HYDROLOGIC, SOILS AND VEGETATION MEASUREMENTS FOR A SOUTHERN NEW JERSEY HARDWOOD SWAMP

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Abstract.--A 10 x 10 meter grid system was established for a 1.02 ha. hardwood swamp consisting of *Acer rubrum*, *Nyssa sylvatica*, and *Magnolia virginiana*. The grid system was used to map the precise locations of all trees and to establish 29 permanent wells evenly distributed throughout the site. The wells consisted of 2.0 meter sections of 5.1 cm. diameter PVC pipe. Soil samples were collected, and chemically analyzed. The elevations of all wells were determined, and water levels were periodically measured. Computer maps (SYMAP, Harvard) of tree locations, well elevations, and water table levels were drawn and analyzed to determine if horizontal tree distribution patterns were related to soil differences and/or variations in water table depth. The maps revealed precise spatial distribution patterns for the various tree species. Significant chemical soil differences are coincidental with differing patterns of tree distribution, but do not appear to explain these differences. Water table fluctuations account for the soil differences and provide the best explanation for differences in tree distribution pattern.

Additional keywords: Computer mapping, New Jersey Pine Barrens, red maple, tupelo, (blackgum), sweetbay magnolia.

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Little information is currently available concerning the hydrologic features of southern New Jersey wetland forests. These forests which vary floristically in composition are widespread in over half of New Jersey's landscape. More importantly, they are typical of forest wetlands distributed throughout most of the eastern United States. (Hall and Penfound, 1943; Reiners, 1972; Robichaud and Buell, 1973; Conner and Day, 1976; Schlesinger, 1978; and Brown et al., 1979).

These New Jersey wetlands are located primarily in The Outer Coastal Plain physiographic province of New Jersey. Topography for the region is characterized by slight, almost imperceptible relief. Elevation for the Outer Coastal Plain rises from 1.0 meter above sea level on the coast to 120.0 meters on the inland edge of the Plain. The Plain which constitutes 45% of New Jersey's land mass, consists of marine sandy soil deposits up to 2,100 meters thick. Forested wetlands in the area are interspersed with upland pine-oak or oak-pine forests. Wetland forests may be as little as 3.0 meters above sea level and contrast with upland forest areas only 9.0 meters above sea level.

Major tree species which may be encountered in these wetlands include red maple (*Acer rubrum* L.), tupelo or blackgum (*Nyssa sylvatica* Marsh.), sweetbay magnolia (*Magnolia virginiana* L.), Atlantic white cedar (*Chamaecyparis thyoides* L.), American holly (*Ilex opaca* Ait.), sweetgum (*Liquidambar styraciflua* L.), and southern red oak (*Quercus falcata* Michx.). Recent studies focusing on forest biomass, nutrient characteristics, and productivity have provided much new information on the quantitative ecology of these forested wetlands (Reynolds et al., 1978a, 1978b, 1979).

Information on the hydrology of these wetland forests has lagged behind that for other types of forest ecosystems. Much is known concerning the hydrologic characteristics of mountainous forested watersheds (Likens et al., 1967; Hornbeck et al., 1970; Johnson and Swank, 1973; and Harris, 1977). Despite this experience gained in working with other types of forested ecosystems, approaches for obtaining hydrologic data from ecosystems such as the one at Hubbard Brook are useful only in a general way when applied to wetland ecosystems not directly underlain by a bedrock base. New hydrologic approaches need to be and are in the process of being developed for studying forested wetlands. This need is especially prominent in southern New Jersey where forested wetlands are principally underlain by sand and bedrock is at an approximate depth of 2,100 meters.

In these wetland forests, it has long been felt that water first and soil second are the primary factors affecting plant species distributions (Harshberger, 1970 and Robichaud and Buell, 1973). Numerous investigators working with other ecosystems have applied statistical methods to this long

standing ecological problem in an attempt to positively correlate vegetation distributions with specific environmental parameters. In recent years a fundamental approach to this problem has been to utilize the technique of principle components analysis (Walker and Wehrhahn, 1970; and Page, 1976).

In the last decade the technique of computer graphics was first utilized to study plant community structure (Siccama, 1972). Despite its potential applicability to old ecological problems, computer graphics has not been capitalized upon to the fullest extent possible. When applied in new and imaginative ways, computer graphics provide a powerful tool for examining water and vegetation characteristics in wetland ecosystems. When applied to New Jersey forested wetlands, computer graphics provide (1) a new hydrologic approach for investigating an ecosystem atypical of previously studied forested ecosystems and (2) a new approach for examining the unsolved and recurring ecological problem of whether vegetation distributions are positively or negatively correlated with environmental parameters such as water or soil.

In this paper we have used computer graphics to study a southern New Jersey hardwood swamp with the intent of showing that computer graphics (1) can be used to monitor hydrologic events in wetland ecosystems and (2) positively correlate the distributions of wetland vegetation with water and soil parameters.

METHODS

Site Description

The study site (Figure 1) is located on the Stockton State College campus within Atlantic County, New Jersey (latitude 39° 27'; longitude 74° 33'), and has been previously described in detail (Reynolds et al., 1978a; Reynolds et al., 1979). The site is a part of a larger swamp ecosystem within the Stockton Ecological Preserve which includes an Atlantic white cedar stand (Reynolds et al., 1978b). The study site is 1.02 ha. in size, varies from 40 to 70 meters wide, and is 190 meters long.

Major tree species for the study site include red maple (*Acer rubrum* L.), tupelo (*Nyssa sylvatica* Marsh.), and sweetbay magnolia (*Magnolia virginiana* L.). Table 1 summarizes the major phytosociological characteristics for these species. The tupelos occur on the drier edges of the swamp, whereas the magnolias and large maples occur primarily in the center of the swamp. A few of the red maples are as large as 40.6 cm. diameter, although most are under 30.5 cm. dbh. Individuals in the population which are most numerous are those 10.2 or 17.8 cm. dbh. Most tupelos are under 15.2 cm. diameter, and most magnolias are under 7.6 cm. dbh. Respective heights for the three species do not exceed 16.9, 14.7, and 13.2 meters. Ages for the three species range from 51 to 101

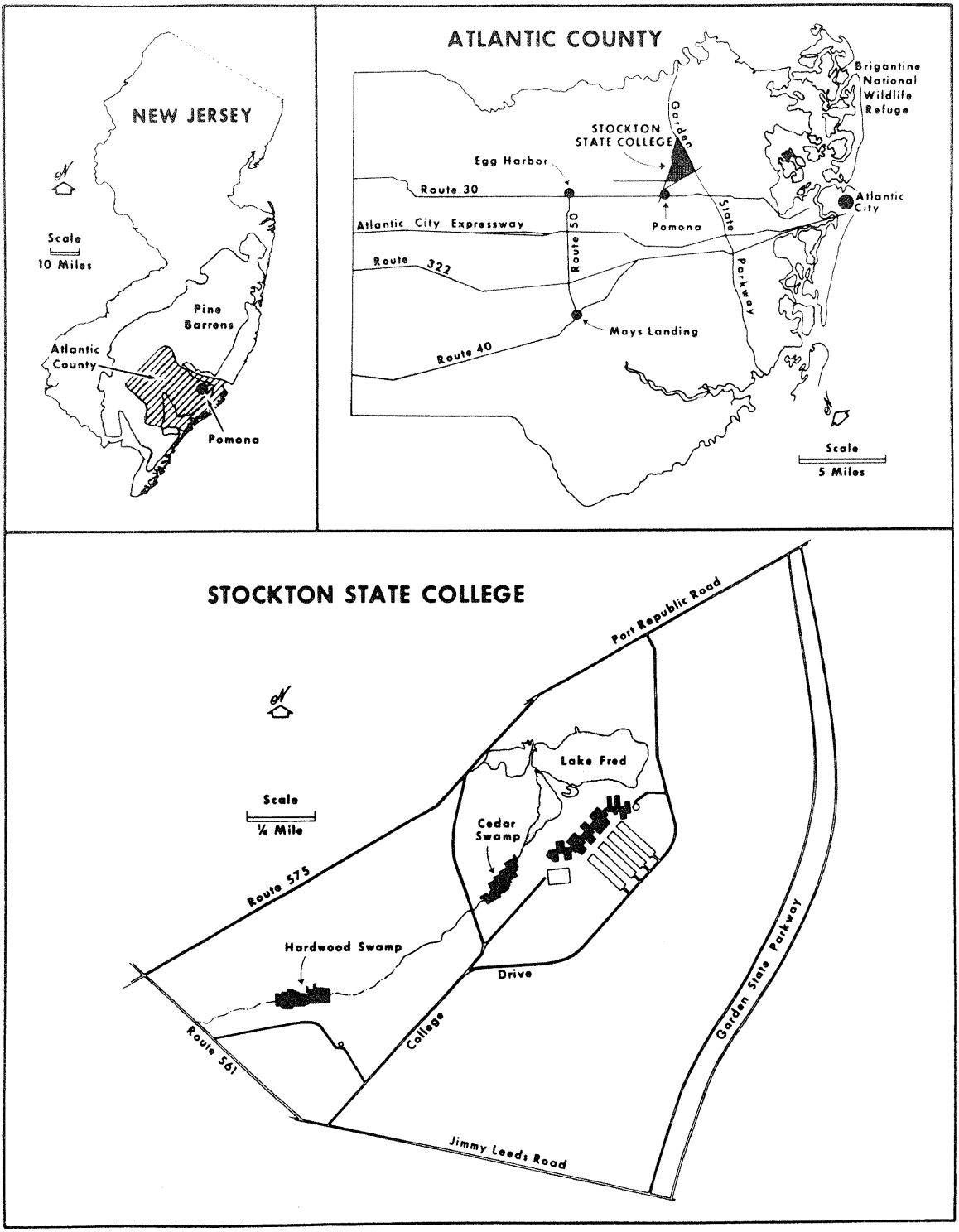

Figure 1.--Location of the hardwood swamp.

years for maple, from 46 to 63 years for tupelo, and from 16 to 82 years for magnolia. Productivity for the three species varies: maple is the most productive and tupelo is the least productive (Reynolds et al., 1979).

Table 1.--Summary of vegetation characteristics for the hardwood swamp

Species	Density (stems/ha.)	Basal Area (m^2/ha.)	Frequency (% occurrence)	Above-Ground Standing Crop Biomass (kg./ha.)
Red maple	756	11.85	88	295,535
Tupelo	511	3.17	66	13,387
Sweetbay magnolia	361	0.41	67	7,182
Total	1,628	15.43		316,104

Various physical parameters for the study site are known. Absolute elevation for the study site ranges from 10.83 to 12.92 meters above sea level. Soils for the site have been described by Johnson (1978) as Atsion Sand (sandy, siliceous, mesic, typic haplaquod, spodosol), and Muck (histosol). Elsewhere on the Stockton campus, Epstein and Sawhill (1977) have monitored fluctuations in water table depth and state that "the water table on the Stockton campus dips northward, lying above the surface in the lowest part but over 1.52 meters beneath the surface at the highest elevation; during the growing season, the water table drops by 0.46 meters in the low elevation and 1.37 meters in the high elevation." Annual precipitation on the Stockton campus ranged from 100 to 122 cm. during the time these water table measurements were recorded. The construction of a road (College Drive) through the Stockton campus has interrupted the normal water table flow across the campus. Since the Ecological Preserve is located to the west of this road and the site monitored by Epstein and Sawhill is to the east of the road, the above information on water table fluctuations is only a general approximation of similar phenomena in the Ecological Preserve.

Establishment of a Permanent Grid System

Permanent 10 x 10 meter plots, marked with metal stakes, were established for the study site. The overall plot system was carefully laid out in order to conform to the irregular boundary between the swamp vegetation and the upland forest vegetation. A total of 102 plots (1.02 ha.) were installed.

Determination of Topography

Following the establishment of the grid system, the absolute elevations at all stake points within the system were determined using a theodolite and a leveling rod. Within the study site, the elevation at stake number one was established as a bench mark for intrasite surveying of other elevations. The theodolite was moved a minimum number of times to minimize elevation error.

Installation of Permanent Well Sites

A total of 29 wells were installed at designated stake points within the grid system (Figure 2). The well pipes consisted of 2.0 meter lengths of 5.1 cm. diameter PVC pipe. Angled slits were cut in the pipe to permit the entrance of water while prohibiting the influx of sediment. The pipe was installed by drilling 1.5 meter deep holes at the various well locations using a power auger.

Monitoring of Wells and Atmospheric Precipitation

Water table change and precipitation reported here was monitored during the period April 20 to May 14, 1978. This period was representative of a high water spring flooding condition within the study site, and offered an ideal opportunity for studying the distributions of swamp plants in relation to high water table conditions. During this period, the wells were monitored on an average of 3 to 5 day intervals.

Forest Inventory

After establishing the plot system, the diameters and coordinates of all trees growing within each plot was determined and recorded. This information was used to generate species specific computer vegetation maps showing the precise locations of the three tree species according to size within the study site.

Soil Sampling and Analysis

Soil profiles were observed while drilling the holes for the permanent wells. Relying upon this information, representative soil pits were dug within the study site, and samples of each horizon were collected for chemical analysis. All soil samples were analyzed for pH, organic content, cations, phosphorus, and nitrogen according to standard procedures and those defined by Hajek et al. (1972). Cations were measured using a 306 Perkin-Elmer digital atomic absorption spectrophotometer equipped with a recorder output. Nitrogen and phosphorus were Kjeldahl extracted and read on a Technicon Autoanalyzer II set up to read N and P content of each sample simultaneously.

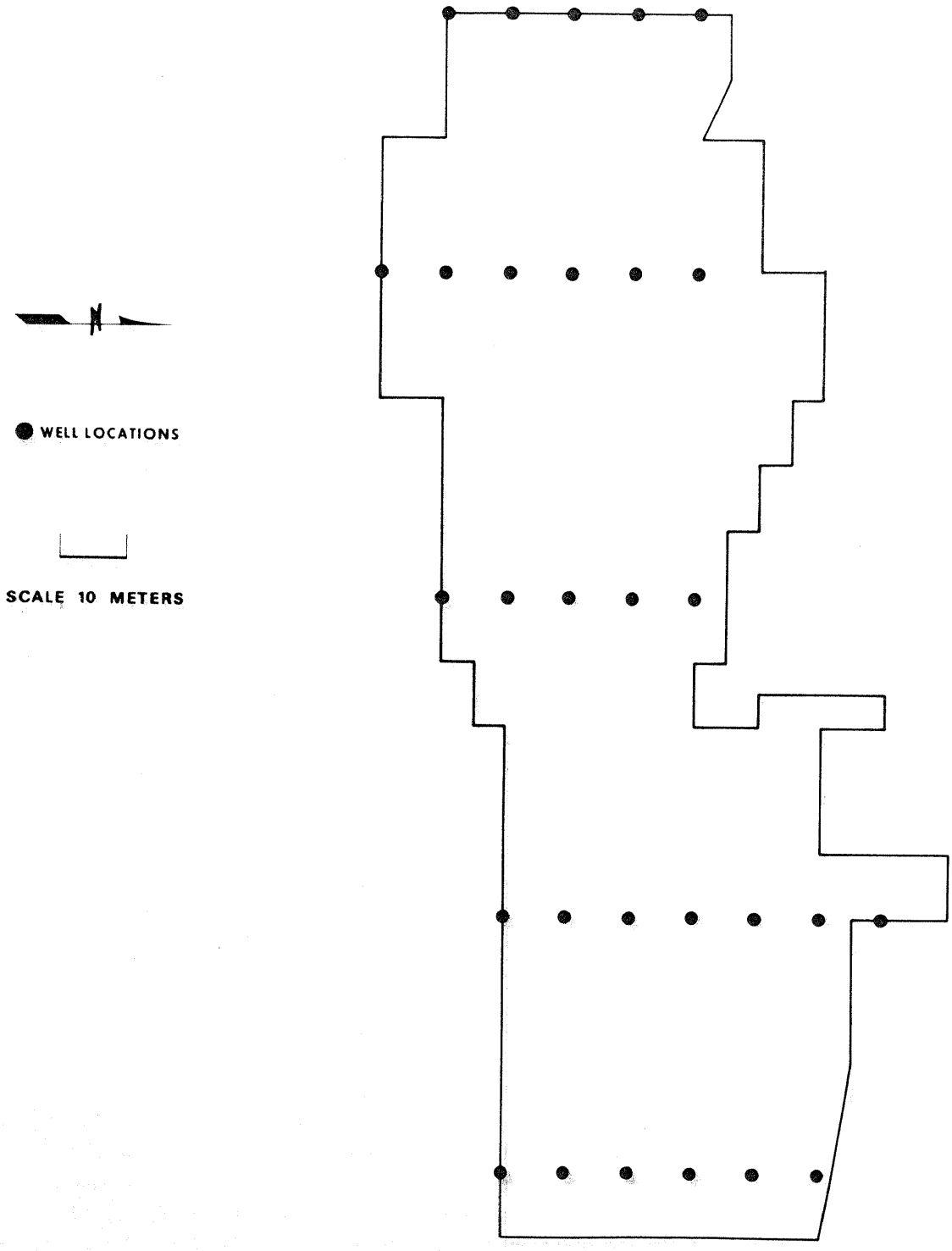

Figure 2.--Map of the hardwood swamp showing well locations.

Computer Graphics

Using SYMAP, a computer mapping program developed by the Harvard School of Graphics and Design, we constructed maps of (1) tree species distribution, (2) topography, (3) water table elevations, and (4) water table height or depth (distance above or below ground surface) based on data gathered from the site. This was accomplished by keypunching onto computer cards (1) the coordinates of all trees, stakes, or wells and (2) value data of trees (d.b.h.), absolute elevations at all stakes or wells (meters), water table elevations of all wells (meters; adjusted to mean sea level), and water table height or depth (distance below or above ground surface) of all wells (meters).

Eleven computer maps were produced including three vegetation maps, two topographic maps, and six water table maps. The six water table maps consisted of (1) three elevation maps based upon Low, Intermediate, and High Flood Period and (2) three height or depth maps based upon Low, Intermediate, and High Flood Period. Considered as a whole, the eleven maps facilitate the visual correlation of the distributions of the major tree species in relationship to topographic variations and water table fluctuations.

RESULTS

Topographic Maps

A computer map of topography (mean sea level) for the study site based upon elevations obtained at all grid stakes, shows the site as being low in the central portion of the swamp and elevated on the edges of the swamp (Figure 3A). Two depressions at the upper and the upper central end of the plot system are evident. In addition, three raised hummock areas in the central portion of the swamp are present. A more simplified computer map of elevation, based upon elevations at the well stakes only, shows basically the same results as Figure 3A with a few exceptions (Figure 3B). In Figure 3B, the raised hummock areas and one of the lowland depressions discernible in Figure 3A are not evident.

Tree Species Maps

Computer vegetation maps for the major tree species growing at the study site are presented in Figure 4. As shown in Figure 4A, all large maple trees grow in the central lowland portion of the swamp. By contrast, tupelos, particularly the larger ones, are found along the upland edges of the swamp (Figure 4B). Most magnolias are quite small; however, the largest individuals are found in the central portion of the swamp (Figure 4C).

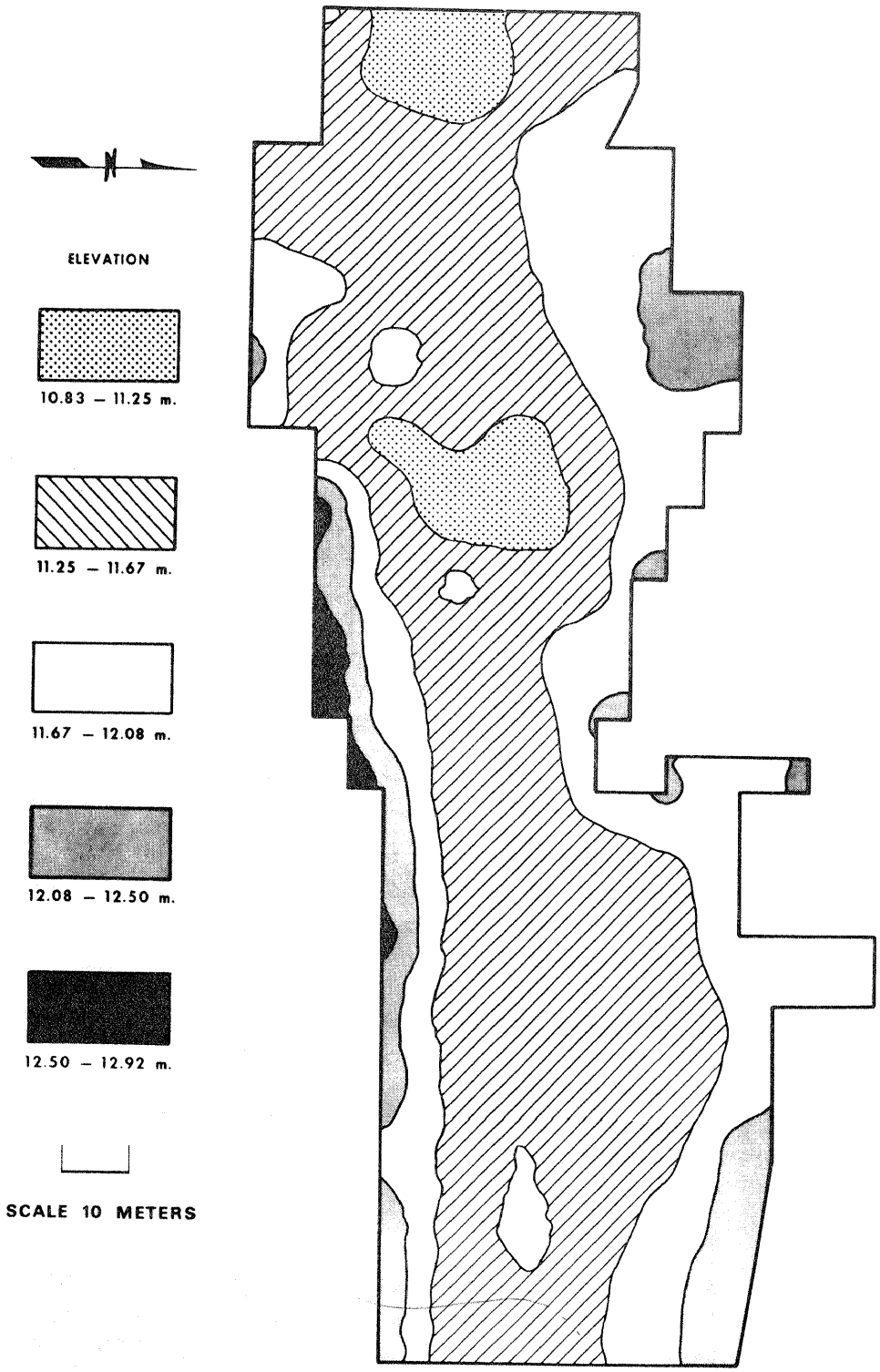

Figure 3A.--Topographic map of the hardwood swamp based upon elevations at all grid stakes (mean sea level).

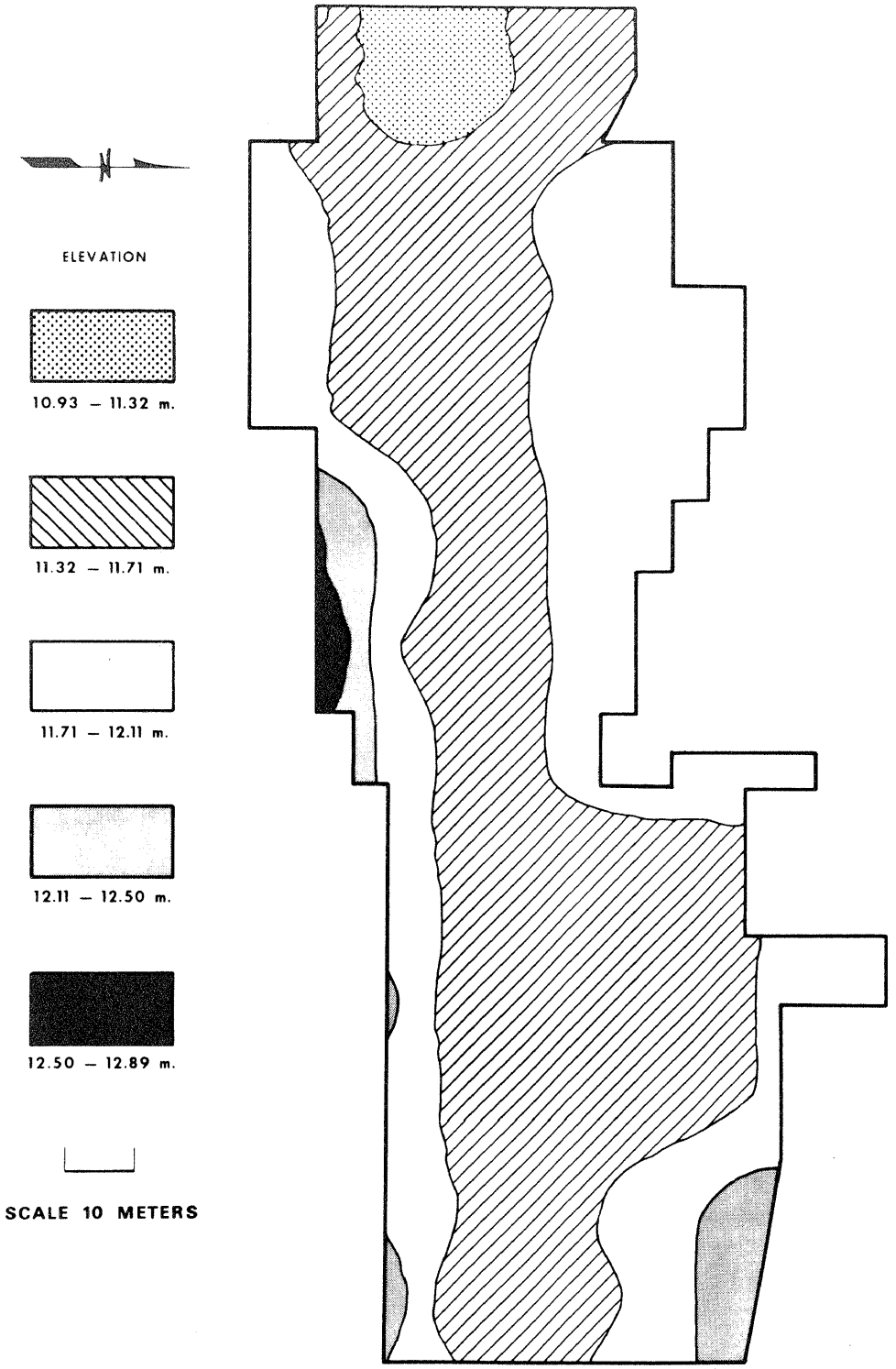

Figure 3B.--Topographic map of the hardwood swamp based upon elevations at well locations only (mean sea level).

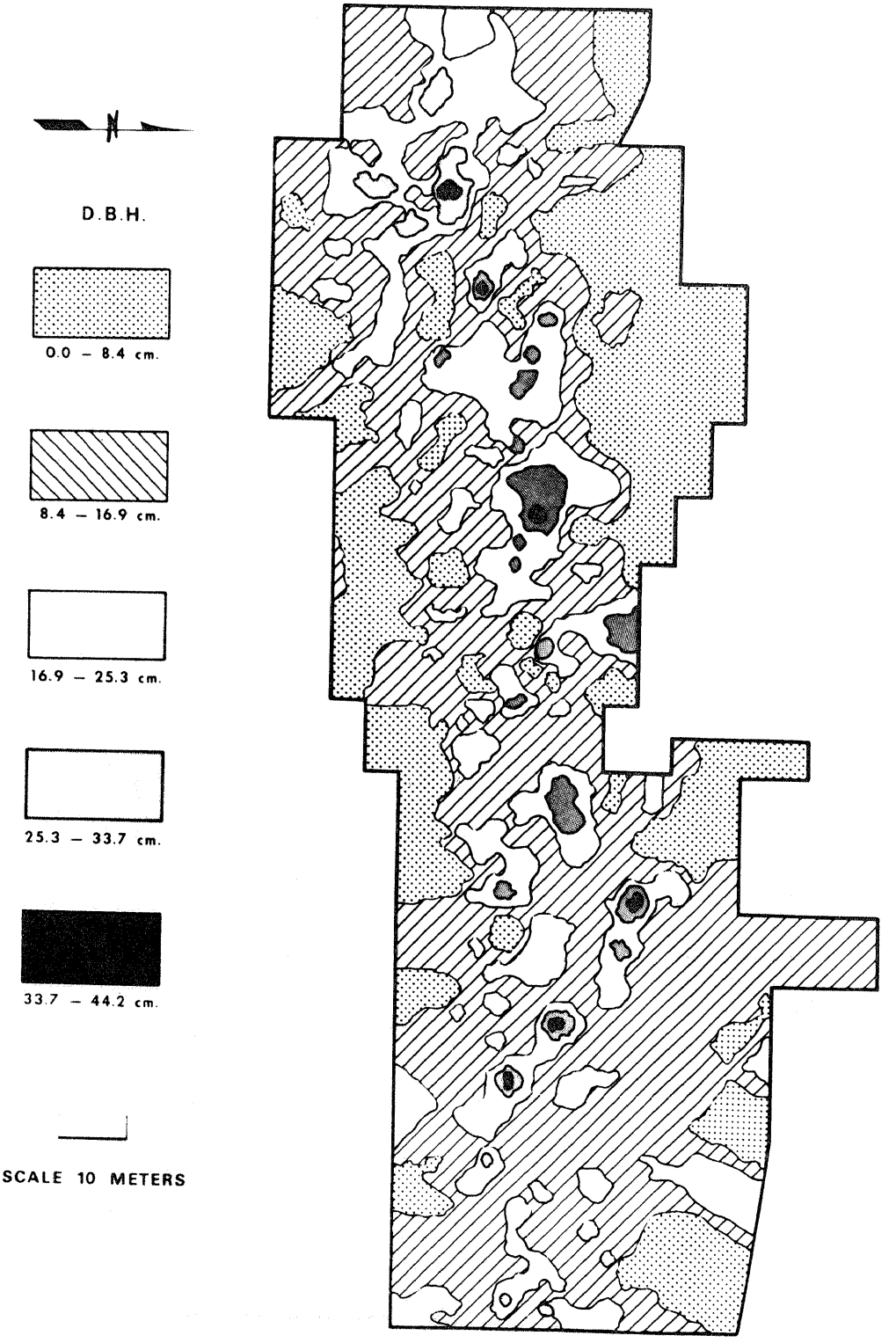

Figure 4A.--Map of red maple (Acer rubrum L.) distribution within the hardwood swamp.

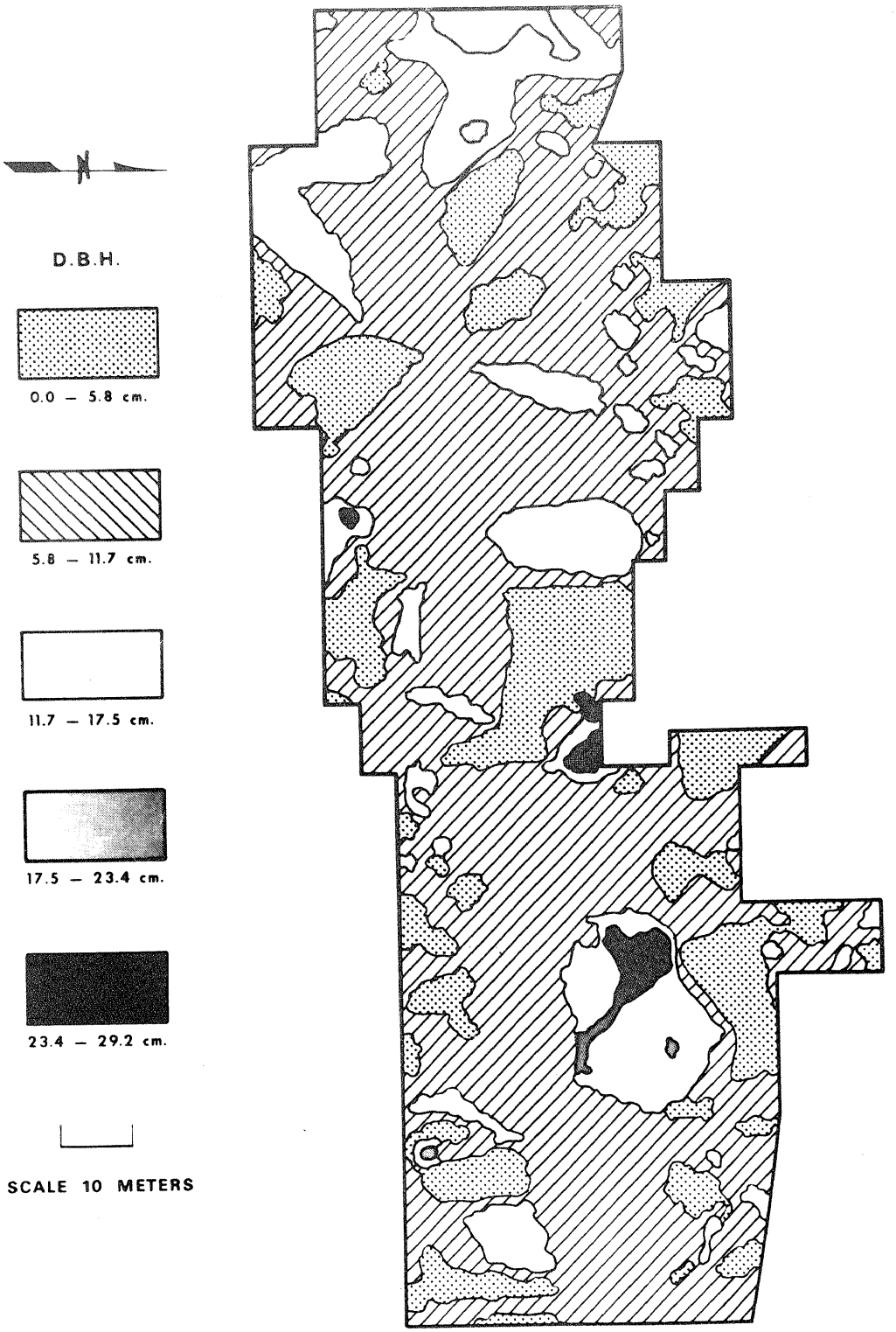

Figure 4B.--Map of tupelo (Nyssa sylvatica Marsh.) distribution within the hardwood swamp.

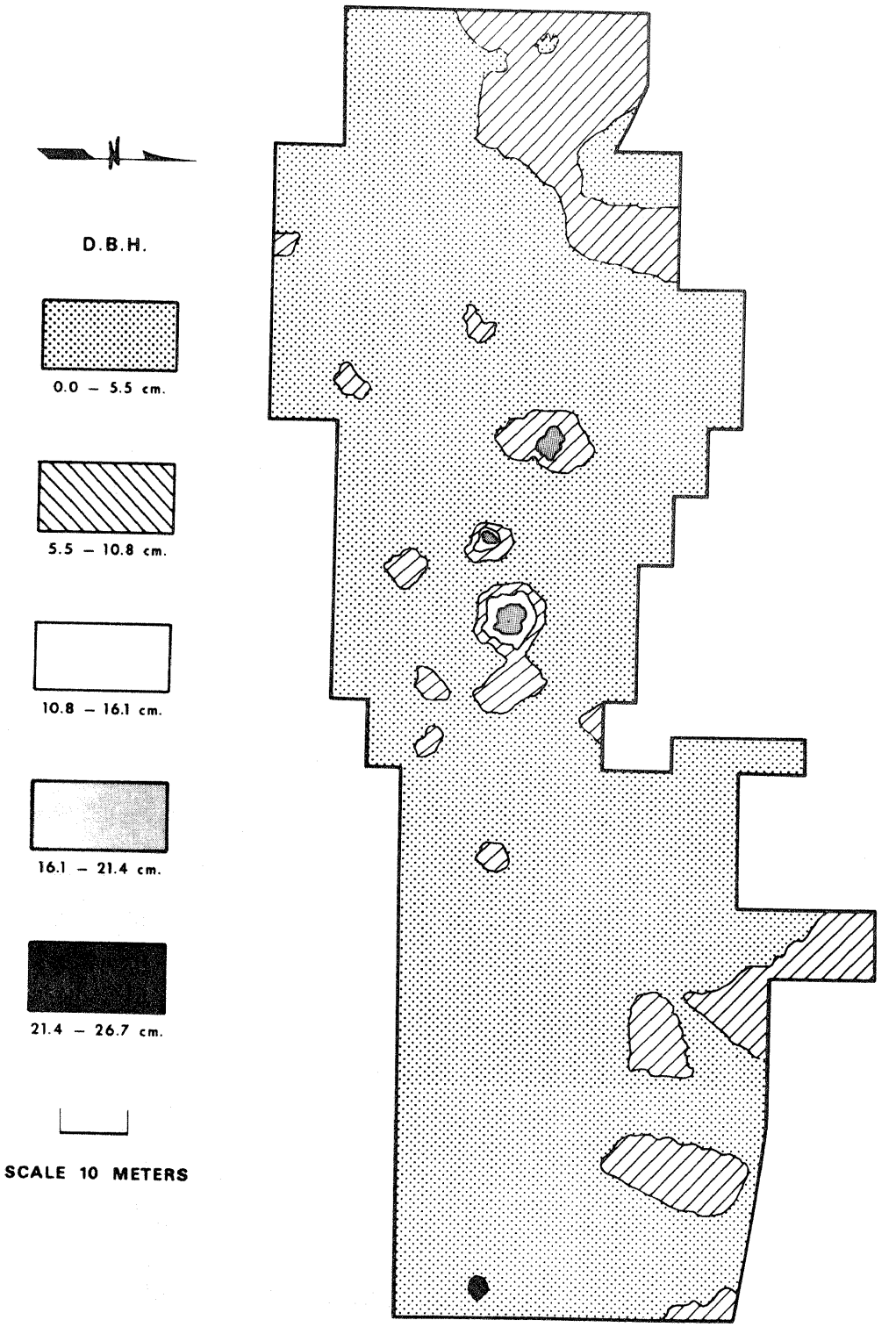

Figure 4C.--Map of sweetbay magnolia (Magnolia virginiana L.) distribution within the hardwood swamp.

Water Table Maps

Two types of maps are necessary to help visualize water table variation. Computer maps of water table height or depth (distance above or below surface) are presented in Figure 5. A progression of flooding in the central portion of the swamp is apparent in Figure 5A, B and C as the water table steadily rises. In Figure 6A, B and C, water table level is presented in reference to ground elevation where water level distance below or above surface has been adjusted to absolute elevation (mean sea level). Water table elevation along the edge of the swamp rises in relation to the degree of surficial swamp flooding. As presented in this format, it becomes clear that water table elevation mirrors the topography of the site.

Relationship of Water Table Level to Precipitation

Minor precipitation measured on April 27 resulted in a slight rise in the water table on April 28. In response to rain measured on May 5 and daily precipitation until May 10, the water table rose and then subsided by May 12 (Figure 7).

Soil Variation

Based upon numerous corings in the swamp, it appears that water is held near the surface in beds of sand and gravel extending approximately 1.68 meters deep. Below this a dense bed of white clay acts as an aquaclude preventing any further downward movement of water. This clay bed is 0.05 to 0.1 meters thick and has the consistency of modeling clay.

The soil profile for the central portion of the swamp (Table 2A) differs significantly from that for the upland edge of the swamp (Table 2B). Whereas the profile for the central portion of the swamp is not strongly developed, that for the upland edge is more complex and developed. The central portion of the swamp is a histosol, and lacks a B horizon. Evidence for this is provided in the aluminum and iron values for the profile. Although these elements normally accumulate in the B horizon, there is clearly no such increase in aluminum and only a slight elevation in iron. By contrast, a classic case of aluminum and iron accumulation is evident for the upland edge of the swamp, a spodosol, where a B horizon is developed. The bright colors of this B horizon contrast with the dull colors of the truncated profile for the central portion of the swamp.

A thick organic layer is characteristic of the central swamp. Nitrogen and phosphorus concentrations are highest in this layer. By contrast, the upland edge profile lacks a true organic horizon (less than 20% organic matter) and nutrient concentrations for N and P are less. In addition to

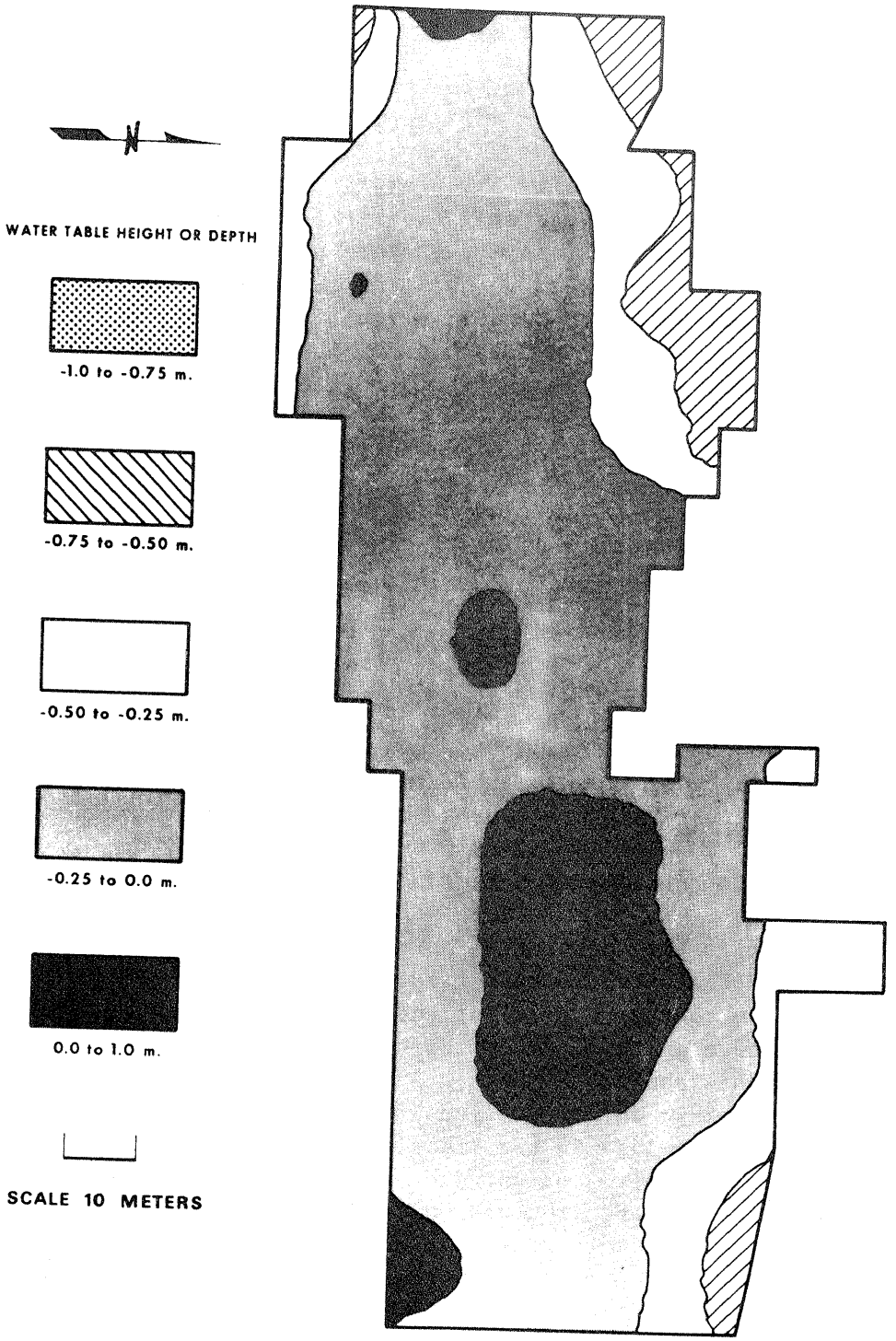

Figure 5A.--Map of water table height or depth (distance above or below ground surface): Low Flood Period (May 3, 1978).

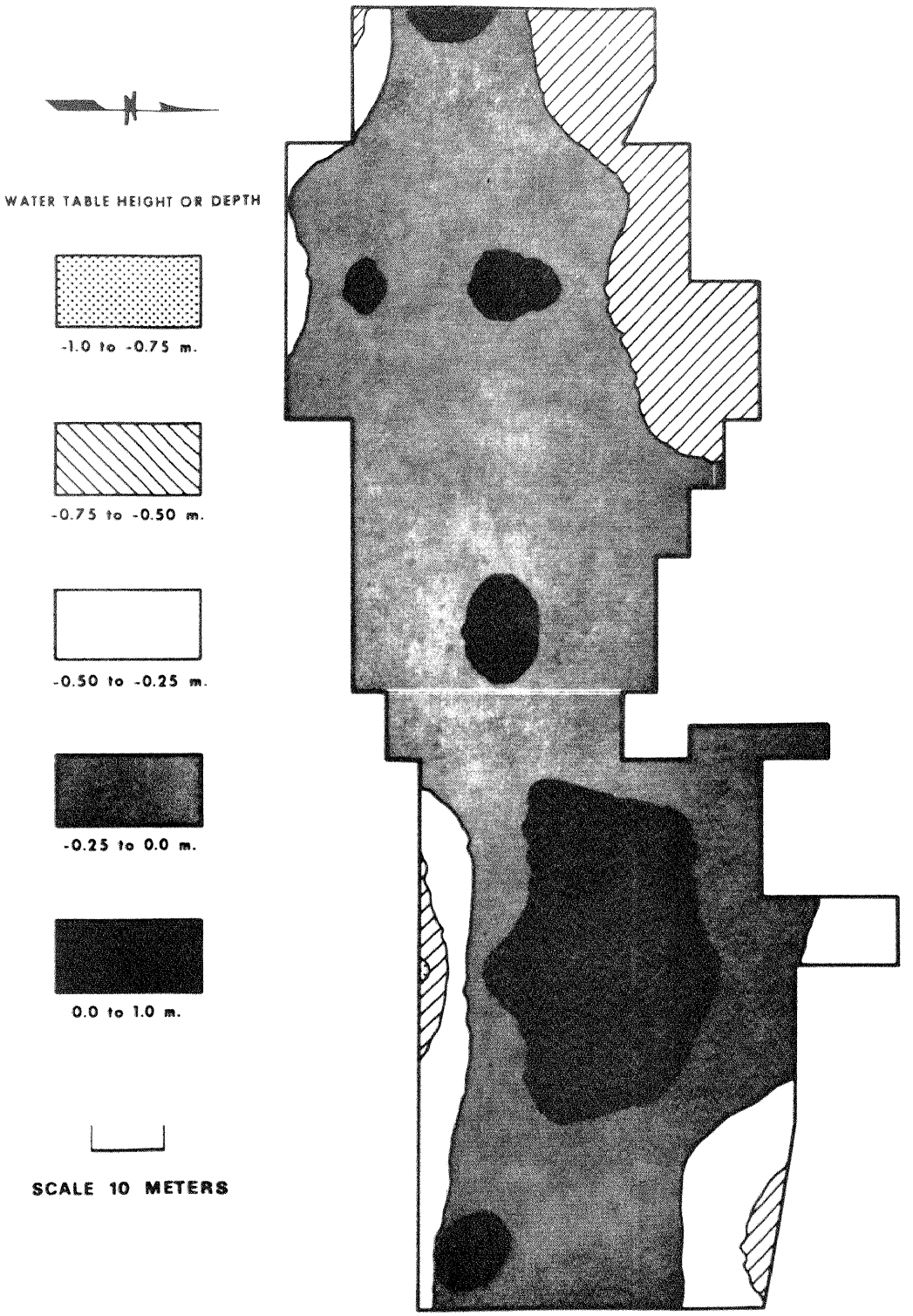

Figure 5B.--Map of water table height or depth (distance above or below ground surface): Intermediate Flood Period (May 6, 1978).

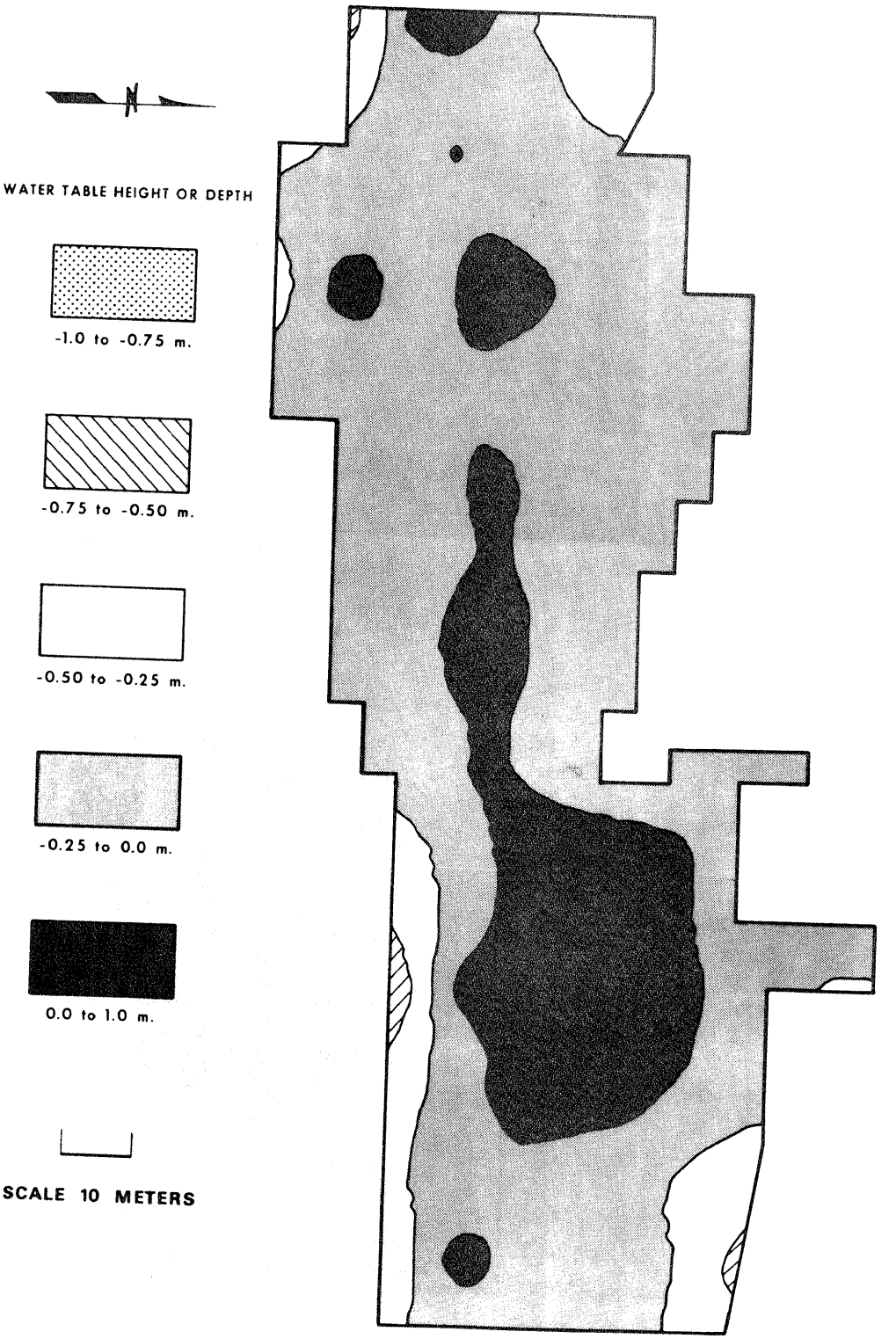

Figure 5C.--Map of water table height or depth (distance above or below ground surface): High Flood Period (May 9, 1978).

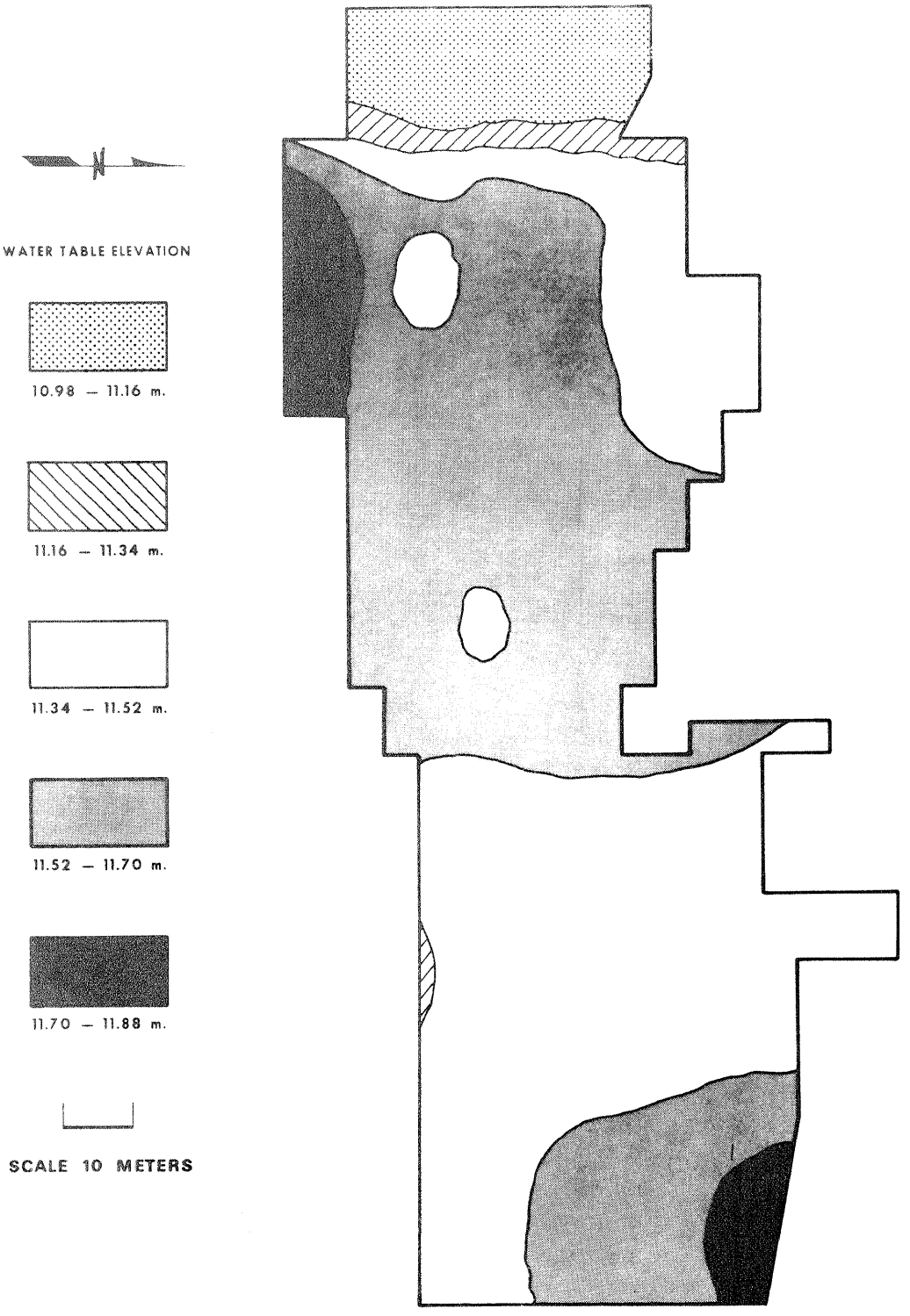

Figure 6A.--Map of water table elevation: Low Flood Period (May 3, 1978).

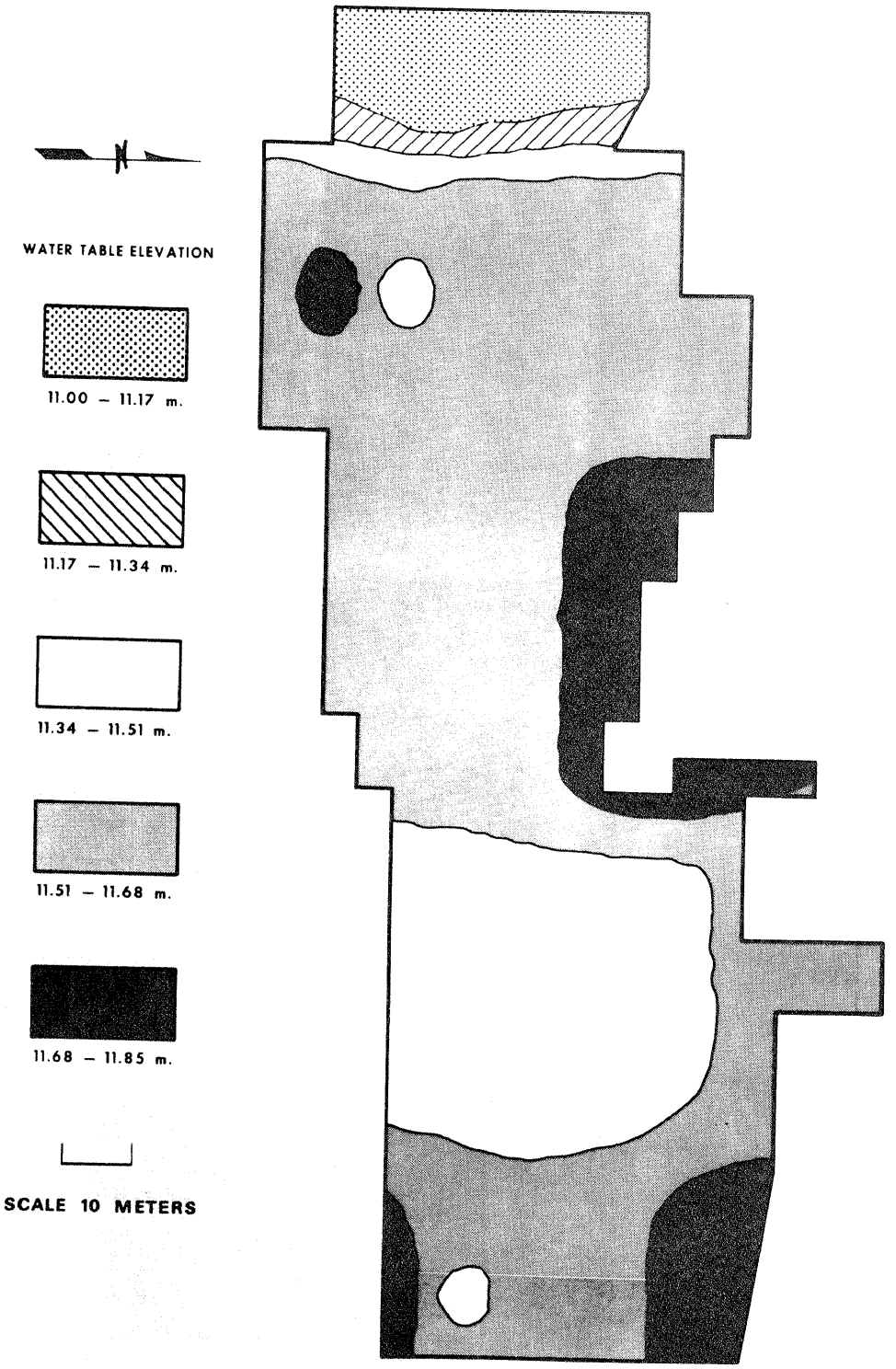

Figure 6B.--Map of water table elevation: Intermediate Flood Period (May 6, 1978).

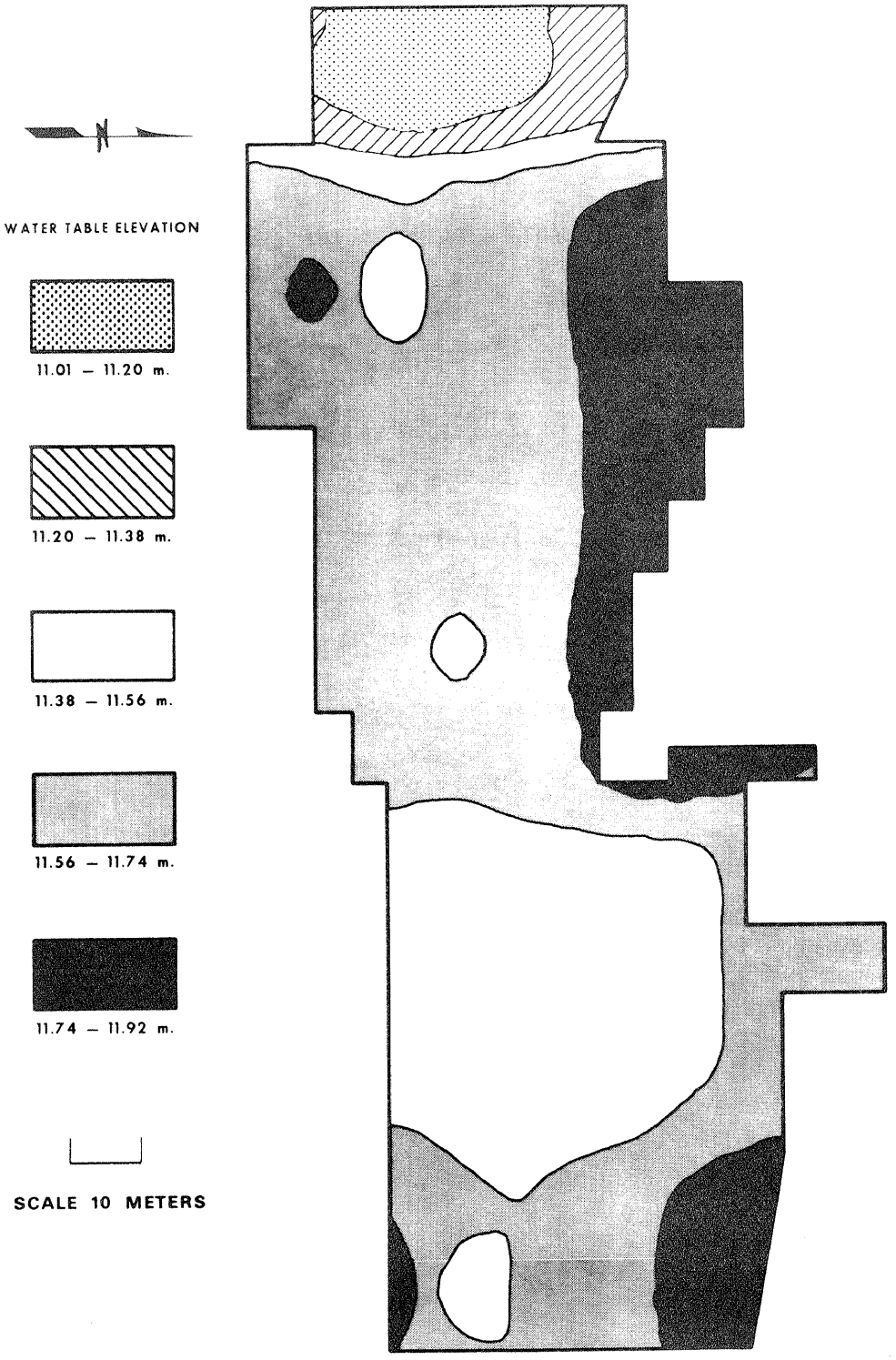

Figure 6C.--Map of water table elevation: High Flood Period (May 9, 1978).

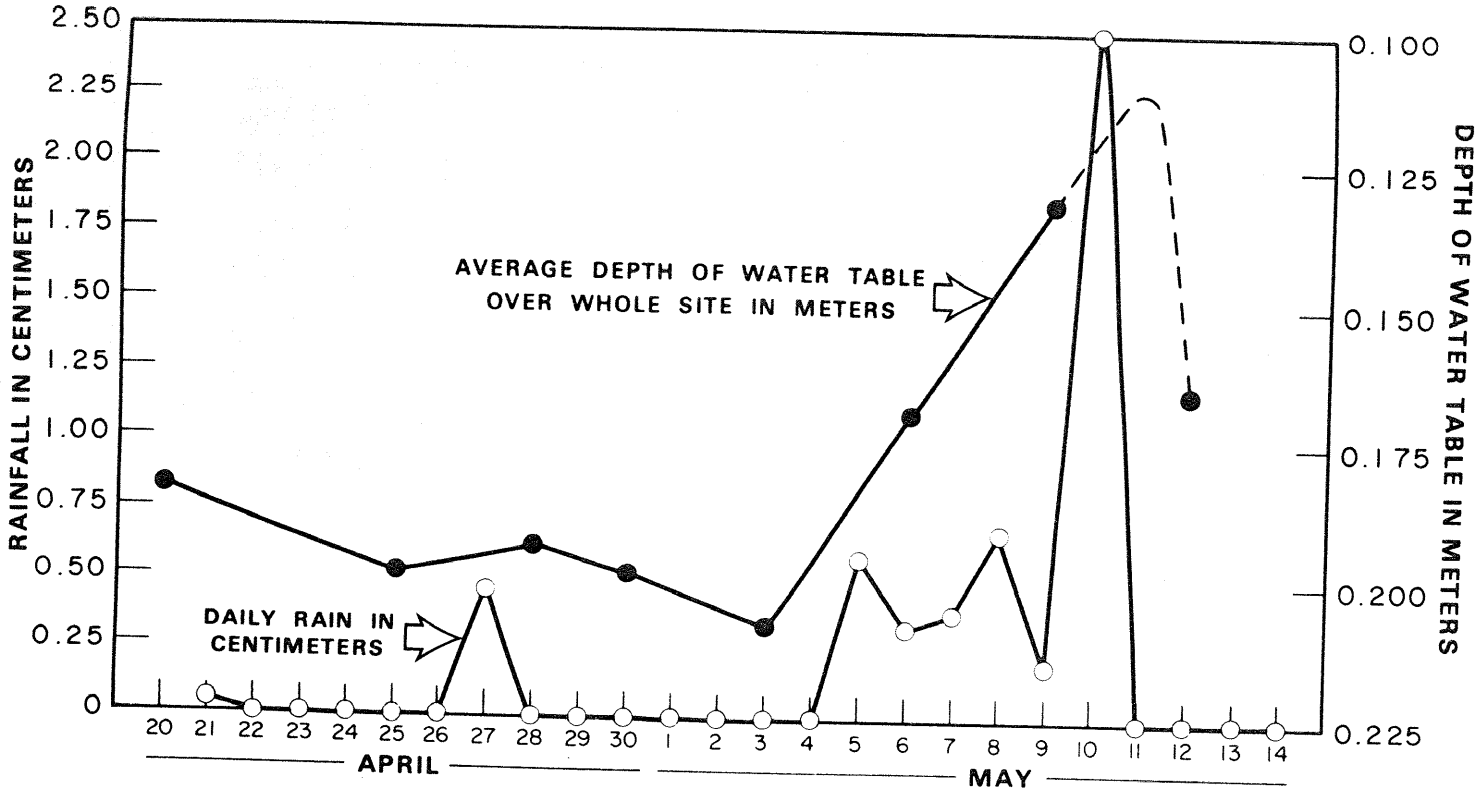

Figure 7.--Water table depth versus precipitation.

N and P, cation concentrations for potassium, calcium, and magnesium are also greater for the center of the swamp. Micronutrient concentrations for Fe, Zn, and Mn do not appear to be greater for the center of the swamp compared with the upland edge.

Table 2A.--Chemical soil characteristics for the center of the hardwood swamp

Horizon	Color	Thickness	Organic Content	N	Al	P	K
Organic	Brown	31.8 cm	88.4%	7060*	791.2	370	72.8
A	Black	43.2 cm	21.5	780	1113.2	80	33.2
C	White	17.8 cm	5.3	***	47.6	3	16

Horizon	Mg	Na	Ca	Fe	Zn	Mn
Organic	74	25.2	20.4	8.0	3.4	5.8
A	13.6	12.4	0.21	5.2	1.44	***
C	2.4	5.6	1.48	12.4	0.56	***

Table 2B.--Chemical soil characteristics for the edge of the hardwood swamp

Horizon	Color	Thickness	Organic Content	N	Al	K	P
A_1	Gray-white	31.8 cm	9.2%	400*	65.2	45.6	15.5
A_2	Pink	22.9 cm	2.8	95	17.6	26.8	3.0
B_{21h}	Black	17.8 cm	17.1	780	765.2	62.8	55.0
B_{21hir}	Red	26.7 cm	15.2	575	1300	19.6	28.5
B_3	Yellow	31.8 cm	5.1	250	1278.4	34.0	28.5
C	White	-	-	-	-	-	-

Horizon	Mg	Ca	Na	Fe	Zn	Mn
A_1	13.2	13.6	11.2	9.2	3.04	***
A_2	6.8	22.4	6.8	6.8	1.52	***
B_{21h}	8.4	***	43.6	3.6	2.12	***
B_{21hir}	6.4	***	19.6	10.4	1.04	***
B_3	2.4	***	14.4	6.8	1.44	***
C	-	-	-	-	-	-

* Elemental values are expressed as ppm.
*** Indicates the concentration of element was too low to measure.

DISCUSSION

Dual presentation of water table fluctuations in Figures 5 and 6 allows one to visualize water table fluctuations for both the upland and central portions of the hardwood swamp. In the central portion of the swamp, where the water table is always near or above the ground surface, the amplitude of water table fluctuation is smaller as compared with the upland swamp edge. The central portion of the swamp is generally flooded (Figure 5) during periods of water input, and the degree of this flooding may be viewed best in terms of a water table height or depth (distance above or below ground surface) presentation. On the upland edge of the swamp, where the water table never rises above the ground surface, the amplitude of water table fluctuation is larger as compared with the central swamp lowland. Water table level for the upland edge of the swamp (Figure 6) is a greater distance below ground surface during low flood period than it is during high flood period, and this is observed best through use of a water table elevation format.

The effect of water table fluctuations on soil profile development is evident for the hardwood swamp. The soil at the upland edge of the swamp shows a well developed and brightly colored profile. By contrast, the soil profile for the lowland central portion of the swamp is poorly developed and dull in color. Spurr and Barnes (1973) have noted that "the typical layered forest soil profile is developed only under conditions of good drainage, when water can move down through the soil. The presence of a high water table in the soil... will result in a truncated and modified profile. In the zone of a fluctuating water table, oxidation is periodically restricted, giving rise to a mottled soil profile of yellow or gray (unoxidized) and brown or reddish (oxidized) minerals. A permanent or stagnant water table will prevent soil oxidation and may even result in the extraction of oxygen (i.e., reduction from previously oxidized soil minerals, forming a gley horizon)." Lyford (1964) reported similar results for New England soils subjected to fluctuating water tables and suggested that (1) "soil morphology provides a basis for predicting the height of the water table" and (2) "soil development in periodically wet soils in any one year may take place continuously, intermittently, or perhaps not at all."

The thick organic layer of the central swamp is also a consequence of the normally high water table for this portion of the study site. Such a thick organic layer is indicative of a slow litter decomposition rate, and is the result of chemically reduced conditions caused by poor aeration. Under these conditions, there is a low turnover rate of essential plant nutrients. For the study site, the highest concentrations of nitrogen and phosphorus in the central swamp soil profile occur in the organic soil horizon (Table 2A).

Although N and P concentrations for the central swamp organic horizon are high relative to N and P concentrations for various soil horizons of the swamp edge profile, these concentrations are not high for organic horizons in general (L.O. Safford, personal communication). Organic horizons of most forest soils run around 1% N. Nitrogen concentration for the central swamp organic horizon (approximately 0.7%) is quite typical. Total P concentrations for most forest soil organic horizons usually run between 400 and 600 ppm. Phosphorus concentration for the central swamp organic horizon reflects the lower end of this range.

Studies performed by Reiners and Reiners (1970) for a Minnesota northern white cedar (Thuja occidentalis L.) swamp with a thick organic soil layer indicate that the turnover time for nitrogen in the forest floor is 503 years and 194 years for phosphorus. These values compared with 39 and 27 years for a Minnesota upland oak forest, lacking thick organic litter deposits. Turnover times for calcium and magnesium in the swamp forest floor were 312 and 141 years compared with 10 years for both in the upland oak forest. The effects of nutrient availability on forest growth have been commented upon (Schlesinger, 1978). He reasoned that a low standing crop of foliage in a Georgia cypress swamp may be an adaptation for coping with nutrient deficiencies such as those occurring in continuously flooded stagnant water swamps. He further estimated the mass of organic sediments in the Georgia cypress swamp to be three times larger than the standing crop biomass of that forest.

From the above it appears clear that water table fluctuations explain soil nutrient concentration differences for the hardwood swamp. This raises the question: Do chemical soil differences explain the tree species distributions for the hardwood swamp? Of major importance to this question is the availability of nutrients for plant growth. A number of parameters affect nutrient availability in a swamp forest including (1) the extent of water circulation within the swamp (stagnant vs. flowing), (2) turnover time for nutrients in the forest floor, and (3) the effects of soil bulk density on soil nutrient levels.

Brown et al. (1979) state that nutrient availability for flowing water swamps is much improved compared with stagnant water swamps. The present site must be regarded as a stagnant water hardwood swamp forest since (1) there is limited visual water flow through the swamp, (2) an aquaclude prevents downward water movement and helps to hold the water near the surface, and (3) standing pools of water are evident in the central portion of the swamp in the spring even during periods of low or no precipitation. For the study site, nutrient availability ought to be especially restricted in the central swamp.

The relationship of site water conditions to rates of litter decomposition, and ultimately to nutrient turnover rates, has been discussed. Relying on the work of Reiners and Reiners (1970) it is possible to conclude the turnover rates for nutrients in the center of the hardwood swamp are longer than those for the edge of the swamp.

As reported, soil macronutrient concentrations were generally higher for central swamp soils than for edge soils. Assuming varying soil bulk densities for these soils, it is reasonable to suggest certain macronutrient levels may be lower for central swamp soils as compared with swamp edge soils. This condition arises since highly organic soils tend to have a low bulk density compared with more mineral soils. No major difference in soil micronutrient concentrations (upland edge or lowland central region) were noted. Assuming higher bulk densities for the edge soils, micronutrient levels are probably higher in these soils as compared with those from the central swamp.

For the hardwood swamp, most tupelos occur on the upland edge of the swamp, whereas most maples and magnolias occur only in the center of the swamp. Since nutrient availability appears to be greater along the swamp edge than in the central swamp, does tupelo have a greater demand for nutrients than maple or magnolia? Recent nutrient studies for the three major tree species composing the hardwood swamp provide information important for answering this question (Reynolds et al., 1978a). Micronutrient tissue concentrations for tupelo are generally less than for maple or magnolia. In some instances, macronutrient tissue concentrations (stem, branch, and leaf) for tupelo are higher than for maple or magnolia. In other instances, a reversed pattern holds. In nearly all instances, variability in macronutrient tissue concentrations for the three species appears insufficient to provide evidence for a greater nutrient demand in tupelo when compared with maple or magnolia. Since the nutrient demand of tupelo does not appear greater than that for maple or magnolia, it seems reasonable to conclude that chemical soil differences do not satisfactorily account for tree species distribution differences for the hardwood swamp reported upon in this paper.

If differences in soil nutrient chemistry do not adequately account for differences in tree species distributions, then other explanations must be sought. The favored alternative explanation is species variation in moisture tolerance. For this hardwood swamp, tupelo grows on the upland edge of the swamp where it is exposed to lesser amounts of water. Whereas the central portion of the swamp is often flooded, the upland edges are not subjected to flooding and the moisture regime of the soil varies as the water table fluctuates.

Harms (1973) has addressed the question of variability in moisture tolerance for two species of tupelo. Studies conducted by Harms showed that swamp tupelo (Nyssa aquatica L.) has a greater moisture tolerance than blackgum (Nyssa sylvatica Marsh.). These results suggest that Nyssa sylvatica prefers drier sites, and if the moisture tolerances of maple or magnolia are assumed to be greater than that for tupelo, they would appear to explain why the three species are distributed as they are in the present swamp system.

In summary, soil chemical differences within the hardwood swamp reflect water table fluctuations reported on in this paper. These soil chemical differences do not appear to satisfactorily explain tree species distributions within the swamp, and are probably coincidental with tree species distributions rather than causitive of them. Variations in the amplitude of water table fluctuations, coupled with flooding or the lack of it, appear to be the best explanation for tree species distribution patterns. Tupelo grows primarily on the upland drier edge of the swamp, since it is less tolerant of soil moisture, whereas maple and magnolia trees grow in the frequently flooded central portion of the swamp since they are more tolerant of soil moisture.

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