Snow, Ice and Frozen Ground Observations in A Pond/Marsh Wetland

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INTRODUCTION

Hydrologic and biologic functions of northern wetlands are seasonally influenced by the presence of snow, ice and frozen ground, and the temperature of unfrozen soil and water. Winter influences the annual water budget of a wetland through the capture and conservation of moisture as snow and ice which, in turn, affects the moisture available in spring (Johnson 1985). Wetlands may function as efficient heat sinks during the growing season (Woo and Valverde 1982) and sources of heat in the winter. Change in climate or local land use may alter the volume and temperature of water entering a nearby wetland, modifying the wetlands thermal regime.

We need to understand winter wetland processes in order to predict the influence of natural or manmade changes on wetlands. Smith (1984) monitored ground and water temperatures in a forested mid-latitude swamp through an entire year and concluded that a vertical conduction model provided a good simulation of the thermal regime of that environment. Though relatively few studies have specifically addressed the winter environment of mid-latitude wetlands, extensive existing knowledge about thermal conditions in lakes and rivers (e.g., Pivovarov 1973, Ashton 1986), thermal properties of soils (e.g., Farouki 1981) and physics of the plant environment (e.g., Van Wijk 1963) provides a platform for winter wetland research.

This paper describes snow, ice and soil conditions encountered during mid-winter and early spring in a pond/marsh wetland associated with a series of beaver dams. The goal of this first season's work was to observe the distribution of frozen materials and the progression of spring thaw in relationship to thermal and hydrologic regimes. The longer-range objective is to quantify heat and moisture fluxes in pond/marsh wetlands during winter and generalize these for the distribution of plant and soil properties typically encountered. The information derived will allow a better assessment of the influence of winter processes on the hydrologic and biologic functions of wetlands.

SITE AND METHODS

The study site is located 4.8 km south of Lyme, in west-central New Hampshire, in a pond/marsh wetland created by a series of beaver dams. One small stream and three streamlets enter the marsh along the east margin. The watershed increases from approximately 1.6 to 3.4 km in drainage area along the reach sketched in Fig. 1.

Six transects (Fig. 1) were established beginning upstream in an emergent vegetation zone (Transect A) and continuing downstream into a progressively deeper pond zone (Transects B,C,D,E and F). Transect A is predominantly cattail marsh but includes a small reach of shallow pond at its low point and is bordered by sedge at its upland margin. The pond transects (B,C,D,E, and F) are bordered by cattails at the pond edge and sedge at their upland margins. Pond depths, including ice, varied from 37 cm at Transect B to 132.5 cm at Transect F. Soil temperature and frost depth data along Transect A will be reported separately (Melloh and Racine, in prep.).

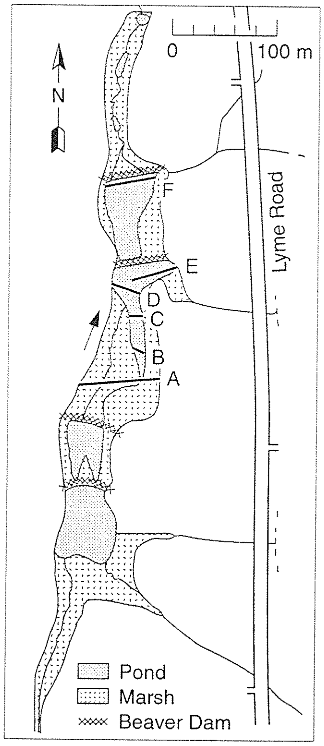

Figure 1. Location map.

Ice and Frozen Soil

Ice and frozen soil thicknesses were measured along the shallow pond zones on five transects (B,C,D,E and F, Fig. 1) in mid-February. Holes were drilled with a 5-cm-diameter ice auger and a 3.5-cm-diameter soil auger. The thicknesses of snow ice, pond ice and frozen soil were recorded. The locations of the bottom of a soft organic zone and a firm soil horizon were probed by first dropping, then pushing a pointed steel rod into the unfrozen soil. In addition, 22 ice and soil cores were collected along the transects using an 8.6-cm-diameter core barrel equipped with a powerhead. The majority of the ice cores and thickness measurements were obtained on 19, 20, 21, and 25 February. The elevations of ice and soil horizons were corrected to relative elevations using level surveys of the surface topography.

Pond and Channel Ice Melt and Soil Thaw Progression

Observations of thaw progression in channels and ponds were recorded on field notes and photographs during March and early April.

Snow

A snow depth profile (Fig. 2) of a partially ablated snowpack was recorded on 29 January through sedge and cattail zones bordering the pond between Transects B and C. Snow

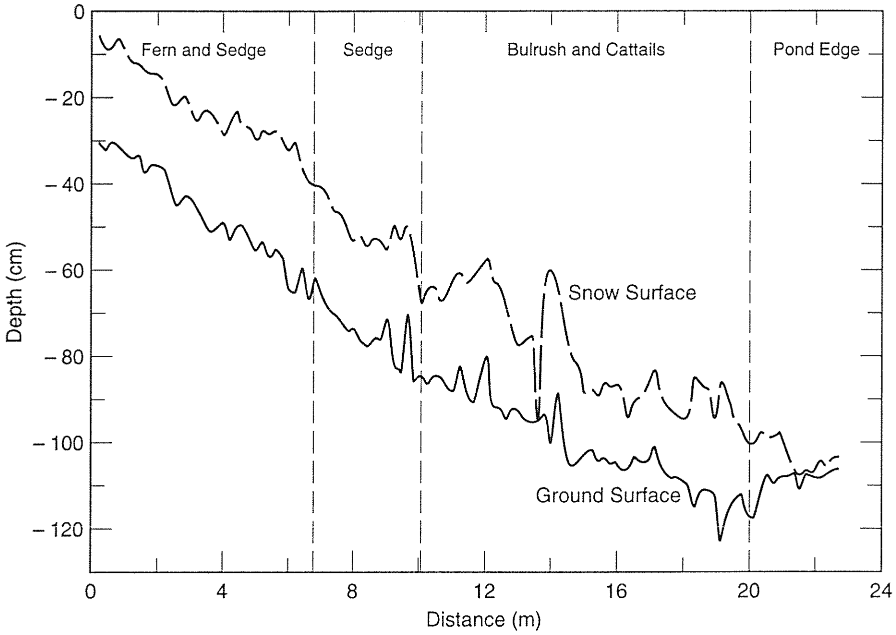

Figure 2. Snow depth profile between Transects B and C, 29 January 1991.

and ground surface elevations were measured at 10-cm intervals using a string level to establish a reference datum.

RESULTS AND DISCUSSION

Ice and Frozen Soil Thickness Comparisons

In general, the thickness of frozen material, whether composed entirely of ice, entirely of soil or a combination of the two were similar across the shallow pond transects (Fig. 3). Frozen material thickness increased in the downstream direction and was slightly more pronounced where the entire frozen thickness consisted of ice over water. Maximum ice thicknesses were 37 cm at Transect B over unfrozen sediment, and 37, 46.5, 52 and 57.5 over water at Transects C, D, E and F, respectively, an increase of 20.5 cm overall. Snow-ice depths were 10, 10, 12, 12 and 12 cm at Transects B,C,D,E and F respectively, contributing only a fraction of the downstream increase in ice thickness.

A method of graphical comparison of the frozen soil and ice thicknesses was used to recognize and interpret thermal regime changes from point to point in the wetland. Frozen soil and ice thickness data points were plotted on Figure 4, representing each drilled hole shown on Figure 3. Points plotted on the x-axis (Fig. 4) represent frozen thicknesses that consisted entirely of ice over either unfrozen soil or water. Points on the y-axis represent sites where the entire frozen thickness consisted of soil, without a surface layer of ice. The remaining points represent ice over frozen soil.

Reference lines were drawn (Fig. 4) representing the approximate assumptions that the water and highly water-saturated bottom sediments have equivalent thermal properties, that the thermal regime is entirely one of vertical conduction driven by temperature differences between the shallow pond and cold atmosphere above, and that the temperature in the soil and water is uniform at the onset of freezing. The assumption excludes heat influx from below the freezing layer, convection by water currents, lateral conduction, solar radiation and surface moisture flux terms of the heat budget equation (e.g., Pivovarov 1973). We chose to draw the reference lines starting at the maximum ice thickness along the x-axis for each transect, assuming that the thickest ice was the least affected by heat gain due to such factors as convection by warm currents or heat influx from the bottom. This hypothetical condition is illustrated on Figure 5 (Case 1). Departures from this assumption, resulting in deeper (Case 2) or shallower (Case 3) soil frost depths relative to the same maximum ice thickness, would plot as shown on Figure 5. We may now speculate

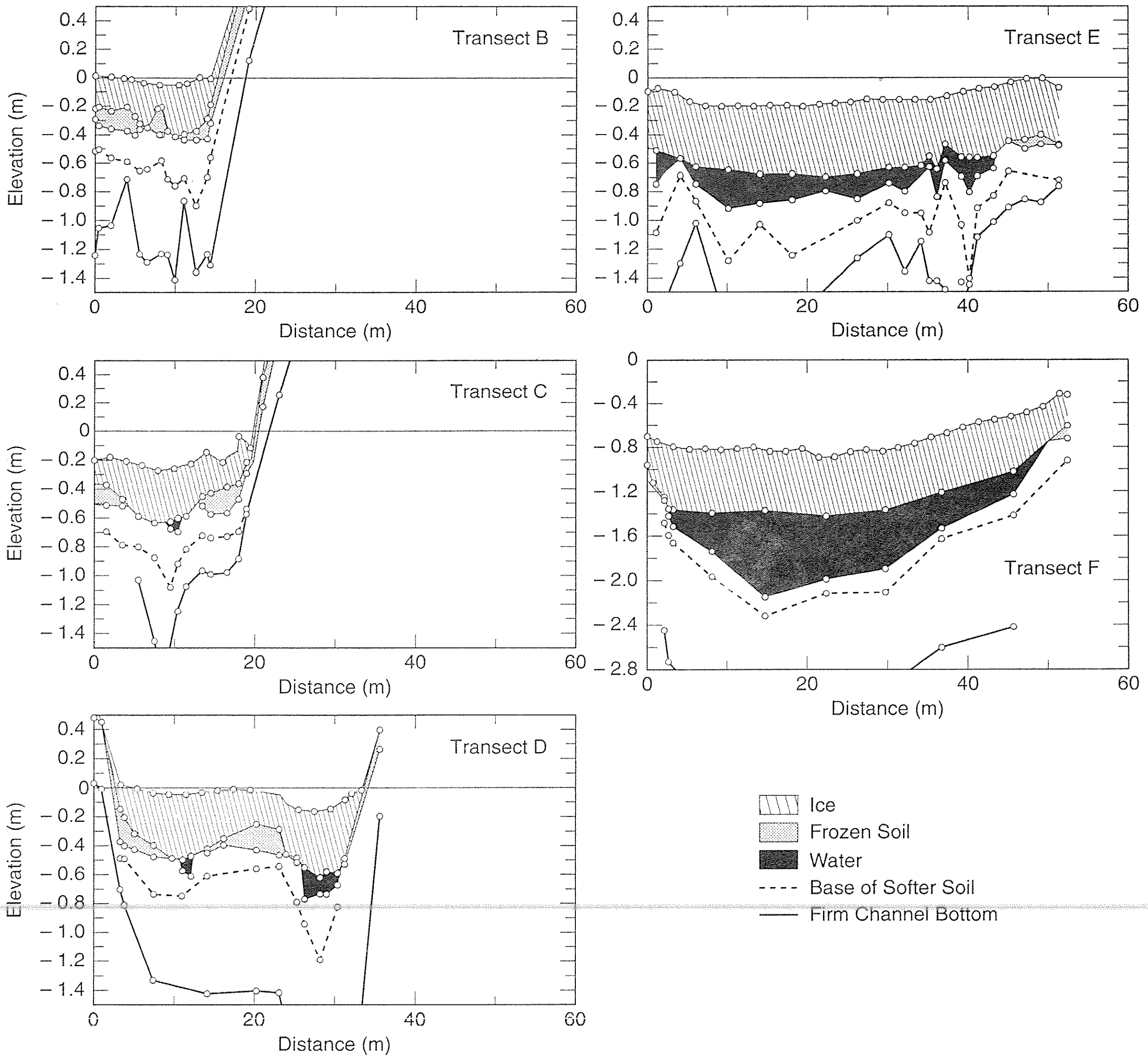

Figure 3. Frozen depth measurements, Transects B, C, D, E and F.

on why the actual data vary from the reference line assumption at each transect and why the reference lines vary from transect to transect.

Points above the reference line (Transects B and C, Fig. 4) represent higher frost susceptibility than our approximate assumption because mineral and organic fractions of the water-saturated sediment will reduce the heat capacity and the required latent heat of fusion of ice by reducing the unit volume of water. Plotted points that lie furthest above the reference line would be expected to contain the larger volume fractions of sediment.

Points below the line represent less frost susceptibility due to 1) less heat loss due to insulation by surface snow or vegetation or 2) heat added by warm groundwater inflow,

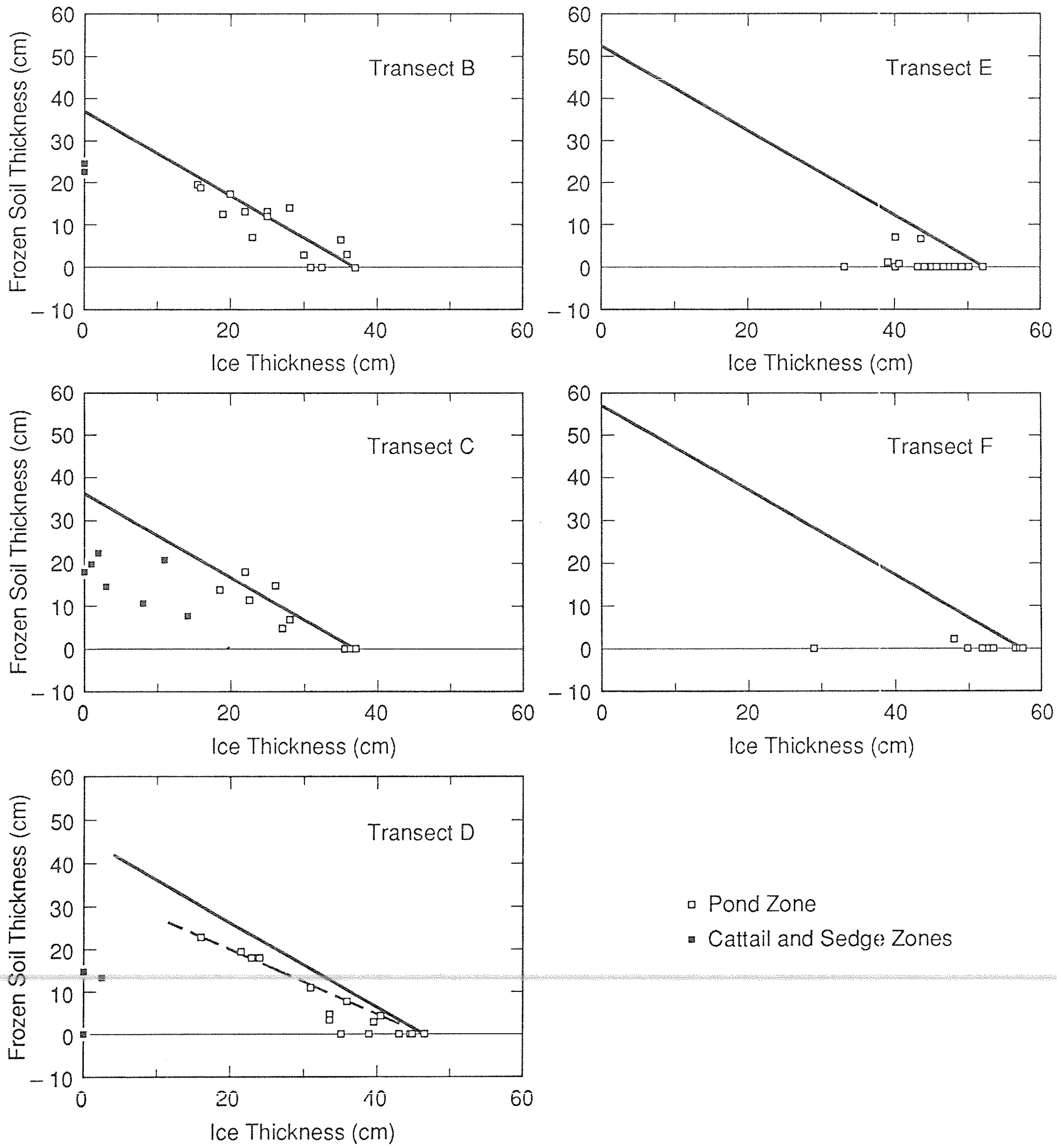

Figure 4. Frozen soil and ice thickness comparisons and reference lines.

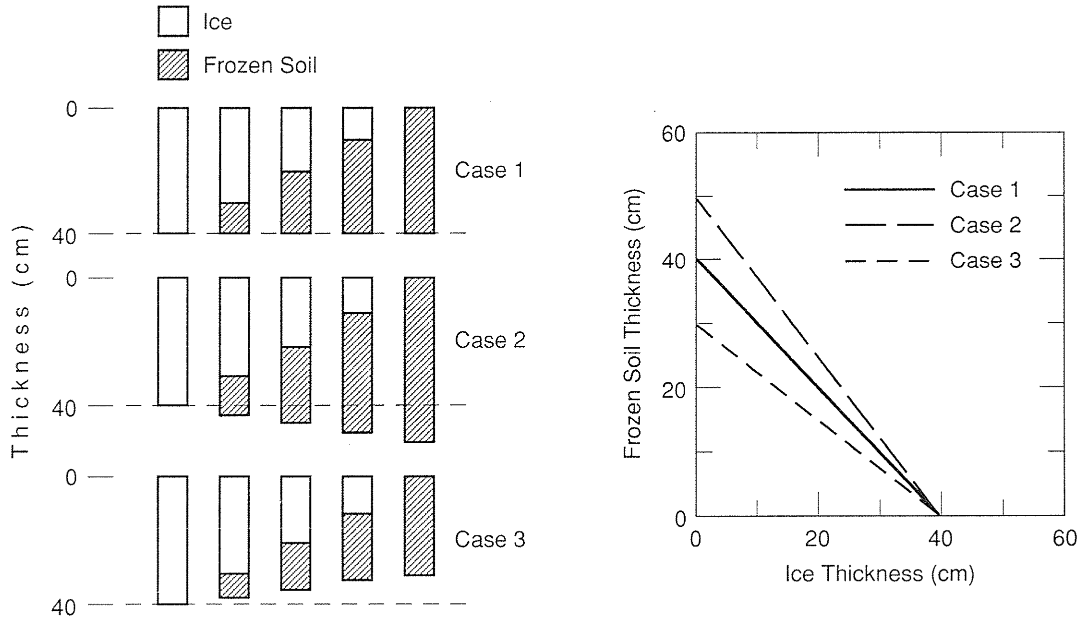

Figure 5. Hypothetical frozen soil and ice comparison plots.

stored ground heat, convection by warm water currents or solar radiation. These factors that conserve or add heat, when large enough, can cause points that represent the more frost-susceptible soils to fall below the reference line as well. Sedge and cattail zones maintained a light snow cover, a surface layer of undecomposed vegetation and dried plants that remained standing through the winter. Surface insulation may have decreased the depth of frost in these zones; these data points plot far below both the trend and the reference lines (Transects C and D, Fig. 4). We also encountered occasional unfrozen spots in the emergent zones (Transect D, Fig. 4), hinting of warm groundwater source points along the west edge of the wetland, at the foot of Lyme Hill.

Moderate ice thickness (37 cm) and resistance of sediments to freezing suggests there may be warm groundwater influx through the sediments at Transects B and C. On Transect B the bottom line of frozen material points upward at two points below frozen water channels (7 and 9 m, Fig. 3), and on Transect C the relatively thin ice abuts unfrozen sediment over an 8-m width of pond bottom (5 - 13 m, Fig. 3).

Surface flow paths observed during periods of runoff indicated the location of primary convection zones. Low current in a constricted reach just upstream of Transect B coincided with a zone of early ice out. Anomalously low ice thicknesses on Transect E (33 cm, Fig.4) and a wave on the bottom of the ice layer at that point on (36 m, Fig. 3) coincide with the entry of a streamlet, a shallow bottom and a submerged flow path through the beaver dam.

Increased maximum ice thicknesses over water cause the chosen reference lines to progress toward the right of the graphs for downstream Transects D, E and F (Fig. 4). The increased ice thickness over the deeper pools represents more effective freezing degree-days, the result of thermal regimes that allow earlier ice initiation and higher rates of ice growth. In contrast, noted convection currents and probable warm groundwater influx near Transects B and C would have delayed ice initiation and slowed ice growth in the shallower reach of the pond. Thin sections of ice samples of the pond surface show massive, spontaneously nucleated ice crystals at Transect F, while columnar c-axis horizontal crystals occur at Transect B; the idea of ice cover initiation at different times and by different processes is supported by this difference in ice structure.

Ice over frozen soil data points at Transect D fall below the reference line and have a trend of 0.75 frozen soil to 1.0 ice. This conflicts with expectations that water-rich sediments would freeze more readily than water alone. One factor may be heat stored in the sediments of the shallow zones during summer and fall. Another minor factor may be that the floating ice portions of the transects were slightly lower in elevation and were subject to overflows more frequently, decreasing the albedo of the surface compared to more persistent thin snow cover over the grounded ice.

Pond and Channel Ice Melt and Soil Thaw Progression

The progression of ice melt in the ponds consisted first of edge retreat adjacent to the south-facing banks of the beaver dams at the downstream end of each pond beginning around 5 March. Warm water emanating from below the dams began to melt the ice cover above them. The thermal plumes gradually proceeded downstream from the dams until they intersected the upstream progressing edge retreat by the end of March. The remaining ice cover was primarily grounded ice and was flooded by snowmelt runoff and rainfall. Border ice sheets extended from the shallow to nearby deep pools. On one occasion thinned border ice was seen to break at a landward hinge and sink rather than float; dispersed sediment on the ice surface had melted the ice under it and collected in numerous coin-sized pocks.

The progression of ice melt and soil thaw in channels through the cattail marsh was intriguing. Runoff initially flowed on top of the channel ice, separated from slower moving or stagnant water and unfrozen bottom sediments. Frozen channel walls persisted well into spring even though water was moving through the channels. The water was clear and sedimentation rates appeared minimal. The presence and persistence of frozen materials may help minimize erosion of wetland sediments during the period of peak spring runoff.

Snow Conditions

The winter of 1990-1991 was one of mild temperatures and sporadic snowcover, the last significant snowfall occurring on 13 January. The partially ablated snow cover of 29 January showed a snow surface topography similar to the frozen ground below it (Fig. 2). A less erratic snow surface occurred in the predominantly sedge zone compared to the predominantly cattail zone lower in the profile. There were occurrences of zero snow depths adjacent to dense groupings of bulrush or cattail stems that had shed snowfall. The sedge zone snow cover was more uniform and on this particular date would have provided a better insulating layer between atmosphere and ground. An abrupt transition in snow depth occurred at the pond edge; there was only a light dusting of fresh snow on the frozen pond because earlier snowfalls had been incorporated in the pond ice cover following overflow or radiational melt.

PRELIMINARY CONCLUSIONS

The frozen soil and ice thicknesses generally fell below the simple reference line assumption of vertical conduction and equivalent thermal properties of soil and water, indicating the significant influence of factors that conserve or add heat to the system. Light snow cover, a surface layer of undecomposed vegetation and dried standing plants probably reduce net heat loss, resulting in lesser frost depths in the cattail and sedge zones. Moderate frozen soil and ice thicknesses in the shallow end of the pond might be explained by a combination of groundwater influx, convection and, perhaps, residual ground heat. The graphical method, though not definitive, helped identify zones where measurements of heat flux and water movement would be most revealing.

The presence of ice in the channels through the cattail marsh and the persistence of frozen soil in channel walls may minimize erosion of wetland sediments during periods of peak spring runoff.

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