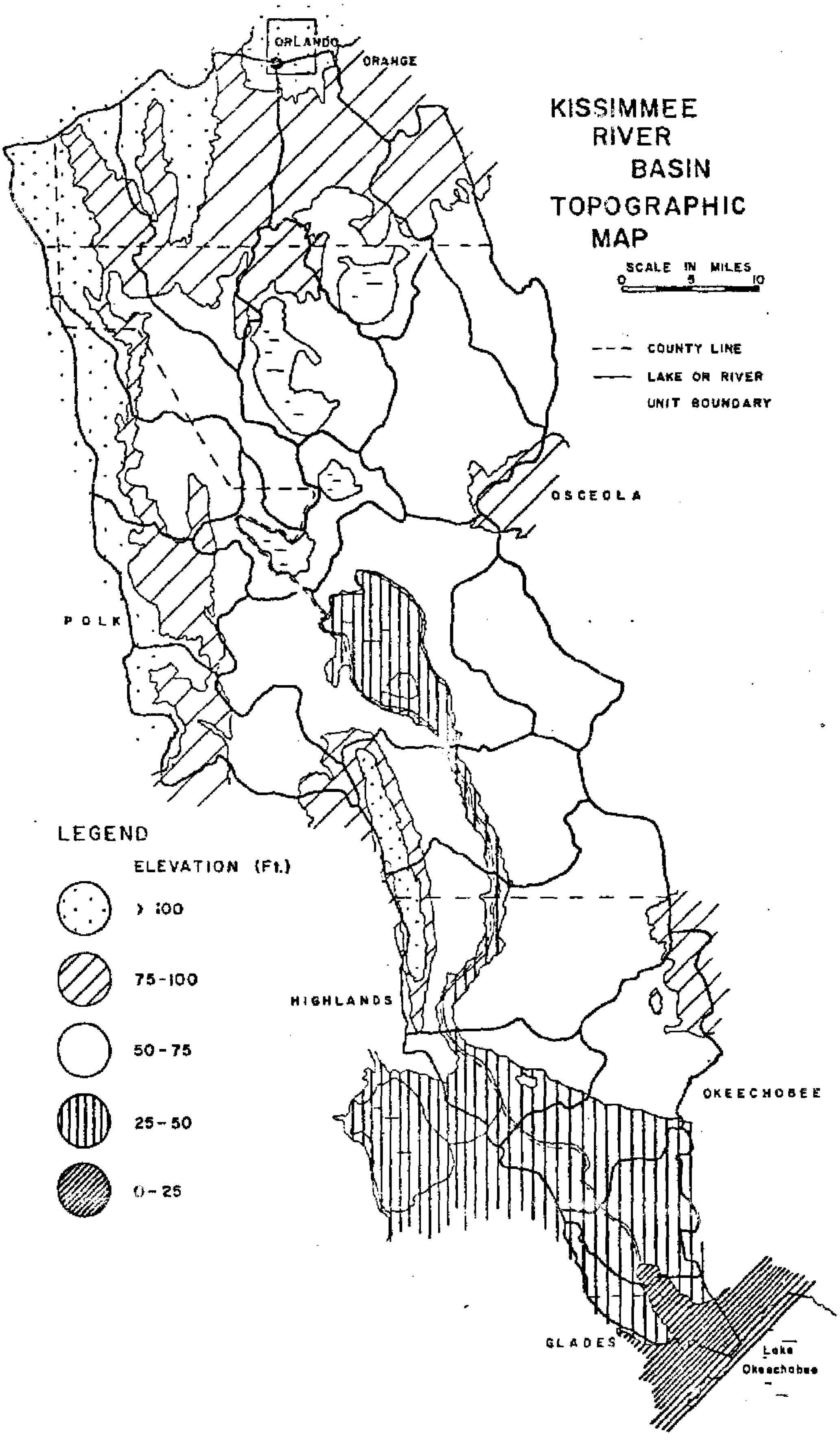

Figure 2.3. Topographic Map of the Kissimmee River Basin (SCS, 1973a)

Table 2.1. Surface Area of the Larger Lakes in Kissimmee-Everglades Area (SCS, 1973a)

Lake	Surface Area (sq mi)
Okeechobee	717
Kissimmee	47
Istokpoga	42
Tohopekaliga	26
East Tohopekaliga	16
Weohyakapka	11
Hatchineha	10

Table 2.2. Land by Capability Class in the Kissimmee River Basin

Water Problem Class (Land Capability Classes)	% of Basin	Area (1000 Acres)
1 (I, II, III)	8.9	132.7
2 (IV)	68.6	1024.7
3 (V, VI)	12.5	186.4
4 (VII, VIII)	10.0	149.2
Total	100.0	1493.0

The lower basin section of the Kissimmee River and adjacent drainage areas convey an average annual runoff of 10 inches to Lake Okeechobee. The average annual rainfall of 53 inches on Lake Okeechobee is approximately equal to the evaporation from the lake surface, and therefore most of the water supplied to the lakes comes from the Kissimmee River flow. The Kissimmee River drains mostly agricultural pasture, crops, citrus and natural slough systems. Water quality in the channelized river has become a serious problem in recent years based on extensive monitoring programs on the river as well as in Lake Okeechobee, which is considered to be in an early eutrophic condition (Joyner, 1971).

Lake Okeechobee, with over 700 square miles of surface area, is by far the largest lake in the region. It is regulated by control structures on outlet canals to maintain elevations between 15.5 and 17.5 feet (MSL). The stored water is used to irrigate farmland, supply the Everglades National Park with at least 315,000 acre-feet per year, and recharge the aquifers of Broward, Dade and Lee Counties for water supply purposes. The quality and quantity of water in Lake Okeechobee is thus an extremely important issue for all of South Florida.

Soils

The soils of the basin range from deep, excessively drained sandy soils on the ridges to very poorly drained swamp soils in the lowland areas. The general soils map (Figure 2.4) shows the distribution of five major groups of soils for the Kissimmee River Basin.

Detailed soil surveys have been completed by the Soil Conservation Service for Orange and Okeechobee Counties (SCS, 1960,1971), while the survey for Osceola County is nearing completion. These surveys provide a basis for estimating the location and extent of the most significant soil types within each lake or river planning unit for most portions of the basin.

Soils are grouped into larger units such as land capability classifications for various kinds of interpretations (SCS, 1961). This classification is based on the soil's capability to produce crops and pasture plants without long-term deterioration. Subclasses are groups of capability units within classes that have the same kinds of limitations for agricultural use such as erosion (e), wetness and poor drainage (w), and root-zone problems (s). The approximate amounts of land in terms of capability classes and subclasses in the basin are listed in Table 2.2.

Vegetation

Natural vegetation in the basin is directly related to climate and soils. The vegetation map in Figure 2.5 shows the distribution

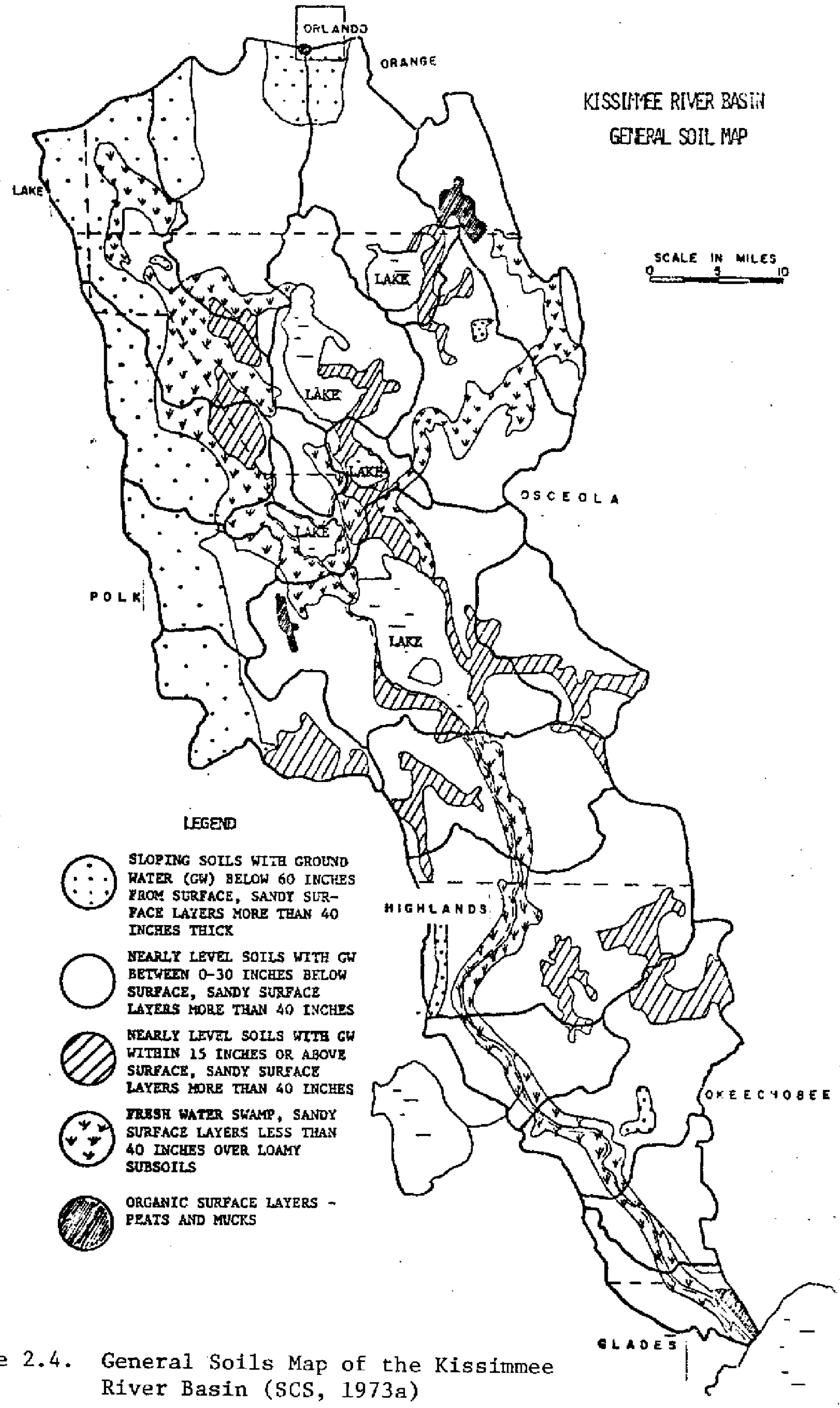

Figure 2.4. General Soils Map of the Kissimmee River Basin (SCS, 1973a)

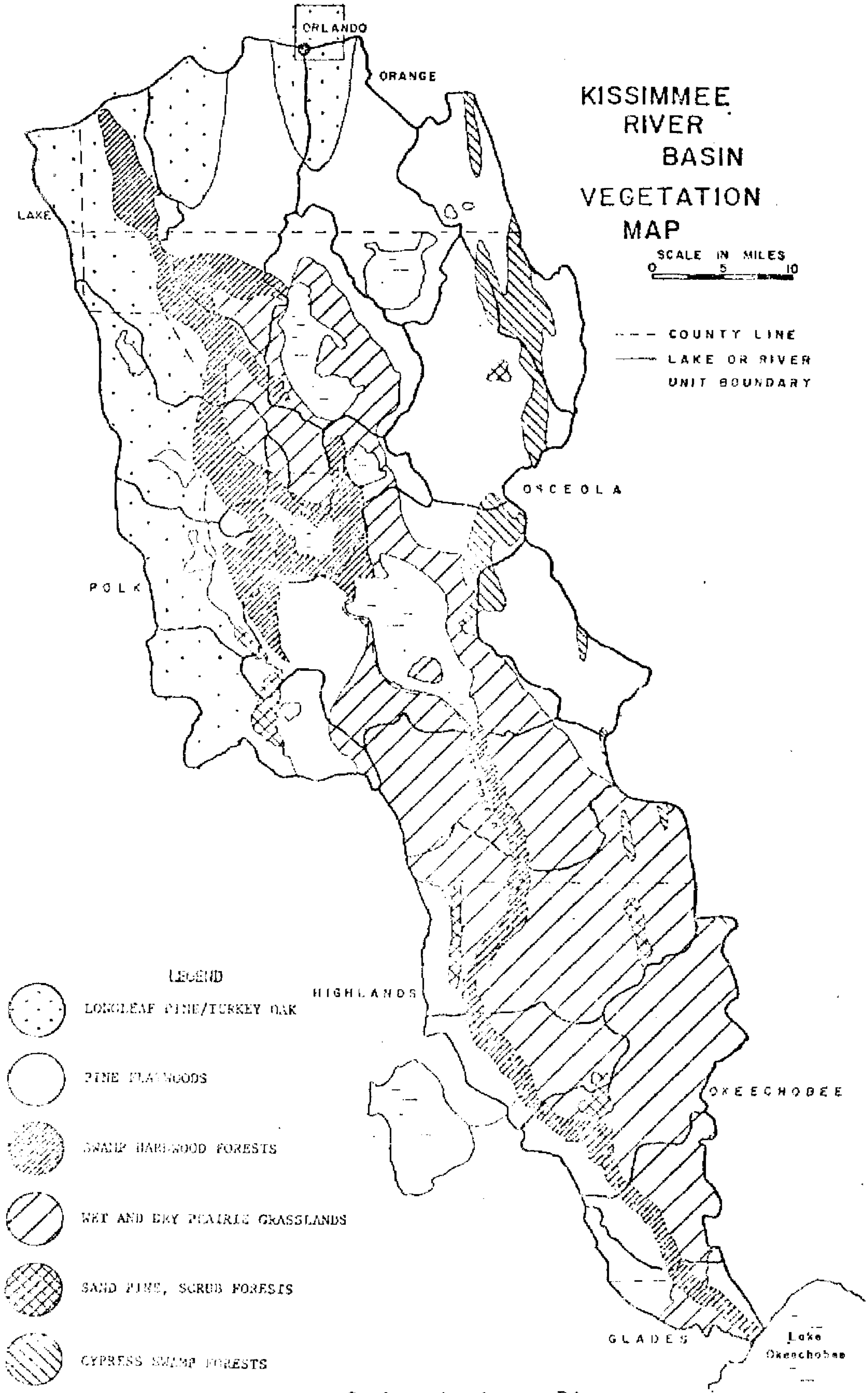

Figure 2.5. Vegetation Map of the Kissimmee River Basin (SCS, 1973a)

of various types throughout the basin. The central ridge is dominated by forests of longleaf pine, pinus palustris, and turkey oak, Quercus laevis, with wire grass as a common ground cover. Many former areas of this type have been converted to citrus groves.

The low, flat area east of the ridge and in the eastern parts of Orange and Osceola Counties is composed of the pine flatwood community. Open woodlands include one to three species of pine: longleaf, slash, or pond pines. Many herbs, saw palmetto, shrubs, and small trees from the understory, and small hardwood forests, cypress swamps, and wet prairies are interspersed in depressions or along drainage ways.

A wide band of wet prairie grassland dominates border regions of the large upper basin lakes and adjacent drainage areas along the Kissimmee flood plain. Swamp forests, mostly hardwoods, border streams in northwestern Osceola County and line the narrow strip along the Kissimmee River flood plain. Many former wet prairies have been drained and converted to improved pasture, especially along the river. Dry prairie grasslands exist throughout the basin.

Fish and Wildlife Resources

The lakes furnish some of the finest fishing in Florida, especially for large mouth bass, bluegill, black crappie and redear sunfish. Lake Kissimmee and the Kissimmee River are rather distantly removed from population areas and receive less fishing pressure than the upper lakes. The river is productive from the standpoint of a bass fishery (Florida GFWFC, 1957).

Waterfowl populations vary considerably from one lake to another and Lakes Kissimmee, Tohopekaliga, Cypress, Istokpoga, and Hatchineha winter the bulk of the waterfowl in the basin. Peak populations generally occur in January, and ringneck ducks tend to be the predominant species. A comparison of the waterfowl population with the magnitude of fluctuation of lake level from August to January indicates a significant correlation because shoreline vegetation must be inundated before it is available to waterfowl (Florida GFWFC, 1957).

WATER AND LAND RESOURCE PROBLEMS

Agricultural Land

Most of the soils of the Kissimmee River Basin have excess water hazards for agricultural or urban use. Some relatively wet soils are suitable for unimproved pasture or forest production, but require drainage for production of more intensive crops such as pasture, vegetables, or citrus. Most of the soils which are drained of excess water are used for improved pasture in the basin.

The natural surface removal rate of storm water is slow, and although inundation is shallow, flooding is characterized by long duration. Flooding causes damage to crops and improved pasture by affecting yields and creating delays in harvesting. Agricultural lands that suffer from flooding in the wet season of June to October are also affected by droughts during periods of low rainfall. Availability of water is one of the most pressing problems affecting agricultural productivity.

Soil erosion and sedimentation are of minor importance in the basin due to the extremely flat topography. Areas of organic peat and muck which are drained for agriculture are subject to subsidence at a rate of about one foot in ten years. Drainage allows the organic soil to oxidize in an aerobic environment, and at present oxidation rates, the organic soils south of Lake Okeechobee are expected to be used up by 2020. This will present a problem because the area supplies a major share of the nation's fresh vegetables during the winter months, as well as sugarcane and beef cattle (SCS, 1973 a).

Urban Land

The problems associated with the use of land for urban purposes generally result from the same conditions which contribute to agricultural problems. Periods of heavy rainfall on flat, poorly drained urban areas cause flood damages. But many of the residential areas are poorly planned, with inadequate provisions for drainage or flood proofing. Developments have been allowed to build in flood-prone areas with poorly drained soils.

Planned developments, which involve large tracts of land in the basin, also create problems because increased runoff rates from streets and paved areas cause additional flooding downstream of the development. Thus the problem of excess water is transferred offsite to a more vulnerable downstream user. On-site storage of excess runoff water appears to be one possible solution for the water problems inherently associated with rapid urban development.

Natural Land

Land in the basin includes forests, marshes, swamps, and grasslands which are generally uninfluenced by man's activities. In the past, marshes have been drained for improved pasture, and forests have been cut over for short-term returns. The present environmental consciousness has created a new awareness for the natural system, especially wetland areas with high biological productivity. Marsh and swamp systems are being studied intensively to determine their structure and function as water storage areas, waste treatment units, and fish and wildlife sanctuaries (Odum, 1971; EPA, 1973a; Shih and Hallett, 1974).

Competition for available natural land among urban, agricultural, and preservation interests is the key environmental problem in the Kissimmee River Basin. The ultimate balance which is achieved among these three interests will determine to a large extent future levels of water availability, water quality, flood damages, economic productivity, and a host of other related parameters.

Water Availability

Large quantities of surface and subsurface water are located in the basin, but rapidly increasing demands by agricultural, municipal, recreational, and industrial uses may create problems in the future.

South of Lake Okeechobee the chloride and sulfate concentrations in the deep Floridan aquifer are too high for most uses. These concentrations are a result of salt water remaining in areas which were formerly inundated by the ocean. The Floridan aquifer is of high enough quality for municipal and agricultural uses in the Kissimmee River Basin.

Numerous lakes in the upper basin provide large amounts of surface storage. Lake Okeechobee and Lake Istokpoga are the major sources of surface water used by agriculture. Lake Okeechobee is also utilized to meet the needs of the Everglades National Park and to recharge shallow aquifers on the east and west coasts. In very dry years, the demand for the lake water exceeds the supply, and as urban areas continue to expand along the coast, the problem of water allocation will become more acute.

The majority of water used for irrigation in 1968 came from subsurface sources in the Kissimmee River Basin, while south of Lake Okeechobee most of the supply was from surface storage. According to Soil Conservation Service projections, irrigation water requirements are expected to increase along with agricultural expansion, especially in the Kissimmee Basin (SCS, 1973a). Table 2.3 presents the projected irrigation requirements by county in the Kissimmee-Everglades area for 1968, 1980, and 2020. According to the SCS, organic soils south of Lake Okeechobee will be depleted to the point where farming operations are no longer feasible by 2020, and the Kissimmee Basin is projected to increase agricultural productivity to make up the difference. Irrigation requirements for Glades, Highlands, Okeechobee, Osceola and Polk Counties register large increases between 1980 and 2020 as shown in Table 2.3. Other counties south of Lake Okeechobee will undergo decreases in irrigation use as the organic soils are depleted.

The allocation of available water resources among competing users depends to a large extent on the land-use changes which are projected

Table 2.3. Acres Irrigated - Kissimmee-Everglades Area - 1968, 1980, 2020 (1000 Acres) (SCS, 1973a)

County	1968			1980			2020		
	Crops	Pasture	Total	Crops	Pasture	Total	Crops	Pasture	Total
Broward	24.4	31.2	55.6	19.9	22.3	42.2	6.1	2.9	9.0
Charlotte[a]	4.4	4.5	8.9	9.0	7.7	16.7	6.3	17.9	24.2
Collier	21.4	4.8	26.2	22.4	7.0	29.4	25.0	65.5	90.5
Dade	41.4	6.3	47.7	49.1	5.9	55.0	31.9	0.7	32.6
Glades	13.6	33.2	46.8	20.0	42.9	62.9	95.3	90.8	186.1
Hendry	53.6	45.4	99.0	59.3	70.4	129.7	207.3	130.1	337.4
Highlands[a]	37.5	26.7	64.2	51.0	42.0	93.0	146.3	69.3	215.6
Lake[a]	3.5	----	3.5	4.5	----	4.5	5.1	0.2	5.3
Lee	17.6	5.8	23.4	18.2	8.1	26.3		----	
Martin	47.0	19.7	66.7	53.4	27.1	80.5	103.3	52.8	156.1
Okeechobee[a]	3.1	14.8	17.9	3.4	21.2	24.6	60.0	53.2	113.2
Orange[a]	10.7	0.1	10.8	15.3	1.4	16.7	2.5	0.8	3.3
Osceola[a]	13.2	2.1	15.3	18.3	6.5	24.8	34.1	37.9	72.0
Palm Beach	298.2	127.3	425.5	345.2	138.3	483.5	102.8	82.0	184.8
Polk[a]	40.2	1.5	41.7	51.7	2.8	54.5	57.9	14.5	72.4
St. Lucie[a]	52.3	9.4	61.7	59.4	18.5	77.9	90.7	38.8	129.5
Total	682.1	332.8	1014.9	800.1	422.1	1222.2	974.6	657.4	1632.0

[a]Partial county.

to occur in the basin. Subsidence of the organic soils and the shift of agricultural activity to mineral soils of lower productivity requires increased acreages to attain projected levels of production.

By assuming that agricultural productivity will meet projected levels for the whole Kissimmee-Okeechobee area, the Kissimmee River Basin will come under increasing developmental pressure from agricultural interests. Irrigation, drainage, flood control, and production needs will compete with the needs of other users. Municipal, recreational, and preservation interests also require a share of the available water resources. An equitable arrangement among competing users will certainly include a longer term objective than simply maximization of economic productivity. Other considerations, such as the influence of land use changes on runoff, downstream flooding, and water quality, should be included in the overall evaluation as will be discussed in subsequent chapters.

Flood Control Plan

In October of 1956 the Corps of Engineers (COE) released a general design memorandum (COE, 1956) on the Kissimmee River Basin. It cited the need for flood control and water conservation in the basin. Due to prolonged seasonal rainfalls, inadequate secondary drainage canals, and limited outlet capacity, large areas of the watershed were periodically flooded. Tropical hurricanes, which usually occur during the rainy season, also served to intensify the problems. Extensive and costly flooding occurred numerous times before the publication of the GDM, e.g., years 1945, 1947, 1948, 1951, and 1953, and the expanding agricultural economy in central Florida indicated that the flood damages would only increase in the future.

An overall plan proposed for flood control and water conservation in central and southern Florida was to be maintained by the Central and Southern Florida Flood Control District (FCD). This area comprises about 15,000 square miles and extends from Orlando to the Everglades National Park. The plan provided for channelization and control structures on the Kissimmee River and below the larger upper basin lakes. These lakes included Mary Jane, Preston, Alligator, Gentry, East Tohopekaliga, Tohopekaliga, Hatchineha, and Kissimmee. These works were to provide flood water storage to reduce the rates of runoff to the Kissimmee River as well as to conserve flood waters and maintain a favorable groundwater table for water supply during the periods of deficient rainfall.

The system of canals and control structures was to perform the following functions:

1. Remove a 10-year flood runoff from the lower basin watershed area.

2. Provide sufficient regulation capacity for the lakes in the middle and upper basin to limit the rise in lake stage during the 10-year flood to two feet or less.

3. Provide sufficient regulation capacity for Lake Kissimmee to prevent maximum stages resulting from occurrence of the standard project storm from exceeding those stages that could be expected under existing conditions.

4. Provide capacity in the Kissimmee River for the 10-year flood discharge from Lake Istokpoga.

5. Provide water control for the basin to maintain the lakes at desirable elevations, approximating the present mean stages.

6. Provide for navigation of the Kissimmee River and all lakes in the upper Kissimmee River Basin. Locks were to be provided at each control structure on the main waterway between East Lake Tohopekaliga and Lake Okeechobee.

7. Maintain levels in the lakes of the upper Kissimmee River Basin in consideration of recreational and fish and wildlife interests.

There would be a total of 11 canals, 16 water-control structures, 3 locks and 12 boat lifts. Secondary drainage structures were planned at all inflow points. Excavated material would form spoil banks along the canal. Six structures, designated S-65, 65A, 65B, 65C, 65D, and 65E, were to be constructed in the Kissimmee River for water control and regulation (see Figure 2.1). Tieback levees would prevent flow from bypassing structures during floods greater than the design flood.

The Florida Game and Fresh Water Fish Commission (GFC) agreed that the above plan would meet the flood control, water control, and navigation requirements of the entire area under consideration. The GFC felt, however, that the plan would not provide optimal conditions for fish and wildlife. It therefore released a recommended program for the Kissimmee River Basin which would provide for fish and wildlife interests (Florida GFWFC, 1957).

The GFC first presented a biological report on the basin. This was followed with an economic study of the value of fish and wildlife in the basin. The COE plan would result in minimum fluctuation in lakes in the Kissimmee River Basin, when compared to the natural seasonal fluctuation of up to 10 feet. Fish and wildlife benefits are increased by seasonal fluctuations according to the GFC and they indicated that fluctuations of about 4 feet would be satisfactory to fish and wildlife interests.

The GFC also conducted a study of the upper basin lakes to determine the effects of lake fluctuation and flood duration on the waterfowl in the area. The duration is a primary factor in determining the location and abundance of various species of submerged vegetation which serve as food for the waterfowl. It was estimated that the waterfowl populations could be reduced by as much as 75 percent if the seasonal lake fluctuations did not occur. Thus variable lake levels were provided for in the COE plan. Although the GFC felt that the magnitude of fluctuation was adequate to maintain waterfowl values, they believed that the regulation schedule was not ideal for many of the vegetative species upon which waterfowl are dependent.

The GFC also expressed a similar interest in lake fluctuation for the fish resource. In conjunction with fishing and other forms of water recreation, the Commission indicated a need for flexibility in the operation of the locks along the canal or even self-service of the lifts by the public. They recommended that the natural channel and oxbows in the Kissimmee River be left open rather than sealed off as these waters are very productive for fish populations.

The flood control plan proposed by the COE, and somewhat amended by the GFC, was adopted and implemented in the early 1960's. The plan transformed the upper lakes into controlled reservoirs, and turned the Kissimmee flood plain into a channelized floodway governed by six control structures. With the coming of flood control to the upper lakes and lower basin, it was possible to transform flood plain marsh and nature range into improved pasture through drainage activities.

Environmental Concerns

After completion of the channelization project on the Kissimmee River Basin, objections were raised by ecologists and conservation groups over the destruction of a unique natural meandering river and its rich marshes, and the decline of fish and waterfowl resources. Concern over degrading water quality and the ultimate effect on eutrophication of Lake Okeechobee was also expressed. As a result, a report was presented to the Florida cabinet in 1972 by Marshall et al. The report recommended that a Water Quality Master be appointed by the Governor in order to coordinate efforts to restore water quality in the basin.

OVERVIEW OF MANAGEMENT STUDY

Traditional approaches to river basin studies have placed little emphasis on linkage mechanisms which relate land use and drainage conditions to resulting hydrologic and water quality responses in the watershed. Environmental indices which serve as useful measures of quality include the volume of surface runoff and streamflow, and associated nutrient concentrations or loadings which stimulate aquatic plant growth. Alterations in land use, drainage practices, and structural configurations can have significant impacts on these hydrologic and water quality measures.

The main objective of this research is to describe and quantify various hydrologic-land use interactions which occur within the Kissimmee River Basin. This requires that a technique be devised to characterize surface runoff quantity and quality as a function of land use and drainage patterns. Influences of soil storage, vegetative cover, drainage intensity, land use, topography, and climate must be directly considered because they all affect hydrologic and water quality responses.

It is important to consider these interactions at several levels of detail in order to better understand the overall response of the watershed. Levels of resolution which are investigated include the river basin, tributary systems (planning units), lake units, and marsh areas. Analyzing these different components allows quantification of source areas of runoff and nutrients as well as associated transport mechanisms through the system.

The Kissimmee River Basin in central Florida is undergoing pressure for rapid expansion. Chapter II describes the environmental resources in the basin, along with observed land use changes and water quality responses. For convenience, the basin is divided into subwatersheds or planning units. The upper portion of the basin consists of a chain of large lakes undergoing rapid urbanization. The lower basin is undergoing transition from its natural state as a marsh and slough system to a regime dominated by improved pasture with drainage canals. In addition, a flood control project exists throughout the basin in the form of control structures, canals, and channelization of the main river. Water quality degradation in the form of high nutrient loading in one of the upper lakes and along the river channel has been increasing over the last two decades. There is concern for protecting water quality, since the Kissimmee River is the main inflow tributary to Lake Okeechobee, which provides water supply to all of south Florida and the Everglades.

Chapter III describes the results of the land use analysis. Data on historical and present land use patterns are presented. The critical question of projected land use is examined using a linear programming model which provides an automated procedure for projecting alternative future land uses depending on the assumed conditions. These projections are meant to indicate what future land use conditions in the Kissimmee River Basin could be; they are not intended to be taken as a prescription of what type of growth should take place in the basin. The results from the land use analysis provide input to the hydrologic studies presented in Chapter IV.

Because the hydrologic response of the drainage basin is the controlling link for land use and water quality considerations, a hydrologic modeling technique has been developed which directly incorporates land use changes and drainage practices. The model is based on determining a water balance for each soil-land use complex within each planning unit, thus providing an estimate of storage effects in the basin. Hydrologic output from the model includes surface and subsurface runoff volumes on a daily basis which are then routed through the river system to Lake Okeechobee. The output is a function of rainfall distribution and land use patterns within each planning unit. Both historical and predicted future land uses can be simulated. These results are described in the first part of Chapter IV.

While the hydrologic model estimates source areas which contribute runoff volumes, non-point sources of nutrients are primarily a function of land use, with agricultural lands contributing the highest loads due to fertilization or cattle density. Water quality degradation, primarily due to nutrient loading in the Kissimmee River Basin, has been monitored both in the upper lakes and in the lower river and tributaries. In this section of Chapter IV potentional nutrient loading rates are calculated for lower basin planning units using measured concentrations of total phosphorus and predicted runoff volumes.

Detailed analyses of land use and drainage patterns along the lower river system indicate the importance of the drainage density index, defined as the total length of waterways divided by the associated watershed area. Drainage density provides a useful general indicator of land use intensity, runoff volumes, and nutrient concentrations associated with the various tributaries in the Kissimmee River Basin. Drainage density is directly related to the average length of overland flow, soil moisture storage capacity, surface runoff volumes via canals, and detention times. In this respect, the index serves as an indicator of transport of runoff and nutrients for a particular land use type or for an entire planning unit. The results are presented in the last part of Chapter IV.

Characteristics of the hydrologic and nutrient cycles in the Kissimmee River Basin provide a valuable conceptual framework for understanding the overall system dynamics. Each of these cycles is distinguished by a set of specific inflows, outflows, storages, and other losses which determine the response of a particular component of the system, e.g., soil, marsh, pasture, stream, lake or planning unit. Thus, if a group of characteristic storage and transport parameters can be defined and quantified for each of these components in the region, then the concept of management strategies which alter the characteristic parameters can be better evaluated. With regard to the hydrologic characterization, various components in the river basin can be viewed as a spectrum of reservoir storages with different volumes, inflow rates, and outflow rates. An important parameter is the detention time, T, defined as the ratio of storage volume to outflow rate. Reservoirs with high values of T have relatively large storage or relatively small outflow rates. The reservoir concept can be applied to streams or lakes as well as to units of land use, e.g., marsh, pasture, cropland, urban, and units of soil type.

Detention time is important not only as a hydrologic parameter, but also it plays a key role in nutrient cycling, loading rates, and uptake rates. In this respect, treatment rates on the land, in the soil, and in various aquatic systems are dependent on T to provide the necessary time for physical, biological, or chemical uptake mechanisms to operate. In general, the longer the detention time, the greater the uptake of nutrients either as plant biomass or as sediments.

Following a discussion of these concepts, the balance of Chapter V uses these ideas to analyze C-38, the upper lakes, and swamps and marshes in the basin. Conventional flood routing techniques are used to estimate the impact of C-38. The lakes are examined using simple budgeting procedures. Lastly the impact of swamps and marshes is evaluated using a computer simulation model called MARSH which routes daily flows through the marshes over a two or three year period. The results are expressed in terms of the overall flood attenuation and water quality control achieved by these units.

The concluding chapter presents a summary of the results and suggests a management strategy for dealing with the problems described earlier in the report. The need to preserve available wetland areas is stressed. Results of field interviews with farmers in the area are included. This chapter concludes with a description of further research needs.

III. LAND USE ANALYSIS

PAST AND PRESENT LAND USE

Land use in the Kissimmee River Basin has undergone rapid and significant changes in the last 15 years. In the past, activities in the upper part of the basin were dominated by urban interests, especially around the Orlando area, and agricultural interests involved in citrus on the western ridge, small amounts of improved pasture around the upper lakes, and large areas of unimproved pasture throughout the remainder of the basin. By far the dominant category was freshwater marsh and swamp around the large lakes and scattered throughout the basin. Figure 3.1 shows the general land use pattern which existed in 1958, based on the analysis of aerial photographs of the basin provided by the FCD.

Figure 3.2 shows the major shifts which have taken place following the construction of flood control structures and canals in the 1960's. These land use patterns were obtained in the same manner as the 1958 values. The most obvious changes may be seen in the conversion of swamp and marsh land to some type of pasture. This results in approximately a 25 percent reduction of the <u>natural</u> areas. Approximately 40 percent of the land which was formerly unimproved pasture has been moved into the improved range through diking or drainage procedures. In addition, urban expansion is evident south of Orlando, around lake borders, and in the Disney World area of western Orange County.

The type of land use changes evident from 1958 to 1972 is expected to continue, with urban and agricultural expansion, and a reduction of those areas in swamps and marshes. This will be illustrated more clearly in the following section.

PROJECTED LAND USE

Introduction

This section describes procedures used to project future patterns of the land use in the Kissimmee River Basin. Since the bulk of the land use is for agriculture, a logical point of departure is to review available estimates of the Soil Conservation Service (SCS and the US Department of Agriculture).

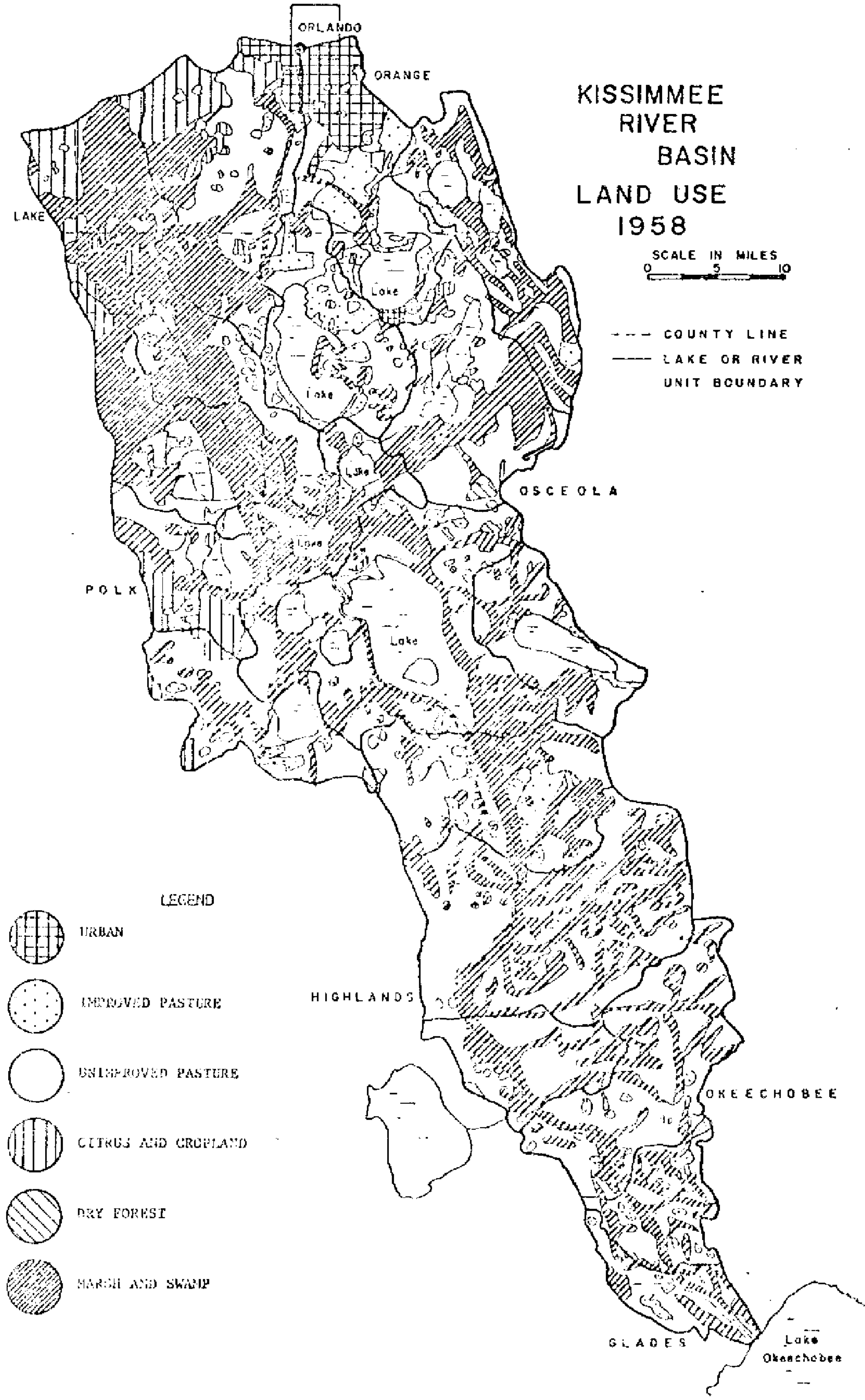

Figure 3.1. 1958 Kissimmee River Basin Land Use, from Analysis of Aerial Photos

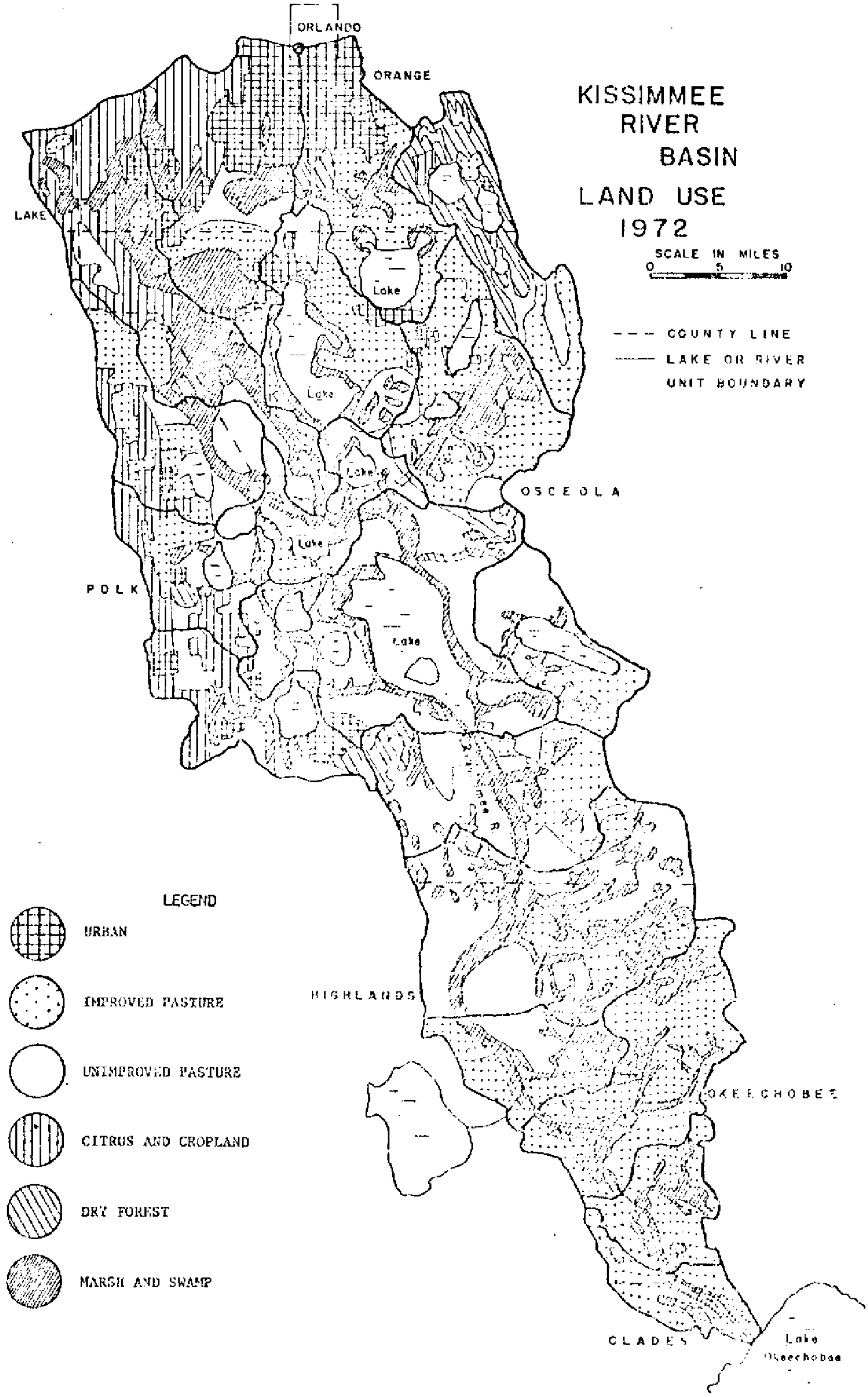

Figure 3.2. 1972 Kissimmee River Basin Land Use, from Analysis of Aerial Photos

Briefly the SCS estimates future land use based on a wide variety of procedures from sophisticated linear programming techniques to ad hoc procedures based on their many years of experience. Their approach seems to be a reasoned and realistic one. The results of this analysis are projections, to the years 1980, 2000, and 2020, of what land use could be. It does not state that this is what the use should be, for that represents a policy choice beyond the planner's realm of responsibility. It is important for the reader to keep this distinction clear so that the analysis to follow is not construed to be the well-publicized circular analysis whereby projects are justified to meet future demands which could only be met if the project is built, i.e., self-fulfilling prophecies.

The SCS projections provide one estimate of the future (see Figure 3.3). Alternative futures are generated by varying assumptions regarding agricultural productivity, demand levels, and the level of on-site control of drainage water. A linear programming model is used to assist in the accounting and bookkeeping associated with making these projections which are described in the next sections.

Overview of the Model

The mathematical programming model has been shown to be an effective tool in the analysis of both the present and future status of land areas. A recent study by Heaney and Huber *et al.* (1974) made extensive use of this type of modeling in an economic analysis of the Upper St. Johns River Basin. The development of such a model for the Kissimmee River Basin requires that the interactions in the basin be viewed as three major forces: the natural system (marsh, swamp, and woodland), the agricultural system, and urbanization. The model will evaluate the agricultural and natural systems. Urbanization shows its effect by removing land from possible agricultural and natural uses.

The model allocates available land to various activities to satisfy certain specified objectives. These objectives are normally based on economic criteria, i.e., minimize cost or maximize profit, and/or certain environmental criteria such as minimizing storm water runoff.

A descriptive analysis of the model is presented below. In concept, the model allocates a "pool" of available land to various activities in a way that satisfies certain requirements. These might include economic efficiency, conformation to existing land use patterns, satisfaction of demands for commodities and services, and many others.

To permit this type of manipulation, each acre of land was identified by a vector of characteristics: geographic location, (possible) land use activity, agricultural productivity, and water problem class. Thus, the number of acres assigned to a unique land use category was identified by the decision variable or structural element,

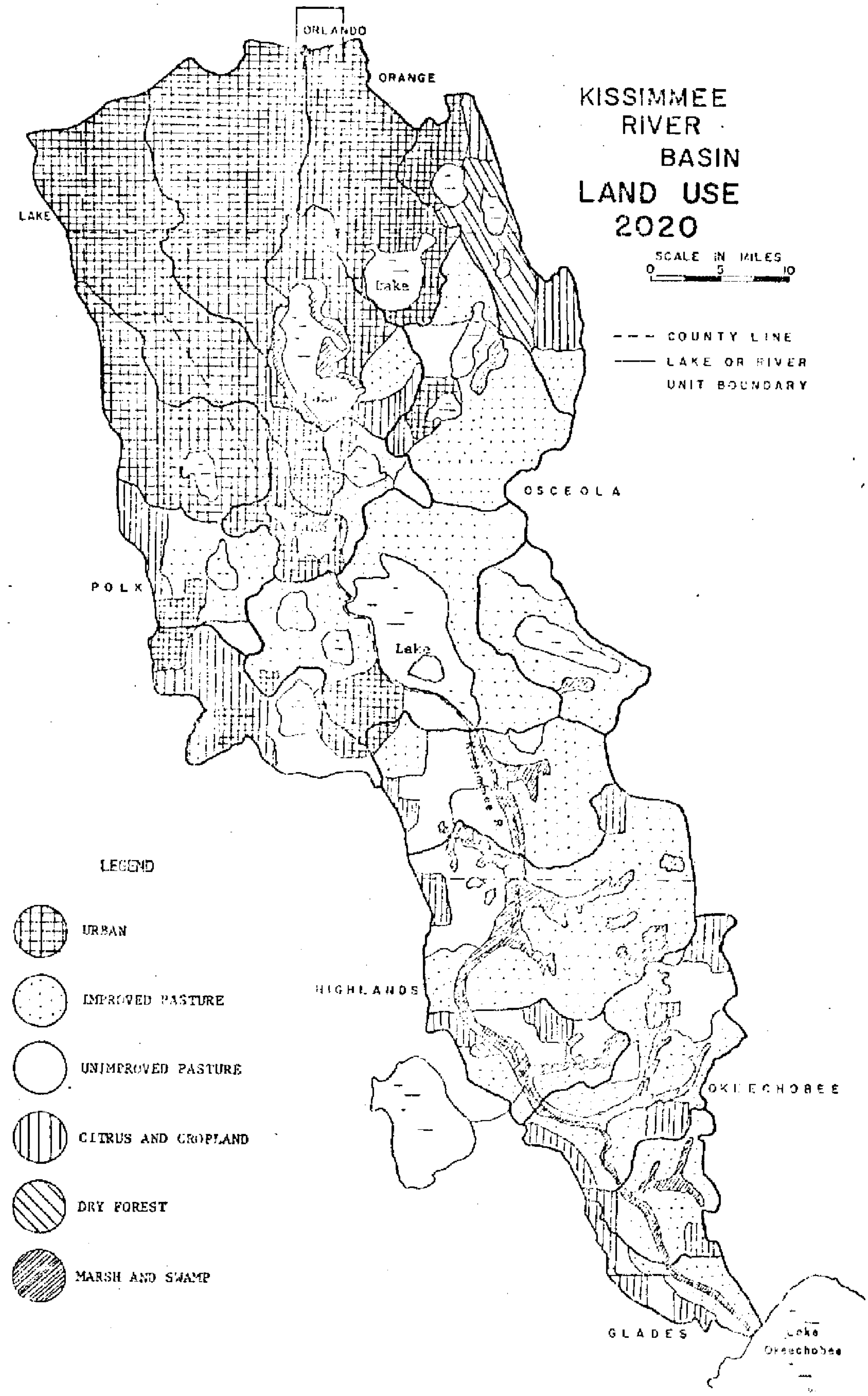

Figure 3.3. Projected 2020 Kissimmee River Basin Land Use (SCS, 1973a)

$$x_{i\ j\ k\ l} \tag{3.1}$$

- l — water problem class, l
- k — soil productivity group, k
- j — land use activity, j
- i — hydrologic (SCS) planning unit, i

Using this basic structural element, any number of criteria or phenomena can be introduced into the model. For example, by determining a cost for each type of land use activity, the total basin costs can be expressed as,

$$\text{cost} = \sum_i \sum_j \sum_k \sum_l (c_{ijkl})(x_{ijkl}) \tag{3.2}$$

where c_{ijkl} = the cost per acre per year associated with each (ijkl).

It is also important to keep a running account of available soil types to make sure that the acres allocated to various uses do not exceed the supply for that particular soil. Thus, for each planning unit i,

$$\text{available soil} = \sum_j x_{ij(kl)} = s_{i(kl)}, \text{ for each } (kl) \tag{3.3}$$

where $s_{i(kl)}$ = the supply of soil (acres) in planning unit i of type (kl).

In an agricultural model of this type, production is a vital consideration. Hence, the basic decision variable can be used to keep track of farm outputs which can be compared to demands whenever required, i.e.,

$$\text{production} = \sum_i \sum_j \sum_k \sum_l (y_{ij(kl)})(x_{ij(kl)}), \text{ for each } j \tag{3.4}$$

where $y_{ij(kl)}$ = the annual per acre yield in planning unit i from land use activity j in soil type (kl).

In addition to these basic features, other factors can be added to the model at the discretion of the analyst. As an example, one may wish to "track" the shifts in surface runoff produced by various land use patterns, i.e.,

$$\text{surface runoff} = \sum_i \sum_j \sum_k \sum_l (r_{ijkl})(x_{ijkl}) \qquad (3.5)$$

where r_{ijkl} = the volume of runoff per acre associated with each (ijkl) for a storm of given frequency and duration.

Using these or similar structural expressions, various land allocation schemes may be formulated. One familiar approach would be that of economic efficiency whereby land is parceled out to various activities in a way that minimizes the total cost of meeting agricultural demands. These investigations may focus on the total basin, each separate planning unit, or any subset of planning units considered together. This fits nicely into a standard linear programming format such as minimize costs (equation 3.2) subject to the upper limit on available soil types (equation 3.3) and the fact that demands for each activity (j) must be met. Since many different formulations can be used, the next section will describe the structural element as an introduction to specific approaches used in this study.

Land Use Activities

The selection of which land uses should be given consideration by the model is actually a question of manageability. It is desirable to consider all the major land uses, but it would be impossible to represent the entire spectrum of agricultural activities within the basin. For this reason, the final number of activities must be kept small and still cover the broad agricultural picture.

Two means for selection of these categories would be the dollar value (cost and/or profit) and the amount of land required for production. Using these criteria, three major land uses become obvious: (1) beef, (2) citrus, and (3) vegetables. While citrus and vegetables do not constitute a large percentage of the total basin acreage, they are very high return crops and therefore obvious selections in terms of profit. The citrus operations were considered a single crop, oranges, rather than being separated into various categories because other types of citrus production are negligible.

When considering vegetable production, the same analysis is used. Rather than attempting to account for each separate vegetative type, tomatoes are used as the representative crop for the entire vegetable category for two reasons: (1) they are the largest vegetable crop in terms of volume produced, and (2) the most reliable production figures are available for tomatoes.

Since beef is currently the largest agricultural commodity in the basin, it was felt that production should be separated into two major categories: unimproved and improved pasture. With approximately 80 percent of the basin in some type of beef cattle production, all other livestock operations were considered minor. A possible exception might have been dairy cattle. However, dairy production and cost figures were difficult to document, and dairies were not included on land use maps. This group is included because of its environmental rather than its economic impact.

Forests, swamps, and marshes are placed in the residual category. No direct economic valuation for these uses exists. Thus, their "value" to the system will be evaluated by quantifying the environmental responses, e.g., hydrologic and water quality which occur if they are reduced or eliminated. Thus, their value needs to be derived as a result of the analysis. It is not assumed beforehand. This procedure does not introduce an economic bias against these land use categories.

The final land use grouping used in the model is urban, citrus, vegetables, improved pasture, unimproved pasture, and a residual category of forest, swamp, and marsh.

Detailed Soils and Land Use Analysis

The various systems of soil classification range from taxonomic groups based on physical factors to schemes which classify soil properties as they relate to various uses. Specific requirements are focused on agricultural production and its water-related problems; it is logical therefore to develop the soil and land analysis on this basis. Before presenting the classification systems, it is appropriate to identify the predominant soil types associated with agriculture in the basin. Figure 2.4, a general soil map from the SCS Report for Kissimmee-Everglades Area (1973a), depicts the general soil types and swamp areas of interest. The following is a summarized list of the general soil types and related agricultural enterprises which commonly locate on them:

1. Sandy soils, sloping terrain, sandy to 40 inches or more, water table below 60 inches, little or no surface runoff, drainage mostly to aquifer.

   Found only along extreme upper and upper western portion of basin. Occupies less than 20 percent of the basin north of Lake Okeechobee. Not found in other areas tributary to the lake. Supports most of the citrus and limited acreage of cattle production.

2. Sandy soils, nearly level terrain, sandy to 40 inches or more, water table normally 30 to 60 inches, little surface runoff, drainage lateral to streams or canals. Insignificant in overall area.

3. Sandy soils, nearly level terrain, sandy to 40 inches or more, often including organically cemented layer, water table normally 0 to 30

inches, slow surface runoff during wet weather, slow lateral internal drainage to streams or canals.

Predominates basin naturally tributary to Lake Okeechobee. Supports most of the beef and dairy cattle production, limited acreage of vegetables and some citrus.

4. Sandy soils, nearly level terrain, sandy to 40 inches or more, water table normally within 15 inches of surface and frequently rises above surface, slow surface runoff if drainage gradient is provided. Little internal drainage unless ditched.

   Found along the Kissimmee River, in large areas among the lakes in the upper Kissimmee Basin, and over the entire basin. Supports low density beef cattle production, unless drained, when improved pastures and some citrus have been planted.

5. Organic soils, virtually level terrain, surface layers of peat or muck (muck is the term applied to farmed peat) from a few inches to several feet, water table seldom more than a few inches beneath the surface and normally above the surface under natural conditions. Slow surface drainage if gradient is provided. Little internal drainage unless intensive, pumped ditching is provided.

   Small pockets of little areal significance over most of basin. Supports vegetable and sugarcane production.

As a basis for classifying soil into water problem classes, an adjusted system taken from the USDA Handbook 210 "Land Capability Classification" (1961) is used. This system divides all soils into the eight major classifications and four subclassifications. The eight major classifications are as follows:

Class I	Soils in Class I have few limitations that restrict their use.
Class II	Soils in Class II have some limitations that reduce the choice of plants or require moderate conservation practices.
Class III	Soils in Class III have severe limitations that reduce the choice of plants or require special conservation practices, or both.

Class IV Soils in Class IV have very severe limitations that restrict the choice of plants, require very careful management, or both.

Class V Soils in Class V have little or no erosion hazard but have other limitations impractical to remove, that limit their use largely to pasture, range, woodland, or wildlife and food and cover.

Class VI Soils in Class VI have severe limitations that make them generally unsuited to cultivation and limit their use largely to grazing, woodland, or wildlife.

Class VII Soils in Class VII have very severe limitations that make them generally unsuited to cultivation and grazing and limit their use to woodland or wildlife.

Class VIII Soils and landforms in Class VIII have limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, or water supply or to esthetic purposes.

The four subclassifications, erosion (e), root zone (s), climatic limitations (c), and water-related problems (w), can be simplified because climatic limitations and erosive conditions are virtually nonexistent in the basin, and root limitations exist only in a small portion of the study area. Now, by grouping the eight major classifications, a reasonable system for input into the model can be produced. Water-problem classes and their percentage of the basin are shown with comparable SCS capability classes in Table 3.1. Table 3.2 lists the soil series and their respective problem classes.

Lastly, the soils are classified according to their productivity of the various soil types. Soils with similar productivity are aggregated into a single productivity class using beef production as the ranking criterion. The soils are lumped into six productivity groups containing soil types already possessing similar water problems. In this way, the productivity of a soil decreases as the productivity class number increases. Table 3.3 presents the final grouping of soils into water-problem class and soil productivity categories for the Kissimmee Basin.

Table 3.1. Water Problem Classes vs SCS Capability Classes (SCS, 1973a)

	SCS Capability Class			
	Iw, IIw, IIIw	IVw	Vw, VIw	VIIw, VIIIw
Water Problem Class	1.0	2.0	3.0	4.0
Percentage of the Basin	8.9	68.6	12.5	10.0

Table 3.2 Soil Series Within Water Problem Classes

Water Problem Class							
1		2		3		4	
(1)	St. Lucie	(13a)	Myakka	(22)	Basinger	(27)	Swamp-Marsh
(15)	Adamsville	(23)	Pompano	(3)	Lake		
(24c)	Felda	(23b)	Immokalee				
(24a)	Manatee						
(12a)	Tavares						
(26)	Everglades						
(11)	Pomello						
(18c)	Parkwood						

Note: Numbers in parentheses indicate SCS classification numbers.

Table 3.3. Final Categorization into Productivity Groups and Water Problem Classes

Soil Productivity Group	Water Problem Class 1		2		3		4	
1	(26)	Everglades	(23)	Pompano	(22)	Basinger	(27)	Swamp-Marsh
2	(24a)	Manatee	(13a) (13b)	Myakka Immokalee	(3)	Lake		
3	(24c)	Felda						
4	(18c)	Parkwood						
5	(15) (12a)	Adamsville Tavares						
6	(11) (1)	Pomello St. Lucie						

Note: Numbers in parentheses indicate SCS classification numbers.

Development of Input Data

Costs and Profits --

The decision to allocate an available soil for a specified activity, j, is based partially on the cost associated with the development and continued production of some agricultural activity. These costs are normally separated into fixed costs, which include land acquisition, preparation, drainage, irrigation, and other "capital" expenditures, and variable costs encompassing feed, labor, maintenance and repairs, and fertilizers. The values presented in Table 3.4 are average annual costs for each category and land use activity. These figures are a composite of information obtained from discussions with county agents, local producers, and published reports. The amortized annual cost of land varies depending on the soil type, slope, location, root zone, depth, and response to fertilization. One can look at the cost of land use activities and estimate the average annual cost for the soils. The annual costs are constant, that is, no attempt is made to inflate annual costs to 1980 and 2020 time periods because the main concern in the model is relative, not absolute, costs.

Incomes, like costs, are subject to wide fluctuation depending upon the current demand and economic structure at harvest time. Therefore, it is not practical to estimate prices for various time periods and locations, but rather to select a single value for each activity and apply it throughout the basin. The prices are obtained from much the same sources as costs and should be reasonable. The values presented in Table 3.5 reflect typical 1972 figures in the basin.

Productivity --

The necessity of developing reliable productivity data on a per acre basis is essential when one remembers the general structure of the model. To obtain the 1972 productivity values (yields), four major sources were consulted:

1. Florida Statistical Abstracts (1973)
2. Kissimmee-Everglades Area Report (SCS, 1973a)
3. County Agents
4. Soil Conservation Service publications.

The citrus and vegetable yields are well documented, and the recent report by Anderson and Hipp (1974) is considered by beef experts to provide excellent information for productivity rates of improved and unimproved pasture on Florida flatwood soils.

Table 3.4. Average Annual Costs per Acre of Production (c_{ijkl})[a]

1. Land

Use	$/yr
Citrus	51.00
Improved Pasture	44.00
Vegetables	60.00
Unimproved Pasture	44.00

2. Additional Variable Cost

Use	$/yr
Citrus	235.00
Improved Pasture	20.00
Vegetables	628.00
Unimproved Pasture	5.00

3. Drainage

Use	Water Problem Class			
	1	2	3	4
Citrus	N/A[b]	51.00	60.00	Inf.[c]
Improved Pasture	N/A	10.00	15.00	25.00
Vegetables	N/A	30.00	35.00	Inf.
Unimproved Pasture	N/A	N/A	N/A	N/A

4. Irrigation

Use	Water Problem Class			
	1	2	3	4
Citrus	60.00	50.00	50.00	Inf.
Improved Pasture	5.00	4.00	4.00	2.00
Vegetables	30.00	20.00	20.00	Inf.
Unimproved Pasture	N/A	N/A	N/A	N/A

[a]Sources: Brooke, 1973a, Brooke, 1973b, Anderson and Hipp, 1974, Harrison, 1974, Heaney and Huber et al., 1974.

[b]N/A = not applicable.

[c]Inf. = infeasible.

Table 3.5. Income From Various Agricultural Commodities[a]

	Sales Price per Unit Product		
Year	\$/90 lb Box	\$/40 lb Box	\$/lb
1958	1.93	2.80	0.20
1972	2.10	6.00	0.30
1980	2.10	6.00	0.30
2020	2.10	6.00	0.30

[a]Sources: Brooke, 1973a, Brooke, 1973b, Savage, 1973, and Anderson and Hipp, 1974.

As urban pressure drives agricultural lands toward more intensive use, productivity values will increase accordingly. Increased production figures for the next 10 to 30 years range from a low of 10 percent to a high of 30 percent. Since any selection from this range for a given period would be speculative, the decision was made to use the potential yields published by the Soil Conservation Service in their soil survey interpretations. These potential yields provide an upper limit which can be parameterized from present levels for various selected study years. Table 3.6 illustrates the predicted productivities of various soil types for the 1980, 2000, and 2020 study years.

Demands --

Because the land use activities are viewed as a response to some external demand for the commodities produced, the prespecified level of output becomes a major component of the model. The model is simply an attempt to determine if the basin, when placed under a certain magnitude of stress, can ensure that these demands will be satisfied. No value judgment is intended regarding whether this level of activity should be satisfied.

Considering future production for the basin, two major questions arise regarding what the total basin should be required to produce, and how this production should be divided among basin subgroups (planning units). Well-documented figures are not available for either the basin or the planning unit level, so the following scheme was developed for allocating the required outputs.

If productivity information for each soil type is considered and the 1972 land use maps provided by the FCD are employed, it is possible to calculate the total production for an individual planning unit, or the entire basin, by multiplying the area of land use on a certain soil type by the productivity of that soil type. These values are then prorated by area and compared to total 1972 production for each county presented in Florida Statistical Abstracts (1973) to check their accuracy. Given the 1972 values, future study years can be explored. The Kissimmee Everglades report presents demands for low (1968), medium (1980), and ultimate (2020) productivities. By use of these values and by stipulating that the basin produce the same proportion of agricultural commodities for future years as it now produces, the basin and planning unit demands can be projected. For example, if the total production of oranges for the Kissimmee-Everglades area in 1972 was one million boxes, and the Kissimmee River Basin contributed 100,000 boxes, then it is required that the Kissimmee River Basin produce 10 percent of the oranges required from the Kissimmee-Everglades area in future years. This same analysis was used in moving from the basin to the planning unit level. Table 3.7 shows the demand levels of various planning units for the medium and ultimate productivities.

Table 3.6. Productivity Values Assigned to Various Soil Types During the 1980 and 2020 Study Periods

		Soil Type	Year	Citrus (90-lb box)	Vegs (40-lb box)	Improved Pasture (lb/ac)	Unimproved Pasture (lb/ac)
SPG[a] 1 WPC[b]	1	Everglades	1980	0	0	680	102
			2020	0	0	800	102
	2	Pompano	1980	298	553	357	54
			2020	350	650	420	54
	3	Basinger	1980	298	533	357	54
			2020	350	650	420	54
	4	Swamp,	1980	0	0	319	50
		Marsh	2020	0	0	375	50
SPG 2 WPC	1	Manatee	1980	361	255	439	66
			2020	425	300	516	66
	2	Myakka	1980	298	638	325	49
		Immokalee	2020	350	750	383	49
	3	Lake	1980	425	0	210	31
			2020	500	0	248	31
	4		1980	0	0	0	0
			2020				
SPG 3 WPC	1	Felda	1980	361	298	389	58
			2020	425	350	458	58
	2		1980	0	0	0	0
			2020				
	3		1980	0	0	0	0
			2020				
	4		1980	0	0	0	0
			2020				
SPG 4 WPC	1	Parkwood	1980	382	340	357	54
			2020	450	400	420	54
	2		1980	0	0	0	0
			2020				
	3		1980	0	0	0	0
			2020				
	4		1980	0	0	0	0
			2020				

Table 3.6 (continued)

		Soil Type	Year	Citrus (90-lb box)	Vegs (40-lb box)	Improved Pasture (lb/ac)	Unimproved Pasture (lb/ac)
SPG 5	1	Adamsville	1980	340	298	325	49
WPC		Tavares	2020	400	350	383	49
	2		1980	0	0	0	0
			2020				
	3		1980	0	0	0	0
			2020				
	4		1980	0	0	0	0
			2020				
SPG 6	1	Pomello	1980	213	0	194	29
WPC			2020	250	0	229	29
	2		1980	0	0	0	0
			2020				
	3		1980	0	0	0	0
			2020				
	4		1980	0	0	0	0
			2020				

[a]SPG - Soil Productivity Group

[b]WPC - Water Problem Class

Table 3.7. Projected Demand Levels of Various Planning Units (PU's) in the Kissimmee River Basin (SCS, 1973a)

PU No.	Citrus (million 90-lb boxes)		Vegetables (million 40-lb boxes)		Beef (million pounds)	
	1980	2020	1980	2020	1980	2020
1	27.9	44.5	0.0	0.0	6.2	15.3
2	6.7	10.6	0.0	0.0	2.0	7.2
3	0.8	1.3	1.2	1.8	5.0	12.3
4	1.2	1.9	0.0	0.0	3.9	9.6
5	0.8	1.3	0.0	0.0	9.9	24.3
6	1.7	2.8	0.0	0.0	10.8	26.4
7	7.2	11.4	0.0	0.0	5.3	12.9
8	0.0	0.0	0.0	0.0	4.7	11.4
9	11.3	18.1	0.0	0.0	2.9	7.2
10	1.4	2.2	0.0	0.0	5.8	14.1
11	0.1	0.1	0.0	0.0	4.7	11.4
12	12.3	19.7	0.0	0.0	0.7	1.8
13	0.0	0.0	0.4	0.7	9.2	22.5
14	0.4	0.6	0.0	0.0	12.6	40.9
15	0.0	0.0	0.0	0.0	3.8	9.3
16	0.0	0.0	1.3	1.9	20.8	51.0
17	0.0	0.0	0.0	0.0	7.8	19.2
18	0.0	0.0	0.0	0.0	5.5	13.5
Total	71.8	114.5	2.9	4.4	122.5	300.3

This restriction was later removed at the planning unit level, so that each planning unit would contribute its maximum until basin demands were met but would not be required to produce on an individual basis. That is, if in the year 2000 (high conditions) planning unit 2 has no land available for agriculture, the model will simply move into an area where land is available and bring the necessary activities into use.

Constraints --

The model must be limited, or constrained, by certain means to prevent trivial results. For example, if the model is required to minimize cost and no constraints are placed on production, it will elect to produce nothing (cost = 0). On the other hand, if maximizing profit is the goal, the model will choose the most profitable activity and place all available land into that production activity.

In order to prevent the above situation, upper and lower bounds were set on production so that a planning unit must produce at least some lower limit of a commodity but may not produce more than some prespecified upper limit. When attempting to meet the demands, the model must also consider the amount of land available in various study periods. These land values are input as fixed or stationary bounds, thereby placing an additional upper limit on production.

The major environmental constraint in the model is stormwater runoff. The effect of man's control of land use is a decrease in the volume of natural storage of rainfall and a subsequent increase in surface runoff. This runoff is reflected in higher peak flows and volume and a generally lower water quality.

By stipulating runoff volume, the model is constrained in two ways. First, if the runoff for a certain area exceeds a prespecified level, the farmer must store the water on site, causing a reduction in the land available for production. This, coupled with the cost of diking or building facilities which will contain the runoff until it may be released at an allowable rate, places an additional cost on the operation. Secondly, as has already been mentioned, urban use normally competes successfully with agricultural and natural vegetation for certain soils. To control this problem, consideration will be given to the flooding hazard of a soil type. For present purposes, urban development will be prohibited from soils which lie in the 100-year flood plain or having a flooding hazard in excess of one month per year. A list of soils in the Kissimmee Basin along with their flood frequencies and suitability is shown in Table 3.8.

The actual calculation of runoff values can be made to fit nicely into the 6 x 4 productivity water problem class matrix. Since the main focus is on agricultural and natural land uses, a condensed version of the curve number (CN) method developed by the SCS (1969) may be used to obtain the necessary runoff values for each soil type-land use activity.

Table 3.8. Flood Frequencies and Suitability for Urban Development of Soil Types in the Kissimmee River Basin (SCS, 1960, 1971)

Soil Type	Flood Frequency	Suitability for Urban Development
Parkwood	Every year for 7-30 days	Poor
Manatee	Every year for > 6 months	Not Allowed
Everglades	Every year for 7-30 days	Poor
Tavares	Every year for 7-30 days	Poor
Felda	Every year for 7-30 days	Poor
Adamsville	Every 1 to 5 years for 2-7 days	Good
Pompano	Every year for 1 to 6 months	Very Poor
Myakka	Every 1 to 5 years for 2-7 days	Good
Immokalee	Every 1 to 5 years for 2-7 days	Good
Lake	Every year for 1 to 6 months	Very Poor
Basinger	Every year for 1 to 6 months	Very Poor
Pomello	None	Excellent
St. Lucie	Every year 7-30 days	Poor
Swamp-Marsh	Every year > 6 months	Not Allowed

The SCS National Engineering Handbook, Section 4 "Hydrology" (1969), outlines a procedure for estimating the volume of runoff to be expected from a given soil type and land use following a storm of prespecified depth. This capability satisfies nicely the requirements of the land use model, and runoff (r_{ijkl}) was generated in the following sequence:

1. Two rainfall events were selected for analysis, the 5-year storm of 6.5 inches in 24 hours and the 50-year event of 12 inches in 24 hours.

2. Through the use of Tables 3.9 and 3.10, taken from the National Engineering Handbook, selection of the proper curve number is made.

3. Given the 6.5 or 12-inch rainfall and the proper curve numbers, the expected runoff for each soil type-land use combination is taken from Figure 3.4 which is also adapted from the National Engineering Handbook.

The total volume of runoff from each planning unit is calculated based upon the land use for various years. By dividing this total volume of runoff by the total amount of land remaining in the residual category (land available for storage), the volume of water that each acre of land would be required to store is calculated. Table 3.11 shows the results of these calculations for each planning unit and the total basin during the two study years.

RESULTS OF THE LAND USE ANALYSIS

As alluded to earlier, the main asset of the LP model lies in its ability to do a vast number of calculations while keeping track of several different variables. This type of analysis may be used to evaluate economic, social, or environmental objectives, and in addition combine one or more of these objectives for comparative purposes. This type of analysis was used in the evaluation of the Upper St. Johns River Basin in Florida and includes coalitions, various flexible parameters, and a comparison of the acceptability of various plans using different objective functions (Heaney and Huber et al., 1974).

Although the KRB model includes the necessary programming, and a more extensive data base to perform these types of analysis, it was felt that the fundamental results would closely compare with the St. Johns analysis, and perhaps this duplication was unnecessary. The principal function of the LP model then became the projection of future land use patterns for input into a hydrologic model (Bedient, 1975) capable of generating runoff hydrographs for these future conditions.

There are, however, several general items about future land use in the KRB that warrant mention. Of the objective functions employed

Table 3.9. SCS Hydrologic Soil Groups (SCS, 1969)

Soil Group	Description
A	LOWEST RUNOFF POTENTIAL. Includes deep sands with very little silt and clay; also deep, rapidly permeable loess.
B	MODERATELY LOW RUNOFF POTENTIAL. Mostly sandy soils less deep than A, and less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.
C	MODERATELY HIGH RUNOFF POTENTIAL. Comprises shallow soils and soils containing considerable clay and colloids, though less than those of group D. The group has below average infiltration after presaturation.
D	HIGHEST RUNOFF POTENTIAL. Includes mostly clays of high swelling percentage, but the group also includes some shallow soils with nearly impermeable subhorizons near the surface.

Note: A mixed designation, i.e., B/D, refers to drained/undrained situation.

Table 3.10
Runoff Curve Numbers for Hydrologic Soil-Cover Complexes -- For Average Conditions of Antecedent Soil Moisture and Initial Abstraction (SCS, 1969)

Land Use or Cover	Treatment or Practice	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and Terraced	Poor	61	72	79	82
Close-seeded[a] legumes or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	59	75	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		-	59	74	82	86
Roads (dirt)[b]		-	72	82	87	89
(hard surface)[b]		-	74	84	90	92

[a]Close-drilled or broadcast.

[b]Including right-of-way

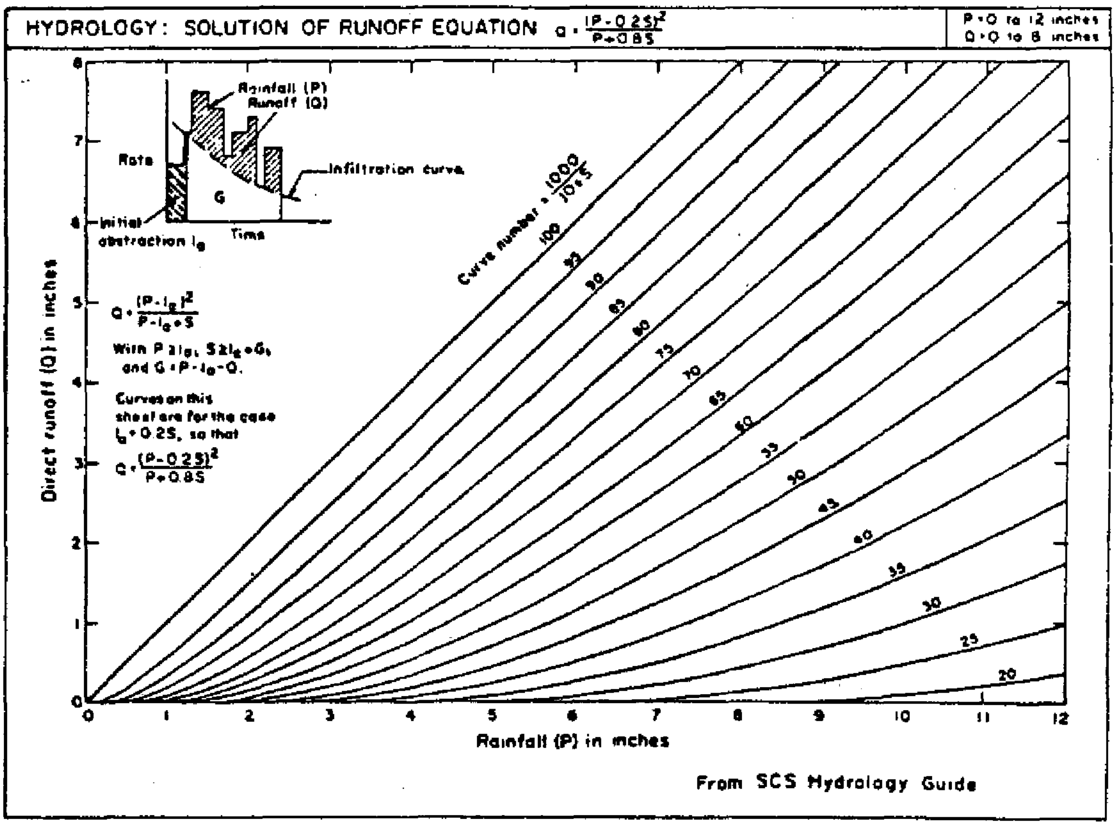

Figure 3.4. SCS Curves Used to Determine Runoff from Various Soil Type-Land Use Complexes (SCS, 1969)

Table 3.11. Inches of Depth Required per Acre of Residual Land to Contain the 5- and 50-Year Storms on Site During the 1980 and 2020 Study Periods

	1980		2020	
Planning Unit	5 yr	50 yr	5 yr	50 yr
1	10.7	26.5	294.1	582.4
2	4.0	10.0	*	*
3	14.1	34.3	*	*
4	11.2	30.6	*	*
5	10.1	27.5	*	*
6	9.1	23.9	11.2	31.4
7	11.5	31.0	*	*
8	9.2	26.3	58.3	175.0
9	15.7	38.6	45.0	125.0
10	6.7	20.0	15.6	40.1
11	11.2	32.5	15.3	36.0
12	30.0	72.0	48.6	105.7
13	48.6	114.3	500.0	1171.4
14	10.5	29.1	51.5	123.2
15	5.3	16.8	14.4	34.9
16	23.6	52.0	51.1	112.8
17	14.9	42.6	27.2	63.6
18	14.5	36.3	48.1	103.7
Basin	11.08	28.6	44.07	107.04

*No residual land available.

by the model, i.e., minimizing cost, maximizing profit, and minimizing runoff, the runoff constraint is the most limiting in terms of allowing the area to meet projected production. The LP results compare favorably with the Soil Conservation Service projections in that both indicate a large shift from unimproved to improved pasture, and increased acreage being used for citrus and vegetable production in future years.

There will be considerable impact on the KRB in future years due to the depletion of the muck lands south of Lake Okeechobee. These rich organic soils have long been the source of the large quantities of vegetables and sugar cane produced in Florida. As the oxidation of these soils continues, some vegetable and sugar cane industries will tend to push northward and claim land north of Lake Okeechobee, thereby placing an increased stress on the quantity and quality of water in the KRB.

The results of the land use analysis for various soil types and land uses are shown for the 18 planning units in the basin in Appendix A. Tables 3.12 to 3.14 summarize the results for the upper basin, lower basin, and total basin respectively. Land use acreage and fractions by water problem class are shown in Tables 3.15 to 3.18 for 1958, 1972, 1980, and 2020 conditions. The SCS Soil Series numbers have been used to aid in identifying the soil types, and allow use of the various county maps available from the SCS. The conditions illustrated in these tables show that increased urban pressure and the movement toward higher intensity agriculture will necessitate extensive man-made storage/treatment facilities within the individual planning units as the marsh/swamp areas are removed, if additional degradation is to be prevented.

The results of these impacts and the type of procedures which might be implemented to evaluate and control them will be the subject of discussion in the next chapters.

Table 3.12. Land Use in the Upper Kissimmee River Basin - Planning Units 1 to 12 - 1000 acres

Land Uses	1	2	3	4	5	6	7	8	9	10	Upper Basin Total
Study Year	Urban	Crop Land	Improved Pasture	Unimproved Pasture	Citrus	Forest	Swamp	Marsh	Barren Land	Surface Water	
1968	25.4	0.4	98.3	380.0	100.6	17.1	118.5	159.9	0.0	138.5	1038.7
1972	91.7	1.2	234.6	236.0	107.1	38.2	61.6	129.8	0.0	138.5	1038.7
1980	131.6	7.4	243.3	184.7	97.4	54.9	60.4	120.5	0.0	138.5	1038.7
2020	520.0	13.6	143.0	40.4	60.0	63.2	29.9	30.1	0.0	138.5	1038.7

Table 3.13. Land Use in the Lower Kissimmee River Basin - Planning Units 13 to 18 - 1000 acres

Land Uses	1	2	3	4	5	6	7	8	9	10	
Study Year	Urban	Crop Land	Improved Pasture	Unimproved Pasture	Citrus	Forest	Swamp	Marsh	Barren Land	Surface Water	Lower Basin Total
1958	0.0	0.3	32.9	280.6	1.3	3.2	130.9	2.8	0.0	0.0	452
1972	1.3	1.6	223.2	133.2	1.0	7.5	78.9	2.2	3.1	0.0	452
1980	3.2	2.0	268.7	86.5	2.5	8.0	67.5	10.5	3.1	0.0	452
2020	10.6	43.6	293.2	53.4	12.0	12.0	33.8	0.0	3.1	0.0	452

Table 3.14. Land Use in the Kissimmee River Basin - 1000 acres

Land Uses	1	2	3	4	5	6	7	8	9	10	Basin Total
Study Year	Urban	Crop Land	Improved Pasture	Unimproved Pasture	Citrus	Forest	Swamp[c]	Marsh[c]	Barren Land	Surface Water	
1958[a]	25.4	0.7	131.2	660.6	101.9	20.3	249.4	162.7	0.0	138.5	1490.7
1972[a]	93.0	2.8	457.8	369.2	108.1	45.7	140.5	132.0	3.1	138.5	1490.7
1980[b]	134.8	9.4	512.0	271.2	99.9	62.9	127.9	131.0	3.1	138.5	1490.7
2020[b]	530.6	57.2	436.2	93.8	62.3	75.2	63.7	30.1	3.1	138.5	1490.7

[a]Based on analysis of aerial photographs.

[b]Based on predictions of linear programming model.

[c]Lower Kissimmee River flood plain is 60.8 thousand acres.

Table 3.15. Acreages and Fractions Occupied by Different Soil Group and Land Use Combinations, 1958 Land Use - Lower Kissimmee River Basin - PU 13-18.

Land Use	Soil Group by Water Problem Class 1	2	3	4	Total Acres
Urban	A) 0 B) -	A) 0 B) -	A) 0 B) -	A) 0 B) -	0
Crops	A) 0 B) -	A) 300 B) .001	A) 0 B) -	A) 0 B) -	300
Improved Pasture	A) 5,600 B) .012	A) 24,000 B) .053	A) 3,300 B) .007	A) 0 B) -	32,900
Unimproved Pasture	A) 17,300 B) .038	A) 254,700 B) .564	A) 8,600 B) .019	A) 0 B) -	280,600
Citrus	A) 300 B) .001	A) 1,000 B) .002	A) 0 B) -	A) 0 B) -	1,300
Forest	A) 1,700 B) .004	A) 1,400 B) .003	A) 100 B) .0002	A) 0 B) -	3,200
Swamp	A) 49,200 B) .109	A) 75,200 B) .166	A) 6,500 B) .014	A) 0 B) -	130,900
Marsh	A) 0 B) -	A) 100 B) .0002	A) 2,700 B) .006	A) 0 B) -	2,800
Barren	A) 0 B) -	A) 0 B) -	A) 0 B) -	A) 0 B) -	0
Total Acres	74,100	356,700	21,200	0	452,000

A) Acres

B) Fraction of Total Basin

Table 3.16. Acreages and Fractions Occupied by Different Soil Group and Land Use Combinations, 1972 Land Use - Lower Kissimmee River Basin - PU 13-18.

Land Use	Soil Group by Water Problem Class 1	2	3	4	Total Acres
Urban	A) 0 B) -	A) 1,300 B) .003	A) 0 B) -	A) 0 B) -	1,300
Crops	A) 0 B) -	A) 1,600 B) .004	A) 0 B) -	A) 0 B) -	1,600
Improved Pasture	A) 25,100 B) .056	A) 194,600 B) .431	A) 3,500 B) .008	A) 0 B) -	223,200
Unimproved Pasture	A) 7,600 B) .017	A) 114,800 B) .254	A) 10,800 B) .024	A) 0 B) -	133,200
Citrus	A) 1,000 B) .002	A) 0 B) -	A) 0 B) -	A) 0 B) -	1,000
Forest	A) 2,600 B) .006	A) 4,300 B) .010	A) 600 B) .001	A) 0 B) -	7,500
Swamp	A) 35,000 B) .077	A) 39,800 B) .088	A) 4,100 B) .009	A) 0 B) -	78,900
Marsh	A) 0 B) -	A) 0 B) -	A) 2,200 B) .005	A) 0 B) -	2,200
Barren	A) 2,800 B) .006	A) 300 B) .001	A) B)	A) 0 B) -	3,100
Total Acres	74,100	356,700	21,200	0	452,000

A) Acres

B) Fraction of Total Basin

Table 3.17. Acreages and Fractions Occupied by Different Soil Group and Land Use Combinations, 1980 Land Use - Lower Kissimmee River Basin - PU 13-18.

Land Use	Soil Group by Water Problem Class 1	2	3	4	Total Acres
Urban	A) 400 B) .001	A) 2,800 B) .006	A) 0 B) -	A) 0 B) -	3,200
Crops	A) 200 B) .0004	A) 1,800 B) .004	A) 0 B) -	A) 0 B) -	2,000
Improved Pasture	A) 26,000 B) .058	A) 237,500 B) .525	A) 5,200 B) .012	A) 0 B) -	268,700
Unimproved Pasture	A) 5,600 B) .012	A) 71,600 B) .158	A) 9,300 B) .021	A) 0 B) -	86,500
Citrus	A) 2,500 B) .006	A) 0 B) -	A) 0 B) -	A) 0 B) -	2,500
Forest	A) 3,200 B) .007	A) 4,100 B) .009	A) 700 B) .002	A) 0 B) -	8,000
Swamp	A) 33,400 B) .074	A) 28,100 B) .062	A) 6,000 B) .013	A) 0 B) -	67,500
Marsh	A) 0 B) -	A) 10,500 B) .023	A) 0 B) -	A) 0 B) -	10,500
Barren	A) 2,800 B) .006	A) 300 B) .001	A) 0 B) -	A) 0 B) -	3,100
Total Acres	74,100	356,700	21,200	0	452,000

A) Acres

B) Fraction of Total Basin

Table 3.18. Acreages and Fractions Occupied by Different Soil Group and Land Use Combinations, 2020 Land Use - Lower Kissimmee River Basin - PU 13-18.

Land Use	Soil Group by Water Problem Class: 1	2	3	4	Total Acres
Urban	A) 1,500 B) .003	A) 9,100 B) .020	A) 0 B) -	A) 0 B) -	10,600
Crops	A) 9,400 B) .021	A) 34,200 B) .076	A) 0 B) -	A) 0 B) -	43,600
Improved Pasture	A) 23,500 B) .052	A) 255,200 B) .565	A) 14,500 B) .032	A) 0 B) -	293,200
Unimproved Pasture	A) 4,600 B) .010	A) 43,600 B) .096	A) 5,200 B) .012	A) 0 B) -	53,400
Citrus	A) 2,100 B) .005	A) 0 B) -	A) 200 B) .0004	A) 0 B) -	2,300
Forest	A) 7,300 B) .016	A) 3,900 B) .009	A) 800 B) .002	A) 0 B) -	12,000
Swamp	A) 22,900 B) .051	A) 10,400 B) .023	A) 500 B) .001	A) 0 B) -	33,800
Marsh	A) 0 B) -	A) 0 B) -	A) 0 B) -	A) 0 B) -	0
Barren	A) 2,800 B) .006	A) 300 B) .001	A) B)	A) 0 B) -	3,100
Total Acres	74,100	356,700	21,200	0	452,000

A) Acres

B) Fraction of Total Basin

IV. QUANTITY AND QUALITY OF RUNOFF

This chapter provides estimates of the historical and projected quantity and quality of runoff from the planning units. Primary emphasis is placed on runoff quantity estimates due to the paucity of quality data. The results from the quantity analysis are presented in the next section which is followed by a brief section on quality analysis. The relationship between drainage density and the quantity and quality of runoff is explored in the latter sections of this chapter.

HYDROLOGIC ANALYSIS

Introduction

Available watershed models do not address the problems associated with watersheds dominated by marsh and lake storage, extremely flat slopes, and long-term seasonal rainfall and flooding (Bedient, 1975). These are termed depressional watersheds, and are most commonly found along the Coastal Plain of the Southeastern United States. South Florida watersheds including the Kissimmee-Everglades region fall into this category.

The primary purpose of the hydrologic analysis is to estimate the historical, present and projected rainfall and runoff patterns in the Kissimmee River Basin. Included in this analysis is the impact of the wide variety of control structures which have been installed. Unfortunately, depressional watersheds, lacking the normal dendritic drainage pattern, are not easy to monitor. This fact is reflected in Figure 4.1 which shows the USGS gaging stations in the basin as of 1974. Note that the entire lower basin (S65 to S65-E) is monitored only at the upper and lower boundaries. Thus, it is quite difficult to characterize the hydrology of this vast area which is undergoing significant changes due to channelization and upland drainage. From a water quality and water quantity point of view, it is important to estimate the volume and transport pathway of water entering the main river, i.e., overland flow vs. subsurface flow. Unfortunately, data are lacking to make this judgment. Only with an adequate monitoring program can the hydrology of the Kissimmee River Basin be evaluated properly. But planning programs are needed now to properly manage the area. Thus, hydrologic models have been developed to provide some preliminary judgments regarding the study area. Existing data are used whenever possible for calibration purposes.

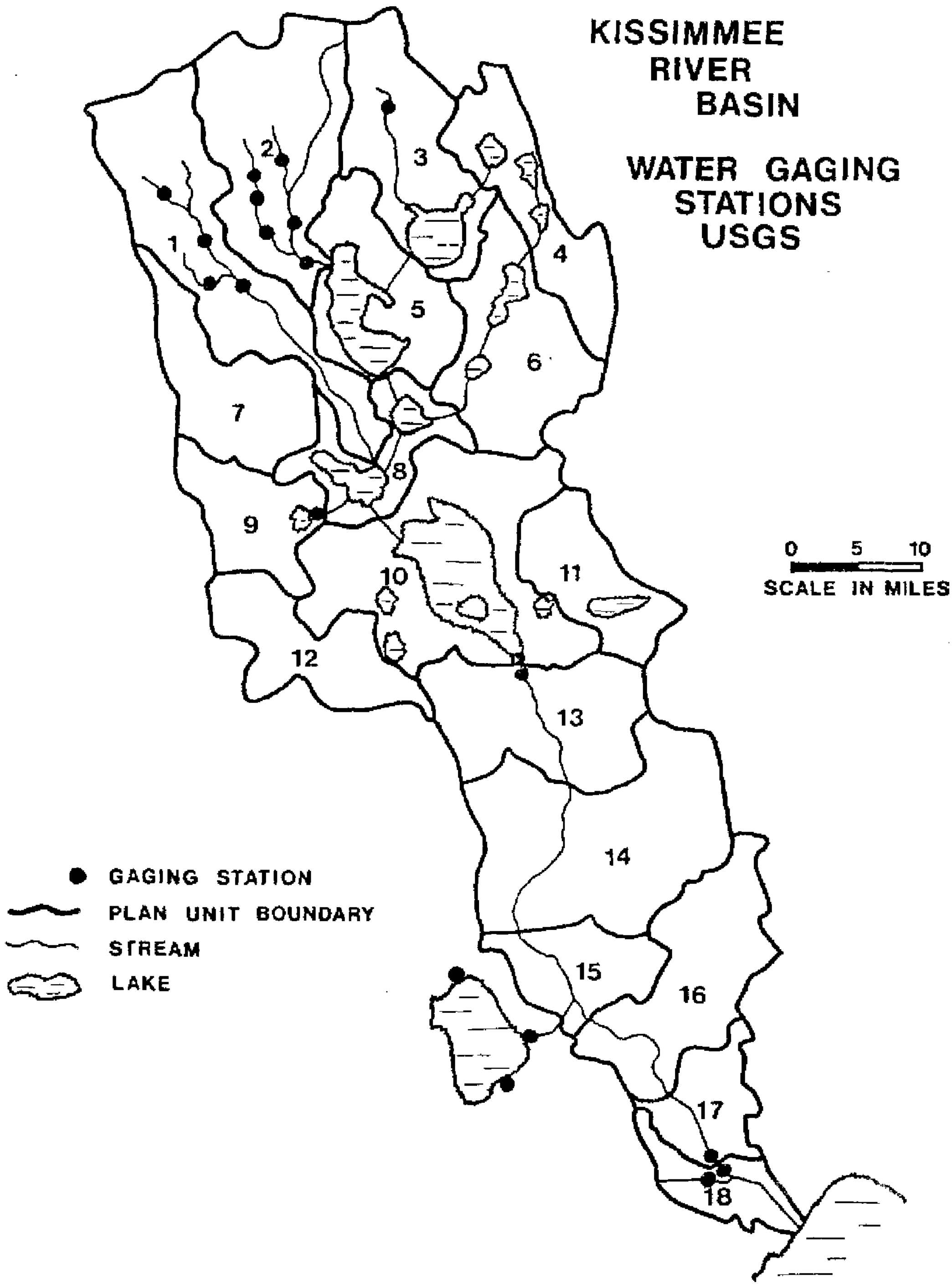

Figure 4.1. USGS Gaging Stations in the Kissimmee River Basin.

The modeling of depressional watersheds requires a strong emphasis on soil storage and evapotranspiration changes over long periods of time. As the soil becomes saturated, the surplus water above the surface is available for runoff at specified rates dependent on the vegetative cover and several other factors. Because the rainy season lasts up to five months in these areas, the model must be capable of simulating long-term seasonal hydrologic response. During the dry season, streamflows are maintained largely by slow seepage of base flow from soil storage. These relationships must also be included in the model. Thus, depressional watersheds are characterized by very slow vertical movements of soil moisture and the water table as a function of rainfall. Lateral runoff is largely determined by land use and soil storage, but is difficult to measure due to poorly defined drainage paths.

In order to provide a realistic simulation for these depressional watersheds, a hydrologic model has been developed based on the daily water balance technique of Thornthwaite (1948). The procedure, discussed in detail in the next section, places primary emphasis on soil storage and potential evapotranspiration dynamics for long-term seasonal effects. This approach is well suited for modeling of depressional watersheds.

The Water Balance

The regional hydrologic analysis is based on a water balance which monitors inputs, outputs, and changes in storage for surface and subsurface components of each soil-land use complex in the basin. The results from these individual budgets are combined for an entire planning unit depending on the soil and land use pattern.

The climatic water balance was first developed by Thornthwaite (1948) in an effort to characterize the moisture condition of an area based on a balance between precipitation (P) which adds moisture to soil storage and evapotranspiration (ET) which removes it. Knowledge of the relationship between P and ET provides information on periods of moisture surplus (S) and moisture deficit (D), which in turn provides data on irrigation requirements, surface runoff, groundwater recharge, and soil moisture storage.

Thornthwaite recognized that the actual water loss from vegetation varied with the amount of moisture in the soil, but it was not until 1955 that modifications were incorporated into the bookkeeping procedure to allow 1) variation in the available soil moisture from a few millimeters to over 300 mm, and 2) variation in the rate of water loss from the vegetated soil surface depending on the existing soil moisture content. These revisions make it possible to include different soils with different water holding capacities as well as different root-zone depths of vegetation. The revised version was published along with detailed instructions on how to evaluate each component in the water balance (Thornthwaite and Mather, 1955).

The various terms and relationships involved in the water balance are shown in Figure 4.2. The budget can be run on a monthly, weekly, or daily basis depending on the desired accuracy. Measured values of precipitation (P) and calculated potential evapotranspiration (PE), which can be determined for a region by any one of the available techniques (Tanner, 1967), provide the initial value of excess precipitation (P-PE). If this value is positive, then soil moisture storage (ST) is increased up to the maximum level (SM), and actual evapotranspiration (AE) equals PE. A water surplus (S) is generated above the ground surface if (P-PE) exceeds (SM-ST) for a given time increment. For this condition,

$$S = (P-PE) - (SM-ST). \qquad (4.1)$$

If the value of (P-PE) is negative, then a loss occurs from soil moisture storage. The loss is not linear, because as the soil dries, plants are less able to remove water via evapotranspiration due to capillary forces. Thornthwaite assumes that the actual amount of removal is proportional to the level of soil moisture content. This condition can be expressed by an exponential relation of the form

$$ST = (SM)\ e^{-(DWL \times AWL)} \qquad (4.2)$$

where

DWL = depletion coefficient, and

AWL = accumulated potential water loss.

Thornthwaite and Mather (1957) have prepared extensive tables of these functions, examples of which, for three levels of SM, are plotted in Figure 4.3. Thus, for the case of curve A, if the accumulated potential water loss is 50 mm, the resulting soil moisture retained (ST) is 60 mm. When plotted on semi-log paper, the data shown on Figure 4.3 appear as straight lines, the slopes of which are the values of DWL.

Because ST is less than SM, the AE term is no longer equal to PE for the case of negative (P-PE). Instead,

$$AE = P + |\Delta ST| \qquad (4.3)$$

where

$|\Delta ST|$ = available moisture which can be removed from the soil, over one time step.

The difference between PE and AE is termed the water deficit (D).

The above figures refer to average rather than instantaneous conditions and cannot adequately represent brief periods of heavy rainfall

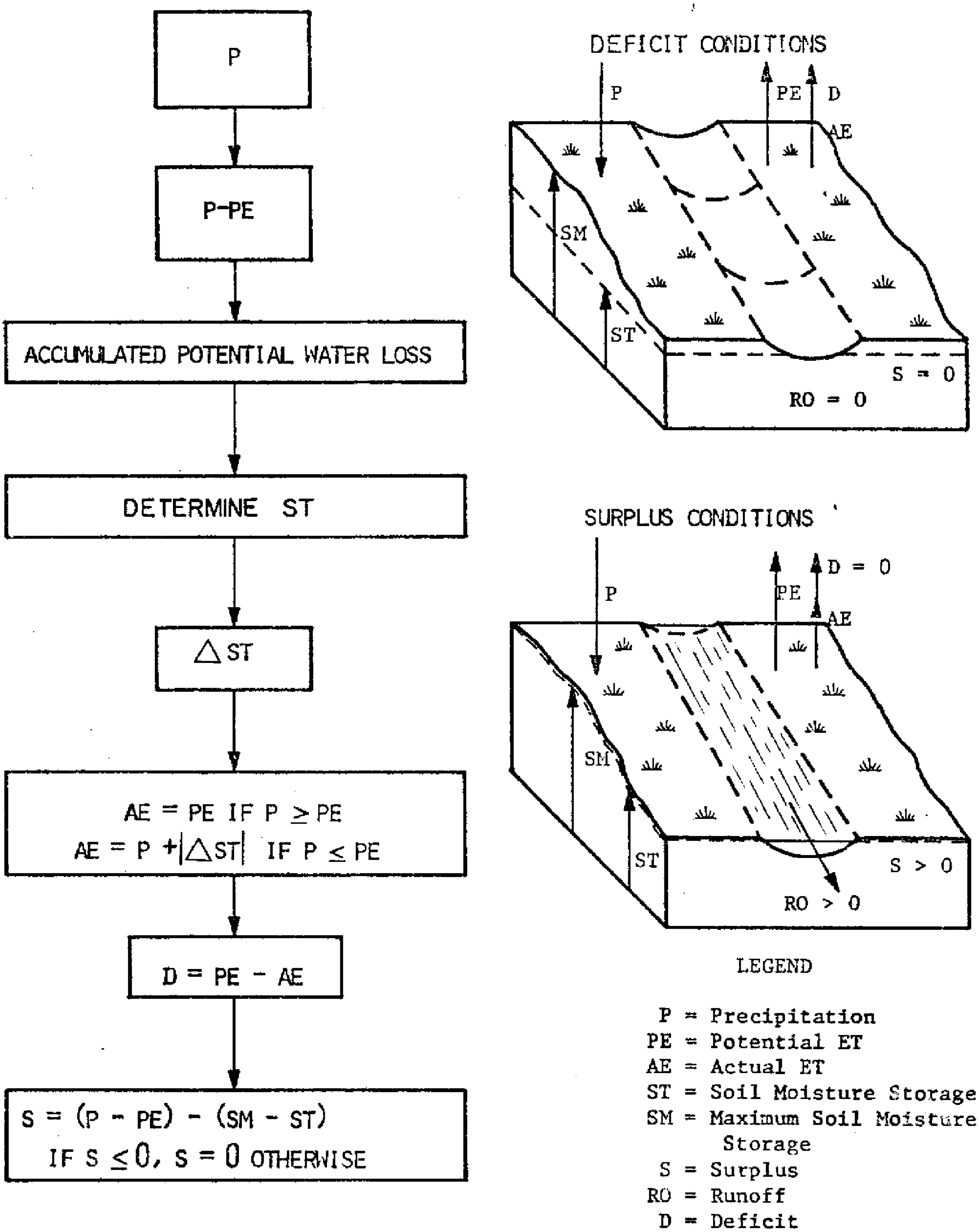

Figure 4.2. Schematic of the Water Balance.

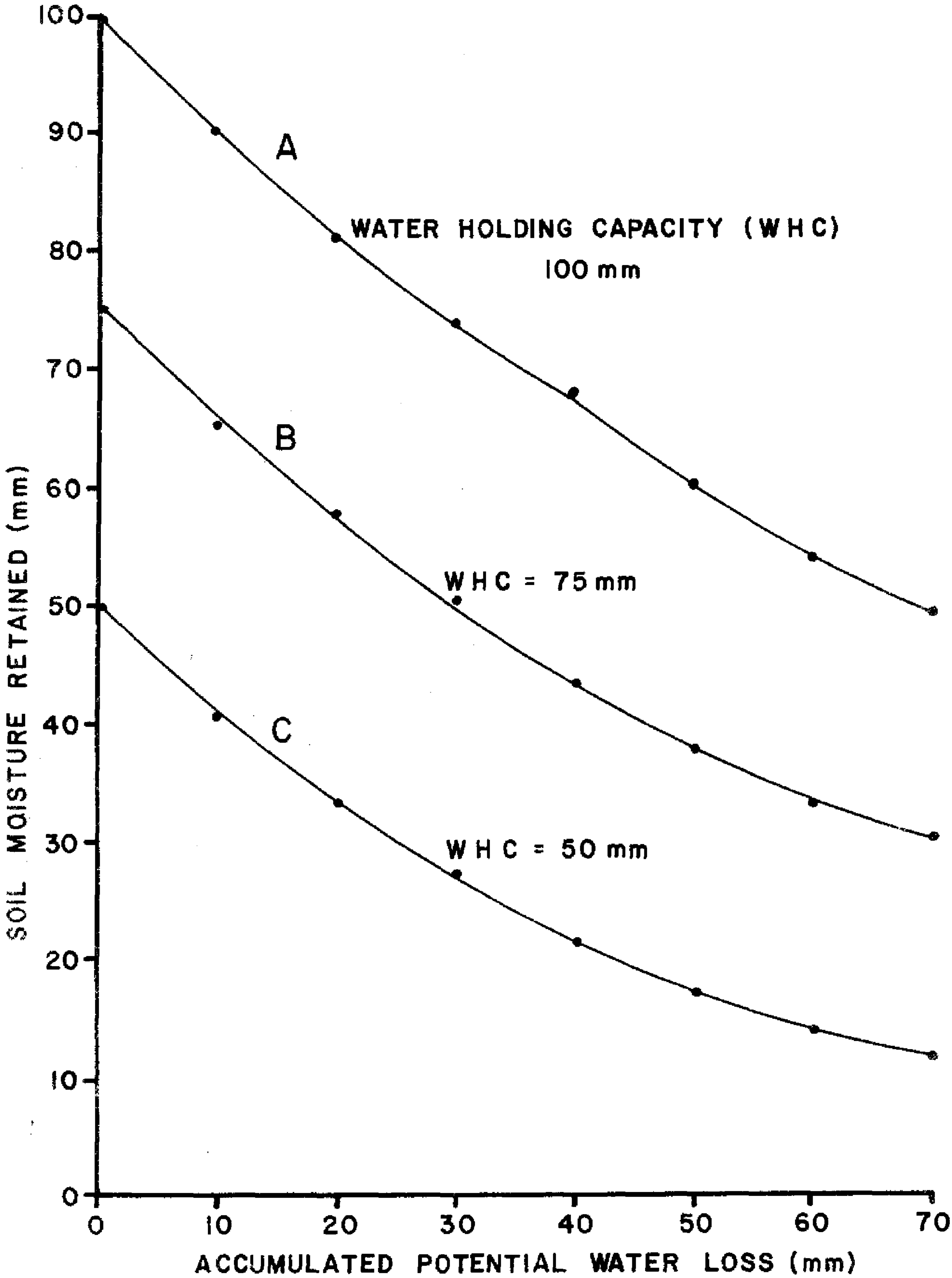

Figure 4.3. Soil Moisture Depletion Curves (Thornthwaite and Mather 1957). For WHC = 100, 75 and 50 mm, values of DWL (equation 4.2) are 0.0104, 0.0139 and 0.0215 mm^{-1} respectively.

or extended drought. Such local conditions can be better modelled using water balance computations on a daily basis.

Information provided by the water balance is useful for many reasons. First, it allows the determination of AE, the actual water loss from plant and soil surfaces, which is usually different from PE. Second, the difference between PE and AE provides a measure of moisture deficit which serves as the basis for calculating irrigation requirements or the extent of drought. Third, when water need is greater than P, that part of the demand met by stored soil moisture can be determined from the water balance. Fourth, when P exceeds water needs, the excess moisture is first used to recharge the soil. The water surplus which remains will be lost either by surface or subsurface runoff and will eventually contribute to streamflow or groundwater recharge.

The water balance technique is a powerful predictive tool for areas undergoing land use and vegetative changes, increased drainage, and/or urbanization. Drainage of land generally causes a reduction in soil storage, an increase in surface runoff, and a decrease in groundwater levels, all of which can be quantified using the water balance. Increases in irrigation requirements can also be predicted based on increasing moisture deficits from drainage.

There are several limitations to the water balance procedure as originally developed. Because of the extensive distribution of soil-land use complexes which occur in a river basin, the technique has been computerized for rapid calculations on a daily basis. In addition, a method has been devised to calculate maximum soil moisture storages (SM) as a function of both soil type and land use, as will be explained below.

Several additions have been incorporated into the water balance to better represent the hydrologic response. These are discussed in detail in the next section. Surplus runoff volumes calculated on a daily basis are constrained to flow at specified rates depending on the soil-cover complex. Estimates of base flow are subtracted from soil storage on a daily basis. Finally, runoff contributions are summed for each planning unit and a flood routing option is available.

HYDROLOGIC-LAND USE MODEL

Land Classification

A hydrologic simulation model has been developed which uses the Thornthwaite water balance to calculate surface and subsurface runoff from the watershed being studied. The model, hereafter referred to as HLAND, determines daily runoff contributions from each soil-land use complex and sums these to give the total runoff from the watershed or planning unit.

Specific areas of soil-land use complexes which comprise the watershed must be supplied to HLAND in the form A(I,J,K) where I is the planning unit, J is the land use, and K is the hydrologic group based on the soil type. For the present scheme, there are 18 planning units or subwatersheds in the basin, seven land use types, and four hydrologic groups.

The breakdown by land use type and hydrologic group is shown in Table 4.1 along with other data discussed subsequently. "Hydrologic groups" 1-4 are based on SCS hydrologic soil groups as indicated. Note that this is a <u>different</u> classification than that used in Chapter III, and was used only for the hydrologic modeling. The land use type "marsh" combines the three land uses marsh, swamp and barren of Chapter III. (Barren is only a small percentage of the combined "marsh" land use.) Each additional land use or hydrologic classification adds another row or column to the table and increases the complexity of the analysis. It was felt that the seven by four breakdown adequately described the basin, although improvements may be warranted. For instance, ditched improved pasture was not included as a land use type because its importance to the study in terms of drainage density and pollutant loading became evident only late in the project, after most of the hydrologic work has been completed. Future efforts might logically include it or other classifications.

It will be of use in later analysis to have the spatial breakdown of the Lower KRB (planning units 13-18) for each of the seven by four land use-hydrologic group combinations. Recalling that this distribution differs from that used in Chapter III, Tables 4.2-4.5 give acres and fractions (of the total 452,000 acres) for each combination for the four years 1958, 1972, 1980 and 2020.

<u>SCS Method</u>

The Soil Conservation Service (SCS, 1969) curve number method has been employed to calculate maximum soil moisture storages SM(J,K) for each soil-land use complex. The rainfall-runoff relations depicted in Figure 3.5 for various curve numbers depend on the following expression (SCS, 1969):

$$\frac{F}{S'} = \frac{Q}{P} \tag{4.4}$$

where

F = actual retention,

S' = potential maximum retention ($S' \geq F$),

Q = actual runoff, and

P = potential maximum runoff = rainfall.

The parameter S' is a constant for a particular storm because it is the maximum that can occur. The actual retention F is a variable depending on the difference, i.e.,

$$F = P - Q. \tag{4.5}$$

Table 4.1. Soils Taxonomy, Curve Numbers, CN, and Maximum Soil Storage, SM, for Hydrologic Simulation of the Kissimmee River Basin

	Hydrologic Group 1	Hydrologic Group 2	Hydrologic Group 3	Hydrologic Group 4
SCS Hydrologic Soil Group[a]	A	C	A/D	B/D
Soils Association	1 St. Lucie 3 Lake 12a Tavares	11 Pomello 15 Adamsville 22 Basinger	13a Myakka 18c Parkwood 23 Pompano 26 Everglades 27 Swamp	13b Immokalee 24a Manatee 24c Felda
Land Use[b]	Curve Numbers and Maximum Soil Storage			
1. Urban	72[c] 3.89[d]	85 1.76	88 1.36	88 1.36
2. Crops	67 4.93	85 1.76	89 1.24	89 1.24
3. Improved Pasture	49 10.41	79 2.66	84 1.90	84 1.90
4. Unimproved Pasture	39 15.64	74 3.51	39 15.64	61 6.39
5. Citrus	72 3.89	88 1.36	91 0.99	91 0.99
6. Forest	45 12.22	77 2.99	45 12.22	66 5.15
7. Marsh	30 23.33	71 4.08	30 23.33	58 7.24

[a]Refer to Table 3.9 for definitions. A group such as B/D refers to the drained/undrained situation. However, the presence of drainage channels (land uses 1, 2, 3, 5) is taken to imply high curve numbers (high direct runoff).

[b]Note: The following land use-hydrologic group combinations are not found in the lower KRB for any of the four dates, 1958, 1972, 1980, 2020; however, values are included in the table for completeness: Urban-1, Crops-1, Forest-1, and Marsh-1.

[c]Average SCS Curve Number, CN, (dimensionless). See also Table 3.10 for representative values.

[d]Maximum Soil Storage, SM, (inches).

Table 4.2. Area (100 acres) and Fraction of Total for each Land Use-Hydrologic Group Combination for Lower KRB (Planning Units 13-18) - 1958

Land Use[a]	Hydrologic Group 1	2	3	4	Total Areas (100 acres)
1. Urban	0 0	0 0	0 0	0 0	0
2. Crops	0 0	0	3 0.0007	0 0	3
3. Improved Pasture	2 0.0004	62 0.0137	99 0.0219	166 0.0367	329
4. Unimproved Pasture	50 0.0111	105 0.0232	1209 0.2674	1442 0.3190	2806
5. Citrus	0 0	3 0.0007	1 0.0002	9 0.0020	13
6. Forest	0 0	12 0.0027	3 0.0007	17 0.0038	32
7. Marsh	0 0	99 0.0219	498 0.1102	740 0.1637	1337
Total Areas (100 acres)	52	281	1813	2374	4520

[a] All entries compiled from tables in Appendix A. Land use "marsh" includes "swamp" and "barren".

Table 4.3. Area (100 acres) and Fraction of Total for each Land Use-Hydrologic Group Combination for Lower KRB (Planning Units 13-18) - 1972

Land Use[a]	Hydrologic Group				Total Areas (100 acres)
	1	2	3	4	
1. Urban	0 0	0 0	11 0.0024	2 0.0004	13
2. Crops	0 0	0 0	15 0.0033	1 0.0002	16
3. Improved Pasture	15 0.0033	81 0.0179	958 0.2119	1178 0.2606	2232
4. Unimproved Pasture	27 0.0060	119 0.0263	525 0.1162	661 0.1462	1332
5. Citrus	10 0.0022	0 0	0 0	0 0	10
6. Forest	0 0	15 0.0033	45 0.0100	15 0.0033	75
7. Marsh	0 0	66 0.0146	259 0.0573	517 0.1144	842
Total Areas (100 acres)	52	281	1813	2374	4520

[a]All entries compiled from tables in Appendix A. Land use "marsh" includes "swamp" and "barren".

Table 4.4. Area (100 acres) and Fraction of Total for each Land Use-Hydrologic Group Combination for Lower KRB (Planning Units 13-18) - 1980

Land Use[a]	Hydrologic Group 1	2	3	4	Total Areas (100 acres)
1. Urban	0 0	1 0.0002	22 0.0048	9 0.0020	32
2. Crop	0 0	0 0	17 0.0038	3 0.0007	20
3. Improved Pasture	18 0.0040	100 0.0221	1142 0.2527	1427 0.3157	2687
4. Unimproved	24 0.0053	94 0.0208	344 0.0761	403 0.0892	865
5. Citrus	10 0.0022	0 0	0 0	15 0.0033	25
6. Forest	0 0	23 0.0051	42 0.0093	15 0.0033	80
7. Marsh	0 0	63 0.0139	246 0.0544	502 0.1111	811
Total Areas (100 acres)	52	281	1813	2374	4520

[a]All entries compiled from tables in Appendix A. Land use "marsh" includes "swamp" and "barren".

Table 4.5. Area (100 acres) and Fraction of Total for each Land Use-Hydrologic Group Combination for Lower KRB (Planning Units 13-18) - 2020

Land Use[a]	Hydrologic Group 1	2	3	4	Total Areas (100 acres)
1. Urban	0	1	77	28	106
	0	0.0002	0.0170	0.0062	
2. Crop	0	17	222	197	436
	0	0.0038	0.0491	0.0436	
3. Improved Pasture	20	175	1035	1702	2932
	0.0044	0.0387	0.2290	0.3766	
4. Unimproved Pasture	12	43	319	160	534
	0.0027	0.0095	0.0706	0.0354	
5. Citrus	20	3	0	0	23
	0.0044	0.0007	0	0	
6. Forest	0	38	50	32	120
	0	0.0084	0.0111	0.0071	
7. Marsh	0	7	107	255	369
	0	0.0015	0.0237	0.0564	
Total Areas (100 acres)	52	284	1810	2374	4520

[a]All entries compiled from tables in Appendix A. Land use "marsh" includes "swamp" and "barren".

Equation 4.4 can be rewritten:

$$\frac{P - Q}{S'} = \frac{Q}{P} . \qquad (4.6)$$

Solving for Q produces the equation:

$$Q = \frac{P^2}{P + S'} \qquad (4.7)$$

which is the rainfall-runoff relation with the initial abstraction ignored. The initial abstraction, I_a, consists mainly of interception, and surface storage, which occur prior to runoff. A relation between I_a and S, which includes I_a, was developed by means of rainfall and runoff data from experimental small watersheds. The initial abstraction is brought into the relation by subtracting it from rainfall, thus yielding, in place of equation 4.4,

$$\frac{F}{S} = \frac{Q}{P - I_a} \qquad (4.8)$$

where $F \leq S$, and $Q \leq (P - I_a)$.

The equivalent of equation 4.7 becomes

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (4.9)$$

which is the rainfall-runoff relation with the initial abstraction taken into account, where

$$S = S' + I_a . \qquad (4.10)$$

The empirical relation between I_a and S from experimental data is

$$I_a = 0.2S . \qquad (4.11)$$

Substituting equation 4.11 into 4.9 yields the final equation:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} . \qquad (4.12)$$

The runoff curve number (CN), is a transformation of S used to make averaging and interpolating operations more nearly linear. Thus, given the curve number CN(J,K) for land use J and hydrologic group K, the associated maximum soil moisture storage in inches is calculated by

$$SM(J,K) = \frac{1000}{CN(J,K)} - 10 \qquad (4.13)$$

Table 4.1 presents the values for SM and CN for the various soil-land use complexes used in the Kissimmee River Basin analysis. Values for different land uses are based on Table 3.10.

Changing land use patterns tend to decrease available soil storage when moving toward the future. An indication of the magnitude of this change may be seen if average values of SM are computed for the Lower KRB. This is accomplished by weighting the SM values in Table 4.1 by corresponding fractions in Tables 4.2-4.5. The results are shown in Table 4.6.

Table 4.6. Maximum Average Soil Storages for Planning Units 13-18.

Land Use	SM (inches)
1958	10.51
1972	6.31
1980	5.40
2020	4.04

It may be seen that available soil storages are more than halved when moving from 1958 to 2020. The implication is that there will be a shift toward a greater percentage of surface runoff, as will be seen.

Surface Runoff

As described earlier, if soil storage (ST) is at a maximum (i.e., equal to SM) and if a rainfall quantity is more than enough to satisfy potential evaporation, then surplus water is available above the ground surface for direct runoff: overland flow, interflow and channel flow. (Interflow is flow that passes through the near-surface soil zone on its way to a channel.) Thornthwaite and Mather (1955) do not distinguish between these runoff types nor route this surplus in a hydrologic sense; they only remove it in an exponential fashion described below. This procedure is also followed in HLAND, in which surplus volumes are not explicitly routed through a planning unit but rather lumped into an overall daily direct runoff volume. The actual lag and attenuation of such runoff volumes are approximated using Thornthwaite and Mather's exponential runoff procedure; a useful extension of HLAND might be the inclusion hydrologic routing of direct runoff within a planning unit. However, such an extension would be at the expense of considerable added complexity to the computer program and is most likely not warranted if predictions of hydrographs are desired only at the outlets of planning units. (In HLAND, these hydrographs are then routed down the length of the Kissimmee River, as described in Chapter V.)

Direct runoff is delayed and attenuated by specifying that a fraction, CDET(J,K), of the available surplus water will remain on the land per day. Thus, the lower the value of the detention constant, CDET, the faster the rate of runoff from a given soil type-land use complex. Thornthwaite and Mather provide little information on how to calculate these values. In their 1955 publication they indicate (page 92) that for a large watershed only about 50 percent of the surplus water that is available in any month actually does run off. They also report (pages 24 and 96) for a 40 inch loam soil that about 90 percent of the gravitational water (available for either surface or subsurface runoff) is held over in the soil until the next day, with the percentage becoming smaller as the soil layer thickness decreases and as the amount of sand increases. Similar brief comments about detention constant values are made in their 1957 publication on pages 193 and 198.

Since direct runoff includes interflow, there is some delay in the actual conversion of rainfall to direct runoff. That is, if 50 percent of a daily rainfall amount will appear as direct runoff, it does not necessarily mean that the direct runoff all occurs on the same day. In general, however, the greater the volume of available surplus water, the faster it will run off. Note that HLAND (and the Thornthwaite and Mather technique) assumes that <u>all</u> of the surplus water will eventually appear as runoff; the values of CDET merely delay it.

In the absence of "hard" data, estimates of detention constants were based upon analogy with SCS curve numbers (CN). As shown in Figure 3.5, the higher the CN, the greater the percentage of rainfall that appears as direct runoff, and, as explained in the preceeding paragraph, the faster it is presumed to run off. Values of CDET used in the research are shown in Table 4.7 under the <u>assumption</u> that soils that are well drained under natural conditions (SCS Hydrologic Soil Group A) would have about 10 percent of available surplus water appear as direct runoff per day, while soils that are poorly drained under natural conditions <u>or</u> drained by channels under developed conditions have as much as 40 percent per day. Thus, in general, land use-hydrologic group combinations (Table 4.1) with curve numbers less than 70 have CDET values of 0.9 while curve numbers near 90 have CDET values of 0.6. Variance from this generalization (e.g., unimproved pasture-hydrologic group 4) is due to an attempt to distinguish between radically different curve numbers for the same land use.

Note that CDET values increase (CN decreases) when moving into hydrologic groups 3 and 4 for land uses unimproved pasture, forest and

Table 4.7. Detention Constants, CDET, Used for Delay of Direct Runoff[a], and Equivalent Detention Times, T, (days).

Land Use[b]	Hydrologic Group 1	2	3	4
1. Urban	0.0[c] 0.0[d]	0.0 0.0	0.0 0.0	0.0 0.0
2. Crops	0.9 9.49	0.7 2.80	0.6 1.96	0.6 1.96
3. Improved Pasture	0.9 9.49	0.7 2.80	0.6 1.96	0.6 1.96
4. Unimproved Pasture	0.9 9.49	0.7 2.80	0.9 9.49	0.8 4.48
5. Citrus	0.9 9.49	0.7 2.80	0.6 1.96	0.6 1.96
6. Forest	0.9 9.49	0.7 2.80	0.9 9.49	0.8 4.48
7. Marsh	0.9 9.49	0.7 2.80	0.9 9.49	0.8 4.48

[a]Direct runoff is overland flow, interflow and channel runoff.

[b]Note: The following land use-hydrologic group combinations are not found in the lower KRB for any of the four dates, 1958, 1972, 1980, 2020; however, values are included in the table for completeness: Urban-1, Crops-1, Forest-1, and Marsh-1.

[c]Value of CDET = fraction of direct runoff remaining on land, per day. See text for source of values.

[d]Equivalent detention time, T, (days) calculated from equations 4.15 and 4.16.

marsh. This is because they are assumed to retain their natural characteristics of low runoff (volume and rate) when they are developed, whereas land uses crops, improved pasture and citrus evince the reverse. That is, the latter three land uses exhibit faster runoff rates because of the channelization required for drainage. Urban land use produces very rapid direct runoff rates even in Florida where a larger portion may appear as interflow while en route to drainage channels. Hence, it is reasonable to assume that all direct runoff from urban areas occurs within one day (i.e., CDET = 0.0).

An equivalent exponential decay coefficient may be derived for a CDET value by noting that

$$CDET^{n} = e^{-kn\Delta t} , \qquad (4.14)$$

hence

$$k = \frac{1}{\Delta t} \ln CDET \qquad (4.15)$$

where k = equivalent decay coeffficient, day^{-1},

Δt = time step = 1 day for values of CDET used, and

n = number of time steps.

Average detention time in days is then

$$T = 1/k \qquad (4.16)$$

These values are also shown in Table 4.7.

Soil Moisture

Depletion coefficients are required by HLAND to describe the exponential loss of soil moisture due to evapotranspiration (ET) in the water balance procedure. These are simply the constants, DWL, of equation 4.2 used to fit the data shown in Figure 4.3. Thornthwaite and Mather (1957) provide extensive tables of soil moisture retained (ST) versus accumulated potential water loss (AWL) from which straight-line fits (visual) on semi-log plots provided values of DWL for several values of maximum soil storage (SM). The value of DWL is a function only of

SM and decreases gradually as SM increases. This is a reflection of the greater depth occupied by water in soils with high values of SM (as indicated in Table 4.1). The deeper the water, the more difficult it is for ET to occur, (as implied by a low value of DWL). Since Thornthwaite and Mather (1957) indicate (page 244) that the principal decision lies in choosing the value of SM, their data for the depletion coefficients are assumed applicable to Florida. In HLAND, the value of SM is determined by analogy to the SCS procedure, as discussed previously.

Values of DWL used in HLAND are shown in Table 4.8. They correspond to the values of SM (and curve numbers) given in Table 4.1 and are found by linear interpolation between values calculated from the tables in Thornthwaite and Mather (1957). Extrapolation was used for the one value of SM (23.33 in.) outside the range of their tables. Correspondence with curve numbers accounts for all variations within the table.

Table 4.8. Depletion Coefficients, DWL, Used for Exponential Fit of Soil Moisture Depletion Curves (Figure 4.3).

	Depletion Coefficients (mm^{-1})			
	Hydrologic Group			
Land Use[a]	1	2	3	4
1. Urban	.010	.0232	.030	.030
2. Crops	.00815	.0232	.0328	.0328
3. Improved Pasture	.00406	.0153	.0214	.0214
4. Unimproved Pasture	.00256	.0116	.00256	.00638
5. Citrus	.010	.030	.0406	.0406
6. Forest	.0339	.0136	.0339	.00815
7. Marsh	.00177	.010	.00177	.00563

[a]Note: The following land use-hydrologic group combinations are not found in the lower KRB for any of the four dates, 1958, 1972, 1980, 2020; however, values are included in the table for completeness: Urban-1, Crops-1, Forest-1, and Marsh-1.

Base Flow

Base flow contributions may represent a significant contribution to overall streamflow volumes. During dry portions of the year, stored soil moisture and groundwater seep slowly toward the river following the gradient of the land. During flood times, base flow may contribute large volumes for many days following heavy rainfall events, due to the saturation of the soil system. The rate of base flow is determined by particular characteristics of the geology, topography, and soils of a region. Base flow does not include interflow, a direct runoff component.

Base flow as a function of total storage (soil moisture plus surface storage) has been determined for the total 3260 mile^2 KRB by Langbein (1955) and is depicted in Figure 4.4. Note that the abscissa of Langbein's relation is total storage: soil moisture plus storage in lakes, swamps, surface and water table. It was obtained through the technique of hydrograph separation for 15 years of streamflow data for the Kissimmee River. In developing the relations Langbein noted (p. 545) that the average lag for base flow from time or rainfall to time of appearance at the outlet to Lake Okeechobee is 3.5 months for the period he studied, 1931-1946. This is for the total basin and includes travel time through the soil as well as through channels. Assuming that the time would be roughly halved for travel time through the lower basin alone, an approximate total travel time of 50 days may apply for the lower KRB prior to 1946.

Since the relationship of Figure 4.4 is for the total KRB, it is not possible to use it directly in HLAND. Moreover, it is unclear what fraction soil storage (ST) is of Langbein's total storage. Hence, an equation is used of the following form.

$$Q_B = \begin{cases} BF\ e^{\frac{BK\ (ST+SU)}{10}} & \text{for } ST+SU \geq 0.3SM \\ 0 & \text{for } ST+SU < 0.3SM \end{cases} \qquad (4.17)$$

where Q_B = base flow from PU 13-17 (423,300 ac), cfs,

ST = average soil moisture storage over area, in.,

SU = average surplus moisture (available for direct runoff) over area, in.,

SM = average maximum soil moisture storage over area (from Table 4.6) in., and

BF, BK = constants described below.

Values of the constants, BF and BK, are obtained by calibrating against low flows for the years 1958 and 1972 and are given in Table 4.9. The resulting equations are plotted in Figure 4.5.

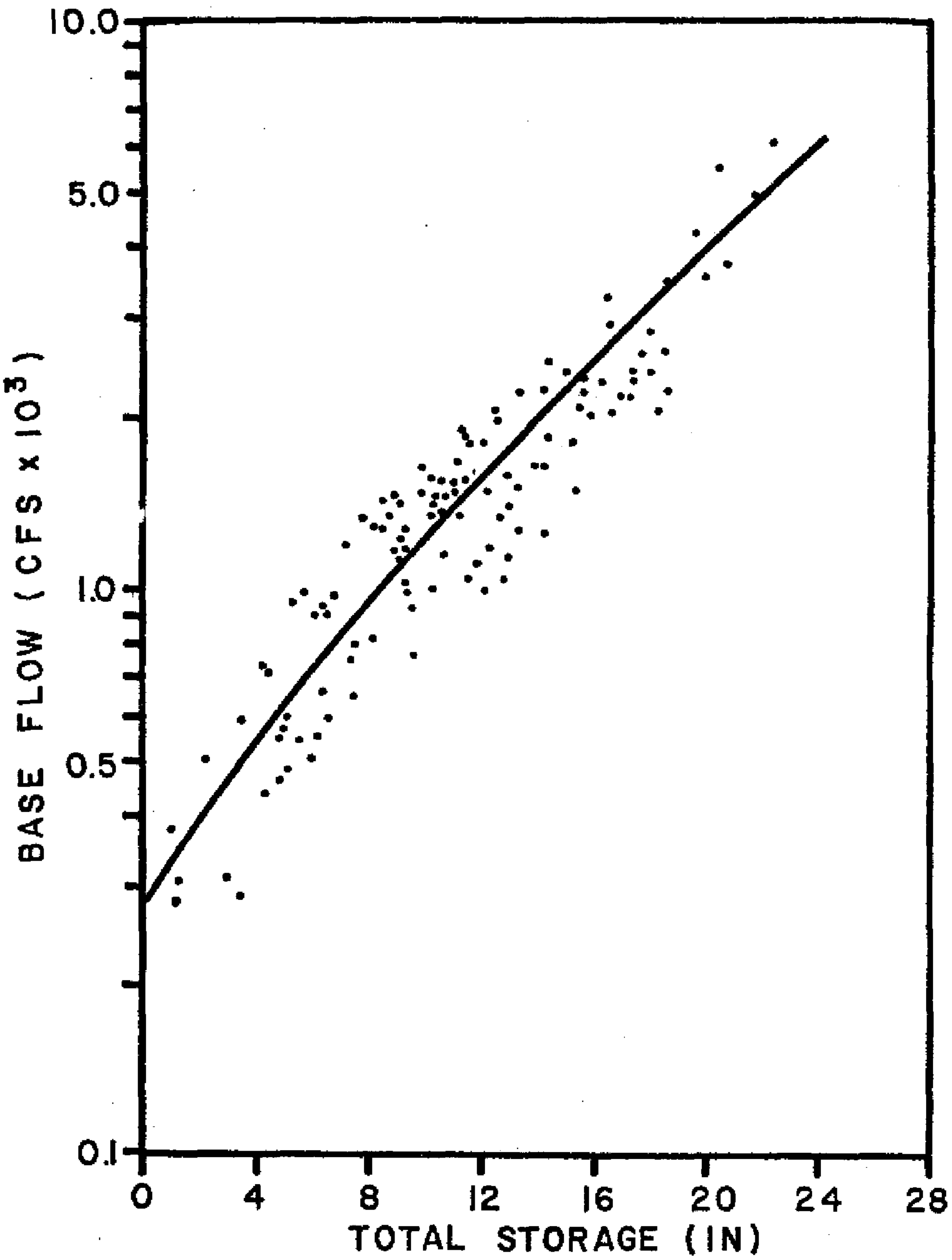

Figure 4.4. Relationship Between Total Storage (Ground and Surface Waters) and Base Flow for Entire Kissimmee River Basin (Langbein, 1955).

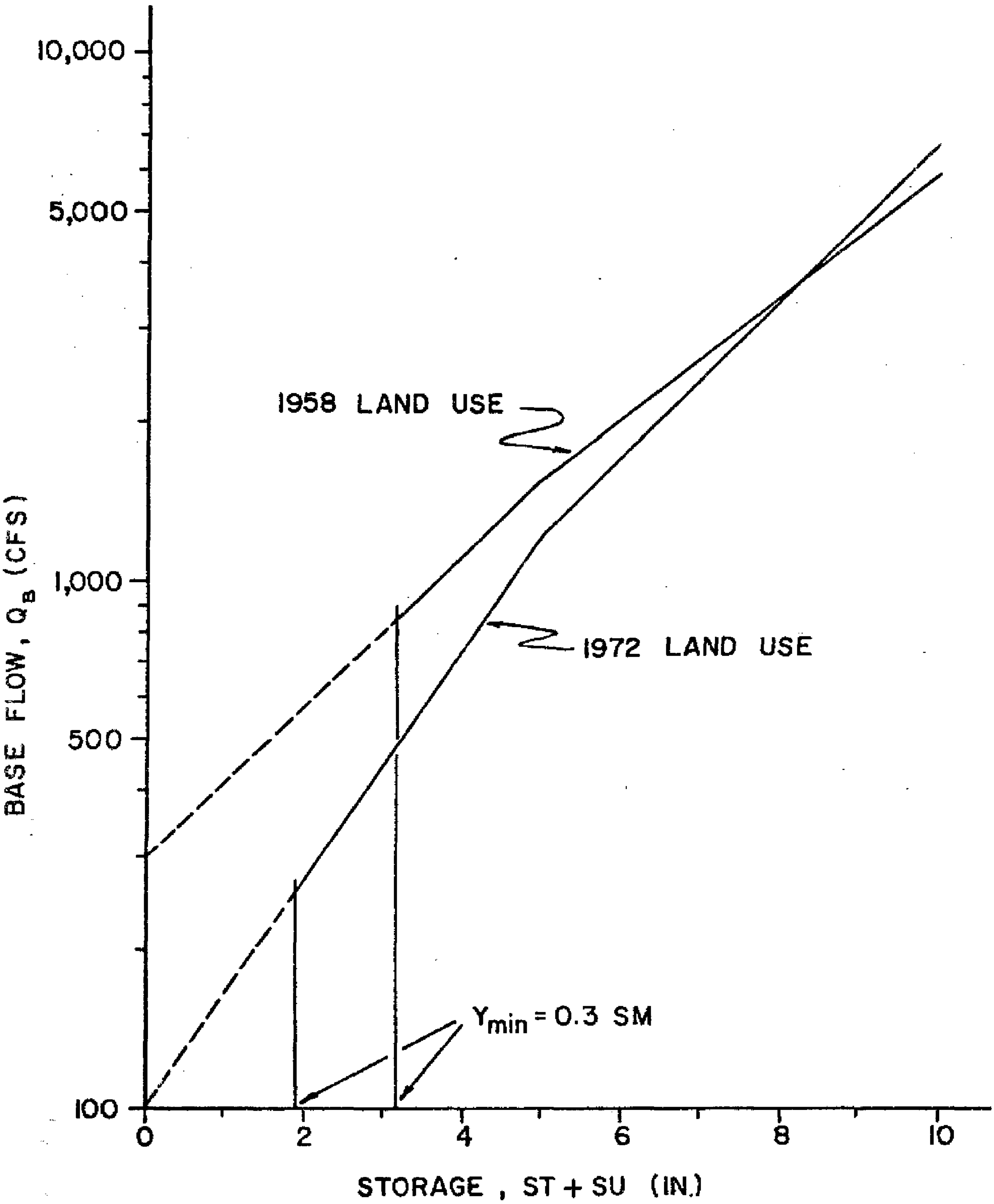

Figure 4.5. Base Flow Relationships (Equation 4.17) Used in HLAND.

Table 4.9. Values of Base Flow Parameters for Equation 4.17.

Land Use	ST + SU (in.)	BF (cfs)	BK
1958	$\leq$ 5.0	300	3.32
	$\geq$ 5.0	400	2.70
1972[a]	$\leq$ 5.0	100	4.97
	$\geq$ 5.0	200	3.67

[a]Values for 1972 were also used for 1980 and 2020 in the absence of calibration data for these future years.

Use of the values given in Table 4.9 provided reasonable agreement between predicted and measured lower basin flows as seen from calibration run described in Chapter V. It should be noted that the use of Equation 4.17 with values from Table 4.9 predicts considerably lower base flows for 1972 than for 1958 for values of ST + SU less than about 5 in. This is a consequence of lower measured base flows that year which, in turn, may be due to increased drainage that occurred in the 14-year interval. The reduction may also be seen in Figure 4.5.

Equation 4.17 is applied to individual planning units by taking the average value of ST + SU over a planning unit and multiplying the resulting Q_B by the fraction of total lower basin area occupied by that planning unit. Base flows from individual planning units are eventually routed down the Kissimmee River, along with direct runoff.

When base flow occurs it is due to release of a fixed number of inches of storage. These inches are back-apportioned over each land use-hydrologic group combination in the planning unit on the basis of the ratio of the ST value for that particular combination to the average value for the planning unit, such that combinations with higher values of ST have relatively more inches subtracted for base flow.

The overall base flow technique adopted for HLAND is open to refinement. For example, Langbein's procedure could be applied to lower basin flows to develop a relation similar to Figure 4.4 but for lower basin flows alone. There is also a need to relate base flow directly to soil moisture. However, the method described represents only the first analysis and may easily be changed if HLAND is altered in the future.

Rainfall

Daily rainfall totals are input to HLAND for the length of the simulation period. Point estimates of rainfall from available U. S. Weather Service rain gages are distributed over the region using the Thiessen polygon technique. The gages and associated Thiessen weights used in the simulation are shown in Table 4.10.

Overall Model

Once surface and subsurface contributions of runoff are calculated for each land use-hydrologic group combination in a planning unit, these are summed over all A(I,J,K) components to yield a total daily runoff from the planning unit. Model output is sensitive to at least three parameters: 1) the rainfall distribution, 2) the maximum soil storage levels, and 3) the soil-land use distribution. Any errors in averaging the daily rainfall values between the few rain gages in the basin are amplifed in the surface runoff predictions. Errors in estimating areas of various land uses from aerial photographs for 1958 and 1972 regimes also affect model output. Predictions for future land use patterns obviously determine to a large extent the type of model response to be expected. Finally, errors in superimposing land uses and soil types and in estimating maximum soil storages from curve numbers provide additional reasons for any observed differences between measured and predicted hydrographs.

The flood routing section provides a detailed description of the calibration phase of HLAND for a series of historical years in the basin. Following this, a complete range of predictive tests are carried out for projected future land use patterns and control strategies in the basin. These results provide the essence of the regional analysis in the Kissimmee River Basin, and provide valuable information for further detailed studies along the river.

Calculated Detention Times

The base flow relation for the lower KRB, equation 4.17, may be analyzed to give an indication of detention (travel) time experienced in

Table 4.10. Thiessen Weights and U.S. Weather Service Rainfall Stations Used in Simulations.

	Thiessen Weights										
	Station No.										
PU	1	2	3	4	5	6	7	8	9	10	11
1								.03	.72	.25	
2	.27								.68	.05	
3	.31	.34							.35		
4		.98	.02								
5									1.0		
6		.39	.41						.20		
7								.24	.32		.44
8			.08					.61	.31		
9								.89			.11
10			.51					.49			
11			1.0								
12								.11	.89		
13			.66	.05			.25	.04			
14			.08	.37		.30	.25				
15						1.0					
16				.42	.01	.57					
17					.52	.48					
18					.87	.13					

Station No.	Name	Station No.	Name
1.	Orlando	7.	Avon Park
2.	Hart Lake	8.	Mountain Lake
3.	Nittaw	9.	Kissimmee
4.	Fort Drum	10.	Clermont
5.	Okeechobee	11.	Lake Alfred
6.	Cornwell		

this flow regime. Base flow per unit area is Q_B/A. When the reciprocal is multiplied by the storage depth, the average base flow detention time for the lower basin is obtained, assuming no effect of drainage density. That is, the resulting equation will give detention times as if subsurface water were flowing through the natural lower basin toward the Kissimmee River. The effects of upland drainage are considered explicitly in the subsequent discussion of drainage density. The resulting equation is

$$T = \frac{A\ y}{1.98\ Q_B\ 12} \simeq \frac{A\ y\ e^{-\frac{BK\ y}{10}}}{24\ BF} \qquad (4.18)$$

where T = detention time, days

$y = ST + SU$ = soil moisture plus surplus storage, in.,

A = area of PU 13-17 = 423,300 ac,

Q_B = base flow from equation 4.17, cfs,

with parameters BF and BK from Table 4.9, 1.98 converts cfs to ac-ft/day and 12 converts inches to feet. Equation 4.18 may be used to estimate detention times for various storage levels or integrated to provide average values. These are shown in Table 4.11. After climbing to a maximum from the initial minimum at zero, T decreases as storage increases because the storage increases linearly while the base flow rate increases exponentially. Values are generally higher in 1972 than in 1958 because of the greatly increased slope of the Q_B versus y relationship for 1972 shown in Figure 4.5. That is, T is proportional to y/Q_B. It is evident from Figure 4.5 that the same y produces a much lower Q_B in 1972 than in 1958 over the lower range of storages.

Clearly a wide range of detention or travel times exists, depending upon the assumed storage. (However, bear in mind that effects of upland drainage have not yet been considered.) The range of storage values actually experienced during the HLAND simulations may be deduced from HLAND results, described subsequently. From the minimum and maximum base flows from the simulation, the range indicated in Table 4.12 may be derived by substitution into equation 4.17. Average detention times for these ranges are included in Table 4.11. Interestingly, the value of 50 days (including channel travel) inferred from Langbein's results may not be far off.

Table 4.12. Range of Storages During HLAND Simulations

Land Use	Min Q_B[a] (cfs)	Date	y_{min} (in)	Max Q_B[a] (cfs)	Date	y_{max} (in)
1958	0	4,5/67	3.15[b]	2,635	6/68	7.0[c]
1972	0	4,5/67	1.89[b]	1,220	6/68	5.0[c]

[a]From Tables 4.15 - 4.20.

[b]y_{min} = 0.3 times average SM, Table 4.6.

[c]y_{max} by solution of equation 4.17.

Table 4.11. Base Flow Detention Times for Planning Units 13-17 (Equation 4.18) With No Effect of Drainage Density

y = ST + SU[a] (in)	T (days)	
	1958	1972
0	0	0
1	45	115
2	65	139
3	70	127
4	67	103
5	60	77
6	56	62
7	50	51
8	43	40
9	37	31
10	32	24
Ave 0-5[b]	53	101
Ave 5-10[b]	44	44
Ave 0-10[b]	48	73
Ave 3.15-7.0[b,c]	56.7	--
Ave 1.89-5.0[b,c]	--	107.4

[a]Sum of soil moisture, ST, plus surface storage, SU.

[b]Average by integration of equation 4.18.

[c]Average over range experienced during simulation. See subsequent analysis.

The preceding analysis of base flow detention times provides an average for the lower KRB acting as a whole; differences within individual planning units are not considered. The latter effect may be important since it is expected that areas with high drainage density, for instance, will allow more rapid drainage of base flow than areas with lower drainage density. Unfortunately, this was not possible within the scope of the study (although base flows from individual planning units are routed down the Kissimmee River as part of HLAND). However, the effect of drainage density on the overall subsurface detention time is considered at the end of this chapter. Final values are given there.

A similar anlaysis was carried out for surface runoff from soil-land use complexes. Detention storage constants CDET(J,K), defined previously and listed in Table 4.7, constrain the runoff rate from each land use in direct proportion to the amount of surplus water. Equivalent decay coefficients and average detention times may be calculated from equations 4.15 and 4.16 and are also presented in Table 4.7. The values range from 2.0 to 9.5 days, considerably less than the range for soil storage.

From the above analysis, average values of T can be calculated for an entire planning unit or basin if the land use-hydrologic group distribution is known. Recalling that this distribution differs from that used in Chapter III, the fractions in Tables 4.2-4.5 may be used to weight corresponding entries in Table 4.7. Average detention times for direct runoff for the lower basin so computed are shown in Table 4.13.

Table 4.13. Average Direct Runoff Detention Times for Planning Units 13-18.

Land Use	T (days)
1958	6.07
1972	4.13
1980	3.15
2020	2.65

As expected, detention times decrease with changing land use because of more rapid drainage mechanisms associated with development. Although lag effects due to hydrologic routing of flows within a planning unit are not explicitly considered, recall that surface detention coefficients, CDET, are chosen to simulate this effect on an overall planning unit basis. Of course, lag effects due to routing down the Kissimmee River are considered explicitly in Chapter V.

Results of HLAND Analysis

The predicted monthly surface and subsurface runoff for planning units 13-17 for 1958, 1972 and 2020 land use conditions are presented in Tables 4.15 to 4.23. Summary totals, illustrating the effect of land use changes, are shown in Table 4.24. For comparison purposes, measured runoff volumes from the lower KRB are given below in Table 4.14. These were computed from USGS streamflow records by subtracting from measured flows at S65-E (entire basin) the measured flows at S65 (upper basin) and flows from Lake Istakpoga.

Table 4.14. Measured Lower KRB Runoff Volumes.

Calendar Year	Annual Runoff (1000 ac-ft)
1967	125
1968	578
1969	819

The measured runoff predicted by HLAND for 1972 land use (Table 4.24) may be compared with the values in Table 4.14. The years 1968 and 1969 compare well, but predicted runoff for 1967 is considerably higher than measured. Of course HLAND is run under constant 1972 land use conditions so the comparison is only approximate in any event. However, since the base flow relation was not calibrated for 1967, it apparently predicts values that are too high in this instance.

Table 4.24 illustrates the expected shift between surface and subsurface (base) flows with changing land use. Under 1958 land use conditions, for example, about 14 percent of the runoff occurred as surface flow compared to 48 and 67 percent for 1972 and 2020, land uses respectively. This is caused by drainage practices associated with development (which alter SCS curve numbers in HLAND).

The total volume of runoff is greater under 1958 conditions compared to 1972 and 2020. That is, the subsurface runoff decreases by more than surface runoff increases. The main reason for this is the altered base flow relation (equation 4.18 and Figure 4.5) used for the different periods. The equation and parameters were derived by calibration against flows and rainfall in 1958 and 1972; hence, they are

Table 4.15. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 1958 Land Use and 1967 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	0	0	0	0	1.6	.6	1.6	.4	.2	0	.1	4.5
13 (G)	1.5	4.2	2.2	0	0	3.4	8.5	13.0	7.7	5.5	0	2.7	48.7
14 (S)	0	.1	0	0	0	.1	.3	0	.4	.4	0	0	1.3
14 (G)	1.5	8.9	6.7	0	0	4.6	19.0	14.0	17.0	21.0	3.2	5.5	101.4
15 (S)	0	.1	0	0	0	.4	0	0	2.6	2.9	0	0	6.0
15 (G)	1.0	4.1	2.8	0	0	3.7	2.7	2.9	10.0	15.0	2.4	2.2	46.8
16 (S)	0	.1	0	0	0	.1	.1	0	.7	1.0	0	0	2.0
16 (G)	1.6	10.0	6.8	0	0	5.7	13.0	6.8	18.0	27.0	4.0	4.9	97.8
17 (S)	0	.1	0	0	0	0	0	0	.8	4.1	0	0	5.0
17 (G)	.6	2.8	2.1	0	0	1.2	3.1	.3	7.1	13.0	1.2	1.4	32.8
Total	6.2	30.4	20.6	0	0	20.8	47.3	38.6	64.7	90.1	26.3	16.8	346.3
Peak [a] (1000 cfs)	.6	1.0	.9	.4	.7	.8	1.4	2.3	3.6	3.9	.6	.7	

[a] Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.16. Predicted Surface (S) and Subsurface (G) Runoff (1000 acre-feet) by Planning Unit 1958 Land Use and 1968 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	0	0	0	2.8	18.0	13.0	0	1.1	3.6	.4	0	38.9
13 (G)	9.3	5.2	4.1	0	3.6	28.0	26.0	6.6	7.3	13.0	11.0	2.9	117.0
14 (S)	0	0	0	0	.2	21.0	16.0	0	0	.6	0	0	37.8
14 (G)	15.0	8.8	6.8	0	3.1	49.0	37.0	8.1	7.7	13.0	14.0	2.8	165.3
15 (S)	0	0	0	0	.7	5.7	.1	.3	.3	.3	0	0	7.4
15 (G)	6.9	3.1	2.6	0	2.4	21.0	6.4	3.2	8.5	7.4	2.9	0	64.4
16 (S)	0	0	0	0	.2	6.6	3.6	0	0	.5	0	0	10.9
16 (G)	18.0	8.0	5.2	0	2.8	45.0	30.0	7.2	11.0	15.0	12.0	.6	154.8
17 (S)	0	0	0	0	.1	6.6	.3	0	.3	.2	0	0	7.5
17 (G)	5.9	2.8	1.2	0	.7	16.0	9.0	2.2	6.3	5.3	4.2	.5	54.1
Total	55.1	27.9	19.9	0	16.6	216.9	141.4	27.6	42.5	58.9	44.5	6.8	658.1
Peak[a] (1000 cfs)	1.5	.8	.7	.2	1.4	6.9	8.1	4.2	3.3	3.0	1.3	.5	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.17. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 1958 Land Use and 1969 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	.2	0	8.0	1.9	3.9	1.5	.9	.3	.3	26.0	0	.3	43.3
13 (G)	7.2	4.0	19.0	9.6	18.0	11.0	9.7	16.0	7.6	29.0	11.0	8.8	150.9
14 (S)	0	0	5.9	.5	1.6	.3	.2	1.0	0	42.0	0	.1	51.6
14 (G)	11.0	6.6	33.0	15.0	31.0	18.0	15.0	27.0	12.0	45.0	16.0	13.0	242.6
15 (S)	0	0	1.3	.3	5.4	.2	.1	.5	0	7.2	0	0	15.0
15 (G)	4.1	2.1	11.0	5.4	11.0	6.4	5.4	9.4	4.2	18.0	6.1	4.5	87.6
16 (S)	.3	0	2.0	.3	.6	.2	.1	.6	0	17.0	0	0	21.1
16 (G)	11.0	5.6	29.0	14.0	28.0	17.0	14.0	25.0	11.0	47.0	16.0	12.0	229.6
17 (S)	0	0	1.2	.2	.3	.2	.1	.3	0	9.3	0	0	11.6
17 (G)	3.6	1.8	10.0	4.4	9.5	5.4	4.6	8.2	3.5	14.0	4.9	3.5	73.4
Total	37.4	20.1	120.4	51.6	109.3	60.2	50.1	88.3	38.6	254.5	54.0	42.2	926.7
Peak[a] (1000 cfs)	4.3	1.1	6.7	4.5	3.8	2.5	1.2	2.3	4.4	17.8	4.2	5.5	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.18. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 1972 Land Use and 1967 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	0	0	0	0	3.3	1.3	3.2	.9	.4	0	0	9.1
13 (G)	.7	3.7	1.8	0	0	2.9	6.9	9.7	6.6	4.7	0	2.5	39.5
14 (S)	0	1.4	0	0	0	1.7	4.2	0	4.8	2.9	0	0	15.0
14 (G)	.4	6.3	5.3	0	0	4.0	13.0	10.0	12.0	14.0	3.2	4.4	72.6
15 (S)	0	.8	0	0	0	2.1	0	0	6.7	5.7	0	0	15.3
15 (G)	.3	2.6	2.2	0	0	2.4	2.0	2.1	6.1	9.4	2.6	1.9	31.8
16 (S)	0	5.1	.1	0	0	5.0	4.4	0	19.0	13.0	0	0	46.6
16 (G)	.3	2.8	2.4	0	0	2.6	4.0	2.5	3.5	4.4	1.8	2.2	26.5
17 (S)	0	1.3	0	0	0	.6	0	0	9.6	8.9	0	0	20.4
17 (G)	.1	.9	.8	0	0	.8	1.1	.1	1.7	2.1	.8	.9	9.3
Total	2.0	24.9	12.6	0	0	25.4	36.9	27.6	70.9	65.5	8.4	11.9	286.1
Peak[a] (1000 cfs)	.3	1.7	.6	.4	.7	1.8	1.5	2.1	5.7	4.5	.4	.5	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.19. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 1972 Land Use and 1968 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	0	0	0	5.6	23.0	14.0	0	2.3	6.6	.8	0	52.3
13 (G)	.9	2.0	2.9	0	2.9	21.0	21.0	6.0	6.5	11.0	8.8	3.1	86.1
14 (S)	0	0	0	0	3.8	38.0	25.0	0	0	6.0	0	0	72.8
14 (G)	2.0	2.9	4.5	0	2.3	31.0	24.0	6.9	6.4	8.9	10.0	3.2	102.1
15 (S)	0	0	0	0	3.2	11.0	.3	1.5	1.4	1.5	0	0	18.9
15 (G)	.8	1.2	1.9	0	1.6	12.0	4.8	2.7	5.4	5.0	2.5	.1	38.0
16 (S)	0	0	0	0	8.5	44.0	20.0	.5	1.5	14.0	0	0	88.5
16 (G)	.8	1.7	2.1	0	1.1	6.8	5.0	2.3	3.3	3.7	3.1	.7	30.6
17 (S)	0	0	0	0	2.3	19.0	4.6	0	5.3	3.2	0	0	34.4
17 (G)	.2	.6	.6	0	.3	2.8	1.9	1.0	1.6	1.5	1.3	.4	12.2
Total	4.7	8.4	12.0	0	31.6	208.6	120.6	20.9	33.7	61.4	26.5	7.5	535.9
Peak[a] (1000 cfs)	.4	.5	.5	.2	2.7	9.8	8.4	4.0	3.3	5.3	1.0	.4	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.20. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 1972 Land Use and 1969 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	2.3	0	13.0	3.6	6.9	3.0	2.0	5.9	.5	30.0	0	.6	67.8
13 (G)	6.2	3.3	14.0	7.9	14.0	8.8	8.0	13.0	6.5	23.0	9.7	8.0	122.4
14 (S)	3.3	0	17.0	4.4	9.1	3.7	2.6	7.0	.7	54.0	0	.9	102.7
14 (G)	8.2	5.2	21.0	11.0	20.0	12.0	11.0	18.0	8.8	29.0	12.0	10.0	166.2
15 (S)	1.0	0	4.6	1.4	2.5	1.2	.8	2.1	.2	12.0	0	.2	26.0
15 (G)	2.9	1.6	7.1	3.8	6.9	4.3	3.9	6.2	3.1	11.0	4.6	3.6	59.0
16 (S)	3.2	0	28.0	8.9	16.0	7.6	5.7	14.0	1.5	52.0	0	2.1	139.0
16 (G)	3.4	2.3	5.4	3.3	4.8	3.3	3.5	4.5	3.1	7.3	4.1	4.0	49.0
17 (S)	1.2	0	9.9	3.2	5.6	2.7	2.1	4.9	.6	18.0	0	.8	49.0
17 (G)	1.3	.8	2.0	1.3	1.9	1.3	1.4	1.7	1.2	2.9	1.6	1.5	18.9
Total	33.0	13.2	122.0	48.8	87.7	47.9	41.0	77.3	26.2	239.2	32.0	31.7	800.0
Peak[a] (1000 cfs)	2.0	1.0	6.1	5.5	4.7	3.6	1.3	2.6	4.2	22.8	3.6	5.3	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.21. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 2020 Land Use and 1967 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	.1	0	0	0	6.9	2.8	6.3	2.1	.8	0	.1	19.1
13 (G)	.9	2.4	1.3	0	0	2.1	4.2	5.1	3.9	3.0	0	2.0	24.9
14 (S)	0	4.1	0	0	0	4.7	11.0	.1	13.0	7.4	0	.1	40.4
14 (G)	.6	3.8	2.9	0	0	3.3	6.7	5.0	5.7	5.8	1.7	2.9	38.4
15 (S)	0	1.8	0	0	0	4.0	.2	0	11.0	8.3	0	0	25.3
15 (G)	.5	1.5	1.4	0	0	1.5	1.3	1.4	3.1	4.6	1.7	1.6	18.6
16 (S)	0	6.2	.1	0	0	6.2	5.2	0	21.0	14.0	0	0	52.7
16 (G)	.5	2.4	2.0	0	0	2.4	3.5	2.2	2.8	3.5	1.4	1.9	22.6
17 (S)	0	1.4	0	0	0	.8	.2	0	9.1	8.9	0	0	20.4
17 (G)	.2	.9	.8	0	0	.8	1.2	.2	1.7	2.4	.8	.4	9.4
Total	2.7	24.6	8.5	0	0	32.7	36.3	20.3	73.4	58.7	5.6	9.0	271.8
Peak[a] (1000 cfs)	.3	2.0	.4	.4	.7	2.1	2.0	2.0	6.6	4.5	.3	.4	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.22. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 2020 Land Use and 1968 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	0	0	0	0	11.0	34.0	19.0	0	4.9	12.0	1.9	0	82.8
13 (G)	.6	1.3	2.1	0	1.9	9.4	9.5	3.5	4.1	5.7	4.8	2.5	45.4
14 (S)	0	0	0	0	10.0	60.0	34.0	.1	.2	16.0	.2	0	120.5
14 (G)	1.1	2.0	2.9	0	1.5	11.0	8.5	3.4	4.1	4.4	5.0	1.6	45.5
15 (S)	0	0	0	0	5.9	16.0	.8	2.9	3.0	2.9	0	0	31.5
15 (G)	.5	.8	1.3	0	1.0	5.9	2.7	1.9	2.8	2.8	1.6	.4	21.7
16 (S)	0	0	0	0	9.9	46.0	21.0	1.2	2.1	15.0	0	0	95.2
16 (G)	.7	1.5	1.8	0	1.0	5.4	3.9	1.9	2.8	3.0	2.5	.4	24.9
17 (S)	0	0	0	0	2.4	19.0	4.4	.6	4.9	3.1	0	0	34.4
17 (G)	.2	.6	.6	0	.3	3.0	2.1	1.1	1.7	1.6	1.4	.6	13.2
Total	3.1	6.2	8.7	0	44.9	209.7	105.9	16.6	30.6	66.5	17.4	5.5	515.1
Peak [a] (1000 cfs)	.4	.4	.4	.2	4.8	12.2	9.2	3.8	3.4	7.0	.9	.4	

[a] Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.23. Predicted Surface(S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit 2020 Land Use and 1969 Rainfall.

Planning Unit	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
13 (S)	8.4	.1	22.0	6.9	12.0	5.9	4.4	11.0	1.1	40.0	.1	1.4	113.3
13 (G)	11.0	5.2	9.2	5.0	7.1	4.7	4.7	6.1	3.9	11.0	5.8	5.1	78.8
14 (S)	14.0	.2	37.0	12.0	21.0	9.9	7.5	18.0	2.1	69.0	.2	2.7	193.6
14 (G)	10.0	5.5	9.8	5.5	7.7	5.1	5.3	6.8	4.5	11.0	6.0	5.7	82.9
15 (S)	3.5	.1	8.5	2.6	4.6	2.3	1.9	3.9	.6	17.0	.1	.7	45.8
15 (G)	6.5	2.7	5.0	2.6	3.9	2.5	2.4	3.3	2.0	5.8	2.8	2.4	41.9
16 (S)	10.0	.4	31.0	10.0	17.0	8.7	7.2	15.0	2.3	55.0	.2	2.6	159.4
16 (G)	5.0	3.0	5.1	2.9	4.0	2.7	3.0	3.6	2.6	5.8	3.3	3.3	44.3
17 (S)	3.6	.2	9.7	3.1	5.5	2.7	2.3	4.7	.8	18.0	.1	.8	51.5
17 (G)	2.9	1.5	2.7	1.5	2.1	1.4	1.4	1.9	1.2	3.1	1.7	1.5	22.9
Total	74.9	18.9	140.0	52.1	84.9	45.9	40.1	74.3	21.1	235.7	20.3	26.2	834.4
Peak[a] (1000 cfs)	5.4	1.1	10.9	7.1	6.3	4.7	1.6	2.9	4.0	28.4	3.4	5.2	

[a]Predicted peak flow rate (total, including inflow at S-65) during month at S-65E.

Table 4.24. Summary Totals of Predicted Surface (S) and Subsurface(G) Runoff (1000 acre-feet) by Planning Unit and Land Use.

Land Use	Year	Rainfall Total[a] (in)	13 S	13 G	14 S	14 G	15 S	15 G	16 S	16 G	17 S	17 G	Totals S	Totals G	Total
1958	1967	41.1	4.5	48.7	1.3	101.4	6.0	46.8	2.0	97.8	5.0	32.8	18.8	327.5	346.3
	1968	53.8	38.9	117.0	37.8	165.3	7.4	64.4	10.9	154.8	7.5	54.1	102.5	555.6	658.1
	1969	56.7	43.3	150.9	51.6	242.6	15.0	87.6	21.1	229.6	11.6	73.4	142.6	784.1	926.7
	Ave.	50.5	28.9	105.5	30.2	169.8	9.5	66.3	11.3	160.7	8.0	53.4	88.0	555.7	643.7
1972	1967	41.1	9.1	39.5	15.0	72.6	15.3	31.8	46.6	26.5	20.4	9.3	106.4	179.7	286.1
	1968	53.8	52.3	86.1	72.8	102.1	18.9	38.0	88.5	30.6	34.4	12.2	266.9	269.0	535.9
	1969	56.7	67.8	122.4	102.7	166.2	26.0	59.0	139.0	49.0	49.0	18.9	384.5	415.5	800.0
	Ave.	50.5	43.1	82.7	63.5	113.6	20.1	42.9	91.4	35.4	34.6	13.5	252.6	288.1	540.7
2020	1967	41.1	19.1	24.9	40.4	38.4	25.3	18.6	52.7	22.6	20.4	9.4	157.9	113.9	271.8
	1968	53.8	82.8	45.4	120.5	45.5	31.5	21.7	95.2	24.9	34.4	13.2	364.4	150.7	515.1
	1969	56.7	113.3	78.8	193.6	82.9	45.8	41.9	159.4	44.3	51.5	22.9	563.6	270.8	834.4
	Ave.	50.5	71.7	49.7	118.2	55.6	34.2	27.4	102.4	30.6	35.4	15.2	362.0	178.5	540.4

[a] Annual total, Thiessen weighted for planning units 13-17.

expected to approximate the true system reasonably well. If anything, the 1972 base flow relation overpredicts flows since the predicted flows for the dry year, 1967, were considerably higher than measured flows. The reduction in the base flow relation (less base flow per inch of storage) presumably results from the larger network of channels in the basin which tends to equalize ground water levels and reduce gradients.

Another factor in the reduction of base flow is the reduced soil moisture storages with changing land use (Table 4.6). The largest drop occurs between 1958 and 1972; succeeding changes are not as great. When the same base flow relation is used (as in 1972 and 2020) Table 4.24 shows that the small drop in soil moisture between these years creates only an insignificant reduction in total runoff volume.

Figure 4.3 shows that evapotranspiration losses are higher with lowered total soil moisture, that is, the greater the slope of the depletion curves, the greater the actual loss of water. Again, this is a reflection of the fact that ET losses occur more easily from shallow soil moisture layers than from deep ones. Thus, later land uses with drainage of soil layers to adjacent ditches would be expected to exhibit increased ET losses. Changing vegetation in the basin can also affect the total water balance; however, this has not been considered explicitly in the model other than in how it may affect SCS curve numbers.

The difference in predicted total annual runoff between 1958 and 1972 conditions of 103,000 ac-ft is equivalent to 2.7 inches per year over the lower basin. This difference is presumed to be lost as additional ET. Since the comparison is for identical rainfalls it is not possible to verify this prediction directly. However, has, in fact, the rainfall-runoff relation for the lower KRB changed between 1958 and 1972? In particular, is less runoff derived from rainfall at present than in the past? Studies summarized by Marban (1976) indicate a trend toward the opposite result for the lower basin (more runoff per rainfall unit) although such trends are not statistically significant at the five percent level (Huber 1976). Nonetheless, the large predicted reduction of 2.7 inches caused by the altered base flow relationship must be considered doubtful, in spite of the reasonable agreement between measured and predicted flows shown in Chapter V. The ratios of surface (direct) to subsurface runoff are expected to be approximately correct, however, since they are evident even when there is no alteration in the base flow function (e.g., between 1972 and 2020). The basic reason for the changing ratios is the reallocation of runoff from the surface soil layers (above the water levels in adjacent channels). Formerly they contributed to subsurface flow. Presently they contribute, via interflow, to the surface runoff component.

In summary, it is apparent from Tables 4.15-4.24 that the major transition which accompanies development is the shift from predominantly subsurface runoff to surface (direct) runoff. Accompanying such a transition would be much higher peak runoff rates and degraded water quality due to less use of the soil system as a purification mechanism. Concerning water quality, shorter detention times contribute to an increase in nutrient loading from intensively drained areas. Surface flows, with relatively short detention times compared to base flow, are assumed to contribute the majority of total phosphorus from the land. Because average surface response occurs over a rather narrow range of detention times, 2.0 to 9.5 days, it is necessary to investigate more carefully the concept of surface drainage mechanisms as they affect water quality. Detailed studies of river, lake, and marsh drainage areas are discussed later.

POLLUTANT LOADINGS

The only readily available method to estimate non-point source loadings of nutrients from a group of land uses is to take field measurements, or use information from the literature. A detailed review of non-point pollution sources from a variety of land uses is presented by Bedient (1975). Figures 4.6 and 4.7 summarize the essence of the problem, showing that nutrient loading rates for precipitation, forest land, and cropland take on a range of values depending on specific land management practices. Where animal densities exceed normal levels as in animal feedlots, nutrient loading rates are several orders of magnitude larger. These values are reported on a per acre basis, and when averaged over an entire watershed feedlot contributions may assume lower values compared to cropland or improved pasture receiving manure. The above results represent loads which are transported off-site.

Few studies have addressed the problem of primary nutrient sources on the land, mainly because it is difficult to generalize about the many interacting variables which influence the results. In attempting to relate fertilizer rates with observed nutrient transport, the transport mechanisms defy an accurate description. Cattle density or loading per animal represents a major source of nutrients in improved pasture areas. But grazing and migration patterns significantly influence the results, and transport mechanisms are difficult to quantify. Drainage practices may cause the release of nutrients from the soil system and thus act as a source, but this mechanism is difficult to isolate from other nutrients being transported through drainage canals. In general, nutrient source loads on the land are difficult to quantify. Most research efforts have been aimed at the measurement of nutrients transported from a site, as a function of land use, cattle density, or fertilizer rates. However, loading parameters were investigated for the Kissimmee River Basin, and results are presented in the next section along with the concept of drainage density as an indicator of transport mechanisms from the land.

DRAINAGE DENSITY

Introduction

Drainage density, D_d, occupies a central position in describing the drainage basin because it is closely related to other basin characteristics,

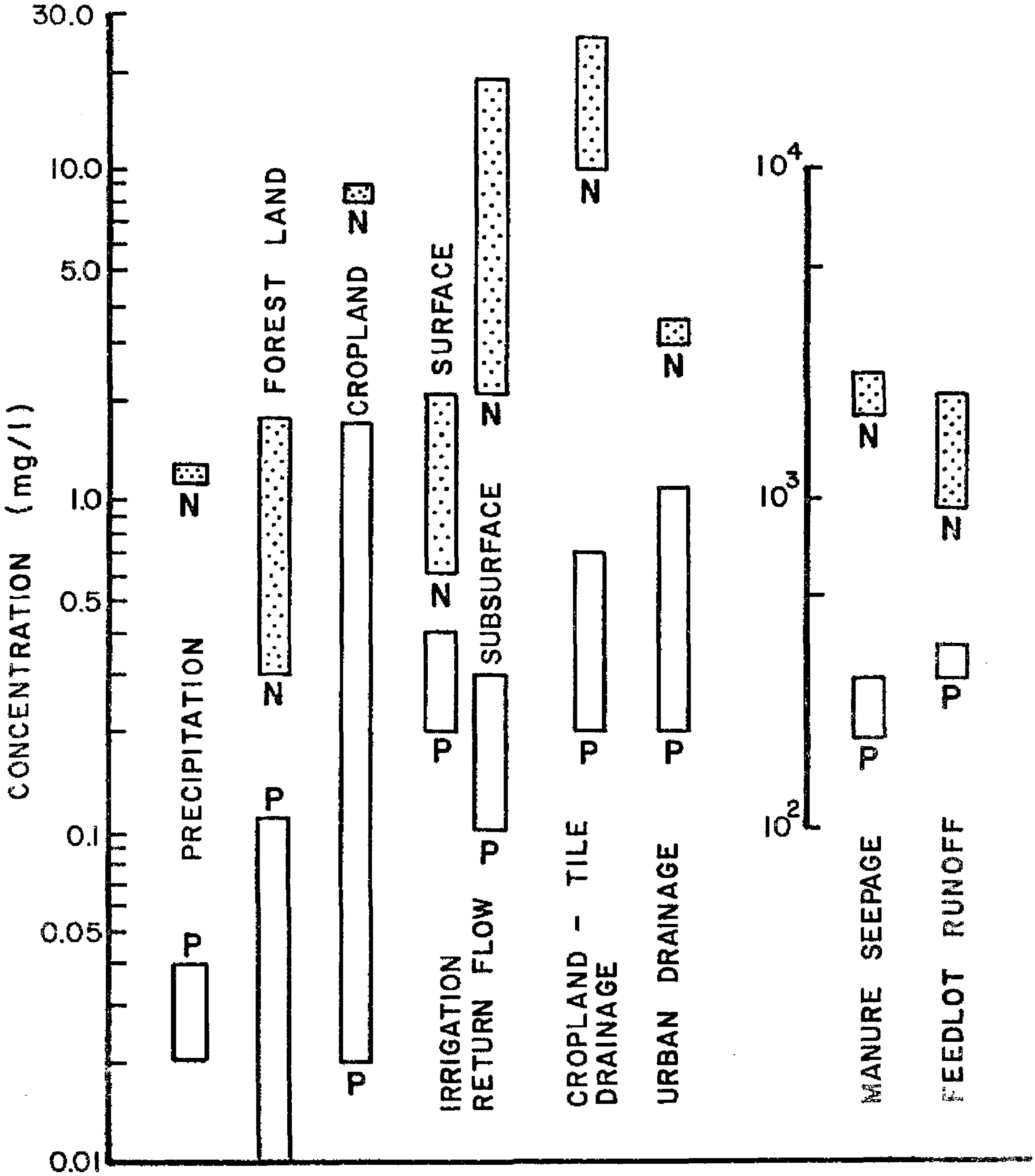

Figure 4.6. Comparison of Non-Point Source Concentrations of Total Nitrogen and Total Phosphorus (Loehr, 1974).

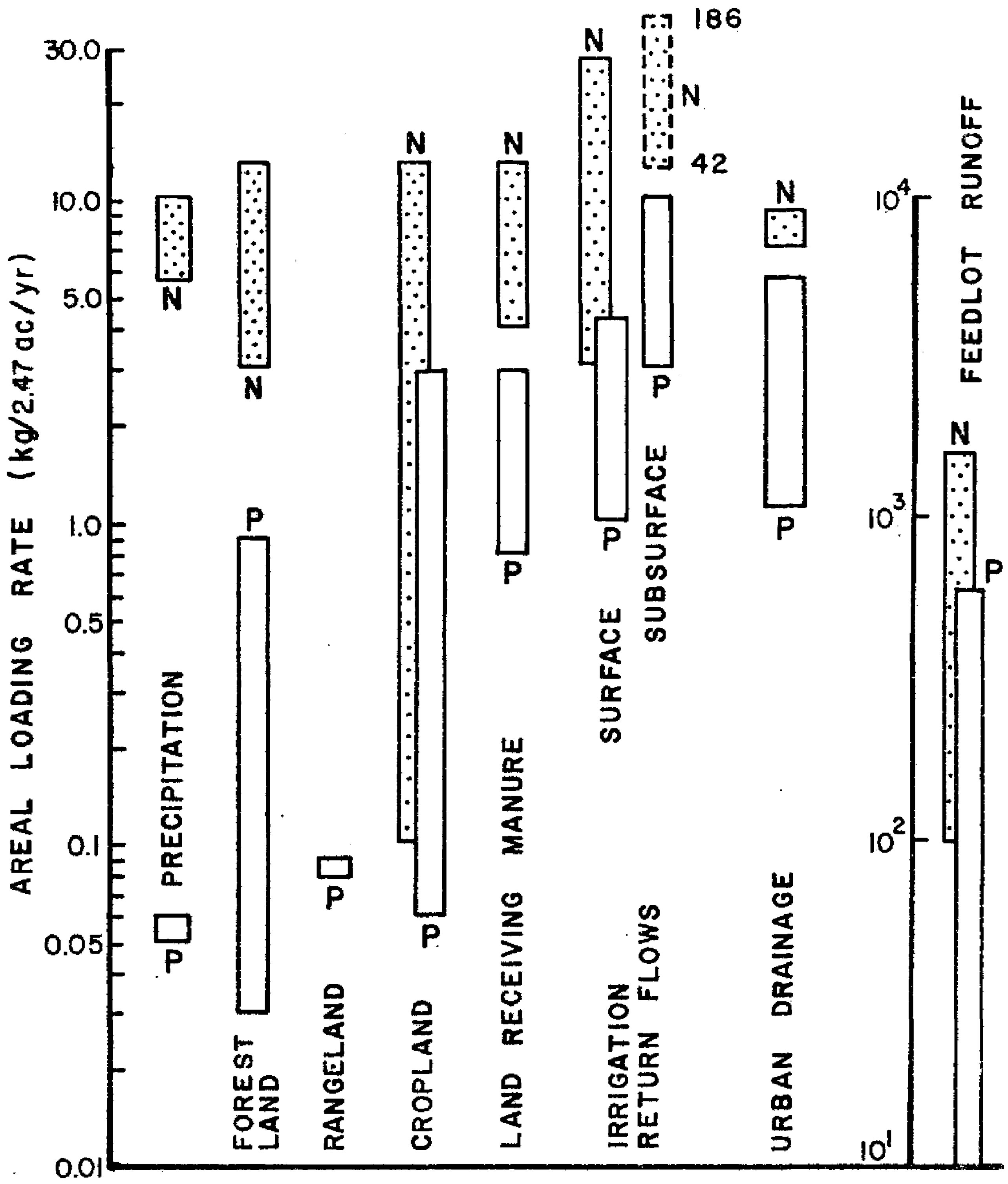

Figure 4.7. Comparison of Non-Point Source Area Yield Rates of Total Nitrogen and Total Phosphorus (Loehr, 1974).

as well as to input to the basin and output from the basin. Defined as the length of streams per unit of drainage area (e.g., miles per square mile), drainage density was found to be a highly significant parameter during the course of this research. Appendix B presents a general background of basin characteristics related to drainage density and the details of measurements for the Kissimmee River Basin. The remainder of this chapter presents the relationships developed between D_d and water quality parameters.

Hydrologic Effects

Attempts have been made to relate the drainage density index to a variety of climatic inputs and basin outputs. The main thrust of these studies has been to look at streamflow response for a variety of watersheds with different soil, topographic, and drainage characteristics. Results usually relate some measure of average annual streamflow to D_d.

The main objective of this effort has been to describe and quantify various hydrologic-land use interactions which occur within a single river basin or watershed. There is a definite need to explain the distribution of effects which are observed at various locations within the river basin, such as surface runoff volumes and nutrient loading rates. If these can be related to various land use activities and drainage practices, then the question of control measures for these problems can be realistically addressed.

Results from the Kissimmee River Basin, with regard to hydrologic response predicted by HLAND, indicate the significance of land use and soil moisture capacity in determining runoff volumes. Figure 4.8 shows the typical response, measured as percent runoff which comes from surface flow, for flood and drought conditions at various locations along the river. About 70 percent of total runoff is via surface routes downstream of planning unit 15 compared to about 30 percent on the upstream side. This predicted response is due primarily to drainage activities which have reduced the fluctuations of the water table and available soil moisture storage below PU 15. If one plots the percent surface runoff against D_d for each planning unit, the result indicates that they are approximately linearly related (Figure 4.9). Annual mean flood in m^3/sec per square mile of watershed has been related to D_d (Figure 4.10) by other investigators. A data point for the Kissimmee River Basin has been inserted onto the graph.

Water Quality Effects

Previous discussions of water quality and non-point source loadings have indicated that land use type is an important parameter in determining

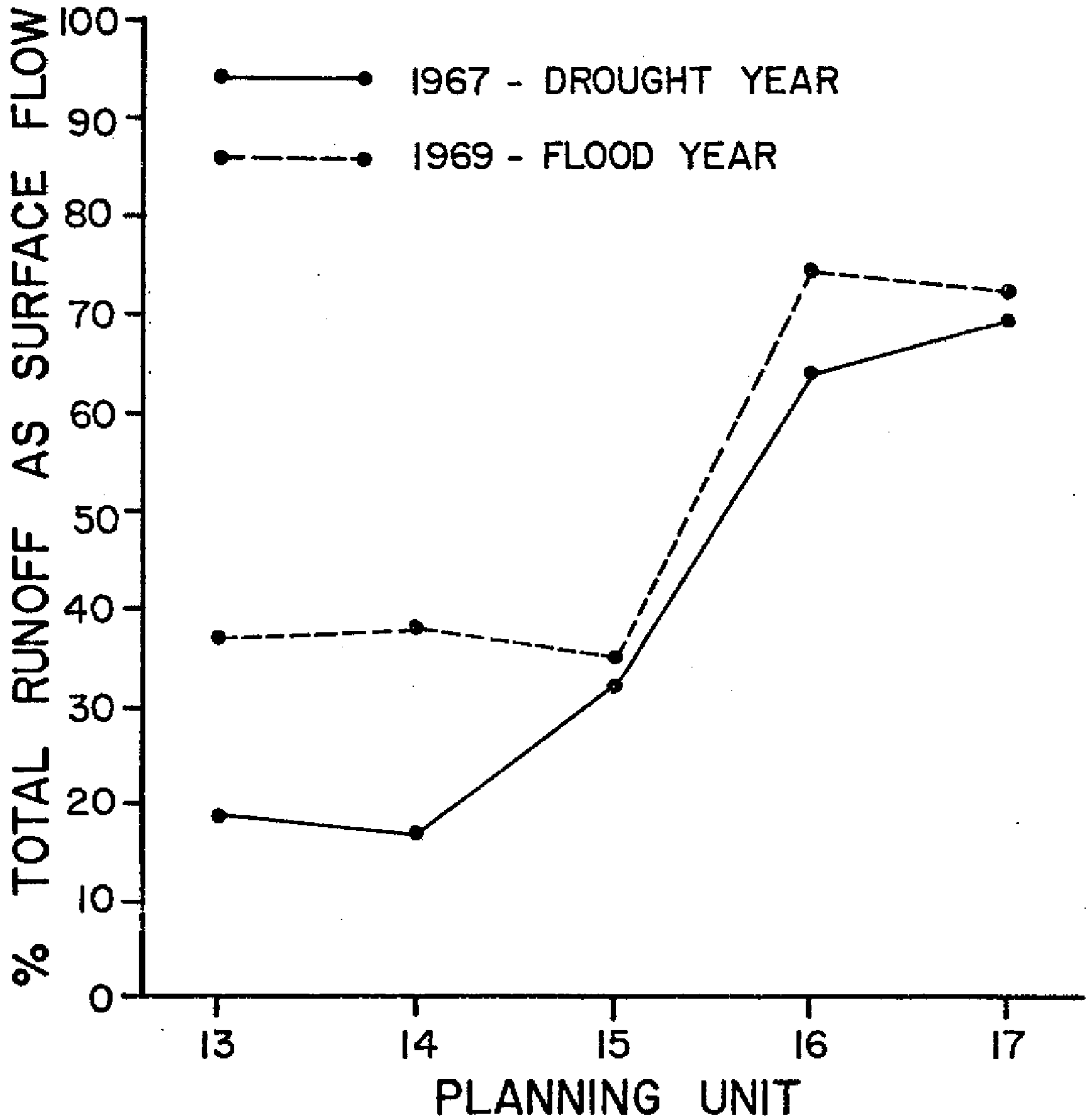

Figure 4.8. Percent Runoff as Surface Flow Along the Kissimmee River. Data are from Table 4.4 for 1972 land use.

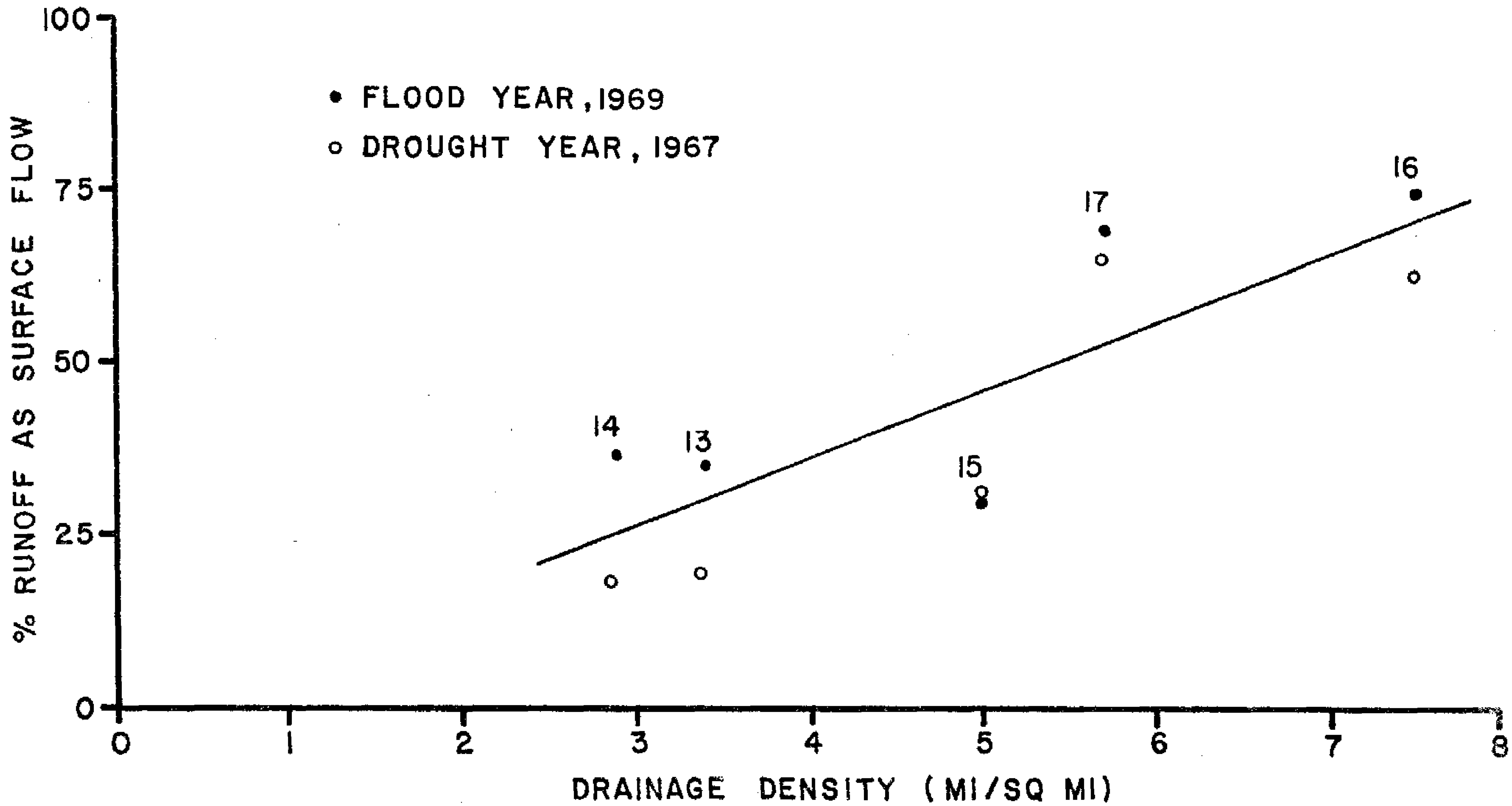

Figure 4.9. Percent Runoff as Surface Flow versus Drainage Density. Percentages are from Table 4.24 for 1972 Land Use and Drainage Densities are from Appendix B. Planning Unit Numbers are Indicated Beside Data Points.

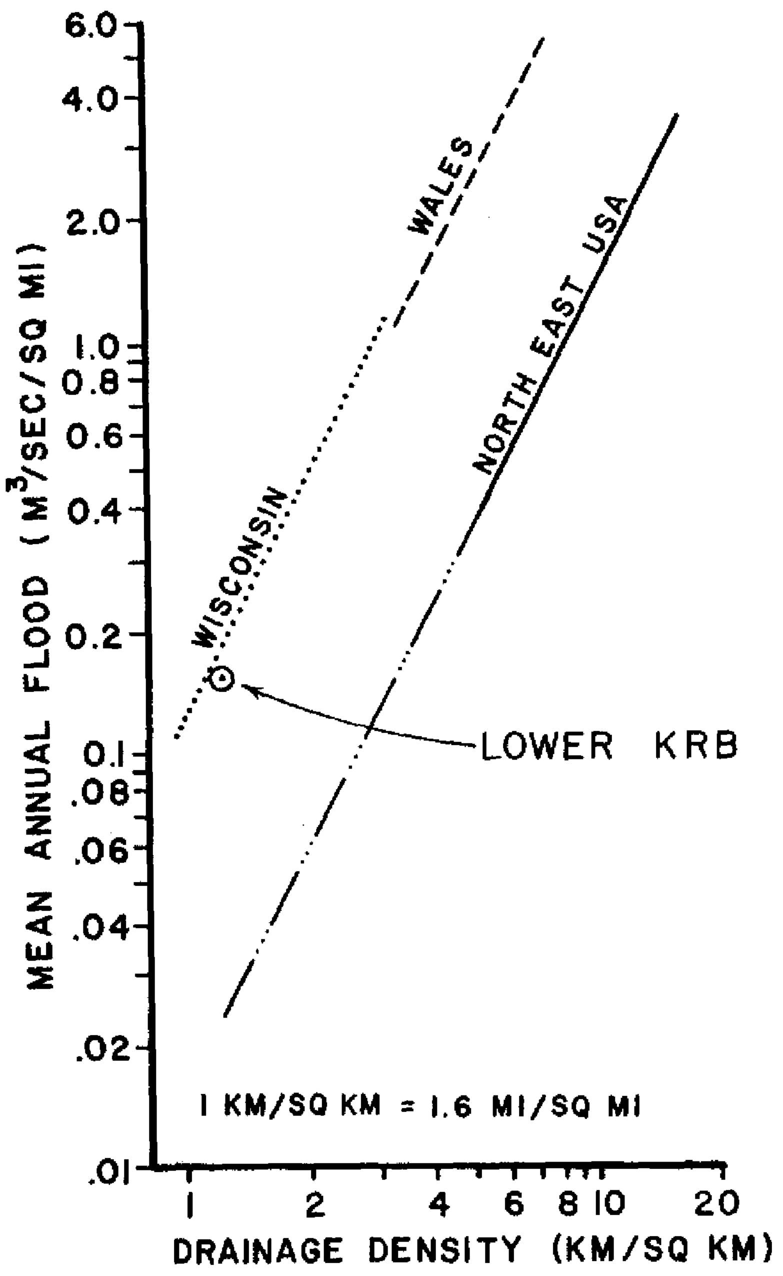

Figure 4.10. Mean Annual Flood ($Q_{2.33}$) versus Drainage Density (Adapted from Gregory and Walling, 1973, p. 270). $Q_{2.33}$ calculated for upper (S65) and entire (S65-E) KRB from flood frequency data compiled by Heath and Wimberly (1971) for period 1929-1961. $Q_{2.33}$ for lower basin calculated as difference: 6130 - 2050 = 4080 cfs = 116 m^3/sec. Area of lower basin = 706 $mile^2$. Drainage density for 1958 = 1.9 mile/sq mile = 1.2 km/sq km (Table 4.27).

specific nutrient loadings. Various ranges in values for nitrogen (N) and phosphorus (P) have been reported in the literature under a variety of climatic and land management conditions. However, the nutrient source loadings which are reported rarely include any measure of intensity of use, which has a definite effect on potential for off-site transport. While cattle density, fertilizer rates, and grazing practices have significant effects on nutrient source loadings in the Kissimmee River Basin, drainage density is by far one of the most representative indices of nutrient transport off-site. Because of the overall uniform slope and character of agricultural land use in the lower basin, it was felt that drainage density might provide a valid general indicator of nutrient concentrations measured in the tributaries.

The relationship of D_d to average length of overland flow, along with nutrient loading potential, is analogous to the concept of sediment delivery ratios, defined as the fraction of gross erosion delivered to a stream (Midwest Research Institute, 1975). This is under the assumption that nutrients are often fixed to sediment or will "erode" in an analogous manner (EPA, 1973). The basic approach considers the size of a unit watershed as a function of the potential for sediment delivery off-site. Figure 4.11 shows the sediment delivery ratio to be expected from various unit watershed sizes. The concept of drainage density can be placed into this same general framework, because the reciprocal of the square of D_d provides an estimate of the area of the unit watershed. The relationship between D_d and unit watershed area is schematically presented in Figure 4.12 for various land use types. Thus, the associated potential sediment delivery ratios increase dramatically for the more intensively drained areas (Figure 4.11). Because nutrients such as phosphorus tend to be associated with the soil, the potential for nutrient loading from these areas also increases. Such reasoning leads to the hypothesis that increased levels of D_d may be associated with increased nutrient concentrations and loading rates.

During 1973-1974 the FCD conducted a monthly water quality sampling program along the Kissimmee River from which an indication of tributary quality may be found. The sampling program is described in more detail in Chapter V; however wet season (May-August 1974) data are shown in Table 4.25. These are selected since most runoff occurs during these months; hence, most of the total P emissions are expected to occur during this period as well. Average total P concentrations are plotted against drainage density (from Appendix B) in Figure 4.13 and peak total P concentrations are similarly plotted in Figure 4.14. The resulting straight line shown on the plots is simply a visual fit, but a positive correlation is definitely indicated in both instances. The importance of these relationships is not the actual measured values of D_d and associated P concentrations (they should not be used for predictive purposes). Rather, they simply illustrate the fact that higher drainage densities tend to be associated with higher concentrations.

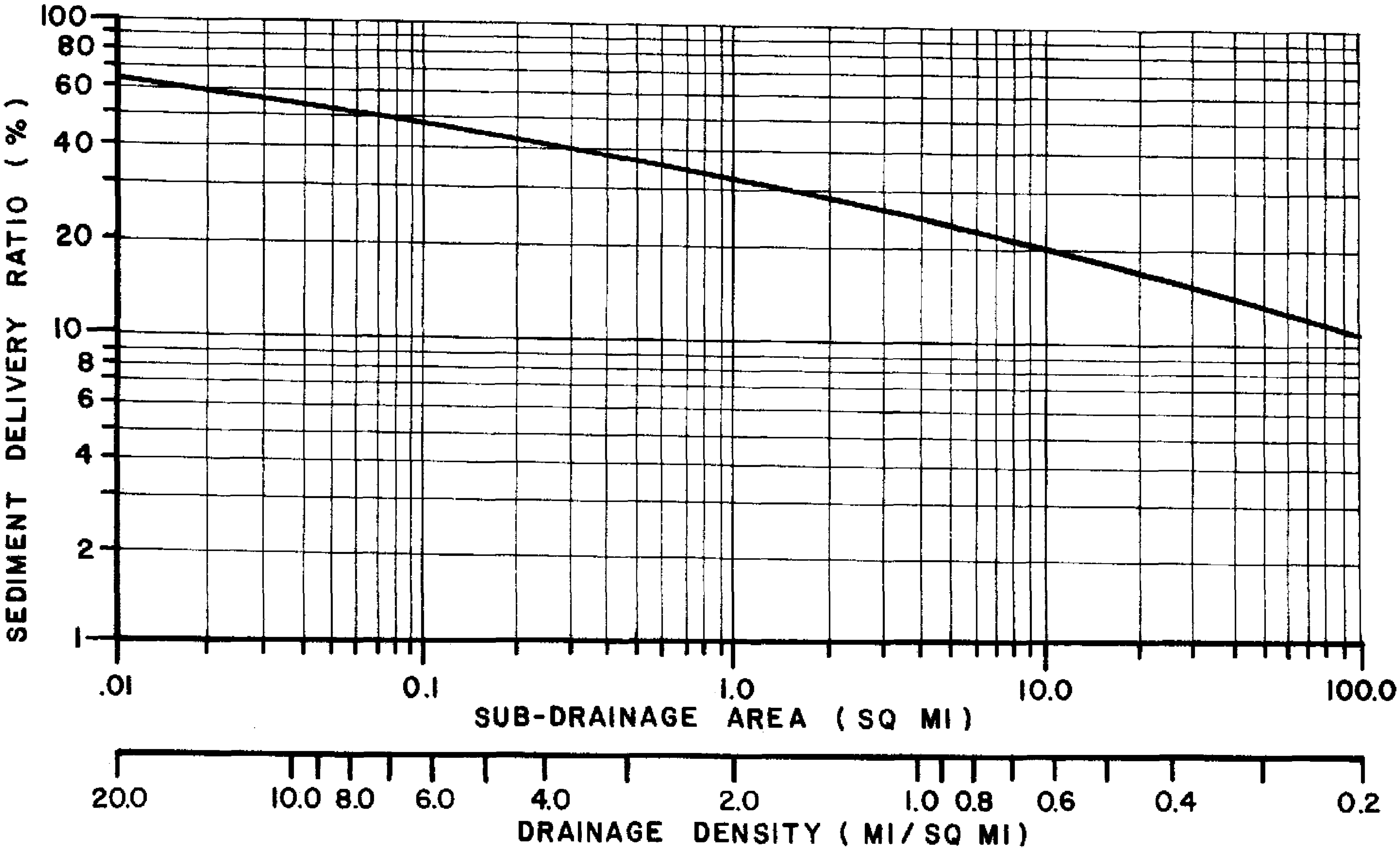

Figure 4.11. Sediment Delivery Ratio versus Drainage Density and Area (Adapted from Midwest Research Institute, 1975 and SCS, 1973b).

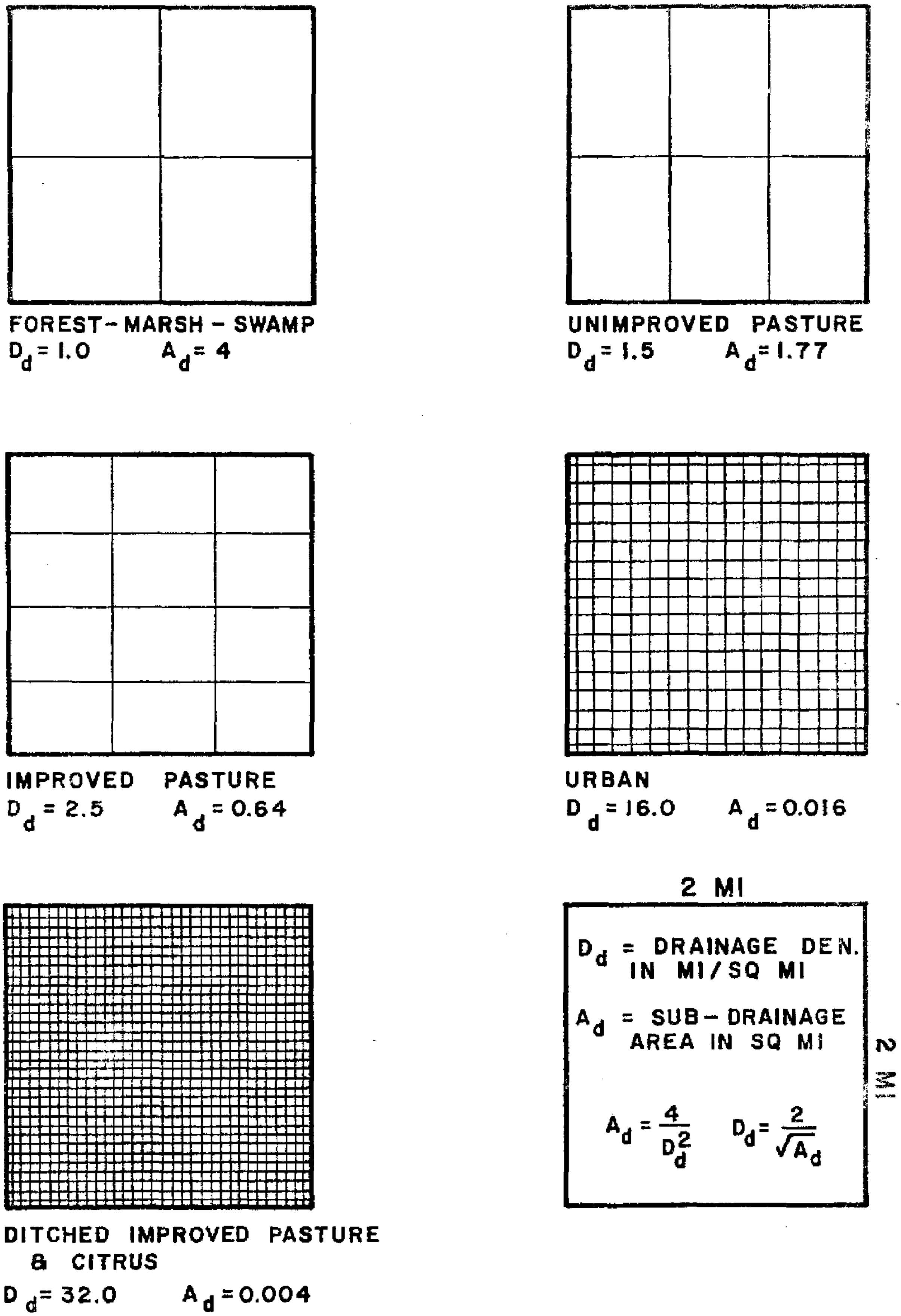

Figure 4.12. Schematic of Drainage Density and Watershed Area.

Table 4.25. Measured[a] Wet Season 1974 Total P Concentrations and Computed Total P Loadings

Tributary Location[b]	Planning Unit	Date of Sample	Total P (mg/l)	T-P, May-Aug. 74, Ave. (mg/l)	Predicted Monthly Surface Runoff[c] (ac-ft)	Predicted Monthly Surface Runoff[c] (inches)	P.U. Area (ac)	P Loading[d] (kg/ac-mo)
Ice Cream Slough	13 (West)	5/8/74	0.024	0.026			94,700[e]	
		6/12/74	0.025					
		7/10/74	0.030		30,150[e]	3.89		0.012
		8/19/74	0.024					
Blanket Bay Slough	13 (East)	5/8/74	0.035	0.183			94,700[e]	
		6/12/74	0.054					
		7/10/74	0.486		30,150[e]	3.89		0.195
		8/14/74	0.160					
Pine Island Slough	14	6/12/74	0.024	0.040			143,100	
		7/10/74	0.062		22,900	1.92		0.012
		8/14/74	0.035					
Oak Creek	15	7/11/74	0.247	0.174	8,950	2.60	41,300	0.066
		8/15/74	0.100					
		10/2/73[f]	0.094		2,580[g]	0.75[g]		
Chandler Slough	16	5/7/74	0.051	0.301			106,100	
		6/11/74	0.089					
		7/9/74	0.357		44,200	5.00		0.435
		8/13/74	0.290					
		10/2/73[f]	0.164		15,650[g]	1.77[g]		
Yates Marsh	17 (East)	5/7/74	0.038	0.178			38,100[e]	
		6/11/74	0.028					
		7/9/74	0.357		12,475[e]	3.93		0.145
		8/13/74	0.290					
Maple River	17 (West)	5/7/74	0.050	0.454			38,100[e]	
		6/11/74	0.409					
		7/9/74	0.796		12,475[e]	3.93		0.322
		8/13/74	0.560					

Notes to Table 4.25.

[a]Unpublished FCD data from 1973-74 monthly sampling program.

[b]See Figure 5.10 for locations of tributaries along Kissimmee River.

[c]Predicted by HLAND using 1972 land use. Values are given only for points shown on Figure 4.15.

[d]From equation 4.20 for July 1974.

[e]Value for entire planning unit.

[f]Additional value shown on Figure 4.15.

[g]Runoff computed for September 1973 since P sample was at beginning of October.

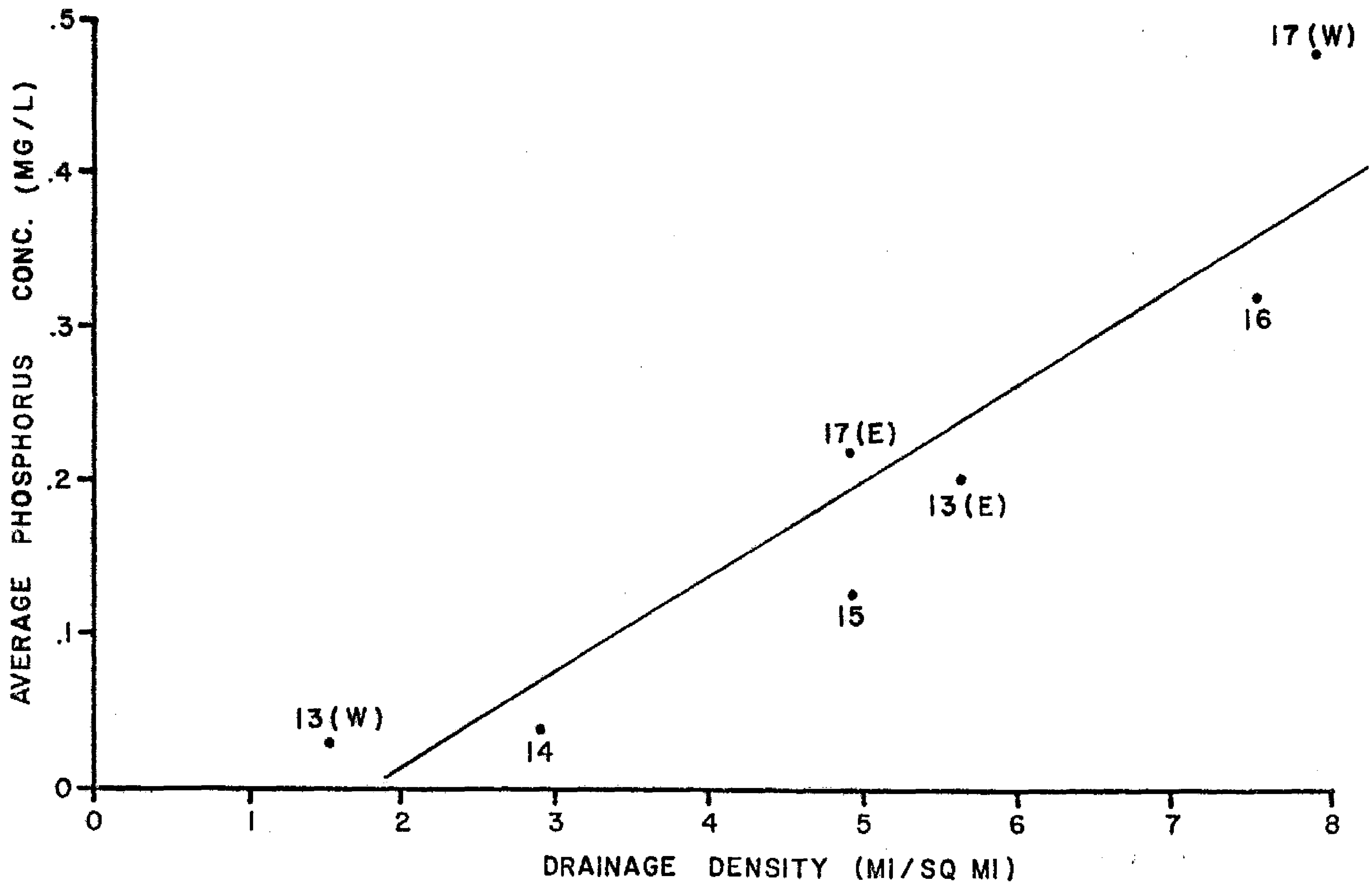

Figure 4.13. Average May-August 1974 Total P Concentration versus Drainage Density. Data are from Table 4.25 and Appendix B.

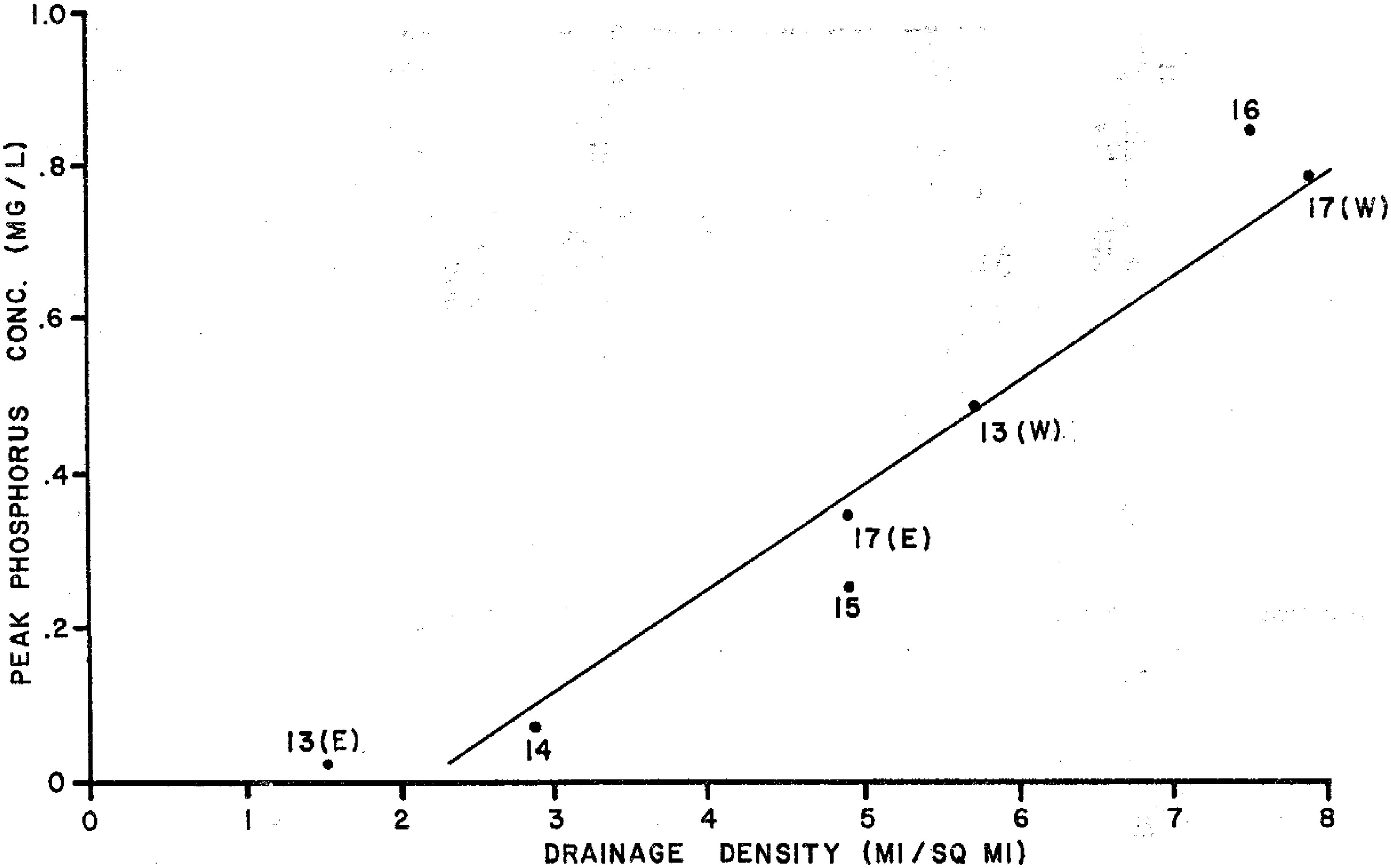

Figure 4.14. Peak Total P Concentration versus Drainage Density. Data are from Table 4.25 and Appendix B.

With regard to nutrient loading rates, data on both hydrologic flows and nutrient concentrations must be available. While water quality monitoring has been extensive throughout the basin, the associated measurement of flows entering the river is unavailable on a continuous basis. However, predictive capabilities of the model HLAND provide for the simulation of surface and subsurface runoff from each planning unit on a daily basis.

Realizing the errors involved in the monthly water quality measurements and in the predicted runoff volumes from each planning unit, a positive correlation appears between measured total P concentration and the predicted surface runoff event (Table 4.25) which corresponds to the measurement (Figure 4.15). In general, the higher the surface runoff, the higher the concentration of total P which is transported via overland flow and tributary to the river. Thus, the phenomenon of dilution by increasing volumes of water is masked by more rapidly increasing volumes of nutrients transported in the runoff. Below S65-C loading rates increase more rapidly due to higher surface runoff volumes and higher nutrient concentrations, combining to yield the nutrient flux into the river. Concentrations are not expected to increase indefinitely as a function of runoff, rather concentrations will tend to decrease as an individual runoff event proceeds. However, short-term data are unavailable in the KRB to illustrate this phenomenon.

When surface runoff is known (from HLAND simulations) quality loadings (mass/area-time) may be calculated as follows:

$$L = 0.103\ R\ C \qquad (4.19)$$

where L = loading, kg/ac-mo,

R = monthly surface runoff over drainage area, in./mo,

C = concentration, mg/l.

The factor 0.103 encompasses various English-metric conversions and the odd mixture of units for L is to facilitate comparison with literature values. Loading calculations are performed for the peak (July, 1974) measured P concentrations in Table 4.25.

Phosphorus loading rates are plotted against D_d, and the resulting relationship is presented in Figure 4.16 which can be explained by considering that higher drainage densities yield higher runoff rates and higher nutrient concentrations. Together, these produce a multiplicative effect on nutrient delivery rates. It may be noted in Table 4.25 that the July loadings will dominate annual P emissions; they may thus be considered indicative of annual loadings although they will in

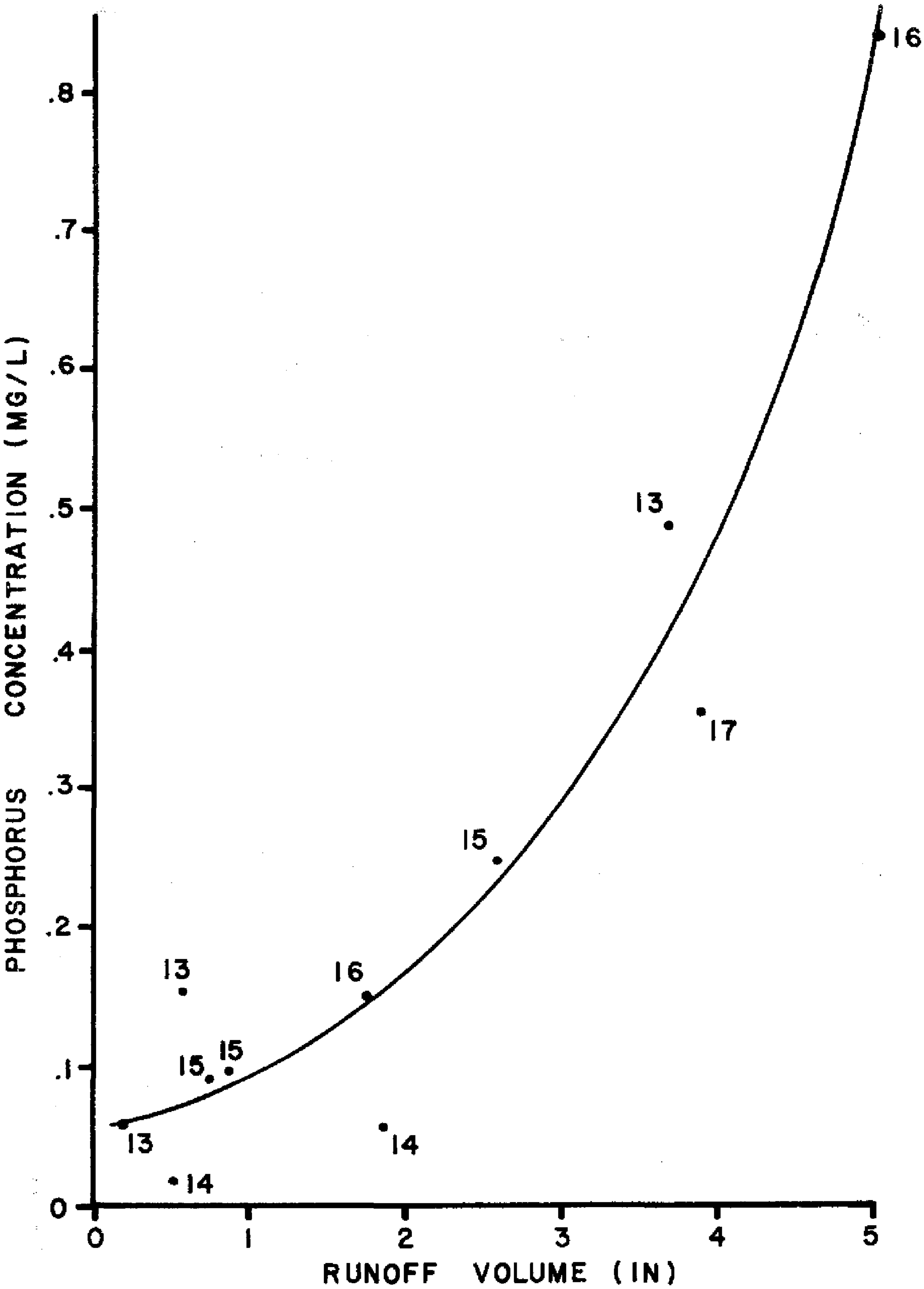

Figure 4.15. Measured Total P Concentration versus Predicted Monthly Surface Runoff Volume. Data are from Table 4.25.

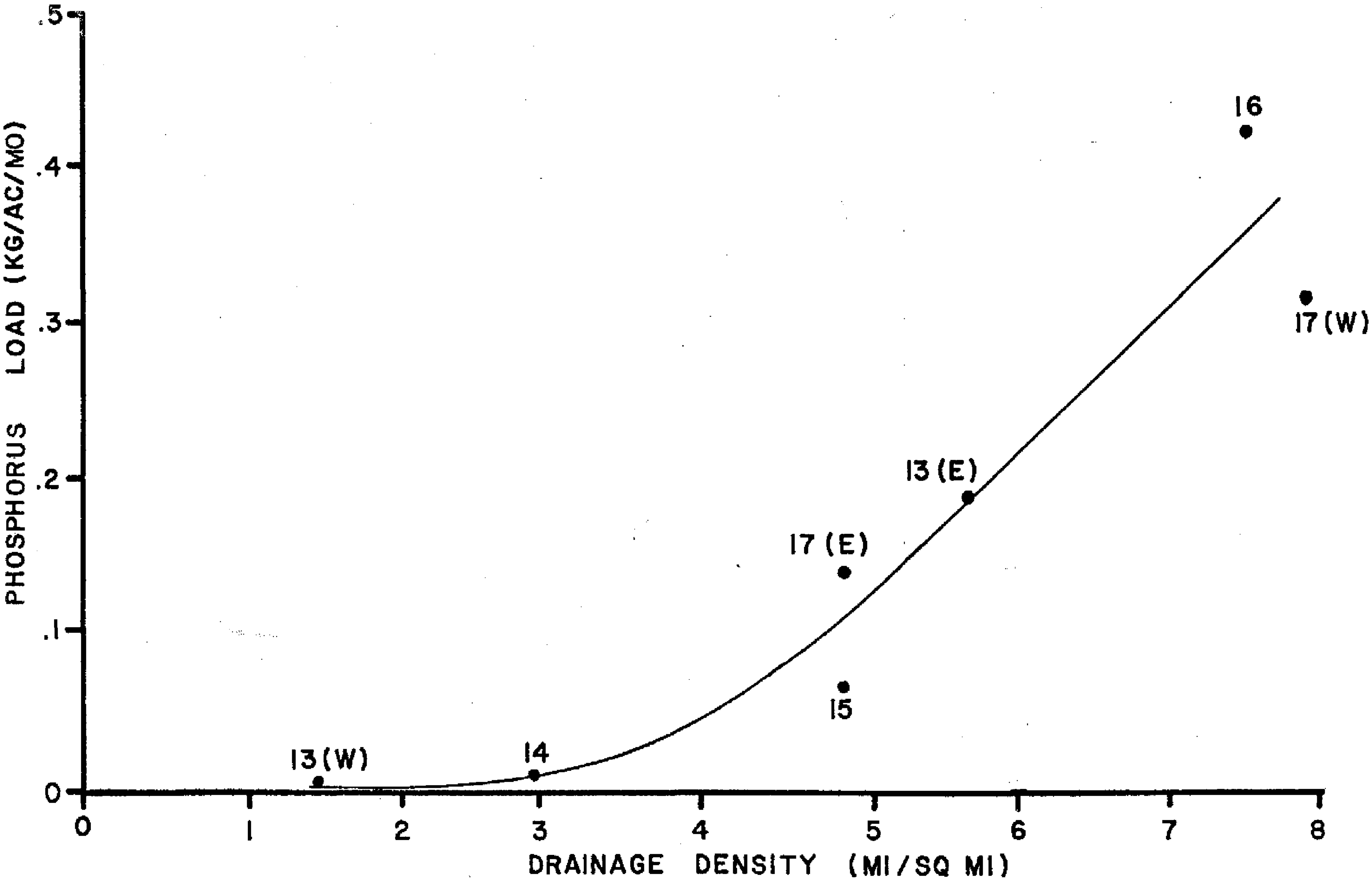

Figure 4.16. Total P Load versus Drainage Density in the Kissimmee River Basin, July 1974.

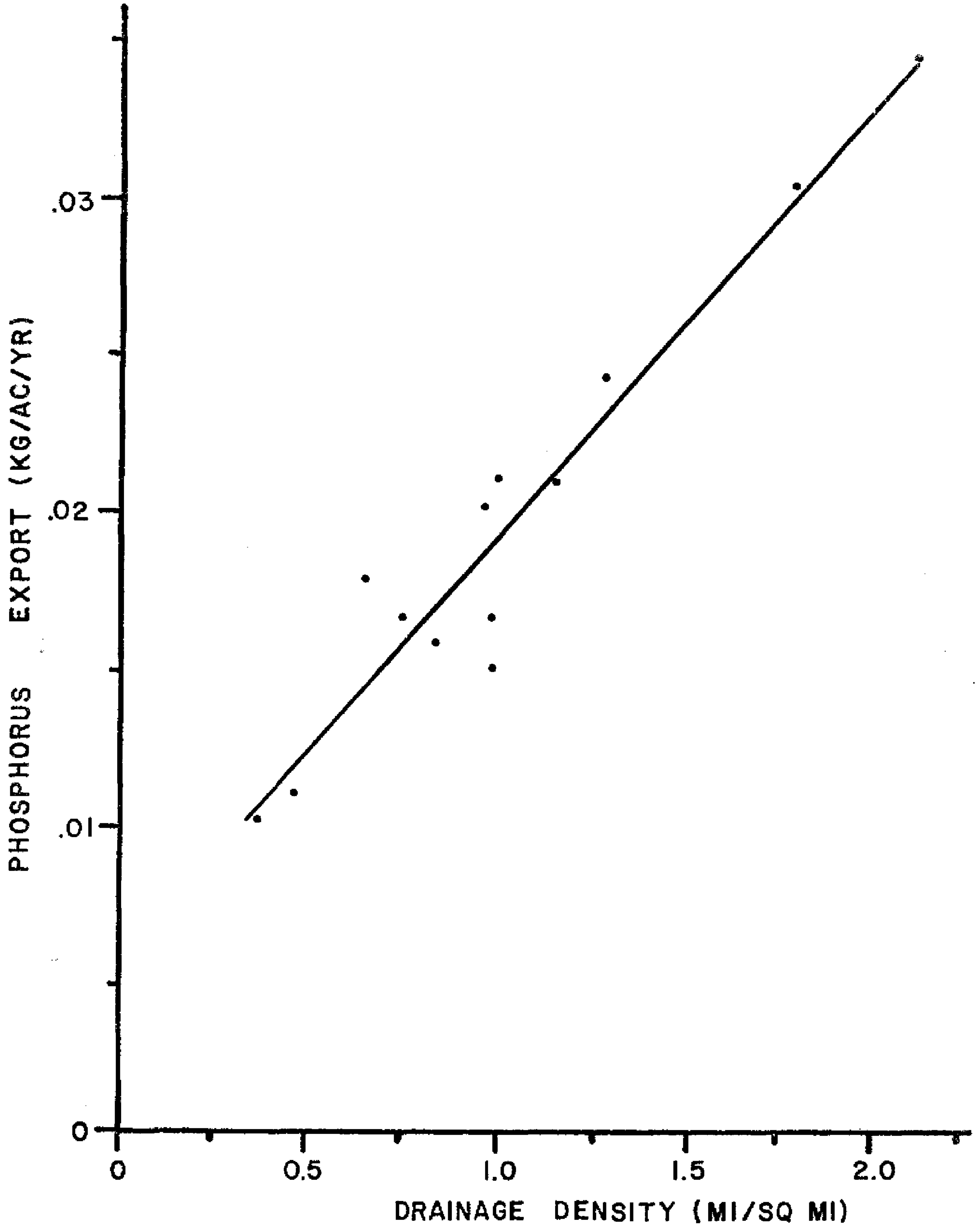

Figure 4.17. Total P Load versus Drainage Density in Canadian Watersheds (Adapted from Kirchner, 1974).

fact be somewhat lower than true annual values. However, the range of 0.012 to 0.435 kg/ac-yr compares favorably with values reported by Uttormark et al. (1974) for similar types of land use.

One other study has indicated similar relationships between nutrient loading of total P and drainage density in Canadian watersheds (Kirchner, 1974). Figure 4.17 shows a linear relationship, with D_d ranging from 0.32 mi/sq mi to 2.24 mi/sq mi, and loading rates up to 0.03 kg/ac/yr. This is at the lower end of the spectrum for results in the Kissimmee River Basin, but values for PU 13 (W) and 14 are quite similar with D_d between 1.0 and 3.0 mi/sq mi in Figure 4.16. Thus, the relationship between D_d and nutrient loading has been observed in other watersheds.

The discussions of off-site effects have described a series of responses which are observed or predicted for a river basin as a function of the drainage density. In general, increased volumes of surface runoff, higher nutrient concentrations, and higher nutrient loadings are associated with higher drainage densities in the Kissimmee River Basin. However, it has been mentioned that more intensively drained areas, such as improved pasture and cropland, have potentially greater source loadings initially applied to the land due to cattle density and fertilization. Thus, the fact that these areas produce higher export rates than more natural areas is not surprising.

Nutrient source loadings from cattle were investigated in the Kissimmee River Basin in order to better evaluate the effect of drainage density. These calculations are shown in Table 4.26. In general, observed nutrient loadings are expected to depend on both the magnitude of nutrient sources and associated drainage density. Figure 4.18 indicates this concept nicely, especially for planning unit 15 where the nutrient source is relatively low but D_d is high and planning unit 16 where both parameters take on large values and produce heavy loadings. It is also interesting to note that the predicted cattle source loading is considerably higher than the predicted T-P loads based on effluent measurements (Table 4.25). This indicates that most P is assimilated within each planning unit or removed by other mechanisms.

Detention Time Effects

Earlier sections of this chapter have described surface (direct runoff) and sub-surface detention times. Surface detention times (Tables 4.7 and 4.13) include effects of drainage because of the use of the CDET values altered for chaning land use. Subsurface detention times, however, (Table 4.11) are based on the assumption that the lower basin

Table 4.26. Phosphorus Loads from Cattle

Values assume 34 kg/yr of T-P per cow, based on USDA information.

Planning Unit	Area (ac)	Cattle Population[a]	Annual T-P Load (kg/ac-yr)
13	94,700	15,226	5.47
14	143,100	18,050	4.29
15	41,300	5,920	4.87
16	106,100	28,533	9.14
17	38,100	14,525	13.0

[a]Best estimate (1975) based on state and federal statistics and typical densities for improved and unimproved pasture. For the calculation, the distribution is assumed to be uniform across the planning unit, whereas in actuality cattle are concentrated in pasture lands. Thus, actual loadings will vary widely.

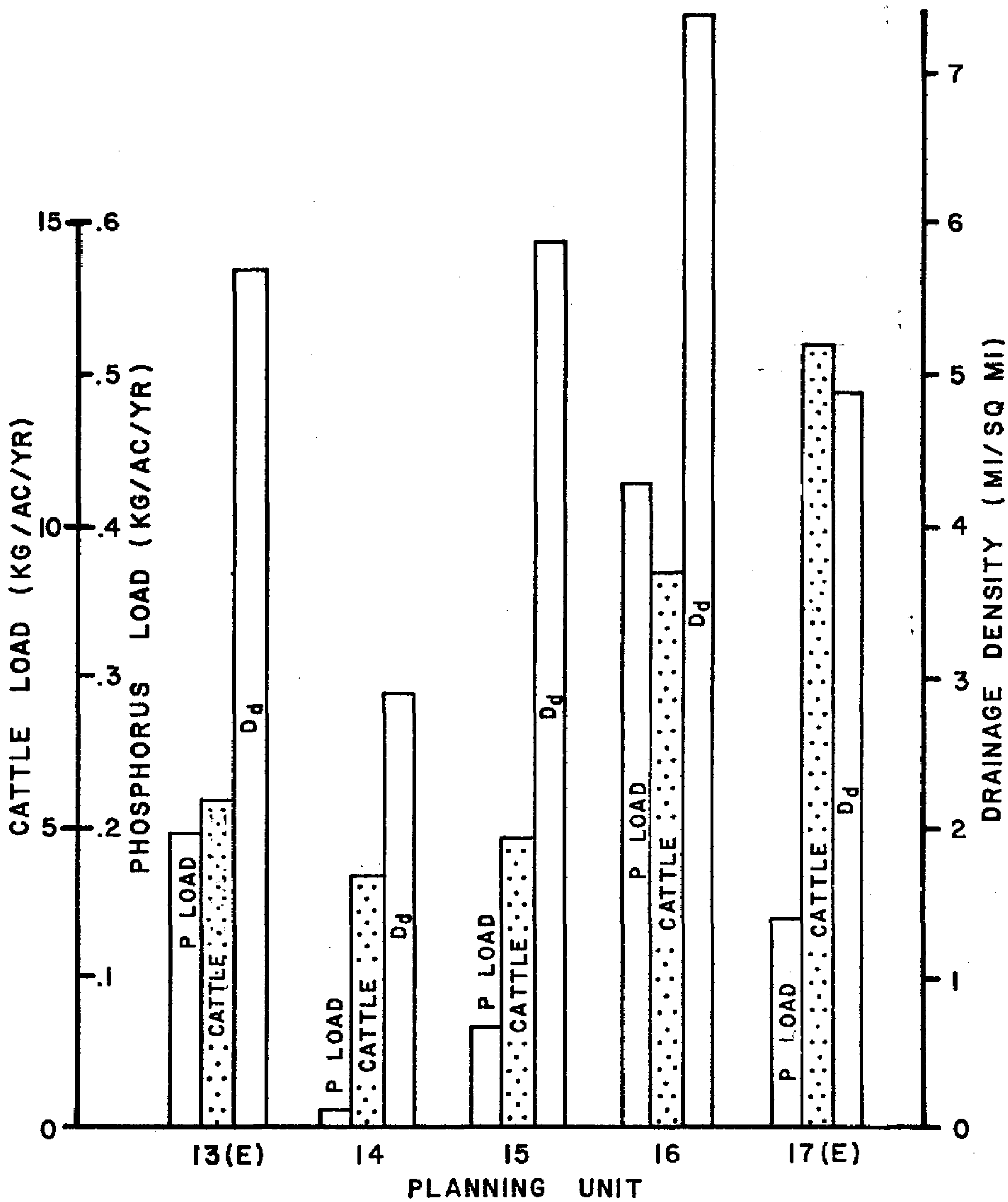

Figure 4.18. Influence of Nutrient Sources and D_d on Nutrient Loads. Data are from Tables 4.25 and 4.26 and Appendix B.

drains in its natural state toward the Kissimmee River in order to predict base flow rates in HLAND. Thus, the effect of changing land use and drainage density are not explicitly considered in the computation of detention times. Only the volumetric effects of storage enter into the calculation resulting in T values of 56.7 and 107.4 days over the range of storages experienced for 1958 and 1972 simulations, respectively (Table 4.11).

It is expected that the actual detention time (travel time) is proportional to the path length traversed as the water moves from the soil water regime toward an open channel. The path length, in turn, is inversely proportional to drainage density, D_d. Thus, the T values of 56.7 and 107.4 days are inversely proportional to the natural drainage density of the lower basin, and it is assumed that actual values for 1958 and 1972 (or any future year) may be found by

$$T_t = T_n \cdot \frac{D_{d_n}}{D_{d_t}} \qquad (4.20)$$

where the subscript t denotes a future year and the subscript n denotes the natural condition.

Values of D_d for natural, 1958 and 1972 conditions are therefore required to make the adjustment indicated in equation 4.20. The natural and 1972 value may be found directly from Table B.5 using area weighted values of the natural and overall drainage densities listed for each planning unit. The value for 1958 is not available from direct measurements. It is calculated instead from the land use values given in Table 4.2 for 1958 and the typical D_d values for different land uses given in Figure B.3. The calculation is shown in Table 4.27. "Improved pasture" is assumed to be 30 percent ditched on the basis of the land use information given in Table B.1. The area weighted D_d for 1958 is thus 1.94 mi/sq mi. Final values of drainage density and adjusted sub-surface detention times from equation 4.21 are shown in Table 4.28. These values of 48 and 34 days appear reasonable in light of earlier discussion and Langbein's (1955) value of about 50 days for total travel time in the lower basin. The values of T are for PU 13-17 since those are the planning units simulated by HLAND. The value of D_d was adjusted using land use fractions for PU 13-18, but the resulting error is not expected to be significant.

The reduction in detention time is primarily the result of altered drainage practices, as indicated in the analysis. This overwhelms the effect of reduced storage divided by an even more reduced base flow that led to the values shown in Table 4.11. The estimates of T_t in Table 4.28 could possibly be improved by examination of groundwater records in the area, but this was beyond the scope of this study. The overall detention time (travel time) for the lower basin will be discussed in Chapter V where the effects of the Kissimmee River itself are included.

Table 4.27. Calculation of 1958 Drainage Density for Lower Basin, PU 13-18

Land Use	Area[a] (100 ac)	Fraction	D_d[b] (mile/sq mile)
Urban	0	0	17.0
Crops	3	0.000664	29.0
Improved Pasture	329	0.0728	0.7 x 2.5[c] 0.3 x 33.0
Unimproved Pasture	2,806	0.621	1.2
Citrus	13	0.00288	29.0
Forest	32	0.00708	0.8
Marsh	1,337	0.296	0.8
Total	4,520	1.00	1.94[d]

[a]From Table 4.2.

[b]From Figure B.3.

[c]Improved pasture is 30 percent ditched from Table B.1.

[d]Area weighted total.

Table 4.28. Drainage Density and Sub-Surface Detention Times for Lower Kissimmee River Basin, PU 13-17

Land Use	D_d (mi/sq mi)	T_n[a] (days)	T_t[b] (days)
Natural	1.6[c]		
1958	1.9[d]	56.7	47.7
1972	5.1[c]	107.4	33.7

[a]Table 4.11.

[b]Equation 4.20.

[c]Area weighted values from Table B.5.

[d]Table 4.27.

V. INTEGRATED ENVIRONMENTAL ANALYSIS

STORAGE-TREATMENT CONCEPTS

Introduction

Characteristics of hydrologic and nutrient cycles can be placed into the general framework of reservoir storage and control. Various hydrologic components in a river basin system are distinguished by a set of specific inflows, outflows, storages, and losses which contribute to the overall response. The detention time parameter provides a useful measure of reservoir storage and outflow, and can be used to characterize various components of the hydrologic system, i.e., soil, marsh, pasture, lake, planning unit, or river.

Detention time also plays a key role in nutrient cycling as it relates to treatment rates for runoff on the land, in the soil, and in lakes or streams. In general, the longer the detention time, the greater the potential for nutrient uptake and/or deposition of sediments. Thus, water quality control through the system can be characterized by the length of time available for physical, biological and chemical uptake mechanisms.

Detention Time for Runoff Control

Surface and subsurface runoff volumes for a particular soil-land use pattern can thus be characterized according to detention time T. The value of T is defined as the ratio of storage volume to outflow runoff rate. Both soil moisture and surface components can be evaluated. Typical stage-volume curves (Figure 5.1) and stage-discharge curves (Figure 5.2) can be constructed from predicted outflows for soil and surface storages. The soil moisture regime is characterized by small volume changes as a function of stage, due to porosity effects. Similarly, the stage-discharge relation indicates a small change in base flow as a function of stage, again due to the mechanisms of flow in porous media.

At the surface, a definite breakpoint occurs for both stage-volume and discharge curves. Small increases in stage are associated with large changes in volume and outflow rates. The particular slope of the surface discharge curve depends on the land cover, as shown for unimproved and ditched improved pasture in Figure 5.2. These curves indicate the effect of drainage practices on increasing rates and volumes

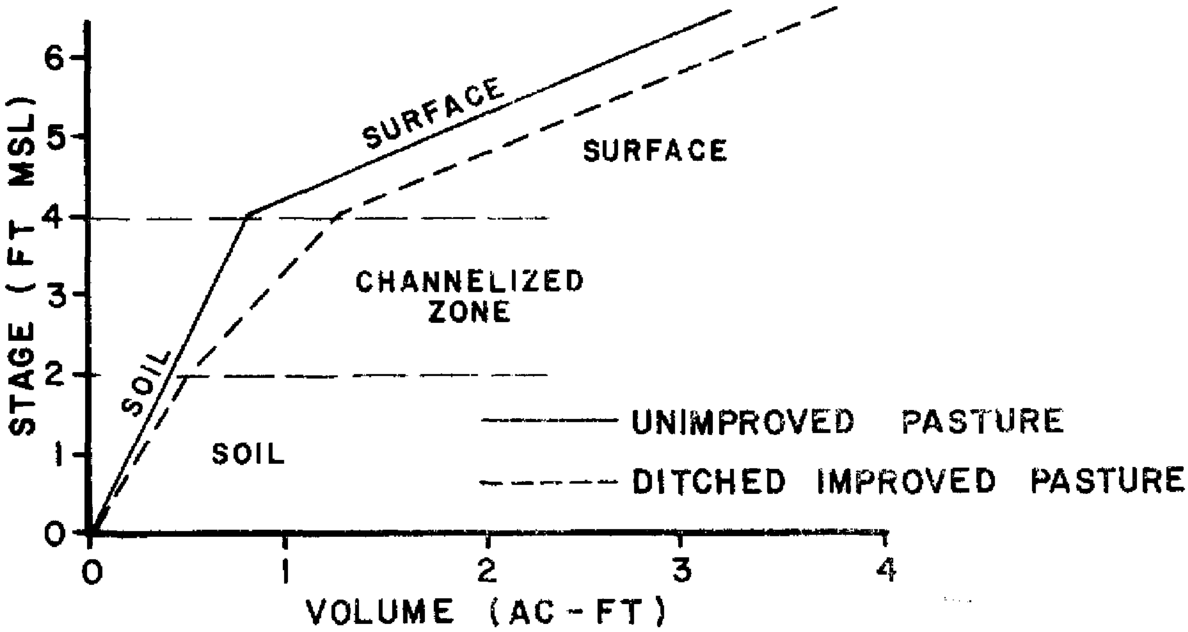

Figure 5.1. Stage-Volume Curves, Surface and Subsurface.

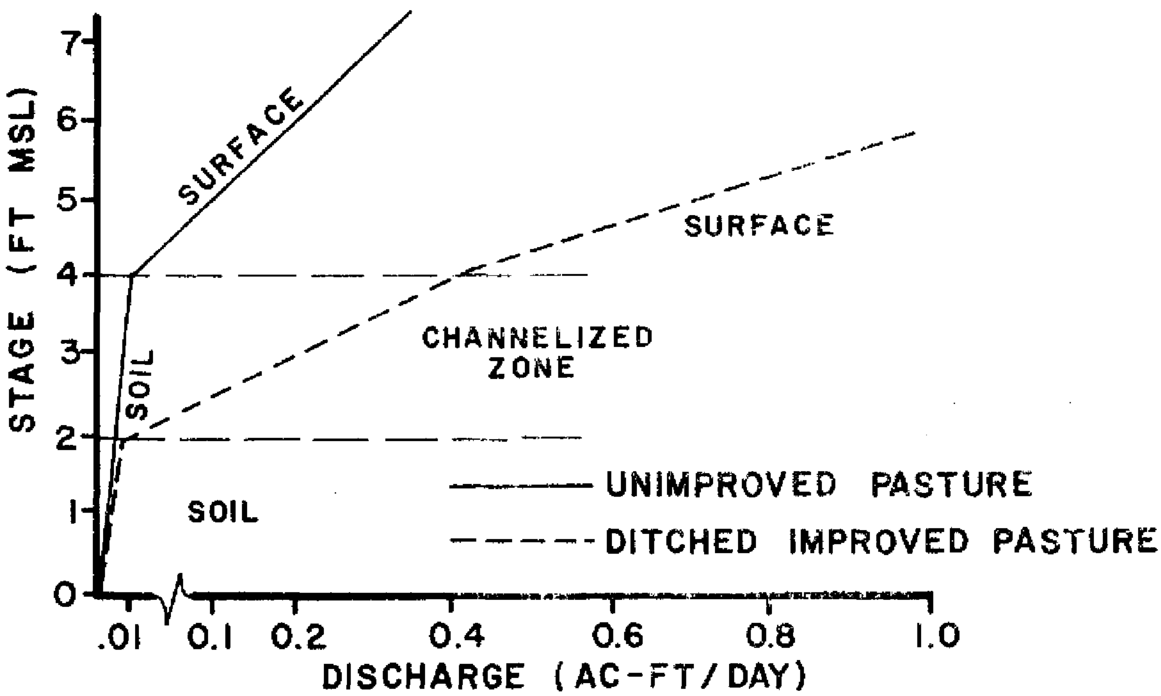

Figure 5.2. Stage-Discharge Curves, Surface and Subsurface.

of surface runoff. Note also the decrease in maximum soil moisture capacity as the water table is lowered from unimproved to ditched improved pasture.

The above concepts can be placed into a more useful context by considering the mechanisms of surface and subsurface runoff. It will be shown in this section on storage concepts that both surface and subsurface runoff rates can be directly related to the amount of reservoir surplus. This relation takes the general form of the continuity equation

$$\frac{dS}{dt} = I - O \qquad (5.1)$$

If inflow I = zero and outflow O = kS, then the solution to equation (5.1) is

$$\frac{S}{S_o} = e^{-kt} \qquad (5.2)$$

where S = reservoir storage on land or in soil,

S_o = initial storage level,

k = storage decay constant, time^{-1}, and

t = time.

The expected value of t corresponding to the above exponential distribution is 1/k, which is an estimate of the average detention time T.

The above analysis provides a framework for considering both surface and soil reservoirs in terms of characteristic detention times. Average values of T can be calculated for various components in the river basin. Specific surface and base flow relations are analyzed and a range of T values calculated for the Kissimmee River Basin. This was done in part in Chapter IV and will be extended in this chapter. Because shorter T values tend to be associated with higher outflows and lower storage capacity, this index provides a useful measure for managing and controlling excess runoff in a river basin.

Detention Time for Water Quality Control

Based on the above concepts for runoff control, water quality control can be placed into a similar context by considering detention time as an index of treatment potential. In the traditional sense, a treatment unit is composed of an input, uptake system, and output. The treatment efficiency depends on storage capacity, uptake capacity, and flow rates. The continuity relation presented in equation 5.1 for water volumes also applies for water quality parameters, but in the form

$$S\frac{dC}{dt} = QC_I(t) - QC - kCS \tag{5.3}$$

where C = concentration of pollutant in a well-mixed reservoir and discharge,

C_I = concentration of pollutant in inflow,

Q = volumetric inflow and outflow rate,

S = volume of tank, and

k = first-order decay constant for concentration.

Figure 5.3 presents a schematic diagram of this relationship.

Equation 5.3 is a first-order, linear differential equation, and can be rearranged to yield

$$\frac{dC}{dt} + aC = \frac{Q}{S}C_I(t) \tag{5.4}$$

where $a = \frac{Q}{S} + k.$

The general solution of equation 5.4 is

$$C(t) = e^{-\int a dt}\left[\int \frac{Q}{S}C_I(t)e^{\int a dt}dt + b\right] \tag{5.5}$$

where b = constant of integration, usually determined from an initial condition.

The integration of equation 5.5 can become very difficult if Q and S are functions of t and/or if C_I is a complex function of t. Rich (1973) presents some representative solutions. Of relevance here is the special case in which Q and S are constant which applies approximately to periods of a few weeks in the natural setting. For purposes of this discussion, the inflow concentration, C_I, will also be taken as constant. The solution of equation 5.5 for the situation of constant inflow, C_I, into a well-mixed reservoir of initial concentration, C_o, is thus,

$$C = \frac{Q}{S}\frac{C_I}{a}(1 - e^{-at}) + C_o e^{-at}. \tag{5.6}$$

This solution simply predicts an exponential change of concentration from C_o to the steady-state value, C_{ss}, where

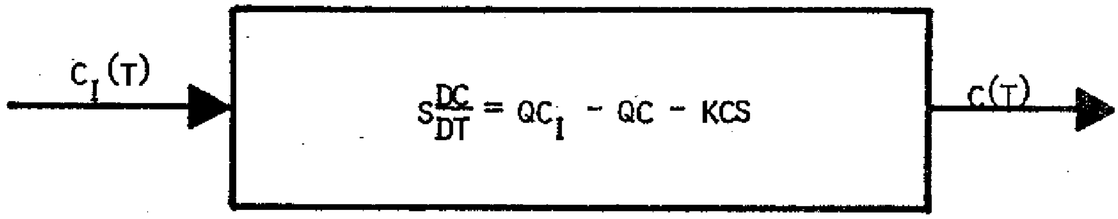

Figure 5.3. Schematic of Well-Mixed Water Quality Treatment System.

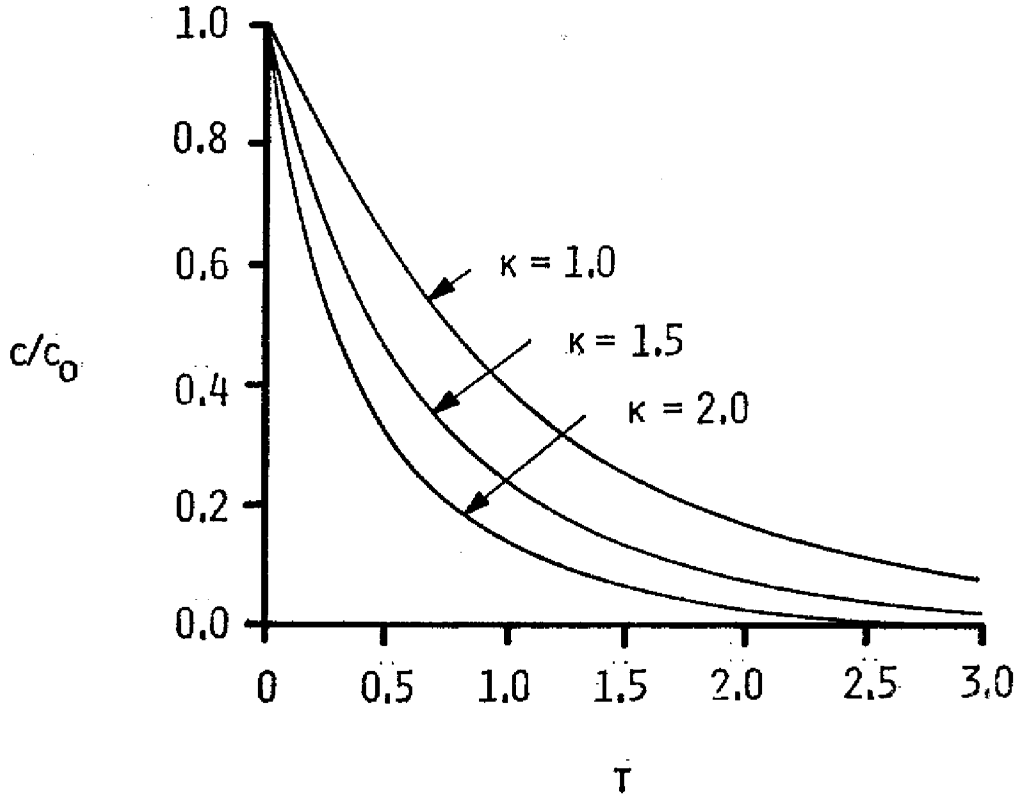

Figure 5.4. Typical First-Order Decay of Pollutant Concentration.

$$C_{ss} = \frac{Q}{S}\frac{C_I}{a} = \frac{C_I}{1 + \frac{kS}{Q}} \tag{5.7}$$

in which the inflow concentration is reduced by a factor involving the product of the decay rate, k, and the average detention time, S/Q.

Unfortunately, many natural water bodies are not at all well-mixed; lakes and impoundments in the Kissimmee River Basin exhibit marked variations in concentration of water quality parameters from one point to another. Hence, a more representative characterization may be that of plug-flow in which parcels of water are simply advected through the water body while pollutants undergo first order decay as they travel. The solution for this situation may be developed from the standpoint of an observer moving with a homogeneous, undisturbed parcel of water, for which Q = 0. Equation 5.6 then reduces to

$$\frac{C}{C_o} = e^{-kt} \tag{5.8}$$

where C = pollutant concentration after time of travel, t, and

C_o = initial pollutant concentration.

For analysis of real water bodies, the time of travel will typically be replaced by length/velocity, volume/flow rate (S/Q) or simply by the average detention time, T. The analytical link between well-mixed and plug-flow systems is diffusion and/or dispersion which have been omitted from the governing equations in this presentation.

A plot of equation 5.8 is shown in Figure 5.4 for three different values of k. The expression describes a first-order decay relationship for concentration, C, similar in form to equation 5.2 for storage, S.

The above analysis provides a technique for characterizing water quality uptake rates as a function of detention time which replaces t, and k which depends on the particular treatment unit (uptake mechanism) and pollutant. Since k is generally fixed for a particular component of the system, it follows that detention time becomes an index of treatment potential C/C_o. Calculations of C/C_o for a variety of hydrologic components in the Kissimmee River Basin are presented in subsequent sections of this chapter. This procedure allows comparisons to be made among different treatment units, e.g., marsh, lake, river, and between different seasons for the same unit. However, it should be recognized that such comparisons will represent only a preliminary level of analysis. In particular, k and T must be held constant over the time period of comparison, e.g., a season; first-order decay coefficients may not be applicable to lakes or for all pollutants; and inflows and outflows along the water body are neglected. Such considerations could be included in a more sophisticated level of analysis.

The concepts of storage and water quality control have led to a unified methodology for considering various components in the river basin. Later sections extend and apply the detention time ideas at various levels of resolution for storage and transport from the land, through marshes, and eventually to lakes and the river. Both water quantity and quality relationships are considered throughout.

EVALUATION OF C-38

Water Quantity Control

Background --

Flood control has long been an important issue in the Kissimmee River Basin dating back to 1949 when the Central and Southern Florida Flood Control District was originally formed. The basin has a history of naturally occurring flood events which have inundated large areas above the lake shorelines and along the river floodplain. In recent years as agricultural and urban developments have located along the lake shorelines, a demand for flood control for the upper basin lakes was expressed. The existing flood control project in the area uses structural controls and channelization to speed the flood waters through the chain of lakes, down the channelized Kissimmee River (C-38), and into Lake Okeechobee.

A comparison of the flood hydrograph with and without the flood control project can be made by investigating the floods of 1953, 1960, and 1969. Figure 5.5 shows the monthly rainfall and daily streamflow for the Kissimmee River near Okeechobee, Florida (S65-E) for the three flood years. The 1969 flood occurred five years after the control works had begun operation and the other floods represent the response of the unchannelized river flood plain. Rainfall patterns are similar for three floods with 1953 recording the highest rainfall amount. Table 5.1 characterizes the three events according to total flood time above 3000 cfs, recession time from peak flow to 3000 cfs, and total volume of flow. The 1953 and 1960 flood hydrographs are similar in all categories except for the actual shape of the curve. The recession for the 1953 event was slightly longer. The 1969 hydrograph is markedly different from the others and is characteristic of a developed drainage system, i.e., a higher peak flow and a shorter lag time between rainfall and response. Recession time is reduced as is total flood time, although reduction of the latter corresponds roughly to the 15 percent reduction in flood volume. Note the secondary flood peaks which are characteristic of a channelized system. In addition, the time of travel through the system has been altered due to the channelization and the reduction in total river length from about 90 miles to 50 miles.

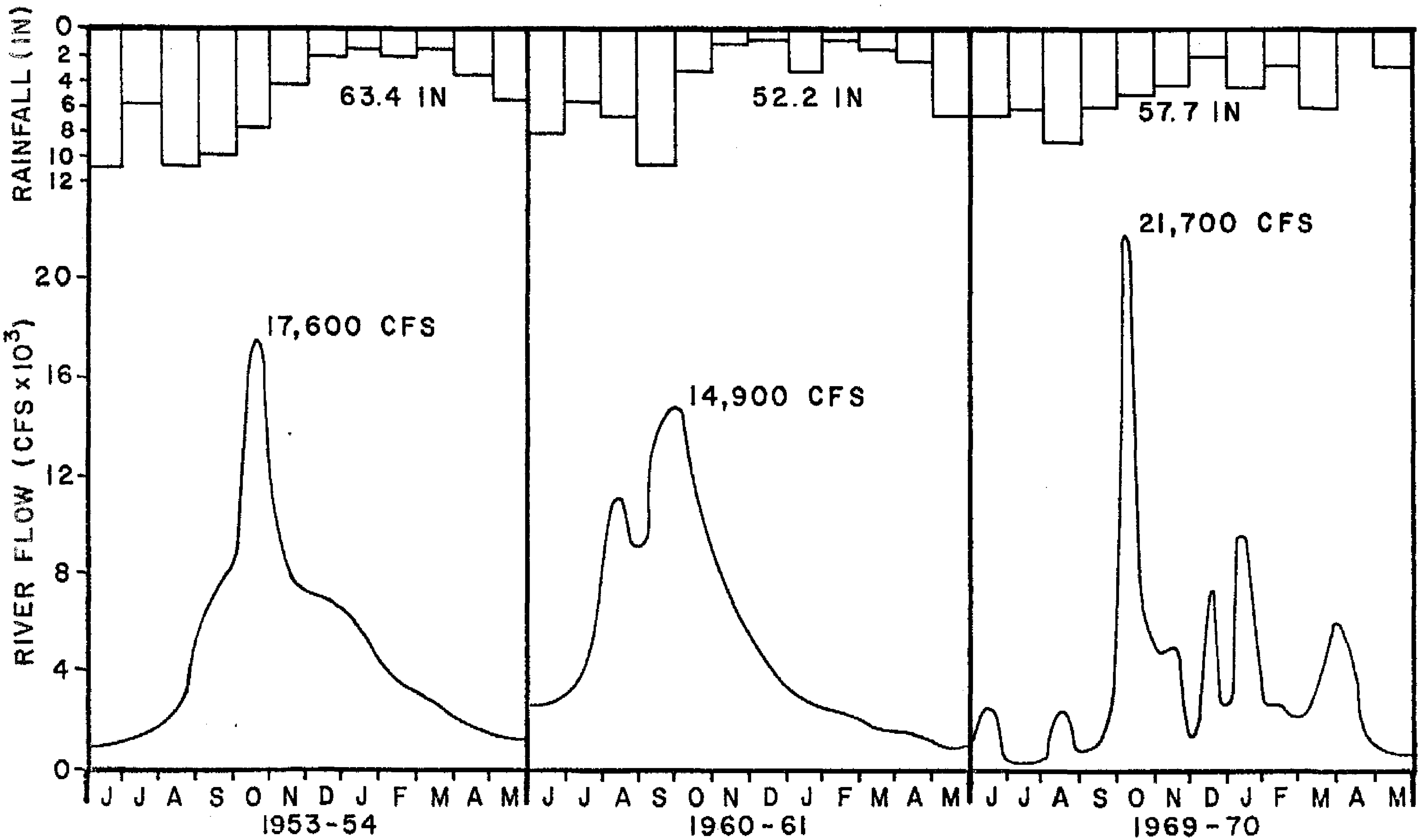

Figure 5.5. Monthly Rainfall and Daily Streamflow for Kissimmee River near Okeechobee, Florida, for Three Flood Years.

Table 5.1. Analysis of Floods in the Kissimmee River Basin.

Year	Rainfall (in)	Recession Time (flow > 3000 cfs) (mo)	Flood Time (flow > 3000 cfs) (mo)	Total Volume (10^3 ac-ft)
1953	63.4	6.5	9.5	321.0
1960	52.2	5.0	9.0	318.0
1969	57.7	2.5	7.0	270.0

This section develops a technique for predicting flood hydrographs discharged from the Kissimmee River Basin. The routing procedure uses input runoff from the HLAND model, and thus can simulate the response for any given land use pattern in the basin. The routing procedure can simulate the present C-38 channel system, or it can be altered to model the original meandering river in its flood plain. This is done simply by altering coefficients in the routing procedure described below. In this way, it is possible to investigate whether the river channelization or the upland tributary drainage activities has caused the greatest change in the observed outflow hydrograph (Figure 5.5).

Description of the Routing Method --

The total runoff predicted by HLAND for each planning unit, plus any inflows from upstream, can be routed through the main stem of the river by considering the governing momentum and continuity equations. While sophisticated methods exist for solution of these equations (e.g., Henderson, 1966; Viessman et al., 1972) simpler techniques usually suffice when long-term seasonal response and daily time steps are of primary concern. A reasonably accurate and widely used technique for this purpose is the Muskingum method (see, for example, Linsley et al., 1975) in which dynamic terms in the momentum equation are neglected and storage is assumed proportional to a linear combination of inflow and outflow from a reach, as described below.

The linear relationship between flow and storage is an approximation; however, it is possible to produce surprisingly accurate results with the Muskingum method by appropriate choices of the two parameters involved. It is for this reason, and its simplicity, that it is such a popular technique. It meshes well with other components of this study since daily time steps can be used to complement the runoff calculations from HLAND.

The Muskingum method is relatively simple in theory, using wedge and prism storage concepts to relate outflow to storage and inflow (Figure 5.6). During the advance of a flood wave, inflow always exceeds outflow, thus producing the wedge storage shown in Figure 5.6. Conversely, during the recession of the wave, outflow exceeds inflow resulting in a negative wedge storage. The wedge storage is represented by $KX(I - O)$ and the prism storage by KO. The total storage is, therefore

$$S = KO + KX(I - O) \tag{5.9}$$

where S = storage

I = inflow

O = outflow

K = travel time parameter, and

X = storage parameter.

This is the Muskingum equation, and may be written for two routing periods (1 and 2) as

$$S_2 - S_1 = K[X(I_2 - I_1) + (1 - X)(O_2 - O_1)]. \tag{5.10}$$

Combining equation 5.10 with the continuity equation for the same two periods yields

$$\frac{1}{2}(F_1 + F_2)\Delta t + \frac{1}{2}(I_1 + I_2)\Delta t - \frac{1}{2}(O_1 + O_2)\Delta t = S_2 - S_1 \tag{5.11}$$

where F_1 and F_2 represent tributary or lateral runoff contributions for two consecutive routing periods. The following equations can be derived:

$$O_2 = O_1 + C_1(I_1 - O_1) + C_2(I_2 - I_1) + C_3(F_2 + F_1) \tag{5.12}$$

where
$$C_1 = \frac{\Delta t}{K(1-X) + 0.5\Delta t} \tag{5.13}$$

$$C_2 = \frac{0.5\Delta t - KX}{K(1-X) + 0.5\Delta t}, \text{ and} \tag{5.14}$$

$$C_3 = \frac{0.5\ \Delta t}{K(1-X) + 0.5\Delta t} \tag{5.15}$$

The solution of equation 5.12 for O_2 is accomplished for consecutive segments of the river reach, since all terms on the right hand side are known. The O_2 from one segment serves as I_2 to the next downstream segment. Tributary contributions of lateral runoff are simply added in for each segment on a daily basis.

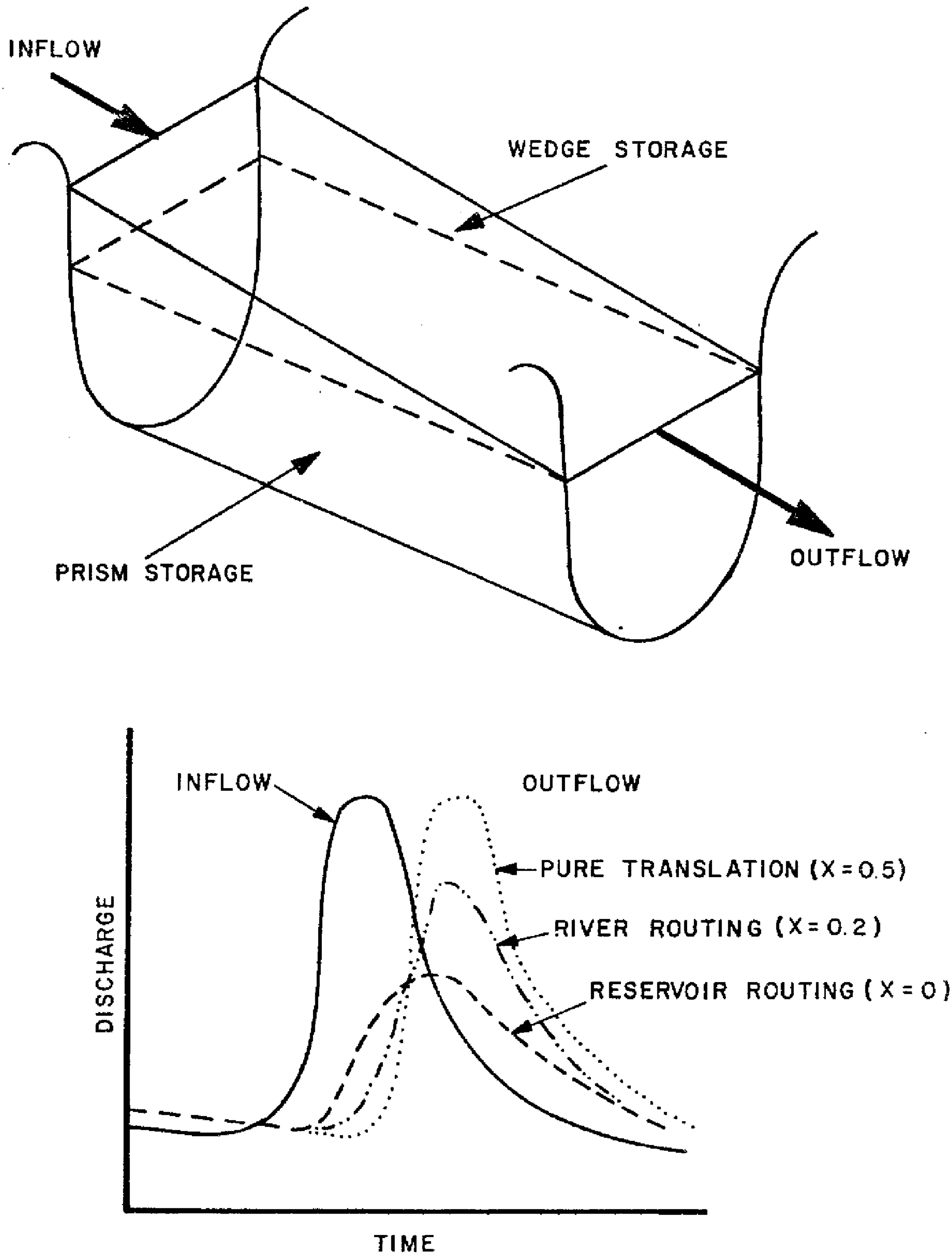

Figure 5.6. Schematic of Muskingum Routing Technique.

Table 5.2. Muskingum Routing Parameters.

Five Reaches	C-38 Length (mi)	X	C-38 K (days)	Natural K (days)
S65				
1	9.5	0.3	0.500	1.90
S65 A				
2	11.7	0.3	0.625	2.30
S65B				
3	8.4	0.3	0.450	1.65
S65C				
4	9.2	0.3	0.500	1.80
S65D				
5	6.9	0.3	0.375	1.35
	45.7		2.450	9.0
S65E				

Routing Parameters --

Values of K and X must be estimated for a particular river segment. Graphical techniques and the analysis of observed inflow and outflow hydrographs are recommended (Linsley et al., 1975). The value of K is essentially the travel time in the reach in days. The value of X varies from 0.0 to 0.5 as a function of storage capacity in the river, with the lower values related to greater storage. The effect of X on the routed hydrograph is depicted in the lower portion of Figure 5.6. Pure translation results when X = 0.5, and storage effectively reduces the peak for X = 0.0 (horizontal water surface). Routing parameters used in modeling the Lower Kissimmee River are shown in Table 5.2.

The same value of X was used for both the natural river and C-38 because the model was relatively insensitive to this parameter. Future use of the routing technique could include lowering X to a value less than 0.3 for simulation of the natural river, although results are not expected to change much.

Possible values for K are discussed in detail below. However, the entire discussion should be prefaced by noting that while results of HLAND (planning unit runoff) are important to overall conclusions of the study, the conclusions are not based to a significant degree on the Muskingum routing exercise itself. For instance, it will be seen below that a range of plausible travel times exist for the river, from which many different Muskingum routing parameters could be derived. Instead, one set of parameters (K and X) is used for a representative simulation while the entire range of travel times is incorporated into the overall analysis. It is important to view the selection of Muskingum parameters in this light.

Travel Times --

As mentioned, a determination of the travel time must be made, both from the standpoint of the Muskingum routing parameter, K, and as an indication of overall detention time in the basin. Data are needed for both the natural and channelized (C-38) river, and consist mainly of velocity determinations, from whence travel times may be computed when the distance is known.

For the channelized river, C-38, computations are simplified because detailed information is known about the cross section and flows. C-38 is a trapezoidal channel averaging 30 ft deep with side slopes of 1 on 2 (vertical:horizontal). The bottom width varies from 90 ft at S65 to 425 ft at S65-E. Velocity computations are shown in Table 5.3 for average conditions using flows over the entire period of record and flows only since construction of C-38 began in 1964, which are about 75 percent of the former. Velocities of 0.20 and 0.15 ft/sec are indicated, respectively. Corps of Engineers design calculations for flood conditions provide for a velocity of 2.5 ft/sec uniformly along the river.

Table 5.3. Velocities and Travel Times for C-38.

	Location		Source
	S65	S65-E	
Cross Sectional Area, ft^2	4,500	14,550	C of E, DDM, 1961
Average Flow, cfs	1,115[a]	2,033[b]	USGS, Surface Water Records, 1974
Velocity, ft/sec	0.25	0.14	
Average Velocity, ft/sec	0.20		
Average Travel Time[c], days	14.0		
Average Flow Since Project, cfs	885[d]	1,504[d]	USGS, Surface Water Records, 1974
Velocity, ft/sec	0.20	0.10	
Average Velocity, ft/sec	0.15		
Average Travel Time[c], days	18.6		
Maximum Design Velocity, ft/sec	2.50		C of E, DDM, 1961
Minimum Travel Time[c], days	1.12		

[a]41 years, 1933-1974 (water years).

[b]44 years, 1928-1962, 1964-1974 (water years).

[c]Using length of river from S65 to S65-E = 45.7 miles.

[d]10 years beginning with construction of C-38, October 1964 to September, 1974.

Under average annual flow conditions, Table 5.3 indicates travel times in C-38 ranging from 14 to 18 days, dropping to 1.12 days under design flood conditions. For flow routing purposes, it is more important to transport highly transient flood peaks properly, for which a Muskingum K value of about 2.5 days was found to give good results. During other portions of the season, gradients within the river are much less and not as sensitive to K. Values were apportioned to each channel reach on the basis of length as indicated in Table 5.2.

Under natural (pre-C-38) conditions, a variety of velocities are possible. Flows were gauged routinely by the USGS, including periodic updates of their rating curves for different stations along the river. Formulation of such rating curves involved actual measurement of velocities under different flow conditions, from which diagrams such as Figure 5.7 can be prepared. The data in Figure 5.7 are based upon recent work performed by the Corps of Engineers (Enge 1975) in which past data from USGS records were analyzed. All of the curves show large reductions in velocity when the river overflows its banks and enters the flood plain. Velocities indicated for average and flood conditions are shown in Table 5.4 with corresponding travel times. Since the flows shown in Figure 5.7 are listed by the USGS as for the whole river, they are assumed to <u>include</u> overbank (flood plain) flow when at higher stages.

A method of calculating velocities has been performed by the FCD (Shahane 1975, 1976). Measured flows from USGS records were divided by areas planimetered from cross sections along the river near the USGS measurement locations. Resulting velocities are given in Table 5.5 and are considerably lower than those of Table 5.4 and Figure 5.7. In addition, the trend of velocities of Table 5.6 is different than that shown in Figure 5.7, that is, there is an increase at higher flows. The reasons for this are unclear; however, at least two facts are evident. First, the USGS velocities were measured primarily in the river channel and would be expected to be higher than an average velocity that includes flow within the flood plain, although presumably an adjustment was made when overbank flow occurred. Second, the cross sections used in calculating the areas shown in Table 5.5 are not necessarily at the same location as the UGSG measurements. In fact, very large cross sectional areas are indicated for average flow conditions in Table 5.5, whereas

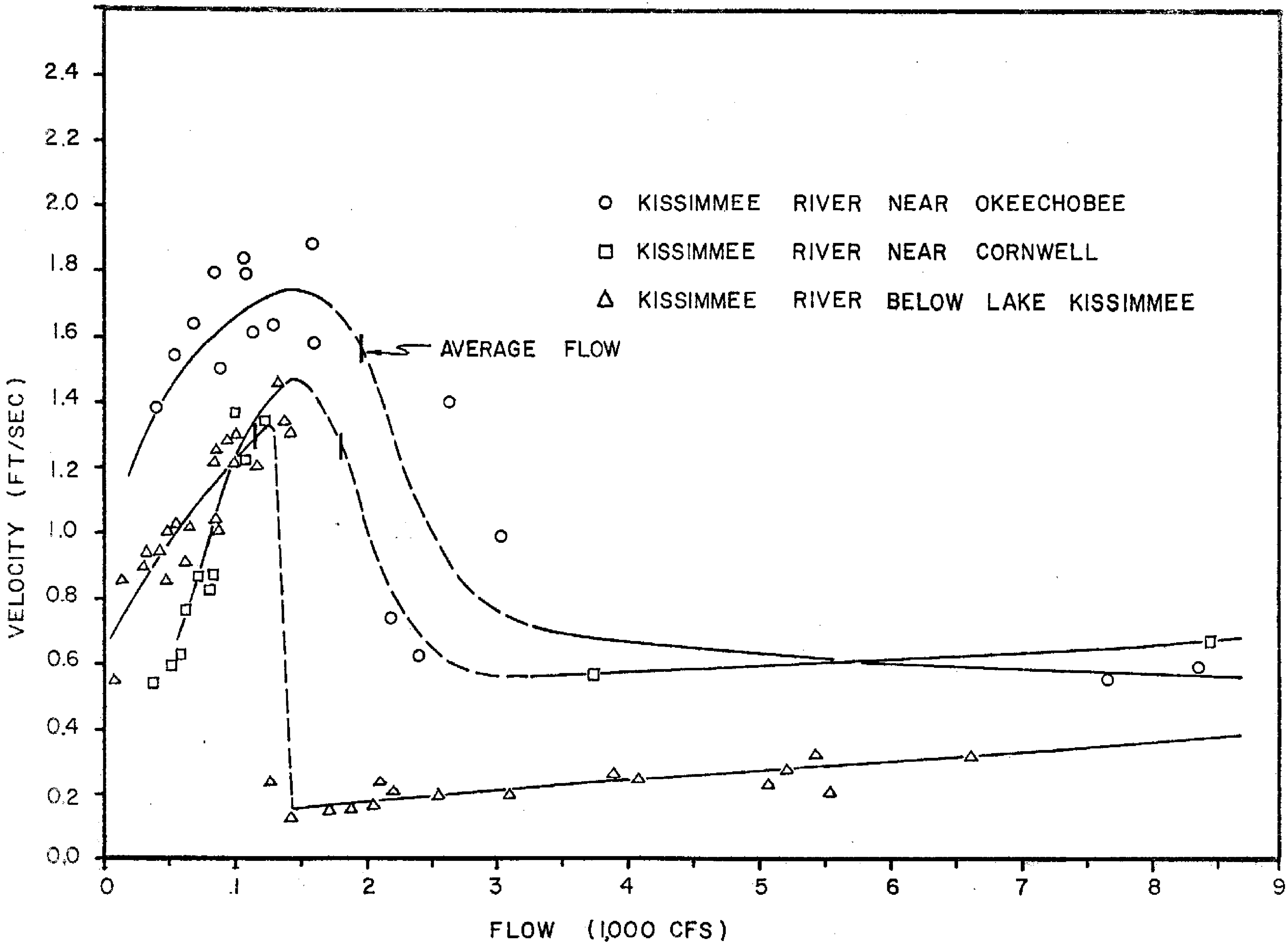

Figure 5.7. Flow-Velocity Relations of Three Kissimmee River Stations (Enge, 1975). USGS data are

Table 5.4. Measured Velocities Along Kissimmee River.[a]

	Kissimmee R. below L. Kissimmee	Kissimmee R. near Cornwell	Kissimmee R. near L. Okeechobee
Average Flow, cfs	1,149[b]	1,824[c]	1,989[b]
Average velocity[d], ft/sec	1.3	1.28	1.58
Three Station Average, ft/sec		1.39	
Average Travel time[e], days		4.0	
Average Flood Velocity[d], ft/sec	0.25	0.60	0.60
Three Station Average, ft/sec		0.48	
Flood Travel Time[e], days		11.4	

[a]After Enge, 1975.

[b]From USGS Surface Water Records, 1931-57.

[c]From USGS Measurements, 1949, 1951.

[d]From Figure 5.7.

[e]Using average of three velocities and river length of 90 miles.

Table 5.5. Computed Velocities on Kissimmee River.[a]

Location	Stage (ft)	Area (ft^2)	Flow (cfs)	Velocity (ft/sec)	Source
Kissimmee River	48.1[b]	1850[b]	302[b]	0.16	USGS WSP 892 (1940)
at Lake Kissimmee	49.4	3280	428	0.13	USGS WSP 952 (1942)
	50.0	5670	534	0.09	USGS WSP 972 (1943)
Record: 1931-57	51.0	11750	707	0.06	USGS WSP 1002 (1944)
	52.0	18000	834	0.05	
	52.6	21240	951	0.04	
	52.9	24540	1000	0.04	
	53.5	27860	1160	0.04	
	54.1	34110	1990	0.06	
	54.5	34490	2550	0.07	
Ave Max Flow[c]			2396		
Ave Flow			1149		
Ave Min Flow[c]			480		
Kissimmee River	27.35[d]	1120[d]	626[d]	0.56	State Board of Con-
near Cornwell	28.7	3110	980	0.32	servation, Water
	29.92	6840	1618	0.24	Survey and Res.
Record: 1949, 1951	31.0	12590	1865	0.15	Paper No. 7 (1952)
(two years)	32.39	19550	6915	0.35	
Ave Max Flow[c]			4267		
Ave Flow			1824		
Ave Min Flow[c]			766		
Kissimmee River	18.8[e]	1370[e]	370[e]	0.27	Same as for Lake
at Lake Okeechobee	20.0	1830	654	0.36	Kissimmee
	21.0	2570	885	0.34	
Record: 1931-57	22.0	4620	1140	0.25	
	23.0	7260	1410	0.20	
	23.7	9400	1720	0.18	
	24.7	12500	2640	0.21	
	25.6	15640	4280	0.27	
	26.6	18780	6800	0.36	
	27.9	22860	11700	0.51	
Ave Max Flow[c]			4303		
Ave Flow			1989		
Ave Min Flow[c]			881		

[a]From FCD memoranda, Shahane (1975, 1976). Velocities computed from measured flows and areas.

[b]From USGS rating curve, developed 1939-44.

[c]Average of annual maxima and minima over period of record.

[d]From USGS rating curve, developed 1949, 1951.

[e]From USGS rating curve, developed 1943-45.

the fact that the average flow occurs high on the transition portion of the flow-velocity curves of Figure 5.7 indicates that probably most of the river flow was occurring within its banks during those measurements. Reference to the original USGS data sheets used by Enge (1975) does show correspondingly low areas. There is also the possibility that differences in the datum exist between USGS and other estimates. Shahane (1976) indicates that the percentage of total cross sectional area occupied by the river channel itself at stages corresponding to average flow conditions are 6.17, 6.27 and 13.6, respectively, proceeding downstream for the three stations. If actual areas corresponding to these percentages are multiplied by velocities taken from Figure 5.7 and Table 5.4, flows higher than the average result for the end stations, and 47 percent of the average flow for the station near Cornwell. Thus, it is not possible (in two of the three cases) to apportion the flow between river and flood plain by coupling the two sets of data. Rather, the FCD calculations by Shahane must be considered as a second, independent assessment of velocities. Arbitrarily considering velocities from Table 5.5 that are within ± 500 cfs of the average at each station, the values shown in Table 5.6 are developed in which quite large travel times of 37 days for average and 20 days for flood conditions are indicated.

Unfortunately, these values do not correspond at all to those of Table 5.4 Moreover, they are counter-intuitive from the standpoint of Mannings equation

$$V = \frac{1.49}{n} R^{2/3} S_{\ell}^{1/2} \tag{5.16}$$

where V = average velocity, ft/sec,

n = Mannings roughness,

R = hydraulic radius, area/wetted perimeter, ft, and

S_{ℓ} = river slope.

As the river stages rise, two effects occur. First, the roughness of overbank (flood plain) flow is considerably higher than that of the main channel, indicating a lower velocity. Second, relatively large changes in area occur for relatively small changes in depth (see Table 5.5). In these situations, the hydraulic radius actually decreases since the wetted perimeter increases more rapidly than does the area as the flow occupies more and more of a wide flood plain. These effects act to decrease the average velocity and increases the travel time under flood conditions, as indicated in Figure 5.7 and Table 5.4. Equation 5.16 could also be used to calculate velocities if all parameters were known. Shahane's (1976) data indicate that a hydraulic radius of 10 to 16 ft is appropriate for the main channel section of the natural river. Using R = 13 ft, n = 0.10 and a slope of 0.0000568 corresponding to a reduction of stage from 51 ft to 24 ft over 90 miles, equation 5.16 gives a velocity of 0.62 ft/sec and a corresponding travel time of 8.9 days. It is obvious that there is considerable latitude in the choice of parameters, in particular Mannings n. The value of 0.10 corresponds to a quite rough channel (Chow 1959), whereas comparison with Table 5.4 indicates that a value of 0.05 might be more appropriate. In any event, the value of 8.9 days calculated above is strictly another estimate.

Still other sources for travel times exist. In 1973, the FCD (Storch 1973) analyzed in detail the September-October 1960 flood event and the October 1969 flood event (see Figure 5.5). On the basis of gaged water surface elevations and floodplain cross sections, water velocities were computed. It was determined that it took a unit of water approximately 10.5 days to move from Lake Kissimmee to Lake Okeechobee during the 1960 event and approximately 3 days during the 1969 event. These values are close to the values of 11.4 and 1.12 days given in Tables 5.4 and 5.3 respectively for the natural and channelized river. It is also of interest that Langbein (1955, page 526) concluded in his runoff analysis that 10 days was sufficient time to discharge all direct runoff from a rainfall event from the entire natural (pre-project) Kissimmee River Basin. This value seems low for the entire basin, but is the same order of magnitude as the values mentioned in this paragraph.

One other estimate of travel times for the natural river has been made by Taylor (1975). For a total flow of 4050 cfs he estimated the travel time through the natural Kissimmee River marsh areas to be 90 days. This might be reasonable when coupled with much higher velocities in the main channel.

A summary of the various travel time estimates is given in Table 5.7 for the natural Kissimmee River. What values should be used? In the opinion of the writers, the large values based on Shahane's (1975, 1976) velocity calculations require further investigation in order to be reconciled with the much lower values that are based on actual USGS gaging. The probable reason for the discrepancies have been mentioned, but focus upon the location of cross sections used in each analysis. It is also possible that discrepancies in the datum used to calculate stages may exist between cross sections used by Shahane and those used by the USGS. Finally, if Shahane's cross sections are across the total flood plain, then an overall river length of 50 miles is more appropriate than the 90 miles of the meandering main channel. If the travel times of Table 5.6 are multiplied by 5/9, they are in better agreement with the other estimates. The lower values of T thus appear more likely.

In running the Muskingum routing model, a value of 9.0 days for the total 90 mile river was found to produce good results when apportioned over each reach, as indicated in Table 5.2. This is but one value; model runs of nearly equal accuracy could quite probably be made with values somewhat different than 9.0 days. Further work on this topic must be postponed for future research. However, the implication is that travel times are longer under average conditions in C-38 than in the natural river.

Table 5.6. Velocities and Travel Times from Computed Values of Table 5.5.

	Kissimmee R. below L. Kissimmee	Kissimmee R. near Cornwell	Kissimmee R. near L. Okeechobee
Average Velocity[a], ft/sec	0.05	0.21	0.18
Three Station Average, ft/sec		0.15	
Average Travel Time[b], days		37.4	
Average Flood Velocity[c], ft/sec	0.07	0.35	0.38
Three Station Average, ft/sec		0.27	
Flood Travel Time[b], days		20.6	

[a] Average of values corresponding to flows with ± 500 cfs of average.

[b] Using average of three velocities and river length of 90 miles.

[c] Velocity for highest flow for first two stations, average of velocities for three highest flows for third station.

Table 5.7. Summary of Different Travel Time Estimates (Days) for Natural Kissimmee River.

<table>
<tr><th rowspan="2">Source</th><th colspan="2">Condition</th></tr>
<tr><th>Average</th><th>Flood</th></tr>
<tr><td>Corps of Engineers[a] (Enge 1975)</td><td>4.0</td><td>11.4</td></tr>
<tr><td>FCD[b] (Shahane 1975, 1976)</td><td>37.4</td><td>20.6</td></tr>
<tr><td>FCD (Storch 1973)</td><td></td><td>10.5</td></tr>
<tr><td>Langbein (1955)</td><td colspan="2">10</td></tr>
<tr><td>Mannings Equation (n = 0.10)</td><td>8.9</td><td></td></tr>
<tr><td>Kissimmee River Marsh (Taylor 1975)</td><td></td><td>90</td></tr>
<tr><td>Used in this Study</td><td>9.0</td><td>11.0</td></tr>
</table>

[a]Table 5.4.

[b]Table 5.6.

Results

HLAND has been applied to the lower basin of the Kissimmee River south of Lake Kissimmee. Surface and subsurface runoff volumes are routed down the river to Lake Okeechobee using the Muskingum routing technique described previously. The river has been segmented corresponding to the various control structures which also define the planning unit boundaries. Measured outflows from Lake Kissimmee are treated as inflows to the routing procedure. The routing is applied on a daily basis, incorporating total runoff from each planning unit, and ultimately providing the outflow hydrograph to Lake Okeechobee.

By using present land use configurations (1972) and a series of daily rainfall patterns over the basin (1965-1970), the predicted outflow hydrograph from the Kissimmee River can be compared to measured streamflows at the gaging station near Okeechobee (S65-E). The predictions of HLAND can then be verified.

A series of verification years, 1965-1970, was selected based on the availability of data and the fact that this sequence includes both drought and extreme flood conditions, which provides a good test of the accuracy of the model. A comparison of measured and predicted streamflows is depicted in Figure 5-8 at the gaging station near Okeechobee (S65-E). It can be seen that the model provides a generally accurate representation of the basin response during conditions of floods (1969-1970), droughts (1965-1967), and average flows (1968). Figure 5-9 shows one year of predicted and measured flows for the lower basin, with inflows from Lake Kissimmee subtracted from outflows at S65-E. This indicates that the model is accurately predicting runoff volumes from each planning unit. A summary of flow data for selected planning units is presented in Table 5.8 in order to indicate the distribution of surface and subsurface runoff volumes. Total volumes of runoff for the basin are compared in Table 5.9.

In addition, HLAND was run for a 2-year period prior to channelization (1959-1960) using the 1958 level of land use for predicting runoff and the original meandering floodplain for routing the flows. (As indicated in Table 5.2 only K was changed to simulate the natural floodplain.) Results are shown in Figure 5.10 for measured and predicted streamflows at S65-E. Based on calibration runs, the basin response seems to be more sensitive to the land drainage characteristics than to the condition of the narrow river floodplain. Travel times were slower under the 1958 regime because upland marsh and slough detention provided additional storage capacity during the wet season. The present regime induces excess water into drainage canals at a faster rate, and thus yields increasing percentages of surface runoff compared to subsurface flows as shown in Figure 4.8.

These effects are summarized in Table 5.10 in which the effects of land use changes on total and component lower basin travel times are shown. The dominant effect appears to be upland drainage within planning units that increases the proportion of surface runoff, rather than the construction of C-38 since the latter has apparently <u>increased</u> travel time by five days. As indicated in the extensive previous discussions, travel times for the natural Kissimmee River and within-planning unit travel times for all conditions are quite uncertain and open to conjecture. Another estimate of subsurface travel times, for instance, could be obtained by analysis of groundwater records. But, specific numbers aside, it appears that there has been a definite reduction in the weighted average travel time for total runoff moving from the upland areas toward the Kissimmee River between 1958 and 1972, if for no other reason than the sizeably increased fraction of those flows that appears as surface (direct) runoff. At the same time, travel times down the natural and channelized Kissimmee River are at least the same order of magnitude. The overall reduction thus appears to result primarily from effects of upland drainage.

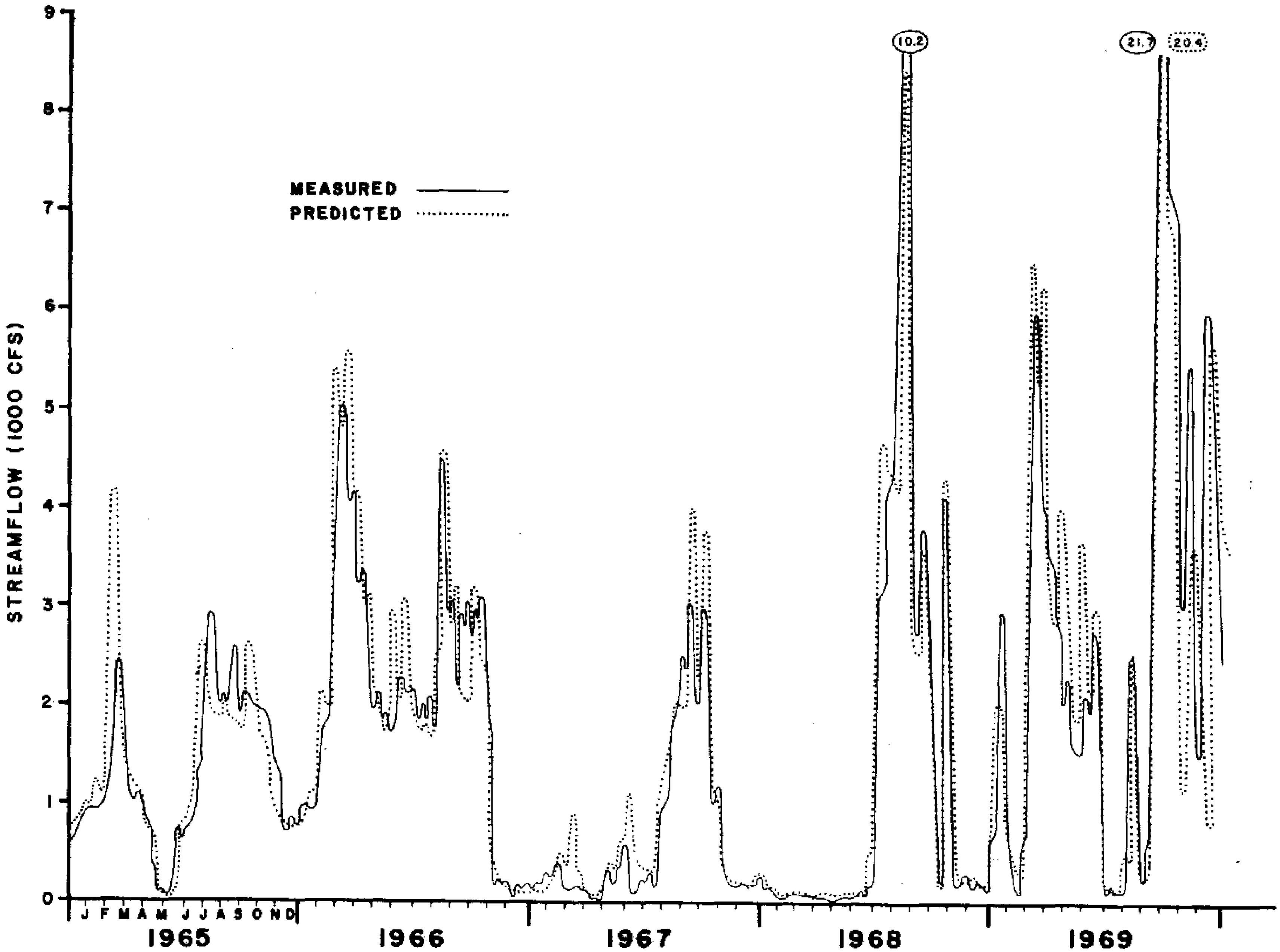

Figure 5.8. Measured and Predicted Hydrographs (1965-1970), Total Kissimmee River Basin (S65-E).

Table 5.8. Surface and Subsurface Runoff by Planning Unit (1967-1969).

Planning Unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
						1967 Runoff (10^3 ac-ft)							
13 (S)[a]	0.0	0.0	0.0	0.0	0.0	3.3	1.3	3.2	0.9	0.3	0.0	0.0	9.0
13 (G)[b]	0.7	3.7	1.8	0.0	0.0	2.9	6.9	9.7	6.6	4.7	0.0	2.5	39.5
16 (S)	0.0	5.1	0.1	0.0	0.0	5.0	4.4	0.0	19.0	13.0	0.0	0.0	46.6
16 (G)	0.3	3.8	2.4	0.0	0.0	2.6	4.0	2.5	3.5	4.4	1.8	2.2	26.5
						1968 Runoff							
13 (S)	0.0	0.0	0.0	0.0	5.6	23.0	14.0	0.0	2.3	6.6	0.8	0.0	52.3
13 (G)	0.9	2.0	2.9	0.0	2.9	21.0	21.0	6.0	6.5	11.0	8.8	3.1	86.1
16 (S)	0.0	0.0	0.0	0.0	8.5	44.0	20.0	0.5	1.5	14.0	0.0	0.0	88.5
16 (G)	0.9	1.7	2.1	0.0	1.1	6.8	5.0	2.3	3.3	3.7	3.1	0.7	30.7
						1969 Runoff							
13 (S)	2.3	0.0	13.0	3.6	6.9	3.0	2.0	5.9	0.5	30.0	0.0	0.6	67.8
13 (G)	6.2	3.3	14.0	7.9	14.0	8.8	8.0	13.0	6.5	23.0	9.7	8.0	122.4
16 (S)	3.2	0.0	28.0	8.9	16.0	7.6	5.7	14.0	1.5	52.0	0.0	2.1	139.0
16 (G)	3.4	2.3	5.4	3.3	4.8	3.3	3.5	4.5	3.1	7.3	4.1	4.0	49.0

[a]Surface runoff

[b]Subsurface runoff

Table 5.9. Comparison of Measured (M) and Predicted (P) Runoff Volumes (1967-1969).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Runoff Volumes (10^3 ac-ft)												
1967 (M)	12.0	14.4	10.5	6.1	23.9	29.3	33.2	104.5	145.8	102.6	15.4	15.2	512.9
1967 (P)	10.3	26.6	20.6	8.2	28.8	43.4	43.0	106.0	160.0	119.0	17.9	20.2	604.0
1968 (M)	14.0	11.7	10.4	6.1	12.1	209.7	415.1	229.2	177.2	124.8	39.7	19.1	1269.0
1968 (P)	14.8	15.6	20.6	7.8	27.5	243.0	292.0	186.0	145.0	91.9	38.7	19.1	1102.0
1969 (M)	89.6	28.5	219.1	164.9	106.8	96.7	22.6	87.1	118.9	614.9	176.9	228.3	1954.3
1969 (P)	88.7	29.0	237.0	155.0	158.0	80.6	33.6	69.6	63.3	552.0	114.0	188.0	1768.8

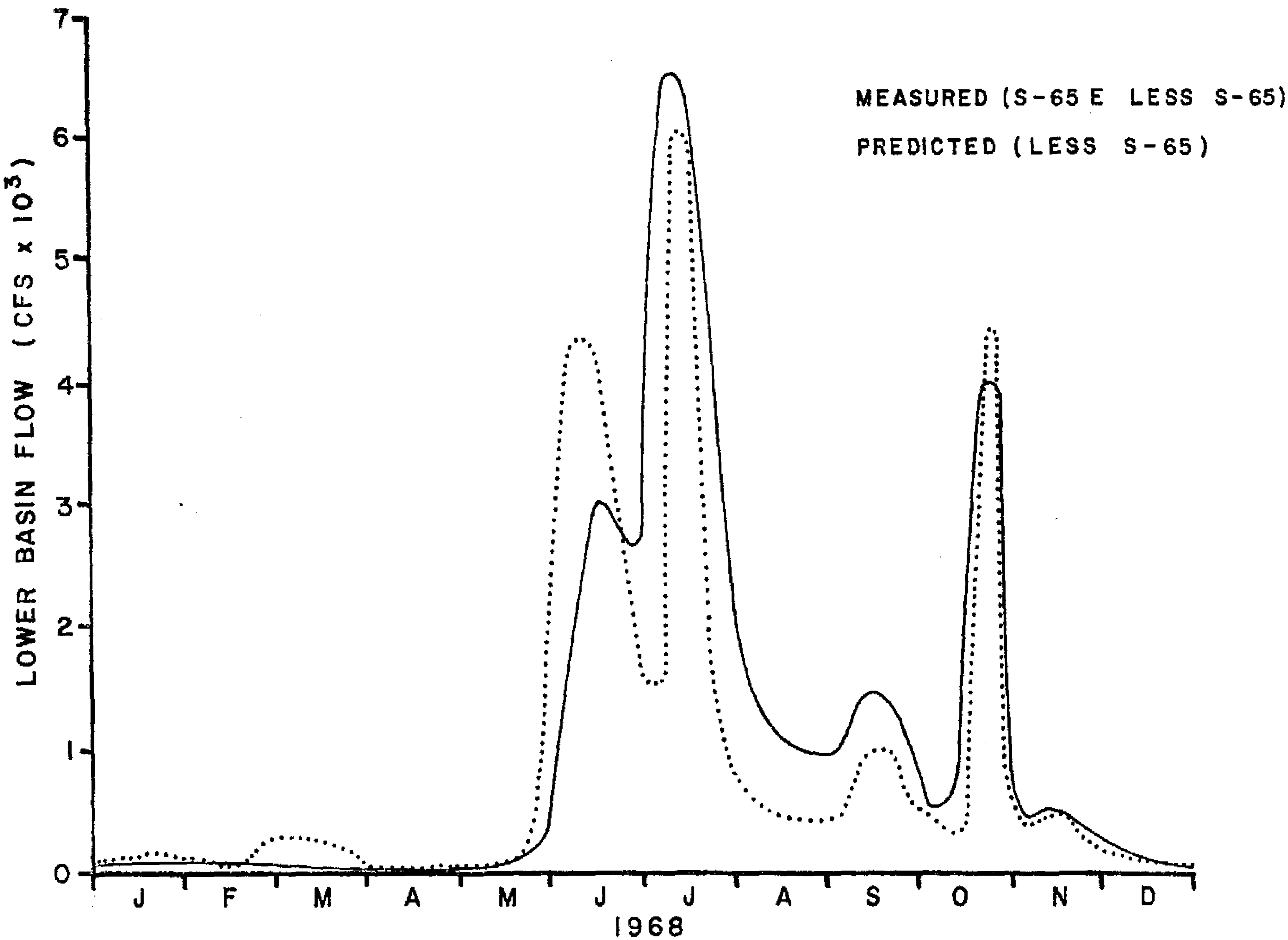

Figure 5.9. Measured and Predicted Hydrographs (1968), Lower Kissimmee River Basin.

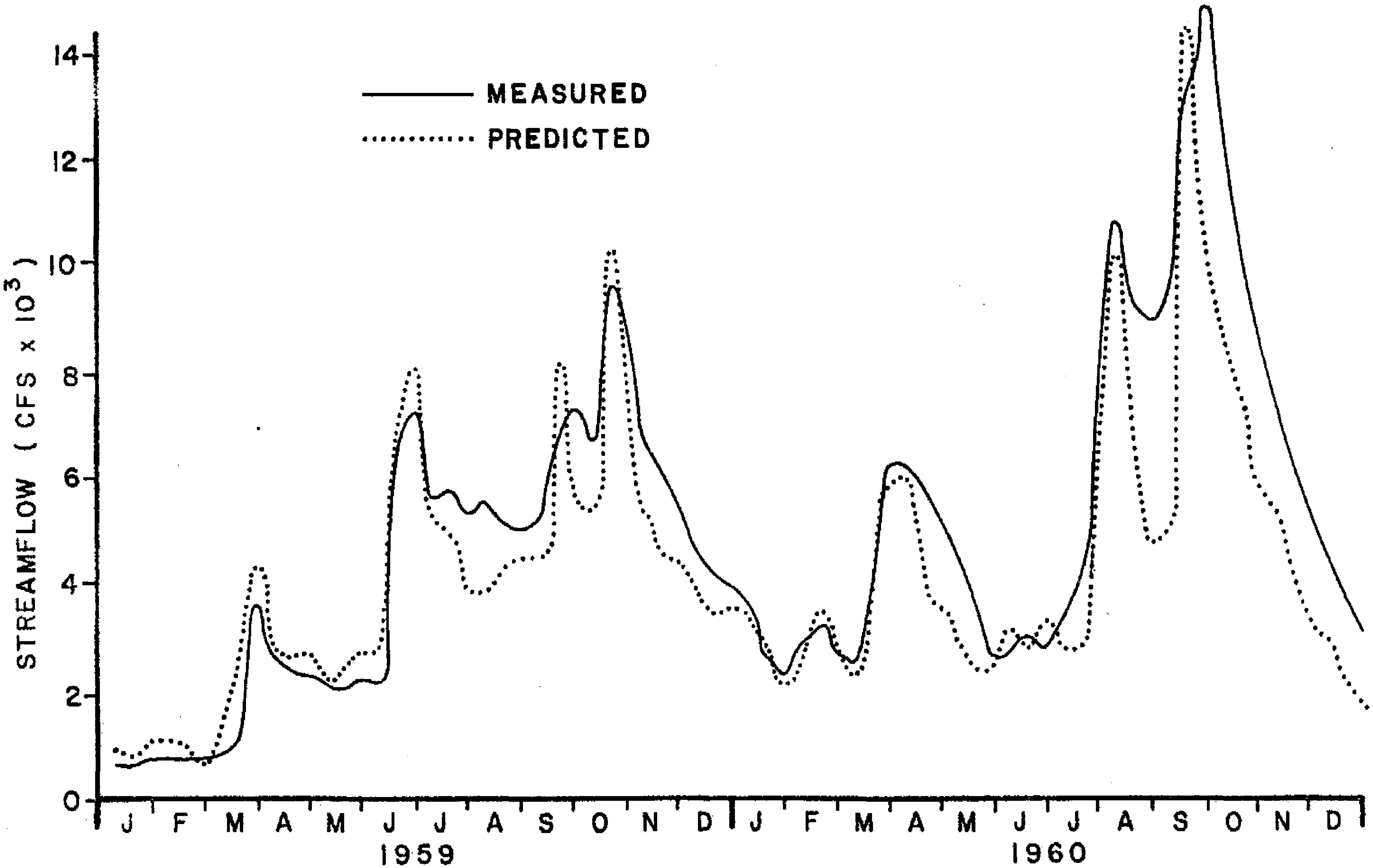

Figure 5.10. Measured and Predicted Hydrographs (1959-1960) for Pre-Channelized Condition, Total Kissimmee River Basin.

Table 5.10. Travel Time Computations for Lower Basin, Planning Units 13-17, Plus Kissimmee River.

	1958 Land Use		1972 Land Use
Fraction of Total Planning Unit Runoff Appearing as Surface Runoff[a]	0.137		0.477
Average Direct Runoff Travel Time[b], days	6.1		4.1
Average Sub-surface Travel Time[c], days	47.7		33.7
Weighted Average Travel Time, days	42.0		19.6
Kissimmee River Travel Time, days	9.0[d]		14.0[e]
Total Travel Time, days	51.0		33.6
Difference, days		17	
Difference due to Upland Land Use Changes, days		22	
Difference due to Channelization, days		-5	

[a]From HLAND simulation using 1967-1969 rainfalls, Table 4.24.

[b]From surface detention constants and computed travel times Table 4.7, weighted by land use and soil type, Table 4.13.

[c]From Table 4.28 based on calibrated base flow rates and drainage density changes.

[d]From Table 5.7.

[e]Calculated from accurate cross section information for average annual flow rate, Table 5.3.

The question arises, could in fact the upland drainage be achieved without construction of C-38? The two features are indeed coupled, and a complete answer would depend upon an analysis of backwater effects created in tributaries to C-38. This might be difficult in view of the paucity of hydrologic data in the lower basin. However, some information may be gleaned from a simple analysis of land areas covered by water at various river stages. Hamrick (1975) calculated the lower basin areas that would be covered by the maximum flood of record using maximum stages recorded along the Kissimmee River. The corresponding envelope contours were planimetered to produce the areas. He found that only 16 percent of the total lower basin was expected to be flooded by the river under such conditions, consisting of the Kissimmee River flood plain and extension up a few major sloughs. It is thus likely that drainage of more than 80 percent of the lower basin could have occurred without C-38. This conclusion is also reached by Marban (1976). Drainage of the flood plain does, of course, depend upon the river channelization. About the only plausible influence of C-38 on upland drainage is the potential psychological effect upon developers of "flood control projects." But, in summary, the answer to the question posed at the beginning of this paragraph appears to be positive.

The analysis procedures have thus revealed several interesting characteristics about the hydrologic response in the Kissimmee River Basin. These are listed below:

1) The basin has a marked wet season between the months of June and October associated with the majority of rainfall and streamflow volumes in the river.

2) Remaining months of the year are dominated by very low flows due primarily to lack of rainfall and flat topography.

3) The 1972 land use regime along with the channelized river produces higher maximum and lower minimum flows for typical flood events compared to the 1958 regime.

4) The increased hydrologic response in the basis is due primarily to upland drainage activities rather than the C-38 channelization itself; upland drainage contributes more surface runoff volume at a faster rate than before, thus creating an increased hydrologic response overall. Regulation of flows by upper and lower basin structures has also altered the hydrologic response of the basin.

5) Planning units dominated by drainage canals tend to produce more surface runoff than planning units in a more natural state, while subsurface flows are less under drained conditions.

Water Quality Control

Water quality data for the Kissimmee Basin have been collected in the river for the past several years, and in tributary inflows for the period September 1973 to October 1974. The original monitoring program on the river was begun by the U. S. Geological Survey, and has been continued and expanded by the Flood Control District (FCD).

While a large number of water quality parameters have been analyzed under the monitoring system, the levels of nitrogen and phosphorus are of most direct concern because of their association with the eutrophication process. An analysis of available water quality data from the FCD (unpublished) indicates that total and inorganic phosphorus levels are the most responsive parameters, while no significant variation is observed for nitrogen levels. This can be explained by the assumption that phosphorus tends to be adsorbed by soil particles and is available for surface transport via runoff and erosion. On the other hand, most forms of nitrogen are soluble and can be leached from the soil or returned to the atmosphere, thus reducing any relationship with surface transport.

Water quality sampling locations are depicted in Figure 5.11 for the lower river and tributaries, where samples were taken monthly for one year (September 1973 - October 1974). Samples were taken on a quarterly basis in the upper lakes. A plot of total P concentration (average May - August 1974) as a function of sampling location for the lakes and river segments depicts a very interesting pattern (Figure 5.12). Wet season average concentrations are quite high in Lake Tohopekaliga, but decline rapidly before reaching Lake Cypress. Concentrations are further reduced to Lake Kissimmee at which point the levels indicate fairly good water quality. From the outlet of Lake Kissimmee to S65-C the levels remain fairly low, but increase rapidly between that point and S65-E.

The high levels of total P in Lake Tohopekaliga are primarily due to nutrient loading from treated sewage, and a complete analysis and budget is presented in a later section on the upper lakes. It appears that uptake mechanisms are presently cleansing the water to a high degree before it leaves Lake Tohopekaliga.

The water entering the Kissimmee River from S65 is of fairly good quality, but concentrations increase rapidly south of S65-C. The obvious question as to the cause of these increased concentrations can be answered by considering nutrient levels of water which enter laterally via tributary flow to the river.

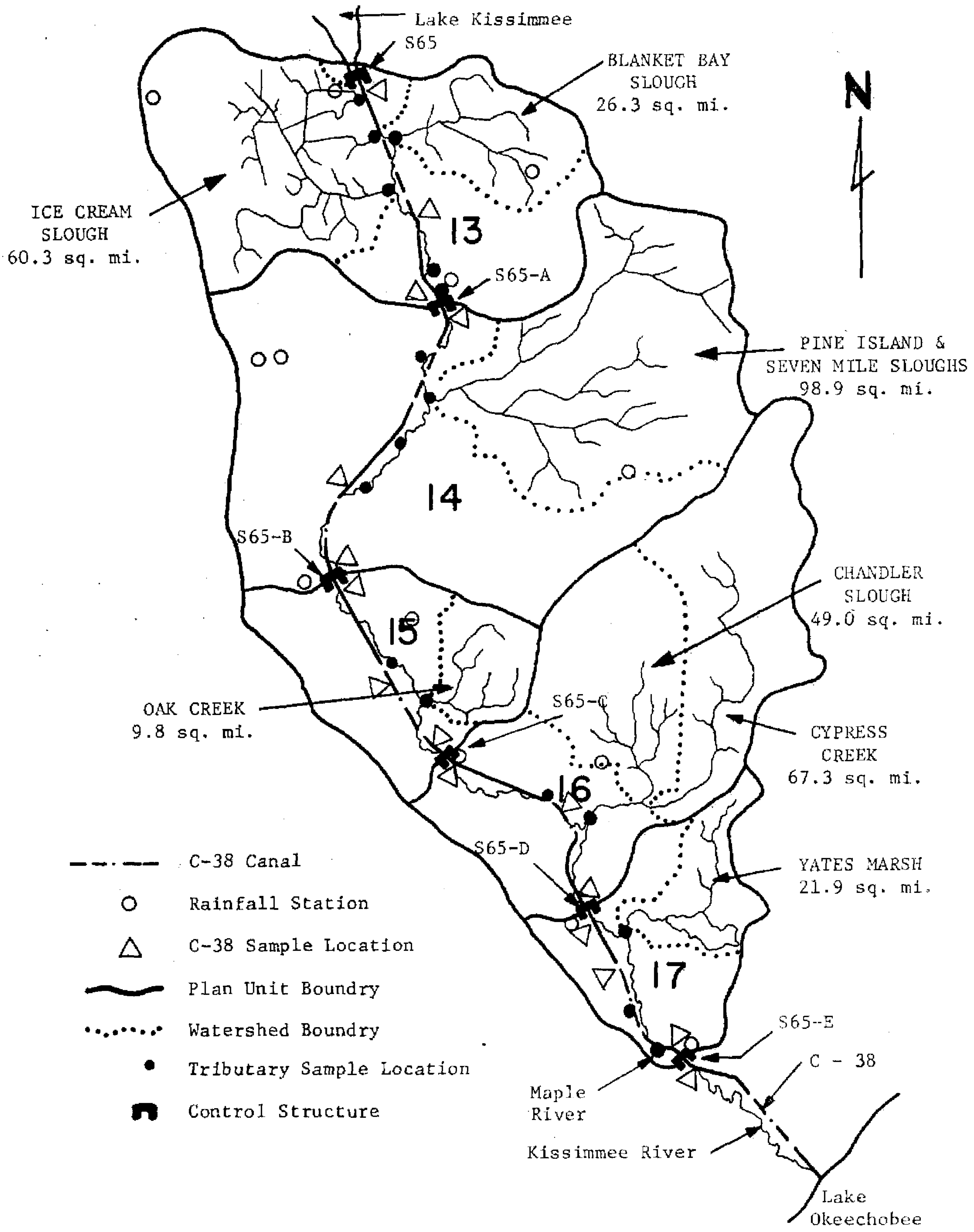

Figure 5.11. Tributary and Water Quality Sampling Locations, Lower Kissimmee River Basin.

Inflow tributaries, which were sampled on a monthly basis, did not yield any significant variation of total N from one location to the next, but total P levels showed a pronounced increase in wet season concentrations south of S65-C. Ice Cream and Pine Island Sloughs produced very low levels throughout the year (Figure 5.13), while Oak Creek, Chandler Slough, Yates Marsh, and the Maple River yielded progressively higher concentrations (Figure 5.14). Blanket Bay in pool A yielded high values, but inflows from Lake Kissimmee and Ice Cream Slough kept the average concentration low. It appears that the high phosphorus levels in the river are a direct result of tributary loading, especially south of S65-C.

An approximate idea of the potential for nutrient uptake in the river may be obtained by applying equation 5.8 under the assumption of a first order decay process coupled with pure advection. Reduction in concentration, C/C_o, and uptake, $1 - C/C_o$, will be a function of the decay constant, k, and detention time, T. Commonly accepted values for k for nutrients are on the order of 0.1 day^{-1} at 20^oC but a somewhat better estimate may be obtained by considering the data plotted in Figure 5.15. In order to determine possible uptake that would occur in the absence of lateral inflows along C-38, a mass balance computation was performed. Using a known initial concentration and flow at S65, mass inflows were subtracted using predicted lateral inflows from planning units (by HLAND) and measured inflow concentrations (Table 4.25). The resulting concentration distribution is also shown in Figure 5.15. If a velocity of 0.2 ft/sec is assumed in C-38, a decay constant of 0.05 day^{-1} is computed, which is comparable to the value of 0.1 mentioned previously.

Table 5.11 illustrates uptake potential that might exist in the Kissimmee River under various assumptions. The same value of k is used for both the natural and channelized condition for lack of other data, although the value might be expected to be higher for the natural condition (creating greater uptake). Under average conditions an uptake potential of 35-50 percent may exist, although this is considerably lower for the critical section of the river below S65-C. For this section where most of the nutrient loading is generated, Table 5.11 indicates uptake potentials of 15 and 22 percent for the natural and channelized river, respectively, and under average flow conditions. Only under flood conditions is there a significant change in uptake potential between the natural floodplain and C-38. However, this is also expected to be the time of greatest nutrient concentrations.

The above simplified analysis of nutrient uptake potential indicates the relative range in values to be expected under both channelized and original floodplain regimes. For either case, the river and floodplain alone do not provide nearly the nutrient uptake which one might expect based on previous studies (Marshall

Table 5.11. Predicted Uptake in Kissimmee River Using $k = 0.05\ day^{-1}$.

Land Use	Distance	Condition	T (days)	Uptake[a]
1958	L. Kiss. to	Average	9	0.36
1958	L. Okee.	Flood	11	0.42
1958	S65-C to	Average	3.2[b]	0.15
1958	L. Okee.	Flood	3.9[b]	0.18
1972	L. Kiss. to	Average	14	0.50
1972	L. Okee.	Flood	1.1	0.05
1972	S65-C to	Average	4.7[b]	0.22
1972	L. Okee.	Flood	0.4[b]	0.02

[a]Calculated as $1 - C/C_o = 1 - e^{-kT}$ (equation 5.8).

[b]Apportioned on basis of relative distance from S65-C to S65-E.

et al., 1972). The main reason for this is the fact that the rapidly flowing river environment does not provide enough detention time for physical, biological, and chemical mechanisms to operate. The amount of additional uptake provided by the floodplain under natural conditions is still undetermined because of the difficulties in apportioning flow between the river channel and floodplain, as previously discussed.

It has been mentioned that nutrient uptake requires relatively long detention times. This implies that the greatest potential would occur in lakes and marsh areas scattered throughout the basin. If one could route agricultural runoff, enriched with nutrients, through these areas prior to entry into the river, then the observed trend in Figure 5.12 could possibly be averted. The next section examines the lakes in the upper part of the basin.

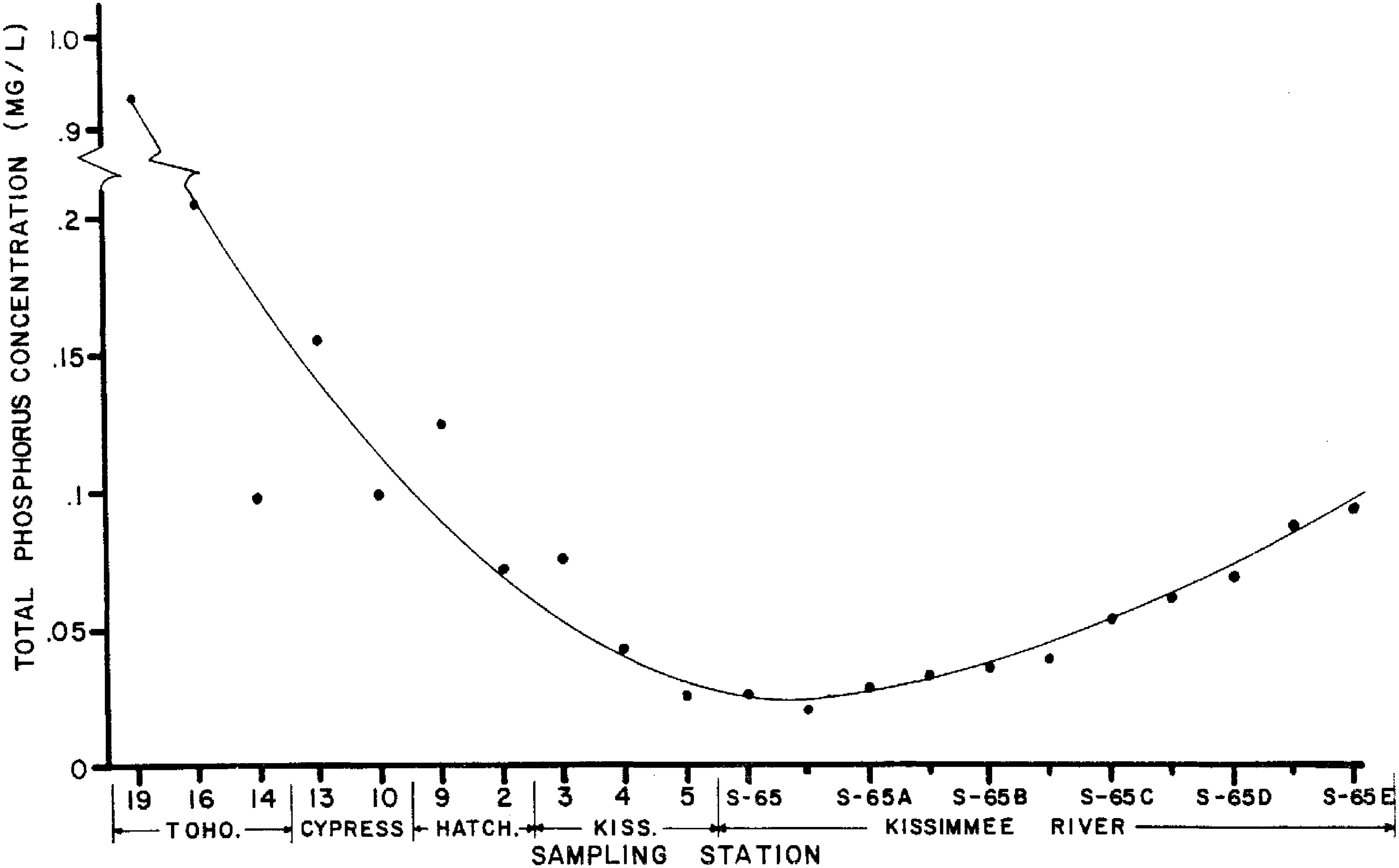

Figure 5.12. Total P Concentration as a Function of Sampling Location, Kissimmee River Basin, May-August 1974.

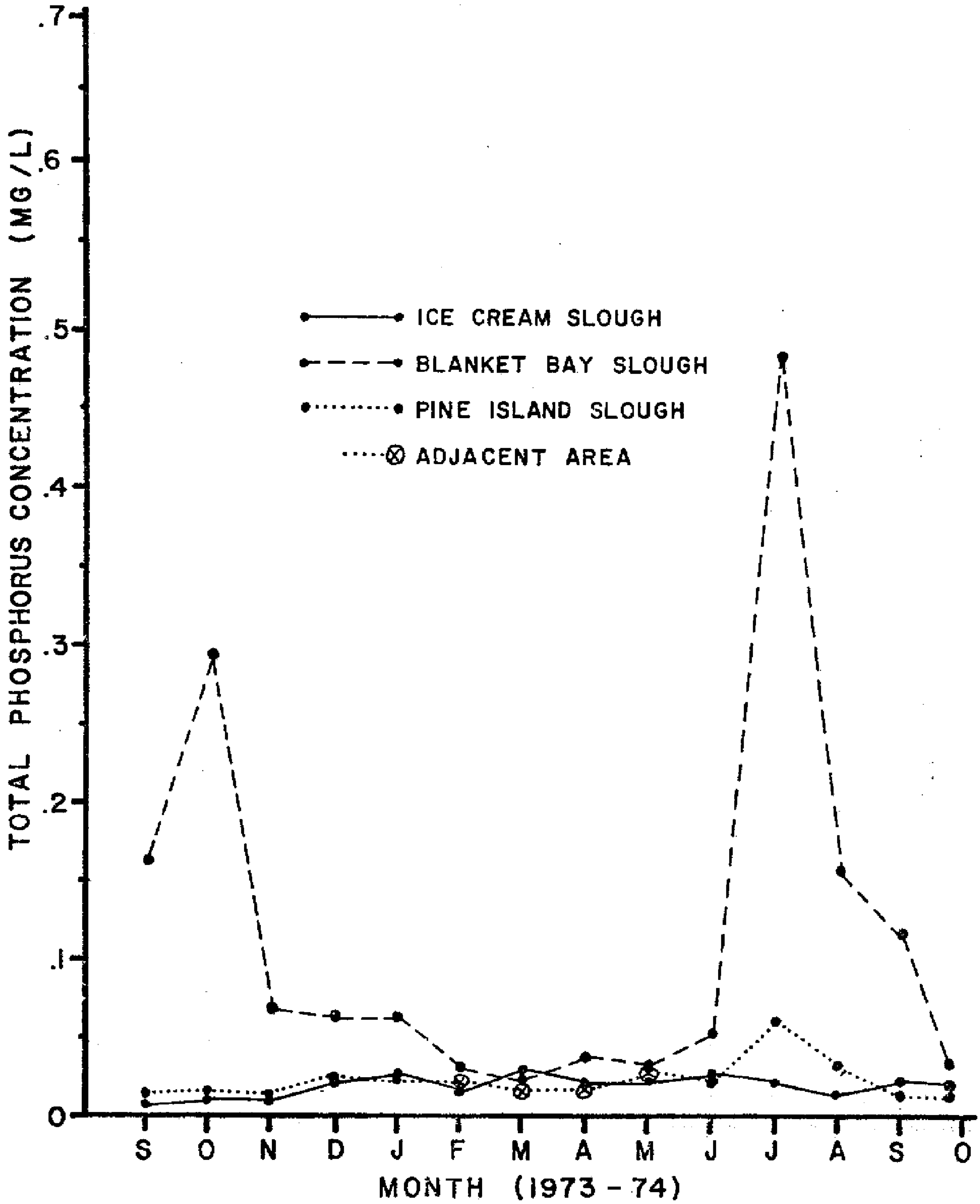

Figure 5.13. Total P Concentration in Tributary Inflows, Planning Units 13 and 14 of the Kissimmee River Basin.

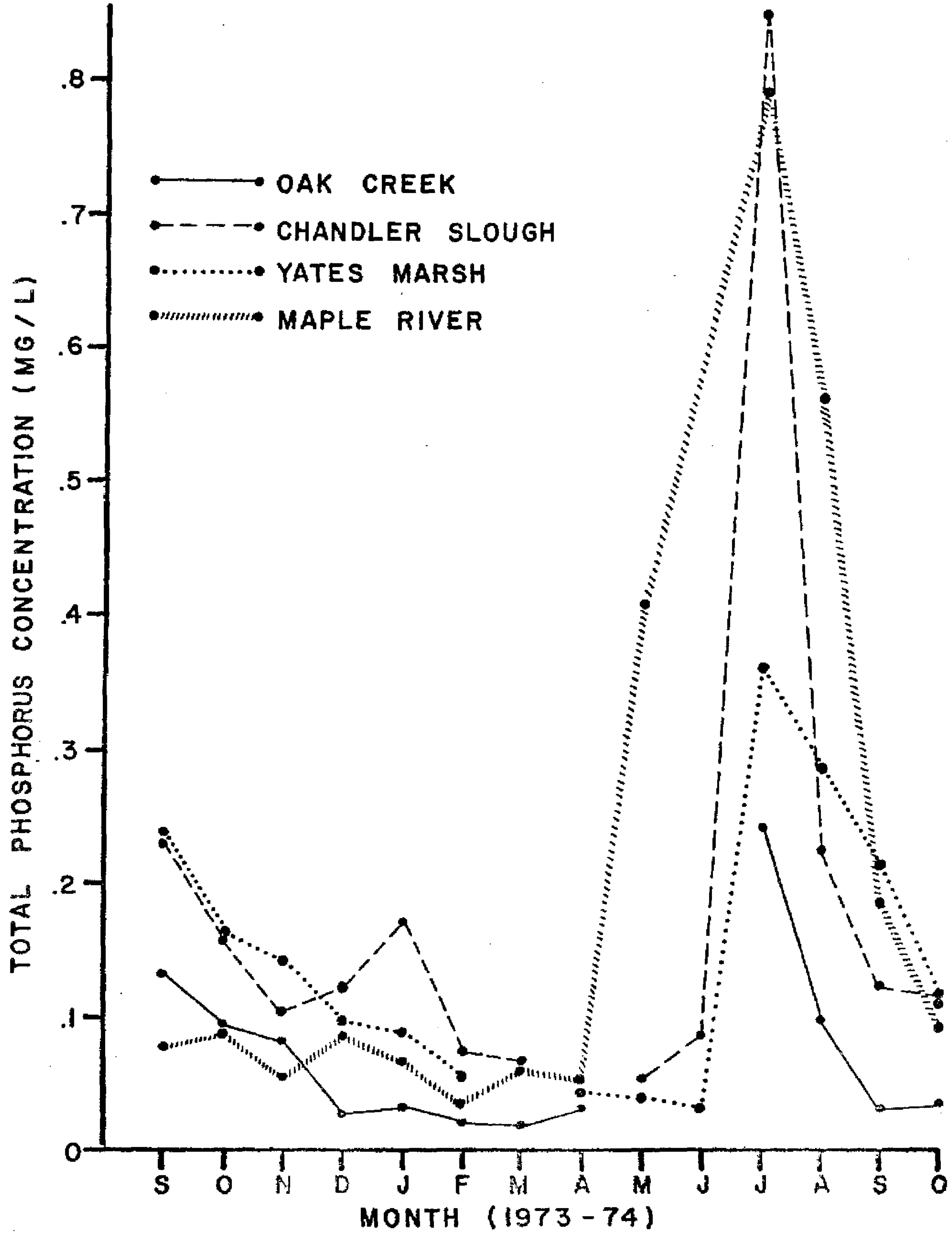

Figure 5.14. Total P Concentrations in Tributary Inflows, Planning Units 15, 16, and 17 of the Kissimmee River Basin.

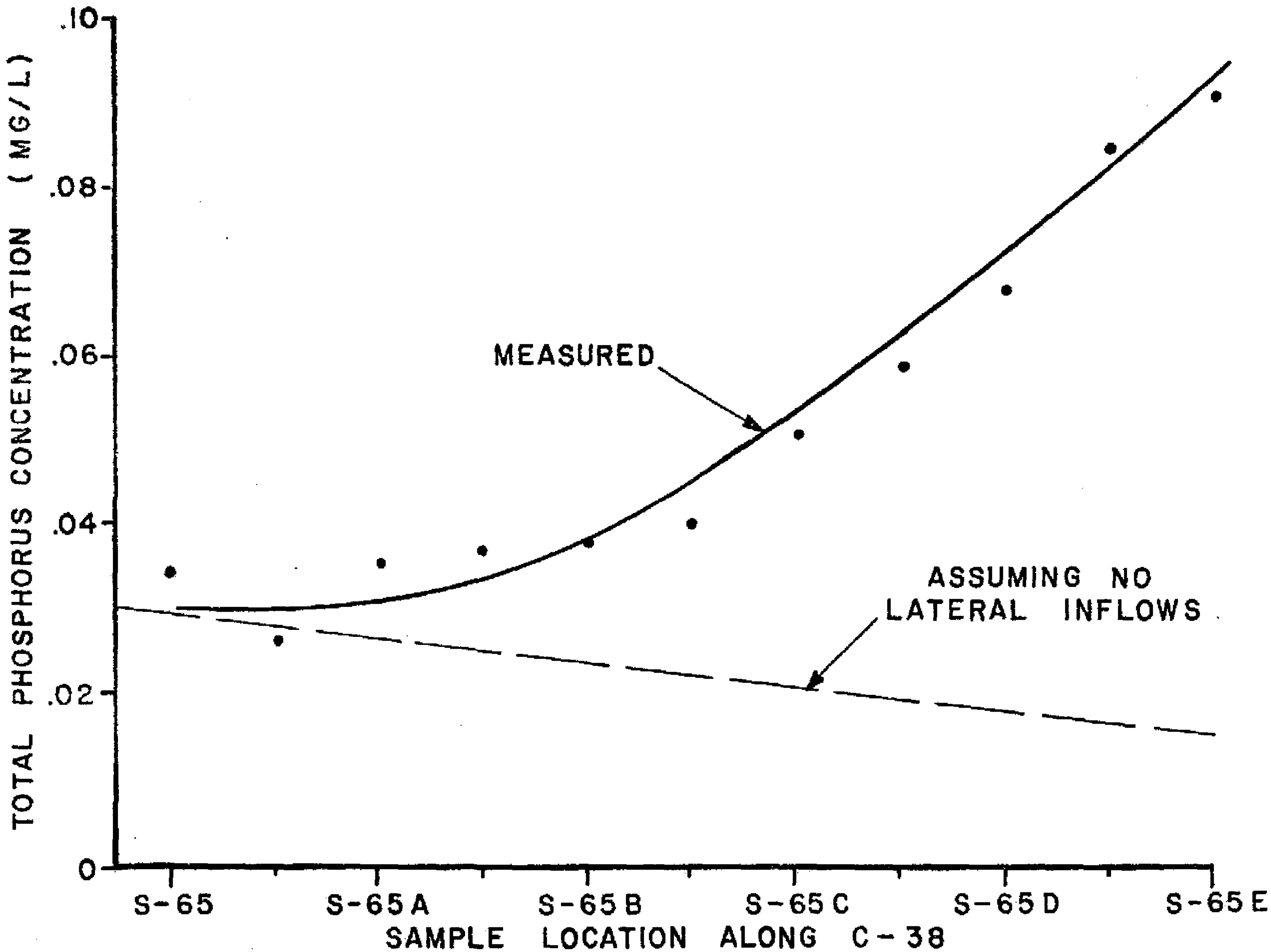

Figure 5.15. Water Quality (Total P) Along the Kissimmee River, With (Measured) and Without (Predicted) Tributary Inflows.

EVALUATION OF LAKES

Lake Level Fluctuations and Flood Control

Prior to 1964 the level of Lake Toho naturally varied from an extreme low of 48.9 feet to an extreme high of 59.4 feet (mean sea level), a range of 10.5 feet, although the average range was 51.5 - 55.5, only four feet. The high water line is exceeded 15 percent of the time and the low water line 85 percent of the time, based on the stage-duration curve in Figure 5.16. The stage-area curve then determines the lake area for low, mean, and high water conditions (Figure 5.17).

The FCD and Corps of Engineers completed construction on a concrete lock and spillway at the lake outlet for flood control purposes. The original planned water regulation schedule (COE 1956) would permit a 2 foot fluctuation between 53 and 55 feet MSL, although this has not been implemented. The current interim range is 52 - 55 feet, with a proposal to reduce the lower limit to 51.5 feet. When lakes are regulated as in the Kissimmee River Basin, the zone of regulated fluctuation is usually reduced over natural conditions. Table 5.12 indicates the relative area of lake fluctuation for several Kissimmee Lakes under natural and regulated conditions. Lake Toho and Lake Hatchincha/Cypress register decreases in fluctuation from 29 percent and 100 percent to 11 percent and 65 percent of the total lake area, respectively.

Figure 5.18 depicts the zones of fluctuation under natural and regulated conditions for Lake Toho. The lake naturally ranged from 51.1 feet to 55.5 feet on the average during the year. The original planned regulation schedules allow an absolute range from 53 feet to 55 feet, which would represent a significant reduction in lake area previously in the littoral zone. Even under the broader interim schedule, some areas of marsh fringes are now inundated all year. These areas not only are vital and productive for fish and wildlife, but also represent vegetated buffer zones for urban and agricultural runoff waters. Recent studies have quantified the uptake of nutrients by such marsh/swamp areas (Shih and Hallett, 1974; Gleason, 1974). As these areas are reduced in size, waste assimilative capacity is also reduced.

The fluctuations under natural conditions provided for flood storage in the large, flat buffer zones. Present regulation schedules maintain high pools in the dry season for recreation and irrigation, and keep lower pools in the wet season for flood storage. Such flood control strategies induce agricultural and urban expansion within the lake basin. Drainage of these adjoining land

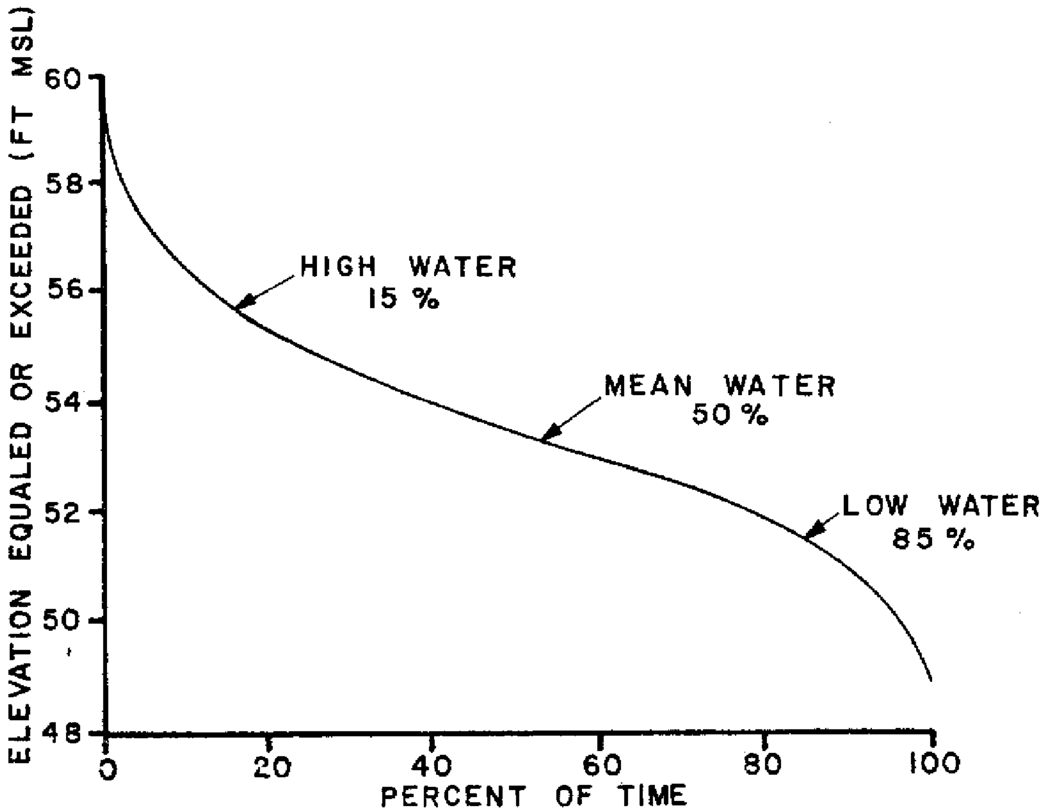

Figure 5.16. Stage-Duration Curve for Lake Tohopekaliga (Bishop, 1967).

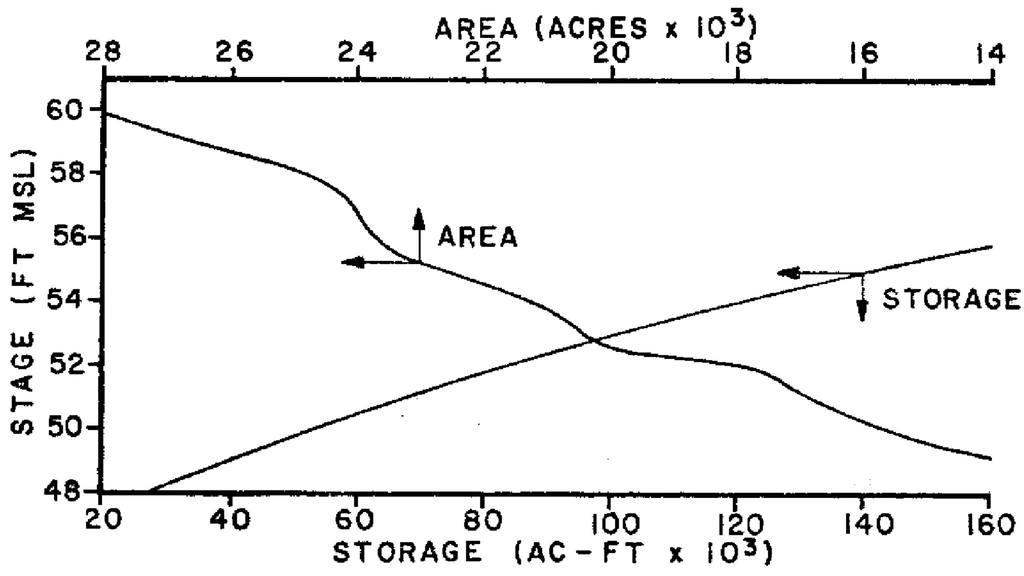

Figure 5.17. Stage-Area and Volume Curves for Lake Tohopekaliga (Corps of Engineers, 1956).

Table 5.12. Natural and Regulated Lake Fluctuation.

Natural Water Level / Regulated Water Level	Lake Tohopekalegia Stage (ft msl)	Lake Tohopekalegia Area (1000 acres)	Lake Kissimmee Stage (ft msl)	Lake Kissimmee Area (1000 acres)	Lake Hatchineha/Cypress Stage (ft msl)	Lake Hatchineha/Cypress Area (1000 acres)
Natural Low Water	51.5	17.2	48.0	31.0	49.2	10.0
Natural Mean Water	53.5	20.7	50.5	35.0	51.3	14.5
Natural High Water	55.5	23.3	52.5	40.5	53.4	24.5
Zone of Natural Fluctuation	4.0	6.1	4.5	9.5	4.2	14.5
(Percent of Mean)		(29)		(27)		(100)
Regulated Low Water	53.0[a]	20.4	48.5	31.2	48.5	9.6
Regulated High Water	55.0	22.7	52.5	40.5	52.5	19.0
Zone of Regulated Fluctuation	2.0	2.3	4.0	9.3	4.0	9.4
(Percent of Mean)		(11)		(27)		(65)

[a]Original plan. Present interim schedule has low water value at 51.0 ft.

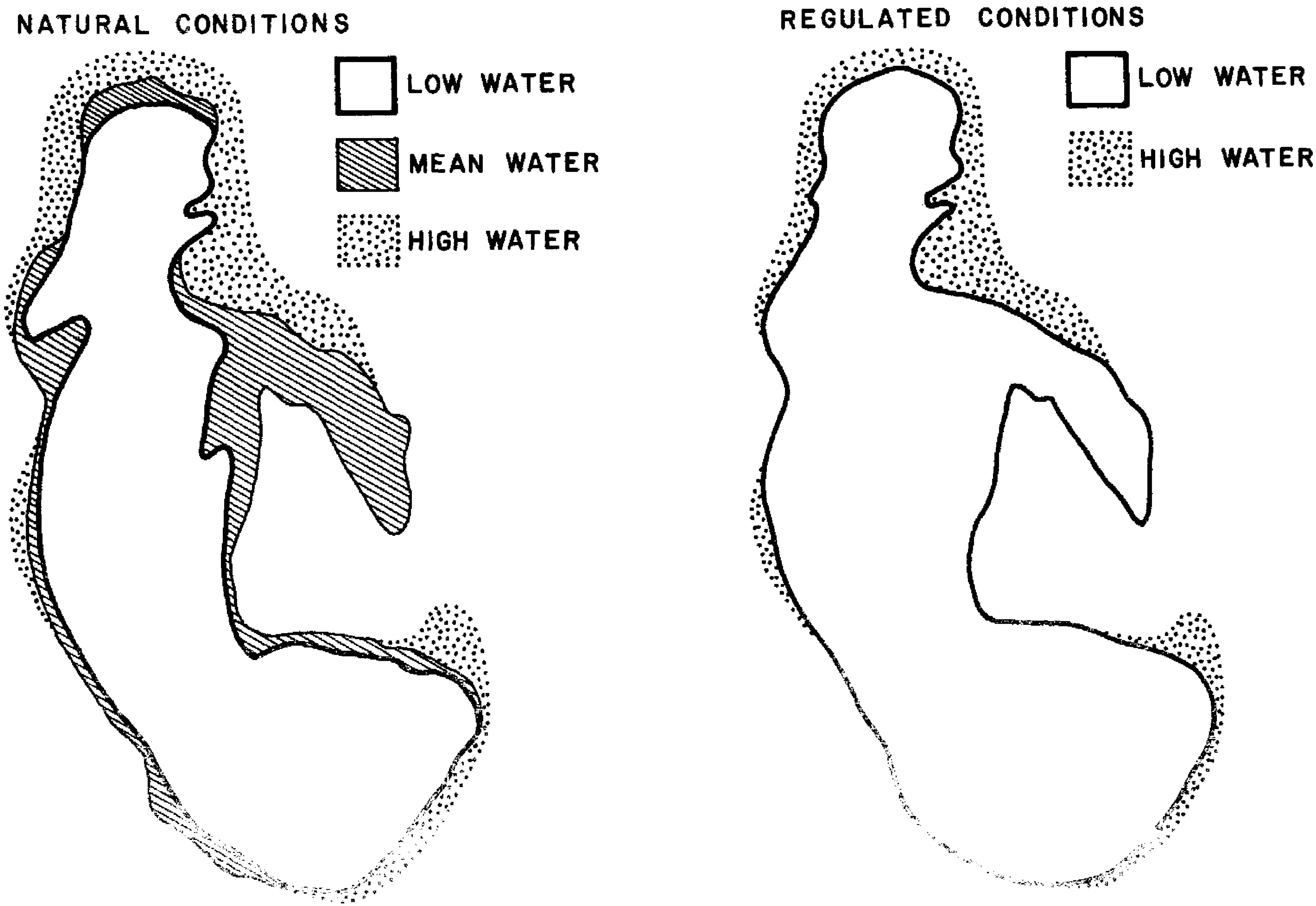

Figure 5.18. Zones of Natural and Regulated (Original Corps of Engineers Plan) Fluctuations in Lake Tohopekaliga. Present fluctuations under interim schedule are somewhat greater.

areas increases the rate of runoff, which in turn increases the flood storage capacity which must be provided to protect existing floodplain developments. A point will soon be reached where natural lake capacity may be exceeded, and the conversion to a diked reservoir has traditionally been used to increase the storage capacity. In the process, the benefits of vegetated buffer zones are eliminated, fish and wildlife habitat is altered irreversibly, and water quality is degraded.

The effect of lake level regulation is depicted for two of the largest and most recent flood years in Figure 5.19. The majority of the rainfall occurs in the wet season between June and October. The lake level fluctuates four feet on the average, but fluctuation was almost twice as great during the flood year 1960. The area of the lake fluctuated between 17,500 acres and 25,500 acres while the storage volume varied from 45,000 ac-ft to 125,000 ac-ft. For shallow lakes, small increases in stage can store tremendous volumes of water. Lake stages were regulated during the 1969 flood period.

In order to better understand the dynamics of the lake basin, hydrologic budgets have been prepared for the lake to provide an estimate of detention times and inflow and outflow volumes. The resulting balance of inflows, outflows, and changes in storage is shown in Table 5.13 for the year 1973, which represents an average year for rainfall. The monthly budget is based on applying the continuity equation to the lake basin (equation 5.1). Rainfall, evaporation, tributary inflows, surface runoff, and lake outflow are used to obtain an estimate of change in storage in the lake. Estimates of surface runoff were obtained by applying the HLAND model to the lake basin for present land use conditions. The calculated storage changes in the lake compare favorably with the observed values as shown in Table 5.13.

Detention time in the lake is defined as the total lake volume divided by the outflow of water. From the hydrologic budget, detention time T is calculated to be about 6.0 months during the dry season of January to June, and 4.0 months during the wet season of July to October. These values are influenced by the extent of flood or drought conditions. For the flood of 1960, detention time varied from about 1.0 to 3.0 months during the wet season and up to 7.0 months for the following dry season. During the drawdown experiment and drought conditions of 1971, the detention time exceeded 1.0 year since outflows from the lake were zero for most of the months during the experiment.

Based on the above hydrologic analysis, average detention time in the lake is assumed to be about 5.0 months, which implies that the lake turns over 2.4 times per year, on the average. It is difficult to say whether detention times have increased or

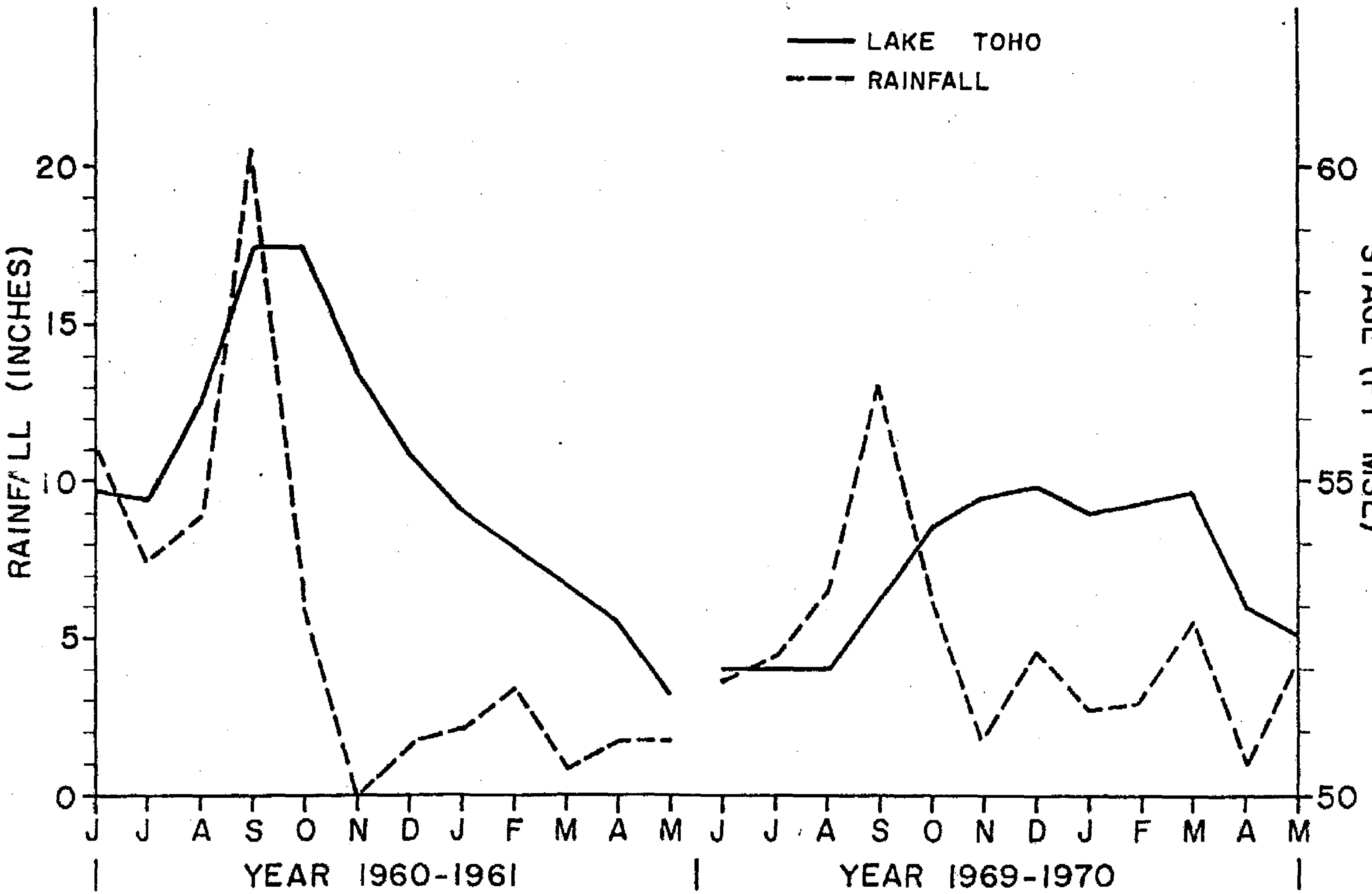

Figure 5.19. Effect of Regulation on Hydrologic Response. Lake stages were regulated during 1969-70 event.

Table 5.13. Hydrologic Budget for Lake Tohopekaliga.

1973	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation[a] (P)	4.9	2.4	2.4	2.2	4.4	6.4	8.2	8.0	11.7	1.0	0.8	1.9
Evaporation[a] (E)	2.2	2.6	4.3	5.0	5.4	5.0	5.2	4.2	4.3	3.9	3.2	2.1
P-E	4.9	-0.4	-3.5	-4.6	-1.5	2.8	4.9	6.3	13.0	-5.2	-4.3	-0.4
Shingle Creek	5.2	6.3	2.3	3.0	0.7	1.2	3.7	9.2	13.3	7.4	1.7	1.5
C-31	0.0	0.7	17.2	12.6	12.9	0.0	1.4	7.6	16.7	11.8	0.0	0.0
Runoff	11.0	3.2	0.1	0.0	1.9	2.4	5.6	3.6	17.0	4.2	0.1	0.0
Total Inflow	21.8	10.2	19.6	15.5	15.6	5.8	15.6	26.6	59.9	23.3	1.8	1.5
C-35	0.0	0.1	32.2	37.9	27.4	0.0	1.7	27.2	35.3	9.7	0.0	0.0
Total Outflow	0.0	0.6	35.7	42.5	28.9	0.0	1.7	27.2	35.3	14.9	4.3	0.3
Volume (S)	124.0	142.0	133.0	101.0	84.0	85.0	92.0	92.5	120.0	123.0	121.0	126.0
Calculated ΔS	21.8	9.6	-16.1	-27.0	-13.4	5.8	13.9	0.5	24.6	8.4	-2.5	1.2
Lake Elevation[b]	54.1	55.0	54.5	53.1	52.0	52.0	52.5	52.6	53.9	54.2	54.1	54.3
Observed ΔS	21.0	18.0	-9.0	-32.0	-15.0	1.0	7.0	0.6	27.5	3.0	-2.0	5.0

Note - all values in 10^3 ac-ft except where noted

[a]Units of inches

[b]Units of feet (msl)

decreased due to lake level regulation schedules. Because average storage capacity in the lake has been decreased while inflows have probably increased, one might conclude that average detention times have decreased since 1964. However, average outflows have probably decreased during the dry season due to the regulation schedule which maintains high pools. These conditions contribute to longer detention times for the dry season. During the wet season, outflows have probably increased while the average storage has been reduced for flood control, thus producing shorter detention times. In general, the value of detention time depends on the hydroperiod variation in the lake, and because wet season inflows and outflows represent the greater percentage of volume over the year, the average weighted detention time is reduced under the regulated condition. These changes in detention time due to the flood control regulation are important from a water quality standpoint as discussed in the next section.

Lake Drawdown and Water Quality

The primary purpose of lake drawdown is to reduce consolidated sediment depth by exposing sections of lake bottom to the air. In this way, a better habitat is produced for bottom plants and game fish. The process of drawdown is expected to result in reductions in ammonia, total organic nitrogen, and volatile solids. Phosphates and nitrates generally remain in the newly consolidated sediment. Several lakes in Florida have been studied in relation to the effects of drawdown (Fox et al., 1975), and consolidation of sediments has been observed.

The drawdown sequence on Lake Tobo proceeded from a high pool of 55 feet in March, 1970 to a low pool of 52 feet in June. Following seven months of drought, the scheduled drawdown began in February, 1971 with a drop in elevation to 48 feet by June, exposing up to 50 percent of the lake bottom to the air. Reflooding occurred gradually until February, 1972 when the water level stood at the low pool stage of 52 feet. Complete results of the drawdown experiment such as the response of fish, vegetation, sediments, and algae are available (Florida GFWFC, 1972, 1973). Water quality and nutrient loading effects are discussed below.

The general response to lowered water level and reduced volume was a gradual increase in concentration of most constituents and a reduction as reflooding progressed. Table 5.14 shows the average water quality at three lake stations before, during, and after drawdown. The table demonstrates a concentration gradient from north to south because several major pollution sources enter at the northern side of the lake (see Figure 5.20). Measurements of transparency, pH, and total organic nitrogen (TON) are comparable

Table 5.14. Averaged Water Quality of Lake Tohopekaliga Before, During, and After Drawdown.

	Station 1			Station 2			Station 3		
	1970	1971	1972	1970	1971	1972	1970	1971	1972
Secchi (inches)	18.00	14.00	22.00	42.00	36.00	24.00	37.00	32.00	21.00
Field pH	7.50	7.90	7.30	6.40	8.20	8.70	6.60	7.70	8.60
Spec. cond.[a]	133.00	222.00	196.00	123.00	164.00	183.00	115.00	159.00	188.00
P. Alk.	0.00	1.00	0.00	0.00	1.00	4.00	0.00	0.00	4.00
T. Alk.	21.00	62.00	46.00	10.00	14.00	21.00	8.00	12.00	20.00
Sulphate	9.80	14.70	10.80	10.70	14.30	12.00	10.70	14.30	11.10
Turb. (unfilt.)[b]	85.00	219.00	85.00	49.00	40.00	68.00	47.00	51.00	82.00
Turb. (filt.)[b]	68.00	53.00	53.00	42.00	25.00	33.00	32.00	23.00	15.00
Ca	9.40	19.90	17.20	6.00	6.20	9.70	5.50	5.20	7.90
Mg	2.40	4.60	2.80	2.30	3.40	2.80	2.30	3.20	2.80
Na	9.40	14.50	15.30	9.10	17.80	17.80	9.00	17.00	19.40
K	2.60	4.10	2.60	2.30	3.10	2.80	2.10	3.20	3.10
NO_3-N	0.08	0.09	0.02	0.07	0.04	0.02	0.05	0.04	0.02
NH_3-N	0.09	0.10	0.11	0.04	0.02	0.10	0.03	0.02	0.08
TON	1.10	1.74	1.26	0.77	0.86	1.40	0.85	0.97	1.60
DON	0.72	0.83	0.87	0.69	0.60	1.00	0.61	0.58	0.84
PON	0.36	0.90	0.38	0.08	0.26	0.42	0.24	0.40	0.75
PO4 (ortho)	1.30	1.90	1.80	0.63	0.50	0.64	0.29	0.30	0.18
PO4 (total)	1.70	3.17	2.47	0.77	1.41	1.10	0.53	1.28	0.64

Note - data in milligrams per liter unless otherwise noted (Florida GFWFC, 1972)

[a] Micromhos/cm

[b] Jackson turbidity units

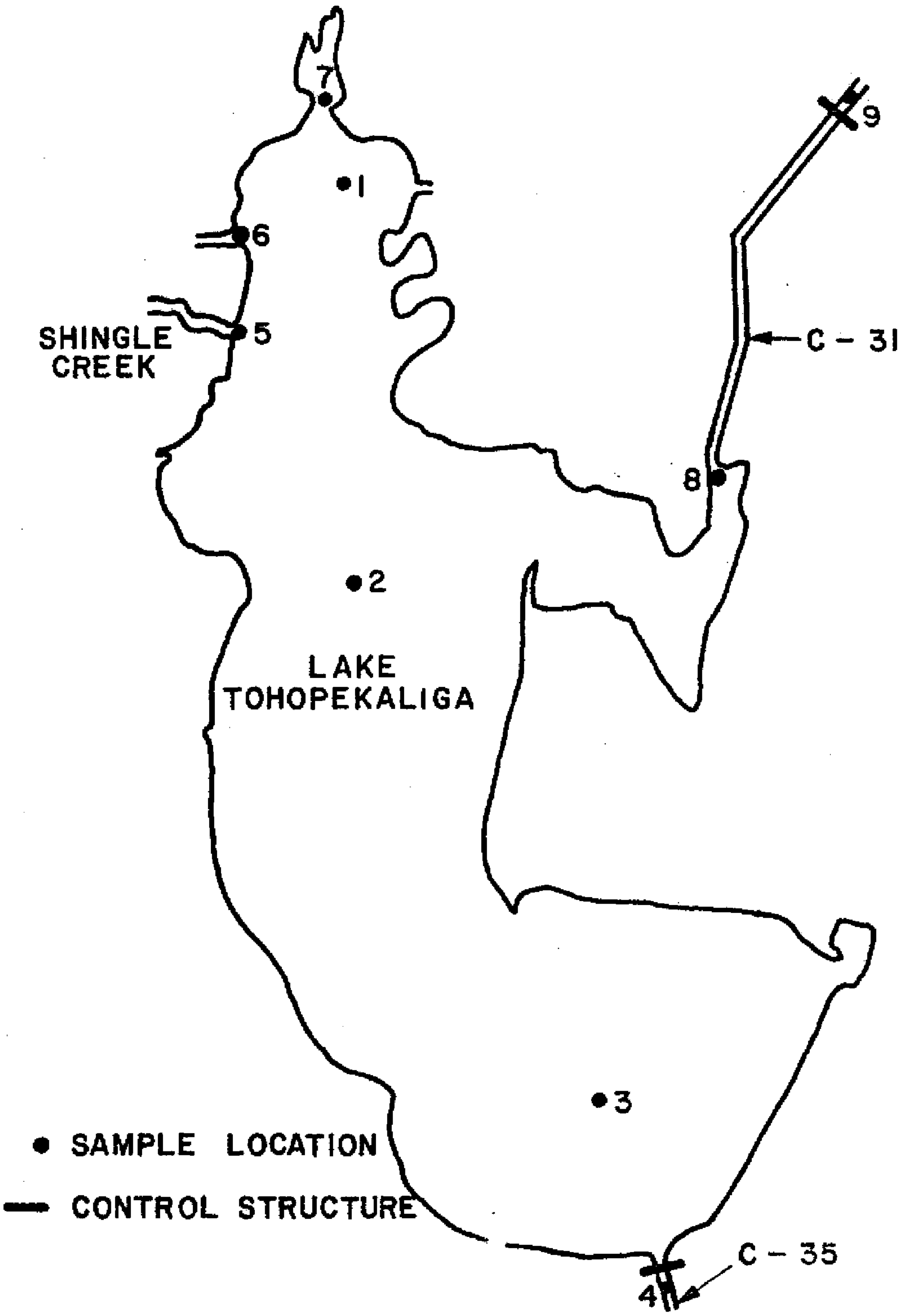

Figure 5.20. Water Quality Monitoring Stations for Lake Tohopekaliga.

to pre-drawdown levels at station 1. Stations 2 and 3 register reduced transparency, increased pH, and increased TON corresponding to increases in algal blooms at these stations. Cation levels decline over drawdown levels but remain above pre-drawdown concentrations.

Reduction in NO_3-N reflects a conversion to organic forms due to increased productivity in the lake. Total phosphate levels are lower at all stations compared to the drawdown period, but remain higher than the pre-drawdown concentrations.

The major source of nutrients to the lake is from treated sewage effluent from five plants serving cities around the north shore of the lake. These are depicted as stations 5 through 9 in Figure 5.20. Agricultural runoff is a secondary source of nutrients to the lake. Loading rates from the sewage treatment plants have been calculated by the Florida GFWFC (1972).

The above information on nutrient sources combined with previous data on non-point sources allows a nutrient budget to be prepared for Lake Toho. The nutrient budget approach is similar to the one used by Shannon and Brezonik (1972). Table 5.15 presents the results of the annual budget for nitrogen and phosphorus, where it can be seen that the sewage treatment plants are the major source of nutrients. Comparing the areal and volumetric loading rates to the critical loading rates in Table 5.16 it can be concluded that volumetric loading rates exceed dangerous levels for both nitrogen and, in particular, phosphorus. The exceedingly high levels for phosphorus compared to nitrogen provide a readily available source for the growth of algae and aquatic weeds in the lake.

Although the drawdown experiment did not result in improved water quality, it did succeed in establishing the major source of the problem during the water quality monitoring program. The Florida GFWFC (1972) feels that the treated effluent is the predominant factor accelerating the degradation of Lake Toho at the present.

Water Quality and Detention Time

Further water quality monitoring efforts by the FCD during the past two years in the upper chain of lakes have revealed an interesting response (Figure 5.21). The distribution of total phosphorus concentration declines significantly from the northern part of Lake Toho to the outflow from the lake, and then a much slower decline occurs through Lakes Cypress, Hatchineha, and Kissimmee. These data suggest that uptake rates in Lake Toho

Table 5.15. Nutrient Budget of Lake Tohopekaliga.

Source	Nitrogen (10^7 g/yr)	Phosphorus (10^7 g/yr)
#5	7.93	36.80
#6	1.21	1.77
#7	0.10	0.20
#10	1.29	2.70
Agric Land	6.87	1.45
Rainfall	3.47	2.72
Outflow	6.31	3.44
I-O	14.56	42.20
Areal Load	1.71 $g/m^2/yr$	4.96 $g/m^2/yr$
Volumetric Load	1.31 $g/m^3/yr$	3.80 $g/m^3/yr$

Table 5.16. Critical Loading Rates for Nitrogen and Phosphorus.

Reference	Units	Permissible (up to) N	Permissible (up to) P	Dangerous (in excess of) N	Dangerous (in excess of) P
Shannon & Brezonik (1972)	Volumetric (g/m^3-yr)	0.86	0.12	1.5	0.22
Ibid.	Areal (g/m^2-yr)	2.0	0.28	3.4	0.49
Vollenweider (1968)[a]	Areal (g/m^2-yr)	1.0	0.07	2.0	0.13

[a]For lakes with mean depths of 5 m or less.

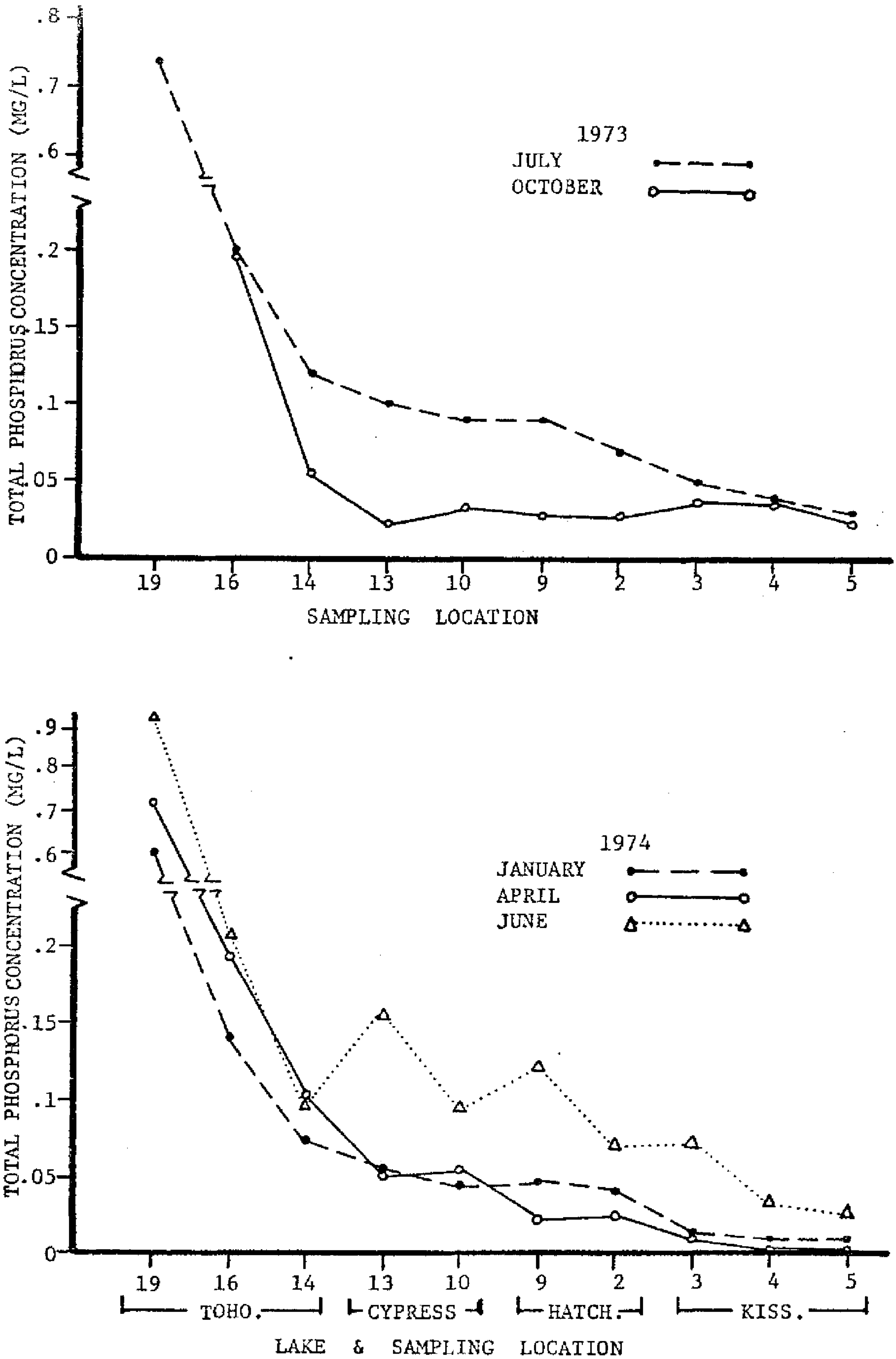

Figure 5.21. Water Quality (Total P) in the Upper Chain of Lakes.

are reducing the total P concentrations by approximately 85 percent by the time the water leaves the lake, depending on the season.

The concept of detention time T can be used to explain the observed decline in concentration. As in the case of the river, equation 5.8 can be applied to Lake Toho to estimate the reduction as a function of T and k, the first-order decay coefficient. Since C/C_o is known (Figure 5.21) and T is assumed to vary from 4.0 to 6.0 months, one can solve for the value of k at 20°C. These average values range from 0.02 day^{-1} for the wet season to 0.01 day^{-1} for the dry season. Compared to 0.1 day^{-1} reported for rivers, these k values are an order of magnitude less, but with the long detention time in the lake, it is possible to obtain about 85 percent uptake compared to about 20 percent in the lower part of the river below S65-C (Table 5.11).

The reason for the low value of k in Lake Toho is difficult to explain, because the nutrient uptake in the lake is greater than in most other components of the river basin. One possible explanation is that the exponential decay (Figure 5.21) is, in reality, a two-stage process, with an initial rapid loss of nutrients over several days and a final decay stage of several months. This type of response would yield a value of around 0.1 day^{-1} for the initial stage. Unfortunately, the frequency of data collected by the FCD on Lake Toho does not allow a more accurate determination of k.

From a water quality standpoint, nutrient uptake depends on both the first-order decay coefficient and the detention time. Decay coefficients tend to increase with temperature, which affects biological and chemical activity. Detention times are shorter in the wet season when decay coefficients and nutrient concentrations are at their peak, and longer in the dry season when uptake rates are at a minimum. Thus the hydroperiod variation in the lake significantly influences the potential for nutrient uptake, especially in the wet season. These relationships imply that regulation schedules might be altered in order to retain water longer during the wet season, rather than drawing the lake down as rapidly as possible. These changes should also consider the needs of flood storage, so that a balance can be secured between objectives of water quality and flood control.

The results for Lake Toho compare favorably to a relationship for Canadian lakes developed by Kirchner and Dillon (1975). They relate the phosphorus detention or uptake to the areal water load in the lake (m/yr), defined as the lake outflow divided by lake surface area. For Lake Toho, the areal water load is 2.64 m/yr on the average, and this corresponds to phosphorus uptake of 66 to 82 percent/yr from their relation. The observed uptake is 85 percent.

Lake Toho, although receiving excessive loads of nutrients at the present time, is able to process a large percentage by biological or physical uptake. Water quality leaving the lake is much improved over water entering the northern side of the lakes, and other lakes in the chain further reduce total phosphorus concentrations to a low level prior to entry into the Kissimmee River.

It should be mentioned that this situation is subject to change if future developments around the lake should increase the loading and runoff rates such that detention times are reduced. If, for example, average wet season detention times were reduced from 4.0 to 2.0 months, then uptake would drop from 89 percent to 67 percent, assuming a constant first-order decay. Such a reduction would have a large impact on water quality passing through the chain of lakes.

If the viability and habitat of Lake Toho are to be maintained, some form of nutrient diversion should be considered. Advanced waste treatment and spray irrigation of waste water are two possible alternatives. The next section describes the hydrologic and water quality impact of swamps and marshes in the Kissimmee River Basin.

EVALUATION OF MARSHES AND SWAMPS

Background

The utilization of natural areas, such as swamps, marshes, or simple depressions, for the storage and possible treatment of storm water runoff has been the subject of much discussion in recent years. Studies conducted by Shih and Hallett (1973) indicate that, at least initially, a portion of the nutrients contained in runoff water are taken up in traversing marsh areas, and the longer the residence time of the water within the treatment area, the greater the amount of removal.

A storage/treatment model was developed to examine the detention time, which will be defined as the amount of time a parcel of water spends in a designated control area, and the quantitative and qualitative effects of this time. A flow chart of this model, which will be referred to as MARSH, is shown in Figure 5.22 (see Bowden, 1975, for a more complete description). Given an inflow hydrograph and initial values of storage and outflow, MARSH is capable of determining: 1) the flow through the control area 2) the volume in storage and its associated detention time, 3)

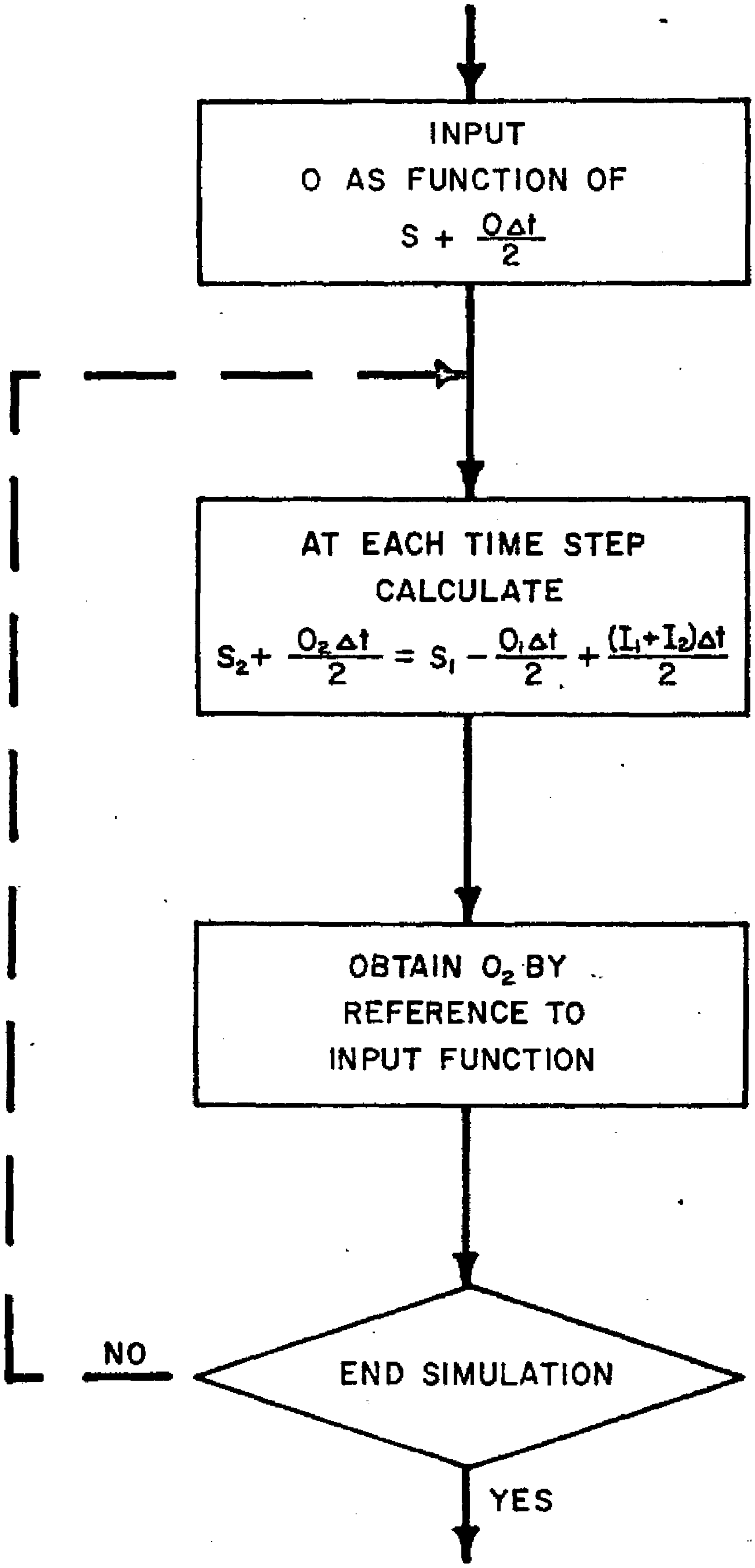

Figure 5.22. Flow Diagram of Level-Surface Storage Routing Used in MARSH Model. Subscripts 1 and 2 Refer to Old and New Time Steps, Respectively.

the cumulative distribution of volume versus detention time, and 4) the amount of flood attenuation and percentage of treatment of the volume of water.

Description of the MARSH Model

In routing flood movement through an area the main elements in the calculation are the balancing of inflow, outflow and volume of water in the control unit as described earlier in this chapter. MARSH employs the Manning equation and a relationship between depth and Manning's roughness coefficient (n) to calculate the discharge for various depths in the control area. The coefficients were taken from a report by the FCD on marsh uptake rates performed in the Chandler Slough area and should be applicable for this analysis (see Figure 5.23).

The basic form of the Manning equation (5.16) for flow is:

$$Q = \frac{1.49}{n} \ A \ R^{2/3} S_{\ell}^{1/2} \qquad (5.17)$$

where Q = flow, ft^3/sec,

n = Manning's roughness coefficient,

A = cross-sectional area, ft^2,

R = hydraulic radius, ft, and

S_{ℓ} = slope, ft/ft.

Assuming that the hydraulic radius (R) approximately equals the depth for a very shallow, wide, outlet, equation 5.17 may be re-written in the following form:

$$Q = \frac{1.49}{n} \ W d^{5/3} S_{\ell}^{1/2} \qquad (5.18)$$

where W = width of the marsh, ft, and

d = depth of the marsh, ft.

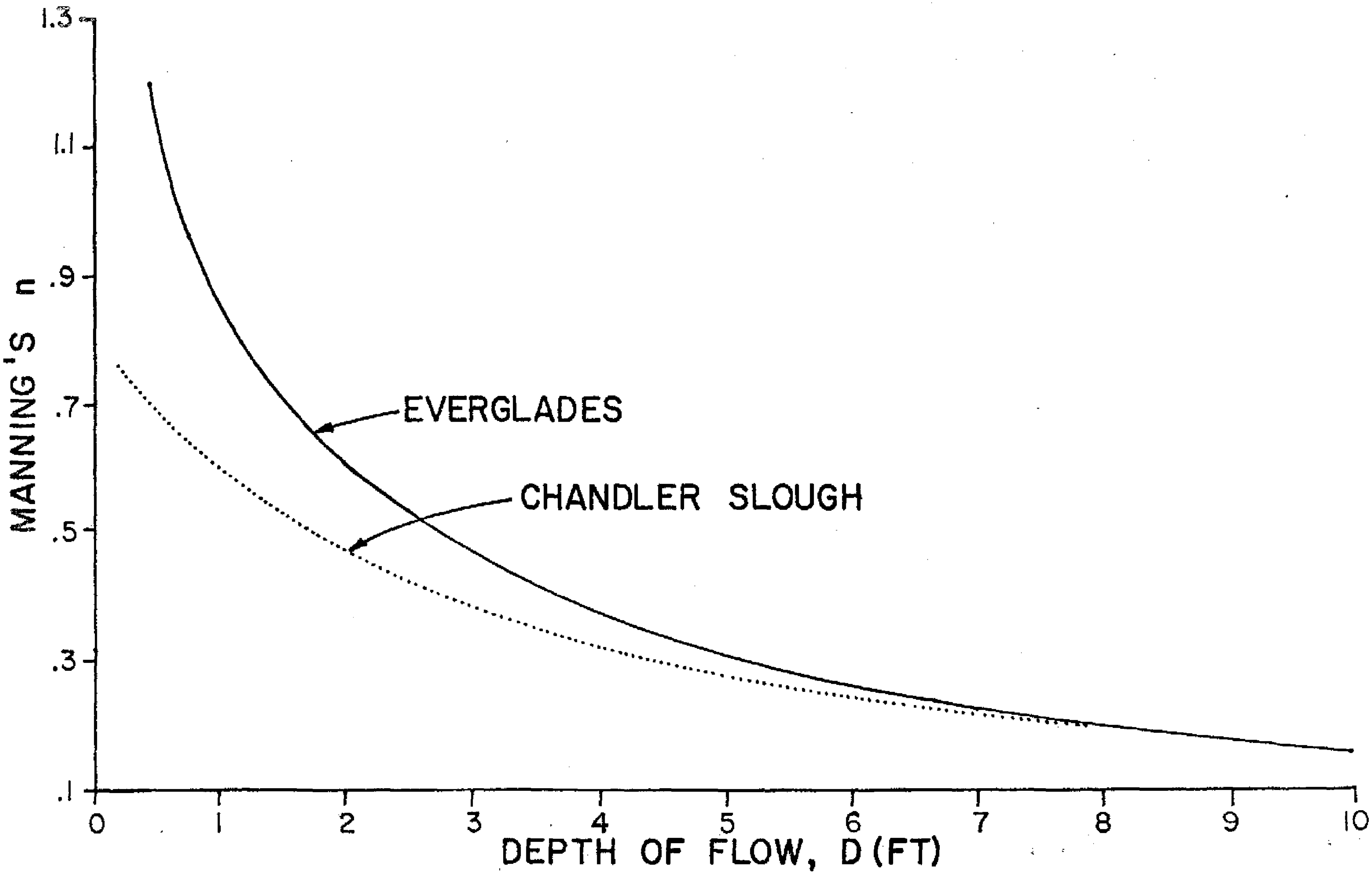

Figure 5.23. Variation of Manning's n with Depth (Shih and Hallett, 1974).

Using equation 5.18 and the relationship of n to various depths, the depth (stage) vs. discharge curve shown in Figure 5.24 is produced. In MARSH, arrays are formed containing the depth, discharge, storage and storage + 1/2 discharge rate. These values are computed in 0.25 foot increments from 0 to 5 feet, with intermediate values being assigned by linear interpolation.

The plug flow subroutine, PLUGS, (Smith, 1975) computes the time a parcel of water spends in the treatment area based on a first in, first out basis. A "parcel" of water is the volume leaving on a given time step. PLUGS assumes no mixing of these parcels as they pass through the control unit, so each parcel can be considered a single and separate unit as it enters and travels through the system. The control unit type of routing is illustrated in Figure 5.25.

In this manner the oldest water is removed from the storage facility when outflow occurs. In addition to the detention time for each parcel, the PLUGS routine calculates a cumulative distribution of the volume and detention time. That is, the length of time a parcel of water spends in storage is added to all other parcels which spent identical time, and then divided by the total volume to obtain what percent of the total spent more than the indicated time in storage.

It should be noted that MARSH does not consider the time lag which occurs as flow is routed through the system other than as a horizontal surface reservoir. Rather all flow entering the area is capable of being discharged within the same daily time step. For example, even though large quantities of water entering the upper reaches of the area may in reality require one day or more to reach the outlet of the system, this physical horizontal flow time is not taken into consideration in the model's calculations. These times were omitted for two reasons: 1) sufficient data for determining the travel times were not available, and 2) this allows the detention time calculated by MARSH to be conservative (i.e. the detention times are actually <u>longer</u> than those reported by MARSH).

The calculation of the percentage treatment given a parcel of water as it flows through the area was made using equation 5.9 presented earlier. The k value in equation 5.8 may be expressed as:

$$k = k_{20}(1.047)^{T_e - 20} \tag{5.19}$$

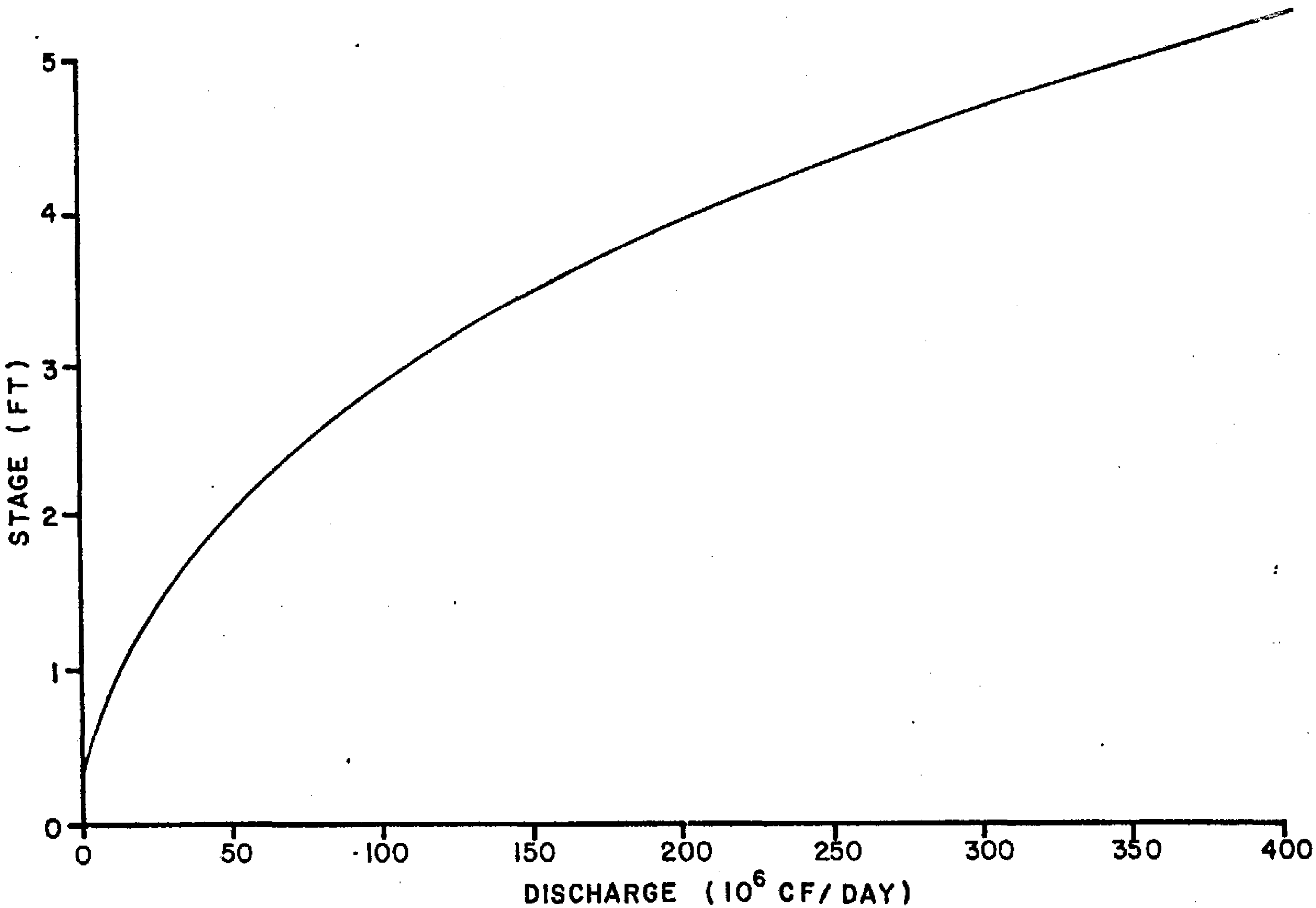

Figure 5.24. Stage-Discharge Relationship in Planning Unit 16, Kissimmee River Basin.

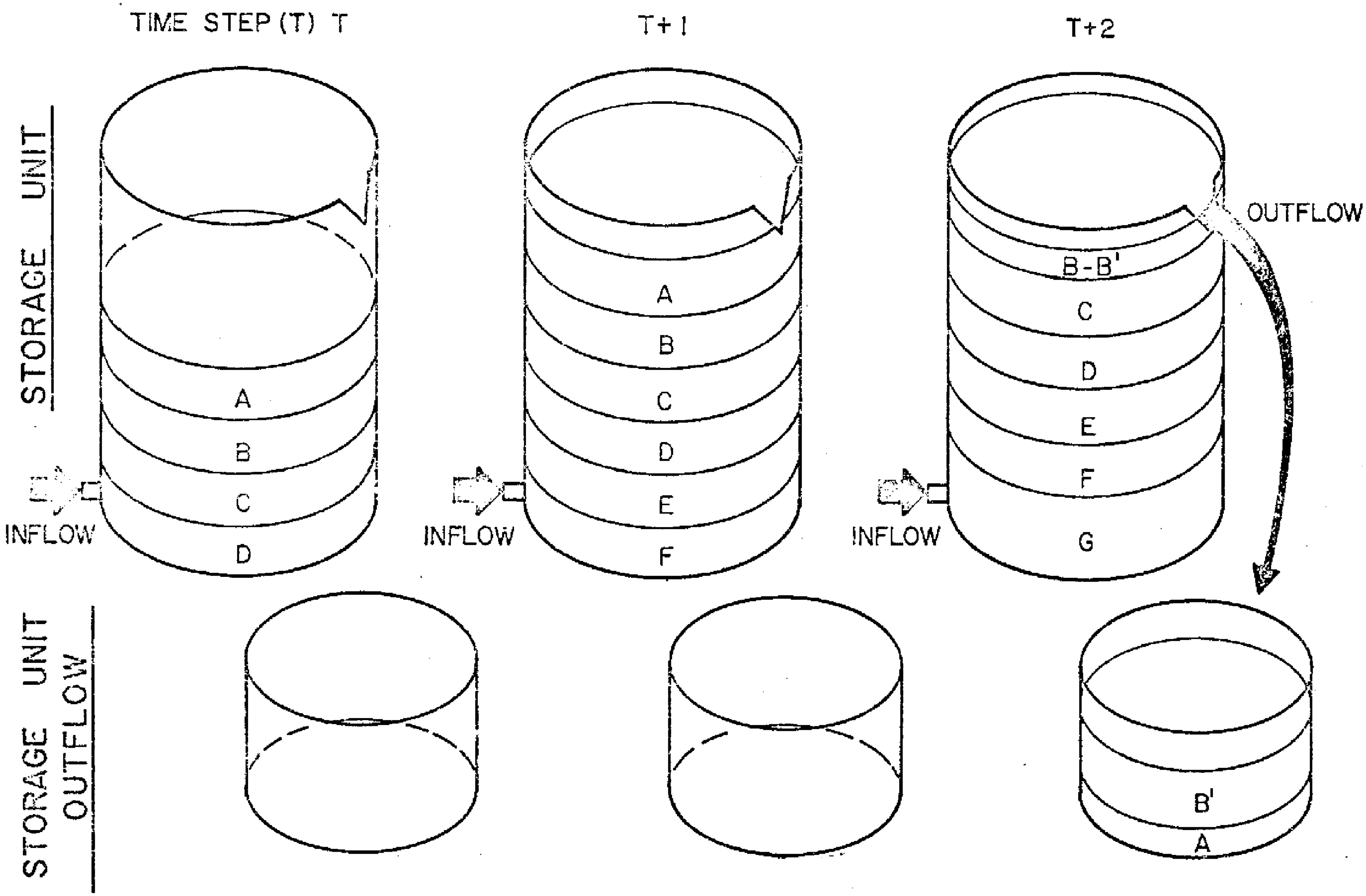

Figure 5.25. Illustration of PLUGS Flow Routine.

where T_e = water temperature, ^{o}C, and

k_{20} = reaction coefficient at $20^{o}C$.

This allows the first order decay coefficient variation on a seasonal basis. In this analysis, k was varied based on the mean monthly water temperatures provided by the FCD which are shown in Table 5.17.

Results

Study Area--

In this section the results of MARSH will be discussed when inputs such as land use, runoff, and size of the drainage and treatment areas are varied. It should be made clear at the outset that the analysis presented here is based on the assumption that the regions referred to as marsh areas will become, in essence, control units with inflow, outflow, storage, and bypass constraints imposed upon them. This explanation is presented so that the reader will not confuse the marsh in its natural state with the term marsh in the context of the model.

Planning Unit 16, specifically an area known as Chandler Slough, is the portion of the basin selected for analysis. The main reason for choosing this area is that the FCD used a 970 acre marsh in this area for the water quality studies alluded to earlier, and there are sloughs extending northward from the 970 acre area which might be classified as control or marsh areas. The total of the sloughs and 970 acre area provided a large marsh area (4,441 acres) which may be used for comparative purposes. Figure 5.26 shows the approximate location and shape of the two marshes, along with the type of agricultural drainage they receive.

The MARSH analysis is divided into two phases: the first, dealing with the quantity aspect, will discuss detention time, total volume for various land uses, drainage vs. control area ratios, and flood attenuation. The second portion will deal with detention time related to quality, and the effects of the detention time using first order decay parameters. A point worth noting is that due to the lack of available data on ground water inflow, and evaporation outflow, these hydrologic characteristics were assumed to offset each other and were not considered in the quantity and quality analysis.

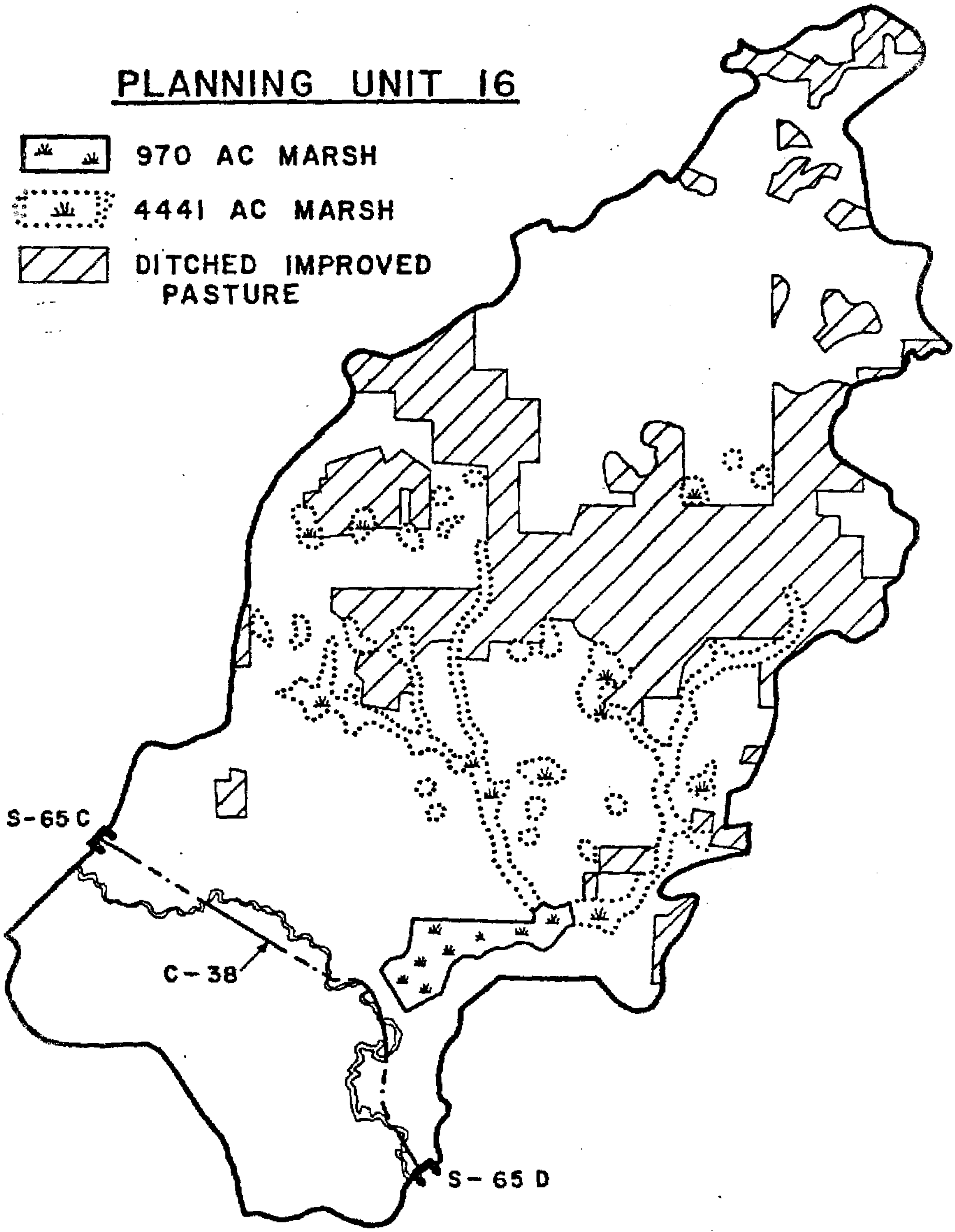

Figure 5.26. Marsh Study Area in the Chandler Slough Area of the Kissimmee River Basin.

Table 5.17. Mean Monthly Water Temperatures for the Kissimmee-Everglades Area (Shih and Hallett, 1974).

Month	Mean Monthly Temperature ^{o}C
January	21.0
February	16.5
March	20.0
April	22.0
May	25.0
June	28.0
July	27.0
August	26.5
September	25.0
October	22.0
November	22.0
December	21.5

Water Quantity --

Using the land use patterns projected by the linear programming model (Chapter III) it is possible to examine the relationship between the size of the marsh and the amount of time a percentage of the volume spent in storage for various study years. Figures 5.27 and 5.28 illustrate the effects of the 4,441 and 970 acre marshes on the detention time for the years 1958, 1972, and 2020. Observe that the larger marsh provides a greatly increased detention time, and the effect of changing the runoff volume (moving from 1972 to 2020) has less impact on the detention time over most

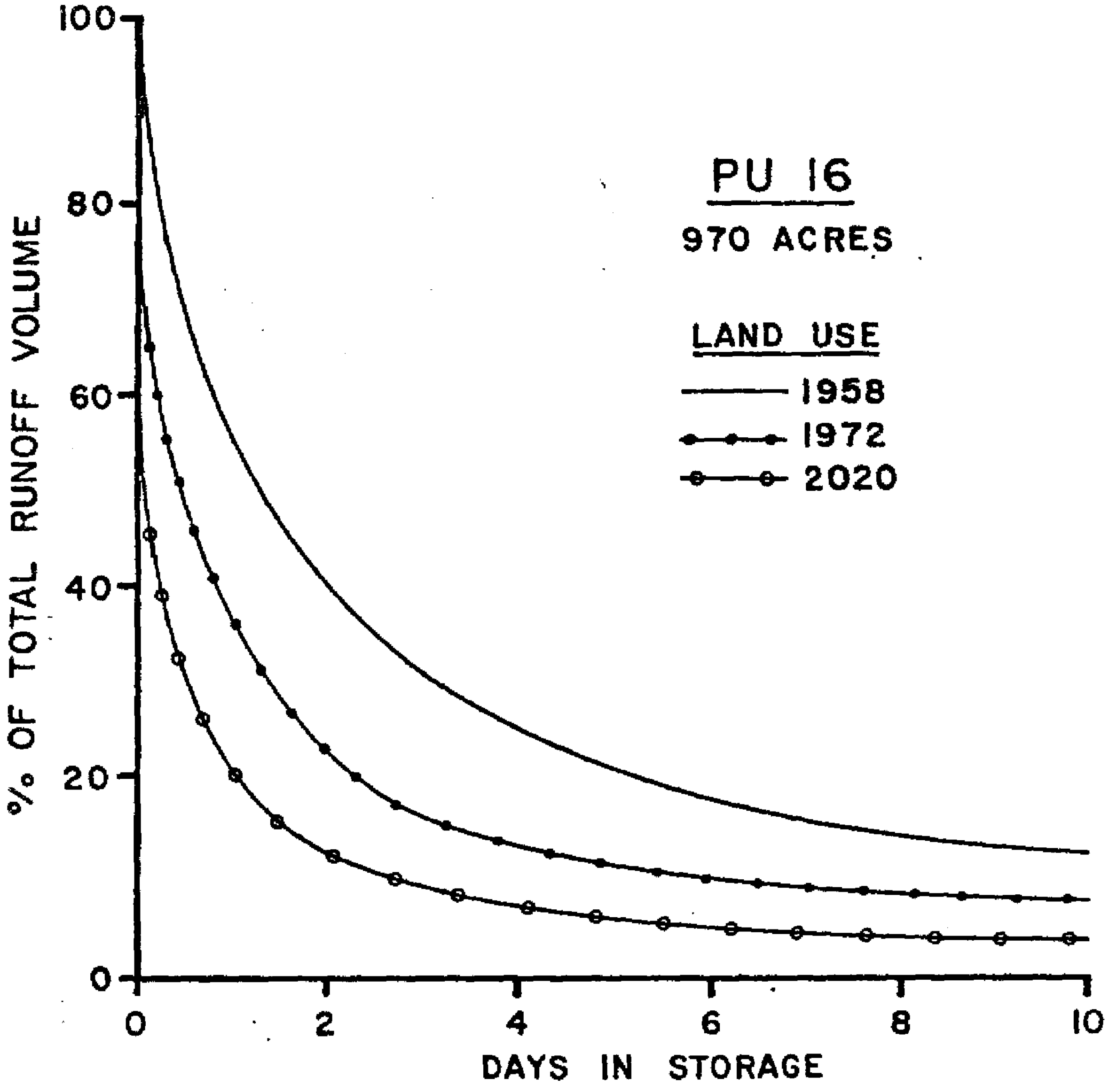

Figure 5.27. Residence Time of Runoff Volume in Chandler Slough Area for the January 1967 to June 1970 Rainfall--970 Acre Marsh.

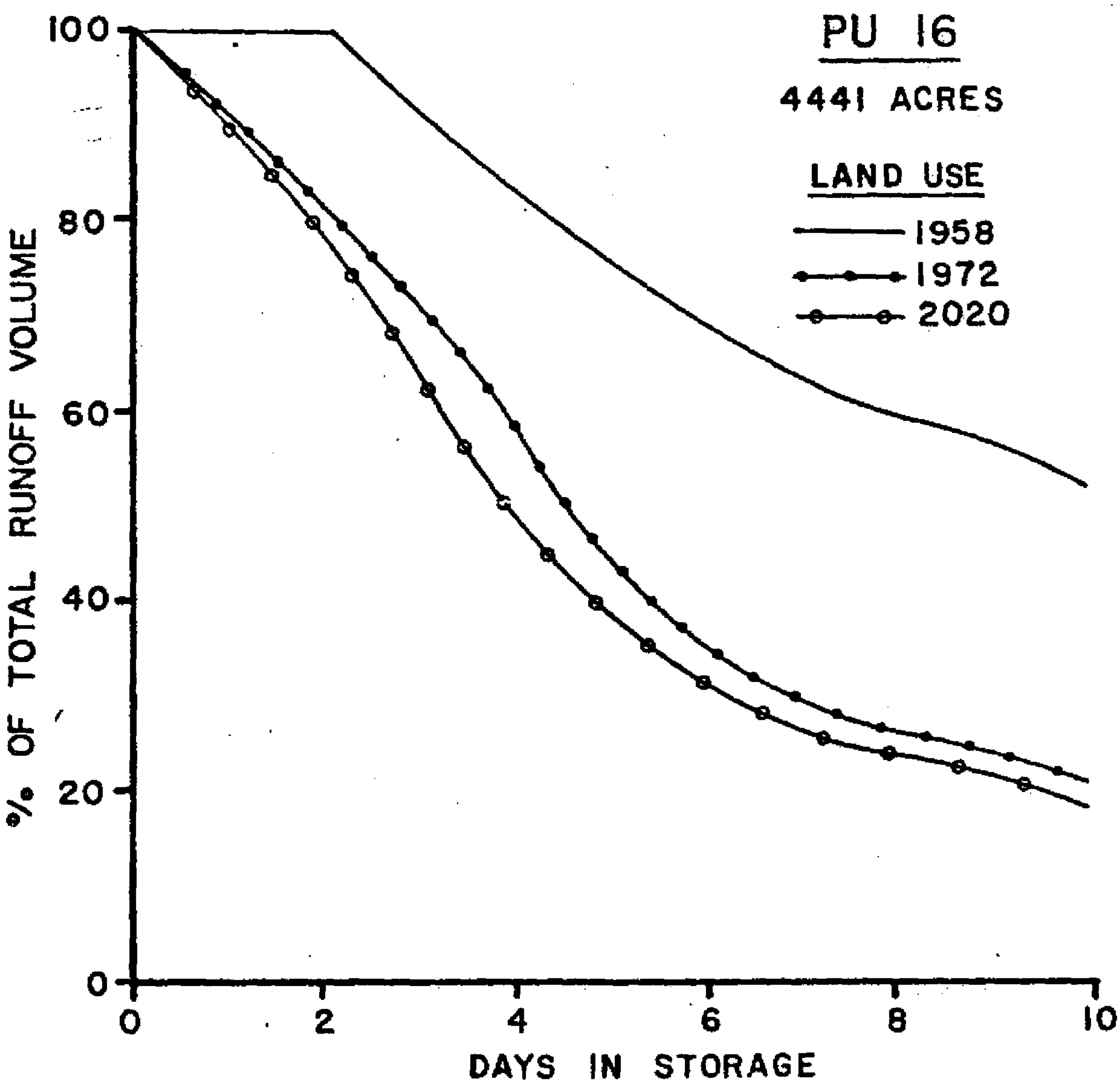

Figure 5.28. Residence Time of Runoff Volume in Chandler Slough Area for the January 1967 to June 1970 Rainfall--4441 Acre Marsh.

of the range for a given volume in the larger marsh. As an example note that under present land use conditions (1972), the small marsh can detain only approximately 20 percent of the runoff for more than two days, while the larger (4,441) area detains about 80% for the same time period. In addition, moving from the 1972 to 2020 land use causes only a 5 percent (80 to 75) decrease in the percentage of volume receiving two days of storage for the large area, while the same change causes a 10 percent change (20 to 10) in the smaller marsh.

The analysis assumes more meaning if some type of runoff control is implemented. If, for instance, it is required that all runoff leaving Planning Unit 16 spend at least five days within the planning unit (on site) before being released into the canal or river systems, the impact of the larger marsh is much more noticeable. If the marsh area is retained at 4,441 acres during the 2020 study period, the planning unit is capable of handling approximately 35 percent of the runoff without the construction of additional storage facilities. The reduction of the marsh area to 970 acres allows only 5 percent to be detained the required time.

One of the major problems involved with using marsh areas as storage-treatment units is the way in which alteration in the natural cycle of detention time vs. season or months occurs. Figure 5.29 shows the detention time vs. season for the natural condition from January 1967 through June 1970. In the natural state portions of the water had very large detention times, indicating low flow, and a dying back or decreased growth rate in the marsh. By utilizing the marsh as a storage-treatment unit, these natural periods will be altered. This will constitute a leveling out of the natural periods such as shown in Figure 5.30. At the present time there are no data available to examine the effect of removing the peaks, which perform a flushing action. This study makes no inferences as to how the buildup of material in the marsh areas might be handled, however this problem must be confronted if the natural cycle is altered.

The detention times discussed through this analysis play a very important role in the attenuation or lowering of peak outflows through the marsh area. The amount of attenuation varies greatly with the size of the marsh and the volume of water it must accept. In recent years three major floods, November 1954, September 1960, and October 1969 (Bedient, 1975) have occurred. For the attenuation analysis the October 1969 rainfall will be chosen as the reference event. Figure 5.31 shows the attenuation of the October 1969 runoff through a 4,441 acre marsh under the 1958 land use conditions. The percentage of this attenuation is approximately 66 percent while the lag period is approximately three days. In comparison, Figure 5.32 shows the effect of 1972 land use conditions using the same marsh area and runoff period. The percentage of

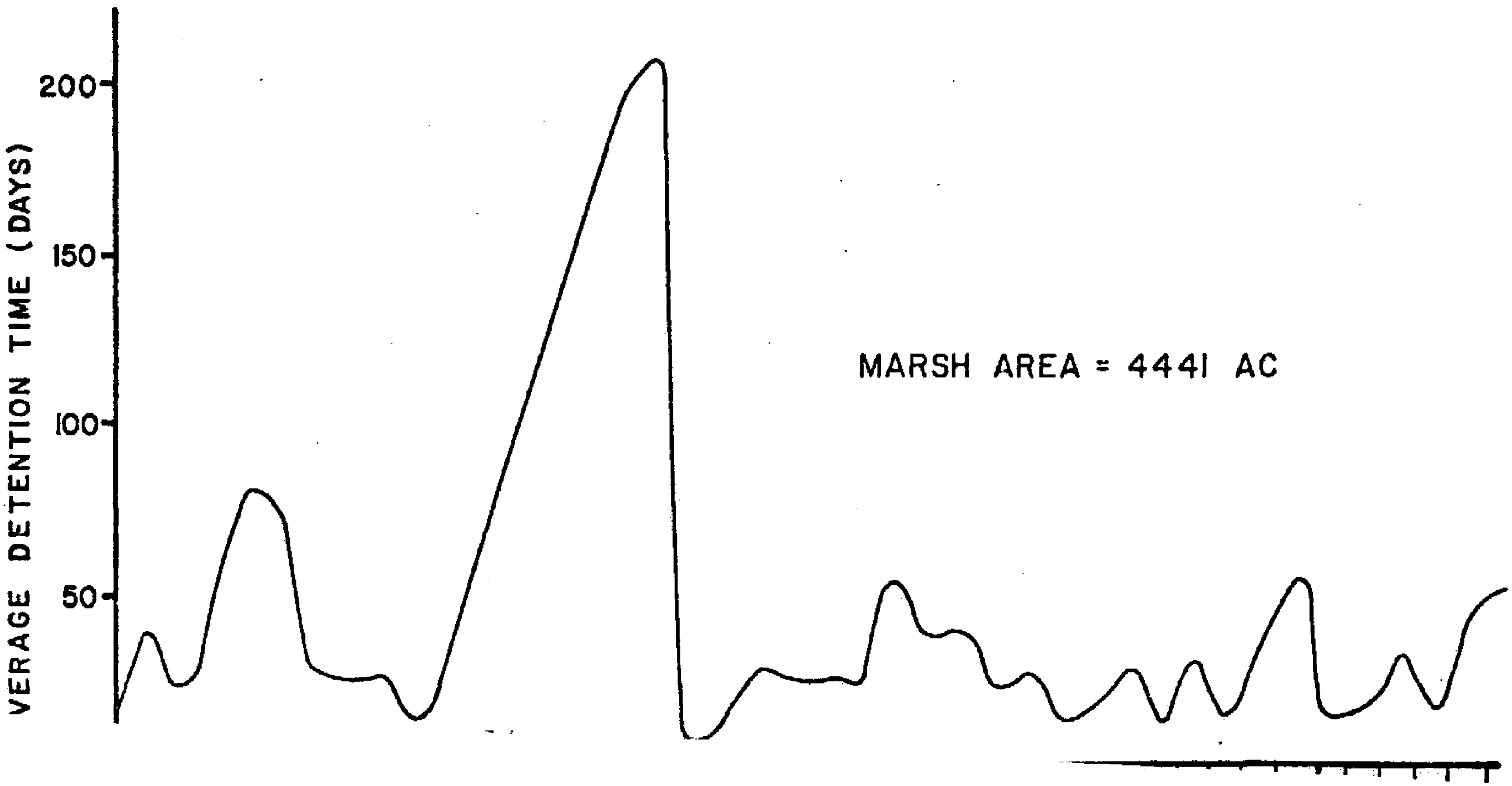

Figure 5.29. Detention Time in Chandler Slough - 1958 Land Use with No Diversion of Peak Flows - Natural Cycle.

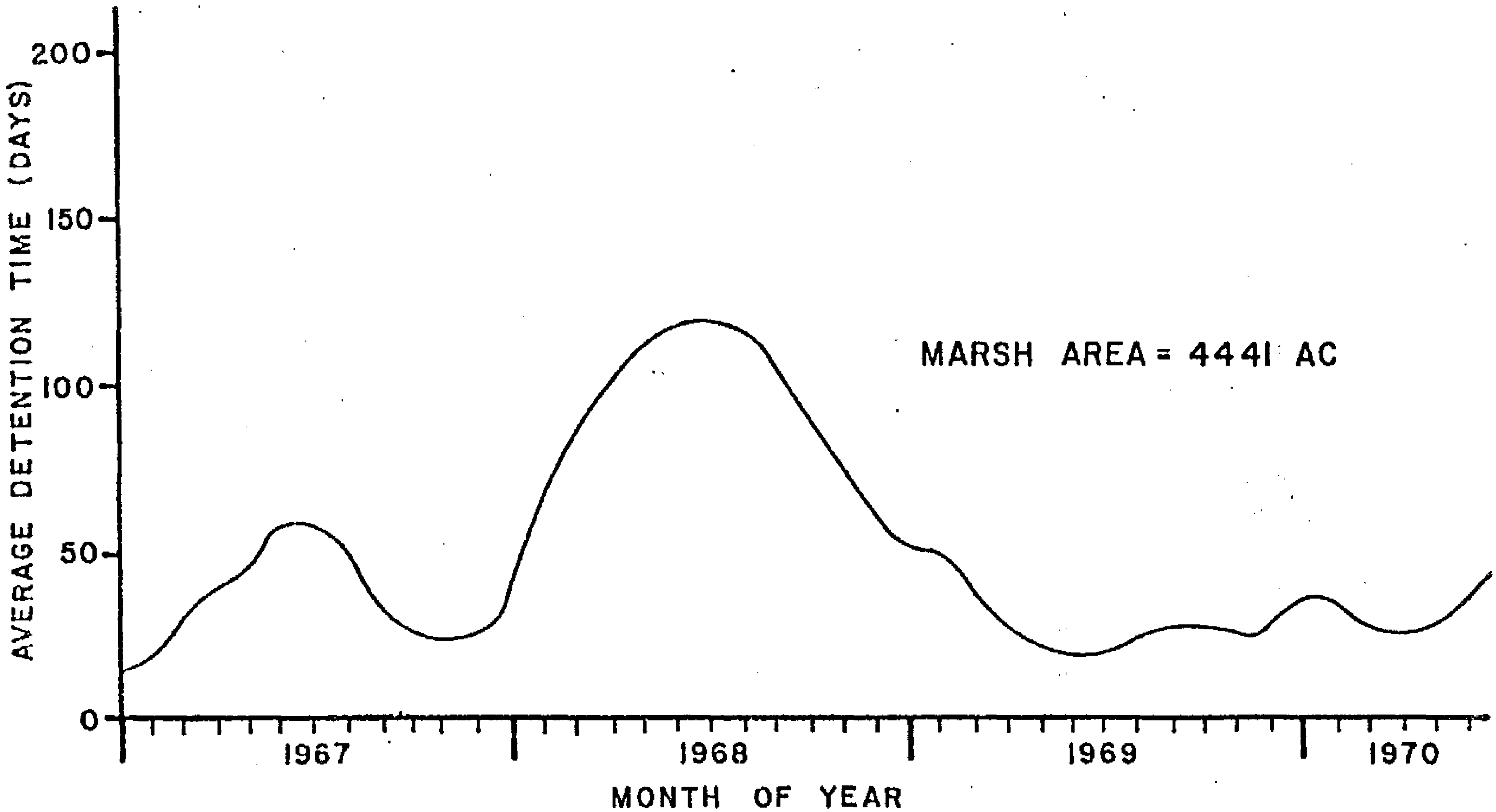

Figure 5.30. Detention Time in Chandler Slough - 1972 Land Use with Diversion of Peak Flows - Natural Cycle.

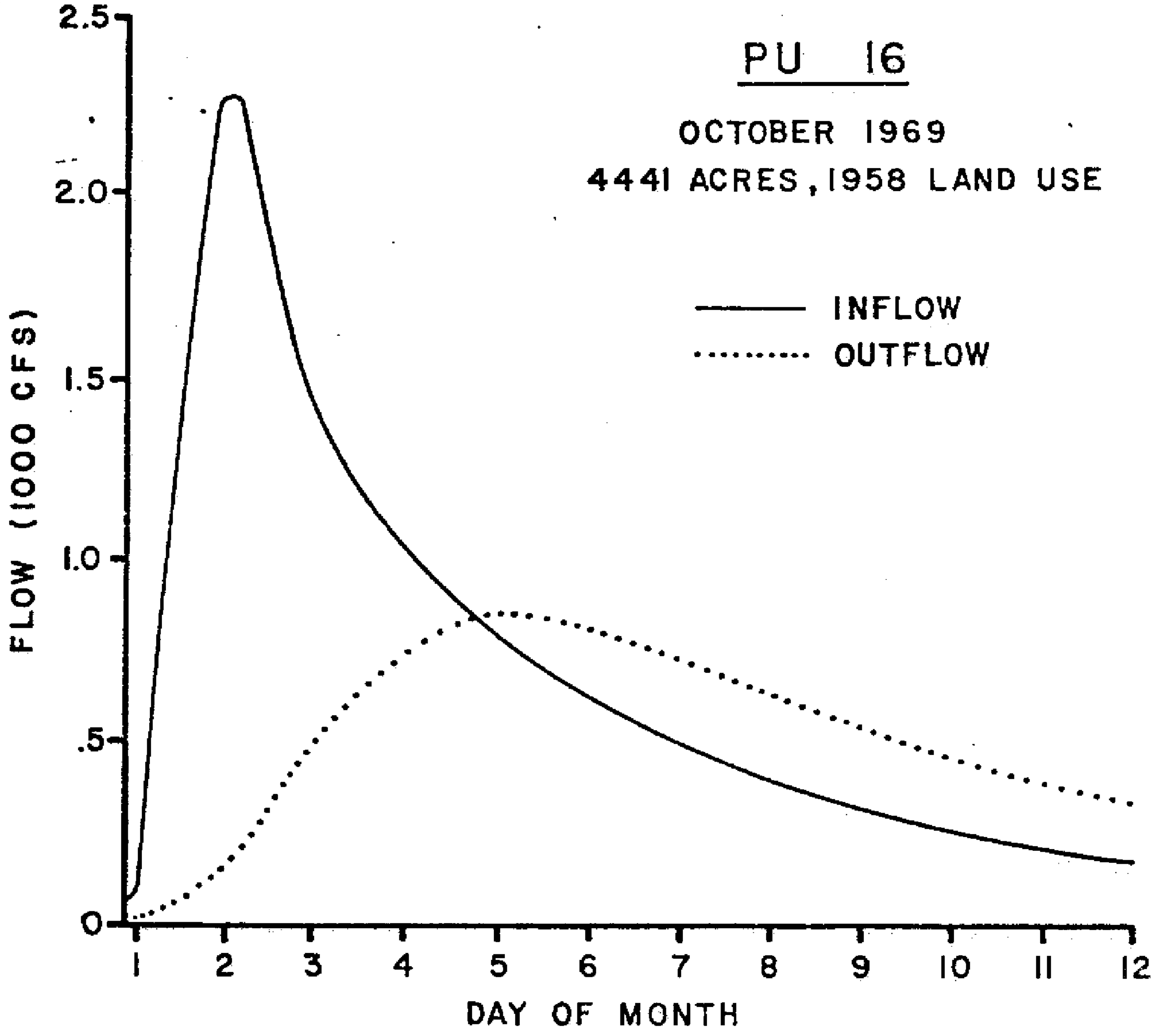

Figure 5.31. Flood Attenuation October 1969 Rainfall Under 1958 Land Use Conditions.

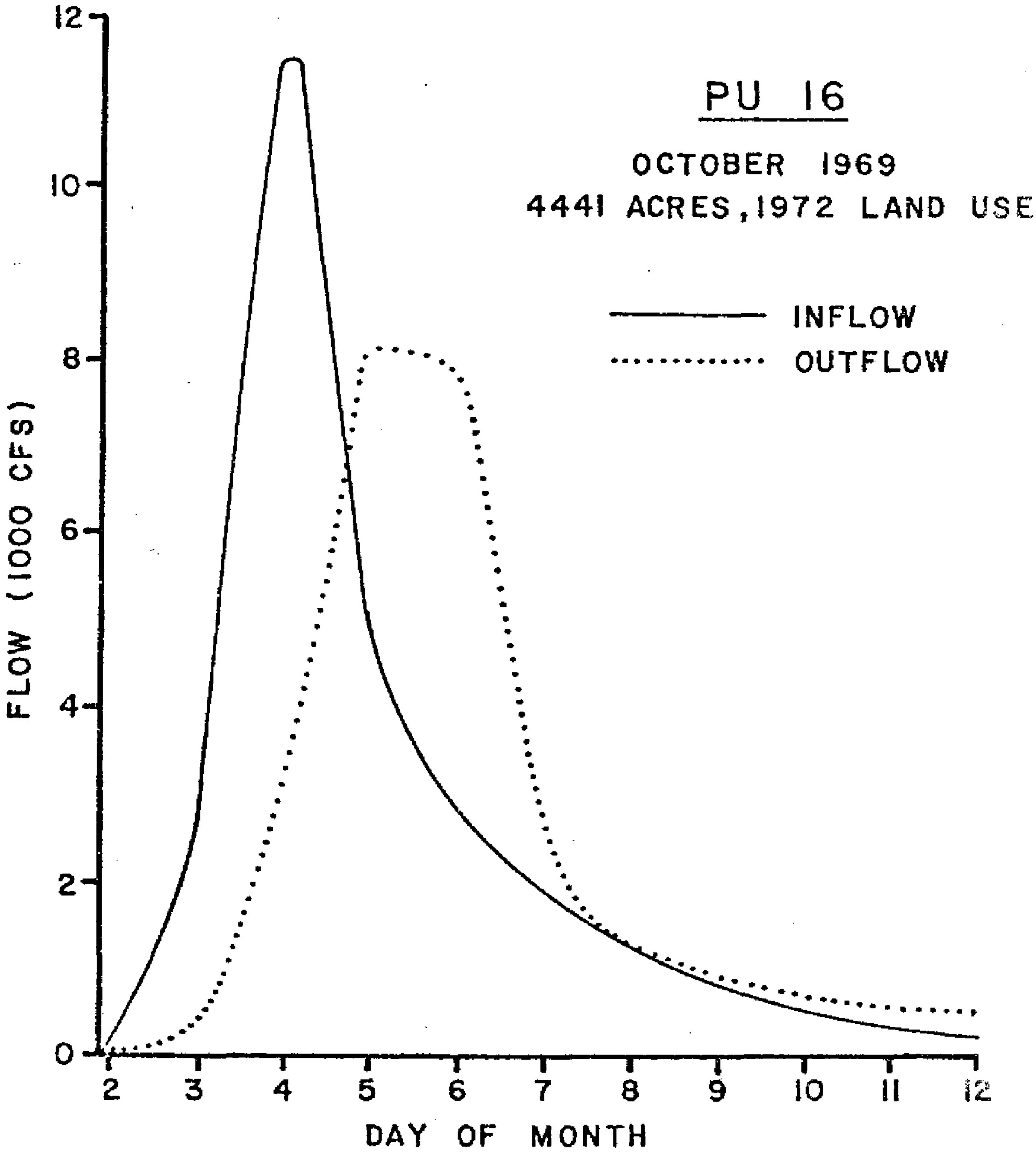

Figure 5.32. Flood Attenuation of October 1969 Rainfall Under 1972 Land Use Conditions.

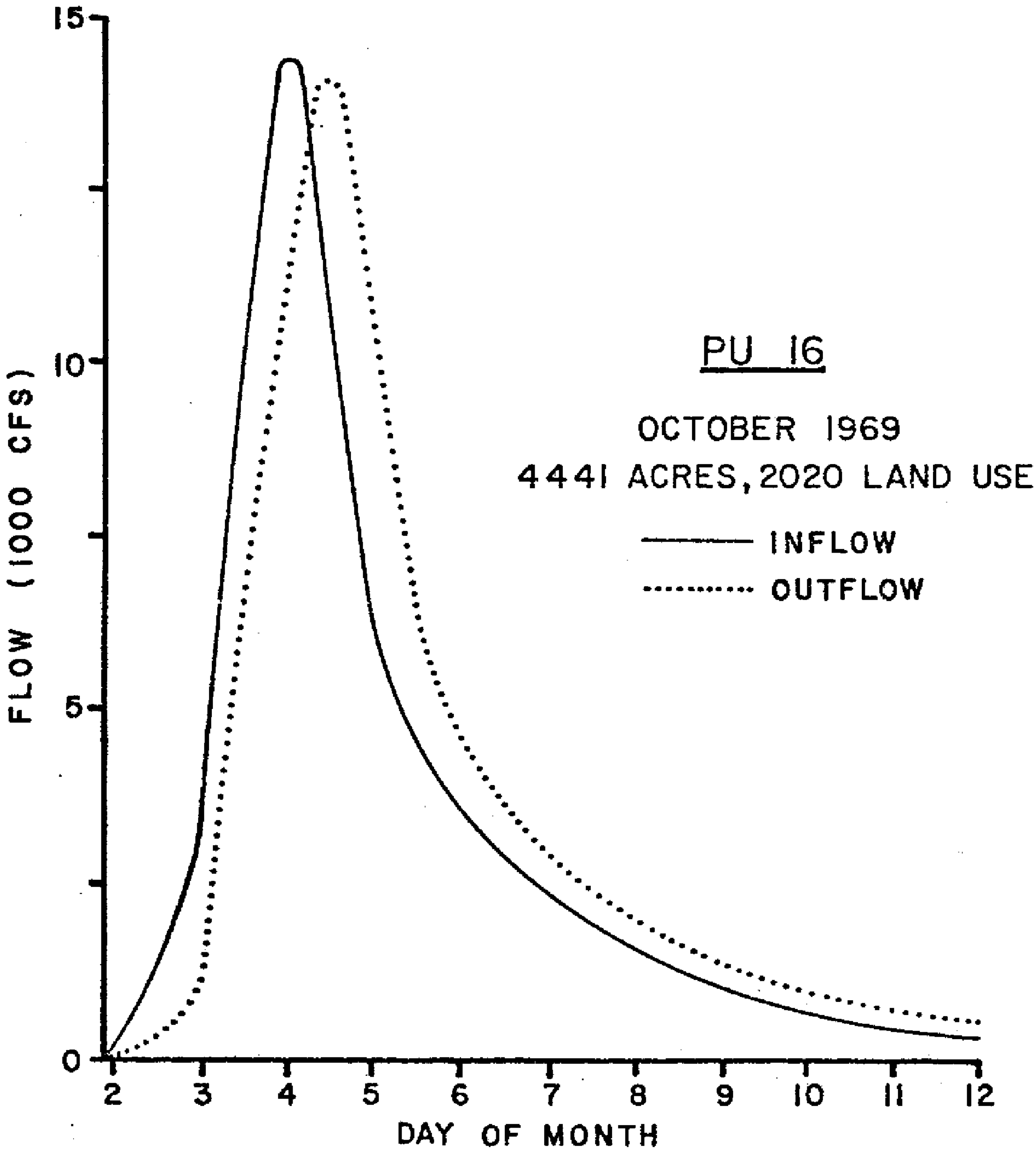

Figure 5.33. Flood Attenuation of October 1969 Rainfall Under 2020 Land Use Conditions.

attenuation has decreased to about 30 percent and the lag period to approximately 1 to 1.5 days. In addition, a dramatic rise in inflow between the 1958 and 1972 periods may be seen due to the large amount of unimproved pasture being converted to the improved category. Finally, Figure 5.33 shows the 2020 land use conditions which create in essence a pure translation of the hydrograph, with almost zero attenuation and a lag period of less than 0.5 days. At this point it would seem that the marsh has exceeded its carrying capacity and is no longer effective for flood protection.

The analysis presented above has significant implications concerning flood protection (amount of attenuation) in the Kissimmee River Basin. It has been previously shown that a decrease in the size of the marsh and swamp areas will effectively reduce the storage time, implying thereby that a decrease in the amount of attenuation will also take place. The same problem (decreasing flood attenuation) may be brought about through increased intensification of land use, even though marsh and swamp areas are unchanged. Thus, one needs to determine the preferred mix of runoff into the control areas and the size of the control areas.

The results of the MARSH model concerning the hydrologic impact of the swamps and marshes can be compared to a widely used procedure to estimate the mean annual floods in river basins throughout the United States (Barnes and Golden, 1966). They found that lakes and swamps attenuate the estimated mean annual flood in a river basin in proportion to the percentage of the total basin in lakes and swamps. Thus, their recommended procedure is to use a flood attenuation factor taken from the curve shown in Figure 5.34.

For comparative purposes the October 1969 event using the 1972 land use and the 4,441 acres of marsh was analyzed by varying the drainage/control area ratio and calculating the amount of attenuation obtained. Although the October 1959 event is not a mean annual flood, it supplies sufficient conditions for comparison with the Barnes and Golden analysis. By simply converting the drainage/control area ratio, say A_d/A_c, into the form used by Barnes and Golden (A_c/A_c+A_d), it can be seen that although the curves do not represent an exact fit, the comparable shape of the curves indicates agreement between these independent analyses. Note that both curves indicate a significant decrease in the flood attenuation when the percentage of an area in lakes and swamps is less than 15.

Water Quality--

The use of equation 5.8 allows the examination of quality in much the same manner that attenuation of peak discharge was performed. If the equation is considered to represent some type

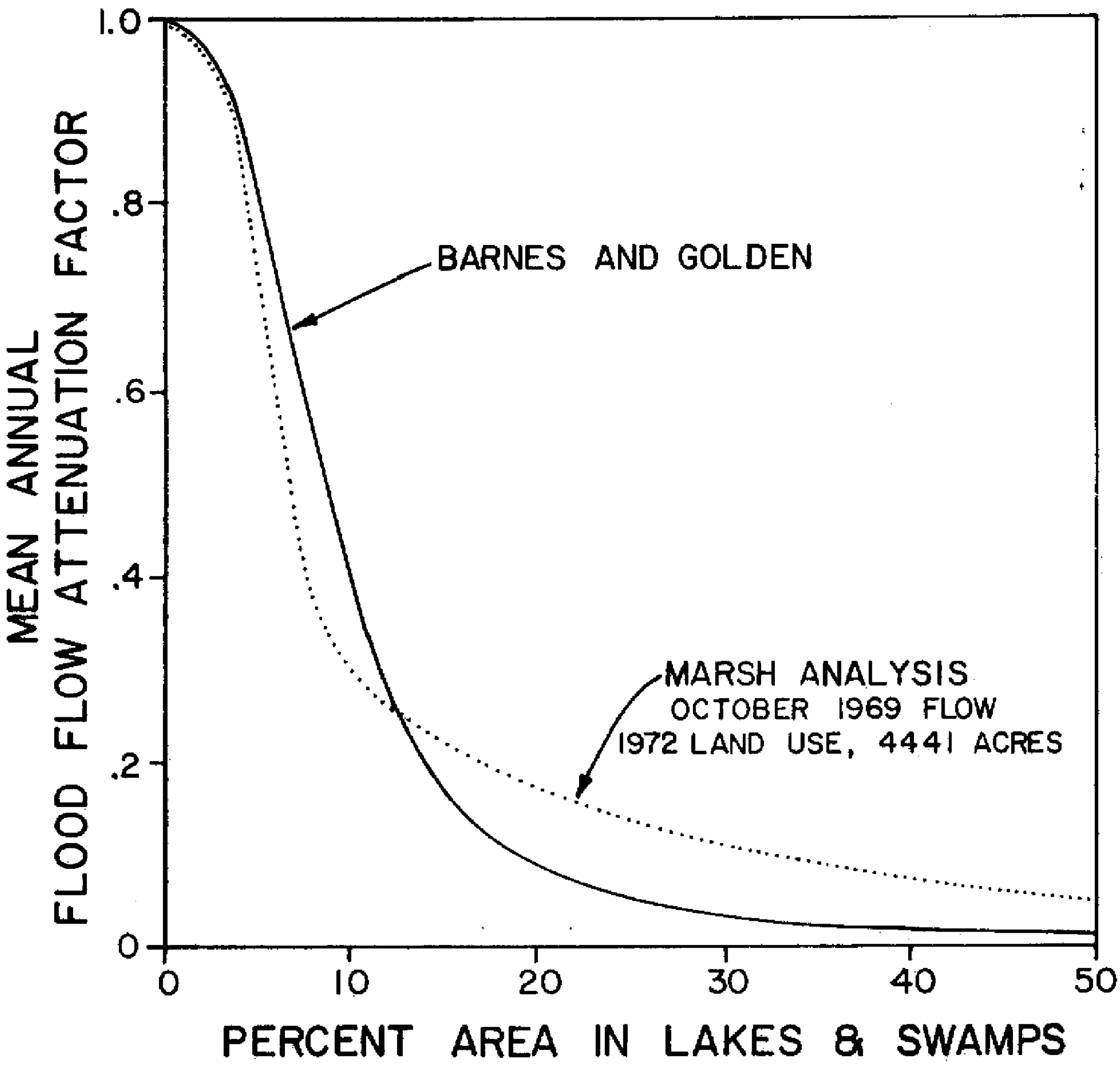

Figure 5.34. Comparison with Barnes and Golden Analysis for the Attenuation of Mean Annual Flood (Barnes and Golden, 1966).

of nutrient uptake or treatment in the marsh area, the effect of varying the drainage to treatment ratio may be examined for the 970 and 4,441 acre marshes, respectively. Figure 5.35 shows the effect of this variation on the 970 and 4,441 acre marshes. Though the break points are not as accentuated as in the quantity analysis, the increasing percentage of water that becomes untreated with increasing drainage/treatment area ratio should be clear. The question might arise at this point, why should the size of the marsh have any effect if the ratio is the same? That is, should not a 1,000 to 10 ratio be essentially the same as a 10,000 to 100? The answer is, of course, yes. However, MARSH assumes that the widths of the areas are constant and thereby forces the entire volume of water through the same size outlet. In other words, regardless of marsh size the discharge characteristics were assumed to remain constant. This causes larger marshes to empty more slowly and thereby have longer detention times.

An additional reason for the observed variation is the assumption that the water is instantaensously available for input in the marsh area. This ignores the flow characteristics and increased flow time across the drainage area, but because of the lack of available data comparable to those used in the earlier C-38 evaluation to provide accurate estimates of these times, they were not considered.

The dot on the 970 acre curve of Figure 5.35 indicates where Planning Unit 16 presently is on the curve if 970 acres of marsh are available, which places the planning unit at a rather insensitive point, i.e., the percent untreated will not increase dramatically with intensified land use. The dot * on the 4,441 acre curve on the other hand shows the position of 16 if 4,441 acres of marsh are utilized and maintained. At this point, the percentage treatment is still rather high, and decreases more slowly with the increased ratio. Allowing the marsh area to remain in the 25:1 area would seem to assure fairly effective treatment for future years.

Up to this point the ratio has been varied by changing the runoff volume while holding the marsh area constant. If the opposite technique is employed (Figure 5.36), the change is slightly more dramatic in that the slope of the curve becomes quite steep for small marsh areas. This analysis seems more reasonable. The encroachment of urban and agricultural areas will tend to cause drainage of marsh area, thus decreasing them in size. The dots show the positions of the 970, 4,441, and 12,000 (1958 area) acre marshes.

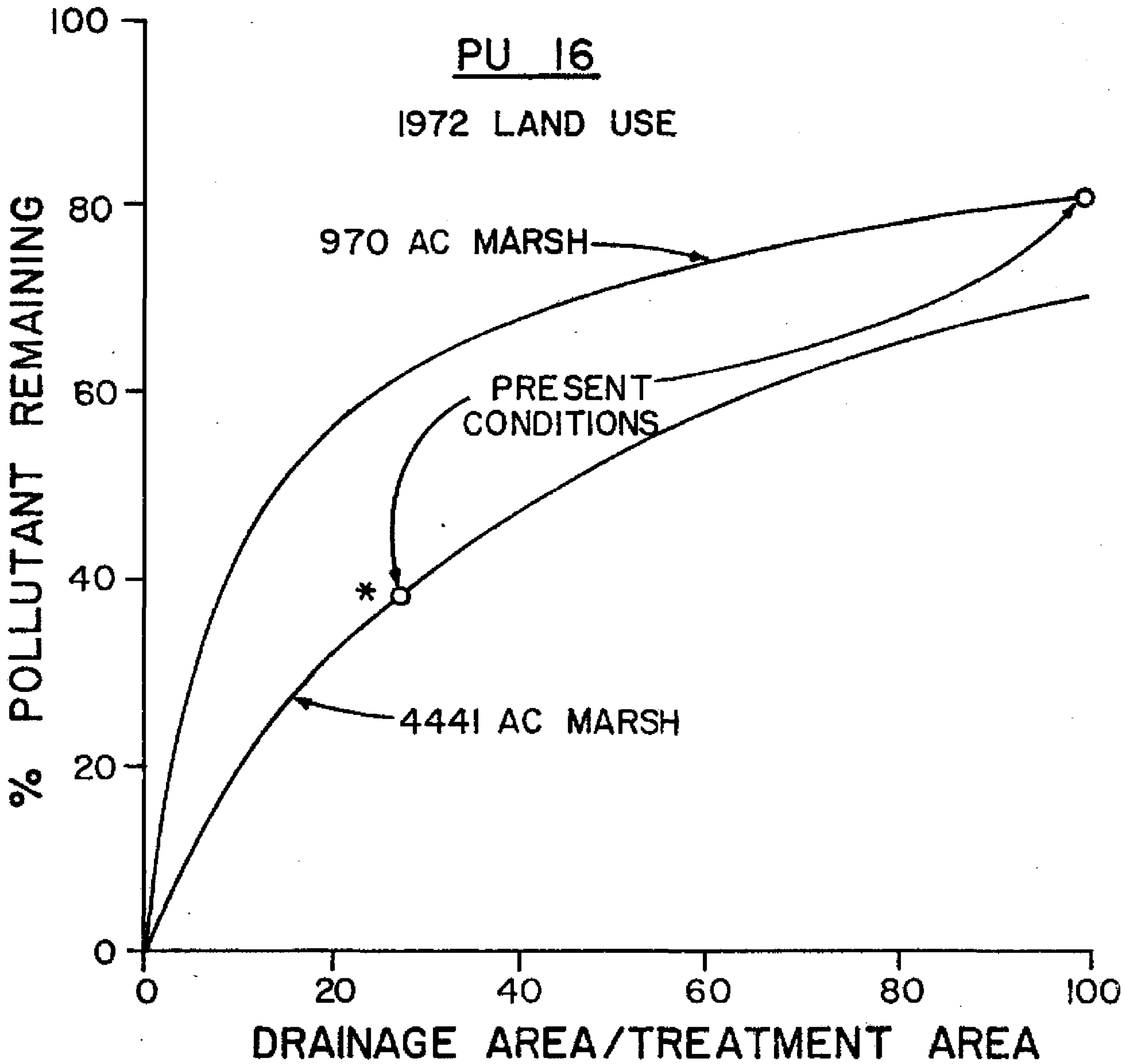

Figure 5.35. Percentage Treatment for Various Drainage/Treatment Area Ratios Utilizing 970 and 4441 Acre Marshes.

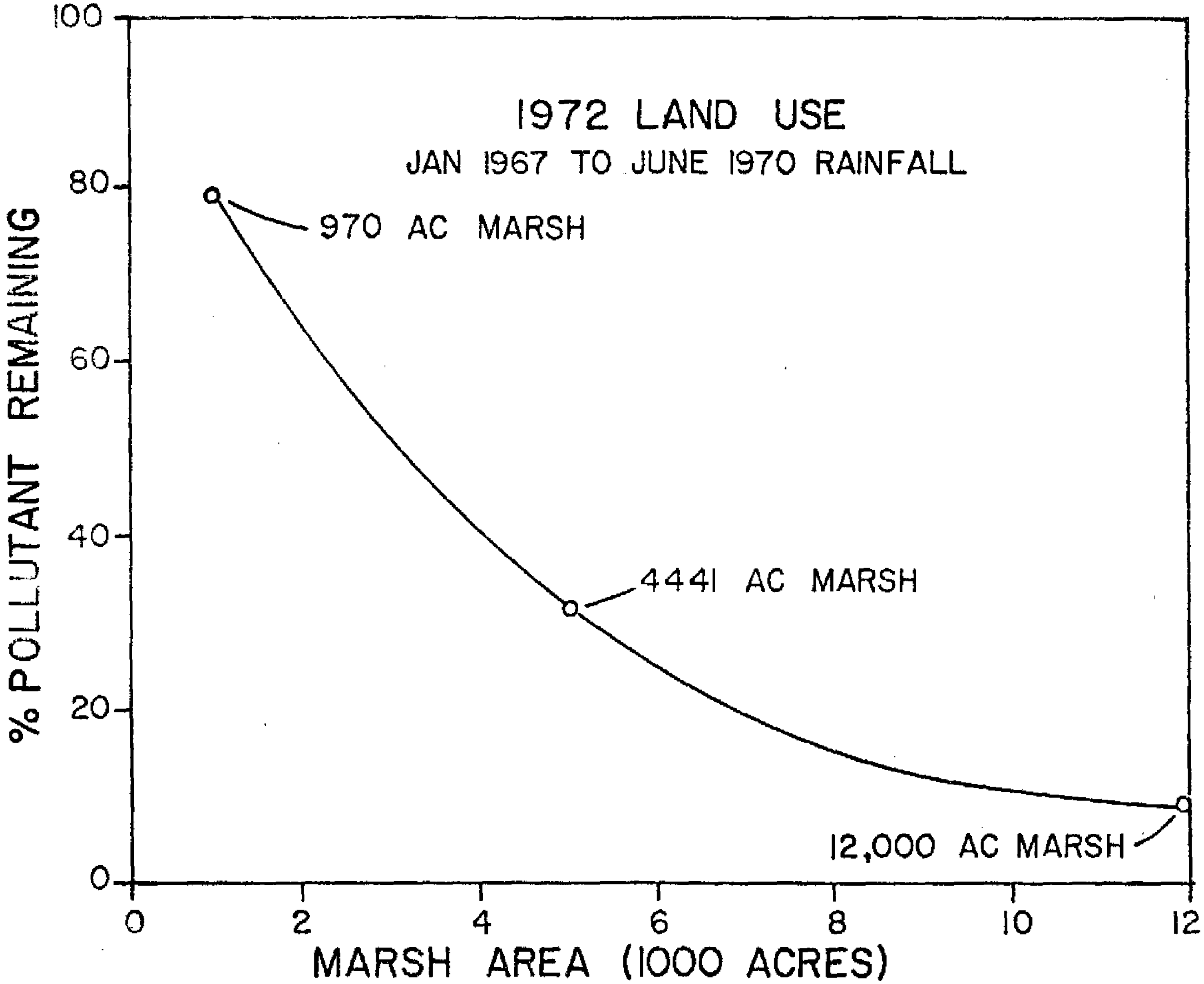

Figure 36. Percentage Treatment for Various Marsh Areas with 100,600 Acre Drainage Area in Planning Unit 16.

Summary

In summary, the marsh analysis has established four major points:

1) The size of marsh area and amount of inflow runoff determine the transition of the outflow hydrograph, i.e., translation and attenuation.

2) Approximately 15 percent of an area should remain in some type of natural treatment system to obtain a good degree of flood attenuation.

3) The percent of treatment of runoff decreases with increasing drainage area/treatment area ratio, but decreases more slowly for larger marsh areas.

4) Detention time is a good indicator of nutrient uptake and flood attenuation rates in the marsh.

VI. SUMMARY

INTRODUCTION

The Kissimmee River Basin, located in Central Florida, originates near Orlando and passes through a series of shallow lakes in the upper reaches before emerging south of Lake Kissimmee as a meandering river. It then flows south to Lake Okeechobee through a relatively narrow floodplain (see Figure 6.1).

In October of 1956 the Corps of Engineers (COE) released a report citing the need for flood control and water conservation in the basin. Due to prolonged seasonal rainfalls, inadequate secondary drainage canals, and limited outlet capacity, large areas of the watershed were periodically flooded. Tropical hurricanes, which occur occasionally during the rainy season, also served to intensify the problems. Extensive and costly flooding occurred numerous times before the publication of the COE report, e.g., years 1945, 1947, 1948, 1951 and 1953, and the expanding agricultural economy in central Florida indicated that the flood damages would only increase in the future. The overall plan, proposed for central and southern Florida, provided for channelization and control structures on the Kissimmee River and below the larger upper basin lakes.

After completion of the channelization project on the Kissimmee River Basin, objections were raised by ecologists and conservation groups over the destruction of a unique natural meandering river and its rich marshes, and the decline of fish and waterfowl resources. Concern over degrading water quality and the ultimate effect on eutrophication of Lake Okeechobee was also expressed. As a result, a report was presented to the Florida cabinet in 1972 by Marshall *et al*. The report recommended that a Water Quality Master be appointed by the Governor in order to coordinate efforts to restore water quality in the basin.

During the past two years, intensive studies by several agencies, university groups, and consultants have been underway to examine problems associated with Lake Okeechobee and its drainage basin which includes the Kissimmee River Basin. This study dealt with a water resources investigation of the Kissimmee River Basin. Included in this analysis was an evaluation of the extent to which the channelization of the lower Kissimmee River has caused water quality

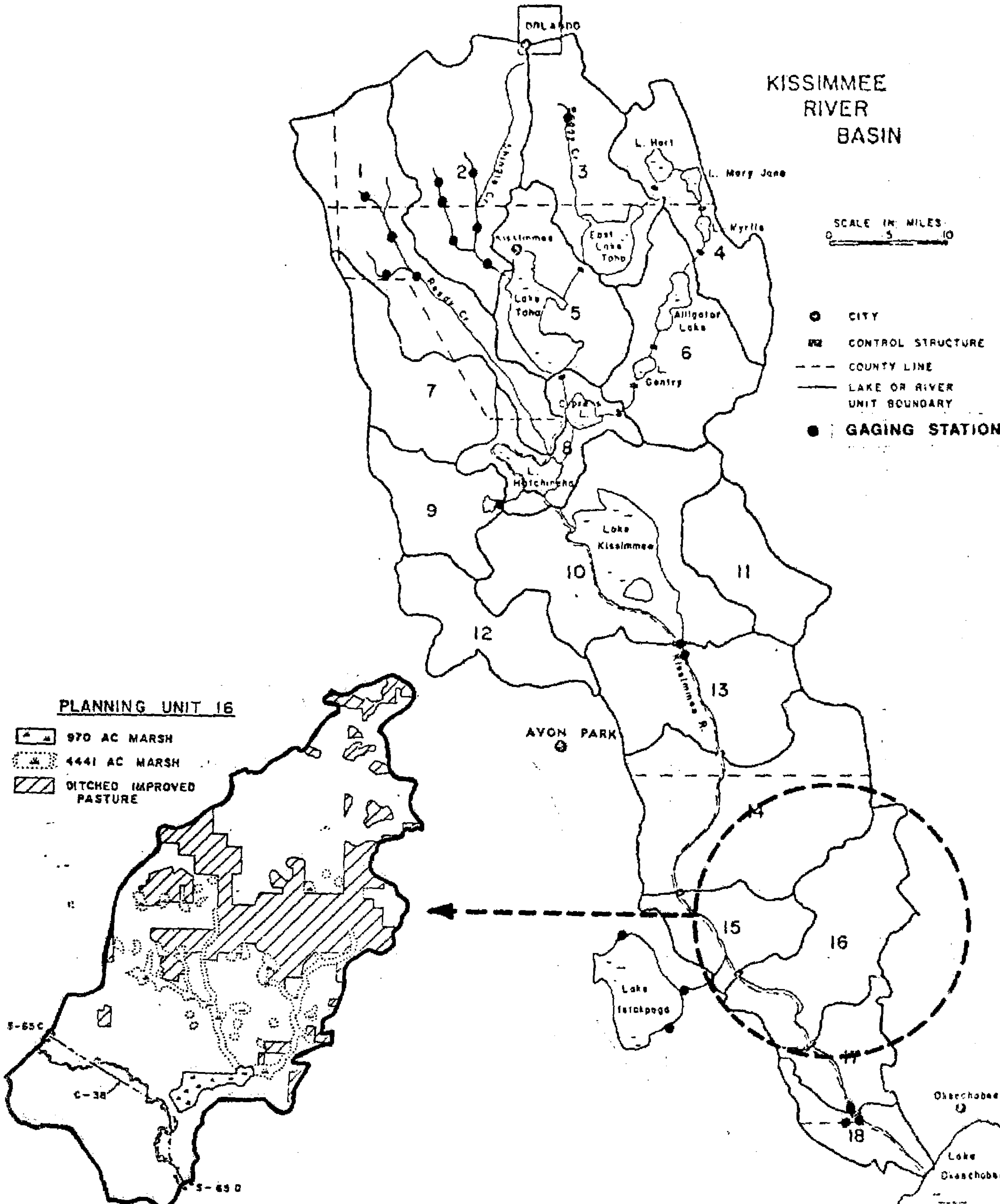

Figure 6.1. Map of Kissimmee River Basin and Detailed Study Area (Chandler Slough) in Planning Unit 16.

problems in Lake Okeechobee. The remainder of this section presents the findings of this study and is a summary of earlier chapters of this report.

LAND USE ANALYSIS

Land use in the Kissimmee River Basin has undergone rapid and significant changes in the last 15 years. Past activities in the upper part of the basin were dominated by urban interests, especially around the Orlando area, and agricultural interests involved in citrus on the eastern ridge, small amounts of improved pasture around the upper lakes, and large areas of unimproved pasture throughout the remainder of the basin. Approximately 40 percent of the land which was formerly unimproved pasture has been improved through diking or drainage procedures. In addition, urban expansion is evident south of Orlando, around lake borders, and in the Disney World area of western Orange County.

Future patterns of land use in the Kissimmee River Basin have been projected using estimates of the Soil Conservation Service (SCS) and the U.S. Department of Agriculture in conjunction with a linear programming model developed in the study. The results of this analysis are projections to the years 1980, 2000 and 2020, of what land use could be. It does not state that this is what the land use should be, for that represents a policy choice beyond the planner's realm of responsibility. It is important to keep this distinction clear so that the analysis to follow is not construed to be the well-publicized circular analysis whereby projects are justified to meet future demands which could only be met if the project is built, i.e., self-fulfilling prophecies.

The results, shown in Table 6.1, indicate major shifts in land use to urban and improved pasture. Swamps and marshes are expected to decline significantly. Note that the lower Kissimmee River flood plain comprised only about 15 percent of the available swamps and marshes in 1958. There could also be considerable future impact on the Kissimmee River Basin due to the depletion of the muck lands south of Lake Okeechobee.

QUANTITY AND QUALITY OF RUNOFF

Hydrologic Analysis

Relatively little research has been done on problems associated with watersheds dominated by marsh and lake storage, extremely flat

Table 6.1. Land Use in the Kissimmee River Basin - 1000 acres

Land Uses / Study Year	1 Urban	2 Crop Land	3 Improved Pasture	4 Unimproved Pasture	5 Citrus	6 Forest	7 Swamp[c]	8 Marsh[c]	9 Barren Land	10 Surface Water	Basi[illegible] Tota[illegible]
1958[a]	25.4	0.7	131.2	660.6	101.9	20.3	249.4	162.7	0.0	138.5	1490.[illegible]
1972[a]	92.5	2.8	457.8	369.2	108.1	45.7	140.5	132.0	3.1	138.5	1490.[illegible]
1980[b]	134.8	9.4	512.0	271.2	99.9	62.9	127.9	131.0	3.1	138.5	1490.[illegible]
2020[b]	530.6	57.2	436.2	93.8	62.3	75.2	63.7	30.1	3.1	138.5	1490.[illegible]

[a]Based on analysis of aerial photographs.

[b]Based on predictions of linear programming model, Chapter III.

[c]Lower Kissimmee River flood plain is 60.8 thousand acres.

slopes, and long-term seasonal rainfall and flooding. These are termed depressional watersheds, and are most commonly found along the Coastal Plain of the southeastern United States. South Florida watersheds including the Kissimmee-Everglades region fall into this category. Unfortunately, depressional watersheds, lacking the normal dendritic drainage pattern, are not easy to monitor. Figure 6.1 shows the USGS gaging stations in the basin as of 1974. Note that the entire lower basin (S65 to S65-E) is monitored only at the upper and lower boundaries. Thus, it is quite difficult to characterize the hydrology of this vast area which is undergoing significant changes due to channelization and upland drainage. From a water quality point of view, it is important to estimate the volume and transport pathway of water entering the main river, i.e., direct (surface) runoff (overland flow plus interflow) vs. subsurface flow. Unfortunately, data are lacking to make this judgment. Only with an adequate monitoring program can the hydrology of the Kissimmee River Basin be evaluated properly. But planning programs are needed now to properly manage the area. Thus, hydrologic models have been developed to provide some preliminary judgments regarding the study area. Existing data are used whenever possible for calibration purposes. The results from simulating what might occur if the precipitation of 1967 to 1969 falls on planning units 13-17 for 1958, 1972 and 2020 land uses are shown in Figure 6.2. Under natural conditions most of the water reaching the lower Kissimmee River Basin was from subsurface runoff. Thus, it took longer to reach the river and the water was purified by the soil. If present drainage practices continue, it appears that most of the future runoff will be surface runoff via drainage canals. This water will reach the river sooner and carry more pollutants with it. This change is due to the fact that surface soil layers (above the level of water in adjacent drainage channels) now contribute to surface runoff (via interflow) where they formerly contributed to the subsurface flow regime.

Pollutant Loadings

The water running off the land carries with it pollutants from man's activities. Only recently has the seriousness of this problem been recognized. Thus, few data exist to evaluate the magnitude of this source with the desired accuracy. Loehr (1974) has surveyed the available literature. Based on his studies one can determine the approximate relative importance of various land uses in generating pollutants. The results are shown in Table 6.2.

Available water quality data were compared with the extent of surface drainage in the basin to determine if a correlation exists. Drainage density, measured in miles of drainage network per square mile of land, is also shown in Table 6.2.

Based on the detailed investigations of drainage density levels in each planning unit and slough system along the river, measured

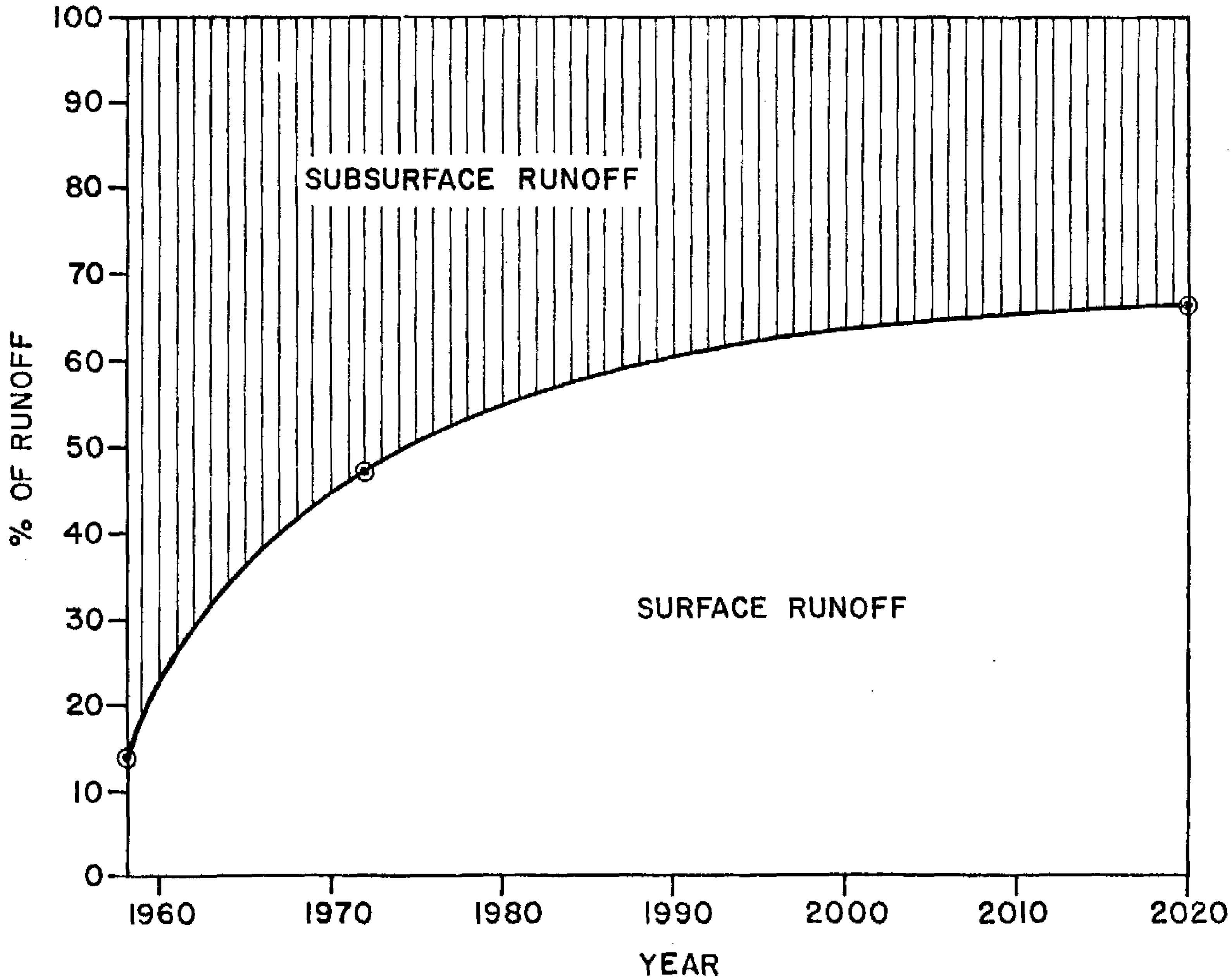

Figure 6.2. Variation in Percent of Surface (Overland Flow plus Interflow) and Subsurface Runoff from Planning Units 13-17. Change occurs because of reallocation of flow from surface soil layers.

Table 6.2. Relative Non-Point Source Loadings and Drainage Density.

Land Use Category	Relative Pollutant Weight	Drainage Density (miles per square mile of land)	Maximum Distance to Drainage Canal (ft)
Forest, Marsh, Rangeland	1-5	1.0	5280.0
Cropland	2-10	32.0	167.0
Improved Pasture	10-30	2.5	2110.0
Urban Drainage	15-50	16.0	334.0
Feedlot Runoff	50-500	32.0	167.0

concentrations of total phosphorus, the pollutant of primary concern to Lake Okeechobee, for the wet season (1974) were plotted versus measured drainage densities. Although only a limited number of data points are available for the lower basin, positive correlations are obtained as shown in Figure 6.3. It is reasonable to expect this result since the distance a pollutant needs to be transported to reach a drainage canal decreases as drainage density increases (see Table 6.2).

INTEGRATED ENVIRONMENTAL ANALYSIS

Storage-Treatment Concepts

Characteristics of hydrologic and nutrient cycles can be placed into the general framework of reservoir storage and control. Various hydrologic components in a river basin system are distinguished by a set of specific inflows, outflows, storages and losses which contribute to the overall response. The detention time parameter, T, defined as the ratio of storage volume to outflow runoff rate, provides a useful measure of reservoir storage and outflow, and can be used to characterize various components of the hydrologic system, i.e., soil, marsh, pasture, lake, planning unit or river.

In particular, surface and subsurface runoff volumes for a particular soil-land use pattern can be characterized according to detention time, T. Both soil moisture and surface components can be evaluated. Because shorter T values tend to be associated with higher outflows and lower storage capacity, this index provides a useful measure for managing and controlling runoff in a river basin.

Detention time also plays a key role in nutrient cycling as it relates to treatment rates for runoff on the land, in the soil, and in lakes or streams. In general, the longer the detention time, the greater the potential for nutrient uptake and/or deposition of sediments. Thus, water quality control through the system can be characterized by the length of time available for physical, biological and chemical uptake mechanisms.

Based on these concepts for runoff control, water quality control can be placed into a similar context by considering detention time as an index of treatment potential. In the traditional sense, a treatment unit is composed of an input, uptake system, and output. The treatment efficiency depends on storage capacity, uptake capacity, and flow rates.

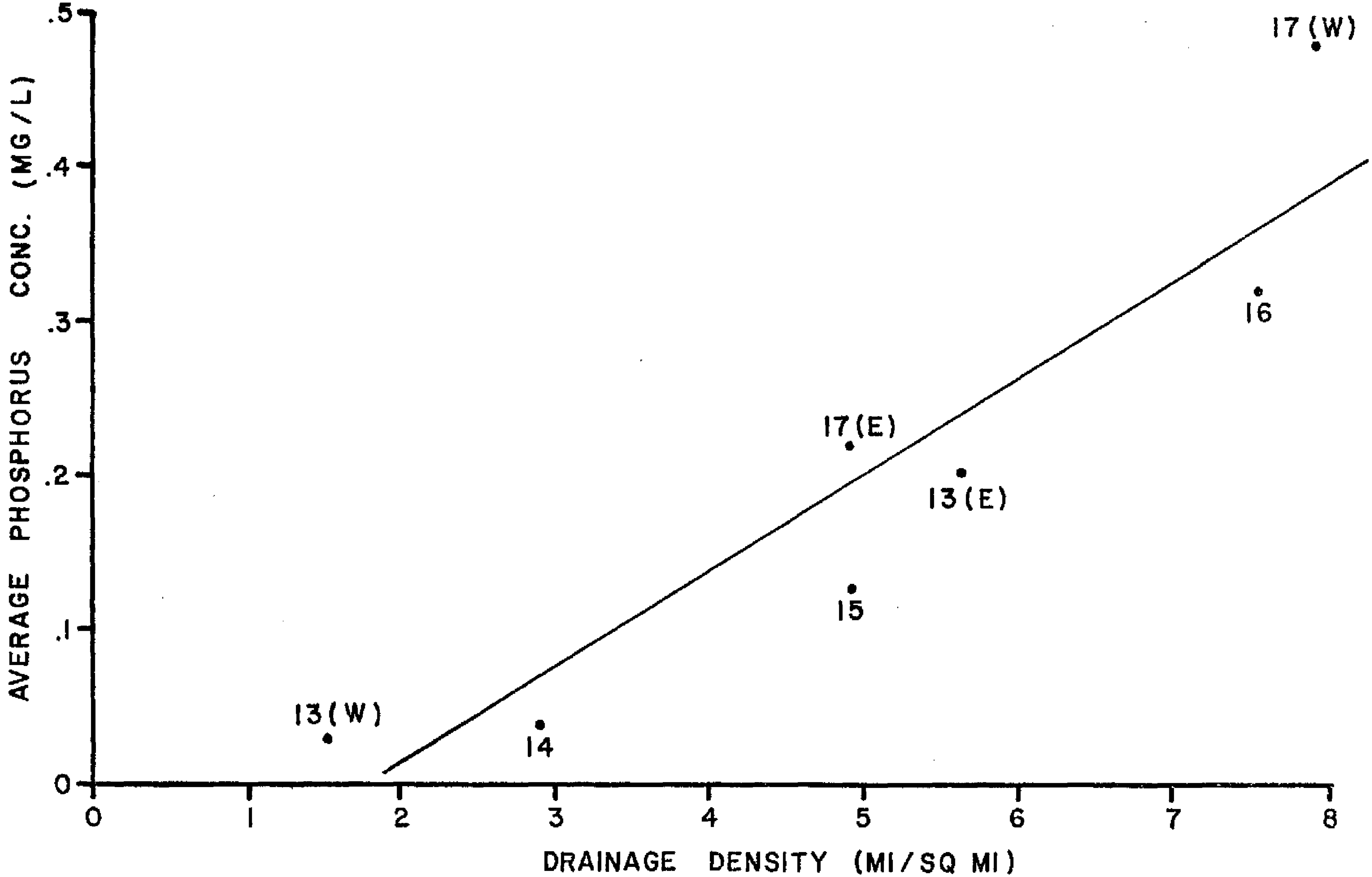

Figure 6.3. Average May-August 1974 Total Phosphorus Concentration versus Drainage Density, for Planning Units in Lower Kissimmee River Basin.

Water pollutant uptake rates can be expressed as a function of detention time, T, and the first order pollutant removal rate, k, which depends on the particular treatment unit and pollutant. Since k is generally fixed for a particular component of the system, it follows that detention time becomes an index of treatment potential. This procedure allows comparisons to be made among different storage and treatment units, e.g., marsh, lake, river.

Evaluation of C-38

Water Quantity--

A comparison of the flood hydrograph with and without the flood control project can be made by investigating the floods of 1953, 1960 and 1969. Figure 6.4 shows the monthly rainfall and daily streamflow for the Kissimmee River near Okeechobee, Florida (S65-E) for the three flood years. The 1969 flood occurred five years after the control works had begun operation and the other floods represent the response of the unchannelized river floodplain. Rainfall patterns are similar for the three floods with 1953 recording the highest rainfall amount. The 1953 and 1960 flood hydrographs are similar in all categories except for the actual shape of the curve. The recession for the 1953 event was slightly longer. The 1969 hydrograph is markedly different from the others and is characteristic of a developed drainage system, i.e., a higher peak flow and a shorter lag time between rainfall and response. Recession time is reduced as is total flood time although reduction of the latter corresponds roughly to the 15 percent reduction in flood volume. Note the secondary flood peaks which are characteristic of a channelized system. In addition, the time of travel through the system under flood conditions has been significantly reduced due to the altered channel characteristics and reduction in total river length.

The model HLAND was verified for the Kissimmee River Basin using present land use configurations and a series of daily rainfall patterns over the basin. HLAND calculates the contribution of total runoff to the river, which is then routed down the river to yield the predicted outflow hydrograph on a daily basis.

A series of calibration years, 1965-1970, was selected based on the availability of data and the fact that this sequence includes both drought and extreme flood conditions, which provides a good test of the accuracy of the model. A comparison of measured and predicted streamflows is depicted in Figure 6.5 at the gaging station near Okeechobee (S65-E). It can be seen that the model provides a generally accurate representation of the basin response

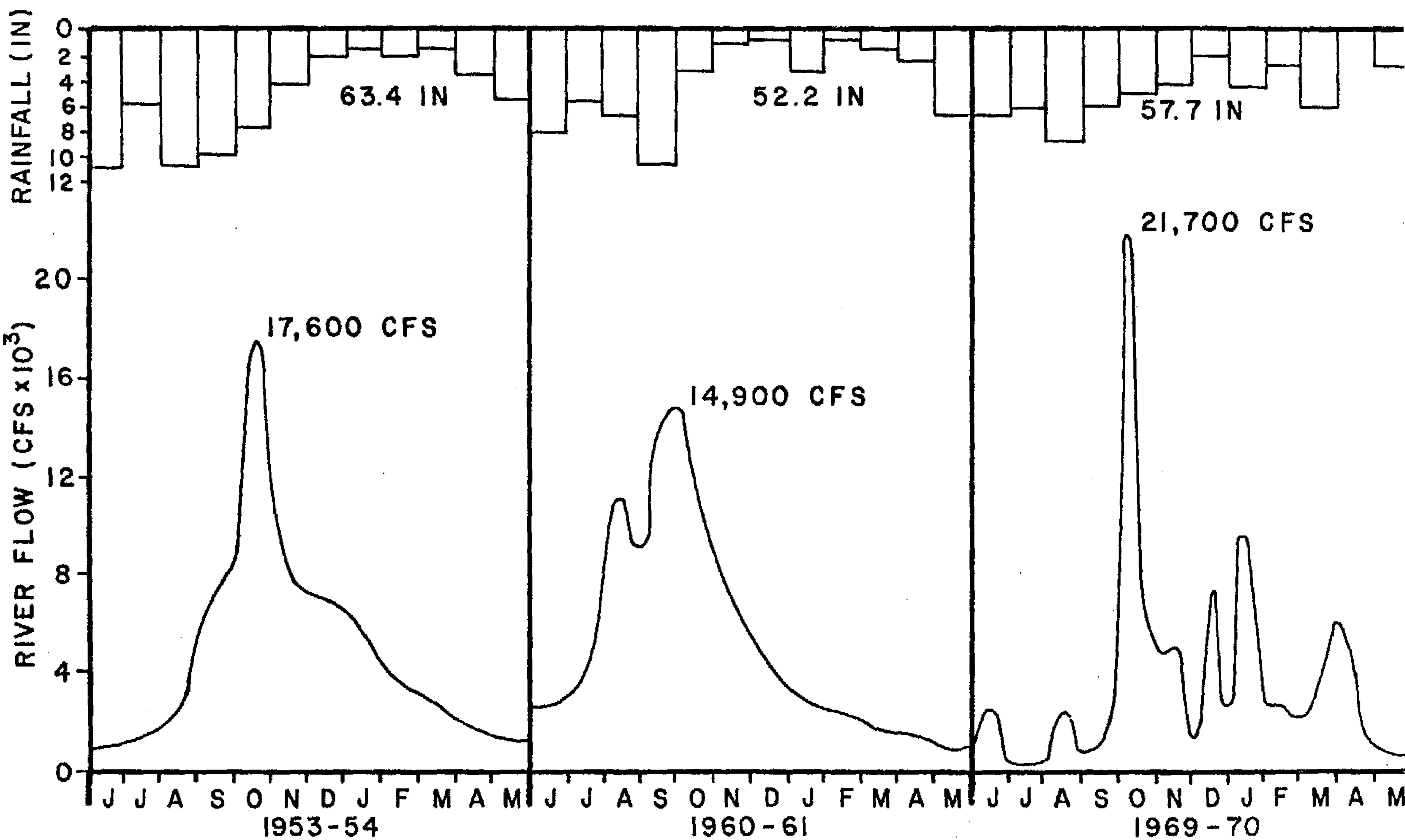

Figure 6.4. Monthly Rainfall and Daily Streamflow for Kissimmee River near Okeechobee, Florida, for Three Flood Years.

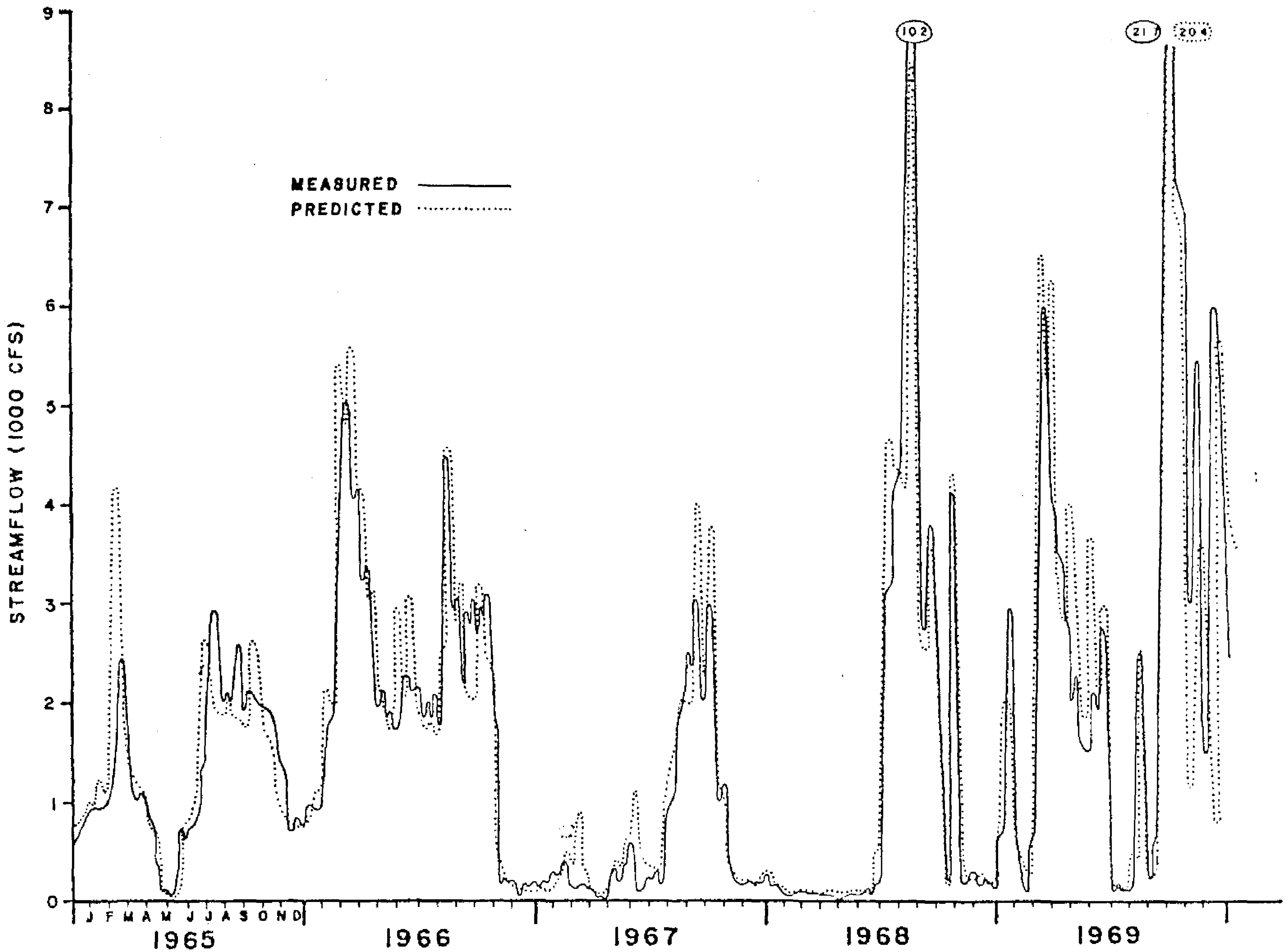

Figure 6.5. Comparison of Measured and Predicted Total Kissimmee River Basin Streamflow at S65-E.

during conditions of floods (1969-1970), droughts (1965-1967), and average flows (1968).

Based upon runs of HLAND and a detailed analysis of lower basin travel times, the basin response seems to be much more sensitive to the land drainage characteristics than to the condition of the narrow river flood plain. Travel times were slower under the 1958 regime because upland marsh and slough detention provided additional storage capacity during the wet season and because much more runoff was in the form of subsurface flows. The present regime induces excess water into drainage canals at a faster rate, and thus yields increasing percentages of surface runoff compared to subsurface flow as shown in Figure 6.2.

These effects are summarized in Table 6.3 in which the effects of land use change on lower basin's travel times are shown. The dominant effect appears to be upland drainage within the planning units rather than the construction of C-38. In addition, drainage of approximately 80 percent of the lower basin could probably have been achieved without construction of C-38 according to an analysis of flood stages and elevation contours.

The analysis procedures have thus revealed several interesting characteristics about the hydrologic response in the Kissimmee River Basin. These are listed below:

1) The basin has a marked wet season between the months of June and October associated with the majority of rainfall and streamflow volumes in the river.

2) Remaining months of the year are dominated by very low flows due primarily to lack of rainfall and flat topography.

3) The 1972 land use regime along with the channelized river produces higher maximum and lower minimum flows for typical flood events compared to the 1958 regime.

4) The increased hydrologic response to the basin is due primarily to upland drainage activities rather than the C-38 channelization itself; upland drainage contributes more surface runoff volume and at a faster rate than before, thus creating an increased hydrologic response overall. Regulation of flows by upper and lower basin structures has also altered the hydrologic response of the basin.

5) Planning units dominated by drainage canals tend to produce more surface runoff than planning units in a more natural state, while subsurface flows are less under drained conditions.

Table 6.3. Travel Time Computations for Lower Basin, Planning Units 13-17, Plus Kissimmee River.

	1958 Land Use		1972 Land Use
Fraction of Total Planning Unit Runoff Appearing as Surface Runoff[a]	0.137		0.477
Average Direct Runoff Travel Time[b], days	6.1		4.1
Average Sub-surface Travel Time[c], days	47.7		33.7
Weighted Average Travel Time, days	42.0		19.6
Kissimmee River Travel Time, days	9.0[d]		14.0[e]
Total Travel Time, days	51.0		33.6
Difference, days		17	
Difference due to Upland Land Use Changes, days		22	
Difference due to Channelization, days		-5	

[a]From HLAND simulation using 1967-1969 rainfalls, Table 4.24.

[b]From surface detention constants and computed travel times Table 4.7, weighted by land use and soil type, Table 4.13.

[c]From Table 4.28 based on calibrated base flow rates and drainage density changes.

[d]From Table 5.7.

[e]Calculated from accurate cross section information for average annual flow rate, Table 5.3.

Water Quality--

Water quality data for the Kissimmee Basin have been collected in the river for the past several years, and in tributary inflows for the period September 1973 to October 1974. The original monitoring program on the river was begun by the U. S. Geological Survey, and has been continued and expanded by the Flood Control District (FCD).

While a large number of water quality parameters have been analyzed under the monitoring system, the levels of nitrogen and phosphorus are of most direct concern because of their association with the eutrophication process. An analysis of available water quality data from the FCD indicates that total and inorganic phosphorus levels are the most responsive parameters, while no significant variation is observed for nitrogen levels. This can be explained by the assumption that phosphorus tends to be adsorbed by soil particles and is available for surface transport via runoff and erosion. On the other hand, most forms of nitrogen are soluble and can be leached from the soil or returned to the atmosphere, thus reducing any relationship with surface transport.

Samples were taken monthly for one year for the lower river and on a quarterly basis in the upper lakes. A plot of total P concentration as a function of sampling location for the lakes and river segments depicts a very interesting pattern (Figure 6.6). Wet season average concentrations are quite high in Lake Tohopekaliga, but decline rapidly before reaching Lake Cypress. Concentrations are further reduced to Lake Kissimmee at which point the levels indicate fairly good water quality. From the outlet of Lake Kissimmee to S65-C the levels remain fairly low but increase rapidly between that point and S65-E.

The high levels of total P in Lake Tohopekaliga are primarily due to nutrient loading from treated sewage. It appears that uptake mechanisms are presently cleansing the water to a high degree before it leaves Lake Tohopekaliga.

The water entering the Kissimmee River from S65 is of fairly good quality, but concentrations increase rapidly south of S65-C. The obvious question as to the cause of these increased concentrations can be answered by considering nutrient levels of water which enters laterally via tributary flow to the river.

Inflow tributaries, which were sampled on a monthly basis, did not yield any significant variation of total N from one location to the next, but total P levels showed a pronounced increase in wet season concentrations south of S65-C. Ice Cream and Pine Island Sloughs produced very low levels throughout the year

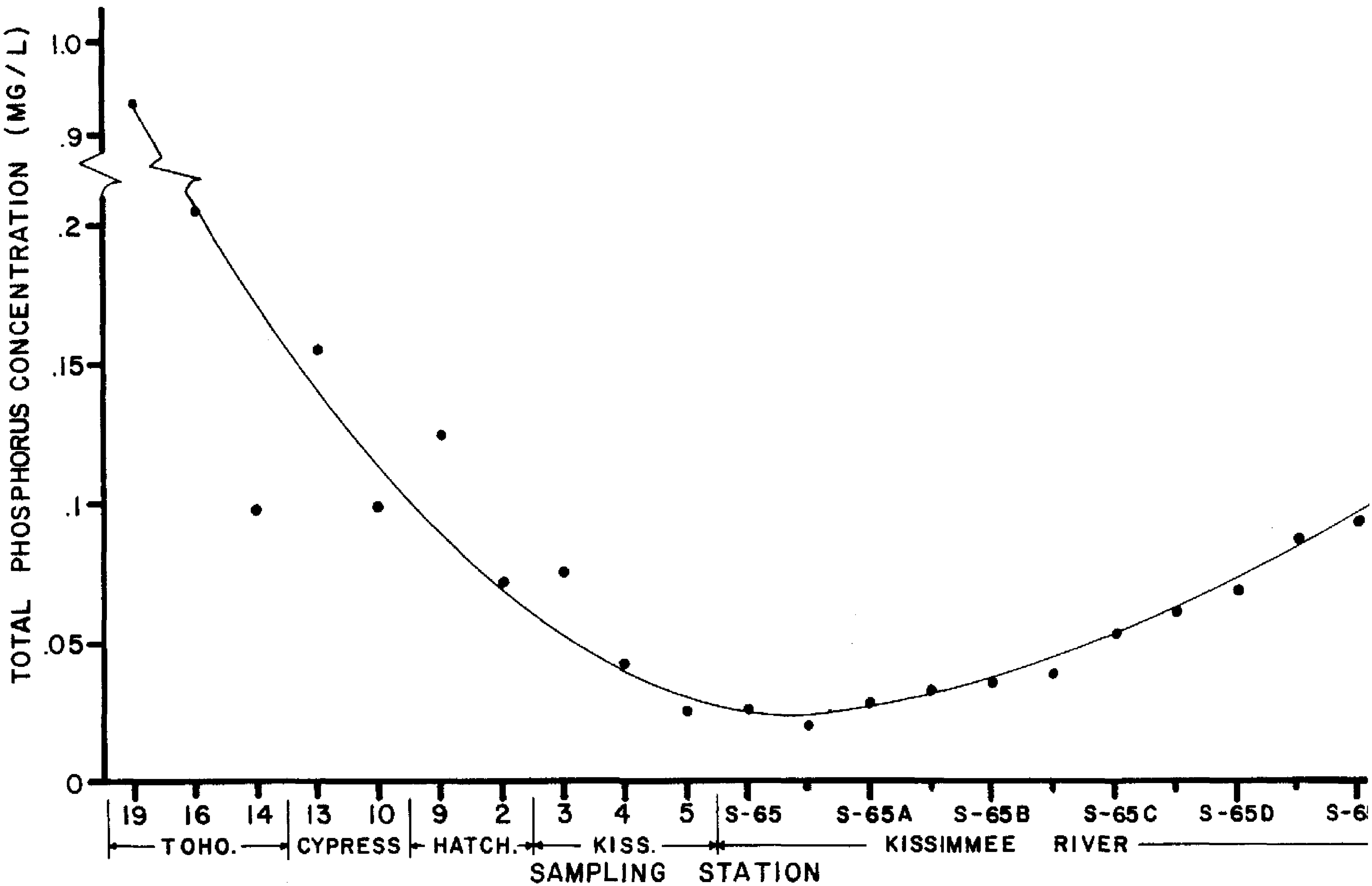

Figure 6.6. Total P Concentration as a Function of Sampling Location, Kissimmee River Basin

(Figure 6.7), while Oak Creek, Chandler Slough, Yates Marsh, and the Maple River yielded progressively higher concentrations (Figure 6.8). Blanket Bay in pool A yielded high values, but inflows from Lake Kissimmee and Ice Cream Slough kept the average concentration low. It appears that the high phosphorus levels in the river are a direct result of tributary loading, especially south of S65-C.

An indication of uptake that might occur under present conditions for C-38 is shown in Figure 6.9. The dashed line was obtained by starting at Lake Kissimmee with a measured flow and concentration and solving a mass balance of measured concentrations and predicted runoff volumes (by HLAND) from downstream planning units. The result indicates potential for approximately 50 percent uptake under present average conditions. Assuming longer flood travel times under the natural floodplain conditions, prior to construction of C-38, uptake potential during those conditions may have been greater, although the opposite is true under average flow conditions. However, it is unlikely for either case that the river and floodplain provide sufficient nutrient uptake to alleviate water quality problems caused by runoff from adjacent planning units. The main reason for this is the fact that the more rapidly flowing river (pre- or post-construction) does not provide sufficient detention times for physical, biological and chemical mechanisms to operate. This is especially true for the critical section below S65-C, where increased surface runoff volumes would tend to reduce the value of T if natural conditions still existed.

As mentioned, nutrient uptake requires relatively long detention times. This implies that the greatest potential would occur in lakes and marsh areas scattered throughout the basin. If one could route agricultural runoff, enriched with nutrients, through these areas prior to entry into the river, then the observed trend in Figure 6.6 could possibly be averted. The next section examines the lakes in the upper part of the basin.

Lakes

Water Quantity--

Hydrologic analyses indicate that the average detention time of water in Lake Toho is about six months during the dry season of January to June and about four months during the wet season of July to October. These values are influenced by the extent of flood or drought conditions. For the flood of 1960, detention time varied from about 1.0 to 3.0 months during the wet season and up to 7.0 months for the following dry season. During the drawdown experiment and drought conditions of 1971, the detention time exceeded 1.0 year since outflows from the lake were zero for most of the months during

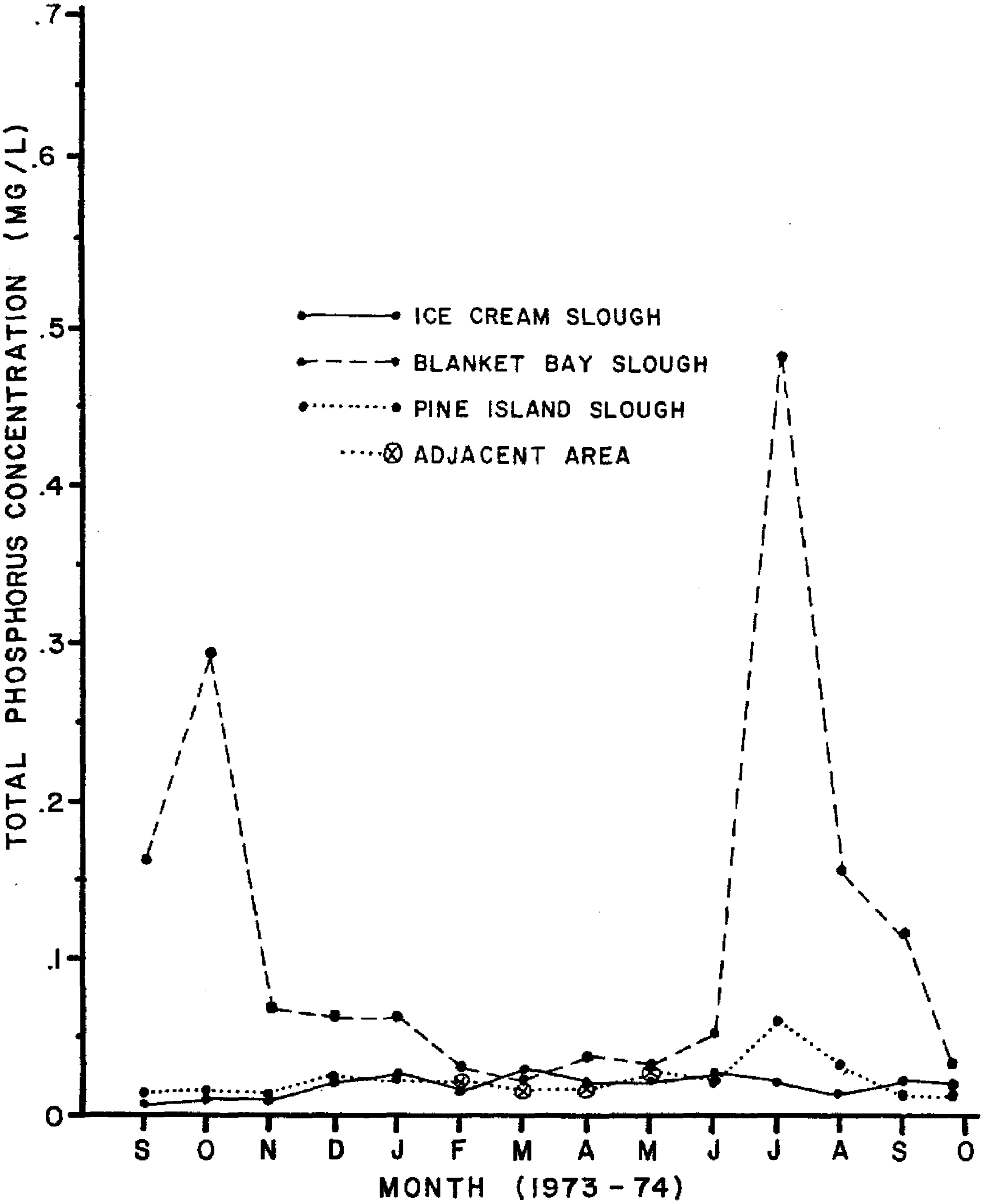

Figure 6.7. Total P Concentration in Tributary Inflows, Planning Units 13 and 14 of the Kissimmee River Basin.

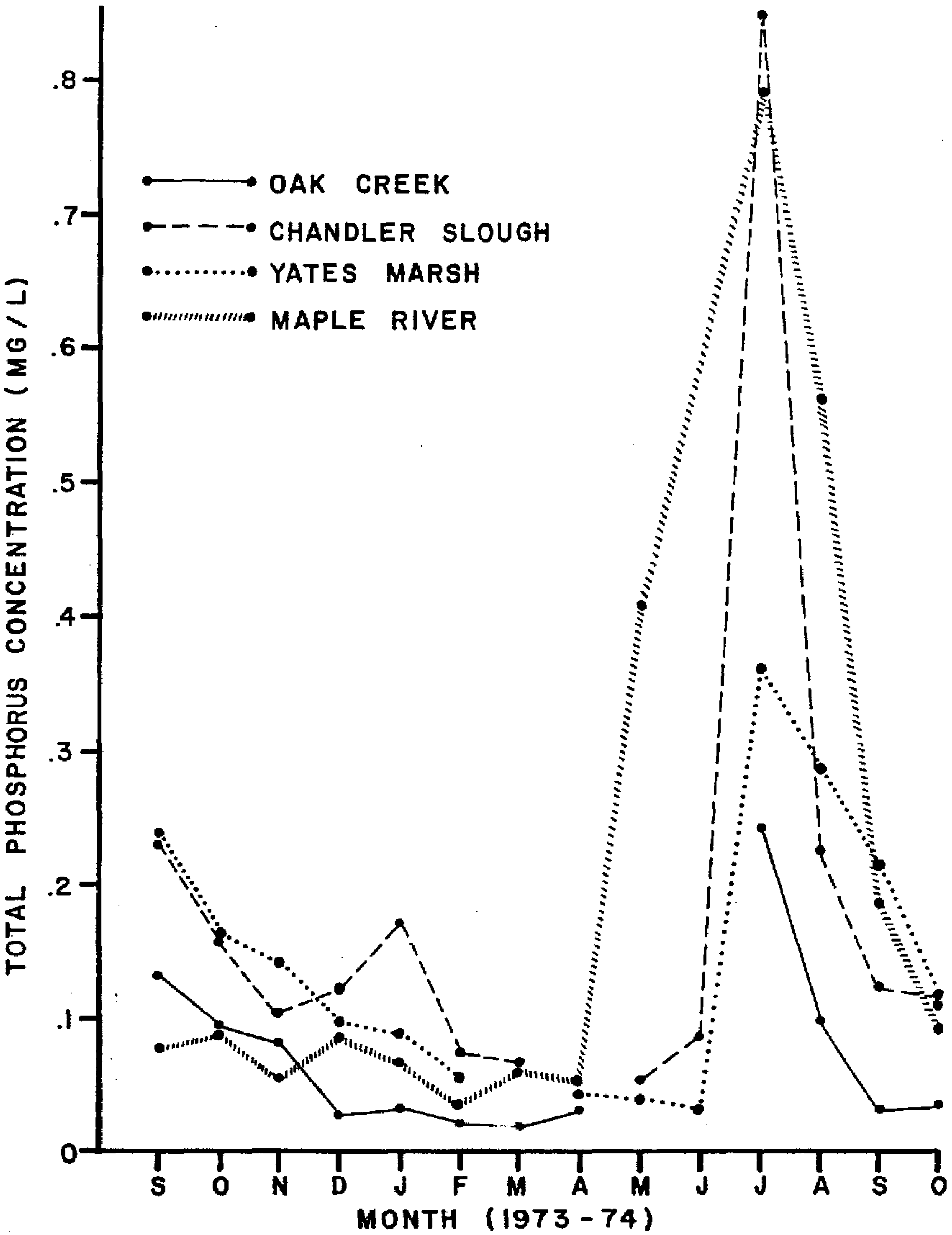

Figure 6.8. Total P Concentrations in Tributary Inflows, Planning Units 15, 16, and 17 of the Kissimmee River Basin.

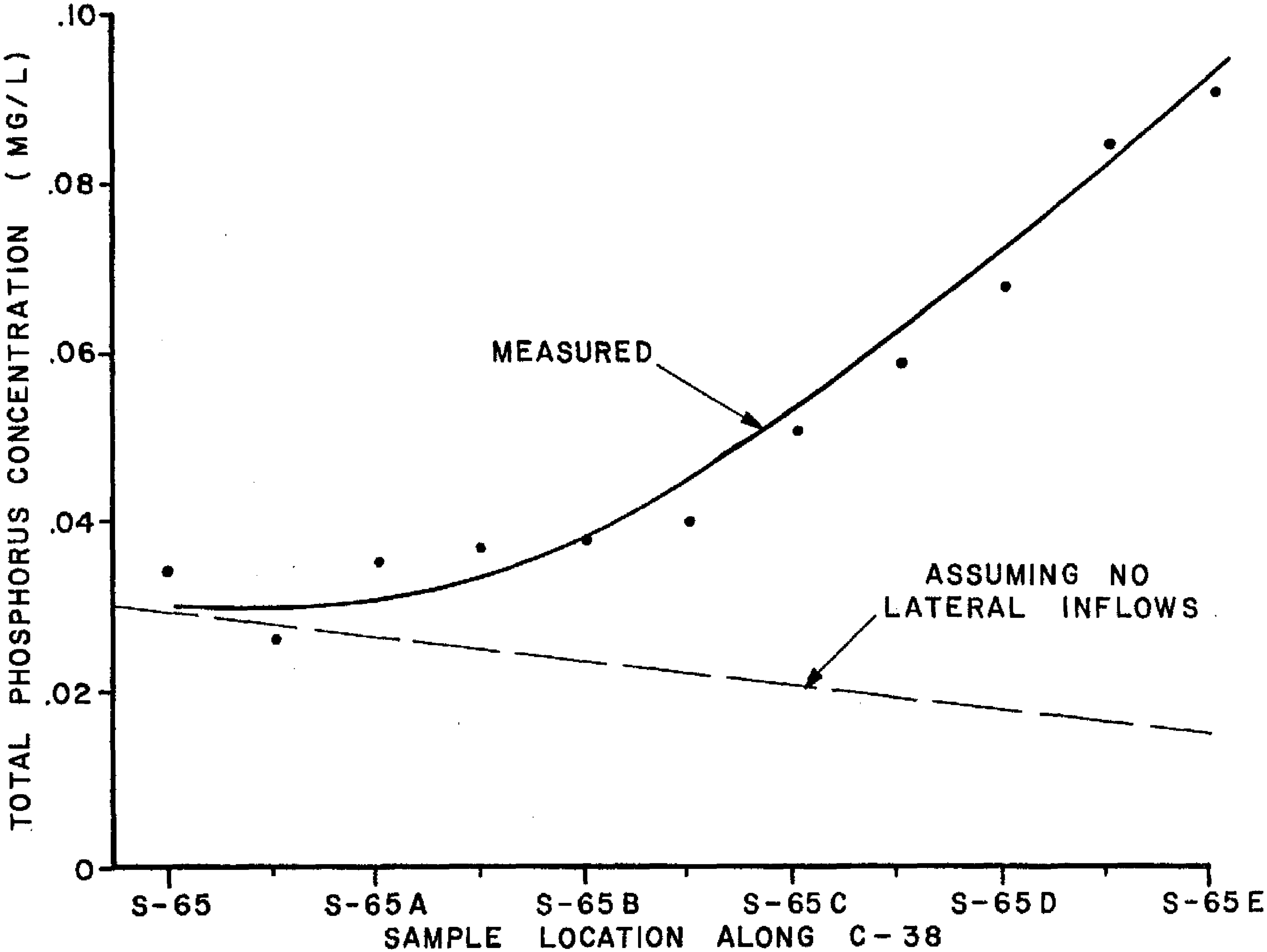

Figure 6.9. Estimated Total Phosphorus Concentrations Along C-38 With and Without Lateral Inflows.

the experiment. Based on the above hydrologic analysis, the average detention time in the lake is assumed to be about 5.0 months, which implies that the lake turns over 2.4 times per year, on the average.

Figure 6.10 depicts the zones of fluctuation under natural and regulated conditions for Lake Toho. The lake naturally ranged from 51.5 feet to 55.5 feet on the average during the year. The present interim regulation schedule allows a range from 52 feet to 55 feet, increasing the area of marsh fringes now inundated all year. These areas not only are vital and productive for fish and wildlife, but also represent vegetated buffer zones for urban and agricultural runoff waters. These changes in detention time due to the flood control regulation are important from a water quality standpoint.

Water Quality--

Water quality monitoring efforts by the Flood Control District during the past two years in the upper chain of lakes have revealed an interesting response (Figure 6.11). The distribution of total phosphorus concentration declines significantly from the northern part of Lake Toho to the outflow from the lake, and then a much slower decline occurs through Lakes Cypress, Hatchineha, and Kissimmee. These data suggest that uptake rates in Lake Toho are reducing the total P concentrations by approximately 85 percent by the time the water leaves the lake, depending on the season.

The concept of detention time T can be used to explain the observed decline in concentration. The reduction can be expressed as a function of detention time, T, and pollutant removal coefficient, k. T is assumed to vary from 4.0 to 6.0 months and k ranges from 0.02 day^{-1} for the wet season to 0.01 day^{-1} for the dry season. Compared to 0.1 day^{-1} reported for rivers, these k values are an order of magnitude less, but with the long detention time in the lake, it is possible to obtain about 85 percent pollutant control.

From a water quality standpoint, nutrient uptake depends on both the first-order decay coefficient and the detention time. Decay coefficients tend to increase with temperature, which affects biological and chemical activity. Detention times are shorter in the wet season when decay coefficients are at their peak, and longer in the dry season when uptake rates are at a minimum. Thus, the hydroperiod variation in the lake significantly influences the potential for nutrient uptake, especially in the wet season. These relationships imply that regulation schedules might be altered in order to retain water longer during the wet season, rather than drawing the lake down as rapidly as possible. These changes should also consider the needs of flood storage, so that a balance can be secured between objectives of water quality and flood control.

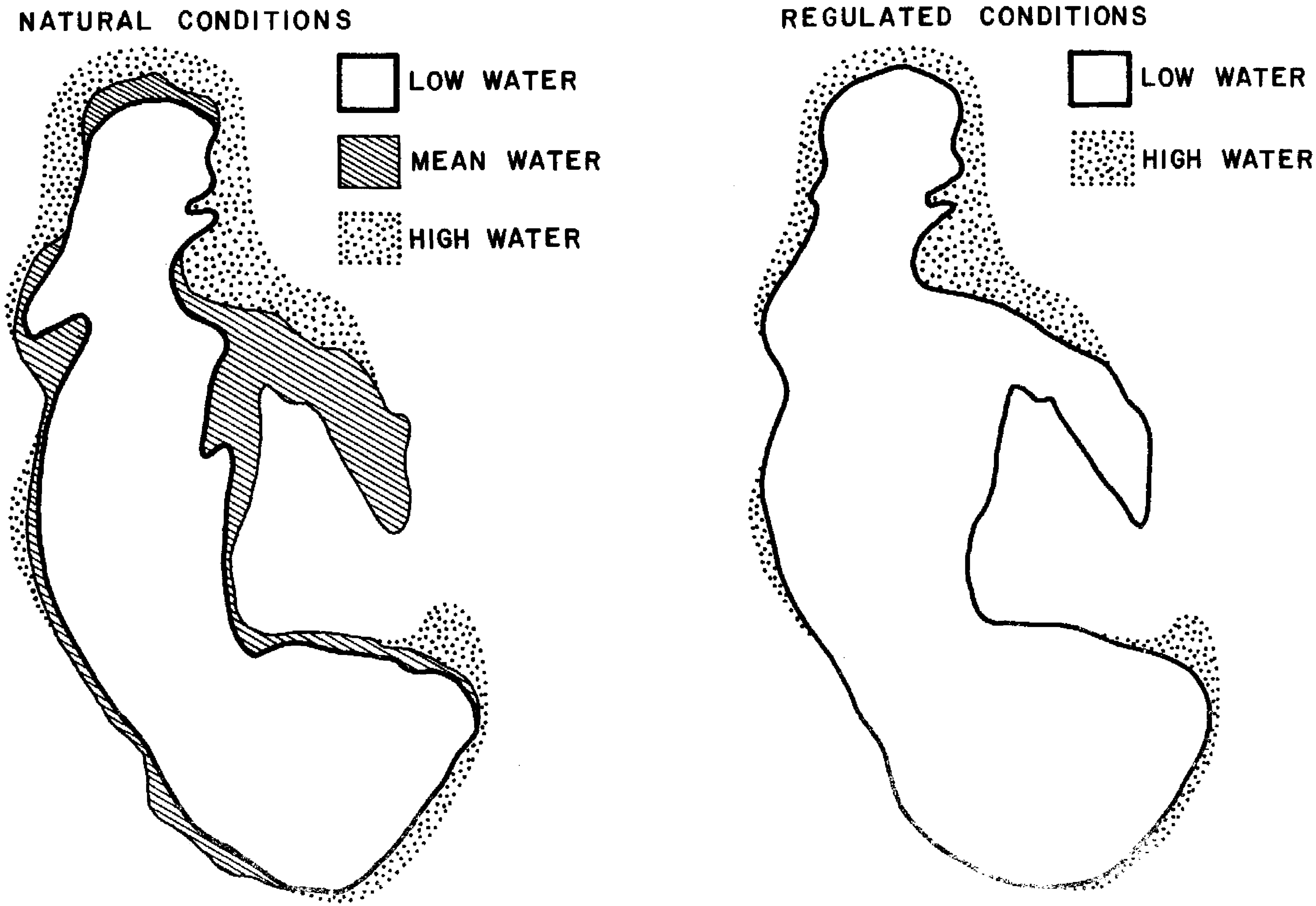

Figure 6.10. Zones of Natural and Regulated (Original Corps of Engineers Plan) Fluctuations in Lake Tohopekaliga. Present fluctuations are somewhat greater under interim operating schedule.

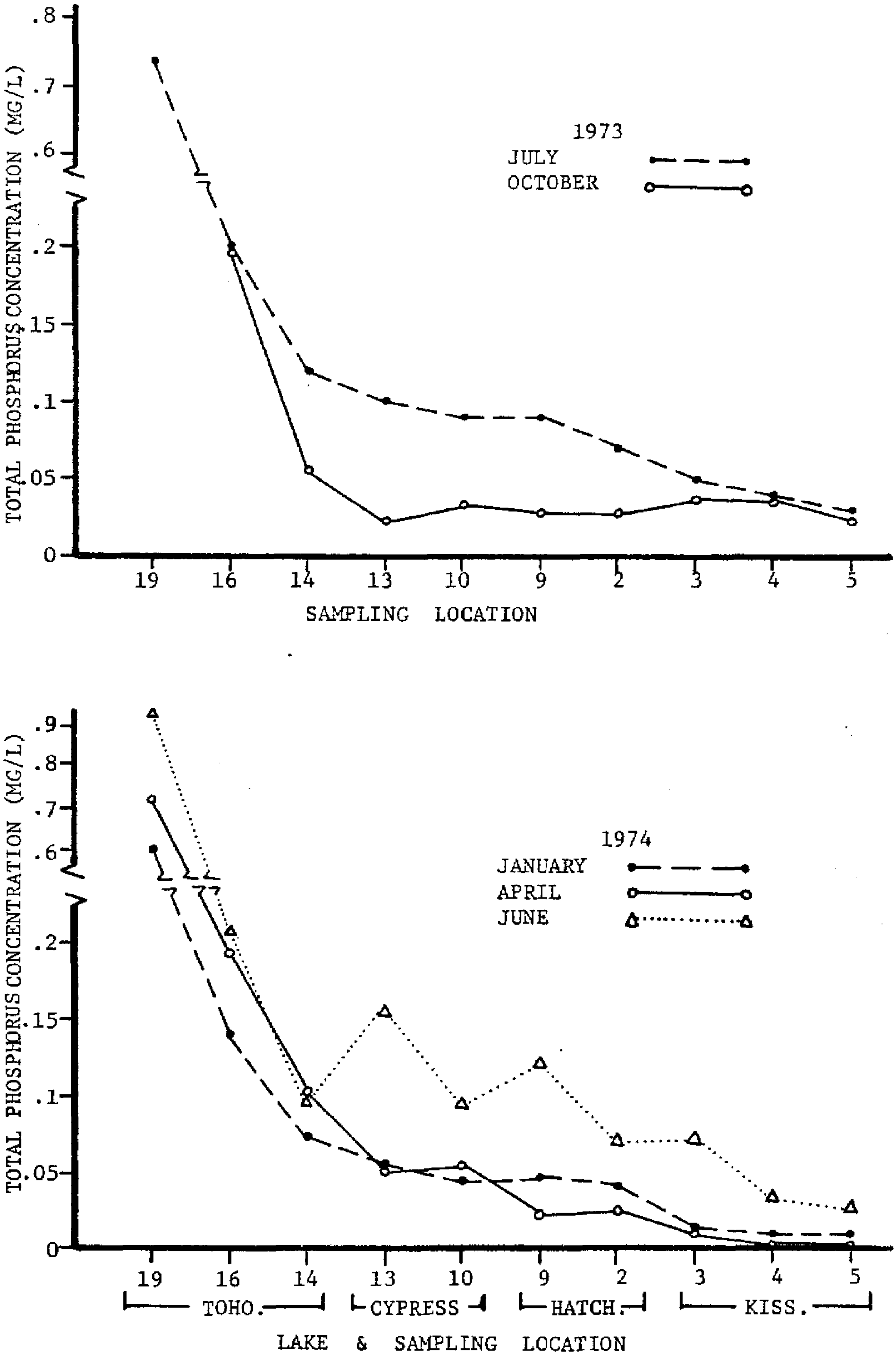

Figure 6.11. Water Quality (Total P) in the Upper Chain of Lakes.

Lake Toho, although receiving excessive loads of nutrients at the present time, is able to process a large percentage by biological or physical uptake. Water quality leaving the lake is much improved over water entering the northern side of the lakes, and other lakes in the chain further reduce total phosphorus concentrations to an acceptable level prior to entry into the Kissimmee River.

This situation is subject to change if future developments around the lake should increase the loading and runoff rates such that detention times are reduced. If, for example, average wet season detention times were reduced from 4.0 to 2.0 months, then uptake would drop from 89 percent to 67 percent. Such a reduction would have a large impact on water quality passing through the chain of lakes.

If the viability and habitat of Lake Toho are to be maintained, some form of nutrient diversion could also be considered. Advanced waste treatment and spray irrigation of waste water are two possible alternatives.

Swamps and Marshes

Water Quantity--

Planning Unit 16, specifically an area known as Chandler Slough, is the portion of the basin selected for analysis. The FCD used a 970 acre marsh in this area for their water quality studies and there are sloughs extending northward from the 970 acre area which might be classified as control or marsh areas. The total of the sloughs and the 970 acre area provided a large marsh area (4,441 acres) which may be used for comparative purposes. Figure 6.1 shows the approximate location and the shape of the two marshes, along with the type of agricultural drainage they receive. A simulation model called MARSH was used in this analysis.

Using the land use projections, it is possible to relate the size of the marsh to the detention time experienced by a given percentage of total annual runoff for various study years. Figure 6.12 illustrates the effects of the 4,441 and 970 acre marshes on the detention time for the years 1958, 1972, and 2020. The larger marsh provides a greatly increased detention time. As an example note that under present (1972) land use conditions, the 970 acre marsh can detain only approximately 20 percent of the runoff for more than two days, while the 4,441 acre marsh detains about 80 percent for the same time period.

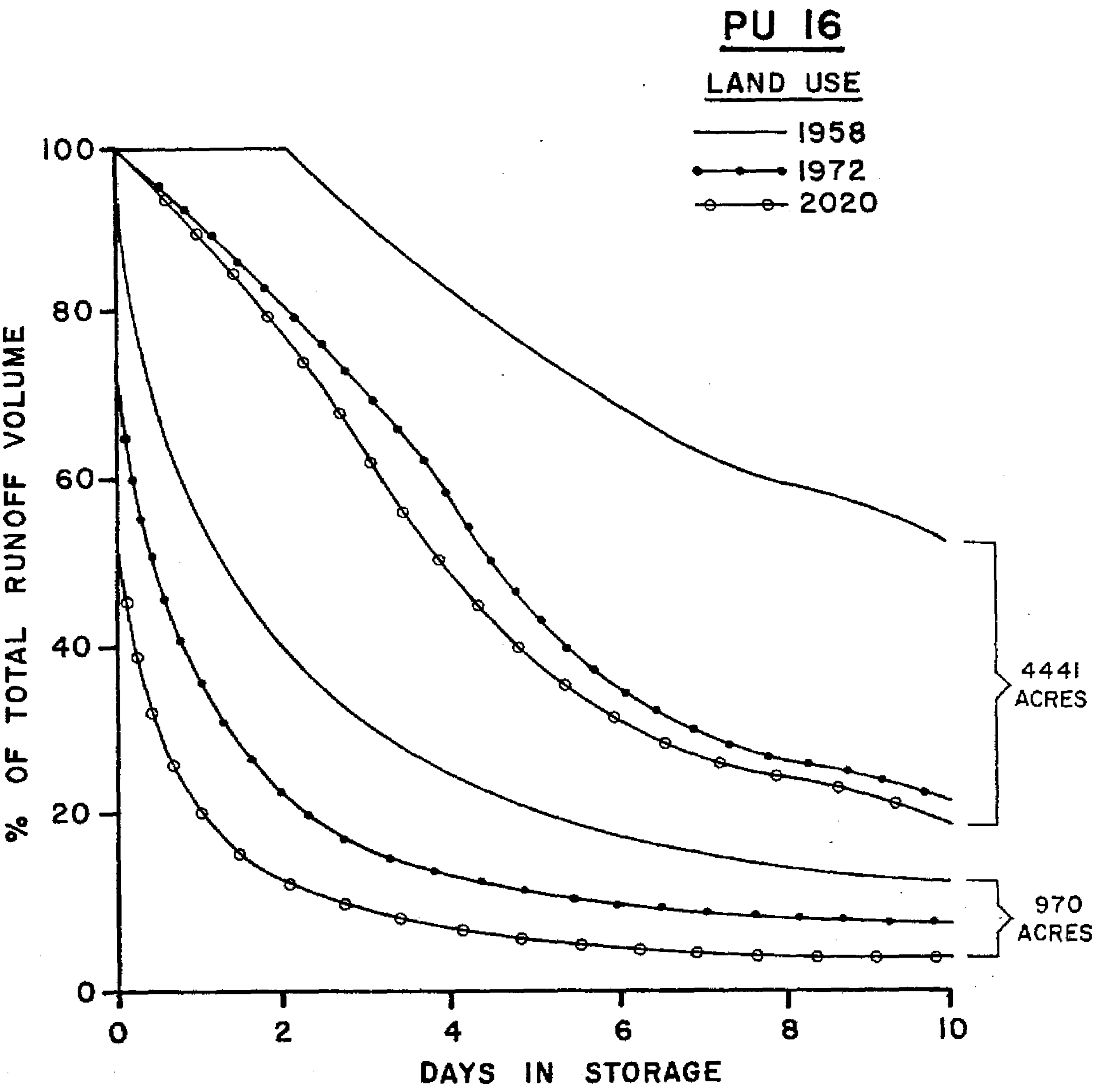

Figure 6.12. Effect of Size of Marsh and Land Use on Residence Time of Water in 970 and 4,441 Acre Marshes.

In recent years, three major floods, November 1954, September 1960 and October 1969, have occurred. Figure 6.13 shows the runoff from the October 1969 flood through the 4,441 acre marsh under the 1958 land use and 2020 land use conditions. Upstream development causes a much higher peak inflow rate to the marsh. Also, the 2020 land use conditions create, in essence, a pure translation of the hydrograph, with almost zero attenuation and a lag period of less than 0.5 days. At this point it would seem that the marsh has exceeded its carrying capacity and is no longer effective for flood protection.

These results can be compared to a widely used procedure to estimate the mean annual floods in river basins throughout the United States (Barnes and Golden, 1966). They found that lakes and swamps attenuate the estimated mean annual flood in a river basin in proportion to the percentage of the total basin in lakes and swamps. Thus, their recommended procedure is to use a flood attenuation factor taken from the curve shown in Figure 6.14.

For comparative purposes the October 1969 event using the 1972 land use and the 4,441 acres of marsh was analyzed by varying the drainage to control area ratio and calculating the amount of attenuation obtained. Although the October 1969 event is not a mean annual flood it supplies sufficient conditions for comparison with the Barnes and Golden analysis. By converting the drainage-control area ratio into the form used by Barnes and Golden it may be seen that although the curves do not represent an exact fit, the comparable shape of the curves indicates agreement between these independent analyses. Note that both curves indicate a significant decrease in the flood attenuation when the percentage of an area in lakes and swamps is less than 15.

Water Quality--

Using the same nutrient uptake analysis as before, the effect on water quality of varying the amount of marsh available in Planning Unit 16 may be evaluated. Figure 6.15 shows that the percent nutrient removal is about 20 percent for the 970 acre marsh, 70 percent for the 4,441 acre marsh, and 90 percent for a 12,000 acre marsh.

One of the major problems involved with using marsh areas as storage-treatment units is the way in which alterations in the natural cycle of detention time vs. season or months occur. Figure 6.16 shows the detention time vs. season for the natural and modified conditions from January 1967 through June 1970. In the natural state portions of the water had very large detention times, indicating low flow, and a dying back or decreased growth rate in the marsh. By utilizing the marsh as a storage-treatment unit, these

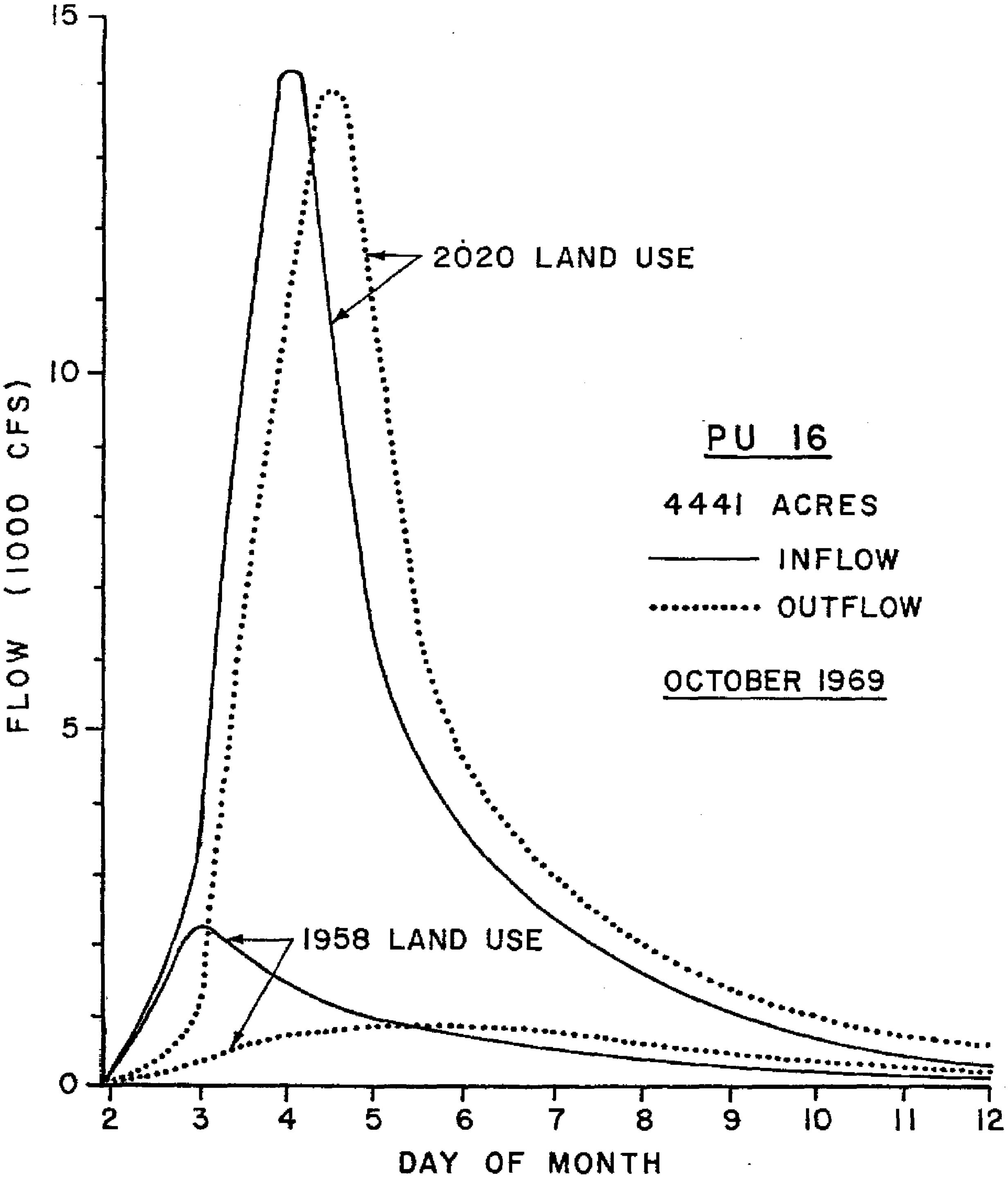

Figure 6.13. Flood Attenuation Through Marsh for 1958 and 2020 Conditions.

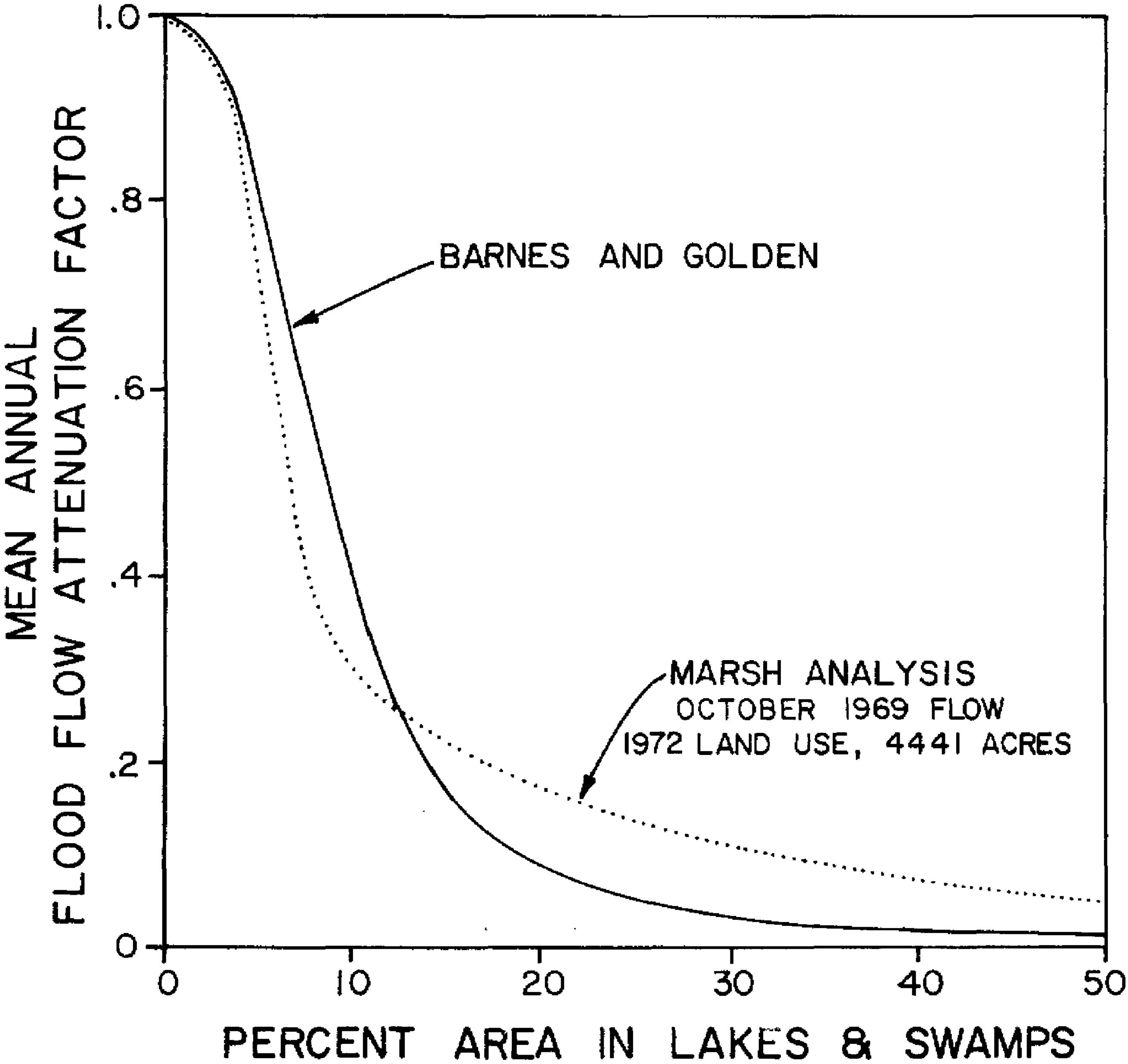

Figure 6.14. Comparison with Barnes and Golden Analysis for the Attenuation of Mean Annual Flood.

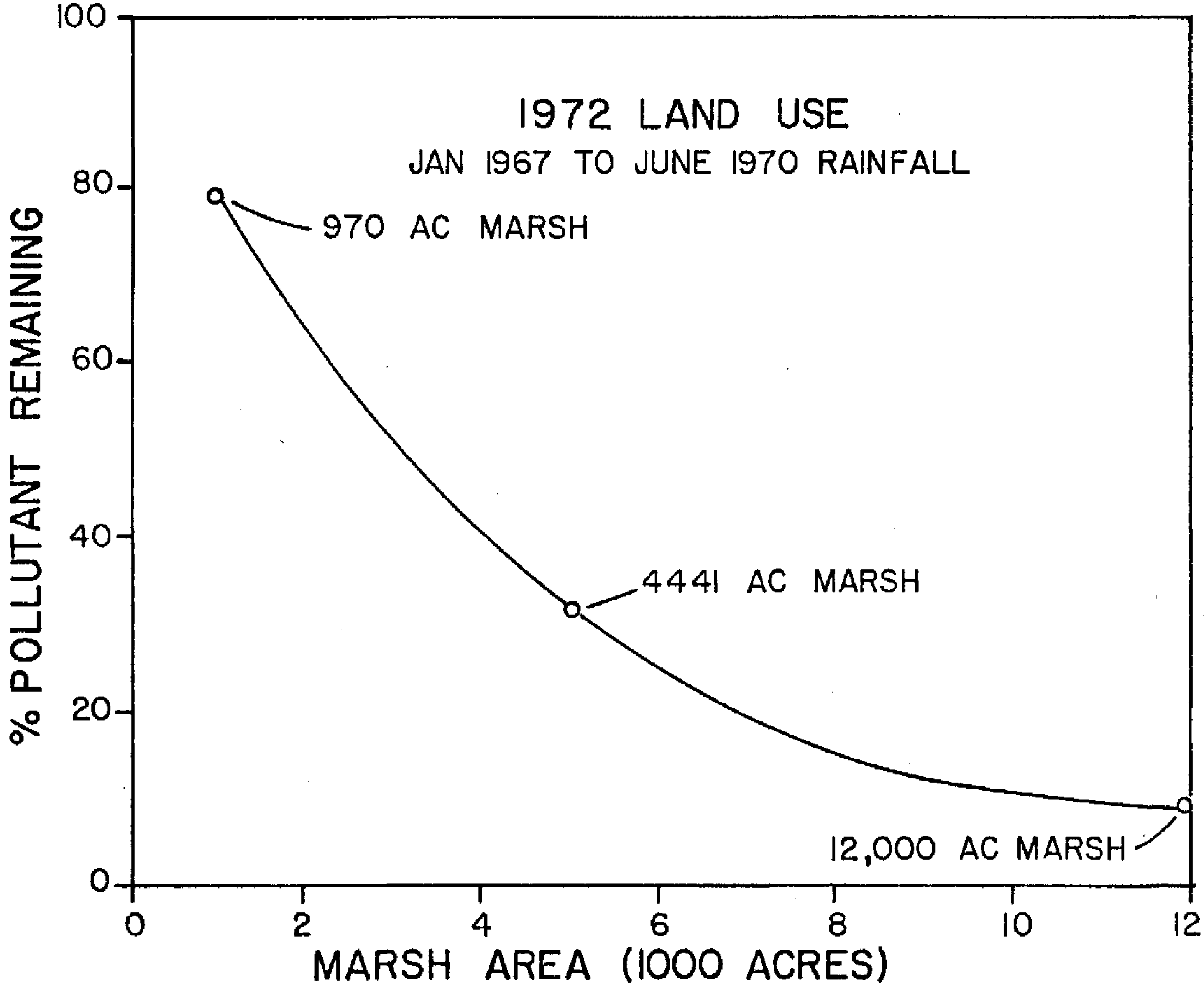

Figure 6.15. Percentage Treatment for Various Marsh Areas with 100,600 Acre Drainage Area in Planning Unit 16.

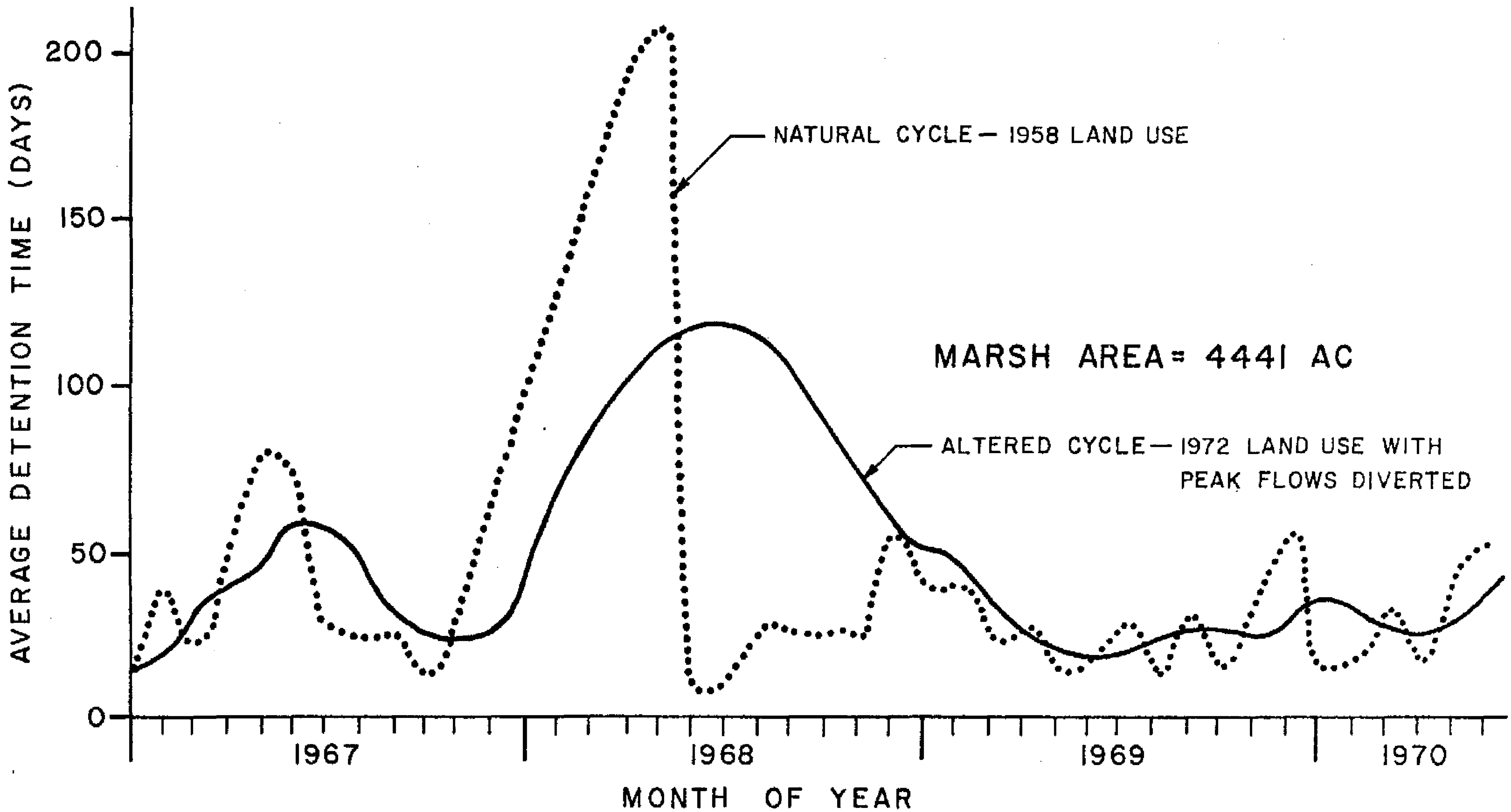

Figure 6.16. Comparative Residence Times in Marsh for Natural and Modified Systems.

natural periods will be altered. At present, data are not available to examine the effect of reducing peak flows through the marsh which perform a flushing action. This study makes no inferences as to how the buildup of material in the marsh areas might be handled; however this problem must be confronted if the natural cycle is altered.

Summary--

The marsh analysis established four major points:

1. The size of marsh area and amount of inflow runoff determine the transition of the outflow hydrograph, i.e., translation and attenuation.

2. Retaining approximately 15 percent of the land area as hydrologic control units provides significant flood attenuation.

3. The percent of untreated runoff increases with increasing drainage area/treatment area ratio. At least 10 percent of land as natural treatment units is needed to obtain a high (90 percent) degree of nutrient control.

4. Detention time is a good indicator of nutrient uptake and flood attenuation rates in the marsh.

MANAGEMENT ALTERNATIVES

Background

Concern exists that the Kissimmee River Basin is contributing significant pollution to Lake Okeechobee. Of course, concern also exists that the integrity of the Kissimmee River Basin itself needs to be protected. No one is certain what the best course of action is due to lack of data and knowledge of how these complex systems behave. Thus, the immediate problem is to identify management alternatives and assign priorities. The concept of detention time enables one to get a first approximation of the effectiveness of control alternatives. The previous analyses indicate that longer detention times enhance greater flood control and water quality control. The report stresses repeatedly that each unit, i.e., land, lakes, rivers, swamps and marshes, acts both as a storage and treatment device. Existing land development decreases the options available for control of water quantity and quality. Thus, off-site control in downstream systems takes place. Within the Upper Kissimmee River Basin the lakes are being stressed as land drainage increases. They appear to be very effective as control devices. However, a price is paid in terms of degraded conditions within the lakes. With regard to the Lower Kissimmee River Basin, it appears that installation of land drainage facilities rather than the C-38 channelization is the major cause of degraded water quality leaving C-38. The Lower Kissimmee River flood plain comprised only 15 percent of the swamps and marshes in the total basin in 1958. Thus, changes in this regime alone could not account for the present degraded conditions. With regard to Lake Okeechobee, it appears that pollution control in planning units near the lake would be more cost-effective since the time of travel from these units to the lake is relatively short. Consequently, the first priority should be given to devising on-site water management programs which are essential to any long-term management program. Modified operating policies in the lakes and C-38 would also be helpful but are of less significance.

On-Site Control

If some marsh and swamp area is available, and knowing that storing runoff in marsh areas provides quantity and quality benefits, then it is possible to discuss a management strategy which utilizes the marsh system. One possible arrangement shown in Figure 6.17 represents the marsh/agricultural conditions which currently exist in Planning Unit 16, and shows one possible means of utilizing the marsh and sand pond areas. Hydrologically, this system lends itself well to the purpose, since in many instances the marshes and ponds have been connected for drainage purposes, thereby requiring only the establishment of control structures at the inflow and outflow points of the area. These structures could be designed to detain small storms for a considerable time, while allowing larger storms to pass through. This type of system would reduce the possibility of flood damages. In addition, if permanent structures (such as concrete V-notch weirs) were installed it would greatly reduce the problem of inspection.

The problems encountered with this system must also be given consideration: First, the areas referred to as marsh and swamp will, in essence, be control units, and will be managed in the same manner as an oxidation pond or other treatment unit, with inflow, outflow and storage regulated on a continuing basis. Second, the effect on a system in which the natural cycle is altered is, at present, unknown, thus making the useful life of the system open to question. Third, during very wet periods the unit may not provide adequate quality or quantity control. Lastly, some

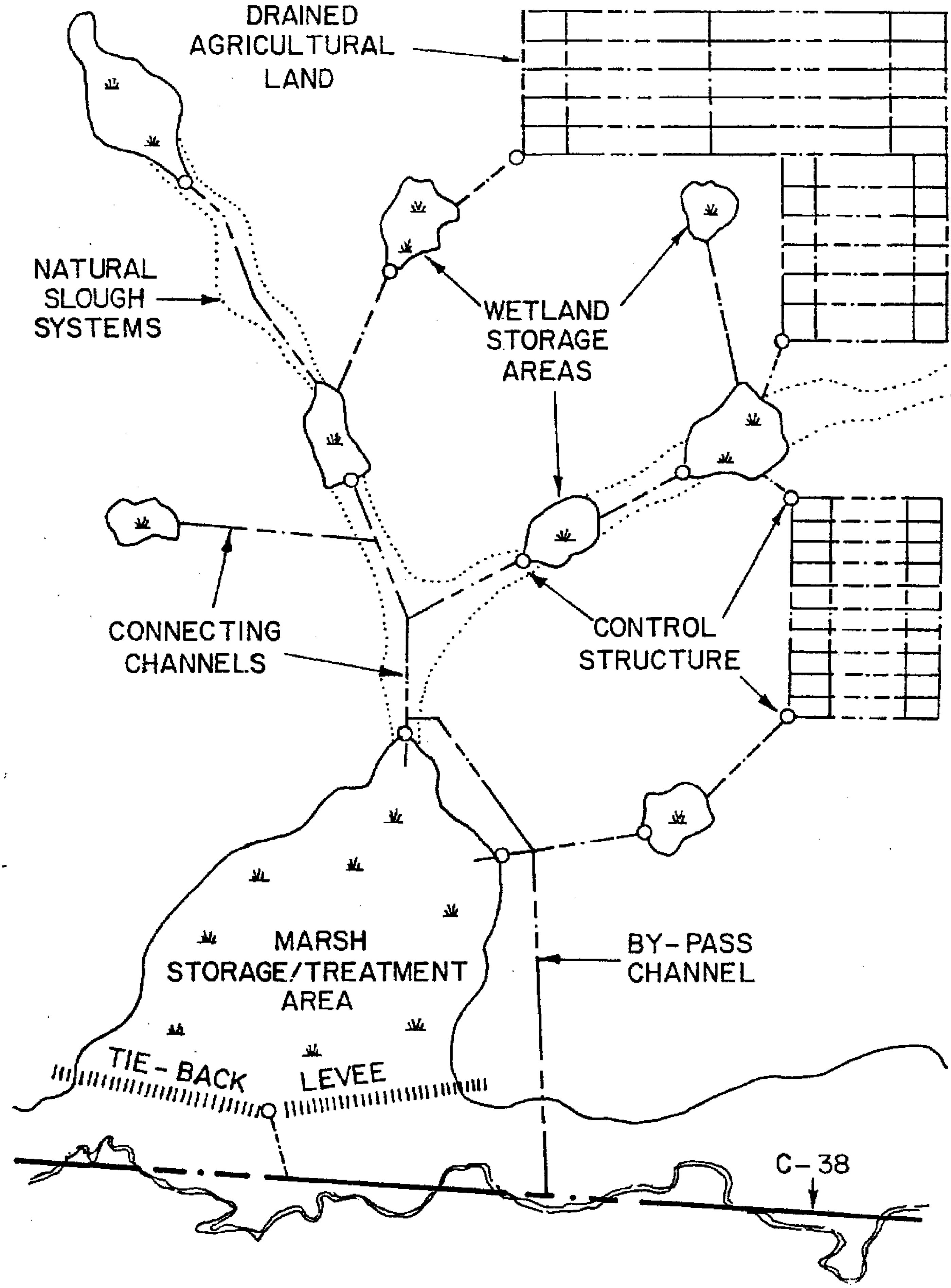

Figure 6.17. Possible Storage/Treatment Design for the Chandler Slough Area.

kind of harvesting procedure is needed to maintain the viability of these units. With these facts in mind, it should be recognized that the marsh/treatment system is not an elixir, but only a possible control which might be implemented in conjunction with other water management practices.

During the course of this study several trips were made through the basin to consult with persons familiar with agriculture in the basin and ascertain their views on which practices they consider economically achievable and effective for the basin. When presented with the alternative shown in Figure 6.17 most farmers indicated that they would be receptive in the event some type of financial assistance might be available, or in several cases people indicated a willingness to expend personal funds providing there was some assurance that this would provide the type of control needed to meet the requirements of the state inspection agencies. This does not seem an unreasonable request on the part of agriculture; however, the control agencies have the responsibility of maintaining certain water management levels, and without the aid of long range data cannot commit themselves to acceptance of untested management policies. Some groups oppose public control of water management policies on their land. Also, many farmers feel that the effort in increasing or retaining present water quality should be pointed toward the restricted development of land now in a natural state, rather than imposing further restrictions on land already in production.

As a final point, it should be noted that many of the farmers are presently attempting to control runoff at their own expense by various means. These include spreading manure from cattle operations back onto the land, producing forage in previously unused areas around dairy farms, and detaining water on the land for irrigation purposes during the dry season.

Recommendations

Based on the results of this research it is felt that the following type of programs should be considered.

1) Implementation of policies that would require on-site detention for all types of developments for specified storms before allowing the runoff to enter the canal or lake system.

2) Enlist the aid of the Agricultural Extension Service and other agricultural agencies for the purpose of education, design, and perhaps financing of water management strategies like those presented in Figure 6.17.

3) Establish a study to evaluate the effectiveness of the marsh on water quality, and the impact on the marsh of altering the natural hydrologic cycle by using it as a control unit.

4) Continue studies directed towards determining the optimal operating policy for existing structures. Strong emphasis should continue to be given to restoration of natural hydroperiods to the extent that it is feasible.

APPENDIX A

RESULTS OF LAND USE ANALYSIS

Results of the land use analysis described in Chapter III are presented in the following tables for planning units 1-18 of the Kissimmee River Basin. Areas are segmented by land use and soil type for the four years 1958, 1972, 1980, and 2020. Values for 1958 and 1972 are taken directly from aerial photos. Values for 1980 and 2020 are predicted by the linear programming model, under the assumptions listed in Chapter III.

PLANNING UNIT 1

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	1	0	12	181	275	3	32	35	0	0
3	1972	5	1	142	0	338	0	29	24	0	0
3	1980	15	4	150	0	319	2	27	22	0	0
3	2020	526	0	0	0	0	6	5	0	0	0
11	1958	0	0	4	3	0	0	0	0	0	0
11	1972	4	0	0	3	0	0	0	0	0	0
11	1980	4	0	0	3	0	0	0	0	0	0
11	2020	7	0	0	0	0	0	0	0	0	0
12A	1958	0	0	0	14	4	0	0	5	0	0
12A	1972	0	0	13	0	4	0	0	6	0	0
12A	1980	0	0	13	0	4	0	0	6	0	0
12A	2020	0	0	7	0	16	0	0	0	0	0
13A	1958	2	0	41	197	21	0	16	60	0	0
13A	1972	11	0	123	58	37	1	17	90	0	0
13A	1980	21	0	149	23	37	2	15	90	0	0
13A	2020	309	0	9	0	9	8	2	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	4	3	0	5	0	3	0	0
15	1972	0	0	0	3	8	3	0	1	0	0
15	1980	0	0	0	3	10	2	0	0	0	0
15	2020	0	0	0	0	15	0	0	0	0	0
18C	1958	0	0	0	34	0	0	0	6	0	0
18C	1972	0	0	0	35	0	0	0	5	0	0
18C	1980	0	0	25	10	0	0	0	5	0	0
18C	2020	40	0	0	0	0	0	0	0	0	0
22	1958	0	0	1	1	3	0	6	3	0	0
22	1972	0	0	2	4	7	0	0	1	0	0
22	1980	0	0	0	7	7	0	0	0	0	0
22	2020	14	0	0	0	0	0	0	0	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	15	0	4	0	13	0	0
24A	1972	0	0	0	18	0	4	0	10	0	0
24A	1980	6	0	0	13	0	4	0	9	0	0
24A	2020	29	0	0	0	0	3	0	0	0	0
24C	1958	0	0	0	0	0	0	5	0	0	0
24C	1972	0	0	0	4	0	0	1	0	0	0
24C	1980	1	0	0	3	0	0	1	0	0	0
24C	2020	5	0	0	0	0	0	0	0	0	0
26	1958	0	0	1	3	2	0	16	4	0	0
26	1972	0	0	0	13	2	0	6	5	0	0
26	1980	4	0	0	7	5	0	6	4	0	0
26	2020	9	0	0	0	12	0	5	0	0	0
27	1958	0	0	2	19	8	3	11	175	0	0
27	1972	8	0	7	18	27	5	14	139	0	0
27	1980	8	0	27	25	20	6	12	120	0	0
27	2020	203	0	0	0	0	10	5	0	0	0
TOT	1958	3	0	65	470	313	15	86	304	0	42
TOTAL ACREAGE		129800 ACRES									
TOT	1972	28	1	287	156	423	13	67	281	0	42
TOTAL ACREAGE		129800 ACRES									
TOT	1980	59	4	364	94	402	16	61	256	0	42
TOTAL ACREAGE		129800 ACRES									
TOT	2020	1144	0	16	0	52	27	17	0	0	42
TOTAL ACREAGE		129800 ACRES									

PLANNING UNIT 2

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	LAND USES / STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	2	70	21	0	0	0	0	0
1	1972	46	0	0	12	32	3	0	0	0	0
1	1980	50	0	0	0	40	3	0	0	0	0
1	2020	93	0	0	0	0	0	0	0	0	0
3	1958	15	0	2	22	66	0	2	5	0	0
3	1972	30	0	9	0	66	2	0	5	0	0
3	1980	30	0	15	0	61	2	0	4	0	0
3	2020	112	0	0	0	0	0	0	0	0	0
11	1956	0	0	0	4	0	0	0	1	0	0
11	1972	3	0	1	0	0	0	0	1	0	0
11	1980	3	0	1	0	0	0	0	1	0	0
11	2020	5	0	0	0	0	0	0	0	0	0
12A	1958	0	0	4	8	6	0	0	5	0	0
12A	1972	3	0	16	0	1	0	0	3	0	0
12A	1980	3	0	18	0	0	0	0	2	0	0
12A	2020	23	0	0	0	0	0	0	0	0	0
13A	1958	45	0	93	180	10	0	26	330	0	0
13A	1972	287	0	68	62	12	8	0	247	0	0
13A	1980	287	0	65	54	28	10	0	240	0	0
13A	2020	684	0	0	0	0	0	0	0	0	0
13B	1958	0	0	0	0	1	2	1	1	0	0
13B	1972	0	0	0	1	0	2	1	1	0	0
13B	1980	0	0	0	0	3	1	1	0	0	0
13B	2020	5	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	4	1	0	0	1	1	0	0
18C	1972	2	0	4	0	0	0	0	1	0	0
18C	1980	2	0	5	0	0	0	0	0	0	0
18C	2020	7	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	2	7	1	1	17	143	0	0
27	1972	15	0	16	4	0	10	4	122	0	0
27	1980	16	0	24	15	3	10	3	100	0	0
27	2020	171	0	0	0	0	0	0	0	0	0
TOT	1958	60	0	107	292	105	3	47	486	0	68

TOTAL ACREAGE 116800 ACRES

TOT	1972	386	0	114	79	111	25	5	380	0	68

TOTAL ACREAGE 116800 ACRES

TOT	1980	391	0	128	69	135	26	4	347	0	68

TOTAL ACREAGE 116800 ACRES

TOT	2020	1100	0	0	0	0	0	0	0	0	68

TOTAL ACREAGE 116800 ACRES

PLANNING UNIT 3

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	LAND USES / STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	1	0	0	2	0	0	0	0	0	0
1	1972	1	0	2	0	0	0	0	0	0	0
1	1980	3	0	0	0	0	0	0	0	0	0
1	2020	3	0	0	0	0	0	0	0	0	0
3	1958	104	0	6	1	39	0	0	0	0	0
3	1972	143	0	6	0	0	0	1	0	0	0
3	1980	146	0	3	0	0	0	1	0	0	0
3	2020	150	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	10	6	6	4	6	2	0	0
12A	1972	5	0	18	0	6	0	0	5	0	0
12A	1980	5	0	9	0	15	0	0	5	0	0
12A	2020	5	0	3	0	26	0	0	0	0	0
13A	1958	52	0	181	118	9	0	81	44	0	0
13A	1972	143	11	151	130	7	16	0	27	0	0
13A	1980	198	0	157	82	5	16	0	27	0	0
13A	2020	438	0	18	14	0	15	0	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	13	1	0	1	7	0	0	0
22	1972	1	0	17	0	1	0	1	2	0	0
22	1980	8	0	10	0	0	0	2	2	0	0
22	2020	22	0	0	0	0	0	0	0	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	1	2	0	0	0	24	0	0
27	1972	0	0	0	0	0	0	0	27	0	0
27	1980	0	0	0	0	0	0	0	27	0	0
27	2020	27	0	0	0	0	0	0	0	0	0
TOT	1958	157	0	211	130	54	5	94	70	0	147

TOTAL ACREAGE 86800 ACRES

TOT	1972	293	11	194	130	14	16	2	61	0	147

TOTAL ACREAGE 86800 ACRES

TOT	1980	360	0	179	82	20	16	3	61	0	147

TOTAL ACREAGE 86800 ACRES

TOT	2020	645	0	21	14	26	15	0	0	0	147

TOTAL ACREAGE 56800 ACRES

PLANNING UNIT 4

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN

(AREAS IN 100 ACRES)

SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARREN LAND	10 SRFCE WATER
1	1958	0	0	0	1	0	1	4	0	0	0
1	1972	0	0	0	4	0	0	2	0	0	0
1	1980	0	0	0	4	0	0	2	0	0	0
1	2020	5	0	0	1	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	4	13	1	3	3	1	0	0
12A	1972	0	0	0	15	1	9	0	0	0	0
12A	1980	0	0	0	15	1	9	0	0	0	0
12A	2020	13	0	0	0	12	0	0	0	0	0
13A	1958	1	0	79	283	6	26	21	76	0	0
13A	1972	8	0	142	34	23	209	10	66	0	0
13A	1980	14	0	106	67	23	206	10	66	0	0
13A	2020	174	30	60	11	30	185	2	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	14	2	0	1	4	3	0	0
26	1972	0	0	5	3	0	6	6	4	0	0
26	1980	0	0	2	3	0	9	6	4	0	0
26	2020	1	15	0	0	0	0	7	1	0	0
27	1958	0	0	3	9	0	3	23	58	0	0
27	1972	0	0	0	16	0	18	34	28	0	0
27	1980	6	0	0	10	0	18	34	28	0	0
27	2020	12	0	0	0	0	75	9	0	0	0
TOT	1958	1	0	100	308	7	34	55	138	0	81
TOTAL ACREAGE		72400 ACRES									
TOT	1972	6	0	147	72	24	242	52	98	0	81
TOTAL ACREAGE		72400 ACRES									
TOT	1980	20	0	108	99	24	242	52	98	0	81
TOTAL ACREAGE		72400 ACRES									
TOT	2020	205	45	60	12	42	260	18	1	0	81
TOTAL ACREAGE		72400 ACRES									

PLANNING UNIT 5

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	LAND USES / STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SURCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	3	42	17	0	0	0	0	0
12A	1972	21	0	22	8	8	0	3	0	0	0
12A	1980	25	2	20	5	10	0	0	0	0	0
12A	2020	33	5	0	0	24	0	0	0	0	0
13A	1958	9	0	64	225	18	0	16	35	0	0
13A	1972	49	0	198	83	1	5	4	27	0	0
13A	1980	138	1	120	70	0	10	3	25	0	0
13A	2020	271	3	23	0	0	70	0	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	20	10	3	0	2	0	0	0
15	1972	2	0	31	0	2	0	0	0	0	0
15	1980	3	1	21	0	10	0	0	0	0	0
15	2020	10	5	0	0	20	0	0	0	0	0
18C	1958	0	0	10	6	0	2	3	0	0	0
18C	1972	0	0	14	5	0	0	2	0	0	0
18C	1980	0	0	15	4	0	0	2	0	0	0
18C	2020	21	0	0	0	0	0	0	0	0	0
22	1958	0	0	20	4	4	0	1	0	0	0
22	1972	1	0	26	2	0	0	0	0	0	0
22	1980	1	0	25	3	0	0	0	0	0	0
22	2020	8	0	0	10	0	11	0	0	0	0
23	1958	1	0	0	34	2	0	0	0	0	0
23	1972	1	0	34	0	2	0	0	0	0	0
23	1980	1	0	34	0	2	0	0	0	0	0
23	2020	37	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	22	4	0	0	10	0	0	0
26	1972	0	0	33	0	0	0	3	0	0	0
26	1980	0	0	34	0	0	0	2	0	0	0
26	2020	36	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	9	0	0	54	30	0	0
27	1972	0	0	1	13	0	2	54	23	0	0
27	1980	0	0	3	11	0	2	54	23	0	0
27	2020	62	0	0	0	0	0	31	0	0	0
TOT	1958	10	0	139	334	44	2	66	65	0	170
TOTAL ACREAGE		85000 ACRES									
TOT	1972	74	0	359	111	13	7	66	50	0	170
TOTAL ACREAGE		85000 ACRES									
TOT	1980	168	4	272	93	22	12	61	48	0	170
TOTAL ACREAGE		85000 ACRES									
TOT	2020	478	13	23	10	44	81	31	0	0	170
TOTAL ACREAGE		85000 ACRES									

PLANNING UNIT 6

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	2	0	0	0	0	0	0
1	1972	2	0	0	0	0	0	0	0	0	0
1	1980	2	0	0	0	0	0	0	0	0	0
1	2020	2	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	3	12	0	5	2	0	0
3	1972	0	0	7	0	15	0	0	0	0	0
3	1980	0	0	15	0	7	0	0	0	0	0
3	2020	22	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	16	2	0	0	0	0	0
11	1972	0	0	17	0	1	0	0	0	0	0
11	1980	0	0	10	0	8	0	0	0	0	0
11	2020	0	0	0	0	18	0	0	0	0	0
12A	1958	1	0	4	26	8	0	0	0	0	0
12A	1972	5	0	25	0	9	0	0	0	0	0
12A	1980	5	0	20	0	14	0	0	0	0	0
12A	2020	5	5	10	0	19	0	0	0	0	0
13A	1958	0	0	53	259	24	6	26	72	0	0
13A	1972	1	0	301	97	0	6	0	35	0	0
13A	1980	13	0	301	62	23	6	0	35	0	0
13A	2020	204	10	159	31	0	6	0	30	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	17	14	0	0	23	3	0	0
22	1972	0	0	20	18	0	0	17	2	0	0
22	1980	3	0	20	15	0	0	17	2	0	0
22	2020	8	0	0	30	0	0	17	2	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	1	3	0	0	14	0	0	0
26	1972	0	0	9	4	0	1	3	1	0	0
26	1980	0	0	10	3	0	3	2	0	0	0
26	2020	0	0	0	0	0	18	0	0	0	0
27	1958	0	0	2	25	6	9	10	138	0	0
27	1972	0	0	54	0	9	7	3	117	0	0
27	1980	5	0	54	0	4	7	3	117	0	0
27	2020	63	0	0	0	0	7	3	117	0	0
TOT	1958	1	0	77	348	52	15	78	215	0	126

TOTAL ACREAGE 91200 ACRES

TOT	1972	8	0	433	119	34	14	23	155	0	126

TOTAL ACREAGE 91200 ACRES

TOT	1980	28	0	430	80	56	16	22	154	0	126

TOTAL ACREAGE 91200 ACRES

TOT	2020	304	15	169	61	37	31	20	149	0	126

TOTAL ACREAGE 91200 ACRES

PLANNING UNIT 7

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN (AREAS IN 100 ACRES)

SOIL TYPE	LAND USES / STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	7	0	29	164	108	27	9	12	0	0
3	1972	28	0	205	17	95	1	0	9	0	0
3	1980	30	0	206	5	115	0	0	0	0	0
3	2020	356	0	0	0	0	0	0	0	0	0
11	1958	1	0	4	6	1	23	6	7	0	0
11	1972	1	0	14	24	0	3	0	6	0	0
11	1980	15	0	14	11	0	3	0	5	0	0
11	2020	48	0	0	0	0	0	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	8	29	1	8	1	14	0	0
13A	1972	3	0	1	41	1	6	0	10	0	0
13A	1980	5	0	17	23	1	5	0	10	0	0
13A	2020	61	0	0	0	0	0	0	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1956	0	0	0	14	0	0	0	5	0	0
18C	1972	0	0	0	16	0	0	0	3	0	0
18C	1980	0	0	0	17	0	0	0	2	0	0
18C	2020	19	0	0	0	0	0	0	0	0	0
22	1958	0	0	8	15	0	2	4	9	0	0
22	1972	1	0	22	5	3	0	0	7	0	0
22	1980	1	0	23	0	7	0	0	7	0	0
22	2020	38	0	0	0	0	0	0	0	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	33	0	0	0	5	0	0
24C	1972	0	0	0	35	0	1	0	2	0	0
24C	1980	15	0	0	22	1	0	0	0	0	0
24C	2020	38	0	0	0	0	0	0	0	0	0
26	1958	0	0	10	5	1	0	0	0	0	0
26	1972	0	0	15	0	1	0	0	0	0	0
26	1980	1	0	14	0	1	0	0	0	0	0
26	2020	16	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	10	0	2	11	88	0	0
27	1972	0	0	4	15	2	2	0	88	0	0
27	1980	0	0	5	15	2	0	1	88	0	0
27	2020	111	0	0	0	0	0	0	0	0	0
TOT	1958	8	0	59	276	111	62	31	140	0	32
TOTAL ACREAGE			71900 ACRES								
TOT	1972	33	0	261	153	102	13	0	125	0	32
TOTAL ACREAGE			71900 ACRES								
TOT	1980	67	0	279	93	127	8	1	112	0	32
TOTAL ACREAGE			71900 ACRES								
TOT	2020	687	0	0	0	0	0	0	0	0	32
TOTAL ACREAGE			71900 ACRES								

PLANNING UNIT 8

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

LAND USES / SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	1	1	1	0	0	0	0	0
3	1972	0	0	1	2	0	0	0	0	0	0
3	1980	3	0	0	0	0	0	0	0	0	0
3	2020	3	0	0	0	0	0	0	0	0	0
11	1958	0	0	1	4	0	0	3	0	0	0
11	1972	0	0	0	8	0	0	0	0	0	0
11	1980	1	0	3	4	0	0	0	0	0	0
11	2020	8	0	0	0	0	0	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	1	28	120	0	2	16	4	0	0
13A	1972	1	0	39	118	0	7	1	5	0	0
13A	1980	1	0	63	97	0	4	1	5	0	0
13A	2020	63	2	13	87	0	0	1	5	0	0
13B	1958	0	0	0	5	0	0	1	0	0	0
13B	1972	0	0	0	5	0	0	1	0	0	0
13B	1980	0	0	0	5	0	0	1	0	0	0
13B	2020	5	0	0	0	0	0	1	0	0	0
15	1958	0	0	0	50	0	2	0	0	0	0
15	1972	0	0	0	50	0	2	0	0	0	0
15	1980	2	0	3	45	0	2	0	0	0	0
15	2020	46	0	0	4	0	2	0	0	0	0
18C	1958	0	0	0	11	0	4	0	0	0	0
18C	1972	0	0	0	15	0	0	0	0	0	0
18C	1980	0	0	10	5	0	0	0	0	0	0
18C	2020	15	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	23	57	0	0	22	0	0	0
23	1972	0	0	93	0	0	0	9	0	0	0
23	1980	2	0	90	3	0	0	7	0	0	0
23	2020	62	0	35	0	0	0	5	0	0	0
24A	1958	0	0	0	4	0	0	65	0	0	0
24A	1972	0	0	0	4	0	0	65	0	0	0
24A	1980	0	0	20	9	0	0	40	0	0	0
24A	2020	61	0	0	0	0	0	8	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	1	0	2	0	0	31	0	0	0
26	1972	0	0	12	0	0	3	14	5	0	0
26	1980	0	0	14	0	0	2	14	4	0	0
26	2020	15	5	14	0	0	0	0	0	0	0
27	1958	0	0	0	1	0	0	8	0	0	0
27	1972	1	0	1	1	0	0	4	2	0	0
27	1980	1	0	0	4	0	0	3	1	0	0
27	2020	1	0	0	4	0	0	3	1	0	0
TOT	1958	0	2	53	255	1	8	146	4	0	84
TOTAL ACREAGE	55300 ACRES										
TOT	1972	2	0	146	203	0	12	94	12	0	84
TOTAL ACREAGE	55300 ACRES										
TOT	1980	10	0	203	172	0	8	66	10	0	84
TOTAL ACREAGE	55300 ACRES										
TOT	2020	279	7	62	95	0	2	18	6	0	84
TOTAL ACREAGE	55300 ACRES										

PLANNING UNIT 9

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

LAND USES / SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	1	2	15	72	168	20	12	18	0	0
3	1972	3	0	69	71	154	4	1	6	0	0
3	1980	4	0	71	26	0	156	50	1	0	0
3	2020	4	0	0	2	157	138	1	6	0	0
11	1958	0	0	0	7	1	0	0	3	0	0
11	1972	0	0	0	8	1	0	0	2	0	0
11	1980	0	0	0	8	2	0	0	1	0	0
11	2020	0	0	0	0	11	0	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	2	27	0	0	3	12	0	0
13A	1972	0	0	21	11	0	0	0	12	0	0
13A	1980	0	1	21	10	0	0	0	12	0	0
13A	2020	0	8	10	19	0	0	0	7	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	15	1	1	9	32	0	0
22	1972	1	0	20	20	0	0	2	15	0	0
22	1980	20	0	21	7	0	0	0	10	0	0
22	2020	41	0	0	0	0	0	2	15	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	1	1	2	0	3	9	0	0
26	1972	0	0	10	0	0	0	0	6	0	0
26	1980	3	0	7	0	0	0	0	6	0	0
26	2020	10	0	0	0	0	0	0	6	0	0
27	1958	0	0	0	0	0	0	2	3	0	0
27	1972	0	0	2	0	0	0	1	2	0	0
27	1980	0	0	2	0	0	0	1	2	0	0
27	2020	2	0	0	0	0	0	1	2	0	0
TOT	1958	1	2	18	122	172	21	29	77	0	56
TOTAL ACREAGE	49800 ACRES										
TOT	1972	4	0	122	110	155	4	4	43	0	56
TOTAL ACREAGE	49800 ACRES										
TOT	1980	27	1	122	51	2	156	51	32	0	56
TOTAL ACREAGE	49800 ACRES										
TOT	2020	57	8	10	21	168	138	4	36	0	56
TOTAL ACREAGE	49800 ACRES										

PLANNING UNIT 10

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1956	0	0	3	15	12	0	0	0	0	0
3	1972	2	0	1	9	18	0	0	0	0	0
3	1980	20	0	5	0	5	0	0	0	0	0
3	2020	30	0	0	0	0	0	0	0	0	0
11	1958	0	0	2	22	1	0	5	0	0	0
11	1972	0	0	2	25	0	3	0	0	0	0
11	1980	5	5	5	12	0	3	0	0	0	0
11	2020	15	10	2	0	0	3	0	0	0	0
12A	1958	0	0	0	15	0	0	0	0	0	0
12A	1972	1	0	0	14	0	0	0	0	0	0
12A	1960	5	3	0	7	0	0	0	0	0	0
12A	2020	7	8	0	0	0	0	0	0	0	0
13A	1958	2	0	44	406	1	3	75	9	0	0
13A	1972	2	0	86	414	1	12	14	9	0	0
13A	1980	7	0	95	400	1	14	14	9	0	0
13A	2020	7	2	499	0	2	30	0	0	0	0
13B	1958	0	0	9	44	0	1	101	0	0	0
13B	1972	0	0	0	153	0	0	0	2	0	0
13B	1980	20	0	0	133	0	0	0	2	0	0
13B	2020	28	0	0	125	0	0	0	2	0	0
15	1958	0	0	4	75	0	0	1	0	0	0
15	1972	0	0	9	65	0	0	1	5	0	0
15	1980	0	10	12	42	5	5	1	5	0	0
15	2020	0	20	15	11	17	11	1	5	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	13	12	0	1	16	0	0	0
22	1972	4	0	10	17	0	2	9	0	0	0
22	1980	20	0	4	5	0	3	10	0	0	0
22	2020	22	0	0	0	0	5	15	0	0	0
23	1958	0	0	1	49	0	0	123	0	0	0
23	1972	0	0	8	44	0	2	119	0	0	0
23	1960	0	40	20	0	0	3	110	0	0	0
23	2020	0	0	100	0	0	5	68	0	0	0
24A	1958	0	0	0	0	0	0	36	0	0	0
24A	1972	0	0	0	1	0	0	35	0	0	0
24A	1980	0	0	1	0	10	0	25	0	0	0
24A	2020	0	0	0	0	36	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1960	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	4	1	0	0	1	4	0	0
26	1972	0	0	6	0	0	0	0	4	0	0
26	1980	0	7	0	0	0	0	0	3	0	0
26	2020	0	0	8	0	0	0	0	2	0	0
27	1958	0	0	2	3	0	0	43	24	0	0
27	1972	0	0	2	3	0	0	43	24	0	0
27	1980	0	0	1	7	0	3	41	20	0	0
27	2020	8	0	0	0	0	3	41	20	0	0
TOT	1958	2	0	82	642	14	5	401	37	0	419

TOTAL ACREAGE 160200 ACRES

TOT	1972	9	0	126	745	19	19	221	44	0	419

TOTAL ACREAGE 160200 ACRES

TOT	1980	77	65	143	606	21	31	201	39	0	419

TOTAL ACREAGE 160200 ACRES

TOT	2020	117	40	624	136	55	57	125	29	0	419

TOTAL ACREAGE 160200 ACRES

PLANNING UNIT 11

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE (LAND USES)	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	2	6	0	0	0	0	0	0
12A	1972	0	0	6	0	0	0	0	0	0	0
12A	1980	0	0	8	0	0	0	0	0	0	0
12A	2020	0	0	4	0	4	0	0	0	0	0
13A	1958	0	0	15	193	1	0	32	0	0	0
13A	1972	1	0	40	196	0	0	0	4	0	0
13A	1980	3	0	50	184	0	0	0	4	0	0
13A	2020	6	1	160	25	0	0	0	49	0	0
13B	1958	0	0	32	110	1	0	5	0	0	0
13B	1972	0	0	99	46	1	0	2	0	0	0
13B	1980	0	0	100	45	1	0	2	0	0	0
13B	2020	0	0	142	0	6	0	0	0	0	0
15	1958	0	0	1	4	0	0	1	0	0	0
15	1972	0	0	3	3	0	0	0	0	0	0
15	1980	3	0	3	0	0	0	0	0	0	0
15	2020	6	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	2	4	0	0	58	0	0	0
23	1972	0	0	6	0	0	0	58	0	0	0
23	1980	0	0	6	0	0	0	58	0	0	0
23	2020	0	0	6	0	0	0	58	0	0	0
24A	1958	0	0	0	5	0	0	20	0	0	0
24A	1972	0	0	0	9	0	0	16	0	0	0
24A	1980	9	0	0	0	0	0	16	0	0	0
24A	2020	18	3	0	0	0	0	4	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	52	322	2	0	116	0	0	61
TOTAL ACREAGE		55300 ACRES									
TOT	1972	1	0	156	254	1	0	76	4	0	61
TOTAL ACREAGE		55300 ACRES									
TOT	1980	15	0	167	229	1	0	76	4	0	61
TOTAL ACREAGE		55300 ACRES									
TOT	2020	30	4	312	25	10	0	62	49	0	61
TOTAL ACREAGE		55300 ACRES									

PLANNING UNIT 12

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	LAND USES STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	5	0	0	0	0	0	0
1	1972	0	0	0	5	0	0	0	0	0	0
1	1980	0	0	0	5	0	0	0	0	0	0
1	2020	5	0	0	0	0	0	0	0	0	0
3	1958	11	0	7	91	131	0	10	8	0	0
3	1972	24	0	1	80	153	0	0	0	0	0
3	1980	40	0	23	45	150	0	0	0	0	0
3	2020	65	0	50	0	143	0	0	0	0	0
11	1958	0	0	0	8	0	1	1	1	0	0
11	1972	1	0	0	7	1	1	0	1	0	0
11	1980	2	0	0	5	2	1	0	1	0	0
11	2020	6	0	0	0	3	1	0	1	0	0
12A	1958	0	0	0	10	0	0	0	3	0	0
12A	1972	2	0	0	11	0	0	0	0	0	0
12A	1980	2	0	0	11	0	0	0	0	0	0
12A	2020	2	4	6	1	0	0	0	0	0	0
13A	1958	0	0	9	110	0	0	5	3	0	0
13A	1972	19	0	0	88	14	0	4	2	0	0
13A	1980	20	0	12	77	12	0	4	2	0	0
13A	2020	40	0	57	20	10	0	0	0	0	0
13B	1958	0	0	0	0	0	0	0	0	0	0
13B	1972	0	0	0	0	0	0	0	0	0	0
13B	1980	0	0	0	0	0	0	0	0	0	0
13B	2020	0	0	0	0	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	4	75	0	0	0	41	0	0
22	1972	25	0	0	31	7	16	2	39	0	0
22	1980	30	0	3	30	0	17	2	38	0	0
22	2020	36	0	20	0	10	20	4	30	0	0
23	1958	0	0	0	0	0	0	0	0	0	0
23	1972	0	0	0	0	0	0	0	0	0	0
23	1980	0	0	0	0	0	0	0	0	0	0
23	2020	0	0	0	0	0	0	0	0	0	0
24A	1958	0	0	0	0	0	0	0	0	0	0
24A	1972	0	0	0	0	0	0	0	0	0	0
24A	1980	0	0	0	0	0	0	0	0	0	0
24A	2020	0	0	0	0	0	0	0	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	2	0	0	0	7	0	0
27	1972	0	0	0	6	0	0	0	3	0	0
27	1980	0	0	0	6	0	0	0	3	0	0
27	2020	0	0	0	9	0	0	0	0	0	0
TOT	1958	11	0	20	301	131	1	16	63	0	99
TOTAL ACREAGE		64200 ACRES									
TOT	1972	71	0	1	228	175	17	6	45	0	99
TOTAL ACREAGE		64200 ACRES									
TOT	1980	94	0	38	179	164	18	6	44	0	99
TOTAL ACREAGE		64200 ACRES									
TOT	2020	154	4	133	30	164	21	4	31	0	99
TOTAL ACREAGE		64200 ACRES									

PLANNING UNIT 13

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

LAND USES / SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	17	0	6	0	0	0	0
11	1972	0	0	0	20	0	3	0	0	0	0
11	1980	0	0	0	13	0	10	0	0	0	0
11	2020	0	0	0	0	0	23	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
1 12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	13	278	0	0	29	0	0	0
13A	1972	0	3	10	280	0	19	5	0	3	0
13A	1980	4	0	136	152	0	20	5	0	3	0
13A	2020	18	1	112	165	0	21	0	0	3	0
13B	1958	0	0	94	233	9	0	55	0	0	0
13B	1972	0	1	260	98	0	0	32	0	0	0
13B	1980	0	1	268	90	0	0	32	0	0	0
13B	2020	0	0	391	0	0	0	0	0	0	0
15	1958	0	0	3	4	0	0	4	0	0	0
15	1972	0	0	7	3	0	0	1	0	0	0
15	1980	0	0	8	2	0	0	1	0	0	0
15	2020	0	0	11	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	31	44	0	0	19	0	0	0
22	1972	0	0	10	70	0	5	9	0	0	0
22	1980	0	0	20	60	0	6	8	0	0	0
22	2020	0	0	72	10	0	7	5	0	0	0
23	1958	0	0	3	21	1	0	35	0	0	0
23	1972	0	0	21	15	0	0	24	0	0	0
23	1980	0	0	21	15	0	0	24	0	0	0
23	2020	0	0	40	19	0	0	1	0	0	0
24A	1958	0	0	0	3	0	0	45	0	0	0
24A	1972	0	0	0	10	0	0	34	0	4	0
24A	1980	0	2	2	10	0	0	30	0	4	0
24A	2020	0	14	17	0	0	0	13	0	4	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	144	600	10	6	187	0	0	0
TOTAL ACREAGE		94700 ACRES									
TOT	1972	0	4	308	496	0	27	105	0	7	0
TOTAL ACREAGE		94700 ACRES									
TOT	1980	4	3	455	342	0	36	100	0	7	0
TOTAL ACREAGE		94700 ACRES									
TOT	2020	18	15	643	194	0	51	19	0	7	0
TOTAL ACREAGE		94700 ACRES									

PLANNING UNIT 14

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

LAND USES / SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	20	0	0	0	0	0	0
1	1972	0	0	3	7	10	0	0	0	0	0
1	1980	0	0	4	6	10	0	0	0	0	0
1	2020	0	0	0	0	20	0	0	0	0	0
3	1958	0	0	2	30	0	0	0	0	0	0
3	1972	0	0	12	20	0	0	0	0	0	0
3	1980	0	0	14	18	0	0	0	0	0	0
3	2020	0	0	20	12	0	0	0	0	0	0
11	1958	0	0	1	12	0	2	1	0	0	0
11	1972	0	0	10	3	0	3	0	0	0	0
11	1980	0	0	12	1	0	3	0	0	0	0
11	2020	0	5	7	0	0	4	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	1	66	0	0	20	1	0	0
13A	1972	0	0	11	66	0	0	11	0	0	0
13A	1980	0	0	42	36	0	0	10	0	0	0
13A	2020	0	5	58	25	0	0	0	0	0	0
13B	1958	0	0	9	.697	0	5	147	0	0	0
13B	1972	0	0	266	486	0	3	103	0	0	0
13B	1980	1	0	500	245	0	3	4	105	0	0
13B	2020	4	20	750	84	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	10	0	0	0
18C	1972	0	0	0	5	0	0	5	0	0	0
18C	1980	0	0	1	4	0	0	5	0	0	0
18C	2020	0	5	5	0	0	0	0	0	0	0
22	1958	0	0	0	5	0	0	45	0	0	0
22	1972	0	0	0	18	0	0	32	0	0	0
22	1980	0	0	5	15	0	0	30	0	0	0
22	2020	0	0	20	30	0	0	0	0	0	0
23	1958	0	0	14	113	0	0	121	0	0	0
23	1972	0	0	124	36	0	0	88	0	0	0
23	1980	0	0	150	18	0	0	80	0	0	0
23	2020	0	15	160	30	0	0	43	0	0	0
24A	1958	0	0	1	8	0	0	100	0	0	0
24A	1972	0	0	2	14	0	0	92	0	1	0
24A	1980	0	0	0	4	15	0	89	0	1	0
24A	2020	0	20	16	16	0	0	56	0	1	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	28	951	0	7	444	1	0	0
TOTAL ACREAGE		143100 ACRES									
TOT	1972	0	0	428	655	10	6	331	0	1	0
TOTAL ACREAGE		143100 ACRES									
TOT	1980	1	0	728	347	25	6	218	105	1	0
TOTAL ACREAGE		143100 ACRES									
TOT	2020	4	70	1036	197	20	4	99	0	1	0
TOTAL ACREAGE		143100 ACRES									

PLANNING UNIT 15

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	LAND USES / STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	1	7	0	1	0	0	0	0
11	1972	0	0	7	1	0	1	0	0	0	0
11	1980	1	0	7	0	0	1	0	0	0	0
11	2020	1	2	4	0	1	1	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1956	0	3	16	173	0	1	12	0	0	0
13A	1972	0	0	99	102	0	0	4	0	0	0
13A	1980	1	3	97	100	0	0	4	0	0	0
13A	2020	5	39	116	45	0	0	0	0	0	0
13B	1958	0	0	0	61	0	0	10	0	0	0
13B	1972	0	0	24	44	0	0	3	0	0	0
13B	1980	0	0	27	41	0	0	3	0	0	0
13B	2020	4	0	47	20	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	7	0	1	1	0	0	0
22	1972	0	0	8	0	0	1	0	0	0	0
22	1980	0	0	8	0	0	1	0	0	0	0
22	2020	0	0	6	0	2	1	0	0	0	0
23	1958	0	0	0	4	0	0	22	0	0	0
23	1972	0	0	0	9	0	0	17	0	0	0
23	1980	2	0	0	9	0	0	15	0	0	0
23	2020	13	0	0	11	0	0	2	0	0	0
24A	1958	0	0	0	4	0	3	64	0	0	0
24A	1972	0	0	0	1	0	1	69	0	0	0
24A	1980	0	0	0	3	0	1	67	0	0	0
24A	2020	0	0	0	10	0	1	60	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	22	0	0	0
26	1972	0	0	1	0	0	3	18	0	0	0
26	1980	0	0	1	0	0	3	18	0	0	0
26	2020	0	0	2	2	0	3	15	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1956	0	3	17	256	0	6	131	0	0	0
TOTAL ACREAGE		41300 ACRES									
TOT	1972	0	0	139	157	0	6	111	0	0	0
TOTAL ACREAGE		41300 ACRES									
TOT	1980	4	3	140	153	0	6	107	0	0	0
TOTAL ACREAGE		41300 ACRES									
TOT	2020	23	41	175	88	3	6	77	0	0	0
TOTAL ACREAGE		41300 ACRES									

PLANNING UNIT 16

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE \ LAND USES	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	3	9	3	2	2	0	0	0
11	1972	0	0	11	4	0	2	2	0	0	0
11	1980	0	0	12	3	0	2	2	0	0	0
11	2020	0	10	5	0	0	2	2	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	8	442	0	0	35	0	0	0
13A	1972	6	9	425	12	0	14	19	0	0	0
13A	1980	8	10	424	10	0	14	19	0	0	0
13A	2020	17	109	335	0	0	14	10	0	0	0
13B	1958	0	0	0	153	0	0	77	0	0	0
13B	1972	0	0	195	0	0	0	35	0	0	0
13B	1980	0	0	200	0	0	0	30	0	0	0
13B	2020	0	42	168	0	0	0	20	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	0	0	0	0	0	0	0
18C	1972	0	0	0	0	0	0	0	0	0	0
18C	1980	0	0	0	0	0	0	0	0	0	0
18C	2020	0	0	0	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	27	0	0
22	1972	0	0	5	0	0	0	0	22	0	0
22	1980	0	0	5	0	0	0	22	0	0	0
22	2020	0	0	27	0	0	0	0	0	0	0
23	1958	0	0	3	79	0	0	57	0	0	0
23	1972	2	3	107	0	0	3	24	0	0	0
23	1980	4	4	106	0	0	0	25	0	0	0
23	2020	19	14	83	0	0	3	20	0	0	0
24A	1958	0	0	0	7	0	0	87	0	0	0
24A	1972	0	0	57	1	0	2	29	0	5	0
24A	1980	0	0	60	0	0	2	27	0	5	0
24A	2020	0	0	65	0	0	2	22	0	5	0
24C	1958	0	0	0	22	0	0	45	0	0	0
24C	1972	0	0	39	0	0	4	24	0	0	0
24C	1980	0	0	40	0	0	4	23	0	0	0
24C	2020	0	0	43	0	0	4	20	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	14	712	3	2	303	27	0	0
TOTAL ACREAGE		106100 ACRES									
TOT	1972	8	12	839	17	0	25	133	22	5	0
TOTAL ACREAGE		106100 ACRES									
TOT	1980	12	14	847	13	0	22	148	0	5	0
TOTAL ACREAGE		106100 ACRES									
TOT	2020	36	175	726	0	0	25	94	0	5	0
TOTAL ACREAGE		106100 ACRES									

PLANNING UNIT 17

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

LAND USES / SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	4	6	0	0	88	0	0	0
13A	1972	3	0	86	0	0	0	9	0	0	0
13A	1980	3	0	86	0	0	0	9	0	0	0
13A	2020	3	0	77	18	0	0	0	0	0	0
13B	1958	0	0	4	132	0	4	8	0	0	0
13B	1972	2	0	139	0	0	3	4	0	0	0
13B	1980	3	0	140	0	0	3	2	0	0	0
13B	2020	3	14	112	19	0	0	0	0	0	0
15	1958	0	0	0	0	0	0	0	0	0	0
15	1972	0	0	0	0	0	0	0	0	0	0
15	1980	0	0	0	0	0	0	0	0	0	0
15	2020	0	0	0	0	0	0	0	0	0	0
18C	1958	0	0	0	9	0	2	1	0	0	0
18C	1972	0	0	6	0	0	6	0	0	0	0
18C	1980	0	0	7	0	0	5	0	0	0	0
18C	2020	0	0	0	3	0	9	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	8	18	0	0	5	0	0	0
23	1972	0	0	27	0	0	0	4	0	0	0
23	1980	0	0	28	0	0	0	3	0	0	0
23	2020	0	25	5	0	0	0	1	0	0	0
24A	1958	0	0	1	22	0	1	50	0	0	0
24A	1972	0	0	46	0	0	1	27	0	0	0
24A	1980	0	0	48	0	0	1	25	0	0	0
24A	2020	7	22	0	0	0	24	21	0	0	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	18	0	0	0
26	1972	0	0	3	0	0	0	10	0	5	0
26	1980	0	0	5	0	0	0	8	0	5	0
26	2020	0	9	0	4	0	0	0	0	5	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	17	187	0	7	170	0	0	0

TOTAL ACREAGE 38100 ACRES

TOT	1972	5	0	307	0	0	10	54	0	5	0

TOTAL ACREAGE 38100 ACRES

TOT	1980	6	0	314	0	0	9	47	0	5	0

TOTAL ACREAGE 38100 ACRES

TOT	2020	13	70	194	44	0	33	22	0	5	0

TOTAL ACREAGE 38100 ACRES

PLANNING UNIT 18

LAND USE BY SOIL TYPE IN THE KISSIMMEE RIVER BASIN
(AREAS IN 100 ACRES)

SOIL TYPE	STUDY YEAR	1 URBAN	2 CROP LAND	3 IMP PAST.	4 UNIMP PAST.	5 CITRS	6 FORST	7 SWAMP	8 MARSH	9 BARRN LAND	10 SRFCE WATER
1	1958	0	0	0	0	0	0	0	0	0	0
1	1972	0	0	0	0	0	0	0	0	0	0
1	1980	0	0	0	0	0	0	0	0	0	0
1	2020	0	0	0	0	0	0	0	0	0	0
3	1958	0	0	0	0	0	0	0	0	0	0
3	1972	0	0	0	0	0	0	0	0	0	0
3	1980	0	0	0	0	0	0	0	0	0	0
3	2020	0	0	0	0	0	0	0	0	0	0
11	1958	0	0	0	0	0	0	0	0	0	0
11	1972	0	0	0	0	0	0	0	0	0	0
11	1980	0	0	0	0	0	0	0	0	0	0
11	2020	0	0	0	0	0	0	0	0	0	0
12A	1958	0	0	0	0	0	0	0	0	0	0
12A	1972	0	0	0	0	0	0	0	0	0	0
12A	1980	0	0	0	0	0	0	0	0	0	0
12A	2020	0	0	0	0	0	0	0	0	0	0
13A	1958	0	0	0	0	0	0	0	0	0	0
13A	1972	0	0	0	0	0	0	0	0	0	0
13A	1980	0	0	0	0	0	0	0	0	0	0
13A	2020	0	0	0	0	0	0	0	0	0	0
13B	1958	0	0	38	71	0	4	9	0	0	0
13B	1972	0	0	118	0	0	1	3	0	0	0
13B	1980	2	0	116	0	0	1	3	0	0	0
13B	2020	4	58	59	0	0	1	0	0	0	0
15	1958	0	0	23	0	0	0	0	0	0	0
15	1972	0	0	23	0	0	0	0	0	0	0
15	1980	0	0	23	0	0	0	0	0	0	0
15	2020	0	0	23	0	0	0	0	0	0	0
18C	1958	0	0	4	0	0	0	0	0	0	0
18C	1972	0	0	4	0	0	0	0	0	0	0
18C	1980	0	0	4	0	0	0	0	0	0	0
18C	2020	1	0	3	0	0	0	0	0	0	0
22	1958	0	0	0	0	0	0	0	0	0	0
22	1972	0	0	0	0	0	0	0	0	0	0
22	1980	0	0	0	0	0	0	0	0	0	0
22	2020	0	0	0	0	0	0	0	0	0	0
23	1958	0	0	25	0	0	0	22	0	0	0
23	1972	0	0	34	0	0	0	13	0	0	0
23	1980	0	0	34	0	0	0	13	0	0	0
23	2020	1	0	39	0	0	0	7	0	0	0
24A	1958	0	0	19	29	0	0	43	0	0	0
24A	1972	0	0	32	7	0	0	39	0	13	0
24A	1980	3	0	26	10	0	0	39	0	13	0
24A	2020	6	7	34	11	0	0	20	0	13	0
24C	1958	0	0	0	0	0	0	0	0	0	0
24C	1972	0	0	0	0	0	0	0	0	0	0
24C	1980	0	0	0	0	0	0	0	0	0	0
24C	2020	0	0	0	0	0	0	0	0	0	0
26	1958	0	0	0	0	0	0	0	0	0	0
26	1972	0	0	0	0	0	0	0	0	0	0
26	1980	0	0	0	0	0	0	0	0	0	0
26	2020	0	0	0	0	0	0	0	0	0	0
27	1958	0	0	0	0	0	0	0	0	0	0
27	1972	0	0	0	0	0	0	0	0	0	0
27	1980	0	0	0	0	0	0	0	0	0	0
27	2020	0	0	0	0	0	0	0	0	0	0
TOT	1958	0	0	109	100	0	4	74	0	0	0
TOTAL ACREAGE		28700 ACRES									
TOT	1972	0	0	211	7	0	1	55	0	13	0
TOTAL ACREAGE		28700 ACRES									
TOT	1980	5	0	203	10	0	1	55	0	13	0
TOTAL ACREAGE		28700 ACRES									
TOT	2020	12	65	158	11	0	1	27	0	13	0
TOTAL ACREAGE		28700 ACRES									

APPENDIX B

DRAINAGE DENSITY STUDIES

DRAINAGE BASIN CHARACTERISTICS

A drainage basin is the entire area providing runoff to, and sustaining part or all of the streamflow of, the main stream and its tributaries. Drainage basin or watershed thus refers to the area enclosed by the boundaries of the surface and groundwater runoff system. The need to study the form and process relationships in the drainage basin derives from the function involved in the hydrologic cycle in conveying water from precipitation to its final destination as streamflow.

Measurement and quantitative description of the drainage basin were firmly established by Horton (1932, 1945) when he initially characterized drainage basins by morphologic, soil, geologic or structural, and vegetational factors. Langbein (1947) extended these ideas to include topographic characteristics which relate to drainage basin functions. A drainage basin can be described by topographic parameters which include area and size, shape and pattern, relief and slope, and drainage density. A variety of interpretations are available in any of the following references: Strahler (1964), Leopold et al. (1964), and Gregory and Walling (1973).

Drainage basin area is difficult to correlate with catchment response due to nonuniform soil, vegetative, and topographic properties. High relief and slope indices tend to be associated with smaller basins. It follows that the highest floods per unit area are found to be characteristic of the smallest catchment areas. For many years a simple relation between an index of streamflow (Q) and catchment area (A) has been used as a guide to basin response. Relations of the form $Q = aA^b$, where a and b are constants, have been used for predicting flood events. Basin area has a different significance depending on catchment characteristics and the index of streamflow. Glymph and Holtan (1969) illustrate different types of relationships which can result when mean annual runoff is related to drainage area (Figure B.1). In humid areas such as Ohio, upland infiltration returns in part to downstream channels causing a gain in streamflow per unit area as basin size increases. In drier regions, runoff per unit area may be constant or decrease with increasing basin size.

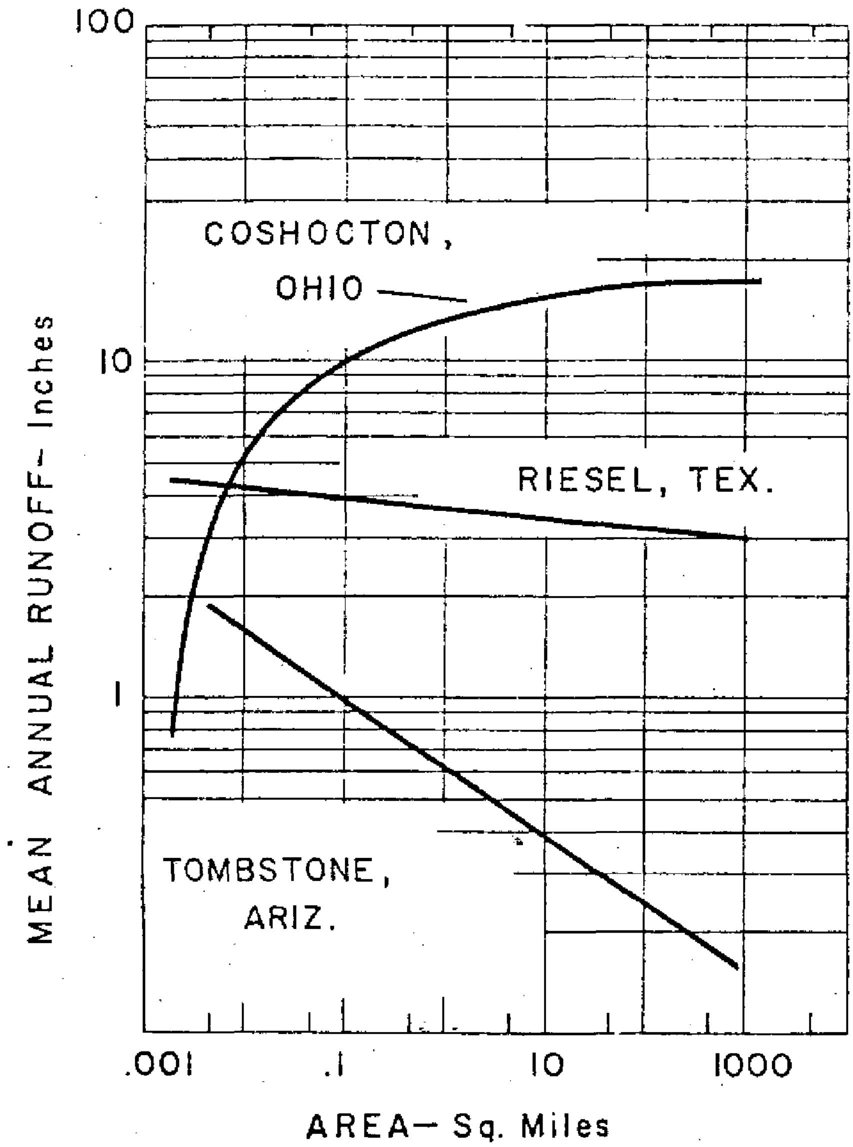

Figure B.1. Mean Annual Runoff versus Drainage Area (Glymph and Holtan, 1969, p. 54).

Other indices of basin size have been used in relationships with watershed response. The length of the longest stream (L) was used by Morisawa (1967) in a relation with mean annual discharge (Q) for watersheds in the eastern United States. Stream order, which measures the amount of branching within a basin, is of limited value in relation to measures of stream discharge unless the method of ordering is directly relevant to runoff production. A complete discussion of various methods for stream ordering is contained in Gregory and Walling (1973).

Basin relief, which refers to channel or valley slope, exercises an influence over peak runoff and sediment production in the basin. The significance of relief is difficult to ascertain because it is bound up with other basin parameters. These same points apply to basin shape, which generally determines the lag time of the basin hydrograph response. This effect can be observed in Figure B-2-A, B, and C from DeWiest (1965). The pattern of the drainage network also affects the hydrograph response as shown in Figure B-2-D and E from Strahler (1964).

Many of the indices discussed above do not respond to the dynamic character of the watershed because they express overall size, shape, or relief of the basin. It is now increasingly appreciated that only part of the basin actually produces runoff and sediment at a particular time. Therefore, of all topographic characteristics, perhaps drainage density is potentially the most useful single index of drainage basin processes. The significance of drainage density stems from the facts that water and sediment yield are very much influenced by the length of water courses per unit area, and that it can be regarded as both an input or a response to input (output) to the basin.

DRAINAGE DENSITY

Drainage density was defined by Horton (1932) as the length of streams per unit of drainage area, and he considered a range of drainage densities from 2.0 mi/sq mi for steep impervious areas to nearly zero in permeable basins with high infiltration rates. More than 20 years of investigation from areas all over the world have shown a greater range in the values. Strahler (1957) described drainage density values less than 5.0 mi/sq mi as coarse, between 5.0 and 13.7 as medium, between 13.7 and 155.3 as fine, and greater than 155.3 as ultra-fine. Values in the medium category have been recorded from large areas of the humid central and eastern parts of the United States, whereas fine values have been measured in the Badlands in South Dakota (Smith, 1958).

Several useful relationships exist for describing stream areas, stream lengths, and stream numbers, all of which are important for

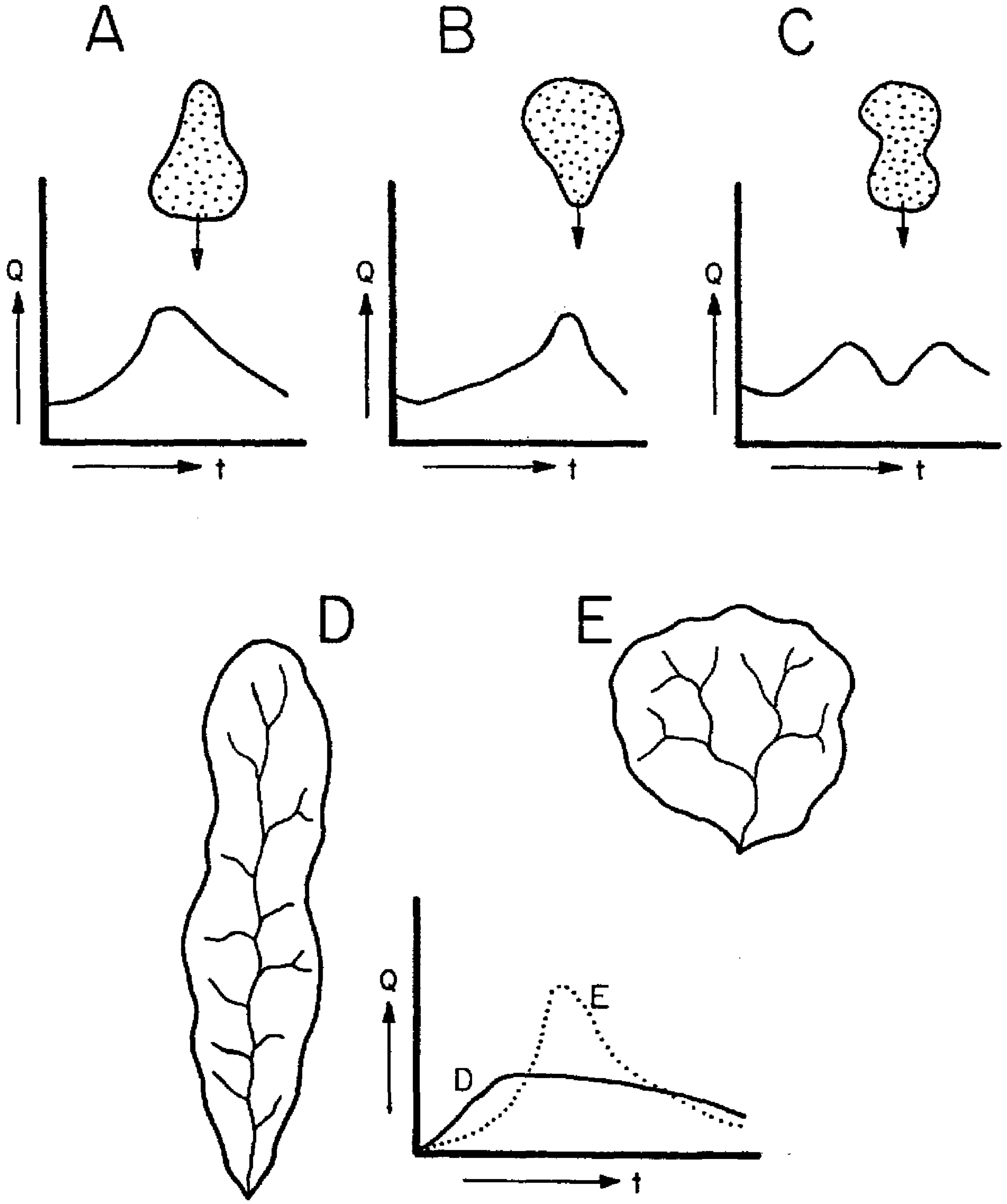

Figure B.2. The Significance of Drainage Basin Shape (A, B, C) and Network Pattern (D, E) on Hydrograph Response (DeWiest, 1965, and Strahler, 1964).

understanding drainage density. The law of stream lengths (Horton, 1945) can be stated as

$$\frac{L_{u+r}}{L_u} = R_L^r \qquad (B.1)$$

where L_u is the mean length of channel of order u, R_L is the ratio of the lengths of different order, and r is a positive integer.

Another measure of network structure is the bifurcation ratio R_b,

$$R_b = \frac{N_u}{N_{u+1}} \qquad (B.2)$$

where N_u is the number of stream segments of order u and R_b is the ratio of N to the number of segments of next higher order. Horton (1945) developed the law of stream numbers from equation B.2 which states that the number of stream segments of each order forms an inverse geometric sequence with order number, or

$$N_u = R_b^{k-u} \qquad (B.3)$$

where k is the order of the trunk segment.

Drainage density was defined by Horton (1932) as the ratio of total channel-segment lengths cumulated for all orders in a basin to the basin area A_k, or

$$D_d = \frac{\sum_{i=1}^{k} \sum_{u=1}^{N_i} L_u}{A_k} \qquad (B.4)$$

Horton (1945) combined the laws of stream numbers and lengths with his definition of drainage density to yield

$$D_u = \frac{L_1 R_b^{u-1}}{A_u} \frac{R_{Lb}^u - 1}{R_{Lb} - 1} \qquad (B.5)$$

where D_u is the drainage density of an entire basin of order u, R_{Lb} is the ratio of R_L to R_b, and other terms are as defined previously. This equation combines all the geometric factors which determine the composition of the drainage net of a stream system into one expression.

The average length of overland flow L_g is approximately one-half the average distance between stream channels, which equals the reciprocal of D_d. When modified for the effect of land and stream slope, Horton (1945) expressed this as

$$L_g = \frac{1}{2D_d\sqrt{1 - (\Theta_c/\Theta_s)}} \qquad (B.6)$$

where Θ_c is channel slope and Θ_s is average ground slope in the area.

Factors controlling drainage density are the same as those that control the characteristic length dimension of any group of first-order basins. In general, low drainage density is favored in regions of highly permeable soils, dense vegetative cover, and low relief. High drainage density is favored in regions of impermeable soils, sparse vegetation, and mountainous relief. Thus humid temperate areas tend to have lower densities compared to semi-arid regions. A comprehensive study of drainage density controls by Melton (1957) indicated a strong inverse relationship to the effective precipitation index of Thornthwaite (1948). Other independent variables such as infiltration capacity, vegetative cover, surface roughness, and runoff intensity were investigated. Of these, only surface roughness had no significant correlation with D_d. In another study, Carlston (1963) interpreted variations in drainage density according to terrain transmissivity.

The relationship of drainage density to basin output is perhaps most significant. The drainage network characterizes the infiltration capacity of soils and creates the density necessary for excess outflow from the basin. If channel patterns are constant, then discharge should be directly related to channel density because channel flow usually dominates the basin response. Runoff intensity depends to a large extent on drainage density (Melton, 1957). Mean annual flood is usually related to D_d in the form $Q_{2.3} \alpha D_d^2$, where $Q_{2.3}$ is flood discharge equalled or exceeded on the average once in 2.3 years, and indices of base flow are correlated to D_d (Orsborn, 1970; Trainer, 1969). Such static interpretations can give ambiguous results if the same values of D_d are related to different flow indices, and Gregory and Walling (1968) suggest an alternative method which considers the dynamic changes of D_d within a given watershed. They indicate that total channel length (L), which is directly related to D_d, increases with actual discharge (Q) in the form $Q \alpha L^2$.

Drainage density has been shown to be related to the average length of overland flow, soil moisture storage capacity, and rates of surface runoff via canals. By serving as a general indicator of volumes and flow rates, drainage density can be associated with a characteristic retention time for a particular land use type or entire drainage area. High values of the index are characterized by low retention times, and _vice versa_. Thus, the concept of drainage density as a measure of land use intensity fits nicely into the reservoir storage concept which has already been introduced.

As discussed earlier, retention time also plays a key role in determining nutrient loading and uptake rates. It follows that drainage density may serve as an indicator of nutrient levels emanating from a watershed because of the close relationships with retention time and land use. These effects are explored in more detail in Chapter IV.

RELATIONSHIP WITH LAND USE

Man-made alterations to the natural drainage patterns are common in regions where flat slopes and excessive rainfall create flooding problems. Such drainage activities tend to be associated with urban developments and high intensity agriculture. Citrus, cropland, and improved pasture are usually characterized by an extensive system of drainage canals, designed for water table control. Thus, drainage density is tied closely to land use patterns, and represents a useful index of land use intensity.

While other studies of drainage density have indicated the range in values to be expected from one watershed to another (Gregory and Walling, 1973), there has been very little work reported on variation within a watershed due to land use modifications. The Kissimmee River Basin has provided a useful study area because of the extremely flat slopes, generally uniform soil types, and the gradient of land use intensity which extends from Lake Kissimmee to Lake Okeechobee.

The initial survey of land use practice in the Kissimmee River Basin revealed a widespread shift to improved pasture condition from the original native range and marsh condition. As reported in Chapter III, the shift has been most pronounced in planning units 15 through 18, while 13 and 14 have remained in a relatively natural condition. Land use data for the original survey were analyzed on county highway maps (scale 1:126,720).

In order to obtain better estimates, a more detailed land use analysis has been undertaken utilizing 1:24,000 aerial photographs of the region, which correspond exactly to the U. S. Geological Survey quadrangle maps. The detailed survey revealed the necessity for distinguishing another land use category, ditched improved pasture, in addition to the others. The original survey only separated total improved pasture and unimproved pasture. Results presented in Table B.1 for major tributary systems depict not only an increase in the percentage of improved pasture below PU 14, but, more importantly, a major shift to ditched improved pasture in five of the seven areas evaluated. The results of the land use survey also indicated the need for more accurately determining the characteristics of the major drainage patterns in each planning unit, with the intent of explaining some of the observed nutrient loading rates.

Table B.1. Land Use Analysis of Kissimmee River Tributaries.
(Areas in Sq Mi and Percent)

Planning Unit & Watershed	Land Use Category: Urban	Crop land	Improved Pasture	Unimproved Pasture	Citrus	Forest	Marsh & Swamp	Ditched Improved Pasture	Total Area	Percent Sampled
(13) Ice Cream Slough	0 0	0 0	2.07 19.2%	6.76 62.8%	0 0	.93 8.6%	1.01 0.4%	0 0	60.34	17.8%
(13) Blanket Bay Slough	0 0	0 0	1.12 22.4%	1.68 33.6%	0 0	.10 2.1%	1.06 21.1%	1.04 20.8%	26.32	18.9%
(14) Pine-Island & Seven Mile Slough	0 0	0 0	3.14 16.7%	9.06 48.2%	0 0	.23 1.2%	5.57 29.7%	.77 4.1%	98.85	19.0%
(15) Oak Creek	0 0	0 0	.91 45.7%	.04 2.0%	0 0	0 0	.48 24.1%	.57 28.6%	9.76	20.3%
(16) Chandler Slough	0 0	0 0	2.30 31.9%	1.39 19.3%	0 0	.01 0.1%	1.31 18.1%	2.25 31.1%	48.96	14.7%
(16) Cypress Creek	0 0	0 0	3.68 22.1%	3.36 20.0%	0 0	.46 2.7%	3.96 23.7%	5.24 31.4%	67.30	24.8%
(17) Yates Marsh	0 0	0 0	2.07 49.9%	.36 8.8%	0 0	.18 4.3%	1.42 34.2%	.11 2.8%	21.91	18.9%

MEASUREMENT OF DRAINAGE DENSITY

The measurement of D_d is a time consuming effort because maps or aerial photographs must be thoroughly searched for the total length of drainage paths. Several techniques are available including (1) the blue line method on U. S. Geological Survey Topographic Maps (Horton, 1945), (2) the rapid line intersections method (Carlston and Langbein, 1960), and (3) the complete analysis of aerial photographs. The first two methods have the advantage of speed, but the third method is decidedly more accurate.

The detailed measurement of drainage lengths and areas on 1972 Mark Hurd aerial photographs was greatly simplified by the use of a Hewlett Packard Calculator (Model 9810) and Digitizer (Model 9864A), which measures lengths to a resolution of 0.01 in. Areas are obtained by integration on the calculator to a resolution of 0.0001 in^2. The analysis of land use areas on the 1:24,000 scale aerial photos involves the use of 12 equally-spaced sample plots, in the shape of circles with 3 in diameters, which are overlaid on each photograph. The sample area represents from 15 to 25 percent of the total aerial photograph area depending on the size of the watershed (see Table B.1). The overall land use pattern is determined by summing all the sample plot results for each subwatershed. The digitizer technique thus provides a rapid and accurate estimate of drainage lengths and land use areas from aerial photographs.

Measurements in the Kissimmee River Basin indicate the relative accuracy of these techniques for selected subwatersheds. Table B.2 shows that for the relatively natural areas, the blue line map method underestimates the value of D_d obtained from 1:24,000 aerial photographs. This is due to the fact that the quadrangel maps do not include all of the drainage lengths contained on the aerials. Conversely, the rapid line intersection method overestimates the value of D_d from the aerials. This method involves drawing a line of known length (L) in miles on a contour map and counting the number of streams (n) which intersect the line. D_d (mi/sq mi) is then approximated by

$$D_d = 1.41 \, n/L \qquad (B.7)$$

Electronic scanning of aerial and infra-red photographs in order to detect changes in film intensity has also been utilized (McCoy, 1971).

Giusti and Schneider (1962) compared maps of different dates and scales for the Piedmont area, finding variation in D_d from 2.3 to 5.2 mi/sq mi and from 0.69 to 3.1 mi/sq mi at two different map scales. The values ranged from 0.23 to 5.2 mi/sq mi on map scales from 1:250,000 to 1:24,000. Similarly, Selby (1968) showed in New Zealand that densities of 5.4 mi/sq mi compared with densities of 2.8 from 1:15,840 scale maps. Morisawa (1957) suggested, based on statistical analysis, that measuring blue lines on topographic maps is inaccurate and should not be used for watersheds less than 2.68 sq mi in drainage area. Similar inaccuracies apply in the Kissimmee River Basin where planning unit areas range from 45 to 223 sq mi.

Table B.2. Drainage Density Measurements in the Kissimmee River Basin (Mi/Sq Mi).

	Planning Unit 13	Planning Unit 14	Lower Basin
Scale (1:24,000)			
Line Intersection Map Method	1.62	2.10	
Blue Line Map Method	1.07	0.64	
Aerial Photographs	1.41	1.17	1.82
Scale (1:126,720)			
County Road Maps	1.19	1.06	1.12
Scale (1:250,000)			
USGS Maps	0.62	0.44	0.45

One of the main sources of map error, then, is the definition of stream length as compared to an associated aerial photograph. Drummond (1974) reviews the standards for including perennial and intermittent streams on topographic maps of various United States agencies. The U. S. Geological Survey includes all of those streams up to 1000 ft from the divide, and greater than 2000 ft in length for intermittent reaches. No length limitations are provided for perennial streams. Standards used by various agencies are presented in Table B.3.

Map scale has a significant effect on the value of D_d in the study area. Table B.2 shows that the larger the map scale, the lower the predicted level of D_d because drainage detail is sacrificed as map scale is increased. In addition, the county highway maps (1:126,720) do not give a proper indication of the differences in D_d for planning units along the river when compared to the 1:24,000 scale results. It appears that the 1:24,000 scale aerial photographs provide the most accurate measure of the drainage network. Because 1972 Mark Hurd aerials were available for the entire Kissimmee River Basin, it was decided to use them to analyze D_d in detail. The aerials correspond to U. S. Geological Survey quadrangle maps of the region, and a list of these along with map dates is presented in Table B.4.

The actual measurement technique distinguishes among natural, modified natural, and man-made drainage paths only in the accounting. No attempt is made to separate hydraulic or nutrient loading capabilities. Drainage lengths which are measured include natural sloughs, tributaries, channels, and agricultural or urban drainage canals. Marsh, swamp, and pond areas are not specifically included unless they are part of a defined drainage path. Typical areas are shown schematically in Figure B.3.

Final results of analyzing the tributaries in the lower basin of the Kissimmee River are presented in Table B.5. Figure B.4 shows the

Table B.3. Standards for Inclusion of Streams on Topographic Maps of U.S. Mapping Agencies.

Agency Basic Scales (> 1:75,000) Date of Information	Perennial: Basic Inclusion Criteria	Perennial: Channel Criteria	Perennial: Minimum Stream Length (ground) (map)	Perennial: Headwaters Termination (ground) (map)	Intermittent: Basic Inclusion Criteria	Intermittent: Channel Criteria	Intermittent: Minimum Stream Length (Ground) (Map)	Intermittent: Headwaters Termination (Ground) (Map)
U.S. Geological Survey 1:24,000—1:31,680—1:48,000 1969 —1:62,500—1:63,360	All Perennial Streams	Established Channels	No Limitations as to Length	1,000 Feet from Divide	All Intermittent Streams	"Dry Wash" Inclusion in Arid Areas	2,000 Feet	1,000 Feet from Divide
U.S. Army Topographic Command 1:12,500—1:25,000—1:50,000 1970	All Perennial Streams	Normal Flow Channels Are Shown	½ Inch (Well-Watered Areas) ¼ Inch (Arid Areas)	½ Inch from Divide	Maximum Number of Drainage Features	Normal Flow Channels Are Shown	½ Inch (Well-Watered Areas) ¼ Inch (Arid Areas)	½ Inch from Divide
Tennessee Valley Authority 1:24,000 1970	Not Distinguished from Intermittent Streams	Established Channels	1,000 Feet	1,000 Feet from Divide	Not Distinguished from Perennial Streams	Established Channels	1,000 Feet	1,000 Feet from Divide
Bureau of Land Management 1:31,680—1:63,360 1970	All Flowing Streams	Established Channels	No Limitations as to Length	——	Every Channeled Stream	Established Channels and Washes	½ Mile	——
Forest Service 1:24,000 1970	All Flowing Streams	Established Channels	Not a Limiting Criterion	——	——	All Established Channels	Not a Limiting Criterion	——
Soil Conservation Service 1:15,840—1:20,000—1:24,000 1969	All Perennial Streams	All Channeled Streams	¼ Inch	To Source of Stream	Some Nonchanneled Drainage Shown	All Established Channels	¼ Inch	To Source of Stream
Coast and Geodetic Survey 1:40,000—1:50,000—1:51,000 1969	All Perennial Streams	Established Channels	No Limitations as to Length	1,000 Feet from Divide	——	Established Channels	2,000 Feet	1,000 Feet from Divide
Oceanographic Office Dept. of the Navy Various Scales 1970	Aid to Navigation	Navigable Streams: to Limit of Navigation; Nonnavigable Streams: Limited to Navigation Aids	No Limitations as to Length	——	Aid to Navigation	Nonnavigable Streams: Limited to Navigation Aids	No Limitations as to Length	——
Lake Survey Center Dept. of Commerce (since 1970) Various Scales from 1:2,500 1970	All Perennial Streams	Any Permanent Channel	½ Inch (Well-Watered Areas)	To Stream Source	——	Any Permanent Channel	1.6 Inch (Well-Watered Areas) ¼ Inch (Arid Areas)	——

(From Drummond, 1974, p. 35-36.)

Table B.4. List of USGS Quadrangle Maps for the Kissimmee River Basin.[a]

USGS Quad Name	Date	Date Revised	Planning Units Included
Winter Garden	1956		2
Orlando East	1956		3
Orlando West	1956		3,2
Lake Louisa	1959		1
Windermere	1953		2,1
Lake Jessamine	1953		2,3
Pine Castle	1953		3,4
Narcoossee NW	1953		4
Lake Louisa SW	1959		1,7
Intercession City	1953		1,2
Kissimmee	1953		1,2,5
St. Cloud N	1953		3,5
Narcoossee	1953	1970	3,4,6
Narcoossee SE	1953		4
Gum Lake	1959		7
Davenport	1953	1970	1,7
Lake Tohopekaliga	1953		1,2,5,7
St. Cloud S	1953	1970	3,5,6,8
Ashton	1953	1970	3,4,6
Holopaw	1953	1970	4,6
Dundee	1953	1970	7,9
Lake Hatchineha	1953		1,8,7,9
Cypress Lake	1953	1970	1,5,6,8,10
Holopaw SW	1953		6,8,10
Holopaw SE	1953		6,11
Lake Wales	1952		9,12
Hesperides	1952		8,9,10,12
Lake Weohyakapka NE	1952		8,10
Lake Marian NW	1953		10,11
Lake Marian NE	1953		11
Babson Park	1952		12
Lake Weohyakapka	1952		10,12
Lake Weohyakapka SE	1952		10,12,13
Lake Marian SW	1953		10,13
Lake Marian SE	1953		10,11,13
Lake Arbuckle NE	1952		13,14
Fort Kissimmee NW	1952		13,14
Fort Kissimmee NE	1953		13,14
Fort Drum NW	1953		14
Lake Arbuckle SE	1952		14
Fort Kissimmee	1952		14,15
Fort Kissimmee SE	1953		14,15,16
Fort Drum SW	1953		14,16
Lorida	1952		15
Basinger NW	1953		15
Basinger	1953		15,16

Table B.4. Continued

USGS Quad Name	Date	Date Revised	Planning Units Included
Taylor Creek NW	1953		16,17
Basinger SW	1953		15,16
Fort Basinger	1953		16,17,18
Taylor Creek SW	1953		16,17
Brighton	1953		17,18
Okeechobee NW	1953		17,18
Okeechobee	1953		18

[a]Corresponding Mark Hurd aerial photographs (1972-73 edition) available from Mark Hurd Aerial Surveys, Inc., 345 Pennsylvania Ave. So., Minneapolis, Minn. 55426.

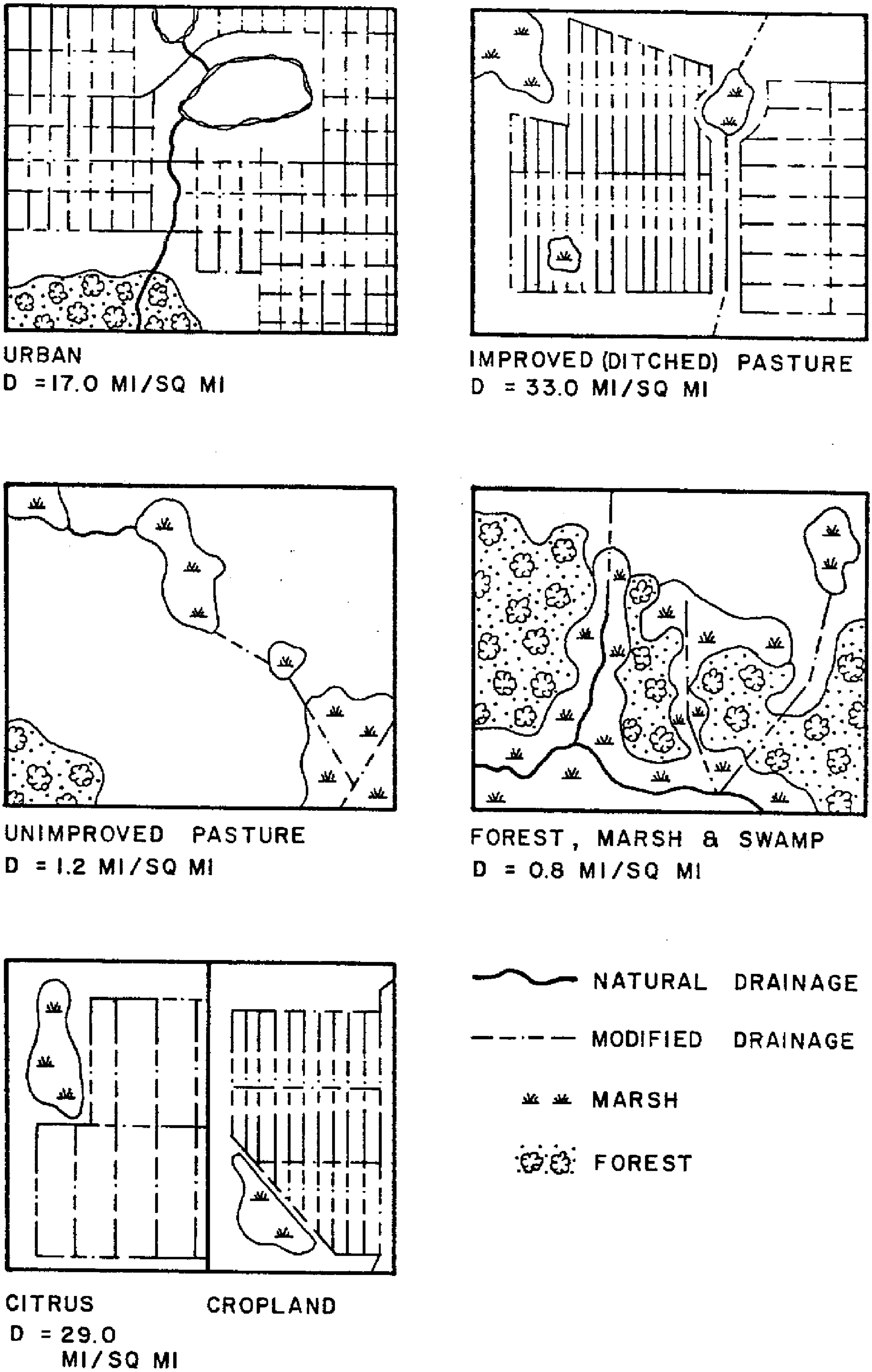

Figure B.3. Schematic of Land Use and Measured Drainage Density.

Table B.5. Drainage Density in the Lower Kissimmee River Basin.

Planning Unit & Watershed	Drainage Characteristics (length (L) in mi, area (A) in sq mi, drainage density (D_d) in mi/sq mi) Manmade	Modified Natufal	Natural	Drainage Density
(13) Ice Cream Slough	L = 5.21 A = 0.23 D_d = 22.65	L = 73.43 A = 60.11 D_d = 1.41	L = 11.52	1.49
13	L = 290.64 A = 9.37 D_d = 31.02	L = 168.50 A = 136.96 D_d = 1.54	L = 42.14	3.42[a]
14	L = 408.03 A = 12.51 D_d = 32.62	L = 103.87 A = 212.47 D_d = 1.17	L = 145.39	2.92[a]
15	L = 205.93 A = 7.09 D_d = 29.04	L = 74.76 A = 60.65 D_d = 2.15	L = 36.36	4.92[a]
(16) Chandler Slough	L = 381.96 A = 14.49 D_d = 26.36	L = 45.73 A = 34.47 D_d = 2.15	L = 28.54	9.32
(16) Cypress Creek and Chandler Slough	L = 739.67 A = 34.25 D_d = 21.59	L = 101.50 A = 82.00 D_d = 1.84	L = 49.69	7.65[a]
(17E) Yates Marsh	L = 135.10 A = 4.75 D_d = 28.44	L = 41.83 A = 38.92 D_d = 2.01	L = 36.53	4.89[b]
(17W) Maple River	L = 94.25 A = 4.58 D_d = 20.60	L = 26.47 A = 10.93 D_d = 2.58	L = 1.75	7.90[b]

[a]Denotes value for planning unit.

[b]Average D_d for PU 17 = 5.68 mi/sq mi.

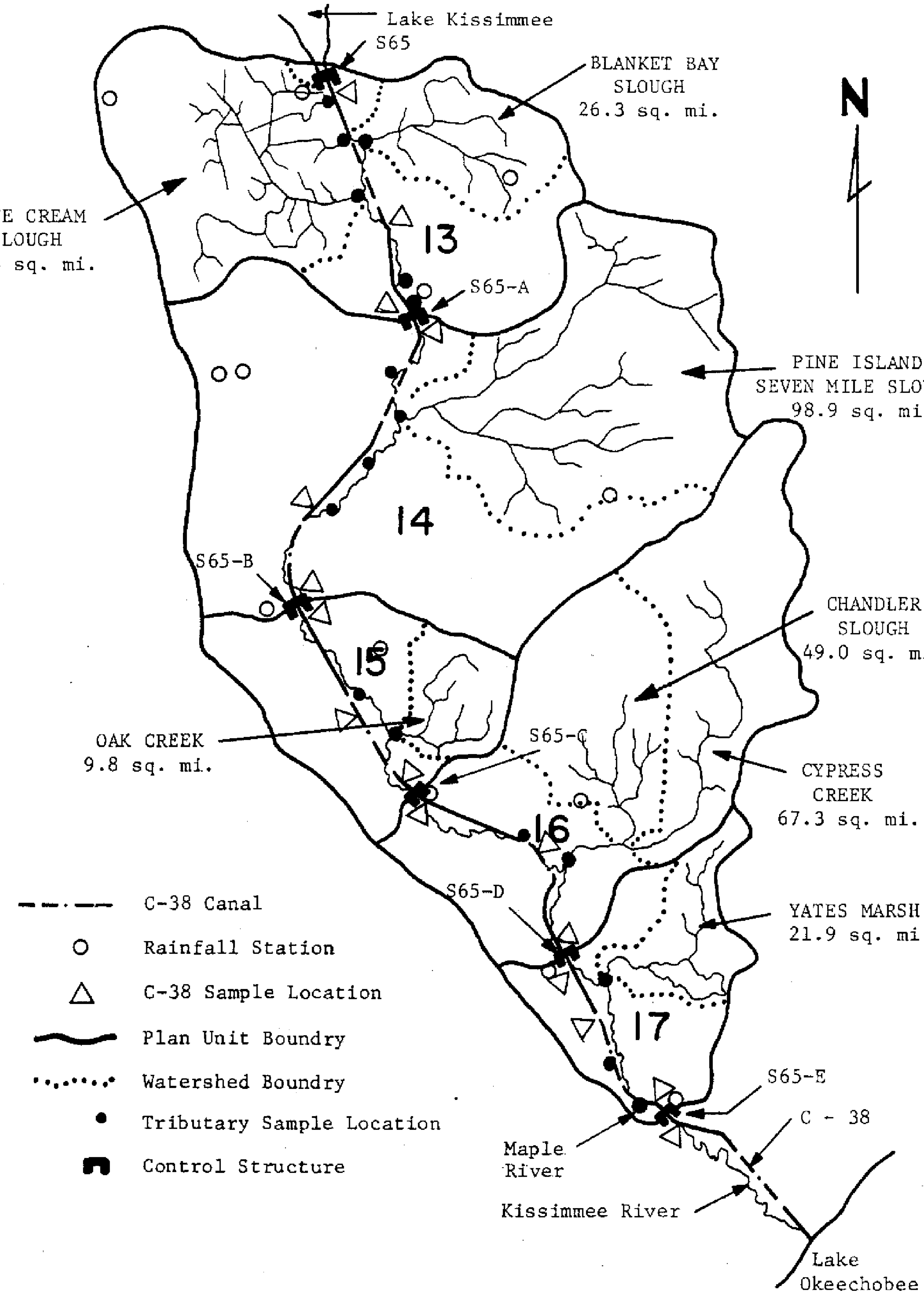

Figure B.4. Tributaries in the Lower Kissimmee River Basin.

respective locations of these subwatershed areas. Man-made densities range from 18 to 33 mi/sq mi and include only those areas which have been intensively ditched for improved pasture, citrus, crops, or urban use. The modified natural category includes natural range, forest, and marsh areas which may have been partially channelized by connecting ponds or sloughs together. Natural densities range from 1.2 to 2.6 mi/sq mi and include all areas of natural drainage devoid of any channel modifications.

The overall average drainage densities combine the three drainage types into a single index for a given planning unit or slough system. Planning unit values range from 2.92 to 7.65 mi/sq mi while individual sloughs range from 1.49 to 9.32 mi/sq mi. Those areas dominated by ditched improved pasture tend to have the highest drainage densities, and these are schematically presented for each planning unit in Figures B.5 through B.9. As one proceeds north from Lake Okeechobee, a definite break-point occurs in the plot of total drainage length versus drainage area, indicating that regions south of S65-C have higher drainage densities (Figure B.10). The values range from 3.33 mi/sq mi to 5.88 mi/sq mi.

The range in measured values of drainage density in the Kissimmee River Basin compares favorably with other values reported for watersheds in the eastern United States where the average is 4.0 mi/sq mi. These are at the low end of the spectrum compared to drainage densities in arid regions, which range from 10 to 100 mi/sq mi (Figure B.11). Further data are available on drainage densities in other parts of the Lake Okeechobee basin as well (Gatewood and Bedient, 1975).

SUMMARY

Accurate measurements of drainage density were made for the Lower Kissimmee River Basin through the use of a digitizer to obtain stream lengths and catchment areas from recent aerial photos. Computed values for natural areas ranged from 1.17 to 2.58 mi/sq mi, placing them in a range characteristic of humid areas with low relief. Agricultural and other areas showed order of magnitude increases over the natural values.

Drainage density is thus likely to be a strong indicator of the effect of modifications of the natural environment. Interrelationships with both water quantity and water quality are discussed in Chapter IV.

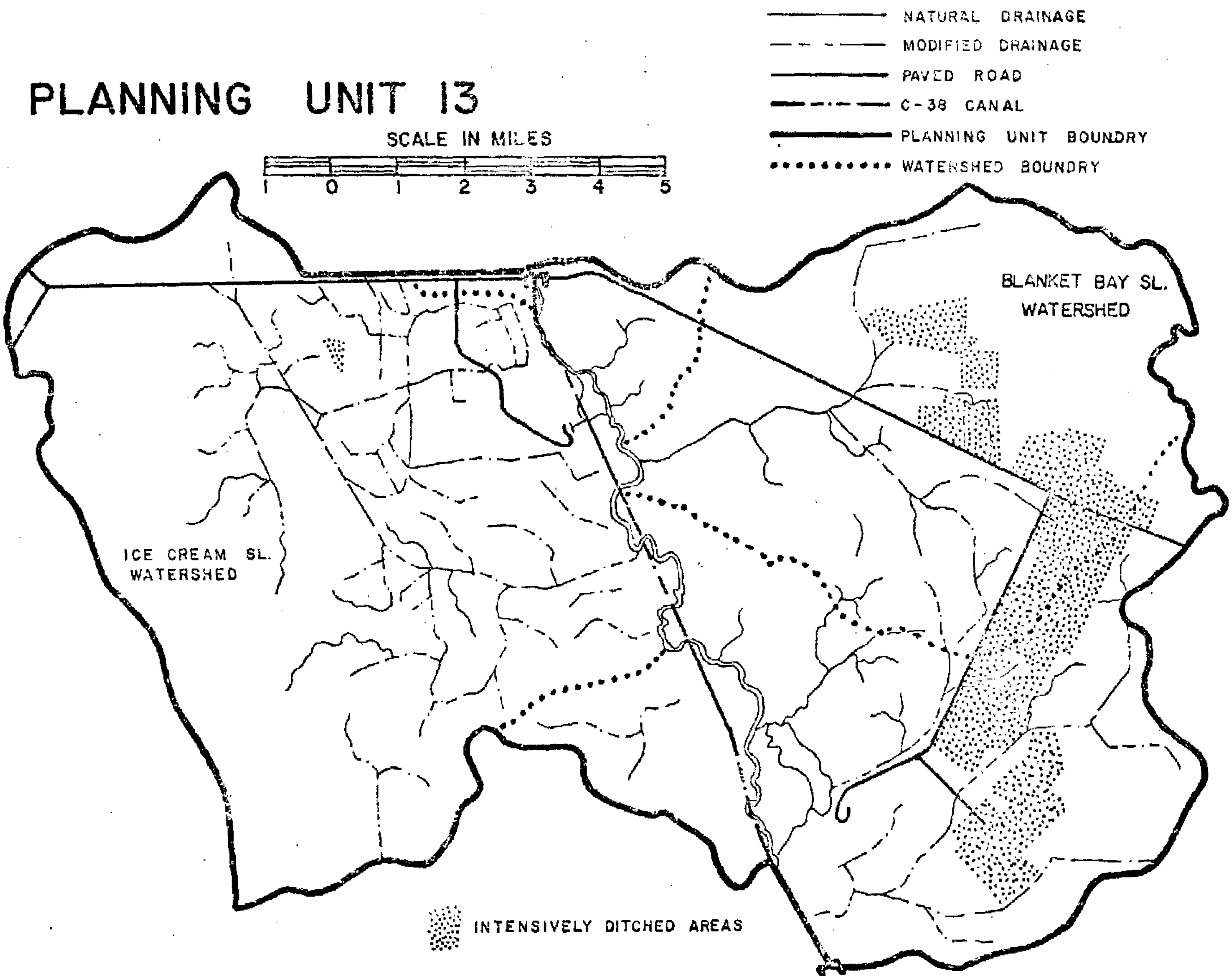

Figure B.5. Drainage Map of Planning Unit 13.

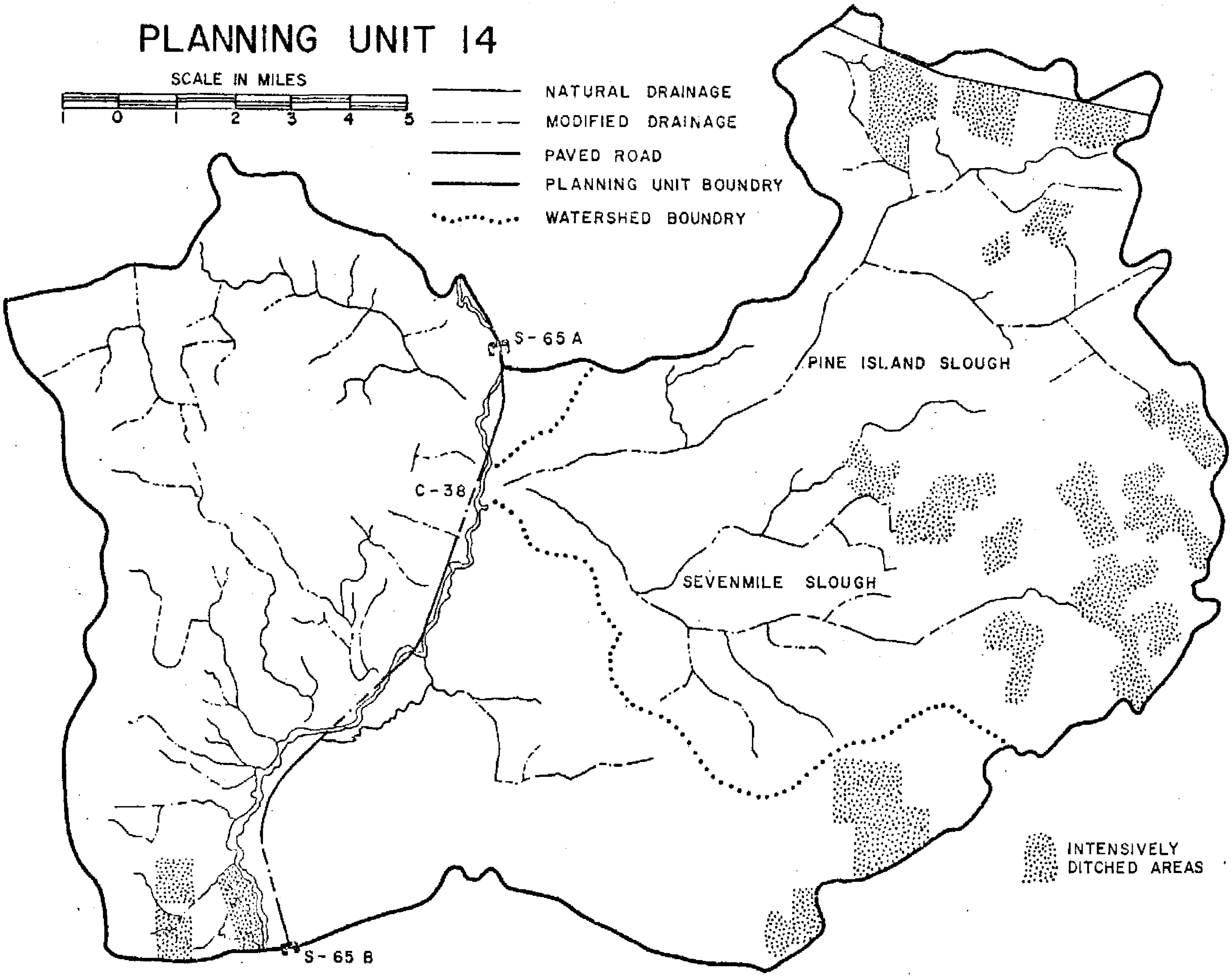

Figure B.6. Drainage Map of Planning Unit 14.

PLANNING UNIT 15

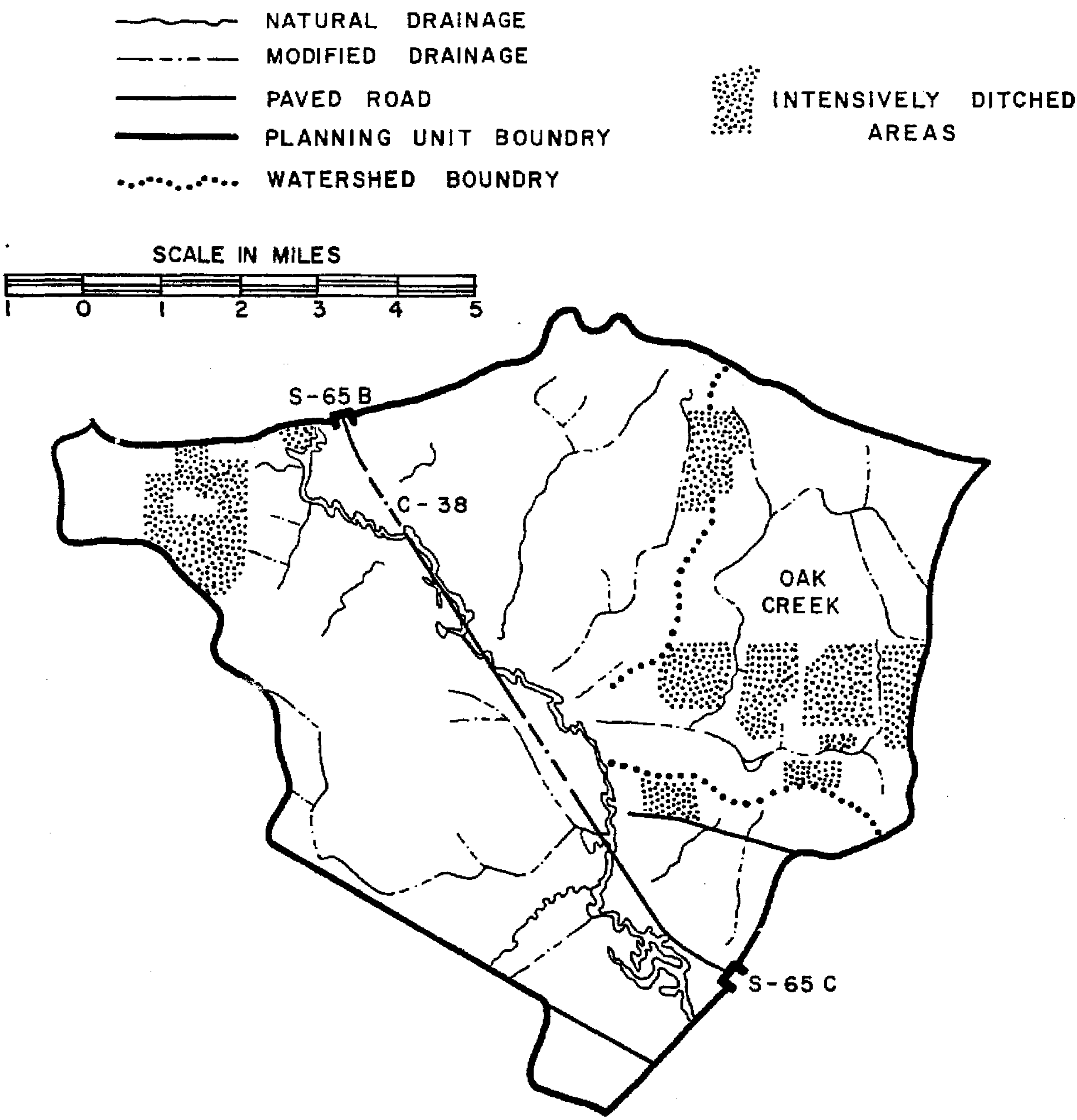

Figure B.7. Drainage Map of Planning Unit 15.

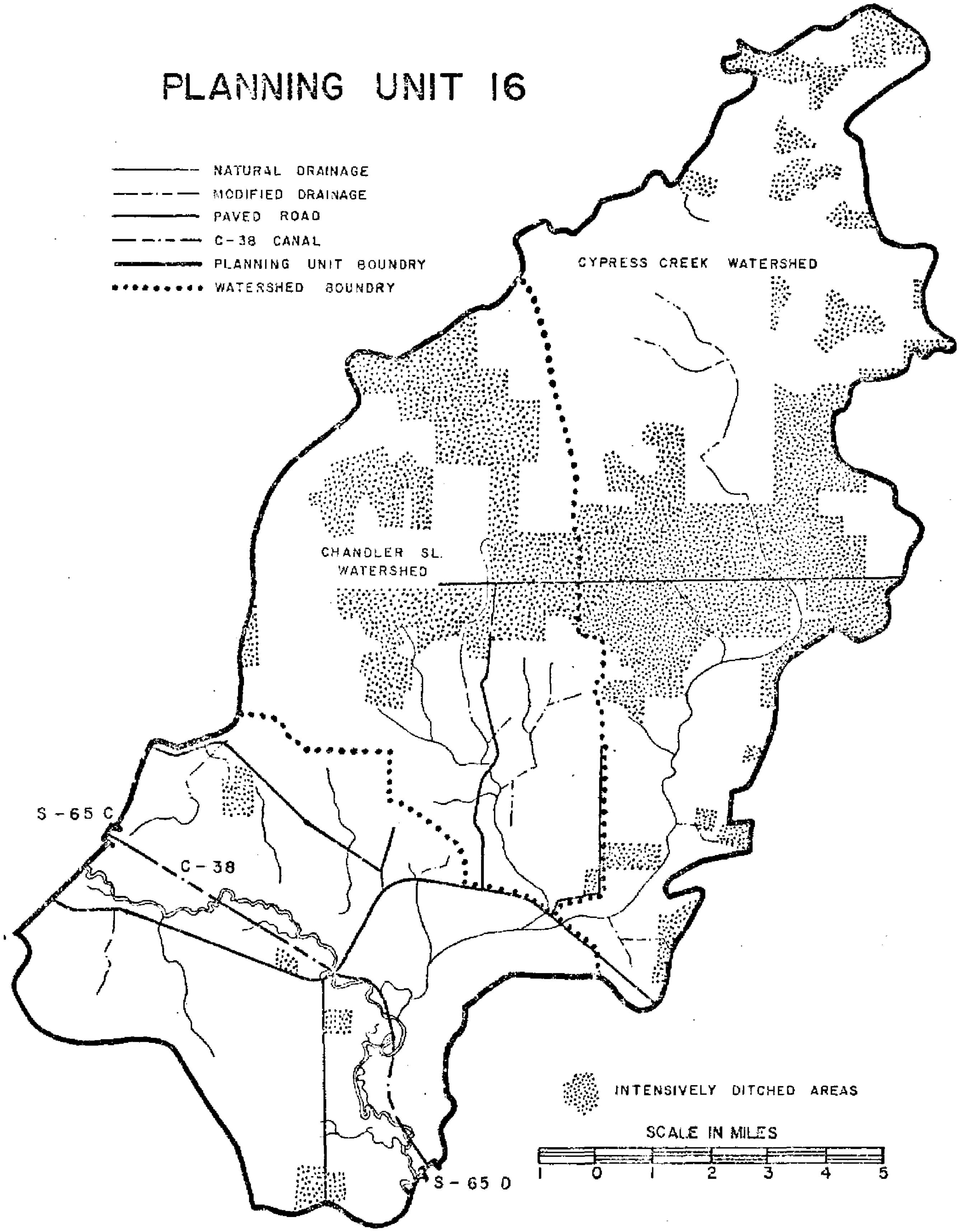

Figure B.8. Drainage Map of Planning Unit 16.

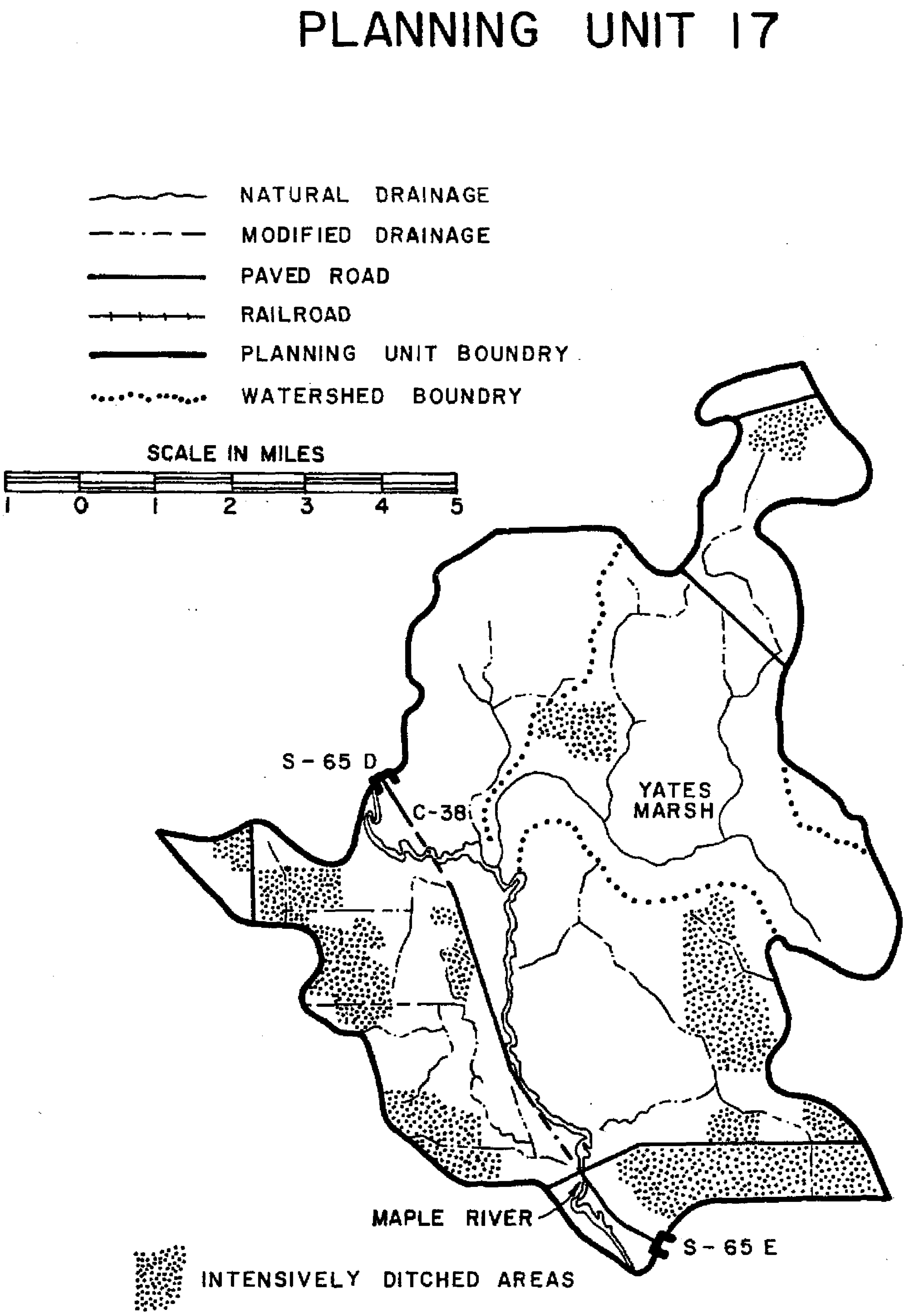

Figure B.9. Drainage Map of Planning Unit 17.

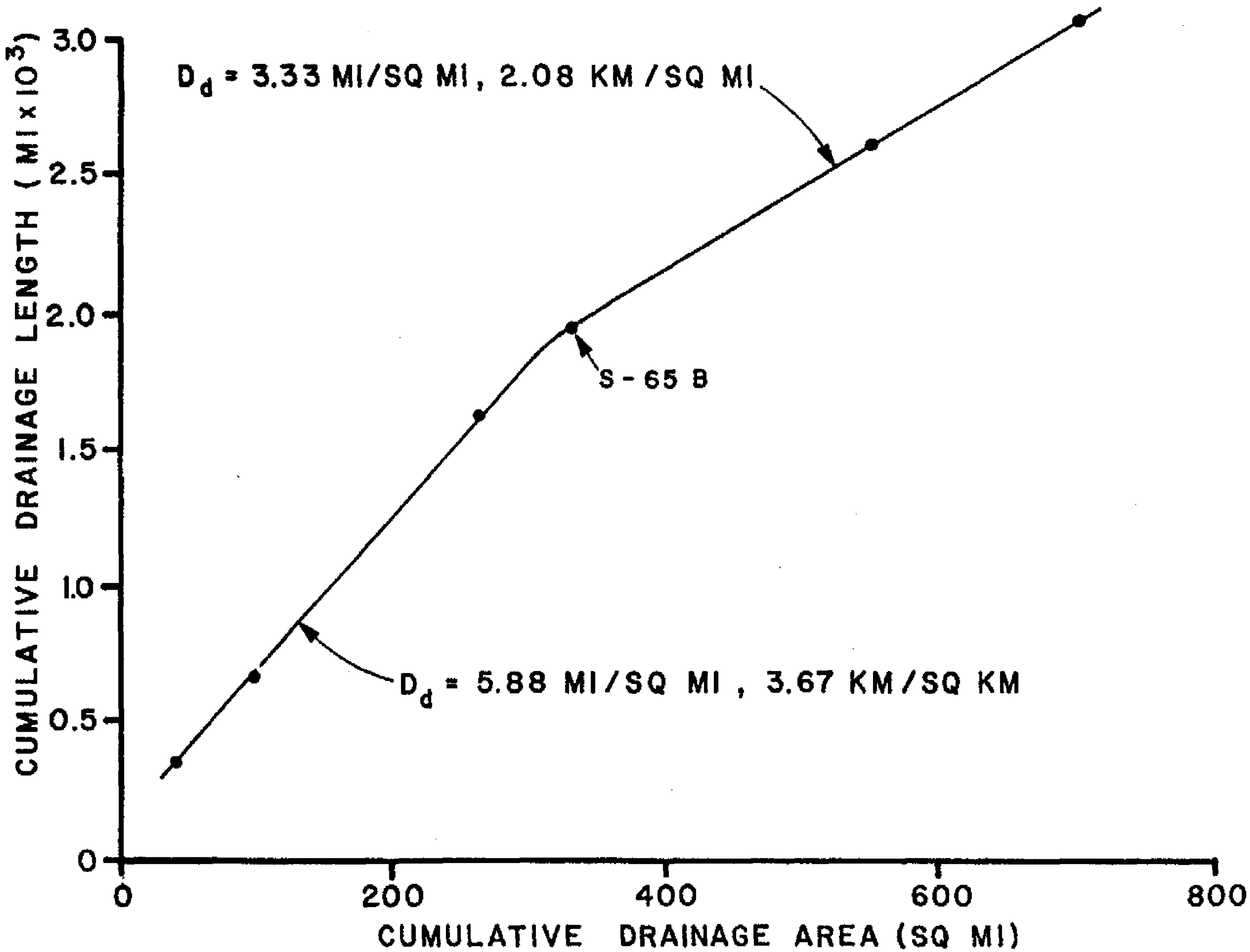

Figure B.10. Drainage Length and Basin Area (North from Lake Okeechobee) in the Lower Kissimmee River Basin.

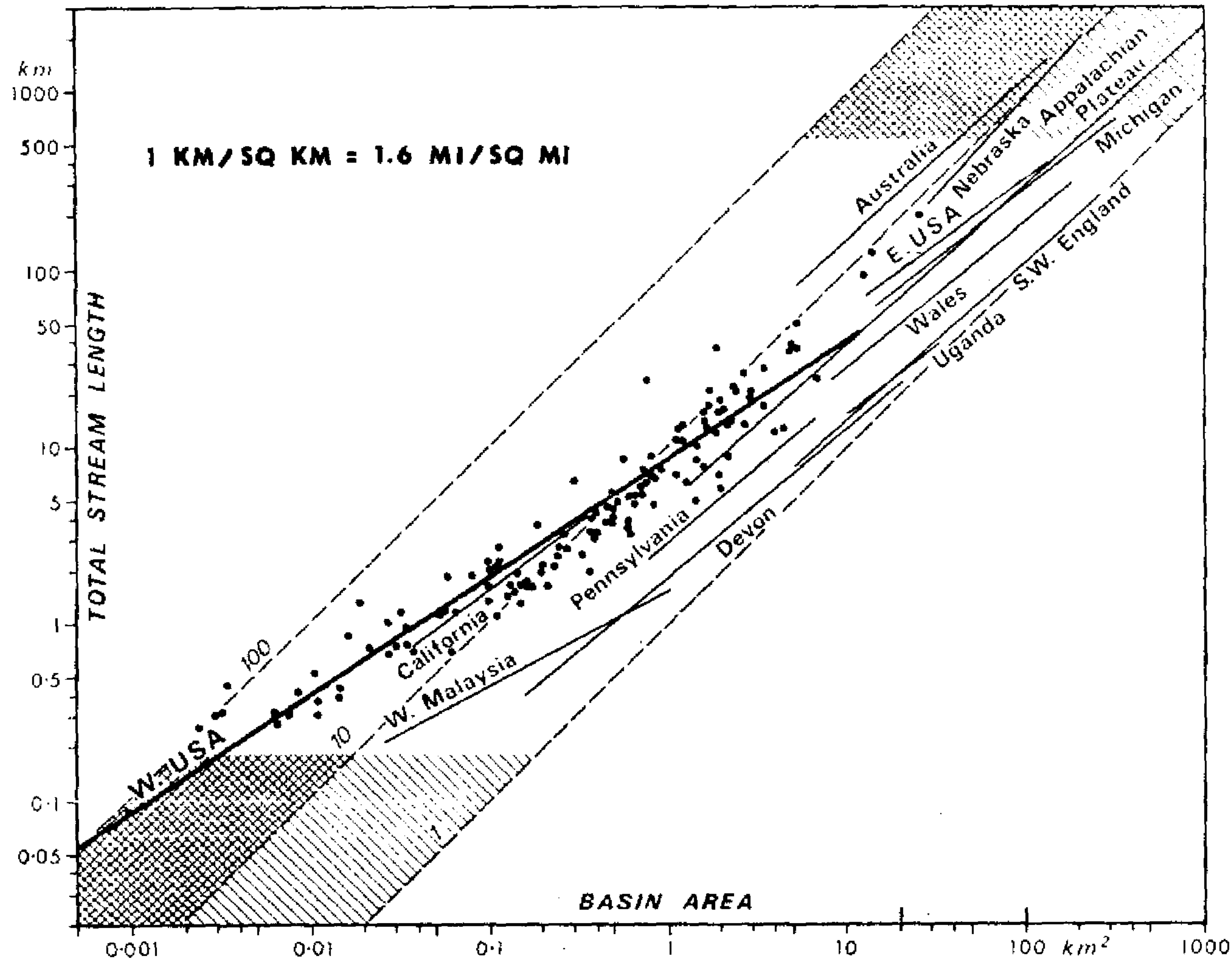

Figure B.11. Drainage Length and Basin Area Relationships (Gregory and Walling, 1973).

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