1989

Relationships Among Hydrology, Vegetation and Soils in Transition Zones of Rhode Island Red Maple Swamps

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RELATIONSHIPS AMONG HYDROLOGY, VEGETATION,

AND SOILS IN TRANSITION ZONES OF

RHODE ISLAND RED MAPLE SWAMPS

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

NATURAL RESOURCES

UNIVERSITY OF RHODE ISLAND

1989

MASTER OF SCIENCE THESIS

OF

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UNIVERSITY OF RHODE ISLAND

1989

THESIS ABSTRACT

Reaching a consensus on wetland boundary determination criteria has been hampered by imprecise definitions of the distinguishing features of wetland and upland. Wetland transition zone research, of which this thesis project was a part, was undertaken in red maple swamps in Rhode Island to examine the relationships among hydrology, vegetation, and soils, and to develop field criteria for locating wetland boundaries using these parameters.

In this thesis, three years of hydrologic data were used in cluster and discriminant analysis to classify sampling stations as wetland or upland. In most cases, the wetland/upland hydrologic break fell on the border between very poorly drained and poorly drained soils. Variables describing the percent of the three growing seasons during which high soil moisture levels occurred within 30 cm of the ground surface were most useful in distinguishing between wetland and upland. The location of the hydrologic break varied between years, and suggested that the location of the break may move upslope to include more of the poorly drained soil zone in years of high precipitation.

Wetland/upland breakpoints based on hydrology, hydric soil status, and herb-layer vegetation were compared. The hydrologic break was lowest on the moisture gradient, and the vegetation-based break was highest. The break based on hydric soil status appeared to be the most reasonable location for the wetland boundary from both ecological and management perspectives. These results suggest that poorly drained soils should be considered wetland, and that hydric soil status is a

useful and consistent parameter for wetland boundary determination in southern New England.

ACKNOWLEDGEMENTS

The research project of which this thesis was part was truly a cooperative effort. Principal and co-investigators were Frank Golet, Arthur Gold, and William Wright, and I thank them all for their interest and advice. Anthony Davis and Thomas Sokoloski bore the brunt of the field work involving site selection and data collection during the first two years of the study. In addition, their thesis efforts were invaluable in the various iterations of data analysis. William DeRagon was more than generous with his time and advice during critical computer dilemmas. Frank Golet, my major professor, was inspirational in his love and respect for wetlands. I thank him for his enthusiasm, support, and inimitable guidance.

I believe I owe my sanity to friends who were always there with shoulders and coffee. In particular, Aram Calhoun and Bonnie Lamb (alphabetical order) were constant sources of discussion, encouragement, and laughter. And Richard, whose love was my anchor.

PREFACE

The research described in this thesis is part of a larger study of wetland transition zones funded by the U.S. Army Corps of Engineers, the Rhode Island Agricultural Experiment Station, and the U.S. Fish and Wildlife Service. The thesis is written in manuscript form and is composed of two papers. The first analyses the hydrologic gradient, classifies sampling stations as wetland or upland, and assesses the influence of annual variation in hydrology on wetland boundary location. The second manuscript compares wetland/upland classifications based on separate analyses of hydrologic, vegetation, and soils data. Both papers are intended for submission for publication to Water Resources Bulletin.

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MANUSCRIPT 2.

HYDROLOGIC RELATIONSHIPS AMONG SOIL DRAINAGE CLASSES IN TRANSITION ZONES OF RHODE ISLAND RED MAPLE SWAMPS

ABSTRACT

Hydrologic data were gathered weekly for three growing seasons along a soil drainage toposequence running from very poorly drained to moderately well drained soils at three forested sites in southern Rhode Island. Cluster analysis was performed using eighteen hydrologic variables for each sampling station. Stations within the cluster diagram were subjectively designated as wetland, transitional, or upland. Discriminant analysis was used to classify the transitional stations as wetland or upland. The wetland/upland break fell most frequently between very poorly drained and poorly drained soils, or within the poorly drained soil zone. These locations were quite low on the moisture gradient and were probably due to the mesic nature of the upland end of the transects.

Using stepwise discriminant analysis, the percentage of the growing season during which air-filled porosities within 30 cm of the ground surface were 15 % or less was selected as the most important hydrologic feature distinguishing between wetland and upland. When hydrologic analyses for individual years were compared, the location of the wetland/upland break was found to vary in accordance with the timing and magnitude of annual and seasonal precipitation levels. In years of high precipitation, much of the poorly drained soil zone might be classified wetland using hydrologic data.

While hydrologic data are vital to our understanding of wetland systems, their use as a wetland boundary identification tool is limited by high annual and seasonal variability, and by the intensity of data collection required to adequately describe a site.

INTRODUCTION

The U.S. Fish and Wildlife Service (FWS) defines wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" (Cowardin et al. 1979:3). As this definition suggests, hydrology is the driving force maintaining wetland conditions (Gosselink and Turner 1978, Carter et al. 1979). Wetland functions such as flood reduction, wildlife habitat, and pollution abatement are largely influenced by hydrologic characteristics such as the extent and duration of surface flooding and degree of soil saturation (Van der Valk et al. 1978, Kadlec and Kadlec 1979, LaBaugh 1986).

Wetland hydrology is difficult to describe due to seasonal, annual, and longer-term fluctuations. As a result, few thorough studies of wetland hydrology have been performed, especially in freshwater wetlands of the Northeastern United States. Most research addressing wetland identification and delineation has concentrated on vegetation and soils, since these two parameters are more easily quantified than hydrology. Although wetland vegetation and soil are generally considered to reflect hydrologic conditions, the precise nature of the relationships among these three parameters is poorly understood.

In 1985, the University of Rhode Island initiated a study of hydrology, vegetation, and soils along a moisture gradient extending from wetland to upland in southern Rhode Island deciduous forests. The goal of that study was to describe the relationships among the three parameters as they changed along the moisture gradient. This paper presents the hydrologic results from that study. The objectives of this paper are:

1) to characterize the hydrologic gradient in the transition zone between forested wetland and the adjoining upland;

2) to determine a wetland/upland boundary based on hydrologic features; and

3) to identify which hydrologic parameters are most useful in distinguishing wetland from upland.

METHODS

Study Sites

Criteria for site selection included: 1) a continuous deciduous forested canopy; 2) freedom from obvious signs of recent disturbance; 3) gradual slope from wetland to upland; 4) stratified glacial deposits; 5) a drainage toposequence including very poorly drained (VPD), poorly drained (PD), somewhat poorly drained (SPD), and moderately well drained (MWD) soils. Three sites were selected and named Great Swamp (GSW), Laurel Lane 1 (LL1), and Laurel Lane 2 (LL2). The Great Swamp site was located at the edge of a large wetland system including a 400-hectare shallow lake and over 800 hectares of forested wetland. The two Laurel Lane sites were located approximately 200 m apart in a small watershed drained by a perennial stream. All sites were within 10 km of the University of Rhode Island in Kingston.

All three sites were dominated by red maple (Acer rubrum) at the lower end of the moisture continuum, and by white oak (Quercus alba) at the upper end. A well-developed shrub layer occurred underneath much of the canopy at each site; sweet pepperbush (Clethra alnifolia) was the most abundant shrub species overall. Soils in the PD, SPD, and MWD zones were predominantly weakly developed Entisols composed of loamy sands and sands. In the VPD zone, Inceptisols with histic epipedons were common, and Histosols occurred in the wettest areas of the Laurel Lane sites (Sokoloski et al. 1989).

Data Collection

At each study site, three transect lines were established perpendicular to the slope contours and spaced 15 m apart. Along each transect line, six sampling stations were located according to soil drainage class. Drainage classes were determined from auger samples, using criteria specified by Wright and Sautter (1979). Station 1 was placed at the lowest end of each transect in VPD soil. Station 3 was located at the border between VPD and PD soils. Station 2 was then located at the elevational midpoint between Stations 1 and 3. Stations 4, 5, and 6 were placed in the middle of PD, SPD, and MWD soil zones, respectively.

A water table well was located at the center of each sampling station. Wells consisted of 3.8-cm inside-diameter, perforated PVC pipe inserted to depths ranging from 1.5 m at Station 1 to 3.0 m at Station 6. Wells were sealed at the soil surface with bentonite clay to eliminate surface water entry and fitted with removable caps. The relative elevation of the ground surface at each water table well was determined to the nearest 1.0 cm using a transit; ground surface elevations also were obtained at 0.5-m intervals along the length of each transect.

Soil moisture potentials were monitored using four soil moisture tensiometers at each sampling station. Tensiometers were constructed according to specifications from Soil Measurement Systems (Phoenix, Arizona). Each tensiometer consisted of a porous ceramic cup attached to a length of 1.5-cm inside-diameter PVC pipe and capped with a septum seal. Tensiometers were placed so that four soil depths were monitored: 15, 30, 45 and 60 cm. A silt slurry was poured around each ceramic cup to ensure hydraulic contact with the surrounding soil. On the day prior to measurement, each tensiometer was checked to ensure that the water level was within 2.5 cm of the top of the column, and that the septum seals were secure. Soil moisture potentials were recorded using a pressure-transducer made by Soil Measurement Systems.

At Laurel Lane 1, soil temperatures were monitored with copper-constantan thermocouples at the same four depths as the soil moisture tensiometers. Measurements were obtained with an Omega Model 650 Thermocouple Thermometer.

Water levels, soil moisture potentials, and soil temperatures were monitored weekly during the growing season. Growing season has been defined by the U.S. Soil Conservation Service (SCS 1985) as that period of the year when soil temperatures at a 50-cm depth exceed 5 °C. A review of our data indicated that temperatures were at or above 5 °C from mid-April through November. Therefore, in the analyses presented in this paper, the growing season was considered to extend from 15 April through 30 November. In the remainder of the year, water levels and soil temperatures were monitored biweekly. Data collection began in May 1985 and continued through April 1988.

At each station, a soil pit was excavated at approximately the same elevation as the water table well. At several of the VPD stations, high water tables and unstable subsoils made pit excavation impractical, and samples were obtained using a soil auger. Soils were described to the series level using standard procedures (Soil Survey Staff 1951). Those series included in the National List of Hydric Soils (SCS 1985) were designated hydric; series not in the list were considered nonhydric. Horizons containing tensiometers were sampled for laboratory analyses of soil texture, bulk density, and percent organic matter by weight. Soil profiles and laboratory techniques are described by Sokoloski (in prep.).

Soil moisture characteristic curves were derived to estimate the water content and air-filled porosity of various soil samples across a range of soil moisture potentials. Mineral soils were divided into three textural classes and eight classes of organic matter content (Appendix A). Organic soils, defined as those horizons with organic matter content of at least 20% by weight (Soil Survey Staff 1951), were divided into three classes of organic matter content, 20%-39%, 40%-59%, and 60%. Undisturbed cores 4.57 cm in diameter were obtained from three horizons representing each soil class, and each horizon was sampled in triplicate. The cores were fully saturated in a slight vaccuum to eliminate entrapped air, and then subjected to pressures of 25, 75, and 150 cm of water for 24 hours each. The weights of the cores were obtained at each pressure increment; changes in weight were ascribed to water lost as smaller-diameter pores drained under increasing pressure (Hillel 1980). The cores were then oven-dried at 105 $^{\circ}$C to drive off all free water and reweighed. Soil water content was expressed as volumetric water content. Since soil aeration, not soil moisture, is frequently restricted in wetlands, air-filled porosity at each soil moisture potential was calculated as the difference between the total soil porosity and the volumetric moisture content. Percent air-filled porosity estimates the percent of the soil core volume filled with air (Hillel 1980).

Statistical Analyses

Exploratory statistics were employed to examine hydrologic relationships among the sampling stations. To achieve an adequate sample-to-variable ratio of at least 3-to-1 (Pielou 1984), the 54 sampling stations from the three sites were combined for all statistical analyses. All analyses were performed using SAS software (Statistical Analysis Systems 1985). Cluster analysis (PROC CLUSTER, CENTROID) was used to group the 54 sampling stations according to the degree of similarity of their hydrologic characteristics. Wetland, upland, and transitional clusters of stations were subjectively identified from cluster dendrograms. Using the hydrologic data from the stations within the wetland and upland clusters, wetland and upland linear discriminant functions were derived using discriminant analysis (PROC DISCRIM). Each station within the transitional cluster was then classified wetland or upland. The hydrologic variables contributing most to the analysis were identified using stepwise discriminant analysis (PROC STEPDISC). A significance level of 5% was set for entry of a variable into the stepwise analysis. Comprehensive reviews of cluster and discriminant analyses are in Neff and Marcus (1980) and Pielou (1984).

RESULTS AND DISCUSSION

The most gradual topographic slopes occurred at GSW; slopes were intermediate at LL1, and steepest at LL2 (Figure 1). At all sites, there was relatively little change in elevation between Stations 1 and 3; most of the rise occurred between Stations 3 and 6.

Inspection of soil morphology in the soil pits corroborated the initial soil drainage class determinations at most of the stations. Station 3, placed on the VPD/PD border, was classified PD on the three transects at LL1, and VPD on all transects at GSW and LL2. On two transects at GSW, where Station 5 initially had been classified SPD, the designation was changed to PD after closer inspection.

Figure 1. Topographic profiles showing station locations and maximum, minimum, and mean water levels calculated from weekly measurements over three growing seasons.

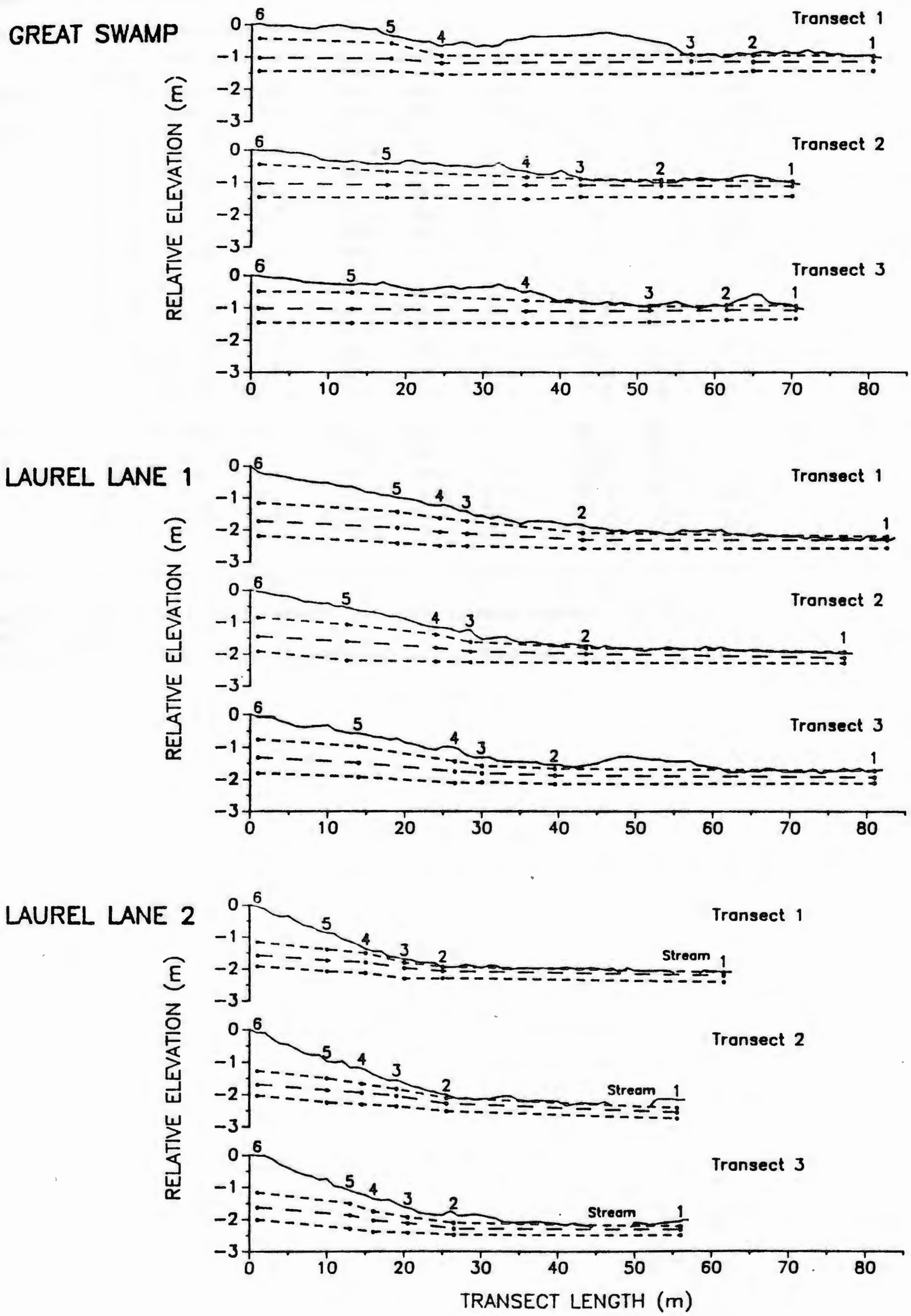

GREAT SWAMP
LAUREL LANE 1
LAUREL LANE 2
Transect 1
Transect 2
Transect 3
Stream
RELATIVE ELEVATION (m)
TRANSECT LENGTH (m)

Table 1. Growing season water level characteristics of the three study sites.[a]

Tran	Sta	GSW Mean WL[b] (cm)	GSW (±SD) (cm)	GSW WL<30[c] (%)	LL1 Mean WL (cm)	LL1 (±SD) (cm)	LL1 WL<30 (%)	LL2 Mean WL (cm)	LL2 (±SD) (cm)	LL2 WL<30 (%)
1	6	-103.0	27.1	1.2	-149.8	32.1	0	-150.9	24.2	0
	5	- 74.7	23.6	1.2	- 88.3	27.4	1.2	- 82.1	21.2	0
	4	- 42.5	17.7	15.4	- 75.9	24.3	1.2	- 53.8	18.2	8.9
	3	- 20.2	17.1	81.3	- 63.1	22.3	8.2	- 33.2	13.3	52.4
	2	- 15.7	15.1	90.4	- 38.9	14.4	29.6	- 18.6	9.0	89.9
	1	- 10.6	13.8	91.5	- 16.9	9.0	93.1	- 12.0	7.9	93.2
2	6	-105.2	27.7	1.2	-139.7	31.6	0	-161.6	24.0	0
	5	- 66.6	24.1	2.5	- 96.0	29.9	0	- 89.0	22.1	0
	4	- 40.1	18.5	31.6	- 61.5	23.6	7.8	- 66.7	19.0	0
	3	- 19.1	18.3	81.3	- 46.2	17.4	15.6	- 40.8	15.7	26.3
	2	- 15.6	16.8	87.3	- 22.2	13.1	82.2	- 33.3	10.9	43.2
	1	- 10.1	14.8	92.7	- 20.7	9.5	86.6	- 17.3	9.4	87.6
3	6	-105.2	27.5	0	-128.9	31.0	0	-155.1	26.5	0
	5	- 74.2	25.3	1.2	- 90.3	26.9	1.2	- 82.1	23.3	0
	4	- 59.8	21.1	2.5	- 62.7	18.6	3.5	- 68.5	19.6	0
	3	- 14.4	16.7	90.4	- 46.5	14.2	10.9	- 39.9	13.5	26.1
	2	- 14.7	15.0	90.4	- 27.8	13.0	71.0	- 30.0	8.6	61.7
	1	- 9.1	13.6	91.7	- 16.8	10.3	92.3	- 12.3	7.9	94.6

[a]Calculated from weekly measurements over three growing seasons (n=91-93).
[b]Water level.
[c]Percent of time water level was within 30 cm of ground surface.

Water Levels

In every case, the water table was closest to the surface at Station 1, and its depth increased steadily between Stations 3 and 6 (Table 1, Figure 1). Mean water levels at GSW were consistently shallower than at the Laurel Lane sites throughout the transects; the differences were particularily noticable above Station 3. On all transects, seasonal fluctuations in water levels were greatest at Station 6, and decreased down the transects; the standard deviation of the water level mean at Station 6 was typically two to three times as high as at Station 1 (Table 1).

The duration of soil saturation near the surface directly influences plant species distribution (Huffman and Forsythe 1981, Paratley and Fahey 1986). Examination of soil profiles at the Rhode Island sites indicated that most of the tree, shrub, and herb roots were within 30 cm of the ground surface. For that reason, the percentage of the growing season during which the water level was within 30 cm of the ground surface was determined. The water table was within that zone less than 2% of the growing season at Station 6 on all transects; the percentage increased to 87-95% of the growing season at Station 1 (Table 1).

Monthly precipitation levels for the study period are presented in Table 2. Annual precipitation was roughly equal to the 30-year mean in 1985, about 10% above the mean in 1986, and about 10% below the mean in 1987. The distribution of precipitation within each of the three years varied widely. Growing season precipitation was about 40% above the 30-year mean in 1985, primarily due to unusually heavy rains in August;

Table 2. Precipitation levels (cm) for the study period compared to the 30-year (1951-1980) average. All precipitation data were collected at the URI weather station, Kingston, RI.

Month	30-year mean precip	1985 precip	1986 precip	1987 precip
JAN	10.74	2.59	14.91	15.72
FEB	9.37	4.19	8.66	2.31
MAR	11.81	9.96	8.56	12.93
APR	10.49	3.07	5.51	20.98
MAY	10.46	14.88	4.95	4.60
JUN	7.42	11.96	10.92	3.71
JUL	7.59	7.39	16.79	2.67
AUG	11.33	32.28	10.62	8.00
SEP	10.44	6.99	2.34	15.52
OCT	10.06	6.27	6.88	6.02
NOV	11.81	23.29	20.60	9.63
DEC	11.63	2.54	24.84	8.91
Total	123.15	125.41	135.58	111.00
Growing-season[a] total	73.73	103.82	76.05	58.63

[a]Growing season extends from 15 April until 30 November.

very close to the mean in 1986; and about 20% below the mean in 1987. In 1987, rainfall from May through July was the lowest in 22 years (U.S. Dept. of Commerce, National Weather Service, T.F. Green Airport, Warwick, RI).

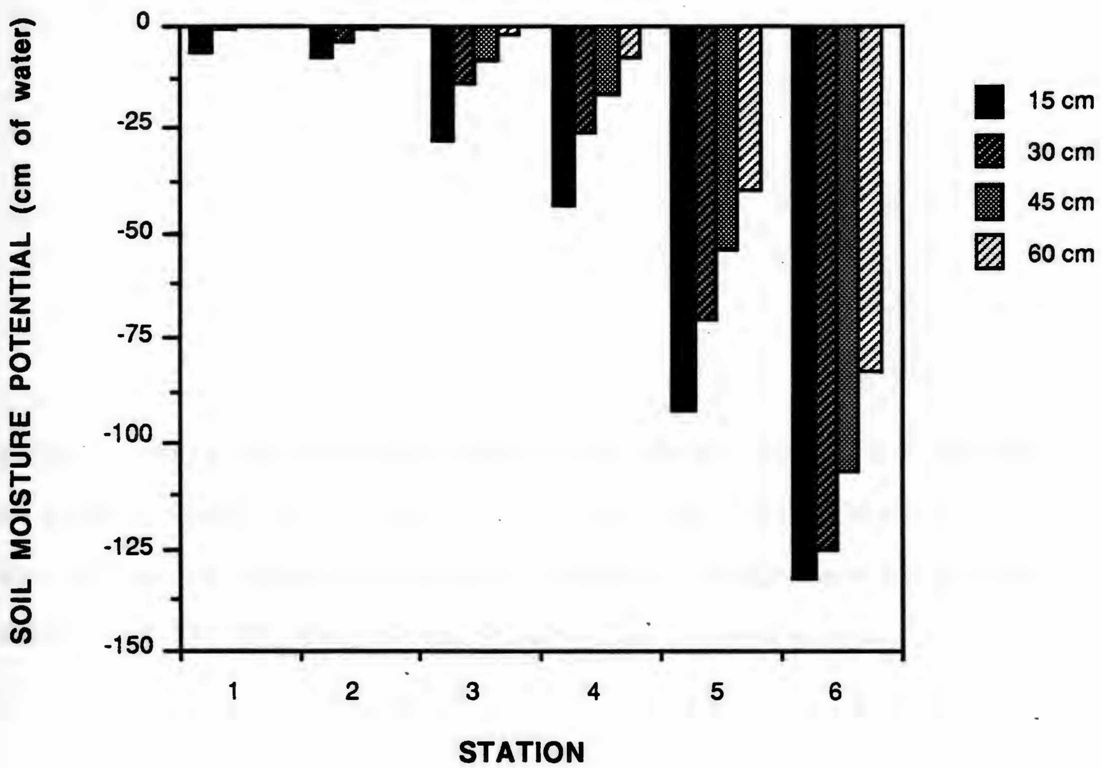
Soil Moisture and Air-filled Porosity

Soil moisture potentials among the 15-, 30-, 45-, and 60-cm depths at the various stations were similar on all of the transects. Figure 2 illustrates the mean soil moisture potentials for the six stations on Transect 2 at LL1 as an example. Consistent with water level trends, soil moisture potentials were highest at Station 1, indicating near-saturated conditions at all depths, and lowest at Station 6. Mean soil moisture potentials for the 54 sampling stations are presented in Appendix C.

The air-filled porosities of the mineral soil samples were significantly higher than those of organic soil samples based on two-sample t-tests ($p<0.05$) at each pressure increment (Figure 3). These findings concur with other studies which have shown that, because of small pore sizes and colloidal properties, well-decomposed organic materials retain more water compared to coarser soils under the same environmental conditions (Taylor 1949, Boelter 1964, Bay 1967). Air-filled porosities were not significantly different within the mineral or organic soil classes.

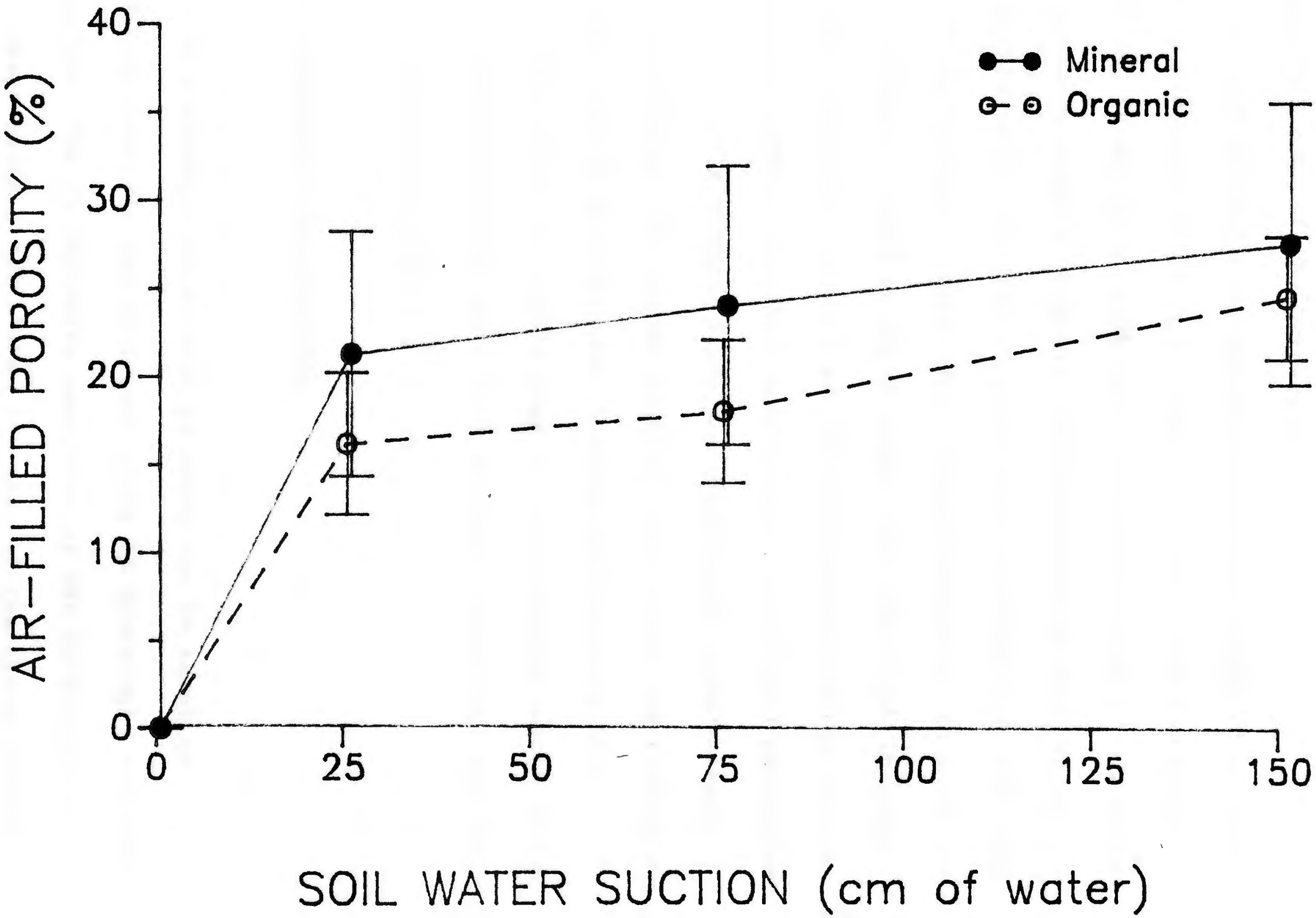
Using the separate air-filled porosity curves derived for organic and mineral soils (Figure 3) and data on the soil type surrounding each tensiometer, field measurements of soil moisture potentials were

Figure 2. Mean soil moisture potentials over the three growing seasons along Transect 2 at Laurel Lane 1.



SOIL MOISTURE POTENTIAL (cm of water)
0
-25
-50
-75
-100
-125
-150
1
2
3
4
5
6
STATION
15 cm
30 cm
45 cm
60 cm

Figure 3. Air-filled porosity means and standard deviations derived from mineral (n=20) and organic (n=21) soil horizons. Cores were placed on porous ceramic plates in a pressure chamber and subjected to pressures of 25, 75, and 150 cm of water for 24 hours each.


Mineral
Organic
AIR-FILLED POROSITY (%)
40
30
20
10
0
0
25
50
75
100
125
150
SOIL WATER SUCTION (cm of water)

converted to estimates of air-filled porosity. Because most of the organic horizons occurred at the lower ends of the transects, this conversion further enhanced the soil moisture differences between the wetland and upland ends of the transects.

The air-filled porosity curves showed a sharp change in slope at 25 cm water of pressure (Figure 3). Several authors (Flocker et al. 1959, Grable and Seimer 1968, Meek and Stolzy 1978) have reported that restricted aeration results when air-filled porosities drop below 10%-20% in wetted soils, leading to oxygen deficiencies, and that above 10%-20% air-filled porosity, sufficient oxygen diffusion can occur to inhibit anaerobiosis. Based on these studies and the break in slope observed in the laboratory-derived air-filled porosity curves, oxygen deficiencies were assumed to occur in soils with air-filled porosities at or below 15% in this study. Since the duration of anaerobiosis affects soil morphology (Zobeck and Ritchie 1984, Evans and Franzmeier 1986) and plant species distribution (Huffman and Forsythe 1981, Paratley and Fahey 1986), the percentage of each growing season during which the air-filled porosity was 15% or less was calculated for the four soil depths at each station.

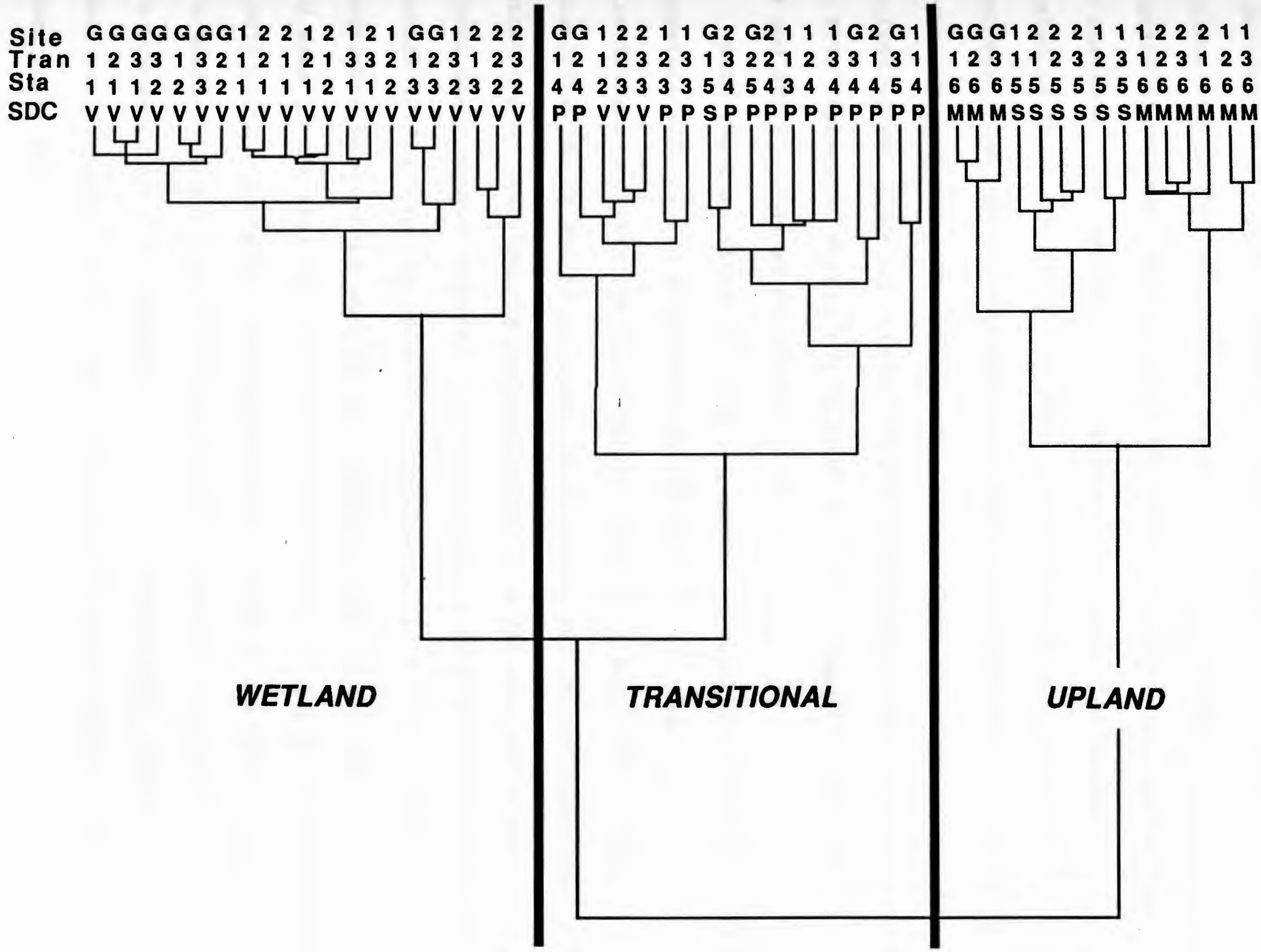
Wetland/Upland Station Classification

To examine hydrologic relationships among the 54 sampling stations, cluster analysis was performed using 18 hydrologic variables for each station. The 18 variables consisted of the following six hydrologic characteristics calculated for each of the three growing seasons: 1) mean water level; 2) percentage of the growing season during which the water table was within 30 cm of the ground surface; and 3-6) percentage of the growing season during which air-filled porosity was 15% or less at depths of 15, 30, 45, and 60 cm. The resulting dendrogram (Figure 4) illustrates the interrelationships among stations. Three large-scale clusters were subjectively identified: the cluster which included stations from the wet end of the transects was labelled "wetland"; the cluster containing stations from the dry end of the transects was labelled "upland"; and the cluster containing the remaining stations was labelled "transitional".

The wetland cluster consisted of 21 stations, all with VPD soils. All Station 1's and all but one of the Station 2's were included in this cluster. Also included were all of the Station 3's at GSW and one from LL2. The upland cluster consisted of 15 stations, including the MWD stations from all three sites and the SPD stations from LL1 and LL2. The linkage of the subclusters within this group suggested that the MWD stations at GSW were hydrologically more similar to the SPD stations at the Laurel Lane sites. This is in keeping with the higher water levels observed at GSW. The transitional cluster consisted of 18 stations: all of the PD stations, 3 VPD stations, and 1 SPD station. This cluster represented stations which were intermediate in wetness. However, the transitional cluster linked first with the wetland cluster, indicating that the transitional stations were more similar hydrologically to the wetland stations than to the upland stations.

Using discriminant analysis, linear discriminant endpoint functions were developed from hydrologic data from stations grouped in the wetland and upland clusters. The coefficients assigned to the 18 variables in each function are listed in Appendix D. Based on these

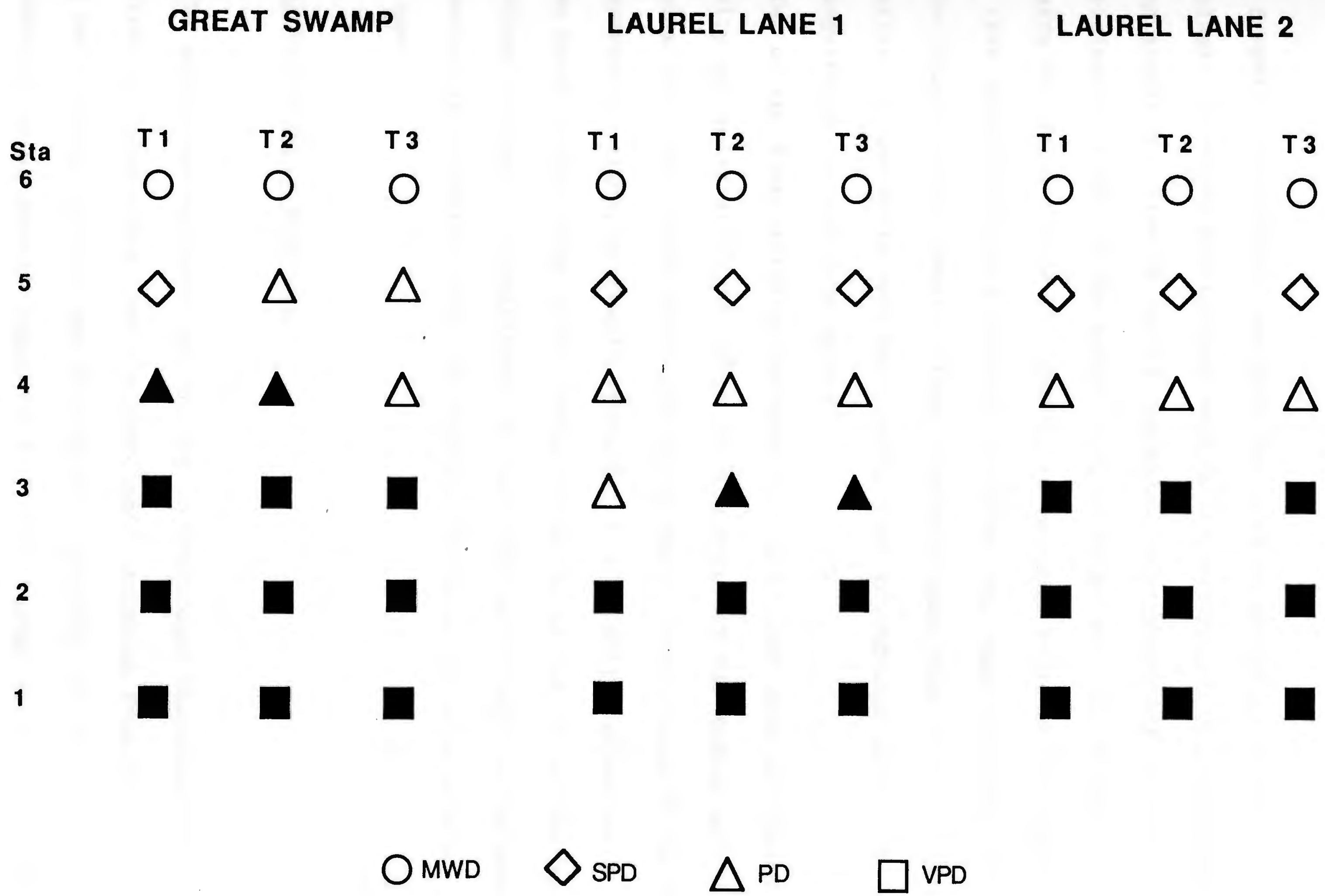
Figure 4. Cluster dendrogram of 54 sampling stations based on 3 years of data for six hydrologic characteristics. Stations are identified across the top of the dendrogram as follows: Site (G = Great Swamp, 1 = Laurel Lane 1, 2 = Laurel Lane 2); Tran = Transect (1, 2, or 3); Sta = Station (1-6); SDC = Soil drainage class (V = very poorly drained, P = poorly drained, S = somewhat poorly drained, M = moderately well drained). Heavy lines separate major clusters of stations designated as wetland, transitional, or upland.


Site
Tran
Sta
SDC
WETLAND
TRANSITIONAL
UPLAND

endpoint functions, each station in the transitional cluster was then classified as wetland or upland. Figure 5 depicts the resulting station classifications at the three sites. Twenty-eight stations were classified wetland, including all of the VPD stations and four of the PD stations. The remaining 26 stations were classified upland, including 10 of the 14 PD stations, and all of the SPD and MWD stations. The posterior probability that each transitional station was correctly classified was 100% in all cases. Over the three sites, the wetland/upland break in classification fell between VPD and PD stations on five transects, within the PD zone on three transects, and between PD and SPD stations on one transect.

Both the composition of, and the degree of separation between, the endpoints affects the classification of unknown stations in discriminant analysis (Neff and Marcus 1980, Williams 1983). Thus, the classification of the transitional stations as wetland or upland was determined by the stations included within the wetland and upland linear discriminant endpoint functions. Had it been possible to include well drained or excessively drained soils in this study, the separation between the wet and dry endpoints would have been greater, and some of the stations classified upland in the present analysis most likely would have been classified wetland. This might have resulted in the wetland/upland break occurring farther upslope. Conversely, had the transects included habitats as wet as the red maple swamps described in Lowry (1984), the wetland/upland break would probably have moved downslope.

Figure 5. Classification of sampling stations as wetland (filled symbols) or upland (open symbols) based on discriminant analysis using three growing seasons of data for six hydrologic variables.


GREAT SWAMP
LAUREL LANE 1
LAUREL LANE 2
Sta
T 1
T 2
T 3
6
5
4
3
2
1
MWD
SPD
PD
VPD

Key Hydrologic Characteristics

Stepwise discriminant analysis was used to determine which hydrologic variables contributed most to the separation of wetland and upland stations. Five of the 18 variables contributed 93% of the discriminatory power of the model; four of these were air-filled porosity variables (Table 3). The first variable to enter the model (the 1986 30-cm air-filled porosity variable) was responsible for 87% of the discriminatory power. These results suggest that the air-filled porosities of the soils were more useful than groundwater levels in distinguishing wetland from upland.

Two of the five variables selected as significant were air-filled porosity variables at 30 cm. This finding supports the hydric soil criteria (SCS 1987) which calls for a high water level within 30 cm of the surface in highly permeable very poorly and poorly drained soils. At the Rhode Island study sites, moisture levels in the 30-cm zone have additional ecological significance in that they are likely to influence vegetation distribution since the bulk of the roots occurred within this zone.

Annual Variation in Hydrology

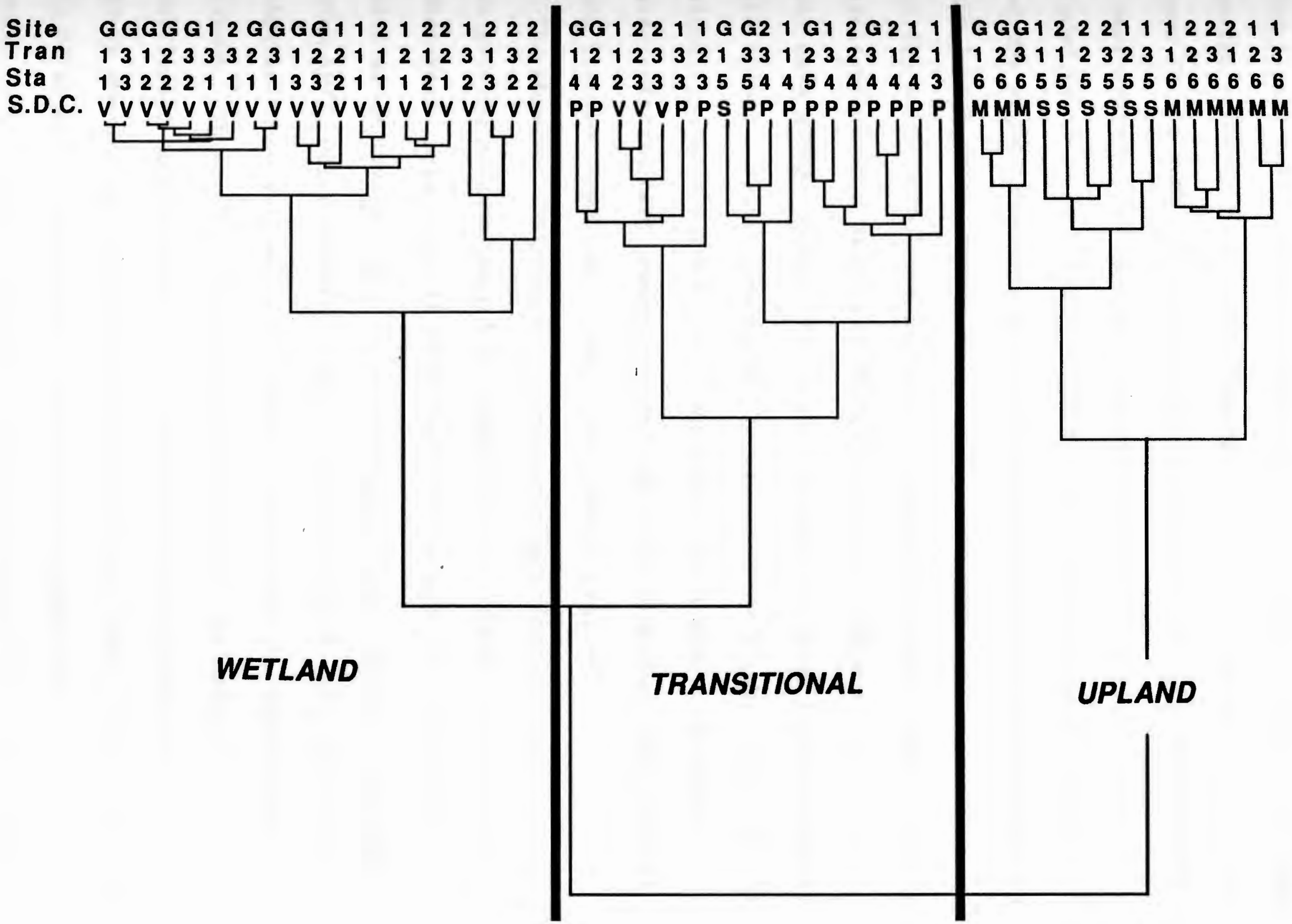
To assess between-year variability in hydrologic characteristics exhibited at these sites, the six hydrologic variables from the 3-year model were used in cluster and discriminant analyses run for the individual growing seasons (Appendix B). The cluster results for 1985 (Figure 6), which had near-normal annual precipitation, but

Table 3. Variables selected in stepwise discriminant analysis using the full hydrologic model (3 years, 18 variables). A significance level of 5% was required for a variable to enter the analysis.

Hydrologic variable	Growing season	Order of entry	Prob > F	ASCC[a]
AFP[b] at 30 cm	1986	1	0.0001	0.871
AFP at 60 cm	1986	2	0.0001	0.904
Mean water level	1987	3	0.0196	0.914
AFP at 30 cm	1985	4	0.0190	0.923
AFP at 45 cm	1985	5	0.0137	0.933

[a]Average squared canonical correlation coefficient.
[b]Percentage of growing season with air-filled porosity ≤15% at the specified depth.

Figure 6. Cluster dendrogram of 54 sampling stations based on 1985 growing-season data for six hydrologic characteristics. Stations are identified across the top of the dendrogram as follows: Site (G = Great Swamp, 1 = Laurel Lane 1, 2 = Laurel Lane 2); Tran = Transect (1, 2, or 3); Sta = Station (1-6); SDC = Soil drainage class (V = very poorly drained, P = poorly drained, S = somewhat poorly drained, M = moderately well drained). Heavy lines separate major clusters of stations designated as wetland, transitional, or upland.


Site GGGGG1 2GGGG1 1 2 1 22 1 2 2 2 GG1 2 2 1 1 G G2 1 G1 2G2 1 1 GGG1 2 2 2 1 1 1 2 2 2 1 1
Tran 1 3 1 2 3 3 3 2 3 1 2 2 1 1 2 1 2 3 1 3 2 1 2 1 2 3 3 2 1 3 3 1 2 3 2 3 1 2 1 1 2 3 1 1 2 3 2 3 1 2 3 1 2 3
Sta 1 3 2 2 2 1 1 1 1 3 3 2 1 1 1 2 1 2 3 2 2 4 4 2 3 3 3 3 5 5 4 4 5 4 4 4 4 4 3 6 6 6 5 5 5 5 5 5 6 6 6 6 6 6
S.D.C. V V V V V V V V V V V V V V V V V V V V V P P V V V P P S P P P P P P P P P P M M M S S S S S S M M M M M M
WETLAND
TRANSITIONAL
UPLAND

above-average rainfall during the growing season, were somewhat similar to the 3-year model. Station classification using discriminant analysis moved the wetland/upland break upslope on three transects in this year (Figure 7). In 1986, with annual precipitation about 10% above normal and near-average growing season precipitation, two PD stations were included in the upland cluster (Figure 8), and discriminant analysis moved the wetland/upland breakpoint downslope on one transect compared to the 3-year model (Figure 7). In 1987, with annual precipitation about 10% below normal and record-low rainfall in early summer, cluster analysis produced a dendrogram dividing the 54 stations into two, not three, main groups (Figure 9); all of the MWD stations linked together in the upland cluster, including the GSW stations which, in all of the previous cluster analyses, had linked first with wetter drainage classes. Discriminant analysis moved the wetland/upland break upslope on one transect compared to the 3-year model (Figure 7).

The observed differences in station classifications between the three growing seasons should be regarded as an underestimate of the between-year variability in hydrologic parameters that is possible. Wetland water levels often reflect precipitation patterns (Bay 1967, O'Brien 1977, Golet and Lowry 1987). In this study, the impact of precipitation on wetland water levels varied with its timing and magnitude. Thus, while the relationship may not be directly proportional, annual variation in precipitation may be used as a rough gauge of the degree of variation in water levels and soil moisture that could be expected among years. The maximum annual precipitation recorded in the 30-year record at the URI weather station was 174 cm; the minimum was 78 cm. The total range in annual precipitation, 96 cm,

Figure 7. Comparison of station classifications resulting from discriminant analysis based on 3-year and 1-year models; the same six hydrologic variables were used in each analysis. Stations below each line were classified wetland for that analysis; stations above the line were classified upland. Distances between stations are illustrated as equidistant for graphical purposes, but varied in reality.

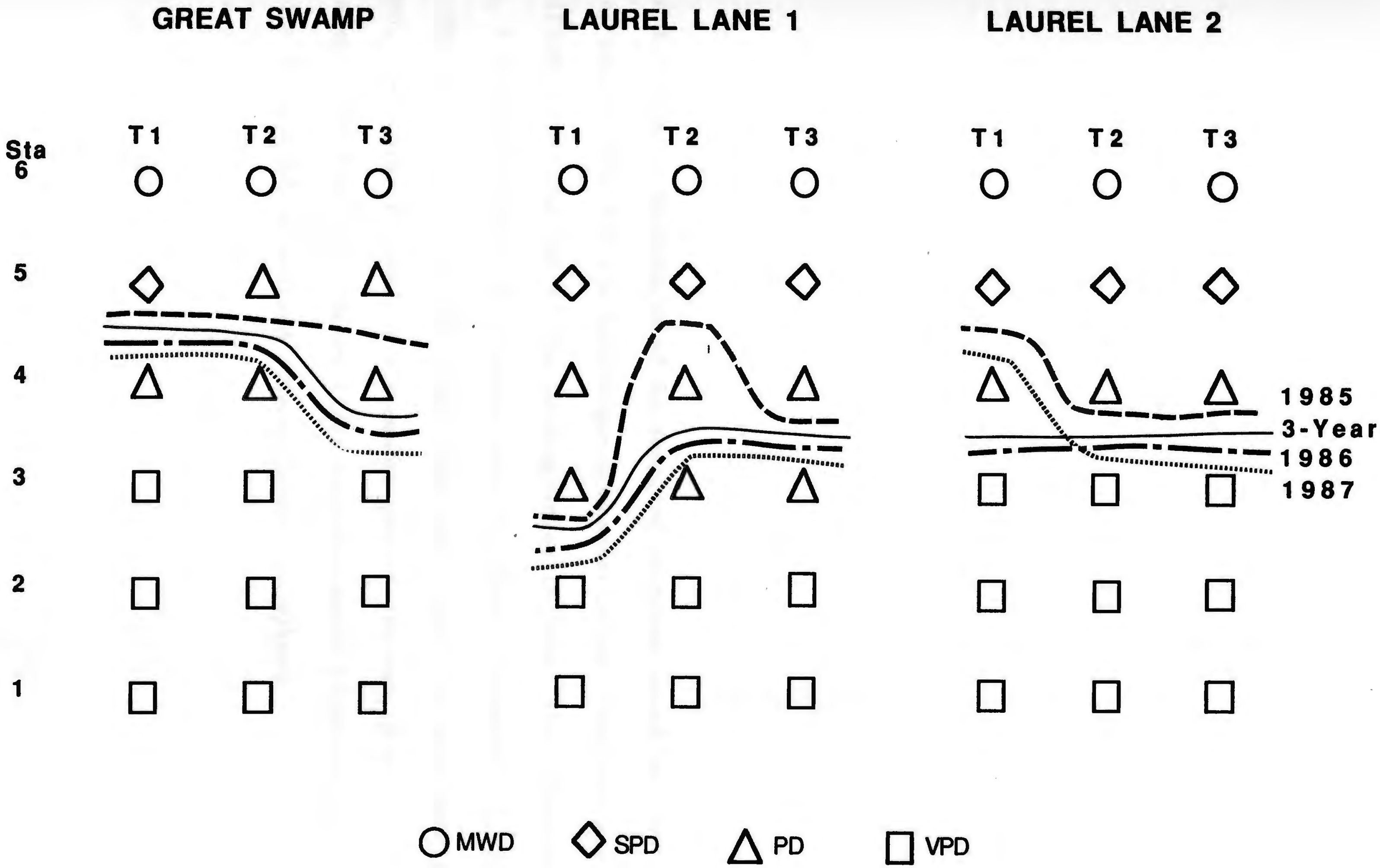

GREAT SWAMP
LAUREL LANE 1
LAUREL LANE 2
Sta
T 1
T 2
T 3
6
5
4
3
2
1
1985
3-Year
1986
1987
MWD
SPD
PD
VPD

Figure 8. Cluster dendrogram of 54 sampling stations based on 1986 growing-season data for six hydrologic characteristics. Stations are identified across the top of the dendrogram as follows: Site (G = Great Swamp, 1 = Laurel Lane 1, 2 = Laurel Lane 2); Tran = Transect (1, 2, or 3); Sta = Station (1-6); SDC = Soil drainage class (V = very poorly drained, P = poorly drained, S = somewhat poorly drained, M = moderately well drained). Heavy lines separate major clusters of stations designated as wetland, transitional, or upland.

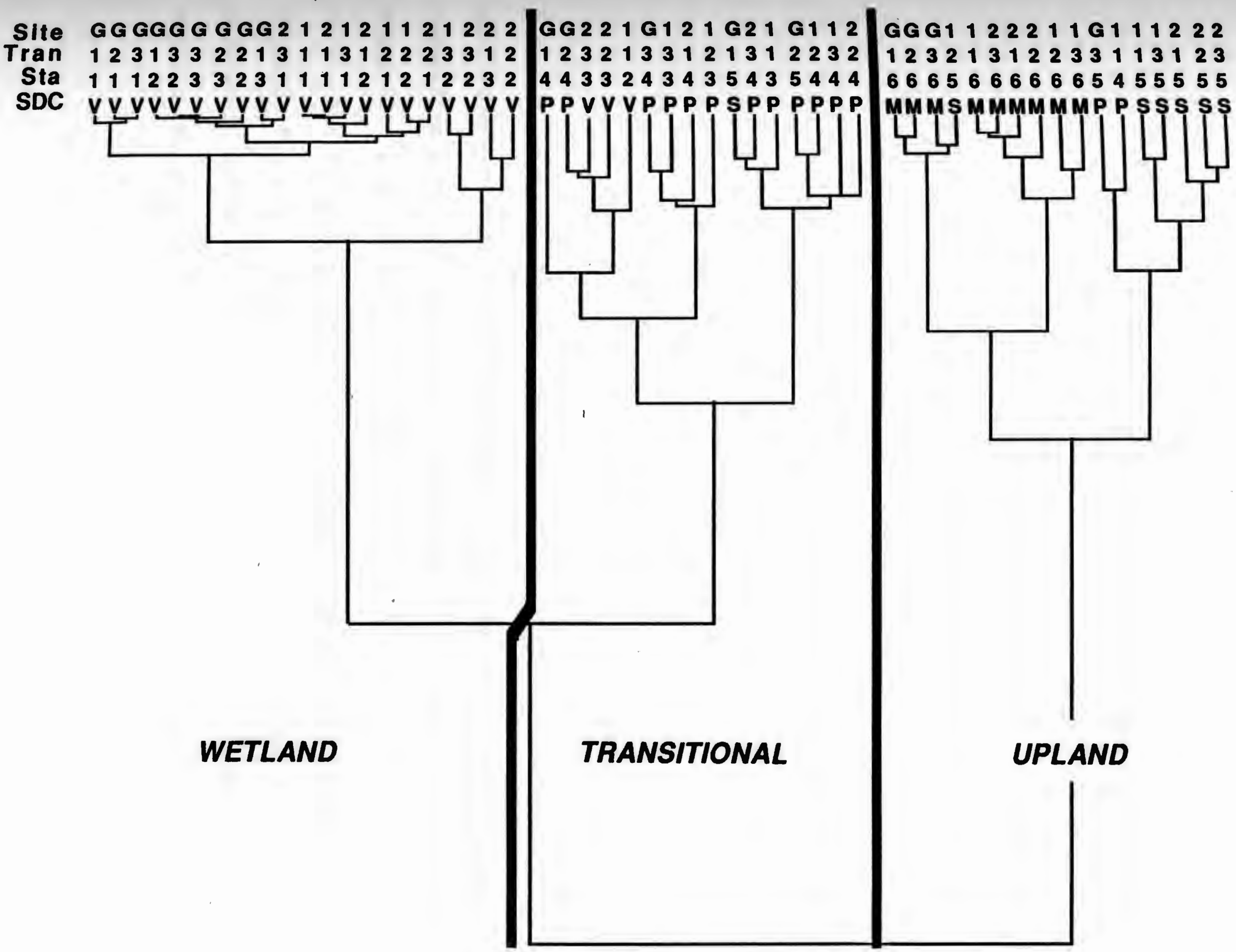
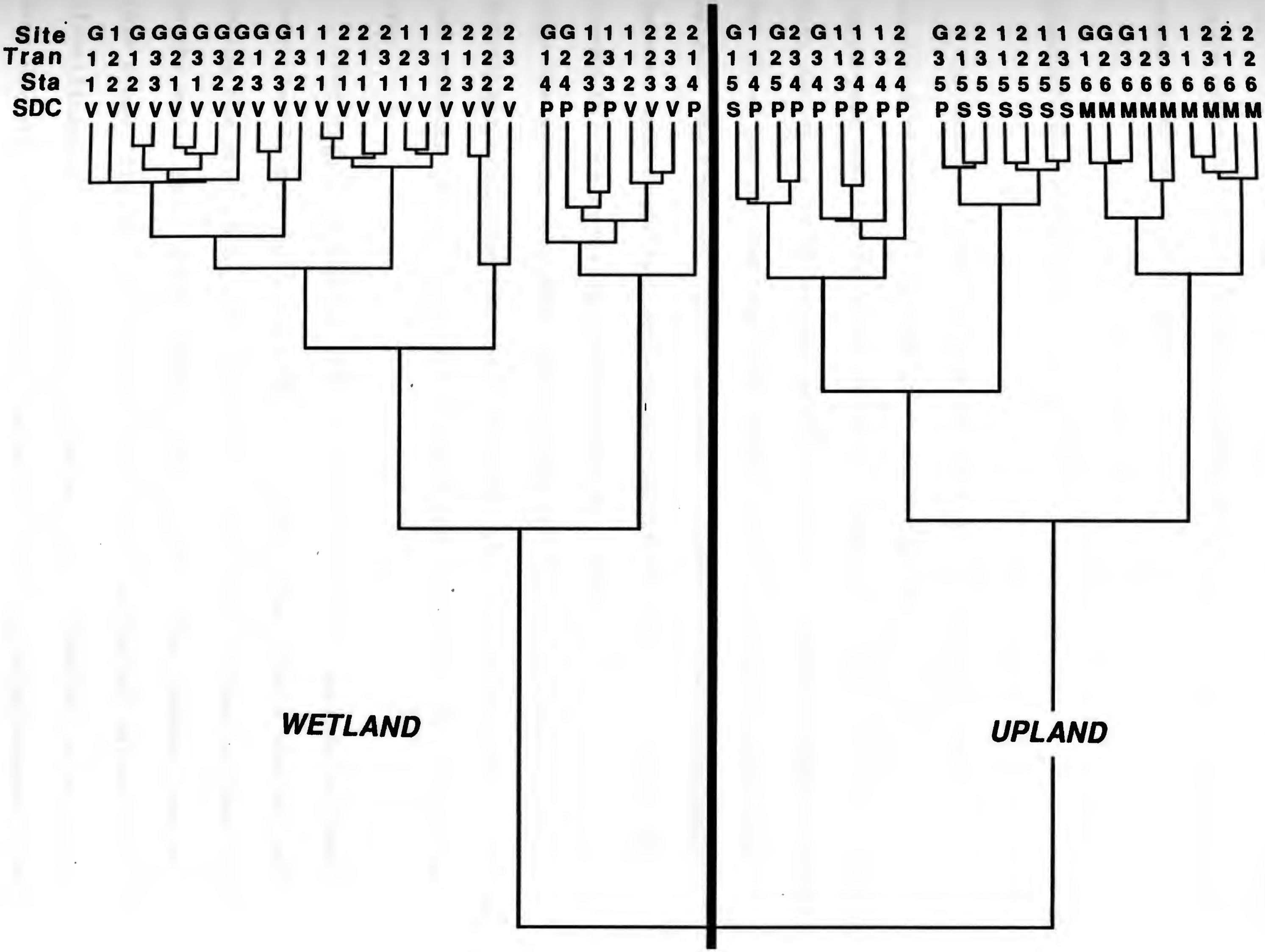

Site
Tran
Sta
SDC
WETLAND
TRANSITIONAL
UPLAND

Figure 9. Cluster dendrogram of 54 sampling stations based on 1987 growing-season data for six hydrologic characteristics. Stations are identified across the top of the dendrogram as follows: Site (G = Great Swamp, 1 = Laurel Lane 1, 2 = Laurel Lane 2); Tran = Transect (1, 2, or 3); Sta = Station (1-6); SDC = Soil drainage class (V = very poorly drained, P = poorly drained, S = somewhat poorly drained, M = moderately well drained). Heavy lines separate major clusters of stations designated as wetland, transitional, or upland.



Site G 1 G G G G G G G G 1 1 2 2 2 1 1 2 2 2 2 G G 1 1 1 2 2 2 G 1 G 2 G 1 1 1 2 G 2 2 1 2 1 1 G G G 1 1 1 2 2 2
Tran 1 2 1 3 2 3 3 2 1 2 3 1 2 1 3 2 3 1 1 2 3 1 2 2 3 1 2 3 1 1 1 2 3 3 1 2 3 2 3 1 3 1 2 2 3 1 2 3 2 3 1 3 1 2
Sta 1 2 2 3 1 1 2 2 3 3 2 1 1 1 1 1 1 2 3 2 2 4 4 3 3 2 3 3 4 5 4 5 4 4 3 4 4 4 5 5 5 5 5 5 5 6 6 6 6 6 6 6 6 6
SDC V V V V V V V V V V V V V V V V V V V V V P P P P V V V P S P P P P P P P P P S S S S S S M M M M M M M M M
WETLAND
UPLAND

was over three times the range of 26 cm observed between 1985 and 1987 (Table 2). This suggests that changes in station classification between years of high and low rainfall could potentially be much greater than those observed in this study.

Correlation with Hydric Soil Status

The hydric status for the soil series at the 54 stations was compared to the wetland/upland classifications resulting from the three-year model hydrologic analysis (Table 4). All 15 of the stations with nonhydric soils were classified upland in the hydrologic analysis, but 10 of the 39 stations with hydric soils also were classified upland. One transect (GSW, Transect 1) showed perfect correlation between hydrologic and soil-based classifications. On six of the transects, the hydrologic break was one station lower on the transect than the hydric/nonhydric soils break and on two transects, the hydrologic break was two stations lower than the soils break. Of the ten stations where discrepancies occurred, nine were PD and one was SPD.

For highly permeable (>15 cm/hr) soils to be considered hydric, water levels must be within 30 cm of the surface for a week or more during the growing season (SCS 1987). When this criterion was applied to the water level data collected during the three growing seasons of this study, six of the stations with hydric soils and upland hydrologic classifications did not meet the water level criterion in any year; four met the criterion during two of the three growing seasons (Table 4). However, the soil morphology at these stations supported the hydric

Table 4. Hydric soil status and wetland/upland classification of the 54 sampling stations.

		Transect 1			Transect 2			Transect 3		
Site	Sta	Hydric soil[a]	Hydrology[b]	Obs WL[c]	Hydric soil	Hydrology	Obs WL	Hydric soil	Hydrology	Obs WL
GSW	6	NH	Up	NH	NH	Up	NH	NH	Up	NH
	5	NH	Up	NH	H	Up*	NH	H	Up*	NH
	4	H	Wet	H	H	Wet	H	H	Wet	NH
	3	H	Wet	H	H	Wet	H	H	Wet	H
	2	H	Wet	H	H	Wet	H	H	Wet	H
	1	H	Wet	H	H	Wet	H	H	Wet	H
LL1	6	NH	Up	NH	NH	Up	NH	NH	Up	NH
	5	NH	Up	NH	NH	Up	NH	NH	Up	NH
	4	H	Up*	NH	H	Up*	H	H	Up*	H
	3	H	Up*	H	H	Wet	H	H	Wet	H
	2	H	Wet	H	H	Wet	H	H	Wet	H
	1	H	Wet	H	H	Wet	H	H	Wet	H
LL2	6	NH	Up	NH	NH	Up	NH	NH	Up	NH
	5	H	Up*	NH	NH	Up	NH	NH	Up	NH
	4	H	Up*	H	H	Up*	NH	H	Up*	NH
	3	H	Wet	H	H	Wet	H	H	Wet	H
	2	H	Wet	H	H	Wet	H	H	Wet	H
	1	H	Wet	H	H	Wet	H	H	Wet	H

[a]Hydric soil status based on series designation by SCS (1987). NH = Nonhydric; H = Hydric.
[b]Up = upland hydrologic classification; Wet = wetland hydrologic classification.
[c]Hydric soil status based on SCS (1987) water level criteria and weekly water level measurements over three growing seasons. NH = Nonhydric; H = Hydric.
*Disagreement between hydric soil status and hydrologic-based classifications of station.

status (Sokoloski et al. 1989), which suggests that the hydrologic classifications and the water level criteria were incorrect at these stations. Since reducing conditions can occur in nearly-saturated as well as as fully-saturated soils, wetland morphology can develop in soils lacking an observable water table (Vepraskas and Bouma 1976, Pickering and Veneman 1984). Therefore, soil moisture potential may be a more precise characteristic than groundwater level to correlate with hydric soil features.

SUMMARY AND CONCLUSIONS

Through cluster and discriminant analysis of hydrologic data collected along a soil drainage toposequence at three sites, VPD stations were classified wetland, and all MWD and SPD stations upland. Stations on PD soils clearly had transitional hydrologic features. Discriminant analysis placed the wetland/upland break between VPD and PD stations on five transects, within the PD soil zone on three transects and between PD and SPD stations on one transect.

The relative and somewhat arbitrary nature of discriminant anaylsis limits the usefulness of this method in wetland delineation for regulatory purposes. In this study, the classification of an individual transitional station as wetland or upland was largely dependent on the hydrologic conditions of the endpoints entered into the model. Had our transects extended into drier or wetter sites, the degree of similarity between certain transitional stations and the endpoint stations might have changed. The wetland/upland classifications resulting from this analysis must be viewed with this artifact in mind.

Soil moisture data, expressed as air-filled porosity, contributed more to the discrimination between wetland and upland stations than did water table data. In particular, the duration of saturated or near-saturated conditions within 30 cm of the surface was key; the percentage of the growing season during which air-filled porosity at a 30-cm depth was at or below 15% was selected as the most important variable in the discriminant analyses. Soil moisture data collected within the top 30 cm were more useful than data from greater depths because the variability in moisture levels along the transects was greater near the surface. The 30-cm depth is also ecologically significant at these sites since most of the plant roots occurred within this zone.

Comparison of hydrologic data among years demonstrated that, in some instances, the wetland/upland break moved one or two stations in either direction on the moisture gradient as a result of changing precipitation levels. Over the three years monitored in this study, annual precipitation means fluctuated only moderately around the 30-year mean. In years of higher precipitation, more of the PD zone might have been classified wetland. This hydrologic variability, coupled with the U.S. Soil Conservation Service's (1985) classification of PD soils as hydric, supports the inclusion of the PD zone as wetland for regulatory purposes.

The variation in hydrologic results between the three growing seasons suggests that additional years of monitoring are required to clearly characterize the hydrology of these sites. While hydrologic information is vital in understanding the biological and physical characteristics of wetlands, the use of hydrologic information in wetland boundary delineation will not be practical in most instances because of the long-term data base required.

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COMPARISON OF WETLAND BOUNDARIES BASED ON HYDROLOGY, VEGETATION, AND SOILS IN RHODE ISLAND RED MAPLE SWAMPS

ABSTRACT

Using three separate parameters -- hydrology, vegetation, and soils, 54 sampling stations in the transition zone of three Rhode Island red maple swamps were classified as wetland or upland. The hydrologic classifications were determined using cluster and discriminant analysis of hydrologic data gathered weekly at each station over three growing seasons. Soil-based station classifications were based on the hydric status of the soil series at the various stations, as designated by the U.S. Soil Conservation Service. Vegetation-based station classifications were calculated using weighted averaging of herb-layer data, U.S. Fish and Wildlife wetland plant indicator status, and a 3.0 wetland/upland breakpoint.

The wetland/upland break based on hydrology was lowest on the transects; only very poorly drained soils and some of the poorly drained soils were classified wetland. The vegetation-based break was highest; all stations except for some moderately well drained soils were classified wetland. The break based on hydric soil status generally was located between these two extremes; all of the very poorly and poorly drained stations and a single somewhat poorly drained station were classified wetland. The extent of hydric soils appeared to most reasonably define the wetland boundary for regulatory purposes.

INTRODUCTION

In recent decades, wetlands have become recognized as an important but diminishing resource, serving many functions including flood reduction, wildlife habitat, pollution abatement, and recreation. Of the 87 million hectares of wetlands estimated to exist in the conterminous United States prior to European settlement, 54% had been filled, excavated, or drained by the mid-1970's (Tiner 1984). To stem the rate of wetland loss, regulations controlling human activities in wetlands have been adopted at local, state, and federal levels. The effective implementation of these regulations requires that wetlands be clearly identified and delineated, but universally accepted criteria for distinguishing wetland from nonwetland have yet to be established.

The U.S. Fish and Wildlife Service (Cowardin et al. 1979:3) defines wetlands as

> "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. . . .wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year."

This and similar definitions (e.g., Federal Interagency Committee for Wetland Delineation 1989) suggest that wetlands can be identified by their hydrology, vegetation, and soils, but as yet the relationships among these three parameters remain poorly understood in many wetland types.

In the Northeastern United States, few comprehensive studies of freshwater wetlands have been performed. Pickering and Veneman (1984) correlated soil coloration with soil moisture regimes, temperature, and redox potential in a soil drainage toposequence in Massachusetts. In a Rhode Island study of 12 forested wetlands, 7 years of water level data were correlated with tree growth rates, plant community composition, and microrelief (Lowry 1984). Damman and Kershner (1977) and Messier (1980) described wetland plant communities in Connecticut and demonstrated that floristic differences could be explained by water regimes and nutrient levels.

A few studies have correlated wetland hydrology, vegetation, and soils, but with varying success. In a study of forested wetland transition zones in Connecticut, Anderson et al. (1980) found an inverse relationship between soil moisture content and soil acidity, and that vegetation could be grouped according to soil moisture content and relative elevation. Paratley and Fahey (1986) determined that soil moisture was closely correlated with both soil morphology and the distribution of vegetation in a forested wetland in upstate New York.

In 1985, the University of Rhode Island initiated a three-year study of hydrology, vegetation, and soils along a moisture gradient at three deciduous forested sites in southern Rhode Island. The goals of that study were to determine the relationships among the three parameters as they changed along the moisture gradient and to identify key aspects of each that could be used as field criteria for wetland delineation. Each parameter was analyzed independently and a separate wetland/upland break was identified for each. This paper examines the extent of agreement among hydrologic, vegetative, and soil criteria by comparing the relative locations of the three breaks along the moisture gradient. Possible causes of disagreement among the three breaks are discussed.

METHODS

Study Sites

Three study sites which shared the following features were selected: a continuous deciduous forested canopy; freedom from recent disturbance; a gradual slope from wetland to upland; stratified glacial deposits; and a drainage toposequence including very poorly drained (VPD), poorly drained (PD), somewhat poorly drained (SPD), and moderately well drained (MWD) soils. The three sites were named Great Swamp (GSW), Laurel Lane 1 (LL1), and Laurel Lane 2 (LL2). The Great Swamp site was located at the margin of a large wetland system including a 400-hectare shallow lake and about 800 hectares of forested wetland. The two Laurel Lane sites were about 200 m apart in a small watershed drained by a perennial stream. All sites were within 10 km of the University of Rhode Island in Kingston.

Data Collection

At each study site, three transect lines were oriented perpendicular to the slope contours and spaced 15 m apart. Along each line, six sampling stations were located according to soil drainage class. Drainage classes, determined from auger samples, were based on criteria specified by Wright and Sautter (1979). Stations 1 and 2 were placed in VPD soils, Station 3 was located at the border between VPD and PD soils, and Stations 4, 5, and 6 were placed in the middle of PD, SPD, and MWD soil zones, respectively.

A water table well was located at the center of each sampling station (Figure 1). Wells consisted of 3.8-cm inside-diameter perforated PVC pipe inserted to depths ranging from 1.5 m at Station 1 to 3.0 m at Station 6. Wells were fitted with removable caps and sealed at the soil surface with bentonite clay. The relative elevation of the ground surface at each well was obtained with a rod and transit; ground surface elevations also were obtained at 0.5-cm intervals along the length of each transect.

Soil moisture potentials were monitored using four tensiometers at each sampling station (Figure 1). Tensiometers were constructed according to specifications from Soil Measurement Systems (Phoenix, Arizona) and placed so that soil moisture potentials could be monitored at four soil depths: 15, 30, 45 and 60 cm. Soil moisture potentials were determined with a pressure-transducing tensimeter constructed by Soil Measurement Systems. At each station at LL1, soil temperatures were measured using copper-constantan thermocouples placed at the same four depths as the tensiometers (Figure 1).

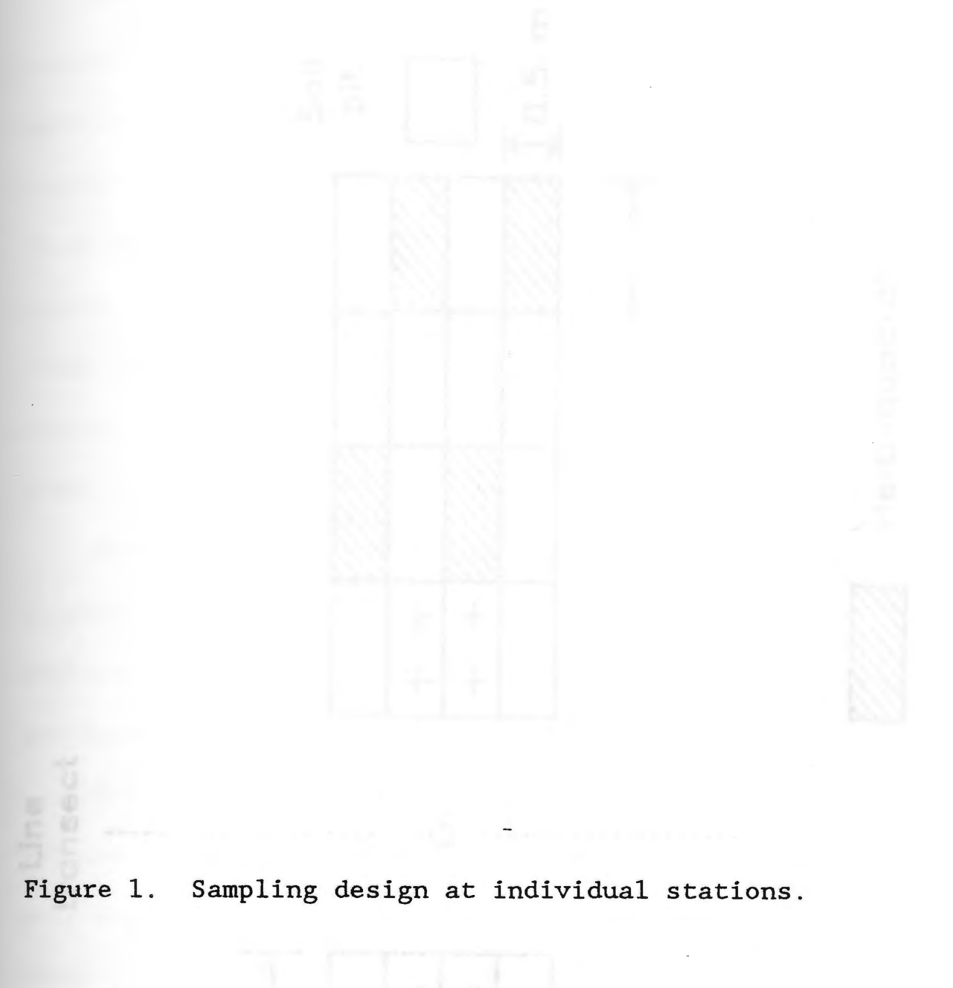
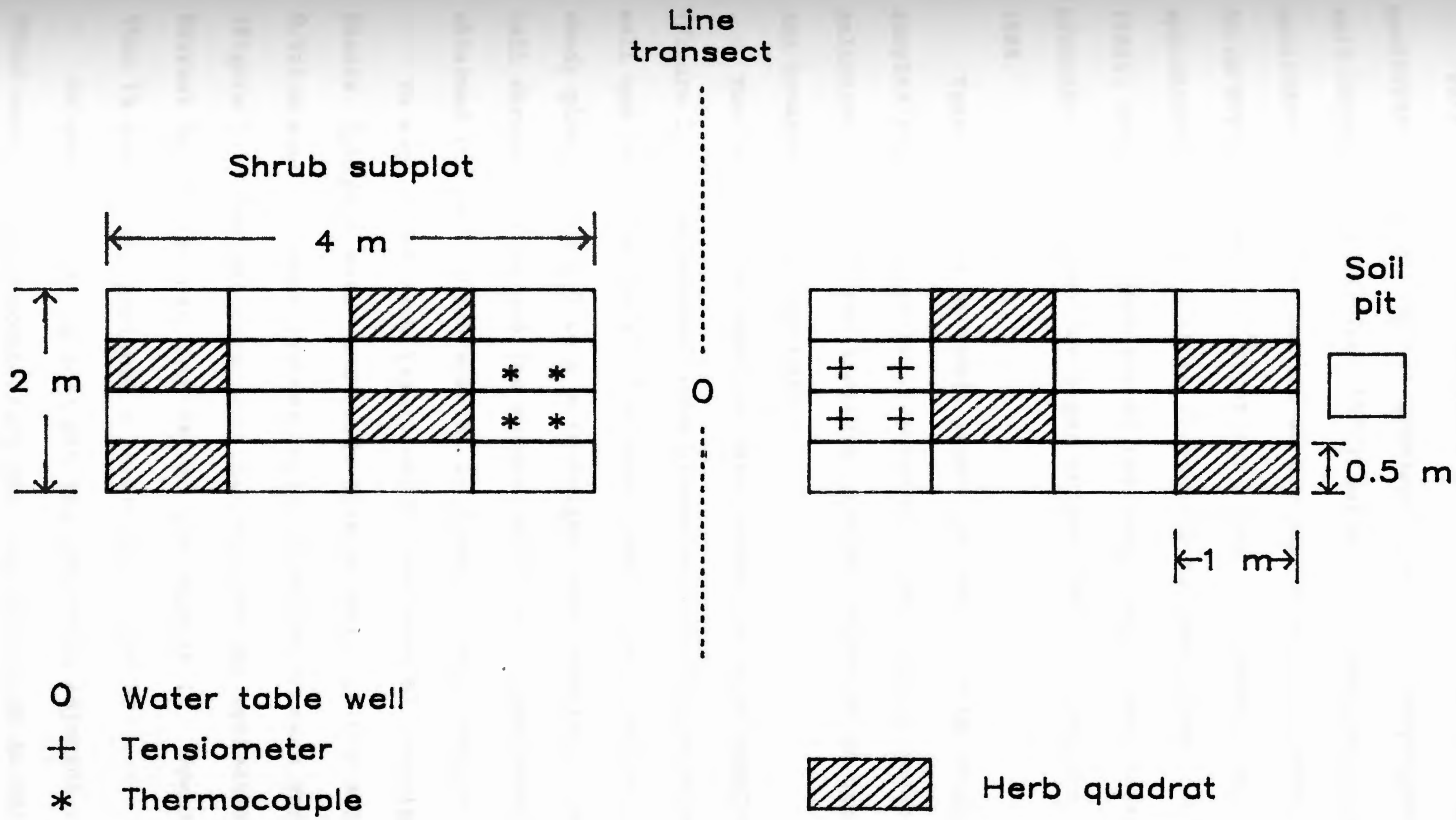


Figure 1. Sampling design at individual stations.



Line transect
Shrub subplot
4 m
2 m
Soil pit
0.5 m
1 m
O Water table well
+ Tensiometer
* Thermocouple
Herb quadrat

Water levels, soil moisture potentials, and soil temperatures were monitored weekly during the growing season. In keeping with the U.S. Soil Conservation Service (1987) definition, the growing season was considered to be that period of the year when soil temperatures at a 50-cm depth exceeded 5 °C; at our sites, this period extended approximately from 15 April through 30 November (Sokoloski et al. 1988). During the remainder of the year, water levels were monitored biweekly. Data collection began in May 1985 and continued through April 1988.

Trees, defined as woody plants at least 6 m in height, were sampled in a 10-m wide belt centered on each line transect. Data collected for each tree included species, diameter at breast height, and location within the belt.

Two 2x4-m shrub subplots were located at each sampling station (Figure 1). The subplots were placed on either side of the water-table well and separated by a 1.5-m wide travel lane. Shrubs, defined as woody plants from 0.5 to 6 m in height, were sampled in two layers, tall shrubs (2-6 m) and low shrubs (0.5-2 m). Stem densities were obtained for each shrub species by layer in each subplot.

To sample the herb layer, which consisted of vascular non-woody plants, Sphagnum moss, and woody plants less that 0.5 m in height, four 0.5x1-m quadrats were systematically arranged in each shrub subplot (Figure 1). Percent cover for each species was estimated to the nearest 5%, or if less than 5%, to the nearest 1%. Species with less than 1% cover were assigned a cover value of 0.5%.

At each station, a soil pit was excavated adjacent to one of the shrub subplots at approximately the same elevation as the water table well (Figure 1). When high water tables and unstable subsoils in several of the VPD stations inhibited pit excavation, samples were obtained using a soil auger. Soil profiles were described using standard terminology (Soil Survey Staff 1951). Soils were classified to the series level and designated hydric if included in the Hydric Soils of the United States (Soil Conservation Service 1987). Each horizon was sampled for laboratory analyses of soil texture and percent organic matter by weight. Soil profiles and laboratory techniques are described by Sokoloski (in prep.).

Soil moisture characteristic curves were derived to estimate the water content of the various soils across a range of soil moisture potentials. Mineral soils were divided into three textural classes and eight classes of organic matter content (Appendix A). Organic soils, defined as soils having an organic matter content of at least 20% by weight (Soil Survey Staff 1951), were sampled in three classes, 20-39%, 40-59%, and 60%. Undisturbed cores 4.57 cm in diameter were obtained from one to three horizons representing each textural class and each category of organic matter content found on the sites. Each horizon was sampled in triplicate. The cores were fully saturated in a slight vaccuum to eliminate entrapped air, and then subjected to pressures of 25, 75, and 150 cm of water for 24 hours each. The weights of the cores were obtained at each pressure increment; changes in weight were ascribed to pore water lost as smaller-diameter pores drained under increasing pressure (Hillel 1980). The cores were then oven-dried at 105 °C to drive off all free water. Soil water content was expressed as volumetric water content. Since soil aeration, not soil moisture, is frequently restricted in wetlands, air-filled porosity at each soil moisture potential was calculated as the difference between total soil porosity and volumetric moisture content. Percent air-filled porosity estimates the percent of the soil core volume filled with air (Hillel 1980).

<u>Data Analysis</u>

Exploratory statistics were employed to determine hydrologic relationships among the sampling stations. Data from all 54 stations from the three study sites were pooled to achieve a minimum sample-to-variable ratio of at least 3-to-1 (Pielou 1984). All statistical analyses were performed using SAS software (Statistical Analysis Systems 1985). Cluster analysis (PROC CLUSTER, CENTROID) was used to group the sampling stations according to similarities in their hydrologic characteristics. Wetland, upland, and transitional clusters of stations were subjectively identified from cluster dendrograms. Using discriminant analysis (PROC DISCRIM), wetland and upland linear discriminant functions were derived from the hydrologic data for stations within the wetland and upland clusters, respectively. Each station within the transitional cluster was then classified wetland or upland. The hydrologic variables contributing most to the separation of wetland and upland stations were identified using stepwise discriminant analysis (PROC STEPDISC). A significance level of 5% was required for a variable to enter the stepwise analysis. Comprehensive reviews of cluster and discriminant analysis may be found in Neff and Marcus (1980) and Pielou (1984).

Stem densities and percent cover values were converted to relative values to permit comparison of species abundance among sample plots (Mueller-Dombois and Ellenberg 1976). Stem densities for the two shrub subplots at each station were combined, as were percent cover estimates for the eight herb quadrats at each station. Because of the close spacing of transects and the proximity of adjacent stations on the steeper slopes, establishment of standard 100-m^2 sample plots for trees (Mueller-Dombois and Ellenberg 1976) was not possible. Instead, trees within each belt were grouped by soil drainage class. The boundaries of the drainage classes were approximated from the elevations of adjacent stations representing different drainage classes. Even using this approach, several tree plots were smaller than 100 m^2.

Each species was assigned a U.S. Fish and Wildlife Service (FWS) wetland indicator status for Region 1 according to the National List of Plant Species that Occur in Wetlands (Reed 1988). The indicator categories, which are based on frequency of occurrence in wetlands, are: Obligate Wetland (OBL), greater than 99% frequency; Facultative Wetland (FACW), 67-99%; Facultative (FAC), 34-66%; Facultative Upland (FACU), 1-33%; and Obligate Upland (UPL), less than 1%. Species that were not in the list, and not under consideration for inclusion in the list (P.B. Reed, FWS, St. Petersburg, FL; pers. comm., 1987) were classified UPL. Species whose classifications were still undetermined by FWS were excluded from analysis, as were plants that could be identified to genus only. The genus *Sphagnum*, an important wetland indicator in the Northeast, was considered OBL even though nonvascular plants are not included in the FWS plant list. The classification of *Rhododendron viscosum* was changed from OBL to FACW, since this is clearly not an OBL species in southern Rhode Island. Appendix E lists the plant species found at one or more of the three study sites, along with the FWS indicator status for each.

Weighted averages, which take into account both the indicator status and the importance value of each plant species in a sample, were calculated for each vegetation layer at each station, following Wentworth and Johnson (1986). Those authors assigned numerical indices to the indicator categories as follows: OBL = 1, FACW = 2, FAC = 3, FACU = 4, UPL = 5. The weighted averaging formula is:

$$W_j = \left(\sum_{i=1}^{p} I_{ij} E_i\right) / \left(\sum_{i=1}^{p} I_{ij}\right)$$

where W_j = weighted average for sample plot j

I_{ij} = importance value for species i in plot j

E_i = ecological index for species i

p = number of species in plot j

Importance measures used were basal area in the tree layer, stem density in the shrub layer, and percent cover in the herb layer. Weighted averages equal to or below 3.0 were considered wetland, while scores above 3.0 were considered upland.

RESULTS

The most gradual slopes occurred at GSW, where the mean slope for the three transects was 1.43%. Slopes were intermediate at LL1 (mean=2.21%), and steepest at LL2 (mean=3.67%). All transect lines showed relatively little change in elevation between Stations 1 and 3, with most of the rise occurring between Stations 3 and 6 (see Figure 1 in Manuscript 1).

Inspection of soil morphology in the soil pits corroborated most of the initial soil drainage class determinations. Station 3, placed on the VPD/PD border, was classified PD on the three transects at LL1, and VPD on all transects at GSW and LL2. On two transects at GSW, where Station 5 initially had been classified SPD, the designation was changed to PD after closer inspection.

Hydrology

Hydrologic analyses were performed using six characteristics for each station: mean growing-season water level, percentage of the growing season that the water level was within 30 cm of the ground surface, and percentage of the growing season during which soil air-filled porosity was 15% or less at each of the four depths monitored (15, 30, 45, and 60cm). Values for each characteristic were calculated for each of the three growing seasons, so that a total of 18 hydrologic variables were entered into the analyses.

Inspection of the dendrogram resulting from cluster analysis showed that the sampling stations fell into three major groups representing the wetland, upland, and transitional sections of the moisture gradient (Figure 2). The wetland cluster consisted of 21 stations, all with VPD soils. The upland cluster contained 15 stations: all of the MWD stations and the SPD stations from LL1 and LL2. The transitional cluster consisited of 18 stations: 3 VPD stations, all of the PD stations, and 1 SPD station.

Each station in the transitional cluster was then classified wetland or upland using discriminant analysis (Figure 2). Ten of the 14 PD stations were classified upland, along with the single SPD station; the remaining 4 PD stations and 3 VPD stations were classified wetland. In all cases, the posterior probability of correct classification was 100%. The wetland/upland hydrologic break fell between VPD and PD stations on five transects, within the PD soil zone on three transects, and between PD and SPD stations on one transect (Figure 3).

Discriminant analyses of hydrologic variables by individual years showed that the location of the wetland/upland breakpoint moved by one or more stations between years (see Manuscript 1). For 1985, in which annual precipitation was near the 30-year mean, but growing season precipitation was 41% above average (primarily due to two storm events in late August), the wetland/upland breakpoint moved upslope on two transects compared to the three-year breakpoint location. For 1986, with annual precipitation 10% higher than average and near-average growing season precipitation, the breakpoint moved downslope on one transect. For 1987, with annual precipitation 10% below average and a

Figure 2. Cluster dendrogram of 54 sampling stations based on six hydrologic characteristics calculated for each of three growing seasons. Soil drainage classes of stations are indicated across the top of the dendrogram: V = very poorly drained, P = poorly drained, S = somewhat poorly drained, M = moderately well drained. The wide gray lines separate major clusteres of stations designated (from left to right) as wetland, transitional, or upland. The wide black line separates stations classified as wetland or upland by discriminant analysis.

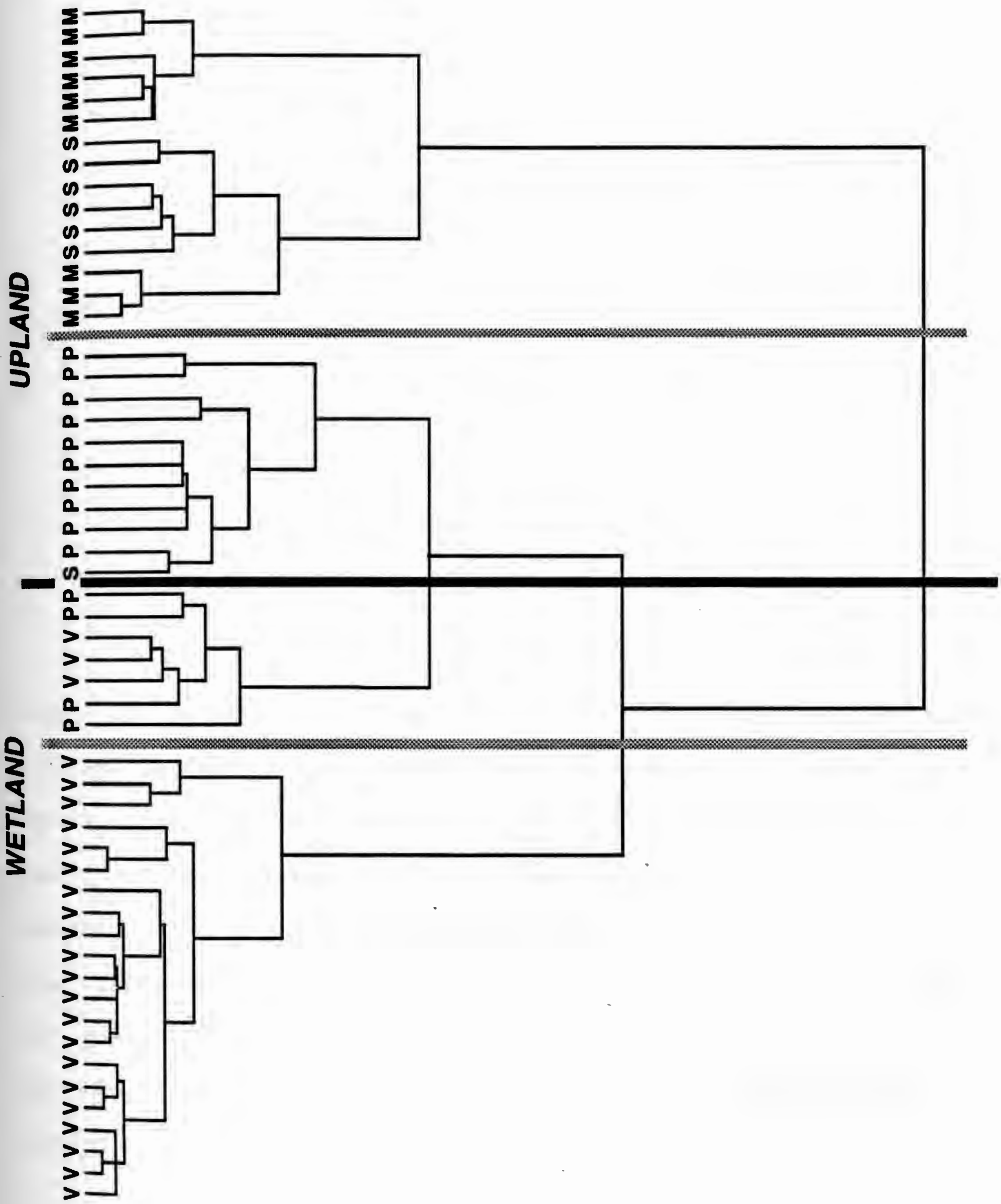
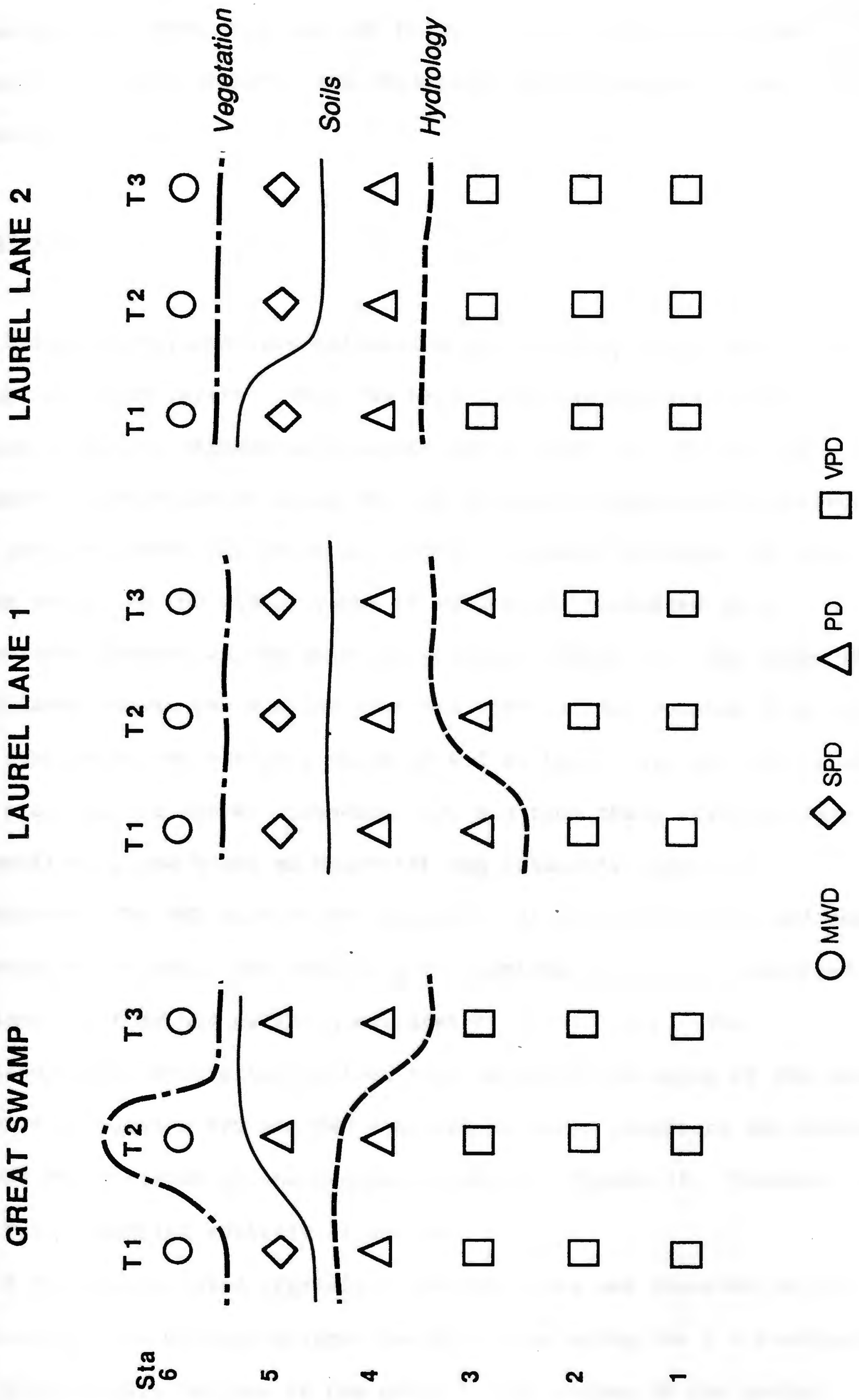

UPLAND
WETLAND

Figure 3. Wetland/upland breakpoint locations according to three separate parameters: vegetation (herb-layer weighted averages), soils (hydric status of soil series), and hydrology (discriminant analysis of six hydrologic characteristics calculated for each of three growing seasons). Boundary lines were drawn for illustrative purposes only, since sampling stations were not contiguous; stations below each line were classified wetland for that parameter, and stations above the line were classified upland. Distances between stations were not equal in reality.


GREAT SWAMP
LAUREL LANE 1
LAUREL LANE 2
T1
T2
T3
Sta
6
5
4
3
2
1
Vegetation
Soils
Hydrology
MWD
SPD
PD
VPD

growing-season mean that was 20% below average (with record-low rainfall in early summer), the breakpoint moved upslope on one transect.

Vegetation

Weighted averages were calculated for the tree, tall shrub, low shrub, and herb layers. Only the herb layer demonstrated both a moisture-related vegetation gradient and a potential for wetland boundary identification using the 3.0 breakpoint proposed by Wentworth and Johnson (1986) (Allen et al. 1989). Weighted averages for this layer exhibited the widest range of values and increased in a consistent fashion up the moisture gradient (Table 1). The range of herb-layer scores was similar over the three sites, running from 1.5 to 3.4 (excluding one outlying value of 4.3 at LL1). All but one of the MWD stations had scores exceeding 3.0, and thus these stations were classified upland based on Wentworth and Johnson's suggested breakpoint. The MWD station on Transect 2 at GSW scored 2.9, and was classified wetland. The remaining 45 stations also were classified wetland, as they had weighted averages of 3.0 or less. The wetland/upland breakpoint derived from weighted averaging of the herb layer fell between SPD and MWD stations on seven transects and between PD and MWD stations on one transect (Table 1, Figure 3). Transect 2 at GSW was classified entirely as wetland.

A moisture-related vegetation gradient also was observed in the tree layer, but wetland/upland classification using the 3.0 breakpoint was unreasonable because of the overall high values of the scores

Table 1. Soil characteristics and herb-layer weighted averages at the three study sites.

Site	Tran	Sta	Soil drainage class	Herb-layer weighted average	Soil series	Hydric status	Years with hydric disagreement[a]
GSW	1	6	MWD	3.3	Sudbury	NH	0
		5	SPD	2.5	Deerfield	NH	0
		4	PD	2.7	Wareham	H	2
		3	VPD	2.6	Scarboro	H	0
		2	VPD	1.8	Scarboro	H	0
		1	VPD	1.6	Scarboro	H	0
	2	6	MWD	2.9	Deerfield	NH	0
		5	PD	2.6	Wareham	H	3
		4	PD	2.7	Wareham	H	0
		3	VPD	1.9	Scarboro	H	0
		2	VPD	1.5	Scarboro	H	0
		1	VPD	1.9	Scarboro	H	0
	3	6	MWD	3.1	Deerfield	NH	0
		5	PD	2.8	Wareham	H	3
		4	PD	2.6	Wareham	H	3
		3	VPD	1.8	Scarboro	H	0
		2	VPD	1.7	Scarboro	H	0
		1	VPD	1.7	Scarboro	H	0
LL1	1	6	MWD	4.3	Deerfield	NH	0
		5	SPD	3.0	Deerfield	NH	0
		4	PD	2.9	Wareham	H	3
		3	PD	3.0	Wareham	H	1
		2	VPD	2.5	Scarboro	H	0
		1	VPD	2.0	Adrian	H	0
	2	6	MWD	3.5	Deerfield	NH	0
		5	SPD	3.0	Deerfield	NH	0
		4	PD	2.9	Wareham	H	1
		3	PD	2.9	Wareham	H	0
		2	VPD	2.2	Scarboro	H	0
		1	VPD	1.8	Scarboro	H	0
	3	6	MWD	3.3	Deerfield	NH	0
		5	SPD	3.0	Deerfield	NH	0
		4	PD	2.9	Walpole	H	0
		3	PD	2.5	Wareham	H	2
		2	VPD	2.4	Scarboro	H	0
		1	VPD	1.9	Scarboro	H	0
LL2	1	6	MWD	3.4	Deerfield	NH	0
		5	SPD	2.8	Wareham	H	3
		4	PD	2.6	Wareham	H	1
		3	VPD	2.2	Scarboro	H	0
		2	VPD	1.9	Adrian	H	0
		1	VPD	1.7	Carlisle	H	0
	2	6	MWD	3.2	Deerfield	NH	0
		5	SPD	2.8	Deerfield	NH	0
		4	PD	2.7	Wareham	H	3
		3	VPD	2.8	Scarboro	H	0
		2	VPD	2.3	Scarboro	H	0
		1	VPD	1.7	Carlisle	H	0
	3	6	MWD	3.3	Deerfield	NH	0
		5	SPD	2.9	Deerfield	NH	0
		4	PD	2.7	Wareham	H	3
		3	VPD	2.3	Scarboro	H	0
		2	VPD	2.2	Carlisle	H	0
		1	VPD	2.0	Adrian	H	0

[a]Number of years in which hydric status based on soil series (SCS 1987) was not supported by observed water levels.

(Appendix F); on only one transect did the weighted average drop below 3.0 (to 2.9) in the VPD soil zone. The high scores were due to the dominance of Acer rubrum (FAC) in the VPD and PD soil zones, and Quercus alba (FACU) in the SPD and MWD soil zones. Together these two species composed 96% of the total basal area at GSW, 90% at LL1, and 72% at LL2.

There was no observable moisture-related gradients in the tall or low shrub layers. Weighted averages in these layers were narrow in range, largely between 2.0 and 3.0, and showed no consistent trends along the transect lines. Both layers were dominated by facultative (FACW, FAC, and FACU) species; for example, Clethra alnifolia (FAC) was both abundant and ubiquitous, comprising 65.5%, 70.6%, and 84.5% of the relative stem density in the low shrub layer at GSW, LL1, and LL2, respectively.

Because both tree- and shrub-layer weighted averages were unsuitable for use in boundary determination, only herb-layer results are discussed in the remainder of this paper. Weighted averages for all layers are presented in Appendix F.

Soils

Soils in the MWD, SPD, and PD zones were predominantly weakly developed Entisols composed of loamy sands and sands. In the VPD soil zone, Inceptisols with histic epipedons (organic surface layers) were common, and Histosols (organic soils) occurred in the wettest areas of the Laurel Lane sites. The typical drainage toposequence at the three sites consisted of the Deerfield (MWD/SPD), Wareham (SPD/PD), and

Scarboro (VPD) series (Table 1). Organic soils were classified into the Adrian and Carlisle series. Sudbury (MWD) and Walpole (PD) series were found at individual stations at GSW and LL1, respectively. Based on the hydric soils list (SCS 1987), all of the VPD and PD soils were hydric, while all of the SPD and MWD soils -- with the exception of a SPD Wareham soil at LL2 -- were nonhydric (Table 1).

The hydric soils list also provides the criteria used to determine which soils should be designated hydric (SCS 1987). The criteria for mineral soils state that, depending on soil permeability and drainage class, the water table must lie within a certain distance of the ground surface for at least one week during the growing season. Using weekly water level measurements recorded during the 3 years of this study, these criteria were applied to the soils at all stations to determine agreement between field measurements and the hydric/nonhydric status based on soil series. The permeability for all series at the study sites was high (greater than 15 cm/h in the top 50 cm), except for the Sudbury and Walpole series which had low permeabilities of 15 cm/h or less (Rector 1981).

The hydric status of the series included in the national list was supported by observed water levels in all 3 years of the study at 42 of the 54 sampling stations (Table 1). At the 12 stations where disagreement occurred, the series were designated hydric in the national list, but observed water levels did not meet hydric criteria in one or more years; at 7 stations, hydric criteria were not met in any year; at 2 stations, disagreement occurred in 2 years; and at 3 stations there was disagreement in only 1 year. Eleven of the 12 cases of disagreement involved PD soils, all of which had highly permeable soils and should have had water levels within 30 cm of the surface for a week or more to meet hydric criteria (SCS 1987). One case of disagreement involved the SPD Wareham station at LL2, where the soils again were highly permeable. The water level should have been within 45 cm of the surface for a week or more to satisfy the hydric criteria in this drainage class.

DISCUSSION

At the three study sites, the wetland/upland break based on hydrology was consistently lowest on the transects and the vegetation-based break the highest (Figure 3). The hydric/nonhydric soils break fell between the hydrologic and vegetation breaks on six transects, agreed with the hydrologic break on one transect, and with the vegetation break on two transects.

In this study, the low position of the hydrologic break was largely a result of the mesic nature of the stations used to create the upland endpoint function for discriminant analysis. Neff and Marcus (1980) and Williams (1983) state that the composition of, and the degree of separation between, the endpoints affects the classification of unknowns. Had it been possible to include well drained or excessively drained soils in this study, the separation between the wet and dry endpoints would have been greater, and some of the stations classified upland in the present analysis most likely would have been classified wetland. Conversely, had the transects been extended into habitats as wet as the red maple swamps described by Lowry (1984), the wetland/upland break might have been pulled further downslope.

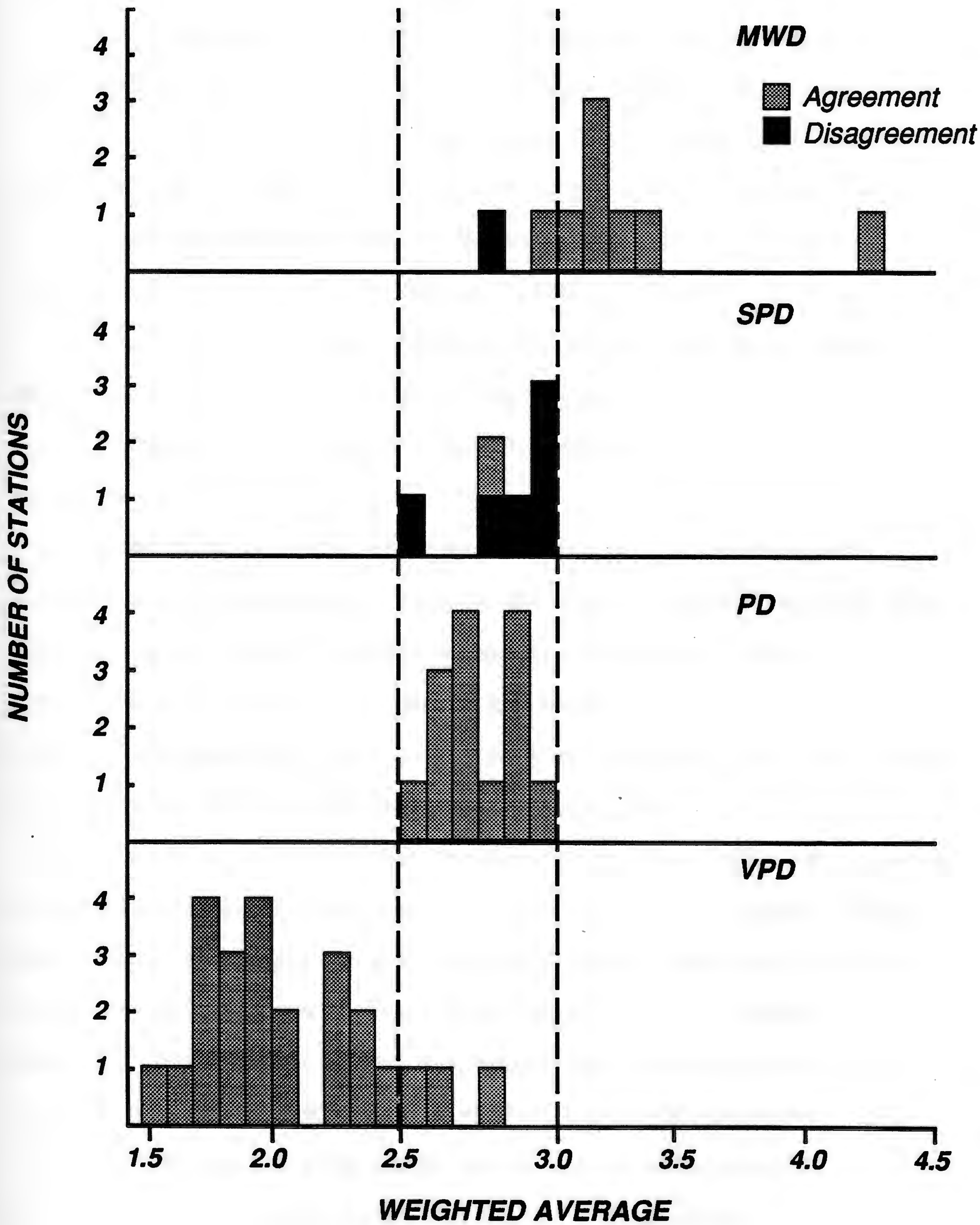
Discriminant analysis of hydrologic data from separate years indicated that the location of the wetland/upland break moved one or more stations between years. During the three years of this study, annual precipitation levels were within 10% of the 30-year mean (see Manuscript 1) -- although considerable variation occurred in seasonal precipitation levels. Since wetland water levels roughly reflect precipitation patterns (Bay 1967, O'Brien 1977, Golet and Lowry 1987), it is likely that the wetland/upland hydrologic break would move upslope to include more of the PD soil zone in years with appreciably greater precipitation. Since engineering constraints and wetland functions such as flood control are of more critical concern during periods of high water levels, the wetland/upland breaks identified here using discriminant analysis should be viewed as conservative. However, the large data requirements and the relative, and somewhat arbitrary, nature of the wetland and upland classifications that result from discriminant analysis limits the value of this method in wetland delineation for regulatory purposes.

Herb-layer weighted averaging results indicated that all of the VPD, PD, and SPD stations, as well as one MWD station supported wetland vegetation. Thus, the wetland boundary based on herbs was one station farther upslope than the soils boundary and two or more stations higher than the hydrologic break on 7 of the 9 transects. The majority of herb-layer species at the PD and SPD stations were classified FACW or FAC, so that weighted averages at those stations were just below or equal to 3.0. The abundance of facultative species throughout the transition zone caused the wetland boundary based on weighted averages to lie too far upslope in most cases.

Wentworth and Johnson (1986) suggested that weighted averages falling between 2.5 and 3.5 represented a "gray zone" and hence were inconclusive; in such cases, they recommended that another parameter such as soils be used to confirm wetland status. In this study, this gray zone was very wide, including 3 VPD stations, all of the PD and SPD stations, and all but one of the MWD stations (Table 1). A somewhat narrower "gray zone" can be identified for this study by comparing station classifications based on hydric soil status and weighted averaging. The distribution of herb-layer weighted averages in each drainage class is shown in Figure 4; darkened bars indicate those cases where the vegetation classification disagreed with the hydric soil status. All cases of disagreement involved weighted averages between 2.5 and 3.0. This range of scores included some stations in every drainage class. All stations with weighted averages above 3.0 were located on MWD soils where an upland status was clearly appropriate.

Inaccurate FWS wetland indicator classifications for plant species may be a source of error in weighted averaging studies. Given the wide geographical extent of FWS Region 1, the local distribution of a species may vary from that described by the regional indicator status. Local misclassifications can affect the accuracy of wetland/upland determinations based on weighted averaging. One species that clearly occurs more frequently in uplands than its OBL status indicates is Rhododendron viscosum. This species occurred throughout the transects

Figure 4. Frequency distribution of herb-layer weighted averages by soil drainage class. Lighter bars indicate agreement between wetland/upland station classifications using a 3.0 breakpoint and hydric soil status; darker bars indicate disagreement.


MWD
Agreement
Disagreement
SPD
PD
VPD
NUMBER OF STATIONS
1
2
3
4
1.5
2.0
2.5
3.0
3.5
4.0
4.5
WEIGHTED AVERAGE

in both shrub layers and in the herb layer. As noted earlier, the indicator status was changed to FACW in this study to better reflect its local distribution. Another example is Ilex glabra, which is classified as FACW in Region 1, but was most abundant at the MWD stations in this study. The distribution of I. glabra at these sites and elsewhere in southern Rhode Island suggests that this species would be more appropriately classified FAC in this locale. I. glabra comprised 31% of the relative percent cover in the herb layer at Station 6, Transect 2, GSW. Changing its wetland indicator status to FAC would have raised the weighted average at that station from 2.9 to 3.2, and would have shifted the vegetation-based classification from wetland to upland.

At most stations, the hydric status assigned in based on soil series appeared reasonable. Even at the twelve "hydric" stations where observed water levels indicated nonhydric conditions in one or more years, a hydric status was probably appropriate in most cases. Although the number of years that a soil must satisfy SCS (1987) water level criteria in order to qualify as hydric are not specified, it seems reasonable to assume that the five PD stations where hydric water level criteria were met at least once during the three growing seasons are hydric. At the six PD stations which did not meet hydric criteria in any of the years, morphologic features in the soil profiles indicated that a hydric status was appropriate (Sokoloski et al. 1988). At all six stations, water levels were within 39 cm (three were within 35 cm) for at least a week during one or more growing seasons; in years of higher rainfall, groundwater levels might rise enough to meet 30-cm criterion. Alternatively, soil moisture potential may better correlate with hydric soil features than observable water level, since reducing conditions, which drive the development of wetland soil morphology, can occur in soils that are not fully saturated (Vepraskas and Bouma 1976; Pickering and Veneman 1984).

A nonhydric status appears to be appropriate for the SPD Wareham station at LL2. At this station, the highest water level observed for at least a week in any growing season was -44 cm. According to the water level criteria (SCS 1987), high-permeability SPD soils must have a water table within 15 cm of the surface for at least a week to be designated hydric (SCS 1987); it is unlikely that water levels would rise an additional 30 cm, even in years of exceptionally high rainfall. Cluster analysis of hydrologic data also indicated that the SPD Wareham station was more similar hydrologically to the nonhydric stations than to the hydric stations. This station was included in the upland cluster and was closely linked with most of the other SPD stations (Figure 2). The single SPD station in the transitional cluster is from the Great Swamp site. The eleven PD stations with disagreement between hydric status based on observed water levels and by series all were contained in the transitional cluster. Tiner and Veneman (1987) noted that the Wareham series has both hydric and nonhydric members. In this study, the PD Wareham soils appear to be hydric while the SPD Wareham member is nonhydric.

CONCLUSIONS

In this study, the wetland/upland break resulting from discriminant analysis of hydrologic data was clearly too low on many transects, falling largely on the VPD/PD soil boundary. Between-year variation in boundary location suggested that the wetland boundary might move farther upslope in years of higher precipitation. Weighted averaging of herb layer vegetation produced a wetland boundary that bordered MWD soils on most transects, which was clearly too high in most cases. If the SPD Wareham soil were considered nonhydric, the hydric/nonhydric soils break would occur consistently at the upper extent of PD soils. The soils break also fell most often between the boundaries described by hydrologic and vegetation data. Soils appear to be both the most stable and expedient parameter for establishing a wetland boundary line. This finding lends support to the hierarchy of decisions in the <u>Federal Methodology for Identifying and Delineating Jurisdictional Wetlands</u> (Federal Interagency Committee for Wetland Delineation 1989), which gives precedence to soil conditions when vegetation measures indicate a facultative community.

Classifying poorly drained soils as wetland also would serve to protect many recognized wetland functions. Flood water storage, reduction of erosion and sedimentation, nutrient removal from sheet flow, and groundwater pollution abatement are obvious wetland functions that are performed well in the poorly drained zone. Wildlife and aesthetic values also would benefit if the wetland boundary extended to poorly drained soils.

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Appendix A. Categories of mineral soil texture and organic matter content used to derive soil moisture characteristic curves from which air-filled porosities were determined.

APPENDIX A.

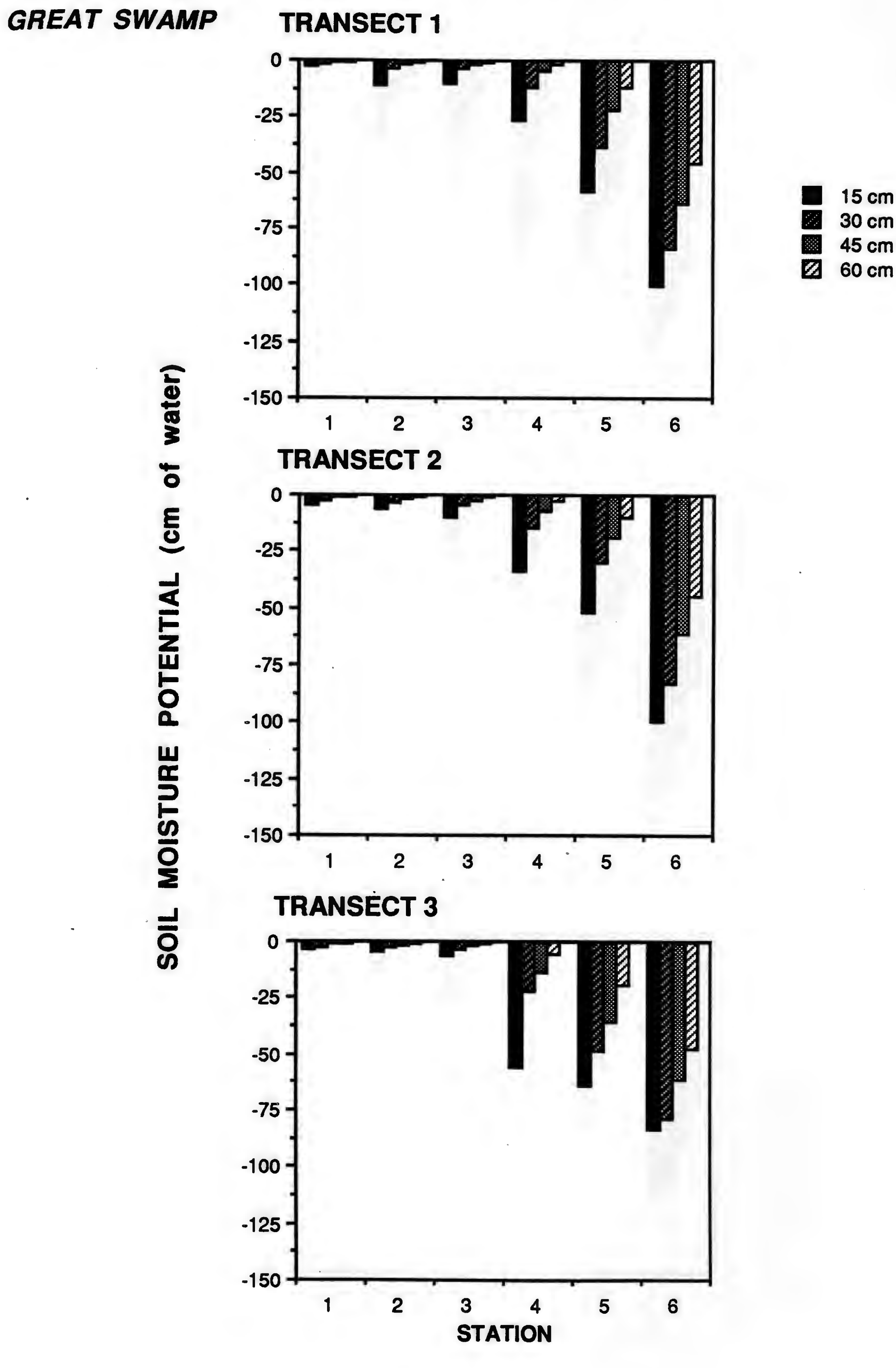
Soil texture	% Organic matter							
	0-0.9	1-2.9	3-4.9	5-6.9	7-8.9	9-10.9	11-12.9	13-19.9
Sand	X							
Loamy sand	X	X	X	X	X	X	X	X
Sandy loam							X	

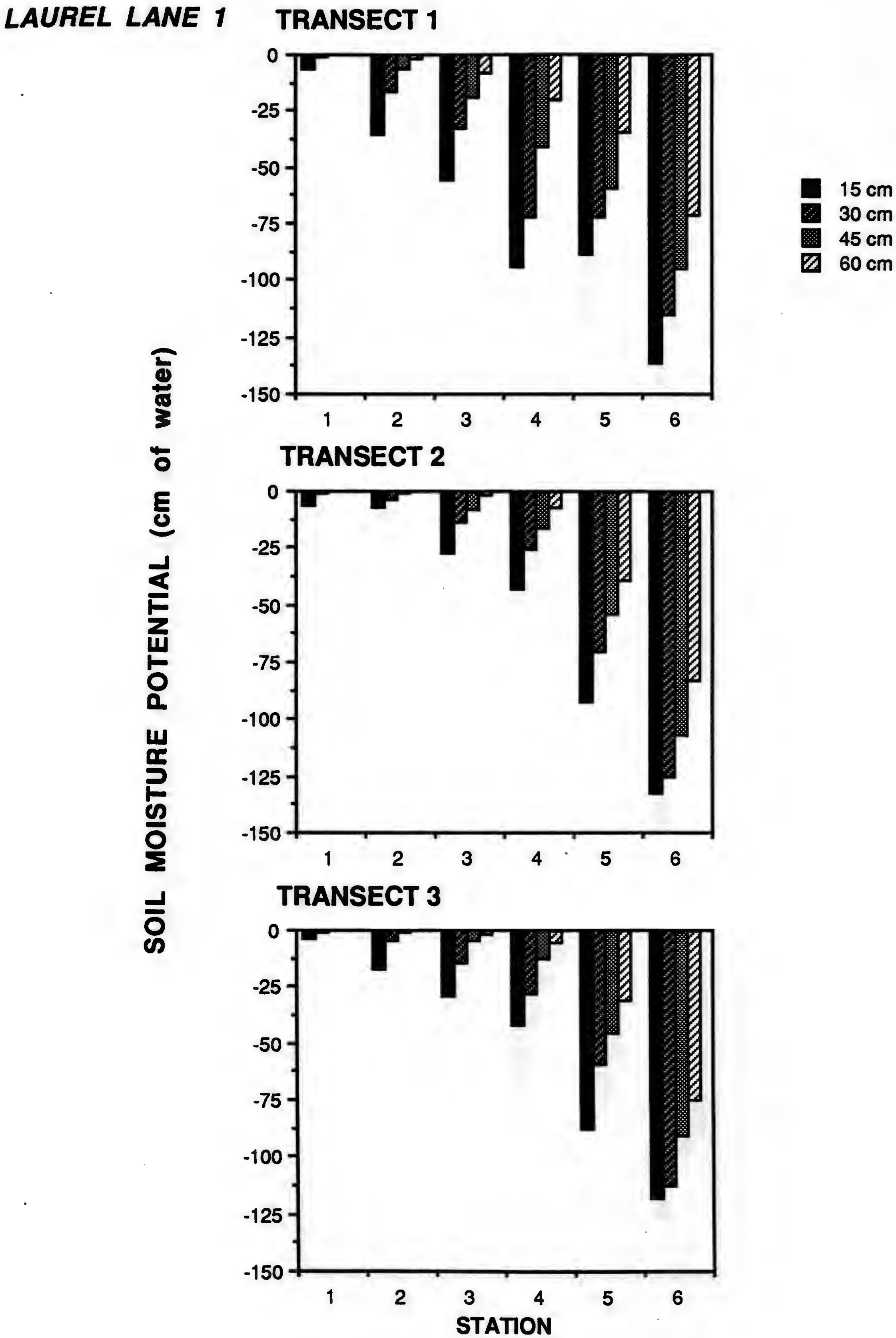
Appendix B. Water table data calculated for the three study sites during the 1985, 1986, and 1987 growing seasons.

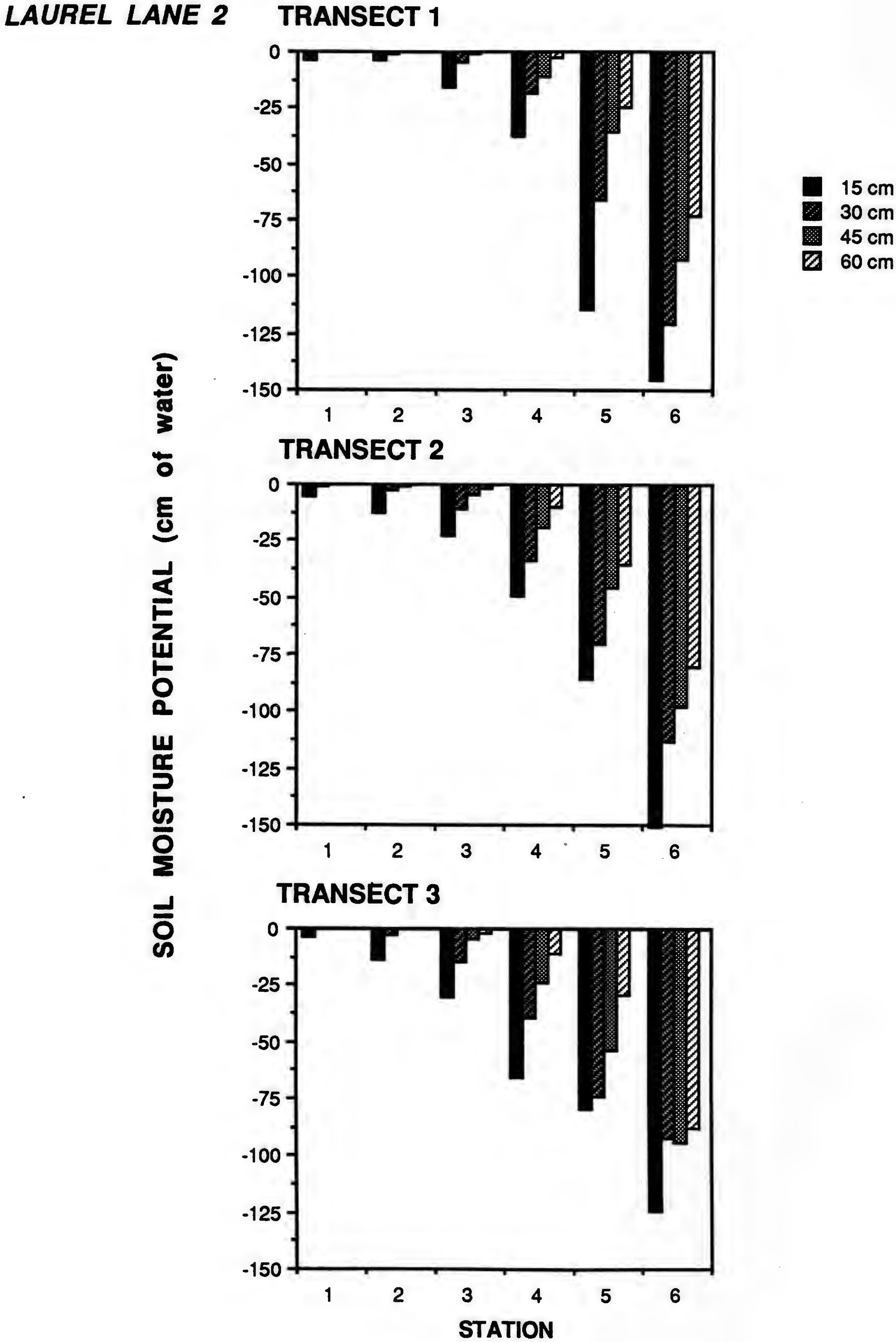
Site	Tra	Sta	Rel. elev.[a]	Soil Drainage class	1985 Mean WT(cm)[b]	1985 MHWT[c] (cm)	1985 WT<30[d] (%)	1986 Mean WT(cm)	1986 MHWT (cm)	1986 WT<30 (%)	1987 Mean WT(cm)	1987 MHWT (cm)	1987 WT<30 (%)
GSW	1	6	1.02	MWD	- 93.4	- 38.3	3.7	- 97.7	- 71.7	0.0	-116.1	- 57.0	0.0
		5	0.71	SPD	- 68.6	- 27.3	3.7	- 68.7	- 45.7	0.0	- 85.6	- 38.0	0.0
		4	0.25	PD	- 38.7	- 17.7	18.5	- 36.4	- 27.3	12.1	- 51.6	- 24.3	18.2
		3	0.09	VPD	- 17.1	1.3	81.5	- 14.2	- 6.7	100.0	- 28.7	- 4.7	63.6
		2	0.03	VPD	- 11.7	5.0	96.3	- 11.2	- 3.3	100.0	- 23.7	- 2.0	75.8
		1	0.00	VPD	- 8.1	5.7	96.3	- 6.3	- 2.3	100.0	- 16.9	0.0	78.8
	2	6	1.12	MWD	- 96.0	- 41.3	3.7	- 98.9	- 73.7	0.0	-118.9	- 60.3	0.0
		5	0.70	PD	- 59.8	- 23.3	7.4	- 59.7	- 40.0	0.0	- 79.0	- 32.3	0.0
		4	0.42	PD	- 37.3	- 15.0	33.3	- 34.3	- 23.0	36.4	- 47.9	- 18.7	27.3
		3	0.21	VPD	- 15.1	0.7	81.5	- 12.1	- 4.3	100.0	- 29.4	- 3.0	63.6
		2	0.17	VPD	- 12.0	1.7	96.3	- 10.1	- 4.0	100.0	- 24.1	- 2.0	66.7
		1	0.10	VPD	- 6.1	4.7	100.0	- 5.1	- 0.7	100.0	- 18.6	- 0.3	78.8
	3	6	1.07	MWD	- 96.5	- 47.0	0.0	- 98.7	- 70.7	0.0	-118.4	- 56.7	0.0
		5	0.75	PD	- 66.2	- 24.3	3.7	- 67.7	- 46.0	0.0	- 87.0	- 31.3	0.0
		4	0.54	PD	- 54.7	- 25.0	7.4	- 52.3	- 38.7	0.0	- 71.1	- 35.7	0.0
		3	0.10	VPD	- 7.7	3.3	96.3	- 11.5	- 6.3	100.0	- 23.4	- 2.3	75.8
		2	0.13	VPD	- 10.4	0.7	96.3	- 11.4	- 5.3	100.0	- 21.8	- 4.0	75.8
		1	0.06	VPD	- 4.7	5.7	100.0	- 4.6	- 1.0	100.0	- 17.4	- 1.0	75.8
LL1	1	6	1.98	MWD	-142.2	- 86.7	0.0	-150.8	-117.3	0.0	-153.9	- 78.3	0.0
		5	1.15	SPD	- 82.5	- 36.3	3.7	- 88.6	- 58.7	0.0	- 92.0	- 36.7	0.0
		4	0.90	PD	- 72.4	- 29.3	3.7	- 75.0	- 49.7	0.0	- 80.2	- 33.3	0.0
		3	0.72	PD	- 60.7	- 21.7	14.8	- 62.4	- 38.7	0.0	- 66.1	- 22.7	12.1
		2	0.29	VPD	- 38.0	- 15.3	29.6	- 36.9	- 23.7	30.0	- 42.3	- 20.0	30.3
		1	0.00	VPD	- 15.5	3.7	88.9	- 17.9	- 9.3	100.0	- 17.8	- 3.7	87.9
	2	6	1.81	MWD	-132.0	- 79.0	0.0	-140.6	-104.3	0.0	-144.3	- 71.0	0.0
		5	1.21	SPD	- 90.0	- 41.7	0.0	- 95.4	- 62.0	0.0	-100.7	- 38.7	0.0
		4	0.67	PD	- 57.8	- 19.0	11.1	- 59.3	- 35.0	3.0	- 66.0	- 20.0	12.1
		3	0.39	PD	- 44.2	- 15.7	22.2	- 43.8	- 29.0	9.1	- 49.7	- 19.0	18.2
		2	0.08	VPD	- 21.9	- 5.0	77.8	- 18.8	- 8.3	93.9	- 25.9	- 5.0	72.8
		1	-0.05	VPD	- 18.3	4.3	81.5	- 20.7	- 12.7	97.0	- 22.6	- 5.7	81.8
	3	6	1.62	MWD	-123.7	- 75.3	0.0	-127.6	- 93.0	0.0	-133.2	- 63.3	0.0
		5	1.06	SPD	- 85.3	- 37.3	3.7	- 87.4	- 58.0	0.0	- 96.3	- 40.0	0.0
		4	0.52	PD	- 60.2	- 27.7	7.4	- 59.5	- 44.3	0.0	- 67.1	- 31.0	3.0
		3	0.31	PD	- 45.9	- 21.7	11.1	- 44.3	- 30.3	6.1	- 48.5	- 25.3	18.2
		2	0.05	VPD	- 27.8	- 9.7	74.1	- 23.9	- 13.7	81.8	- 30.8	- 11.7	60.6
		1	-0.11	VPD	- 14.3	5.3	96.3	- 17.3	- 5.3	100.0	- 18.2	- 0.7	81.2
LL2	1	6	2.01	MWD	-147.0	-112.0	0.0	-150.9	-126.3	0.0	-152.1	- 94.7	0.0
		5	1.16	SPD	- 78.5	- 45.7	0.0	- 80.6	- 59.3	0.0	- 86.0	- 44.0	0.0
		4	0.82	PD	- 51.9	- 24.7	11.1	- 51.2	- 33.0	0.0	- 57.2	- 24.3	18.1
		3	0.43	VPD	- 32.9	- 18.3	59.3	- 28.7	- 20.0	66.7	- 37.4	- 17.0	33.3
		2	0.19	VPD	- 19.3	- 8.3	85.2	- 15.8	- 10.3	100.0	- 20.4	- 4.3	84.8
		1	0.00	VPD	- 15.6	- 2.0	92.3	- 17.8	- 6.3	100.0	- 17.1	- 3.7	90.9
	2	6	2.29	MWD	-157.0	-119.3	0.0	-161.3	-138.3	0.0	-164.8	-109.3	0.0
		5	1.38	SPD	- 85.8	- 49.3	0.0	- 86.7	- 65.7	0.0	- 93.0	- 47.7	0.0
		4	1.08	PD	- 65.0	- 37.7	0.0	- 62.6	- 45.0	0.0	- 71.4	- 38.0	0.0
		3	0.72	VPD	- 40.7	- 20.3	29.6	- 36.0	- 24.7	24.2	- 44.8	- 19.3	27.3
		2	0.41	VPD	- 33.4	- 16.7	40.7	- 29.9	- 22.7	57.6	- 36.3	- 17.7	33.3
		1	-0.03	VPD	- 16.5	- 2.7	84.6	- 17.3	- 6.7	93.9	- 17.7	- 5.3	87.9
	3	6	2.13	MWD	-151.2	-108.3	0.0	-153.2	-130.0	0.0	-159.1	- 98.0	0.0
		5	1.15	SPD	- 80.4	- 43.0	0.0	- 78.7	- 55.7	0.0	- 85.9	- 43.0	0.0
		4	0.86	PD	- 67.1	- 36.0	0.0	- 65.0	- 47.7	0.0	- 72.4	- 39.3	0.0
		3	0.48	VPD	- 40.2	- 21.0	25.9	- 36.4	- 25.7	24.2	- 42.4	- 21.7	30.3
		2	0.21	VPD	- 29.8	- 14.7	59.2	- 27.7	- 19.0	78.8	- 32.1	- 18.3	48.5
		1	0.00	VPD	- 10.7	- 1.3	100.0	- 13.1	- 4.7	100.0	- 12.6	- 2.3	87.9

[a]Elevations for each site are relative to Station 1, Transect 1.
[b]Mean of growing season water levels.
[c]Mean of three highest water levels in growing season.
[d]Percent of time water level was within 30 cm of ground surface.

Appendix C. Mean soil moisture potentials at four depths for each sampling station. Means are based on weekly measurements over three growing seasons.


GREAT SWAMP
TRANSECT 1
TRANSECT 2
TRANSECT 3
SOIL MOISTURE POTENTIAL (cm of water)
STATION
15 cm
30 cm
45 cm
60 cm
0
-25
-50
-75
-100
-125
-150
1
2
3
4
5
6


LAUREL LANE 1
TRANSECT 1
TRANSECT 2
TRANSECT 3
SOIL MOISTURE POTENTIAL (cm of water)
STATION
15 cm
30 cm
45 cm
60 cm
0
-25
-50
-75
-100
-125
-150
1
2
3
4
5
6


LAUREL LANE 2
TRANSECT 1
TRANSECT 2
TRANSECT 3
SOIL MOISTURE POTENTIAL (cm of water)
0
-25
-50
-75
-100
-125
-150
1
2
3
4
5
6
STATION
15 cm
30 cm
45 cm
60 cm

Appendix D. Wetland and upland linear discriminant function coefficients calculated for the eighteen hydrologic variables entered into the 3-year discriminant analysis model.

APPENDIX D.

Variable[a]	Upland	Wetland
Constant	-1298.7502	-48252.0635
AFP≤15,15 cm,1985	0.1839	-39.4189
AFP≤15,30 cm,1985	15.7155	236.9065
AFP≤15,45 cm,1985	3.8563	111.5938
AFP≤15,60 cm,1985	-6.2542	-115.8719
WT,1985	14.0040	30.1974
WT≤30 cm,1985	4.0247	55.5071
AFP≤15,15 cm,1986	9.0011	369.0566
AFP≤15,30 cm,1986	-16.2512	451.3727
AFP≤15,45 cm,1986	4.4755	-150.0005
AFP≤15,60 cm,1986	5.4115	-42.4884
WT,1986	-2.3848	4.6719
WT≤30 cm,1986	1.1737	-22.4984
AFP≤15,15 cm,1987	-4.4832	-7.9288
AFP≤15,30 cm,1987	-0.1058	65.0679
AFP≤15,45 cm,1987	21.6278	-39.8182
AFP≤15,60 cm,1987	9.2976	139.1560
WT1987	-26.4444	-47.6814
WT≤30 cm,1987	0.7730	-51.3604

[a]Variable legend is as follows:

AFP ≤15 = percentage of the growing season that air-filled porosity ≤15%, at given soil depth, for specified year;

WT = mean growing-season water levels for specified year;

WT≤30 cm = percentage of the growing season that the water level was within 30 cm of the surface for the specified year.

APPENDIX E. Plant species occurring at the three study sites, along with their FWS wetland indicator status (Reed 1988) and distribution by layer. Values in the matrix indicate the number of sites at which a species occurred in that layer.

APPENDIX E.

Species[a]	Status[b]	Tree	Tall shrub	Low shrub	Herb
Acer rubrum	FAC	3	3	3	3
Alnus serrulata	OBL		1		
Amelanchier sp.	na			3	3
Anemone quinquefolia	FACU				3
Apios americana	FACW			1	1
Aralia nudicaulis	FACU				3
Arisaema triphyllum	FACW				3
Aronia arbutifolia	FACW		2	3	3
Aster acuminatus	UPL				1
Aster novi-belgii	FACW				2
Aster sp.	na				1
Betula lutea	FAC	2			3
Carex howeii	OBL				2
Carex interior	OBL				1
Carex lonchocarpa	OBL				2
Carex pensylvanica	UPL				3
Carex seorsa	FACW				2
Carex sp.	na				3
Carex stricta	OBL				1
Carex vesicaria	OBL				1
Chamaecyparis thyoides	OBL	1			2
Chimaphila maculata	UPL				1
Cinna arundinacea	FACW				1
Clethra alnifolia	FAC		3	3	3
Cornus amomum	FACW			1	1
Cornus sp.	na				1
Crataegus sp.	na			1	
Cuscuta compacta	na				2
Decodon verticillatus	OBL				1
Dryopteris cristata	FACW				1
Fagus grandifolia	FACU	2		1	1
Fraxinus nigra	FACW				1
Fraxinus pennsylvanica	FACW			1	1
Galium sp.	na				1
Gaultheria procumbens	FACU				3
Gaylussacia baccata	FACU			3	3
Glyceria striata	OBL				1
Hamamelis virginiana	FAC				1
Ilex glabra	FACW			2	3
Ilex opaca	FACU				1
Ilex verticillata	FACW		2	3	3

(continued)

APPENDIX E. (Continued)

Species[a]	Status[b]	Tree	Tall shrub	Low shrub	Herb
Impatiens capensis	FACW				1
Iris versicolor	OBL				1
Kalmia angustifolia	FAC			1	3
Kalmia latifolia	FACU			1	1
Leucothoe racemosa	FACW			3	2
Lilium superbum	FACW				3
Lindera benzoin	FACW		1	2	3
Lycopodium complanatum	FACU				1
Lycopodium obscurum	FACU				3
Lycopus uniflorus	OBL				1
Lyonia ligustrina	FACW		2	3	3
Lysimachia terrestris	OBL				2
Maianthemum canadense	FAC				3
Medeola virginiana	na				3
Melampyrum lineare	FACU				2
Mitchella repens	FACU				2
Monotropa uniflora	FACU				3
Nyssa sylvatica	FAC	3	1	3	3
Onoclea sensibilis	FACW				1
Osmunda cinnamomea	FACW				3
Osmunda regalis	OBL				2
Parthenocissus quinquefolia	FACU				3
Pinus strobus	FACU	1			3
Polygonum arifolium	OBL				1
Polygonum punctatum	OBL				1
Polygonum sagittatum	OBL				1
Prunus serotina	FACU			3	3
Pteridium aquilinum	FACU				2
Quercus alba	FACU	3		1	3
Quercus coccinea	UPL	2			3
Quercus ilicifolia	UPL			1	
Quercus palustris	FACW	1			1
Rhododendron viscosum	FACW[c]		2	3	3
Rosa palustris	OBL			1	1
Rubus alleghaniensis	FACU			1	1
Rubus hispidus	FACW				3
Scutellaria lateriflora	FACW				1
Smilax glauca	FACU		2	2	3
Smilax herbacea	FAC			1	
Smilax rotundifolia	FAC		3	3	3
Solanum dulcamara	FAC				1

(continued)

APPENDIX E. (Concluded)

Species[a]	Status[b]	Tree	Tall shrub	Low shrub	Herb
Solidago rugosa	FAC				1
Solidago uliginosa	OBL				3
Sphagnum spp.	OBL[d]				3
Spiraea latifolia	FAC				1
Symplocarpus foetidus	OBL				3
Thalictrum pubescens	FACW				2
Thelypteris simulata	FACW				3
Thelypteris thelypteroides	FACW				2
Toxicodendron radicans	FAC				3
Toxicodendron vernix	OBL			1	
Trientalis borealis	FAC				3
Uvularia sessilifolia	FACU				3
Vaccinium angustifolium	FACU				3
Vaccinium corymbosum	FACW		3	3	3
Vaccinium vacillans	UPL				3
Viburnum cassinoides	FACW		3	3	3
Viburnum recognitum	FACW		1	3	3
Viola cucullata	FACW				1
Viola pallens	OBL				2
Vitis labrusca	FACU			2	1

[a]Taxonomy of vascular plants is according to the National List of Scientific Plant Names (SCS 1982).

[b]OBL = Obligate Wetland, FACW = Facultative Wetland, FAC = Facultative, FACU = Facultative Upland, UPL = Obligate Upland, na = no status assigned.

cFWS indicator status changed from OBL to FACW to better reflect the distruibution of this species in Rhode Island.

[d]Indicator status assigned by authors; mosses not listed in Reed (1987).

APPENDIX F. Weighted averages calculated for each sampling station by life form layer. Hydric status (SCS 1987) and soil drainage classes are included for reference (MWD = moderately well drained, SPD = somewhat poorly drained, PD = poorly drained, VPD = very poorly drained).

APPENDIX F-1. Tree-layer weighted averages.

Site	Transect	Soil drainage class	Weighted average
GSW	1	MWD	3.85
		SPD	3.95
		PD#	3.78
		VPD#	3.00
	2	MWD	3.88
		PD#	3.59
		VPD#	3.00
	3	MWD	3.96
		PD#	3.93
		VPD#	2.94
LL1	1	MWD	4.00
		SPD	4.51
		PD#	3.62
		VPD#	3.03
	2	MWD	4.64
		SPD	3.37
		PD#	3.00
		VPD#	3.15
	3	MWD	4.00
		SPD	4.15
		PD#	3.72
		VPD#	3.19
LL2	1	MWD	4.08
		SPD#	4.89
		PD#	3.00
		VPD#	3.30
	2	MWD	3.00
		SPD	3.00
		PD#	nd[a]
		VPD#	3.14
	3	MWD	4.30
		SPD	4.47
		PD#	3.52
		VPD#	3.00

#Hydric soil; soils not so designated area nonhydric.

[a]No data; no trees occurred in this plot.

APPENDIX F-2. Shrub- and herb-layer weighted averages at Great Swamp.

Transect	Station	Soil Drainage Class	Tall shrub	Low shrub	Herb
1	6	MWD	2.00	2.24	3.32
	5	SPD	2.27	2.61	2.47
	4#	PD	2.71	2.81	2.67
	3#	VPD	3.00	2.78	2.58
	2#	VPD	2.00	2.71	1.77
	1#	VPD	2.33	2.91	1.58
2	6	MWD	2.23	2.18	2.92
	5#	PD	2.76	2.96	2.63
	4#	PD	2.94	2.97	2.66
	3#	VPD	2.25	2.47	1.94
	2#	VPD	2.75	2.83	1.53
	1#	VPD	2.12	2.41	1.92
3	6	MWD	2.33	2.69	3.11
	5#	PD	2.73	2.75	2.77
	4#	PD	2.20	2.84	2.60
	3#	VPD	2.40	2.82	1.85
	2#	VPD	2.14	2.52	1.74
	1#	VPD	2.00	2.61	1.74

#Hydric soil station; stations not so designated are nonhydric.

APPENDIX F-3. Shrub- and herb-layer weighted averages at Laurel Lane 1.

Transect	Station	Soil Drainage Class	Tall shrub	Low shrub	Herb
1	6	MWD	2.00	3.86	4.34
	5	SPD	3.00	2.99	3.01
	4#	PD	3.00	2.82	2.89
	3#	PD	2.43	2.80	3.05
	2#	VPD	2.60	2.90	2.53
	1#	VPD	3.00	2.99	1.96
2	6	MWD	3.00	3.21	3.46
	5	SPD	3.13	2.98	3.02
	4#	PD	2.36	2.74	2.90
	3#	PD	2.83	2.89	2.88
	2#	VPD	3.00	3.00	2.23
	1#	VPD	3.00	3.00	1.77
3	6	MWD	nd[a]	3.36	3.35
	5	SPD	3.00	2.98	3.00
	4#	PD	3.00	2.91	2.95
	3#	PD	2.50	2.90	2.53
	2#	VPD	2.57	2.88	2.42
	1#	VPD	2.50	2.91	1.89

#Hydric soil station; stations not so designated are nonhydric.

[a]No data; no tall shrubs were rooted within sample plot.

APPENDIX F-4. Shrub- and herb-layer weighted averages at Laurel Lane 2.

Transect	Station	Soil Drainage Class	Tall shrub	Low shrub	Herb
1	6	MWD	3.00	2.98	3.44
	5#	SPD	2.63	2.94	2.79
	4#	PD	3.00	2.90	2.57
	3#	VPD	2.93	2.97	2.23
	2#	VPD	2.92	2.98	1.86
	1#	VPD	2.94	2.96	1.66
2	6	MWD	2.40	3.21	3.17
	5	SPD	2.85	2.97	2.82
	4#	PD	3.00	2.97	2.75
	3#	VPD	3.00	3.01	2.84
	2#	VPD	3.00	3.06	2.29
	1#	VPD	2.57	2.98	1.74
3	6	MWD	2.50	3.31	3.34
	5	SPD	2.73	2.60	2.90
	4#	PD	3.00	2.86	2.69
	3#	VPD	3.00	3.01	2.33
	2#	VPD	3.00	3.01	2.18
	1#	VPD	2.71	3.00	2.03

#Hydric soil station; stations not so designated are nonhydric.

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