MICROTOPOGRAPHY AND WATER TABLE FLUCTUATION IN A SPHAGNUM MIRE

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ABSTRACT

A detailed organic soil profile description, 22 years of continuous water table records, and a hummock-hollow level survey were examined at a small Minnesota mire (a bog with remnants of poor fen vegetation). Variation in the level survey suggests that hollows be used to minimize variation when detailed topographic information is needed and to match profile descriptions from distant locations. Water table and profile information suggests modification of acrotelm and catotelm definitions to recognize drought conditions and a field-identifiable boundary between the two layers.

KEYWORDS: Survey, Ecology, Conservation.

1. INTRODUCTION

The microtopography of natural, intact mires is both a source of frustration when engineering level surveys are made and a cause for ecologic wonder. Hummocks and hollows cause extreme local variation [6-50 cm; (1)] in level surveys compared to surveys on mineral soils. However, their very existence implies that adaptations of Sphagnum species to the saturated environment of bog soils are related to water table position, or more precisely, water table fluctuation. Indeed, the ability of Sphagna to wick water upward (capillary rise) has been intensively investigated by Hayward and Clymo (2), who demonstrated that in different species of Sphagnum, for a given depth of water table, the water content of the apical tuft of branches where growth occurs is greater in hummock species than in lawn or hollow species. Thus, for a given water content in the apex, the water table is at a greater depth below hummock species than it is below hollow species.

Moore and Bellamy (3) concluded that the capillary forces of Sphagnum domes held water against gravity and thus allowed the entire dome to grow upward. Ingram (4) counters this argument saying capillarity does not explain any consistent shape for the entire bog expanse; he provides water balance and groundwater flow information to support the theory of impeded drainage that gives rise to dome breadth and height.

The fluctuating water table in bogs (and other peatlands) was used along with other characteristics to describe the surface layer of intact peatlands as the "active layer" (1, 5, 6, 7, 8): This zone was further defined and renamed the acrotelm (9) along with the underlying zone: an "inert layer", renamed the catotelm.

Specific definitions for these layers are taken from Ingram (9):

> "The upper layer (acrotelm) [1] contains the oscillating water table; [2] possesses high hydraulic conductivity; [3] shows a variable water content; [4] is subject to periodic air entry on de-watering following lowering of the water table; [5] is rich in peat-forming aerobic bacteria and other microorganisms; and [6] has a live matrix of growing plant material."

> "The lower layer (catolem) [1] has a water content invariable with time; [2] possesses a negligibly small hydraulic conductivity; [3] is not subject to air entry; [4] is devoid of peat-forming aerobic microorganisms and is poor in microbes in general."

Ingram (10) further recognized that the acrotelm contains both live Sphagnum and dead Sphagnum (along with other plant material) that is undergoing diagenesis by humification. The bottom of the acrotelm is considered to be the lowest elevation of the water table (4, 8).

This paper tests the definition of water table fluctuation as a lower boundary of the acrotelm, measures capillarity as the height of hummocks and hollows above various measures of water table elevation, and recommends the use of hollow elevations as a practical standard for detailed level surveying in hummock-hollow topography.

2. STUDY AREA AND METHODS

A small mire at the Marcell Experimental Forest in north-central Minnesota (47°32'N, 93°28'W) was studied. This mire lies within a 9.72 ha watershed where peat has accumulated in an ice block depression within an area of glacial moraines. The mire is one-third of the entire watershed (3.24 ha) and lies at lower elevations within the center of the watershed. A small stream drains the mire and leaves the watershed through a low spot in the surrounding mineral soil. Though surrounded by mineral, soil the mire has developed a rudimentary dome and has a lagg restricted to 5 m around its edge.

Mire vegetation is dominated by a mature 115-year-old stand of black spruce (*Picea mariana* [Mill.] B.S.P.) with the following characteristics: height, 13 m; diameter (at 1.4 m), 14 cm; basal area, 26 m^2/ha; total volume, 133 m^3/ha; crown cover, 59%; and site index (50-yr P. mariana), 9 m. Brush cover of speckled alder (*Alnus rugosa* [Du Roi] Spreng.) is restricted to the lagg. Ericaceous shrubs, fine-leaved sedges, and *Sphagnum* moss cover the peat surface. *Sphagnum* species include: *S. fuscum*, *S. rubellum*, *S. capillifolium*, *S. magellanicum*, and *S. fallax (recurvum)* in descending order from hummock to hollow.

The Marcell Experimental Forest receives an average of 762 mm of annual precipitation, with 75% (572 mm) as rain from mid-April to early November and 25% (210 mm) as snow. The strongly continental climate has an annual average temperature of 4° C; the extremes are -46° and 40°C. Average January and July temperatures are -14° and 19°C respectively.

A detailed water and nutrient budget is presented in Verry and Timmons (11).

A level survey was conducted in July 1982 on a rectangular grid having intersections 30.5 m apart. At each grid intersection and the intersection of grid lines with the mire edge (66 in total), the mean sea-level elevation was measured with an engineering level having a precision of plus or minus 9 mm. The level survey began and ended at known bench marks on mineral soil. A temporary turning point was provided in the mire by pushing a large screwdriver into the moss with the handle-end flush with the moss surface. At each intersection the nearest adjacent hummock and hollow elevations were measured, and a contour surface of either hollow or hummock elevations was drawn.

A recording well located near the bog center provided a continuous 22-year record of water table elevations during ice-free periods. The recorder platform was attached to 3-cm diameter steel pipes approximately 5 m long and augered into mineral soil beneath the peat deposit. In December through March (each year), a single water table elevation was determined each month by a level survey from the mineral soil to a 10-cm diameter fiber pipe (to prevent deep freezing) well near the recorder. Water elevation was determined after chopping through the ice and allowing for the water level to equilibrate. Water level extremes were then listed for each of 22 years (1961-1982) and included: winter low, summer low, snowmelt high, rainfall high (its range was included in the snowmelt high range), and the elevation at which streamflow from the mire stopped each year. Each 22-year series of extreme values was evaluated by calculating the mean and the 2.33-year recurrence interval using the Weibull formula (12). The elevation range of concrete frost (solid ice and soil) occurrence was determined from annual surveys using a steel rod penetrometer.

The organic soil profile was described in July 1972 at a site 35 m southeast of the recording well by members of the Lincoln, Nebraska, laboratory of the Soil Conservation Service (SCS), using the fiber content-degree of decomposition methods subsequently described by the Soil Survey Staff (13). Another profile description was made 25 m southeast of the recording well by the author in July 1983, using the von Post system (14). Profile elevations were adjusted slightly to correspond with the mean sea-level elevation of the recording well.

3. RESULTS AND DISCUSSION

3.1 Microtopography

The contour surface of hollow elevations shows that a dome approximately 10 cm in height is centered near the recording well in the upper third of the bog (Fig. 1). The longest slope from the dome center to the outlet stream extends 200 meters and drops 0.27 meter in elevation (a 0.14% slope). Many of the contour lines bend near the mire edge, confirming a lagg visually discerned by the presence of speckled alder. A contour surface that intercepts hummock peaks is shown in Figure 2. There is obviously greater total variation (more contour lines) in hummock elevation than in hollow elevation because the contour interval in both figures is 3 cm. The maximum range in hummock elevations across the bog is 0.57 m compared with the 0.27-m range for hollows. The average elevation difference between adjacent hummocks and hollows was less near the bog edge (19 cm ± 7 std. dev. for 31 pairs) than in the bog interior (25 ± 6 std. dev. for 37 pairs). Over laying Figure 2 on Figure 1 indicated the total range in adjacent hummock-hollow elevation differences. The minimum difference was 10 cm near the exit stream. Maximum differences of 40 cm occurred near the hummock "hills" and reached 50 cm at the hummock extreme near the highest (east) end of the bog.

Figure 1 can be considered a true contour surface because it reflects a surface that near-horizontal water flow will follow. It is less variable than hummocks or a combination of hummock and hollow elevations. Between survey intersections (30.5 m), hollow elevations differ by an average of 3 cm ± .01 std. dev., hummocks differ by 8 cm ± 0.17 std., dev. and combinations differ by 26 cm ± 0.21 std. dev. Thus summertime hollow elevations are the least variable place to measure the elevation of intact peatlands. They are also a living moss reference point to compare descriptions of soil profiles separated by large distances.

3.2 Profile descriptions

The horizon designations for both the SCS and von Post methods are depicted for a peat profile justified at mean sea level in Figure 3. For the most part, horizon boundaries are the same for both systems, but the von Post system allows a finer description. Stanek and Silc (14) have shown that neither rubbed nor unrubbed fiber contents (using a 0.15 mm screen) can differentiate between von Post humification classes 5-10 (partially to completely humified or some to all of the peat squeezes between the fingers). Inability to describe precisely the degree of decomposition can hinder the interpretation of the boundary between acrotelm and catotelm. Even so, the implicit definitions of acrotelm and catotelm, while being functionally descriptive, cannot now be precisely defined by explicit values of water content, hydraulic conductivity, or degree of decomposition.

3.3 Water table fluctuations

The mean value of annual water table extremes was within 1 cm of the 2.33-year recurrence interval value, or essentially within the field precision of the level and rod. Therefore 1-cm ranges are used for the various water table positions. The mean annual winter low (occurring in March) was identical to the mean annual summer low (occurring in July or August). The total range for each water table elevation is: March low (33 cm), summer low (20 cm excluding 1976), annual high (18 cm), and elevation where annual flow stopped (7 cm). The water table extremes, mean annual extremes, and 22-year mean are shown in Figure 4; the total range encompassing the annual thickness of concrete ice is also shown.

The 1976 minimum followed a severe drought of approximately 18 months (Palmer Drought Severity Index = -4). The water table dropped 71 cm below the hollows and deep into quite well humified, usually anaerobic peat. Excluding the severe drought minimum, the water table fluctuated within a 47-cm range. The point at which lateral flow (streamflow) stops, the mean annual minimum, and the nondrought minimum all correspond approximately with horizon boundaries. Ice is confined to the little humified (von Post 1, 2, and 3) or fibric horizons.

4.0 DISCUSSION

The water table and soil profile information at the Marcell mire both rejects and confirms parts of the implicit definitions for acrotelm and catotelm. First, the occurrence of the drought minimum must be considered exceptional, a condition, if it persisted, leading to oxidation, shrinkage, and the possibility of subsequent water erosion in non-rewettable peat (8). Thus it could reverse the process of peat accumulation. Nevertheless, an 18-month drought was not sufficient to affect rewetting, and water levels returned to normal without any discernible impact on the bog soil. The definition that the acrotelm must contain the oscillating water table should be interpreted to exclude severe drought minimums.

Second, the range of capillary rise reported in the literature is 30 to 50 cm, being less for hollow species than for hummock species (1, 2, 15). The nondrought minimum water table is 29 cm below the hollow, where it allows *Sphagnum* species to persist in most dry years with active growth possible when water table elevations are above this. The maximum hummock height is 48 cm above the mean water table at the site of the profile description, but apparently reaches 55 cm above the mean water table as implied from the tallest hummocks mapped with contour lines (Figs. 1 and 2). It may be that the mean water table elevation limits annual hummock development by way of a maximum capillary rise near 50 cm. However, hummocks can be kept moist by intercepting periodic rains even when the water table is lower than 50 cm.

Third, the elevation at which lateral flow (streamflow) stops is about one-third of the distance from the mean annual water table minimum to the mean annual water table maximum. Thus the zone of lateral flow is less than the zone of normal water table oscillation. It is important to note also that lateral flow stops within the fibric horizon (SCS) or at the interface between von Post H2 and H3 (Figure 4).

This phenomenon is common where Sphagnum mires exist in continental climates near the point where evapotranspiration approaches annual precipitation and regularly exceeds it during some summer weeks. An example is the 1400 ha Red Lake Bog in northwestern Minnesota where fibric Sphagnum has accumulated from 100 to 350 cm thick and at its lowest the water table was 150 cm from the surface (16). Most lateral flow occurs within 18 cm of the surface as indicated by maximum accumulations of tritium in the 0-18 cm zone (17). However, when the water table is far from the surface, the deep Sphagnum profile can be wetted by intercepting periodic rains that are not large enough to percolate to the deepwater table. Think of this as a kind of gravity creep of fluvial water downward from the Sphagnum surface (it is common in drier continental climates). This process that supports Sphagnum growth that is directionally the reverse of the capillary rise that is commonly perceived as the major mechanism permitting Sphagnum growth in dry periods in wetter maritime or colder continental climates.

5.0 CONCLUSIONS

The acrotelm [active layer] and catotelm [inert layer] are useful concepts relating to hydrologic, biologic, and mire morphology functions (10). However, the distance between implicit and explicit definitions should be narrowed as a further step in refining field-identifiable features of organic soils. I suggest a slight refinement of the acrotelm and catotelm definitions as presented by Ivanov (8), Romanov (1), and Ingram (10). Underlines indicate changes.

The upper layer (acrotelm) [1] contains the nondrought oscillating water table; [2] is a zone of high hydraulic conductivity but includes the elevation where measurable lateral flow stops and may extend at least 20 cm below this point; [3] shows a variable water content; [4] is subject to periodic air entry on dewatering following the normal lowering of the water table; [5] is rich in peat forming aerobic bacteria and other microorganisms; and [6] has a live matrix of growing plant material, and [7] includes dead plant material undergoing diagenesis by humification, but not yielding peat substance between the fingers when squeezed (von Post H 1-4).

The lower layer (catotelm) [1] has a nondrought water content invariable with time; [2] possesses a negligibly small hydraulic conductivity; [3] is normally not subject to air entry; [4] is normally devoid of peat-forming aerobic microorganisms and is poor in microbes in general.

These refinements in definitions permit a more precise identification of the boundary between the acrotelm and catotelm (Fig. 4). I would place the boundary for the Marcell mire at a mean sea level elevation of 421.76 m or precisely between von Post humification horizons 4 and 5 because [1] the overlying acrotelm contains the nondrought oscillating water table, [2] the degree of von Post humification is low (not yet reaching the point where peat can be squeezed between the fingers though turbid water appears--an easily field-definable characteristic), and [3] it is 30 cm below the hollow elevation, and equal to the height of maximum capillary rise for hollow species.

These tests of definition and conclusions regarding the terms acrotelm and catotelm are limited to one bog, albeit one with long-term water level records. They need to be tested in other intact bogs and fens where water-table records are available in order to sharpen the definitions and suggested field methods that tie profile descriptions to functional zones. Similar investigations in drained and peat-harvested areas where the catotelm is exposed can sharpen our interpretation of water table and soil interactions for these areas too.

6.0 ACKNOWLEDGEMENT

As Ingram (10) has so aptly noted: "Whilst acknowledging the need to be critical, I am very conscious that one must temper criticism with admiration. No one with experience of field work in mire hydrology [or organic soil description] can fail to appreciate the very great effort required to obtain any worthwhile results..." I acknowledge this effort from those who strive to see peatland ecosystems clearly. These data and interpretations are a contribution to the National Science Foundation Study (DEB 7922142): The Ecology and Biogeochemistry of *Spagnum* Bogs in North America, and to the North Central Forest Experiment Station's Aspen-Birch-Conifer (ABC) Ecosystem Program.

1. Romanov, V. V. Gidrofizika bilot. [Hydrophysics of Bogs. Translated by N. Kaner, edited by Heimann. Israel Program for Scientific Translations, Jerusalem. 1968. 299 p.] Gidrometeoizdat, Leningrad. 1961.

2. Hayward, P. M. and R. S. Clymo. Profiles of water content in Spagnum and peat, and their relation to peat bog ecology. Proceedings of the Royal Society of London, Series B--Biological Sciences 215. p 299-325. 1982.

3. Moore, P. D. and D. J. Bellamy. Peatlands. Springer-Verlag New York Inc. 221 p. 1977.

4. Ingram, H. A. P. Size and shape in raised mire ecosystems: a geophysical model. Nature 297 (5864): 300-303. 1982.

5. Lopatin, V. D. O gidrologicheskom znachenii verkhovykh bolot [The hydrological significance of raised mires]. Vest. Leningrad. gos. Univ. vol. 2. p 37-49. 1949.

6. Ivanov, K. E. Gidrologiya bolot. [Hydrology of Mires] Gidrometeoizdat, Leningrad. 256 p. 1953.

7. Ivanov, K. E. Osnovy gidrologii bolog lesnoi zony i raschety vodnogo rezhima bolotnykh massivov [Rudiments of the Hydrology of Mires in the Forest Zone and Computations of the Water Regime of Mire Massifs.] Gidrometeoizdat, Leningrad. 500 p. 1957.

8. Ivanov, K. E. Vodoobmen v bolotnykh landshaftakh [Water Movement in Mirelands. Translated by A. Thomson and H. A. P. Ingram. Academic Press, London. 1981. 276 p.] Gidrometeoizdat, Leningrad. 1975.

9. Ingram, H. A. P. Soil layers in mires: function and terminology. The Journal of Soil Science 29 (2): 224-227. 1978.

10. Ingram, H. A. P. Hydrology. In: Mires: Swamp, Bog, Fen and Moor, A. General Studies (A. J. P. Gore, ed.) Elsevier Scientific Publ. Co., Amsterdam. p. 67-158. 1983.

11. Verry, E. S. and D. R. Timmons. Waterborne nutrient flow through an upland-peatland watershed in Minnesota. Ecology. 63 (5). p 1456-1467. 1982.

12. Chow, Ven Te. Handbook of Hydrology. McGraw Hill Book Co., N.Y. p. 8-29 through 8-31. 1964.

13. Soil Survey Staff. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agriculture Handbook No. 436, U.S. Department of Agriculture Soil Conservation Service, Washington, D.C. 754 p. 1975.

14. Stanek, W. and T. Silc. Comparisons of four methods for determination of degree of peat humification (decomposition) with emphasis on the von Post method. Canadian Journal of Soil Science, 57: 109-117. 1977.

15. Granlund, E. Sver. geol. Unders. Afh C(373). p 16-20. 1932.

16. Farnham, R. S. and D. N. Grubich. Peat resources of Minnesota. Report of inventory no. 3, Red Lake Bog. Beltrami County. Office of Iron Range Resources and Rehabilitation. St. Paul, Minnesota. 24 p. 1966.

17. Gorham, E. Penetration of bog peats and lake sediments by tritium from atmospheric fallout. Ecology 52 (5): 898-902. 1971.

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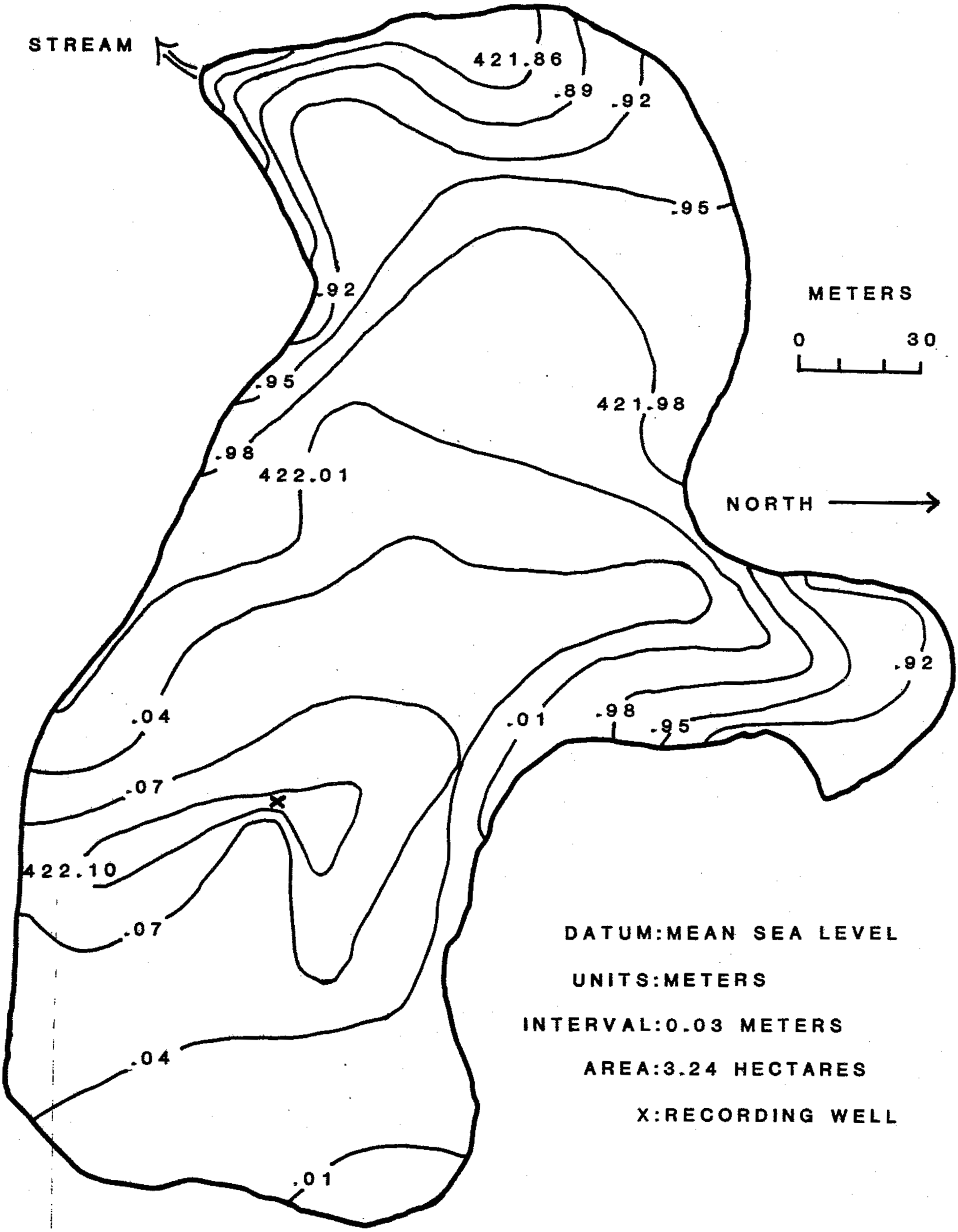

Figure 1. The contour surface of hollow elevations in mire no. 2 at the Marcell Experimental Forest in Minnesota, USA.

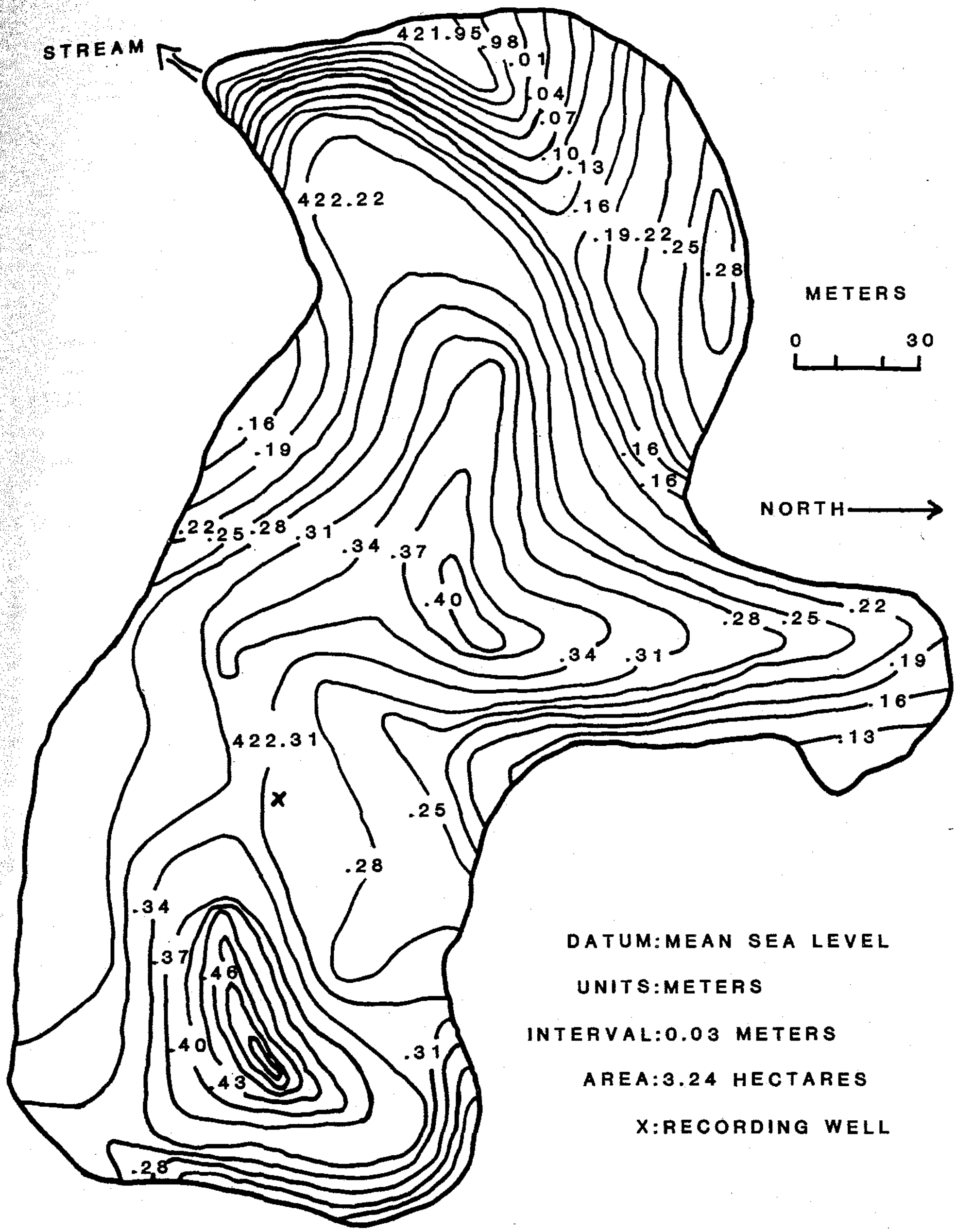

Figure 2. The contour surface intercepting hummock peaks in mire no. 2 at the Marcell Experimental Forest in Minnesota, USA.

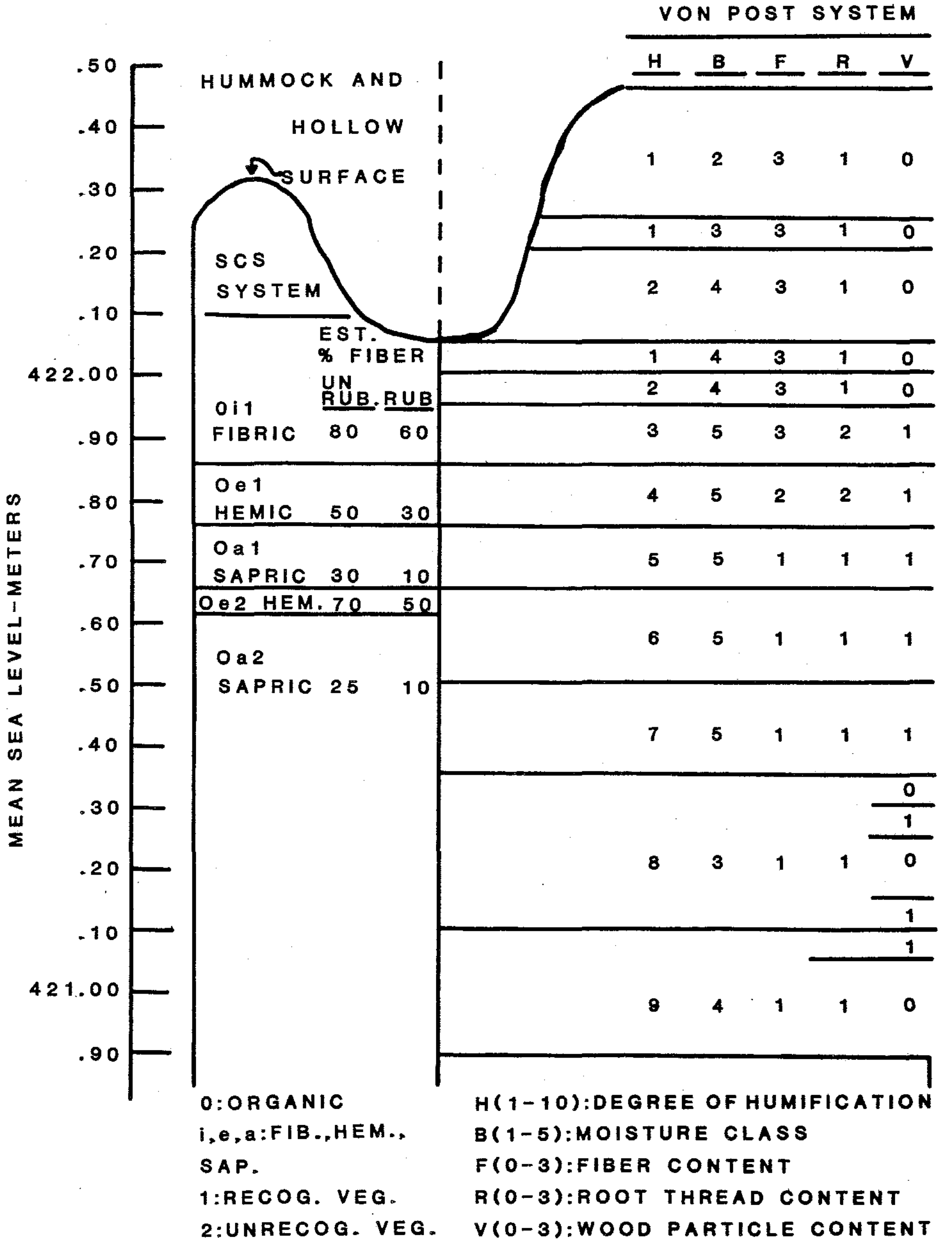

Figure 3. Organic soil profile near the recording well in mire no. 2, Marcell Exp. Forest, using Soil Conservation Service (SCS) and von Post systems for classifying soil horizons

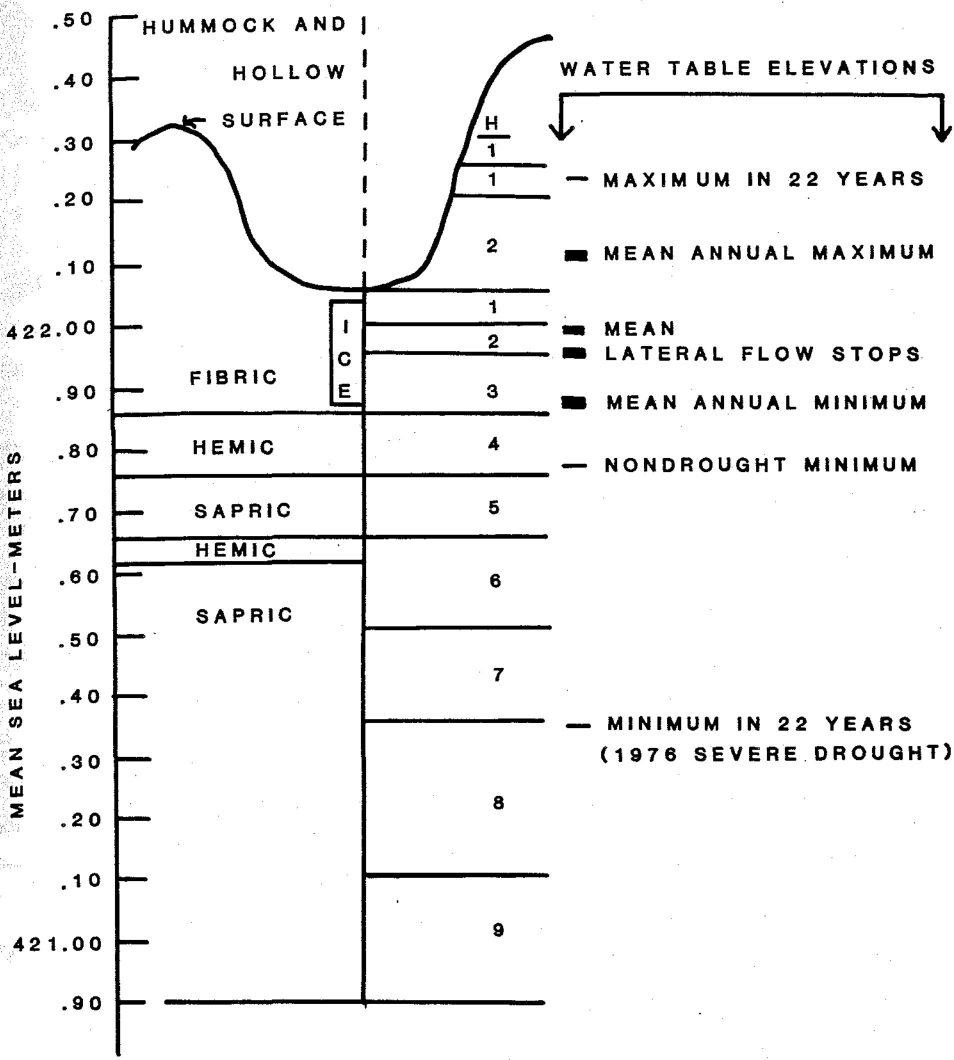

Figure 4. Water table elevations and zone of concrete ice formation near the recording well in mire no.2, Marcell Exp. Forest (see fig. 3 for horizon designations).

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