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An Evaluation of the Accuracy of the Growing Season Used for Wetland Delineation in SE Virginia

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AN EVALUATION OF THE ACCURACY OF THE GROWING SEASON USED FOR WETLAND DELINEATION IN SE VIRGINIA

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In Partial Fulfillment

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Master of Science

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by

Rebecca L. Arenson

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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Rebecca L. Arenson

Approved, May 2003

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DEDICATION

To my family: Mom and Dad, Deb and Jordan, and Naomi, Warren, and Aidan…

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ABSTRACT

Wetland delineation requires that a jurisdictional wetland show characteristic wetland hydrology – inundation or saturation of the soil (within 30 cm of the soil surface) – for a percentage of the growing season. This generally is >12.5% of the growing season, or 5 - 12.5 % of the growing season with other evidence. This study compares the growing season as estimated from air temperature (the usual method of determining the growing season), with the growing season measured on hardwood mineral flat wetlands (using soil temperatures) on the coastal plain of Southeast Virginia from fall 1999 to spring 2002. Research sites were evaluated for characteristic wetland hydrology using the estimated and measured growing seasons. In addition, the plant activity season was determined from observations from fall 1999 to spring 2000.

Hardwood mineral flats (forested, non-tidal wetlands) were used for the study. These seasonally saturated wetlands have been subject to development pressure. A suite of 7 research plots at 4 locations were selected for geographic coverage, and because modifications at the sites produced a hydrologic gradient of drier to wetter sites.

Sites were instrumented with a shallow groundwater well and an Onset HOBO soil temperature recorder at 10 and 50 cm depth. Randomly selected and tagged specimens of common dominant species in three strata – shrub, sapling, and tree – were monitored for readily observable phenologic plant activity. Fall observations included leaf color change and leaf drop, while spring observations included bud swelling, flowering, and leaf-out.

The plant activity season started in early to mid January with bud swelling, followed by red maple (*Acer rubrum*) flowering, and then leaf out in late March and early April. Fall plant activity extended into mid-November to early-December. The measured growing season (based on soil temperatures >5°C at a depth of 50 cm) ranged from 308 to 365 days (82 to 139 days longer than the currently used growing season), and started earlier in the spring and extended later into the fall than the growing season currently used for wetland delineation. Sites had fairly similar patterns of characteristic wetland hydrology when comparing the estimated and experimentally measured growing seasons. However, sites generally had longer periods of characteristic wetland hydrology using the measured growing season (determined from soil temperature). In addition, some sites would need additional supporting evidence for characteristic wetland hydrology when using the estimated growing season. Small, isolated fragments of formerly large hardwood flat complexes were particularly sensitive to fluctuations in precipitation, and were extremely dry during years of low precipitation. An examination of mean monthly groundwater levels and minimum 50 cm soil temperatures for December 1999 to March 2000 show a significant relationship between high groundwater tables and low soil temperatures for December and January. There was not a significant relationship for February and March.

Growing seasons based on soil temperatures were much longer than the growing seasons estimated from air temperature. The length of the growing season did have some impact on the ease with which a site would meet the requirement for characteristic wetland hydrology.

AN EVALUATION OF THE ACCURACY OF THE GROWING SEASON USED FOR WETLAND DELINEATION IN SE VIRGINIA

INTRODUCTION

A current issue in wetland delineation is the concept and definition of the "growing season." The growing season is important for wetland delineation, because while wetland delineation generally requires that wetlands show evidence of all three diagnostic characteristics, vegetation, soil, and hydrology (Environmental Laboratory 1987), the wetland hydrology must occur during the growing season. The 1987 federal delineation manual states for hydrology (Environmental Laboratory 1987):

> "The area is inundated either permanently or periodically at mean water depths ≤ 6.6 ft, or the soil is saturated to the surface at some time during the growing season of prevalent vegetation."

To qualify as characteristic wetland hydrology, the inundation or saturation must occur for a percentage of the growing season; there must be inundation or saturation at the surface (≤ 30 cm) for >12.5% of the growing season or 5-12.5% of the growing season with other evidence (National Research Council 1995). Due to capillary action, a soil is generally considered saturated if the groundwater level is within 30 cm of the soil surface.

Since diagnostic wetland hydrology (saturation or inundation) must take place during the growing season, the definition and thus length of the growing season has critical implications for wetland delineation, especially for those wetlands which are primarily seasonally saturated during the colder times of the year. Vernal pools, which are shallow, intermittently flooded wet meadows, are one example of a seasonally saturated wetland. The hydroperiod for a central California vernal pool would typically show inundation only during the winter and spring (Mitsch and Gosselink 2000). Other examples of seasonally saturated wetlands are pocosins, pine flats, and prairie potholes. The concern with wetlands that are characteristically saturated in cooler parts of the year is that an inaccurately defined growing season might exclude the periods of typical saturation. As a result, the wetlands might not meet the hydrology requirement for wetland delineation, and would not be protected by federal and state wetland regulations and policy.

The growing season definition generally is tied to the concept of biologic zero. Biologic zero is not equivalent to the freezing temperature of water at 0°C. Instead, biologic zero is accepted as the soil temperature at which normal biological activities in the soil, as well as plant growth, cease or are negligible. This temperature is 5°C (41°F) (Hall 1920, Environmental Laboratory 1987, Soil Survey Staff 1993). The growing season is thus defined as “the portion of the year when soil temperatures are above biologic zero at 50 cm (19.7”)” (Soil Survey Staff 1999b). However, the 1987 federal wetland delineation manual (Environmental Laboratory) also allows the growing season to be estimated from the number of frost free days. In practice, this second method – using frost free days to estimate the growing season – is the primary method used in determining the growing season for wetland delineation purposes. County soil surveys, produced by or in conjunction with the Natural Resources Conservation Service (formerly the Soil Conservation Service), United States Department of Agriculture, include tables giving both a length, as well as start and end dates, for the growing season. For example, Table 1 shows the growing season information for York County from the *Soil Survey of James City and York Counties and the City of Williamsburg, Virginia* (Soil Conservation Service 1985). The Norfolk Office of the Army Corp of Engineers uses an air temperature of 28°F (-2.2°C), plus the 5 years in 10 probability of last freezing temperature in spring and first freezing temperature in fall to determine the date the growing season starts and ends (Martin 2000). In this case, the growing season would begin March 30 and end November 12, for a total growing season length of 226 days (Table 2).

Characteristic wetland hydrology is required to occur during the growing season, rather than at any time of the year, because the soil respiration processes (both root and microbial) which use up the oxygen and lead to typical anoxic, reduced wetland soils are believed to be active above biologic zero (National Research Council 1995). Thus, to qualify as a wetland, the plant community, rather than just being able to survive soil saturation during winter dormancy, must be active and hale during this period of stress (i.e. saturated, anoxic soils) in the growing season, which would injure or kill non-wetland adapted plants. However, a report by the National Research Council (1995) lists numerous examples of plant and microbial activity below 5°C, making this temperature threshold somewhat questionable as an absolute temperature.

The growing seasons (based on soil temperature or air temperature) currently in use were designed for agricultural activities (Megonigal et al. 1996), and relate to soil temperatures and soil temperature regimes of Soil Taxonomy (Soil Survey Staff 1996 and 1999b). For example, both hydric and non-hydric soils in the coastal plain of Virginia are in the thermic soil temperature regime (Soil Survey Staff 1999a), which have an assumed growing season of February to October (Soil Survey Staff 1999b). Soils in the thermic soil temperature regime are defined as having a mean annual soil temperature between 15°C and 22°C, with a difference between mean summer and winter soil temperatures of more than 5°C (Soil Survey Staff 1996). However, wetland areas, unless drained, are generally not useful for agriculture. In addition, due to the differences in hydrology and vegetation between wetlands and agricultural fields, growing seasons defined for agricultural lands may not apply to wetlands.

Probably the most immediately striking difference between wetlands and uplands (i.e. agricultural fields) is the amount of water, and although the amount and timing of saturation and inundation of wetlands is variable, basically it is accurate to state that there is more water in a wetland than in an upland. A critical factor in considering differences in soil temperature patterns between hydric and non-hydric soils is the high specific heat of water, which will tend to dampen the affects of daily air temperature changes on a saturated soil, as well as cause a lag in seasonal soil temperature changes. As a result, wet soils will behave differently than dry soils.

The effects of water on soil temperature have been recognized for a long time. Two rather rambling papers from England (Parkes 1844, Denton 1859) in the 1800's investigate 1) the effects of water on soil temperature and 2) the effects on soil temperature when water is drained from a site. Like other studies dealing with the concept of biological zero, Parkes' (1844) and Denton's (1859) interest in soil temperature is agricultural in nature, and their research is found in the Journal of the Royal Horticultural Society of England. Since England is a cool and wet place, drier, warmer soils would clearly be of advantage to farmers – and in fact – Denton found that the modified soils (drained) became warmer and drier. Parkes also found that a modified soil (worked and drained) was warmer than soil in a natural unmodified bog, and he attributed some of this effect to heat entering the modified soil via rainwater.

Several more recent studies of soils in the northeastern and southeastern United States have examined the temperature of hydric soils and explored the effects of water on both the values and variation of soil temperature; the results suggest that the growing seasons currently used for wetland delineation should be reconsidered. Pickering and Veneman (1984) found in their study of central Massachusetts soils that wetter soils had a smaller range of temperature extremes than drier soils, and in fact the only freezing temperature (0°C) was measured within a well drained soil. The entire hydrosequence experienced the highest water table levels from late fall through spring, and the poorly drained soil (wetter) appeared to be buffered from climatic extremes, remaining warm enough in the winter for biological activity and soil reduction. Within a given soil profile, the soil closer to the surface was warmer in summer but colder in winter than deeper soil horizons.

In Virginia and other southeastern states, studies by Megonigal et al. (1993 and 1996), Seybold et al. (2000), and Havens (1997) indicate that hydric soils in these areas stay above the 5°C biological zero threshold for the majority of the winter. Seybold et al. (2000) measured the 50 cm soil temperature in a tidal freshwater marsh (inundated twice a day) on the south shore of the James River in Southeastern Virginia, located about 25 km (16 miles) upstream from Jamestown. Between the beginning of July 1997 and the end of January 1999, the average soil temperature never fell below 5°C. In a fall 1992 study of a seasonally flooded forested system located on the Virginia southeast coastal plain in Virginia Beach, Havens (1997) took weekly measurements of the 15 cm soil temperature. During the study period of September 7 to December 21, the hydric soil temperature never dropped below 5°C, and the lowest temperature measured was about 7°C.

Moving further south, in a 1996 paper, Megonigal et al. discuss hydric soil temperatures in North Carolina, South Carolina, Georgia, Louisiana, and Mississippi. The majority of the data is from their previous studies in bottomland hardwood forest soils (Faulkner and Patrick 1992, Megonigal et al. 1993). Like soils on the southeastern coastal plain of Virginia, all of the study soils are in the thermic soil temperature regime, with an assumed February to October growing season. However, the measured soil temperatures suggest a different scenario. During November, December, January, and February, soil temperatures at a depth of 50 cm never dropped to or below 5°C at any of the 34 study sites in South Carolina, Louisiana, and Mississippi. Even the shallower soil temperatures tended to remain above 5°C; 10 cm soil temperatures in a North Carolina muck almost never went below 5°C between August 1994 and September 1995, and at a depth of 15 cm in a northern Georgia bottomland hardwood forest, only 1 of 81 soil temperature measurements went below 5°C (measurements were taken during daylight hours in November, December, and January).

As mentioned earlier, wetlands and agricultural fields (such as uplands or converted wetlands) are generally different in both hydrology and vegetation. There has been some discussion in the wetlands literature about the effects of saturated soils on soil temperatures. However, I have seen no extensive discussion of the effects of different ecosystem types, forest vs. marsh vs. mono-crop corn, on soil temperatures. Clearly ecosystem type can have a great impact on both air temperatures and soil temperatures within the ecosystem. As a general example, and without considering the multiple, complex variables that come into play such as slope, aspect, and vegetation density, it can be generally stated that in comparison to a bare, open field, vegetation moderates both the temperature extremes and range a soil experiences. The same holds true for air and soil temperatures within a forest, and the forestry science literature gives many examples of the difference in air temperature and soil temperature within and outside of forests (some textbooks with examples include: Lutz and Chandler 1946, Kittredge 1948, Spurr and Barnes 1973, Pritchett and Fisher 1987). There is a great deal of variation between precise results at different study locations and in different types of forests (evergreen vs. deciduous), but some general basic trends when comparing the air temperature within a forest to the air temperature outside of a forest (in an adjacent non-forested, open area) are: 1) the annual, monthly, and diurnal air temperature ranges in the forest are lower than similar ranges outside of the forest, 2) the minimum air temperature in the forest is higher than the minimum air temperature outside of the forest, and 3) the maximum air temperature in the forest is lower than the maximum air temperature outside of the forest. For example, in a deciduous forest in Tennessee, winter air temperatures in the forest were 0.6 to 2.0°F higher in the forest than the open, and summer air temperatures in the forest were 2.1 to 3.5°F lower than in the open (Hursh 1948).

The trends for soil temperature in forests vs. open areas follow the same pattern as air temperatures in forests vs. open areas. In general, when comparing soil temperatures in a forest to soil temperatures outside of a forest (in an adjacent non-forested, open area): 1) the summer soil temperatures in the forest are lower than summer soil temperatures outside of the forest, 2) the winter soil temperatures in the forest are higher than winter soil temperatures outside of the forest, and 3) the range of soil temperatures in a forest is lower than the range of soil temperatures outside of a forest. For example, in a western white pine forest during July and August, the maximum soil temperature on the surface of the uncut forest floor was 64°F cooler than in a clear cut (158°F), and the mean soil temperature at 1 foot was 6°F less than the clear cut (60°F) (Kittredge 1948, p.158).

Further investigation of the accuracy of the wetland hydrology - growing season criteria is prompted by the results of soil temperature studies in the southeast (Megonigal et al. 1996, Havens 1997, and Strayer et al. 2000), the agricultural bias of the growing season concept, observations that wet soils are thermally different than dry soils (Hall

1920, Pickering and Veneman 1984, Stalfelt 1960), and the influences of vegetation (such as a forest) on soil and air temperature. The true length of the growing season can be critical when determining if wetlands that are primarily wet in the cooler "non-growing" season meet the hydrology criteria for federal wetland delineation and are thus jurisdictional wetlands. Due to the high specific heat of water, and based on the hydric soil studies of Pickering and Veneman (1984), Megonigal et al. (1996), Havens (1997), and Strayer et al. (2000), wetland areas in Virginia will most likely have a different soil temperature profile than non-wetland areas in both the range of soil temperatures and the length of time the soil is below biological zero. It seems likely that the thermic hydric soils in southeastern Virginia will have soil temperatures above 5°C at 50 cm for most of the year, and thus exhibit a longer growing season than either the established thermic soil regime growing season of February to October, or the growing season based on air temperatures (from tables in county soil surveys).

Ideally, to further refine and examine the growing season concept, both the microbial activity season and growing season (plant activity season) relationships to soil temperature should be determined, including measurements of soil respiration (microbial and root activity). Megonigal et al. (1996) define the microbial activity season "as the portion of the year when soils are >5°C at 50 cm." The present study focuses on the plant growing season (observations of above-ground phenologic stages such as flowering) and soil temperature (giving a microbial activity season and a growing season).

The growing season concept is critical to wetland delineation, as characteristic hydrology must occur during the growing season. Concerns with this approach have been indicated by Megonigal et al. (1996) and the National Research Council (1995). The expressed concerns in regard to accuracy and appropriateness of the definition of the growing season indicate the merit of further research in this area of wetland delineation.

OBJECTIVES AND HYPOTHSES

This study is an evaluation of the accuracy of the growing season used for federal wetland delineation in Southeast Virginia. Hardwood mineral flat wetlands, a wetland class that might be affected by an inaccurate growing season definition, were selected for the study. These wetlands are typically seasonally inundated in the late fall, winter, and early spring, and dry in the late spring, summer, and early fall. Three parameters -- soil temperature, plant activity, and hydrology -- were measured on a total of seven study plots at four locations on the coastal plain of Southeast Virginia (Figure 1). The study period covered three winters, starting in October 1999 and ending in March 2002. Soil temperature and hydrology were measured for the entire study period, while data on plant activity was collected from October 1999 to April 2000.

Objectives

The objectives of this study were to:

- Determine if the thermic soil temperature regime growing season of February to October is valid for hydric soils in southeast Virginia.
- Determine if the growing season, as estimated from air temperatures in the county soil surveys, is valid for hydric soils in southeast Virginia.
- Determine if wetland soil temperatures in hardwood mineral flats fall below 5°C at a depth of 50 cm (biological zero), and if so, for how long.
- Determine if wetland soil temperatures in hardwood mineral flats fall below 5°C at a depth of 10 cm, and if so, for how long
- Establish the growing season based on soil temperatures at a depth of 50 cm.
- Establish the plant activity season (based on observations) and compare it to the microbial activity season (as defined by Megonigal et al. 1996 – equivalent to the technical definition of the growing season).

- Evaluate the degree to which the soil temperature range and extremes vary along a hydrologic gradient of drier to wetter hardwood mineral flats.

- Compare the soil temperature range and extremes at 10 cm and 50 cm within and between sites.

Hypotheses

H_1: Based on soil temperatures (>5°C at 50 cm), the thermic soil temperature regime growing season of February to October in SE Virginia wetland soils will be invalidated.

H_2: Based on soil temperatures (>5°C at 50 cm), the currently accepted growing season for SE Virginia wetland soils, as estimated from air temperatures (county soil survey tables), will be invalidated.

H_3: The measured growing season (based on soil temperatures above 5°C at 50 cm) will be longer than the thermic soil growing season of February to October.

H_4: The measured growing season (based on soil temperatures above 5°C at 50 cm) will be longer than the currently accepted wetland delineation growing season, as estimated from air temperatures (county soil survey tables).

H_5: The observed plant activity season will be longer than the thermic soil growing season of February to October.

H_6: The observed plant activity season will be longer than the currently accepted wetland delineation growing season, as estimated from air temperatures (county soil survey tables).

H_7: The microbial activity season (as defined by Megonigal et al. 1996) will be longer than the observed plant activity season.

H_8: Wetter sites will have warmer winter soil temperatures than drier sites.

H_9: Wetter sites will show less annual soil temperature variation than drier sites.

LITERATURE REVIEW

Hardwood Mineral Flat Wetlands

Hardwood mineral flat wetlands are primarily located east of the Suffolk Scarp on the flat, coastal plain of Virginia and northern North Carolina (Rheinhardt and Rheinhardt 2000). They are seasonally wet, deciduous, forested wetlands, also known as winter wet woods (Silberhorn 1999), wet flats, and flatwoods (Harms et al. 1998). Hardwood mineral flats have hydric mineral soils (not organic), are located on flat, interfluvial areas with no drainage patterns, and are not influenced by streams or rivers (Fleming and Sandifer 1997, Rheinhardt and Rheinhardt 2000).

Like other wetlands in the flats hydrogeomorphic (HGM) classes such as pocosins or wet pine flats, the primary source of hydrologic input to hardwood mineral flats is precipitation (Smith et al. 1995, Havens et al. 2001, Rheinhardt et al. 2002). Groundwater inputs to hardwood mineral flats are minimal. Evapotranspiration (ET) is the dominant hydrologic output, though there may also be slow export of water via lateral surface and subsurface flow. Due to the extremely low mean surface gradient (a mean slope = 0.2% was measured on reference sites for the hardwood mineral flat HGM guidebook), surface and subsurface flow would clearly be quite slow (Havens et al. 2001). Rates of subsurface and surface flow are probably similar to the rates for wet pine flats mentioned in Rheinhardt et al.'s regional wet pine flat HGM guidebook (2002). Although there is little detailed data on the hydrology of wet pine flats, the guidebook gives a subsurface hydraulic conductivity rate of 10-12 cm/day (Riekirk 1992), which is extremely low, and a surface flow rate of 20-80 cm/hour (Carlisle et al. 1981), which is faster but still fairly low. In addition to slow rates of lateral flow, hardwood mineral flats usually have poor vertical drainage, due to a constraining layer such as a hardpan or clay rich soil horizon.

Because hardwood flat hydrology is dominated by precipitation and ET, the primary hydrodynamic is vertical fluctuation, with the water level at a given time determined by the balance between precipitation and ET. (Figure 2 shows the result of annual precipitation minus potential evapotranspiration for Williamsburg, Richmond, and Norfolk.) This explains the common name of winter wet woods; when ET is less than precipitation, the site is saturated or inundated. During the winter and early spring when deciduous vegetation is bare and weather is cooler, hardwood mineral flats tend to have saturated or inundated soils. Once the vegetation leafs out and the weather warms up, water level drops. Examples of hardwood mineral flat hydrographs are in Appendix B. In Appendix B (1) the groundwater hydrographs for the period February 1999 to January 2000 (in plots Oct 1998 – Sept 1999 and Oct 1999 – Sept 2000) for the Elmington research site show a typical hydrograph for a hardwood mineral flat wetland. As illustrated by the graphs in Appendix B, there can be considerable variability in the level of the water table during the fall. Although this is generally a time of lower groundwater levels in hardwood flats, heavy precipitation associated with hurricanes can cause the water table to rise rapidly.

Small changes in elevation on the low gradient coastal plain result in changes in hydrology, soil, vegetation, and landform type. In their discussion of flatwoods (non-hydric soils) and associated landforms (flats, depressions, floodplains, and rises/knolls) along the South Atlantic and Gulf coasts, Watts et al. (2001) describe changes in elevation from 8 to 30 cm between landform types. Breaks between landforms are not always easy for the untrained eye to discern, and since subtle elevation changes result in landform changes, it is not surprising that hardwood mineral flats are found in association with depressions (personal observations 1998). For example, on the Seaford Elementary research site (York County, Virginia) used in this study, depressional wetlands are immediately adjacent to hardwood mineral flats. Similarly, Reinhardt et al. (2002) found forested depressions interspersed within wet pine flats.

Initial surveys of hardwood mineral flat sites in Virginia for a HGM model (Havens et al. 2001) indicate a common suite of species across the study area, ranging from the most southerly sites in the Dismal Swamp, to the most northerly site located east of Gloucester on Elmington Plantation. Vegetation is characterized by hardwood trees such as oaks (*Quercus lyrata, Q. phellos, Q. michauxii*), black gum (*Nyssa biflora*), sweet gum (*Liquidamber styraciflua*), and red maple (*Acer rubrum*), with some loblolly pine (*Pinus taeda*) (less than 50%); a key component distinguishing hardwood mineral flats from fire-suppressed wet pine flats is the presence of oaks (Rheinhardt et al. 2002). Rheinhardt and Rheinhardt (2000) found similar species in their study of wet hardwood flats in eastern North Carolina and southeastern Virginia. While hardwood flats as a whole have a similar suite of vegetative species, both the Havens et al. (2001) and Rheinhardt and Rheinhardt (2000) studies noted considerable variation in species between sites. For example, while scouting research plots for the Virginia HGM study, we observed that cane (*Arundinaria gigantea*) is quite common in the Dismal Swamp, but is not present on sites north of the James River (pers. obs. 1998).

There are not many studies or documentation of hardwood flats, which Harms et al. (1998) attribute to their low economic importance, sometimes small size, and wide dispersion. However, the sites tend to be very diverse in terms of both species (plants and animals) and ages (trees) and more research is needed to understand these systems (Harms et al. 1998). More information is available from recent studies of hardwood mineral flats by researchers at the Virginia Institute of Marine Science (Havens et al. 2001) and at East Carolina University (Rheinhardt and Rheinhardt 2000).

Rationale for Using Hardwood Mineral Flat Wetlands

Hardwood mineral flat wetlands are a good candidate for evaluating the validity of the current hydrology - growing season linkage, as jurisdictionally they are more marginal wetlands, especially if they are delineated in summer when the water tables are lower. Hardwood flat wetlands in Virginia tend to be inundated in the winter, which is currently not completely within the thermic February to October growing season (or the growing season estimated from air temperatures). Therefore, it is important to establish when the hydric soils are above 5°C at 50 cm, as well as when the wetlands are truly functional in terms of microbial activity and plant activity.

In addition to jurisdictional issues, Virginia's hardwood mineral flats are threatened by development (Silberhorn 1999). Many of the research sites are clearly small remnants of larger complexes. Rapid development in the Hampton Roads area threatens these wetlands, as they have little protection. At the beginning of this study in 1998/99, Virginia had no non-tidal wetland legislation, and federal protection was weak. Until Virginia passed non-tidal wetland legislation the sites could be ditched and drained without a permit.

Summaries of the natural driving forces and anthropogenic impacts to wetland flats on the south Atlantic coastal plain are found in Rheinhardt and Reinhardt (2000), Rheinhardt et al. (2002), Rheinhardt et al. (1997), and Ware et al. (1993). Due to impacts from development, agriculture, and silviculture, there are no virgin stands of hardwood mineral flats. Current hardwood mineral flats are at a minimum second or third growth, and tend to be less than 100 years old. Some sites show relict agricultural furrows, but most original forest microtopography was destroyed (for example pits and mounds).

The hardwood mineral flat sites used in this study have experienced alteration through ditching, agriculture, forestry activities, road building, and development. As a result, the sites are expected to show a range of hydrologic signatures from wetter to dryer, in terms of duration and frequency of saturation, as well as depth to the water table. Therefore, it should be possible to discern how the soil temperature varies along a hydrologic gradient, and by using the same type of wetland, eliminate or minimize some of the factors that would effect soil temperature such vegetation variation, wetland type, and the source of hydrologic input.

Soil Temperatures

There are several reasons why wet, forested soils are expected to show a different soil temperature profile and seasonal signature than drier, agricultural lands. Stalfelt (1972) discusses some of the important effects of vegetation. Because the vast majority of the soil heat is from solar radiation, vegetation that blocks radiation will reduce summer soil temperatures. Vegetation also reduces the diurnal temperature changes, with higher lows and lower highs. The vegetation is a buffer between the atmosphere and the soil – incipient radiation on the plants is reflected or adsorbed, then reradiated, stored, or utilized in transpiration and evaporation. Vegetation still has a similar effect when it dies and forms a litter layer, since litter layers tend to buffer temperature changes. Based on the buffering effects of vegetation and litter, the hardwood flat soils are likely to have a less extreme diurnal as well as seasonal temperature variation than agricultural soils.

The water content of soil also has a significant effect on soil temperature. Water has a much higher specific heat (the number of calories needed to raise the temperature of 1 gram by 1°C) than soil (Stalfelt 1972, Foth 1984), so it takes more energy to warm up a wet soil than a dry soil. As a result, wet soils tend to warm more slowly in the spring. However, wet soils tend to display a smaller range of temperature variation than drier soils, as noted in a Central Massachusetts study by Pickering and Veneman (1984). In addition, their study found that the temperature buffering effect of wet soils allowed biochemical activity in the winter. Because the hardwood flat soils are wet in the winter, a similar buffering effect due to high heat capacity should keep the soils biologically active in the fairly mild SE Virginia climate.

Growing Season

The definition of the temperature of biological zero as 5°C or 41°F seems to be generally consistent (Hall 1920, Environmental Laboratory 1987, Soil Survey Division Staff 1993), with the implication that below this level plant and/or microbial activity is negligible. However, the question remains as to why 5°C or 41°F is the critical temperature. While searching the literature, I did not find the exact origin and rationalization for selecting 5°C as the critical temperature for biologic zero, but an agricultural origin is the most likely. Hall's 1920 book, The Soil: Study of the Growth of Crops, states in Chapter 5:

> "The life of a plant is practically suspended below a certain temperature, which is about 41°F for the majority of cultivated plants; all the various changes which are essential to the development of the plant, such as germination, vegetative activity, and the bacterial processes in the soil, show a similar dependence upon temperature."

However, he then goes on to state that the critical temperature "is not always the same, but may be considered to lie between 40° and 45°F for most plants grown as crops in this country." The table that follows this statement includes minimum temperatures of growth for some crops: Mustard, 32°F; Barley, 41°F; Wheat, 41°F; Maize, 49°F; Kidney Bean, 49°F; and Melon, 65°F. It seems rather significant that the minimum temperature for two important grain crops, wheat and barley, is 41°F, the same as the current temperature definition of biological zero.

Clearly temperature has significant effects on biological, chemical, and physical properties and rates (Stalfelt 1972, Foth 1984, Paul and Clark 1996). However in addition to other authors, Megonigal et al. (1996), Bedford et al. (1992), and the 1995 report by the National Research Council (NRC) question the growing season concept when applied to hydric soils and wetlands. The NRC report states:

> "The implied assumptions are that plants and soil organisms are uniformly active over the growing season and uniformly inactive and that the growing season can be defined by a standard convention for regions of widely differing climate. These assumptions are unrealistically simple, and they can lead to errors in evaluating hydrologic data."

In addition, microbes are the critical force in creating a reducing environment (NRC 1995), and thus wetland soils and conditions. Yet the growing season was designed for indicating what agricultural crops a soil could support, and it is not necessarily appropriate to assume that it can be used to define the time frame of microbial processes (Megonigal et al. 1996) or native wetland plants.

The NRC report (1995) references at least 20 papers which give examples of microbial and biological activities below 5°C. The growing season concept is particularly troublesome for arctic, alpine, and montane areas and species that are active below biological zero. The NRC report (1995) also notes that using the frost-free period to define the growing season can be troublesome because of areas such as the arctic with few frost free days. In addition, there can be a great deal of yearly variation in the number of frost free days for an area (Bedford et al. 1992).

There are many indications that the application of the current growing season definition (Soil Survey Staff 1999b, Environmental Laboratory 1987) to wetlands may not be the most accurate evaluation of actual time periods of microbial and plant activity. Comparing the results of applying the technical definition of the growing season to a suite of hardwood mineral flat wetlands (by monitoring soil temperature at 50 cm) to observations of the plant activity season (observing vegetative and reproductive growth) may help clarify some of the growing season issues.

SITE SELECTION AND DESCRIPTION

The seven plots in this study are a subset of the sites used for the hardwood flat HGM (hydrogeomorphic) model (Havens et al. 2001) developed at the Virginia Institute of Marine Science (VIMS), and are located on the southeast Virginia coastal plain in Gloucester County, York County, and the City of Hampton (Figure 1). Distance between the furthest north plot and furthest south plot is approximately 40 miles. The seven plots were selected for this study for three reasons: 1) proximity to VIMS to facilitate frequent evaluation of plant activity (on an approximately weekly basis during fall 1999 and winter and spring 2000), 2) reasonable geographic coverage to provide better characterization of hydric soil temperatures on the coastal plain of southeast Virginia, and 3) observations indicated that the sites differed in their periods of inundation and saturation, allowing an examination of the effects of water table levels on soil temperature along a hydrologic gradient.

The possible hydrologic alterations to the research sites (caused by human activities) include alterations that could lead to increased draining of water or decreased inputs (relict furrows, ditching, younger trees due to forestry, breaking up wetland/landscape complexes), as well as alterations that could increase water retention (damming of water from roads or overpasses, increased surface water input from road surfaces). Elmington has ditching and relict furrows (draining the site) and is bounded by a paved road on one side (ponding/daming). Coleman Swamp 1 has ditching (draining the site), somewhat younger trees than other sites due to forestry activities (possible increased water level due to decreased evapotranspiration), and a dirt road on one side. Coleman Swamp 2 has ditching on both sides and a dirt road on one side. The Seaford sites have large central mosquito control ditches and smaller side ditches draining the site, although the forest complex is one of the larger undeveloped forested acreages in the area. Seaford 2 was placed closer to one of the main ditches than Seaford 1 in an attempt to set up another paired set of sites (one wetter and one drier) in the same location. Sandy Bottom 1 and Sandy Bottom 2 are located in Sandy Bottom Nature Park, which is right next to Interstate 64 and an overpass for a smaller road, and each site is bounded by raised paved roads and/or overpasses on two sides. Sandy Bottom 2 also has some ditching. In addition, the sites represent the edge of a larger hardwood flat complex that was fragmented by the road system. Sandy Bottom is not a pristine site – the park was used as a source of fill for road construction and also served as a dump site prior to its reincarnation as a park. However, the two small research plots are actually some of the older (tree age and size) hardwood flat sites.

I expected to see a range in hydrology along the sites from observations and data collected prior to the start of the study. I thought that Elmington, Coleman Swamp 1, Seaford 1, and Sandy Bottom 1 would tend to be wetter than the other geographically paired sites of Coleman Swamp 2, Seaford 2, and Sandy Bottom 2 (no pair for Elmington).

DATA COLLECTION

Hydrology

Each site was instrumented with an automatic groundwater monitoring well for continuous readings of groundwater levels. Later in the study, the time period between readings was changed from an initial period of 1 hour to 3 hours, and then to 6 hours. The longer time period between readings reduced the frequency at which the well data had to be downloaded from three weeks to several months. The wells on the seven study plots were installed during the winter 1999, early spring 1999, and January 2000. The 101.6 cm long (40 inch) Remote Data Systems wells (WL 40) record groundwater level as well as surface inundation from approximately 15 to 25 cm (6 - 10 inches) above the soil surface to approximately 76 – 86 cm (30 – 34 inches) below the soil surface. The recording probe fits into a slitted PVC sleeve/well screen; coarse sand was packed around the screen to ensure that the screen does not get clogged. Clay was used to seal the PVC sleeve at the interface between the soil surface and sleeve, to prevent seepage of surface water inputs (such as precipitation) along the sleeve and thus avoid incorrect water level readings.

Plant Activity – Vegetation Data

The period of plant activity was determined by monitoring the vegetation on all sites from Fall 1999 to Spring 2000. Four strata were monitored – trees, saplings, shrubs, and herbs – but only three strata (all but the herb layer) were analyzed. The herb layer was extremely variable between sites, as many sites had little vegetation in the herb layer, and the data collection method was not consistent or adequate, so the herb data is not presented or analyzed.

Dominant Species

Vegetation surveys of the tree, sapling, and shrub strata were completed in September and October of 1999. On each site, one 10 m radius plot was centered on the groundwater well. Measurement parameters for each stratum are summarized in Appendix A (6) and follow the 1989 manual (Federal Interagency Committee for Wetland Delineation 1989), as the '89 manual is generally regarded as being more scientifically sound. The total number of each species within the 10 m radius plot was tallied for the tree, sapling, and shrub strata. For each stratum, species percent frequency was determined for each site, as well as across all sites. The proportion of sites with each species was also determined. For the tree stratum, the Bitterlich method (prism) with a BAF = 10 was also used to confirm species importance - again using the well as the evaluation center point (BAF = basal area factor).

To facilitate comparisons between the sites, the dominant species that were present on at least 2/3 of all the hardwood flat sites were identified. The dominant and/or common species are 1) tree strata – red maple (*Acer rubrum*), sweet gum (*Liquidamber stryraciflua*), and black gum (*Nyssa sylvatica*); 2) sapling strata – red maple, sweet gum, and black gum; and 3) shrub strata - sweet pepperbush (*Clethra alnifolia*) and highbush blueberry (*Vaccinium coryumbosum*). Data from the site surveys is summarized in Appendix A (1 & 2) for saplings, Appendix A (3 & 4) for trees, and Appendix A (5) for shrubs. Data from two plots in the Dismal Swamp are included in the summaries. These two sites were originally considered for the study, but were replaced by other sites.

Site Set-up

Seven individuals of each of two species of trees (i.e. 7 red maple and 7 sweet gum), two species of saplings, and two species of shrubs were monitored on each site, for a total of 14 individuals per stratum and 42 individuals per site. If the two dominant species common to hardwood flats were present on a given site, those species were selected for monitoring. If any of the three dominant flat species were not present on an individual site, the most dominant species (and then next most dominant) on that site was used in place of the missing species. Deciduous species were selected for monitoring, unless a particular site did not have deciduous species in a stratum, such as the shrub strata at the Coleman Swamp 2 site.

The species selected for monitoring on the sites were: 1) trees – red maple and sweet gum (found on all sites) and 2) saplings – red maple (on all seven sites), sweet gum (on six sites), and sourwood (*Oxydendron arboreum*) to replace absent sweet gum at Seaford 1. The shrubs were a bit more complex, as sites sometimes had very few shrubs, no deciduous shrubs, or none of the most common shrub species. The selected species were blueberry (on five sites – Coleman Swamp 1, Seaford 1 & 2, and Sandy Bottom 1 & 2), sweet pepperbush (on three sites – Seaford 1 and Sandy Bottom 1 & 2), paw paw (*Asimina triloba*) and spicebush (*Lindera benzoin*) at Elmington 1, and two non-deciduous shrubs, wax myrtle (*Myrica cerifera*) and red bay (*Persea borbonia*), at Coleman Swamp 2.

Using the site groundwater monitoring well as starting point, the tree (or shrub/sapling) closest to a randomly selected direction (0 to 365 degrees) and distance (maximum distance of 30 m for trees/saplings and 20 m for shrubs) was selected and marked with a numbered tag. Paces (7 paces = 10 m) were used to estimate the distances, as tape measures were found to be inefficient and sometimes difficult to use (on sites with dense vegetation). DBH (diameter at breast height) was measured for trees and saplings. Strata parameters for set-up were a little different than those used for the vegetation surveys and are a compromise of the parameters for the '87 and '89 manuals [see Appendix A (6)]. For Coleman Swamp 1, establishing the site was very difficult due to the thick green briar (*Smilax sp.*), so a modified method was used to select individuals. All sites except Seaford 2 were established in the fall of 1999 before leaf drop. Seaford 2 was added later and established in February 2000.

Monitoring

Vegetation was monitored on an approximately weekly basis during the spring and fall to determine periods of plant activity and dormancy. Fall data collection dates are summarized in Table 3. In the fall, woody plants were evaluated for percent leaf color change (green to red/brown etc.) and percent attachment. Categories for color change were *none, bit, 0-25%, 25-50%, 50-75%, 75-100%, all,* and *n/a (when the trees were bare of leaves)*. Categories for leaf attachment (percent on) were *all, most, 100-66%, 66-33%, 33-0%,* and *bare.* Fall monitoring began in late October, and continued until all monitored individuals in each stratum were bare or nearly bare of leaves.

Spring monitoring began in early January, well before the last killing frost, as red maples in the study area have been observed to flower very early (Silberhorn 1999, pers. comm.). Spring data collection dates are summarized in Table 3. Individuals were evaluated for signs of vegetative or reproductive growth such as bud swelling, bud color change, stem growth or color change, flowering or fruiting, and leaf emergence. Spring vegetation monitoring continued until all monitored tree, sapling, and shrub individuals leafed out. Binoculars were used to look for changes in the taller species.

Soil Temperature

Soil temperatures from fall 1999 to spring 2002 were monitored using Onset HOBO continuous data recorders, placed in waterproof containers. At each site, soil temperature was recorded hourly at soil depths of 10 cm and 50 cm; one soil recorder was placed at each soil depth, for a total of two soil recorders on each site. The 10 cm depth is within the rooting zone of wetland species, which usually have the majority of their roots in the upper 30 cm of the soil (National Research Council 1995). The 50 cm depth is both part of the growing season definition (Soil Survey Staff 1999b), as well as the depth at which the daily temperature fluctuations are barely observable (Soil Survey Division Staff 1993). To keep soil disturbance to a minimum, holes for the temperature recorders were dug with a soil auger (the auger made a hole not too much larger than the waterproof case) to only the depth needed. The soil from the hole was carefully stockpiled in stratigraphic sequence, and then packed back into the hole around and on top of the temperature recorder. For the purposes of the study, soil depth was measured from the top of the first mineral horizon rather than the top of the soil, to ensure consistency between sites, as the O horizon thickness would fluctuate over the course of the year and is very porous.

Soil recorders were located at least one meter from, but within a few meters of, the groundwater wells (random distance and direction from the well, with adjustment for obstacles such as tree roots). To avoid replacing recorders in previously disturbed soil in later deployments (after first retrieval), the random direction and distance were adjusted as necessary. Since all of the sites were near populated areas, no obvious, visible signs of the buried recorders (such as a flag) were left on the site. Thin cord was tied from the cases to the base of reference trees to facilitate retrieval, and the distances and directions from the well and trees were recorded. Reference pictures with temporary flags above the recorders were also taken for back-up. All the soil temperature recorders were successfully retrieved during the study.

Since the waterproof cases for the soil temperature recorders are about 10 cm long and 5.5 cm wide (vs. a narrow probe), it was not possible to place the cases at exactly (and only) the desired soil depths. Figure 12 shows the placement of the soil temperature recorders, which were placed such that the measurement bias/error was to shallower soil depths (shallow depths generally would mean colder winter soil temperatures). The waterproof cases are located so that the center of the HOBO recorder (in the waterproof case) falls at the desired soil depth (10 cm or 50 cm).

The soil recorders were deployed, retrieved, and downloaded four times between November 1999 and March 2002. Deployment periods ranged from five to nine months, and intervals between deployments were only one to two days, giving an almost continuous temperature record. The same recorder was used at each study site and soil depth throughout the Fall 1999 to Spring 2002 data collection. One recorder was replaced when the case leaked in May 2000.

To get a sense of within-site variability of soil temperature, two research sites were evaluated using a hand held soil thermometer. On each site in January 2001, at several locations on each site, temperature measurements were taken at a depth of 20 cm. The thermometer was left in the soil for 5 to 15 minutes for each measurement to ensure an accurate measurement. The two sites were Elmington 1 and Seaford 2.

Air Temperature

Air temperature at each site was recorded hourly at approximately 1.3 meters above the soil surface. Taking the air temperature at 1.3 m above the surface ensured that the temperature recorder was above the highest anticipated water level. To minimize heating effects from solar radiation and protect the recorder from weather (rain and snow), each Onset HOBO continuous temperature recorder (which was in a clear, locking plastic case) was placed (tied) on the north or east side of an average size tree in a white housing, within a few meters of the groundwater well (direction from well was randomly selected). The housing was constructed from a section of white PVC pipe (to reflect vs. absorb solar radiation) with an open bottom, a white painted fiberglass top, and ventilation holes along the side. Recorders were deployed, retrieved, and downloaded on the same schedule as the soil temperature recorders. Some of the air temperature recorders (Coleman Swamp 2 and Seaford 1) were destroyed during the study by vandals.

Soils

Descriptions of the soil profiles at each site were completed by other researchers for the VIMS HGM flats model (Havens et al. 2001). Soil profiles were described from the surface (0 cm) to about 100 to 130 cm deep, and are summarized in Table 10, with soil horizons displayed in Figure 18.

DATA ANALYSIS

Temperature Data

Air and Soil Temperature Data Graphs

The available records of 10 cm soil, and 50 cm soil temperatures for each site are graphed for 1999 to spring 2002. Two representative air temperature graphs are also shown for the same time period in Appendix F (1 & 2). 10 cm depth soil temperature graphs are in Appendix E and 50 cm depth soil temperature graphs are in Appendix C.

50 cm Soil Temperature

Non-Growing Season

Soil temperature records for each of the four deployment periods (A, B, C, and D) were analyzed using a m-file in MATLAB. To avoid losing data during the cold part of the year, recorders were usually not launched or retrieved during the winter months. However, there are data gaps in January 2001 between Deployments B and C. The data loss was minimized by removing half of the temperature recorders (SF1, SF2, SB1, and SB2) in early January, and the other half (EL1, CS1, and CS2) in late January.

To ensure that that the soil temperature records were accurate, and to have consistency between sites, some data points were removed from the ends of the raw records. For example, the analysis records usually start about 12 hours after the raw records, to give the soil column and water table time to settle after the disturbance of the soil profile (when the recorder hole is dug and then repacked).

To determine the growing season, first I determined the non-growing season (the period when the temperature was at or below 5°C at a depth of 50 cm). Soil temperature records at 50 cm were analyzed to determine: 1) the total number of hours (data points) at or below 5°C and the equivalent in days; 2) the first and last time the temperature was at or below 5°C; 3) the length of the non-growing season; and 4) the magnitude and first occurrence of the maximum and minimum temperatures. For the range of soil temperatures found on the research sites, the HOBO recorder accuracy is ± 0.7°C (extrapolated from the Onset Company's HOBO error and accuracy graphs). To account for this error, two new records were created from each original record by adding and subtracting 0.7°C to all the original data points. Then the new records, MIN (+0.7°C) and MAX (-0.7°C), were analyzed for the non-growing season parameters. Adding 0.7°C to the records leads to a shorter cold period (MIN), and subtracting 0.7°C leads to a longer cold period (MAX). The non-growing season for the original unmodified records is also shown in Appendix C as the area below the 5°C reference lines. In some cases, even if the original record did not drop below 5°C, the altered MAX record did have temperatures below 5°C.

The analysis described above provided data on the Fall 1999 – Spring 2000 non-growing season (deployment A) and the Fall 2001 – Spring 2002 non-growing season (deployment D). To determine the Fall 2000 – Spring 2001 non-growing season, the January 2001 data gap between deployments B and C was analyzed. Since half of the sites are missing data in early January (SF1, SF2, SB1, SB2) vs. late January (EL1, CS1, CS2), it was possible to extrapolate the behavior of the soil temperature during the missing periods, by 1) looking at the trends before and after the gap and 2) by comparing the trends of other sites. The estimation was conservative (colder vs. warmer), and was then combined with the analysis of deployments B and C to determine the Fall 2000 to Spring 2001 non-growing season.

The difference in the length of the non-growing season (NGS) calculated from the regular 50 cm soil temperature records (as measured) and the 50 cm MAX soil temperature record (-0.7°C) ranged from 0 to 6.29 days for deployment A (1999 – 2000), about 0 to 30 days for deployment B - C (2000 – 2001), and 0 to 0.1 days for deployment D (2001 – 2002). Since even the MAX NGS are months shorter than the accepted growing season (GS), I used the conservative estimate (MAX NGS) to determine the GS lengths for the sites. The maximum non-growing season lengths are listed in Table 4.

Growing Season

The growing season (GS) length for each period was calculated from the measured non-growing season (basically 365 days – NGS). The GS starts when the NGS ends, and ends when the NGS starts. Table 5 lists the measured growing seasons (MeaGS) and estimated growing seasons (EstGS from air temperature records – county soil survey tables), and Figure 7 shows the MeaGS and EstGS. Table 8 lists the average MeaGS for each site, county, and year.

10 cm Soil Temperature

Non-Growing Season

In addition to measuring the 50 cm soil temperatures to determine the growing season as defined for wetland delineation (temperatures ≤ 5°C at a depth of 50 cm), the soil temperatures at a depth of 10 cm were also measured on each site. Since wetland plants tend to have shallow roots due to the anoxic, saturated soils, the shallow soil temperature will also impact the wetland organisms. The 10 cm non-growing season (NGS) was calculated using the same temperature threshold and method used for the 50 cm NGS. Graphs in Appendix E show the original, unaltered 10 cm soil temperature data, and the area below the 5°C reference line is the regular measured NGS. Table 6 lists the MeaNGS (as with the 50 cm NGS, the most conservative estimate was used, which is the MAX NGS).

Growing Season

The "growing season" based on the 10 cm soil temperatures was calculated with the same methodology used for the 50 cm soil temperature growing season. Since the wetland delineation growing season has a specific definition of soil temperatures above 5°C at a depth of 50 cm, it is more appropriate to refer to the 10 cm "growing season" as a "shallow microbial activity season" (modifying the microbial activity season as defined by Megonigal et. al 1996). Results are in Table 7.

With-in Site Soil Temperature Variability

Within-site soil temperature variability at a depth of 20 cm in January 2001 was only 0.2 to 0.3°C, well within the measurement error for the temperature recorders of ± 0.7°C. Therefore, it is unlikely that the location of the temperature recorders within a site would mask differences between sites, and this will not be a factor in the analysis of the temperature data.

Hydrology

Temperatures and Water Levels

To determine the relationship between the groundwater level and winter soil temperatures, the average minimum 50 cm temperature and average water level were calculated for each site for Winter 2000 (Dec 1999 to Mar 2000). Values are listed in Table 9. Months missing a significant number of data points for either water level or soil temperature for a site were not included in the analysis. Some wells extend deeper into the soil than others (not all the wells were set into the soil with exactly the same amount of the probe below the soil surface), so to avoid bias in the well record, the maximum recordable groundwater depth below the soil surface was set to –70 cm. Readings below this depth were changed to –70cm.

Relative Wetness of Sites

Two methods were used to rank the sites in terms of relative wetness (wetter to drier sites). First, average monthly groundwater levels were used to rank the monthly relative wetness of the sites for December 1999 to March 2000. Second, visual examination of the site hydrographs in Appendix B were used to do a subjective ranking of winter and summer wetness. Factors considered were depth of the water table, length of inundation, and variability of the water table. Ranks are in Table 9.

Vegetation Data – Plant Activity Season

The selected specimens in the three vegetation strata (shrub, sapling, and trees) on each site were each evaluated at approximately one-week intervals in the spring, and two-week intervals in the fall. Since it was usually not possible to check all the sites on the same day, the results of each data collection were grouped into evaluation periods. Each evaluation period was usually 2 to 3 days long. Table 3 lists the specific dates of data collection for each site, as well as the dates included in each evaluation period.

Plant Activity Season

For this study, the plant activity season is the period in which the above-ground portion of plants show evidence of plant activity – simply that the plant is still active and not in winter senescence. In the fall, I looked for evidence that the plants were not active (ex: leaf drop), to define the end of the plant activity season. In the spring I looked for evidence that the plants were active (ex: flowering or bud swelling), to define the beginning of the plant activity season. Different phenologic stages (PS) were analyzed to characterize the time period of each stage (such as red maple flowering). Since the data are nonparametric, the primary period of activity for a PS is defined by the median, first quartile, and third quartile. Onset and cessation of a PS is characterized by the minimum and maximum of the data set. The descriptive statistical analysis was done using Minitab.

In addition to characterizing the time period of the phenologic stages, I also looked for differences and similarities in the timing of PS between strata and species. Timing of the PS for significantly different subgroups (for example: leaf out in red maple saplings vs. red maple trees) was then determined. Data analysis was done in Minitab at the 95% confidence level using two nonparametric tests, the Mann – Whitney Confidence Interval Test (nonparametric analog of a t-test) and the Kruskal – Wallis Test (nonparametric analog of a 1-way ANOVA). Since the Mann – Whitney test is a stronger test than the Kruskal – Wallis (K-W), it was used preferentially when comparing two data sets, and the K-W was used when comparing more than two data sets. Unlike an ANOVA, it is not possible to do ad-hoc comparisons between factors using K-W. Therefore, to determine which factors are grouped together when a K-W analysis shows a significant difference between groups of factors, the summary results for each factor will be first be examined (median, average rank, and Z score) to look for similarities and differences between groups. Next, the likely groupings will be checked with another K-W test (with the most unlike factor or factors removed).

Fall Analysis

The fall data set was fairly small compared to the spring data set, and the infrequent data collection made it hard to track some of the changes closely. In order to get a sense of the rate of color change and leaf drop, the two categories evaluated are 1) first observation of color change of 50% or more and 2) first observation of leaf attachment of 66% or less. Based on these above-ground observations, an ending date for the plant activity season can be established.

For fall tree and sapling analysis, only sweet gum and red maple data were included in the analysis. The sourwood data (a substitute species for sweet gum saplings) was not used.

Spring Analysis

Spring categories selected for analysis are: 1) first observation of enlarged buds (all three strata except for Seaford 2 site, as it was established after bud enlargement had started), 2) time of leaf out (all three strata), 3) first observation of fruit set (red maple, blueberry, and sweet gum), 4) first observation of flowering (red maple, blueberry, spicebush, and sweet gum), and 5) time of main flower buds opening (spicebush and blueberry). The start of the plant activity season will be established from the PS analysis. Not all of the collected data was consistent enough for analysis, primarily due to the unfamiliarity of the observer with some phenologic stages. For example, I missed some of the bud and stem color changes.

RESULTS

Temperature Data

Air and Soil Temperature Data Graphs

The available records of 10 cm and 50 cm soil temperatures for each site are graphed for fall 1999 to spring 2002. Two representative air temperature graphs from the geographic extremes of the study area (north to south) are also shown for the same time period in Appendix F (1 & 2). 10 cm depth soil temperature graphs are in Appendix E and 50 cm depth soil temperature graphs are in Appendix C.

An example of the typical relationship between air, 10 cm soil, and 50 cm soil temperatures is shown in Figure 3 for the period October 2000 to September 2001 at Elmington. As expected, the air temperature has the most diurnal and annual variation, and is both colder and warmer than the soil temperatures. The soil temperature tracks the air temperature – but is warmer in the winter and cooler in the summer, and for part of the spring and fall is about the average air temperature. The soil temperatures show much less diurnal and annual variation than the air temperature. However, the shallow soil temperature has more annual and diurnal variation than the deeper soil temperature. In addition, the shallow soil temperature has higher and lower temperature extremes than the deeper soil temperature.

50 cm Depth

Non-Growing Season

Not all of the sites experienced soil temperatures below 5°C - and in fact each winter the rate was 50% or less. In Winter 2000 only 3 of 7 sites (EL1, CS1, SF1) had 50 cm soil temperatures below 5°C, and the same held true for Winter 2001, with the same 3 sites again experiencing soil temperatures below 5°C. In Winter 2002, 2 different sites (CS2 & SB1) of the 7 had 50 cm soil temperatures below 5°C. The calculated non-growing season (NGS) length, start time, and end time for each site during the three winter seasons (2000 to 2002) are listed in Table 4. Temperatures below 5°C occurred in late December, and throughout January and February.

Growing Season

There is a striking difference between the length and time of the measured growing season (MeaGS) and the estimated growing season (EstGS). When using Method A to calculate the MeaGS (MeaGS = 365 days – length of NGS), the MeaGS ranges from 308 to 365 days long, 82 to 140 days longer than the EstGS calculated from the air temperatures and found in the county soil survey tables (Table 5). The EstGS for Gloucester and York Counties is 226 days (Soil Conservation Service 1980 and 1985), and the EstGS for Hampton is 264 days (National Water and Climate Center 2003).

The average MeaGS over the three years of soil temperature measurements (1999 to 2002) for each site ranges from a low of 336 days for Elmington, to a high of 365 days for Seaford 1 and Sandy Bottom 1 (Table 8). For the counties, the three year average MeaGS ranges from 348 days for Gloucester County to 364 days for Hampton. There is also variation in the yearly average MeaGS across all sites. For 1999 - 2000 the length is 355 days, for 2000 - 2001 the length is 348 days, and for 2001 - 2002 the length is 364 days.

Using Method B to calculate the length of the MeaGS (MeaGS = 365days - #days below 5 deg C for one calendar year), MeaGS were calculated for year 2000 and year 2001 (Table 8). The 2000 MeaGS ranged from the shortest length of 336 days for EL1 to the longest length of 365 days for four sites. Similarly, 2001 MeaGS lengths ranged from 310 to 365 days. The average MeasGS length for all sites was 355 days in year 2000 and 349 days in year 2001, similar to the yearly averages calculated using Method A.

The start and end dates of the MeasGS were also different than the EstGS start and end dates. The MeasGS always started many days earlier than the EstGS start date (33 - 83 days earlier), and extended later in the year than the EstGS (38 - 74 days later). Rather than starting in March and ending in November, the MeasGS (if less than 365 days) starts in January or February and ends in December or January. Details are in Table 5 and Table 8. Figure 13 shows the MeaGS and EstGS for each site from Sept 1, 1999 to March 31, 2002, and clearly illustrates the differences in length and start and stop times, as well as the annual patterns.

10 cm Depth

Non-Growing Season

As expected, the shallower soil temperatures are colder and more variable than the deeper soil temperatures. Using the same temperature threshold used for the 50 cm NGS to establish a "10 cm non-growing season", a quick comparison with the 50 cm soil temperature graphs (Appendix C) shows that the 10 cm NGS (area under 5°C in Appendix E) is usually longer than the 50 cm NGS. However, not every site had temperatures below 5°C; each winter one of the seven sites stayed above the 5°C threshold. In addition, some of the NGS were quite short (Table 6) – for example, in Winter 2000, SB1 had a 10 cm NGS of about 2 days. The10 cm NGS length ranged from 0 to 100 days.

Growing Season

Using the same temperature criteria for the 10 cm MeasGS (soil temperatures above 5°C) as used for the 50 cm MeasGS, gives a 10 cm MeasGS ranging from 270 to 365 days, 38 to 138 days longer than the 50 cm EstGS. The 10 cm MeasGS also begins earlier and extends later than the 50 cm EstGS. Temperatures remain above 5°C starting in January, February, or March, and extending through December or January (Details in Table 7). The average number of days the 10 cm soil temperatures remained above 5°C ranges from a low of 287 days for Elmington 1 (1999 to 2002 data) to a high of 364 days for Sandy Bottom 1. The county three year averages are Gloucester – 306 days, York – 341 days, and Hampton – 359 days, and the averages per year for all the sites are 338 days for 1999-2000, 310 days for 2000-2001, and 345 days for 2001-2002 (Table 8).

Temperature Range

Maximum and minimum 10 cm and 50 cm soil temperatures for 2000 to 2002 are shown in Figure 15 and 17. 10 cm soil temperatures have higher maximum values and lower minimum values than the 50 cm soil temperatures. For both soil depths, the maximum temperatures are consistent from year to year and site to site, and have less spread than the minimum temperatures. The minimum 50 cm soil temperatures (ranging from 2.89°C to 11.38°C) show more variation year to year than the minimum 10 cm soil temperatures (ranging from 0.73°C to 7.83°C), which seem to fall within the same range year to year. Yearly minimum temperatures generally occur in January and February and yearly maximum temperatures generally occur in August.

Water Levels and Soil Temperatures

To examine the relationship between water levels and soil temperatures, the relationship between average minimum 50 cm soil temperatures and average groundwater levels was examined for December 1999 to March 2000 (see Figures 25 – 28). For January (jan T = 7.63 – 0.108 jan water) and December (dec T = 10.3 – 0.0547 dec water) the regressions were significant (Jan: p = 0.027 and R-Sq = 74.3%; Dec: p = 0.040 and R-Sq = 80.3%). Shallower water tables (wetter sites) were associated with cooler temperatures. For February and March the regression was not significant (p = 0.472 and p = 0.794).

Plant Activity Season

Fall – End of Plant Activity Season

Time of leaf color change (from green to fall hues) and leaf attachment (leaf drop as plants loose their leaves) were the measurements used to establish the end of the plant activity season in the fall. The two parameters analyzed were time of color change = 50% or more and attachment = 66% or less, using the assumption that the plant is basically entering senescence once the majority of the leaves have changed color (chlorophyll has degraded).

There is no difference between rates of color change for the three plant strata (tree, sapling, and shrub), but there is a difference in the rate of leaf drop (sapling, tree, shrub) (Table 11). There is also a difference in the rate of color change and leaf drop within each stratum. Between strata, sometimes species also differed in the rate of color change and attachment. For example, there is a significant difference in the rate of leaf drop between red maple trees and red maple saplings (p = 0.0323), which is shown in Figure 19. Based on the summary statistics (Table 12), for red maples the tree stratum loses leaves at a faster rate than the sapling. The median for both is 3 (fall evaluation period 3 – corresponding dates are shown in Table 3), but while half of the saplings have lost 66% or more of their leaves between evaluation period 3 and 4 (quartile 1 and quartile 3), half of the trees have lost 66% or more of their leaves between evaluation period 2 and 3 (quartile 1 and quartile 3). An example of the relationship between the rate of color change and leaf loss for one stratum is illustrated in Figure 20 (p = 0.001). Tree color change happens earlier than tree leaf loss (descriptive stats in Table 12). Figure 21 shows the difference in rate of color change for different species within a stratum. The shrub species paw paw, Clethra, and spicebush change color at the same rate (p = 0.6620), but the rate of color change for blueberry is slower (p = 0.0000 for blueberry, paw paw, Clethra, and spicebush).

The end of the plant growing season is represented by the median for color change for the three strata, as there is no difference in rate of color change between the shrub, sapling, and tree layers (p = 0.8720). The median for tree and shrub = 2, and the median for sapling = 3, while the Q1 = 2 and Q3 = 3 for all three strata. Therefore the end of the plant activity season is in the range of November 6 to 21.

Although the plants generally lost all their leaves by the end of November, in the shrub layer Clethra showed signs of renewed plant activity in evaluation periods 3 and 4 (November 19 to December 6). The terminal buds enlarged and opened to new leaves. Another shrub, spicebush, also showed signs of renewed plant activity. Enlarged buds were observed in evaluation periods 3 and 4 (November 19 to December 6). Therefore, there is evidence that the plant activity season extends beyond mid-November.

Spring Plant Activity Season

The start of the plant activity season in the spring is indicated by evidence of plant activity such as swelling buds, flowering, or leaf-out. Similar to the fall analysis, there are differences in factors (leaf-out, enlarged buds, flowering) between strata, between species within strata, and between strata for a species. Significant differences are indicated in Table 13, with summary statistics in Table 14.

One of the earliest indicators of plant activity is bud swelling, which started in early January for most species. Observation of bud enlargement for trees and saplings (p = 0.0030) are shown in Figure 22. By early February all trees and saplings had enlarged buds, with sapling bud enlargement occurring a bit later than tree bud enlargement. Based on the median, Q1, and Q3 for all three strata, bud swelling primarily occurs in mid-January (12 - 22), but extends to early January (6) and early February (4). There are differences in timing of bud swelling by strata and species.

Other early evidence of spring plant activity is flowering. Red maple tree and sapling flowering and seed set are shown in Figure 23, which also demonstrates that the timing of some events is narrowly defined (seed set) while other events occur over a wider time window (flowering). The vast majority of flowering for both the red maple sapling and trees was first observed between March 2 - 4 (median = evaluation period 8), but flowering is observed as early as January 21-22, and as late as March 22. Seed set was quite uniform and was primarily first observed on March 15-16.

Another common indicator of plant activity which is easily observed is leaf-out. Leaf-out occurred later in the spring than flowering (Figure 24). The trees leafed out just a little bit later than the saplings and shrubs (Tables 13 and 14). The median for all three strata is evaluation period 12, which is late March – early April, with Q1s and Q3s from 10 to 13 indicating the majority of leaf-out for the three strata took place between March 22 and April 6. Some of the differences in leaf-out patterns are due to differences in leaf-out time between species.

Based on bud enlargement, the plant activity season starts in January. The next evidence of plant activity is red maple flowering, which primarily occurs in early March. Some of the latest evidence of plant activity is leaf-out, which primarily occurs between March 22 and April 6.

DISCUSSION

Climate During the Study Period

The measured growing season, as defined by soil temperatures >5°C at a depth of 50 cm in the soil (Environmental Laboratory 1987, Soil Survey Staff 1999b), ranges from a length of 365 days to 308 days. Average growing seasons are in Table 8, and based on the soil temperatures, the growing season starts in January or February, and ends in December or January.

Since the growing season lengths are collected in three years, there is a question of whether they are representative of the true growing season, or if they reflect anomalous years in terms of air temperature and precipitation amounts. Climate data from Norfolk, Virginia were used to address this issue (National Climatic Data Center 2003). Norfolk is located south of the research area on the Virginia coastal plain, and is a NOAA weather station, with quality controlled data. Since the general patterns of precipitation and air temperature for Norfolk should also apply to the research sites (they have roughly similar characteristics in terms of topography, elevation, proximity to large water bodies), climate data from Norfolk was used as a proxy for the climate of the research sites, in terms of whether precipitation and temperature patterns were fairly normal or represented extremes (such as a very wet or cold winter).

Figure 10 shows the average yearly and seasonal air temperatures (°F) for Norfolk, Virginia from 1998 to 2003 (National Climatic Data Center 2003). The average air temperature was about equal in 2000 and 2001. Based on the temperature ranks in Figure 11 (temperatures are ranked from 1895 to 2003, with a low number indicating a cooler temperature and a high number indicating a warmer temperature), the annual average temperatures for 2000 and 2001 were average (rank = 56). Winter average temperatures (Dec – Feb) for 2000, 2001, and 2002, which are probably the most relevant in terms of impacting the measured growing season based on soil temperatures, were highest in 2002, and lowest in 2001. Based on the temperature ranks in Figure 11, Winter 2000 was somewhat warm, Winter 2001 was somewhat cool, and Winter 2002 was one of the warmest winters on record. Fall and spring air temperatures also affect the soil temperatures, and might have an effect on the start and end dates of the growing season. Based on temperature ranks in Figure 11, Fall 1999 was somewhat warm, while Fall 2000 and 2001 were relatively cool. Spring 2000 was very warm, Spring 2001 was average, and Spring 2002 was one of the warmest on record. Based on the seasonal rankings, the growing season parameters most representative of a "typical" growing season or at least a more conservative estimate (cooler vs. warmer) are from Fall 2000 and 2001, Winter 2001, and Spring 2001.

Seasonal and yearly precipitation data for 1998 to 2002 are shown by amount in Figure 8 (in inches) and ranking in Figure 9 (precipitation is tanked from 1895 – 2003, with a low number indicating a drier year and a higher number indicating a wetter year) (National Climatic Data Center 2003). Spring precipitation totals look fairly consistent for 2000, 2001, and 2002, but fall and winter precipitation totals are quite different. Fall 1999 was much wetter than Fall 2000 and Fall 2001 (which was very dry). Yearly precipitation in 2001 was much lower than in 1999, 2000, or 2002. Based on rankings, 2001 was one of the driest years on record, while 1999, 2000, and 2002 were wetter than normal. Looking at seasonal precipitation rankings, Fall 1999 is the wettest year on record, while 2000 is drier than normal and 2001 is one of the driest falls on record. Winter 2000, 2001, and 2002 are all among the driest years on record, and Spring 2000 and 2002 are about average, while Spring 2001 is somewhat drier than normal. Based on the rankings, the seasonal precipitation patterns are fairly extreme in the fall (both wet and dry) and winter (quite dry), but fairly normal in the spring.

Since the main source of water input to the sites (hardwood mineral flats) is most likely from precipitation (Smith et al. 1995, Havens et al. 2001, Rheinhardt et al. 2002), the precipitation patterns might affect the measured growing season. Brady and Weil

(1999) briefly mention rain (and irrigation water) as a factor that might affect soil temperatures (p. 294). If there is a difference in temperature between the rain and the soil, the rain might have a cooling or warming effect. Brady and Weil give the example of a cool rain in the summer reducing soil temperature, while a warm rain in the spring could warm cool soils. Since the temperature of rain can be a factor in surface heat fluxes at the sea-air interface (Anderson 1995, Flament and Sawyer 1995), it seems reasonable that the temperature of rain might affect soil temperatures. However, water/soil interactions are complex, as evaporation of water from a wet soil would reduce soil temperatures, and thus as stated by Brady and Weil (1999), a warm rain could have the end effect of reducing soil temperatures. Regardless, the possible effect of precipitation on soil temperatures (with the relative difference between soil and precipitation temperatures making the precipitation either a soil cooling or warming agent) is still worth considering, especially since the primary hydrologic input to these wetland systems is expected to be precipitation. In fact, an input of cold precipitation (relative to the soil) seems to be a reasonable explanation for sudden, pronounced, but short-lived drops in the soil temperature records during Winter 2002. For example, in early January 2002 there is an abrupt drop in the soil temperature at the 10 cm depth at CS1, CS2, SF1, and SB1 [Oct 2001 – Sept 2002 soil temperature graphs in Appendix E (2-4, and 6)]. The representative air temperature graphs from the sites show cool temperatures at this time [Oct 2001 – Sept 2002 air temperature graphs in Appendix F (1 & 2)], and records from Norfolk (National Climatic Data Center 2003) indicate precipitation and snowfall during this same period [Appendix F (5 & 6)]. Therefore, since winter precipitation (cool rain or melted snow) might be expected to reduce soil temperatures, the low winter precipitation in 2000 – 2002 might contribute to warmer soil temperatures than normal. As a result, the timing and length of the measured growing season could be affected by the precipitation patterns

Evaluation of Hypotheses

Soil Temperature Regime

H1: Based on soil temperatures (>5°C at 50 cm), the thermic soil temperature regime growing season of February to October in SE Virginia wetland soils will be invalidated.

Result: Accept the hypothesis.

H3: The measured growing season (based on soil temperatures above 5°C at 50 cm) will be longer than the thermic soil growing season of February to October.

Result: Accept the hypothesis.

Virginia coastal plain soils are in the thermic soil temperature regime, which has an assumed growing season of February to October (Soil Survey Staff 1996). However, the measured growing season (period with soil temperatures >5°C at 50 cm depth) was longer than this period (Table 5 and Table 8), as it started in January or February, and ended in December or January. In fact, some sites had a 365-day growing season. The thermic soil temperature regime growing season start date of February is within the range of the measured growing season start dates of January and February. The fall growing season end date of October is much earlier than the measured end date of December or January.

Soil temperature regimes are useful for agriculture and forestry since soil temperature is a factor in plant growth and germination (Foth 1984), as well as for soil classification (Brady and Weil 1996). Soil temperature regimes are defined by the mean annual soil temperature at 50 cm, and the difference between the mean summer and winter temperatures (Brady and Weil 1996). However, in this case, the soil temperature regime did not serve as a good estimate of the length of growing season or the timing of the end of the growing season in the wetland soils.

These results (finding a measured period of soil temperatures >5°C at 50 cm depth to be longer than the thermic soil temperature regime growing season) are consistent with the soil temperature data from North Carolina, South Carolina, Georgia, Louisiana, and Mississippi presented by Megonigal et al. (1996).

Growing Season Estimated from Air Temperature

H_2: Based on soil temperatures (>5°C at 50 cm), the currently accepted growing season for SE Virginia wetland soils, as estimated from air temperatures (county soil survey tables), will be invalidated.

Results: Accept the hypothesis.

H_4: The measured growing season (based on soil temperatures above 5°C at 50 cm) will be longer than the currently accepted wetland delineation growing season, as estimated from air temperatures (county soil survey tables).

Results: Accept the hypothesis.

The measured growing season (based on soil temperatures above 5°C at 50 cm) has a longer duration, extends later, and starts earlier than the estimated growing season currently used for wetland delineation. In Gloucester County and York County the estimated growing season is March 30 to November 12 (Soil Conservation Service 1980 and 1985), and in the City of Hampton the estimated growing season is March 10 to November 29 (National Water and Climate Center 2003). The average measured growing season for Hampton is 365 days, 101 days longer the estimated growing season (Table 5 and Table 8). The measured growing season for Gloucester County and York County is 310 to 365 days (Table 5), with an average length of 340 to 346 days for Gloucester County and an average length of 356 to 359 days for York County (Table 8), quite a bit longer than the 226 day estimated growing season currently used. The average length varies a bit with different methodologies (Method A and B in Table 8), but the estimates are all in the same ballpark. The key point is still that the measured growing season is quite a bit longer than the estimated growing season. In addition, the measured growing season starts earlier (in January/February vs. March) and ends later (December/January vs. November).

The estimated growing season from air temperature records gives a quite different growing season length and timing (start and end date) than the growing season measured on the sites (using soil temperatures). These results (soil temperatures above 5°C at 50 cm) are consistent with other studies in Virginia. Seybold et al. (2000) found that the average soil temperature at 50 cm depth, measured in a tidal freshwater marsh along the James River, never fell below 5°C between July 1997 and January 1999. Havens' (1997) study of a seasonally flooded forested wetland found that shallow (15 cm) soil temperatures stayed above 5°C during the September 7 to December 21 study period in 1992, with the lowest temperature measured about 7°C.

Plant Activity Season

H_5: The observed plant activity season will be longer than the thermic soil growing season of February to October.

Results: Accept the hypothesis.

H_6: The observed plant activity season will be longer than the currently accepted wetland delineation growing season, as estimated from air temperatures (county soil survey tables).

Results: Accept the hypothesis.

The plant activity season (as determined from easily observable above-ground phenologic changes) started in January in the spring (bud swelling – especially on red maple trees) and extended at least through mid-November (leaf color change and leaf fall). There was also some visual evidence (new leaves on Clethra and bud swelling on

Clethra and spicebush) that the plant activity season extends later into the fall till early and perhaps mid-December.

The observed plant activity season (based on observations from Fall 1999 to Spring 2000) of mid-January to mid-November/early-December is longer than both the thermic soil regime growing season of February to October, and the estimated growing season used for wetland delineation (March 30 to November 12 for Gloucester and York Counties; March 10 to November 29 for the City of Hampton). However, since Fall 1999 and Winter 2000 were warmer than "average" and Spring 2000 was one of the warmer springs on record (Figure 11, National Climatic Data Center 2003), the observations of bud swelling and new leaf growth might not be typical.

Although for the purposes of this study only above-ground, visual cues of plant activity were observed to determine the plant activity season, it is extremely likely that some of the plants were metabolically and or physiologically active below ground (roots, etc.) and above-ground (sap flow) during November, December, January, and February (though the activity was not observable). As discussed in Tiner (1999), there are many examples of plant activity in the fall and winter, such as root growth in fall and winter, seed set and flowering in the late fall, and shoot growth in December (in the northern U.S).

It seems likely that the observed plant activity season of early/mid-January to mid-November/early-December represents the "minimum" plant activity season. Considering the mild climate in Southeast Virginia, and the many examples of fall and winter plant activity discussed by Tiner (1999), there is probably plant activity on the sites for the majority of the year.

Microbial Activity Season and Plant Activity Season

H7: The microbial activity season (as defined by Megonigal et al. 1996) will be longer than the observed plant activity season.

Results: Not completely clear.

The microbial activity season, defined by Megonigal et al. (1996) as the period in which soil temperatures remain above the 5°C threshold at 50 cm depth, definitely extended later in the fall and winter than the observed plant activity season (for the 1999 – 2000 winter). There was some plant activity observed in early-December (swelled buds and leaf growth) and again in January (swelled buds and red maple flowering), but during this same period all the soils remained above 5°C threshold through December and late January (and some never went below 5°C). So, as a whole, the microbial community was probably more active than the plant community. An analysis of plant activity by site would be useful to more solidly answer this question.

In general, you would expect the microbial community to be able to react much more rapidly than the plant community to advantageous conditions (such as a period of increased soil temperature in the winter). Also, on a given site, you would expect the different members of the microbial community to be active over a larger temperature range (cool temperature microbes giving way to more temperature microbes as the season progresses) than the plant community.

Effects of Groundwater on Soil Temperature

H_8: Wetter sites will have warmer winter soil temperatures than drier sites.

Results: Reject the hypothesis. More analysis is needed to solidly establish if there is a relationship between groundwater water level and soil temperature, as well as the nature of the relationship.

Other studies have shown the high specific heat of water tends to buffer temperature changes, and that wetter sites experiences a smaller range of temperatures (Pickering and Veneman 1984). However, an examination of Winter 2000 mean minimum soil temperatures and average groundwater water levels (December 1999 and January, February, and March 2000) showed a different pattern. In December and

January, there was a significant relationship between high groundwater levels and low temperatures (Figures 25 and 26) – wetter sites had cooler temperatures. However, for February and March (Figures 27 and 28) there was no significant relationship between mean monthly groundwater level and mean minimum monthly temperature.

H9: Wetter sites will show less annual soil temperature variation than drier sites.

Results: Reject the hypothesis.

There does not appear to be a clear observable relationship between relative wetness and annual soil temperature variation (based on graphs - Figures 14 to 17 and Appendix B). To further explore this relationship I need to develop a better mechanism for ranking/establishing site wetness and temperature variables.

Wetland Hydrology Criteria and Growing Season Length

One of the motivations for this study was the concern that an inaccurately defined growing season might exclude seasonal wetlands, especially those that are primarily saturated and inundated in the cooler times of the year (late fall, winter, early spring). Hardwood mineral flats are an example of a wetland that is saturated and/or inundated during these cooler periods, and since these wetlands are threatened by development in southeast Virginia (Silberhorn 1999), they were an idea wetland type for my study.

To determine if the length of the growing season did have an impact on whether the hardwood flats in the study would have met the jurisdictional hydrology requirements, each site was individually evaluated. First an average growing season length, start date, and end date was calculated for each site based the soil temperature records from fall 1999 to spring 2002 (Table 15). Next the hydrology for each site was evaluated for 1999, 2000, 2001, and 2002 using the average measured growing season and the estimated growing season currently in use (due to well malfunctions and damage some hydrology data is missing), to determine if the hydrology met jurisdictional requirements. To qualify as characteristic wetland hydrology, the inundation or saturation must occur for a percentage of the growing season; there must be inundation or saturation at the surface for >12.5% of the growing season or 5 - 12.5% with other evidence (National Research Council 1995). Due to capillary action, a soil is generally considered saturated if the groundwater level is within 30 cm of the soil surface.

The results of the analysis are presented in Table 16 and are quite interesting. Missing or only partial data (only part of the hydrology data for a year) made it particularly difficult to determine if some sites would meet the jurisdictional hydrology requirement in 1999 and 2002 (indicated by "?" if unsure due to missing data). For example, the 2002 hydrology data only goes through late April, and was only available for four of the seven sites. Also, in 1999, hydrology monitoring generally started between February and April, so some sites several months of data are missing during what is typically a wetter period for hardwood mineral flats. However, if a site met the hydrology requirement at the 5-12.5% threshold for the estimated growing season (on a county wide basis as estimated from air temperature), it also did so for the measured growing season (site specific growing seasons based on soil data). But for year 2000 and year 2001 combined, there are three instances in which the >12.5% hydrology threshold is met for the longer measured growing season, but not for the currently used estimated growing season. (See the gray squares in Table 16). In these cases, the jurisdictional hydrology requirement could still be met using supporting evidence plus the percent of the growing season with characteristic wetland hydrology. Realistically, in the 2000 case, the Coleman Swamp 2 site (CS2) was a fairly marginal wetland anyway. In 2001, the Elmington (EL1) and Seaford 2 (SF2) sites were almost at the > 12.5% threshold for the estimated growing season, though when using the longer measured growing season, the two sites have characteristic wetland hydrology for over 20% of the growing season. It is interesting to note for many of the site-year examples, that when using the longer measured growing season, the characteristic hydrology was present for a longer percentage of the growing season than when using the current estimated growing season (for example SF1 in year 2000 – see Table 16).

Based on the analysis of characteristic wetland hydrology, the length of the growing season does not seem to be as critical for delineating hardwood mineral flats as I had anticipated. Most of the sites would meet the characteristic hydrology threshold using the currently accepted growing season (with supporting evidence in some cases), though using the longer measured growing season would make it easier to meet the hydrology criteria, and less likely for an inexperienced delineator to make errors. An interesting phenomenon that becomes clear through this analysis is that hardwood flats that are severely altered (fragmented and separated from the original complex), such as Sandy Bottom 1 and Sandy Bottom 2 (SB1 & SB2), have very variable hydrology. In 2000, SB1 and SB2 had characteristic hydrology for 55 to 128 days (15.1 to 33.4% of the growing seasons), but in the drought year of 2001 (and at least through 4/25 in 2002) the sites are extremely dry and had characteristic wetland hydrology for only 0 to 3 days [see the hydrographs for Oct 2000 – Sept 2001 and Oct 2001 – Sept 2002 in Appendix B (6) and (7)]. Other less altered or at least less fragmented sites [such as Seaford 1 (SF1)] while affected by the drought, still have relatively characteristic hydrology for winter and spring 2001.

CONCLUSIONS

Although the years and seasons that data were collected for this study were not always "average" or "typical" in terms of precipitation and air temperature, the results are still meaningful. The growing seasons measured from the Fall of 1999 to the Spring of 2002 may be longer than the "typical" growing season for part of the measurement period (the 1999 to 2000 winter season) due to warmer temperatures and less precipitation, but the results show that the growing season for wetlands in southeast Virginia is much longer than the estimated growing season based on air temperatures. Even the shallow 10 cm soil temperatures stayed above 5°C for most of the year. It is also important to note that during the non-growing season (for both the 10 cm and 50 cm soil depths) the soil temperature did not consistently stay below 5°C for the entire non-growing season. As Figures 4 (10 cm soil depth) and 6 (50 cm soil depth) show, during the non-growing season, soil temperatures remained below 5°C for 20% to 100% of the non-growing season. As a result, adapted organisms (microbes and plants) are probably active for part of the "non-growing season".

Defining a growing season for wetlands is challenging, but air temperature does not seem to be an accurate way to estimate the growing season. Factors such as vegetation, habitat type (forest vs. fen), and source of water inputs all affect the soil temperatures. This makes it difficult to define regional growing seasons for wetlands, which is a concern, since wetland delineation uses the estimated growing season when characterizing site hydrology.

As Tiner (1999), the 1995 report on Wetlands by the National Research Council, and other authors point out, not only should the growing season – hydrology linkage be reconsidered in terms of a definition, but the point of such a linkage should also be considered. Wetlands have many functions that are not always considered in the jurisdictional definitions. As Tiner (1999) notes, "The functions of wetlands do not cease with the 'growing season.' " For example, animals such as fish need access to water throughout the year (not just when the plants are active). Although the length of the "growing season" was not as critical as I had anticipated for delineating hardwood mineral flats, using a longer growing season would make the delineation process easier and perhaps reduce errors, and would help emphasize the functionality of these and other wetlands throughout the majority of the year.

TABLE 1: Freeze Dates in Spring and Fall for James City County, York County, and the City of Williamsburg (Data recorded in Williamsburg, Virginia from 1951 - 1976)

[Adapted from Table 2, p. 101 in *Soil Survey of James City and York Counties and the City of Williamsburg, Virginia (Soil Conservation Service 1985)*]

Probability	Temperature in degrees F		
	24 or lower	**28 or lower**	**32 or lower**
Last freezing temperature in spring:			
1 year in 10 later than -	March 29	April 14	May 3
2 years in 10 later than -	March 24	April 9	April 27
5 years in 10 later than -	March 14	March 30	April 16
First freezing temperature in fall:			
1 year in 10 earlier than -	November 6	October 29	October 15
2 years in 10 earlier than -	November 12	November 3	October 29
5 years in 10 earlier than -	November 22	November 12	October 29

TABLE 2: Growing Season for James City County, York County, and the City of Williamsburg (Data recorded in Williamsburg, Virginia from 1951 - 1976)

[Adapted from Table 3, p. 101 in *Soil Survey of James City and York Counties and the City of Williamsburg, Virginia* (Soil Conservation Service 1985)]

Probability	**Length of growing season if daily minimum temperature (in degrees F) is:**		
	Higher than 24	**Higher than 28**	**Higher than 32**
	(Days)	**(Days)**	**(Days)**
9 years in 10	231	206	175
8 years in 10	238	213	182
5 years in 10	253	226	196
2 years in 10	268	240	210
1 year in 10	275	247	217

TABLE 3: Dates Plant Data Collected (Fall 1999 to Spring 2000)

Evaluation Period	Season	Time Period	Length (days)	Sites & Date Evaluated						
				EL1	CS1	CS2	SF1	SF2	SB1	SB2
1	Fall	Oct 21 to 31	11	27-Oct	27-Oct (a)	21-Oct (b)	22-Oct	n/a	31-Oct	29-Oct
2	Fall	Nov 6 to 7	2	7-Nov	7-Nov	7-Nov	7-Nov	n/a	6-Nov	6-Nov
3	Fall	Nov 19 to 21	3	21-Nov	19-Nov	19-Nov	20-Nov	n/a	20-Nov	20-Nov
4	Fall	Dec 4 to 6	3	6-Dec	6-Dec	6-Dec	6-Dec	n/a	4-Dec	4-Dec
5*	Fall	After Dec 4 to 6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1	Spring	Jan 6 to 7	2	6-Jan	7-Jan	7-Jan	7-Jan		6-Jan	6-Jan
2	Spring	Jan 12 to 14	3	12-Jan	14-Jan	12-Jan (c)	14-Jan		14-Jan	14-Jan
3	Spring	Jan 21 to 22	2	21-Jan	21-Jan	21-Jan	22-Jan		22-Jan	22-Jan
4	Spring	Feb 2 to 4	3	2-Feb	4-Feb	4-Feb	3-Feb		3-Feb	3-Feb
5	Spring	Feb 9	1	9-Feb	9-Feb	9-Feb	9-Feb	9-Feb (e)	9-Feb	9-Feb
6	Spring	Feb 17 to 18	2	18-Feb	18-Feb	18-Feb	17-Feb	17-Feb	17-Feb	17-Feb
7	Spring	Feb 23 to 25	3	25-Feb	24-Feb	24-Feb	24-Feb	24-Feb	23-Feb	23-Feb
8	Spring	Mar 2 to 4	3	2-Mar	3-Mar	2-Mar	3-Mar	3-Mar	4-Mar	4-Mar
9	Spring	Mar 8 to 9	2	9-Mar	8-Mar	8-Mar	8-Mar	8-Mar	9-Mar	9-Mar
10	Spring	Mar 15 to 19	5	15-Mar	15-Mar	15-Mar	16-Mar	16-Mar	17-Mar (f)	17-Mar
11	Spring	Mar 22 to 24	3	22-Mar	23-Mar	23-Mar	24-Mar	24-Mar	23-Mar	23-Mar
12	Spring	Mar 31 to Apr 1	2	31-Mar	31-Mar	31-Mar	31-Mar	31-Mar	1-Apr	1-Apr
13	Spring	Apr 5 to 6	2	5-Apr	5-Apr	5-Apr	6-Apr	6-Apr	6-Apr	6-Apr
14	Spring	Apr 11 to 12	2	11-Apr	11-Apr	11-Apr	12-Apr	12-Apr	12-Apr	12-Apr
15	Spring	Apr 21 to 22	2	n/a	n/a	22-Apr (d)	n/a	n/a	n/a	n/a

(a) - Shrub on Oct 29
(b) - Shrub on Oct 22
(c) - Shrub & Sapling on Jan 14
(d) - Sap not eval. on Apr 22; Shrub eval. Apr 21
(e) - SF not set up for plant data or eval. till Feb 9
(f) - Sapling on Mar 19

* - Note: Fall Period 5 accounts for those plants that did not have a color change of 55% or more &/or attachment of 66% or less when last checked in early December, the last fall evaluation period.

TABLE 4: Non-Growing Seasons for 50 cm Depth Calculated From Measurements Between Fall 1999 and Spring 2002

Site	Soil Depth	Period Soil Temperature Measured	Non-Growing Season (NGS)				Time Soil Temp at 5 C or Below	Proportion of NGS with Soil Temp at 5 C or less	Proportion of NGS with Soil Temp at 5 C or less
			Starts	Ends	Length (hours)	Length (days)	Total (hours)	(see*)	Corrected Data
EL1	50cm	Fall 1999 - Sept 2000	1/21/00 19:00	2/19/00 2:00	679	28.29	636	0.94	0.94
CS1	50cm	Fall 1999 - Sept 2000	1/23/00 12:00	2/15/00 16:00	556	23.17	557	1.00	1.00
CS2	50cm	Fall 1999 - Sept 2000			0	0	0		
SF1	50cm	Fall 1999 - Sept 2000			0	0	0		
SF2	50cm	Fall 1999 - Sept 2000	1/25/00 20:00	2/10/00 22:00	386	16.08	387	1.00	1.00
SB1	50cm	Fall 1999 - Sept 2000			0	0	0		
SB2	50cm	Fall 1999 - Sept 2000			0	0	0		
EL1	50cm	Oct 2000 - Sept 2001	12/31/00 14:00	2/25/01 19:00	1349	56.21	654	0.48	0.48
CS1	50cm	Oct 2000 - Sept 2001	12/31/00 6:00	2/8/01 23:00	953	39.71	797	0.84	0.84
CS2	50cm	Oct 2000 - Sept 2001			0	0	0		
SF1	50cm	Oct 2000 - Sept 2001			0	0	0		
SF2	50cm	Oct 2000 - Sept 2001	1/11/01 0:00	1/30/01 16:00	472	19.67	235	0.50	0.50
SB1	50cm	Oct 2000 - Sept 2001			0	0	0		
SB2	50cm	Oct 2000 - Sept 2001			0	0	0		
EL1	50cm	Oct 2001 - March 2002			0	0	0		
CS1	50cm	Oct 2001 - March 2002			0	0	0		
CS2	50cm	Oct 2001 - March 2002	1/6/02 16:00	1/6/02 16:00	1	0.04	1	1.00	1.00
SF1	50cm	Oct 2001 - March 2002			0	0	0		
SF2	50cm	Oct 2001 - March 2002			0	0	0		
SB1	50cm	Oct 2001 - March 2002			0	0	0		
SB2	50cm	Oct 2001 - March 2002	1/6/02 15:00	1/7/02 20:00	29	1.21	30	1.03	1.00

* NOTE: Values over 1.00 are an artifact of the analysis process. The length of the NGS is calculated as the number of hours between the start and end. However, for the number of hours below 5 deg C, each value below 5 deg C is counted, rather than the interval between two measurements. Therefore ratios over 1.00 should be corrected to 1.00.

TABLE 5: Growing Seasons for 50cm Depth Calculated From Measurements Between Fall 1999 and Spring 2002

Site	Soil Depth	Period Soil Temperature Measured	Measured Growing Season			Growing Season Estimated From Air Temperature (Currently Used Growing Season) **			Difference Between Measured and Used Growing Season		
			Starts	Ends	Length (days)	Starts	Ends	Length (days)	Starts Earlier (days)	Extends Later (days)	Length (days)
EL1	50cm	Fall 1999 - Sept 2000	19-Feb	21-Jan	336.71	30-Mar	12-Nov	226	39	70	110.71
CS1	50cm	Fall 1999 - Sept 2000	15-Feb	23-Jan	341.83	30-Mar	12-Nov	226	43	72	115.83
CS2	50cm	Fall 1999 - Sept 2000			365.00	30-Mar	12-Nov	226			139.00
SF1	50cm	Fall 1999 - Sept 2000			365.00	30-Mar	12-Nov	226			139.00
SF2	50cm	Fall 1999 - Sept 2000	10-Feb	25-Jan	348.92	30-Mar	12-Nov	226	48	74	122.92
SB1	50cm	Fall 1999 - Sept 2000			365.00	10-Mar	29-Nov	264			101.00
SB2	50cm	Fall 1999 - Sept 2000			365.00	10-Mar	29-Nov	264			101.00
EL1	50cm	Oct 2000 - Sept 2001	25-Feb	31-Dec	308.79	30-Mar	12-Nov	226	33	49	82.79
CS1	50cm	Oct 2000 - Sept 2001	8-Feb	31-Dec	325.29	30-Mar	12-Nov	226	50	49	99.29
CS2	50cm	Oct 2000 - Sept 2001			365.00	30-Mar	12-Nov	226			139.00
SF1	50cm	Oct 2000 - Sept 2001			365.00	30-Mar	12-Nov	226			139.00
SF2	50cm	Oct 2000 - Sept 2001	30-Jan	11-Jan	345.33	30-Mar	12-Nov	226	59	60	119.33
SB1	50cm	Oct 2000 - Sept 2001			365.00	10-Mar	29-Nov	264			101.00
SB2	50cm	Oct 2000 - Sept 2001			365.00	10-Mar	29-Nov	264			101.00
EL1	50cm	Oct 2001 - March 2002			365.00	30-Mar	12-Nov	226			139.00
CS1	50cm	Oct 2001 - March 2002			365.00	30-Mar	12-Nov	226			139.00
CS2	50cm	Oct 2001 - March 2002	6-Jan	6-Jan	364.96	30-Mar	12-Nov	226	83	55	138.96
SF1	50cm	Oct 2001 - March 2002			365.00	30-Mar	12-Nov	226			139.00
SF2	50cm	Oct 2001 - March 2002			365.00	30-Mar	12-Nov	226			139.00
SB1	50cm	Oct 2001 - March 2002			365.00	10-Mar	29-Nov	264			101.00
SB2	50cm	Oct 2001 - March 2002	7-Jan	6-Jan	363.79	10-Mar	29-Nov	264	62	38	99.79

** NOTE: The Growing Season for EL1, CS1, & CS2 (Gloucester County) and SF1 & SF2 (York County) is from the County Soil Survey Tables (Soil Conservation Service 1980 and 1985). The Growing Season for SB1 & SB2 (Hampton) is from the on-line Natural Resources Conservation Service Hampton Growing Season Table (National Water and Climate Center 2003).

TABLE 6: Non-Growing Seasons for 10cm Depth Calculated From Measurements Between Fall 1999 and Spring 2002

Site	Soil Depth	Period Soil Temperature Measured	Non-Growing Season (NGS)				Time Soil Temp at 5 C or Below	Proportion of NGS with Soil Temp at 5 C or less	Proportion of NGS with Soil Temp at 5 C or less
			Starts	Ends	Length (hours)	Length (days)	Total (hours)	(see*)	Corrected Data
EL1	10cm	Fall 1999 - Sept 2000	12/25/99 7:00	2/23/00 13:00	1446	60.25	980	0.68	0.68
CS1	10cm	Fall 1999 - Sept 2000	12/25/99 21:00	2/23/00 14:00	1433	59.71	901	0.63	0.63
CS2	10cm	Fall 1999 - Sept 2000	1/22/00 6:00	2/14/00 7:00	553	23.04	368	0.67	0.67
SF1	10cm	Fall 1999 - Sept 2000			0	0	0		
SF2	10cm	Fall 1999 - Sept 2000	1/18/00 10:00	2/14/00 9:00	647	26.96	604	0.93	0.93
SB1	10cm	Fall 1999 - Sept 2000	1/31/00 3:00	2/1/00 20:00	41	1.71	42	1.02	1.00
SB2	10cm	Fall 1999 - Sept 2000	1/28/00 18:00	2/9/00 13:00	283	11.79	195	0.69	0.69
EL1	10cm	Oct 2000 - Sept 2001	12/19/00 4:00	3/29/01 6:00	2402	100.08	1549	0.64	0.64
CS1	10cm	Oct 2000 - Sept 2001	12/21/00 13:00	3/8/01 13:00	1848	77.00	1195	0.65	0.65
CS2	10cm	Oct 2000 - Sept 2001	12/24/00 5:00	3/8/01 11:00	1782	74.25	700	0.39	0.39
SF1	10cm	Oct 2000 - Sept 2001	1/10/01 7:00	1/28/01 12:00	438	18.25	93	0.21	0.21
SF2	10cm	Oct 2000 - Sept 2001	12/24/00 8:00	3/28/01 10:00	2258	94.08	1146	0.51	0.51
SB1	10cm	Oct 2000 - Sept 2001			0	0.00	0		
SB2	10cm	Oct 2000 - Sept 2001	1/11/01 0:00	1/28/01 13:00	421	17.54	85	0.20	0.20
EL1	10cm	Oct 2001 - March 2002	12/23/01 9:00	3/6/02 11:00	1754	73.08	734	0.42	0.42
CS1	10cm	Oct 2001 - March 2002	1/2/02 5:00	3/2/02 12:00	1423	59.29	193	0.14	0.14
CS2	10cm	Oct 2001 - March 2002	1/6/02 15:00	1/7/02 12:00	21	0.88	22	1.05	1.00
SF1	10cm	Oct 2001 - March 2002	1/6/02 15:00	1/6/02 23:00	8	0.33	9	1.13	1.00
SF2	10cm	Oct 2001 - March 2002	1/9/02 4:00	1/9/02 11:00	7	0.29	8	1.14	1.00
SB1	10cm	Oct 2001 - March 2002	1/6/02 15:00	1/6/02 16:00	2	0.08	2	1.00	1.00
SB2	10cm	Oct 2001 - March 2002			0	0	0		

* NOTE: Values over 1.00 are an artifact of the analysis process. The length of the NGS is calculated as the number of hours between the start measurements. Therfore ratios over 1.00 should be corrected to 1.00.

TABLE 7: Growing Seasons for 10cm Depth Calculated From Measurements Between Fall 1999 to Spring 2002

Site	Soil Depth	Period Soil Temperature Measured	Measured Growing Season			Growing Season Estimated From Air Temperature (Currently Used Growing Season) **			Difference Between Measured and Used Growing Season		
			Starts	Ends	Length (days)	Starts	Ends	Length (days)	Starts Earlier (days)	Extends Later (days)	Length (days)
EL1	10cm	Fall 1999 - Sept 2000	23-Feb	25-Dec	304.75	30-Mar	12-Nov	226	35	43	78.75
CS1	10cm	Fall 1999 - Sept 2000	23-Feb	25-Dec	305.29	30-Mar	12-Nov	226	35	43	79.29
CS2	10cm	Fall 1999 - Sept 2000	14-Feb	22-Jan	341.96	30-Mar	12-Nov	226	44	71	115.96
SF1	10cm	Fall 1999 - Sept 2000			365.00	30-Mar	12-Nov	226			139.00
SF2	10cm	Fall 1999 - Sept 2000	24-Feb	18-Jan	338.04	30-Mar	12-Nov	226	34	67	112.04
SB1	10cm	Fall 1999 - Sept 2000	1-Feb	31-Jan	363.29	10-Mar	29-Nov	264	37	63	99.29
SB2	10cm	Fall 1999 - Sept 2000	9-Feb	28-Jan	353.21	10-Mar	29-Nov	264	29	60	89.21
EL1	10cm	Oct 2000 - Sept 2001	29-Mar	19-Dec	264.92	30-Mar	12-Nov	226	1	37	38.92
CS1	10cm	Oct 2000 - Sept 2001	8-Mar	21-Dec	288.00	30-Mar	12-Nov	226	22	39	62.00
CS2	10cm	Oct 2000 - Sept 2001	8-Mar	24-Dec	290.75	30-Mar	12-Nov	226	22	42	64.75
SF1	10cm	Oct 2000 - Sept 2001	28-Jan	10-Jan	346.75	30-Mar	12-Nov	226	61	59	120.75
SF2	10cm	Oct 2000 - Sept 2001	28-Mar	24-Dec	270.92	30-Mar	12-Nov	226	2	42	44.92
SB1	10cm	Oct 2000 - Sept 2001			365.00	10-Mar	29-Nov	264			101.00
SB2	10cm	Oct 2000 - Sept 2001	28-Jan	11-Jan	347.46	10-Mar	29-Nov	264	41	43	83.46
EL1	10cm	Oct 2001 - March 2002	6-Mar	23-Dec	291.92	30-Mar	12-Nov	226	24	41	65.92
CS1	10cm	Oct 2001 - March 2002	2-Mar	2-Jan	305.71	30-Mar	12-Nov	226	28	51	79.71
CS2	10cm	Oct 2001 - March 2002	7-Jan	6-Jan	364.12	30-Mar	12-Nov	226	82	55	138.12
SF1	10cm	Oct 2001 - March 2002	6-Jan	6-Jan	364.67	30-Mar	12-Nov	226	83	55	138.67
SF2	10cm	Oct 2001 - March 2002	9-Jan	9-Jan	364.71	30-Mar	12-Nov	226	80	58	138.71
SB1	10cm	Oct 2001 - March 2002	6-Jan	6-Jan	364.92	10-Mar	29-Nov	264	63	38	100.92
SB2	10cm	Oct 2001 - March 2002			365.00	10-Mar	29-Nov	264			101.00

** NOTE: The Growing Season for EL1, CS1, & CS2 (Gloucester County) and SF1 & SF2 (York County) is from the County Soil Survey Tables (Soil Conservation Service 1980 and 1985). The Growing Season for SB1 & SB2 (Hampton) is from the on-line Natural Resources Conservation Service Hampton Growing Season Table (National Water and Climate Center 2003). Also note that the growing season definition is tied to the 50cm depth, not the 10cm depth, so technically there is no definition of a growing season for the 10cm depth. The 50cm depth growing season is used for baseline comparisions.

Table 8: Average Growing Season Length

(Growing season in days. Average is calculated using 1999 to 2002 data.)

	Method A		Method B						
	(Using Growing Season = 365 minus Non-Growing Season)		(Using spring to fall data for 2000 and 2001 for 50-cm depth)						
Site (from 1999 to 2002 data)	**50-cm soil data**	**10-cm soil data**	**2000**	**Start**	**End**	**2001**	**Start**	**End**	**2 year average**
EL1	336.83	287.20	336	(Jan 21) 19-Feb**	31-Dec	310	25-Feb	n/a	323.00
CS1	344.04	299.67	342	(Jan 23) 15-Feb**	31-Dec	327	8-Feb	n/a	334.50
CS2	364.99	332.28	365			365			365
SF1	365.00	358.81	365			365			365
SF2	353.08	324.56	349	(Jan 25) 10-Feb**	n/a	346	30-Jan*	n/a	347.50
SB1	365.00	364.40	365			365			365
SB2	364.60	355.22	365			365			365
County									
Gloucester	348.62	306.38	347.67			334			340.84
York	359.04	341.68	357			355.5			356.25
Hampton	364.80	359.81	365			365			365.00
Year			**Year**	**Average**					
1999 - 2000	355.35	338.79	2000	355.29					
2000 - 2001	348.49	310.54	2001	349.00					
2001 - 2002	364.82	345.86							

* Note - Soil temperature above 5 deg C from Jan 1 - 11. ** Note - In 2000 the soils were above 5 deg C from Jan 1 till the Jan date in parentheses - so for example in 2000 EL1 temps were below 5 deg C only between Jan 21 and Feb 19.

Table 9. Monthly Average Minimum Temperature and Average Water Level Data and Site Rankings

	Average Water Level (cm)				Average Minimum 50-cm Soil Temp (deg C)			
Site	Dec-99	Jan-00	Feb-00	Mar-00	Dec-99	Jan-00	Feb-00	Mar-00
El1	-9.7	-2.8	0.5	-1.5	10.0	6.7	5.1	9.3
CS1	3.8	4.4	6.4	5.4	10.2	7.0	5.4	9.9
CS2		-16.8	-8.2	-16.2		9.4	7.0	9.7
SF1	-19.1	-3.9	-1.8	-4	12.2	9.5	7.6	9.8
SF2			-2.5	-4.9			6.3	10.4
SB1	-52.8	-32.9	1.6	-4.5	13.3	11.0	8.5	10.8
SB2	-42	-17.4	-2.9	-8.2	12.2	9.6	7.9	10.9

Average Water Level (cm) - Site Rankings from Wetter to Drier

Rankings	Dec-99	Site	Depth	Jan-00	Site	Depth	Feb-00	Site	Depth	Mar-00	Site	Depth
	1	CS1	3.8	1	cs1	4.4	1	cs1	6.4	1	cs1	5.4
	2	El1	-9.7	2	el1	-2.8	2	sb1	1.6	2	el1	-1.5
	3	SF1	-19.1	3	sf1	-3.9	3	el1	0.5	3	sf2	-4
	4	SB2	-42	4	cs2	-16.8	4	sf1	-1.8	4	sb1	-4.5
	5	SB1	-52.8	5	sb2	-17.4	5	sf2	-2.5	5	sf1	-4.9
	n/a	CS2		6	sb1	-32.9	6	sb2	-2.9	6	sb2	-8.2
	n/a	SF2		n/a	sf2		7	cs2	-8.2	7	cs2	-16.2

Average Minimum Temperature (deg C) - Site Rankings from Colder to Warmer

Rankings	Dec-99	Site	Temp	Jan-00	Site	Temp	Feb-00	Site	Temp	Mar-00	Site	Temp
	1	El1	10.0	1	el1	6.7	1	el1	5.1	1	el1	9.3
	2	CS1	10.2	2	cs1	7.0	2	cs1	5.4	2	cs2	9.7
	3	SB2	12.2	3	cs2	9.4	3	sf2	6.3	3	sf2	9.8
	3	SF1	12.2	4	sf1	9.5	4	cs2	7.0	4	cs1	9.9
	4	SB1	13.3	5	sb2	9.6	5	sf1	7.6	5	sf1	10.4
	n/a	CS2		6	sb1	11.0	6	sb2	7.9	6	sb1	10.8
	n/a	SF2		n/a	sf2		7	sb1	8.5	7	sb2	10.9

Ranking of Relative Wetness Based on Visual Examination of Hydrographs AND Considering Duration, Depth, and Consistency

Site Rankings from Wetter to Drier

Winter		Summer	
Rank	Site	Rank	Site
1	CS1	1	CS1
2	EL1	2	EL1
3	SF1	3	SF1
4	SF2	4	SF2
5	SB2	4	CS2
6	SB1	5	SB2
7	CS2	6	SB1

TABLE 10: Description of Study Site Soil Profiles

Unpublished Data 2000 - from HGM Study at VIMS (Havens et al 2001)

EL1

Meth.	Depth (cm)	Horiz.	Texture
auger	0-10	Ap	SL
auger	10-25	A2	CL
auger	25-72	Bt	CL
auger	72-100	C	SICL

CS1

Meth.	Depth (cm)	Horiz.	Texture
auger	0-2	Oa/e	
auger	2-30	A	CL
auger	30-82	Bw	CL
auger	82-130	C	SIL

Few 2-3cm gravel in the B horizon. Prominent mottles in C horizon decrease with depth.

CS2

Meth.	Depth (cm)	Horiz.	Texture
Pit	0-8	A	SCL
auger	8-30	Bw	SCL
auger	30-55	Bt	SCL
auger	55-75	C1	LS
auger	75-100	C2	LS

Cemented ironstone precipitate was found at ~100cm in holes nearby.

SF1

Meth.	Depth (cm)	Horiz.	Texture
pit	0-3	O	
pit	3-21	A	SL
auger	21-43	Bt	SCL
auger	43-90	C	SL

Bt horizon is water and root restriction. Mottles in C horizon increase with depth.

SF2

Meth.	Depth (cm)	Horiz.	Texture
pit	0-2	O	
auger	2-9	A1	SL
auger	9-27	A2	SL
auger	27-67	E	LS
auger	67-92	Bt	SCL
auger	92-100	B2t	SCL

Some pits and mounds. Some stained leaves in depressions near site.

SB1

Meth.	Depth (cm)	Horiz.	Texture
Auger	0-5	O	
Auger	5-42	A	L
Auger	42-50	Bt	CO SCL
Auger	50-95	Bt1	CO SC
Auger	95-130	Bt2	CO SC
Auger	130-140	2C	FS

Few 8mm rounded silica gravel through profile to 130cm. Profile 75ft from toe of I-64 fill. Several trees between profile hole and I-64 that are >40 yrs old (Quercus sp.).

SB2

Meth.	Depth (cm)	Horiz.	Texture
pit	0-10	A	COSL
auger	10-60	Bw	SCL
auger	60-90	B2w	SCL
auger	90-112	C1	FS
auger	112-120	C2	FS
auger	120-125	C3	FS

Few smooth 1.5cm gravel in B2w. Coarse sand throughout. Some 20-50 year old trees. Area is known for high disturbance.

Table 11: Fall Plant Data: Analysis of Differences in Color Change and Attachment

Strata	Species	Factor	Results (p=)	Significant
Sapling, Shrub, Tree		Color Change	0.8720	
Sapling, Shrub, Tree		Attachment	0.0350	yes
Tree vs. Sapling		Attachment	0.2221	
Tree		Color Change vs. Attachment	0.0001	yes
Sapling		Color Change vs. Attachment	0.0261	yes
Shrub		Color Change vs. Attachment	0.0002	yes
Tree	Red Maple vs. Sweet Gum	Color Change	0.1030	
Tree	Red Maple vs. Sweet Gum	Attachment	0.0323	yes
Sapling	Red Maple vs. Sweet Gum	Color Change	0.0013	yes
Sapling	Red Maple vs. Sweet Gum	Attachment	0.0002	yes
Tree vs. Sapling	Red Maple	Color Change	0.3100	
Tree vs. Sapling	Red Maple	Attachment	0.0236	yes
Tree vs. Sapling	Sweet Gum	Color Change	0.5987	
Tree vs. Sapling	Sweet Gum	Attachment	0.0000	yes
Shrub	Blueberry, Clethra, Paw Paw, Spicebush	Color Change	0.0000	yes
Shrub	Clethra, Paw Paw, Spicebush	Color Change	0.6620	
Shrub	Blueberry, Clethra, Paw Paw, Spicebush	Attachment	0.0000	yes
Shrub	Clethra, Paw Paw, Spicebush	Attachment	0.1550	

Table 12: Fall Plant Data - Descriptive Statistics

Strata	Species	N	Factor	Median	Q1	Q3	Minimum	Maxium
Tree		85	Attachment	3	2	3	1	5
Sapling		78	Attachment	3	2	3	2	4
Shrub		65	Attachment	3	3	4	1	5
Tree		85	Color Change	2	2	3	1	4
Sapling		78	Color Change	3	2	3	1	4
Shrub		65	Color Change	2	2	3	2	4
Sapling	Red Maple	42	Attachment	3	3	4	2	4
Tree	Red Maple	43	Attachment	3	2	3	1	4
Sapling	Sweet Gum	36	Attachment	2	2	3	2	4
Tree	Sweet Gum	42	Attachment	3	3	4	2	5
Sapling	Red Maple	42	Color Change	3	2	3	1	4
Sapling	Sweet Gum	36	Color Change	2	2	3	1	3
Shrub	Blueberry	29	Color Change	3	2.5	4	2	4
Shrub	Clethra, Paw Paw, Spicebush	36	Color Change	2	2	2	2	4
Shrub	Blueberry	29	Attachment	4	3	4	1	5
Shrub	Clethra, Paw Paw, Spicebush	36	Attachment	3	2	3	1	4

TABLE 13: Spring Plant Data - Analysis of Phenologic Events (Flowering, Leaf Out, Fruit Set)

Strata	Species	Factor	Results (p=)	Significant	Notes
Sapling, Tree, Shrub		Enlarged Buds	0.0140	yes	(Did not include SF2 in anlaysis as site not set up till February.)
Sapling vs. Tree		Enlarged Buds	0.0030	yes	(Did not include SF2 in anlaysis as site not set up till February.)
Sapling vs. Tree	Red Maple	Enlarged Buds	0.0030	yes	(Did not include SF2 in anlaysis as site not set up till February.)
Sapling vs. Tree	Sweet Gum	Enlarged Buds	0.3987		(Did not include SF2 in anlaysis as site not set up till February.)
Tree	Red Maple vs. Sweet Gum	Enlarged Buds	0.0001	yes	(Did not include SF2 in anlaysis as site not set up till February.)
Sapling	Red Maple vs. Sweet Gum	Enlarged Buds	0.0000	yes	(Did not include SF2 in anlaysis as site not set up till February.)
Shrub	Blueberry, Paw Paw, Spicebush	Enlarged Buds	0.3070		(Clethra not inlcuded as had enlarged buds and new leaf growth in December.)
Tree vs. Sapling	Red Maple	Flowering	0.3478		
Tree	Red Maple vs. Sweet Gum	Flowering	0.0000	yes	
Sapling, Tree, Shrub		Leaf-out	0.0040	yes	
Tree vs. Sapling		Leaf-out	0.0256	yes	
Tree vs. Shrub		Leaf-out	0.0013	yes	
Sapling vs. Shrub		Leaf-out	0.2925		
Tree	Red Maple vs. Sweet Gum	Leaf-out	0.1306		
Sapling	Red Maple vs. Sweet Gum	Leaf-out	0.4639		
Tree vs. Sapling	Red Maple	Leaf-out	0.0322	yes	
Tree vs. Sapling	Sweet Gum	Leaf-out	0.2326		
Shrub	Clethra, Blueberry, Paw Paw, Spicebush	Leaf-out	0.001	yes	
Shrub	Clethra, Paw Paw, Spicebush	Leaf-out	0.018	yes	n = 7 for both spicebush & paw paw
Shrub	Blueberry vs. Clethra	Leaf-out	0.07		(p=.048 adj for ties, very marginal and have been using the unadjusted result)

TABLE 14: Spring Plant Data - Descriptive Statistics

Group	Species	N	Factor	Median	Q1	Q3	Minimum	Maximum
Sapling		78	Bud Enlargement	3	2	4	1	5
Shrub		43	Bud Enlargement	2	1	4	1	10
Tree		85	Bud Enlargement	2	2	3	1	5
Tree	Red Maple	43	Bud Enlargement	3	2	4	1	5
Tree	Sweet Gum	42	Bud Enlargement	2	2	2	1	3
Sapling	Red Maple	43	Bud Enlargement	4	4	4	1	1
Sapling	Sweet Gum	35	Bud Enlargement	2	2	3	1	5
Sapling		91	Leaf Out	12	11	12	9	14
Shrub		72	Leaf Out	12	10	12	10	13
Tree		99	Leaf Out	12	11	13	10	14
Tree	Red Maple	50	Leaf Out	12	11.75	13	10	14
Tree	Sweet Gum	49	Leaf Out	12	11	12	10	14
Sapling	Red Maple	49	Leaf Out	12	11	12	9	14
Sapling	Sweet Gum	42	Leaf Out	11.5	10.75	12	10	14
Shrub	Blueberry	36	Leaf Out	11	10	12	10	13
Shrub	Clethra	22	Leaf Out	12	10	12	10	12
Shrub	Paw Paw	7	Leaf Out	13	12	13	12	13
Shrub	Spicebush	7	Leaf Out	12	12	12	12	12
Tree	Red Maple	48	Flowering	8	8	8	3	9
Sapling	Red Maple	21	Flowering	8	8	8.5	5	11
Tree	Sweet Gum	26	Flowering	10	9	11	9	12
Tree	Red Maple	24	Seed Set	10	10	10	10	11
Sapling	Red Maple	3	Seed Set	10	10	10	10	10
Tree	Sweet Gum	13	Seed Set	13	13	14	13	14
Shrub	Blueberry	18	Compound Flower Bud Opens	9	8	9.25	3	11
Shrub	Blueberry	15	Individual flowers open	12	11	12	10	14
Shrub	Blueberry	7	Fruits	14	14	14	13	14
Shrub	Spicebush	5	Compound Flower Bud Opens	7	7	8	7	9
Shrub	Spicebush	6	Individual flowers open	10	9	10	9	9

TABLE 15: Number of Days of Continuous Innundation or Saturation Needed to Meet Wetland Hydrology Criteria

site	Measured Growing Season (1)					County	Currently Used Growing Season (2)				
	Average Start*	Average End*	Average Length (days)**	Hydrology Criteria*** (# days to meet criteria)			Start	End	Length (days)	Hydrology Criteria*** (# days to meet criteria)	
				5%	12.5%					5%	12.5%
EL1	5-Feb	7-Jan	337	16.9	42.1	Gloucester	30-Mar	12-Nov	226	11.3	28.3
CS1	29-Jan	8-Jan	344	17.2	43.0	Gloucester	30-Mar	12-Nov	226	11.3	28.3
CS2	1-Jan	31-Dec	365	18.3	45.6	Gloucester	30-Mar	12-Nov	226	11.3	28.3
SF1	1-Jan	31-Dec	365	18.3	45.6	York	30-Mar	12-Nov	226	11.3	28.3
SF2	24-Jan	12-Jan	353	17.7	44.1	York	30-Mar	12-Nov	226	11.3	28.3
SB1	1-Jan	31-Dec	365	18.3	45.6	City of Hampton	10-Mar	29-Nov	264	13.2	33.0
SB2	1-Jan	31-Dec	365	18.3	45.6	City of Hampton	10-Mar	29-Nov	264	13.2	33.0

(1) Growing season as defined by soil temperatures above 5°C at 50 cm depth

(2) Growing season as estimated from the air temperature using the 28°F threshold (tables in county soil survey reports)

* Average start and end of measured growing season calculated for each site from 3 years of measured start and end dates. (Fall 1999 to Spring 2002)

** Average growing season length calculated as average of three measured growing seasons.

*** Wetland hydrology criteria: Continuous innundation or saturation for 5% (with other evidence) or 12.5% of the growing season; innundation or saturation defined as period when groundwater is at or within 30 cm of the soil surface or when water level are above the soil surface.

TABLE 16: Impact of Growing Season Length on Whether Research Sites Meet Wetland Hydrology Criteria

	year	1999				2000				2001				2002			
		Longest period of continuous inundation &/or saturation (1)		Does site meet wetland hydrology thresholds? (2)		Longest period of continuous inundation &/or saturation (1)		Does site meet wetland hydrology thresholds? (2)		Longest period of continuous inundation &/or saturation (1)		Does site meet wetland hydrology thresholds? (2)		Longest period of continuous inundation &/or saturation (1)		Does site meet wetland hydrology thresholds? (2)	
site		# of days	% of Growing Season	5 - 12.5%	>12.5%	# of days	% of Growing Season	5 - 12.5%	>12.5%	# of days	% of Growing Season	5 - 12.5%	>12.5%	# of days	% of Growing Season	5 - 12.5%	>12.5%
EL1	MGS	86	25.5	Y	Y	90	26.7	Y	Y	79	23.4	Y	Y	53	15.7	Y	Y
	EGS	41	18.1	Y	Y	37	16.4	Y	Y	26	11.5	Y	▨	26	11.5	Y	▨
CS1	MGS	53	15.4	Y	Y	103	30	Y	Y	105	30.5	Y	Y	n/a	n/a		
	EGS	53	23.5	Y	Y	91	40.3	Y	Y	46	20.4	Y	Y	n/a	n/a		
CS2	MGS	n/a	n/a			63	17.3	Y	Y	n/a	n/a			n/a	n/a		
	EGS	n/a	n/a			16	7.1	Y	▨	n/a	n/a			n/a	n/a		
SF1	MGS	44	12	Y	?	126	34.5	Y	Y	84	23	Y	Y	7	1.9	?	?
	EGS	41	18.1	Y	Y	38	16.8	Y	Y	32	14.1	Y	Y	7	3.1	?	?
SF2	MGS	n/a	n/a			44	12.5	Y	NO	77	21.8	Y	Y	n/a	n/a		
	EGS	n/a	n/a			36	15.9	Y	Y	25	11.1	Y	▨	n/a	n/a		
SB1	MGS	42	11.5	Y		55	15.1	Y	Y	0	0	NO	NO	1.5	0.4	?	?
	EGS	42	15.9	Y	Y	55	20.8	Y	Y	0	0	NO	NO	1.5	0.6	?	?
SB2	MGS	43	11.8	Y	?	122	33.4	Y	Y	3	0.8	?	?	8	2.2	?	?
	EGS	43	16.3	Y	Y	58	22	Y	Y	3	1.1	?	?	8	3	?	?

MGS = Measured Growing Season

EGS = Estimated Growing Season (based on air temperatures and found in the County Soil Survey Reports)

(1) Inundation or saturation defined as period when groundwater is at or within 30 cm of the soil surface or when water levels are above the soil surface.

(2) Continuous inundation or saturation for 5 - 12.5% (with other evidence) or > 12.5% of the growing season.

? = need a more complete well record before evaluating

▨ "= when meets hydrology for measured growing season but not estimated growing season"

NOTES:

EL1	1999 record starts 2/13 (impacts 1999 % hydro for MGS) ; 2002 record ends 4/24 (impacts 2002 % hydro for MGS)
CS1	1999 record starts 4/3 (impacts 1999 % hydro for MGS); 2001 record ends 6/5
CS2	1999 - Missing over 50% of well record; 2001 & 2002 - broken well not replaced
SF1	1999 - record starts 3/27 (impacts 1999 hydro % for MGS); 2002 - record end 4/27
SF2	2000 - record starts 1/11 & missing data 3/9-25 (impacts % hydro for MGS); 2001 - record ends 12/17 & well not replaced
SB1	1999 - record starts 2/14; 2002 - record ends 4/25
SB2	1999 - record starts 2/26 (impacts 1999 hydro % for MGS); 2002 - record ends 4/25

FIGURE 1. Location of Research Sites on the Coastal Plain of SE Virginia

Location of Research Sites

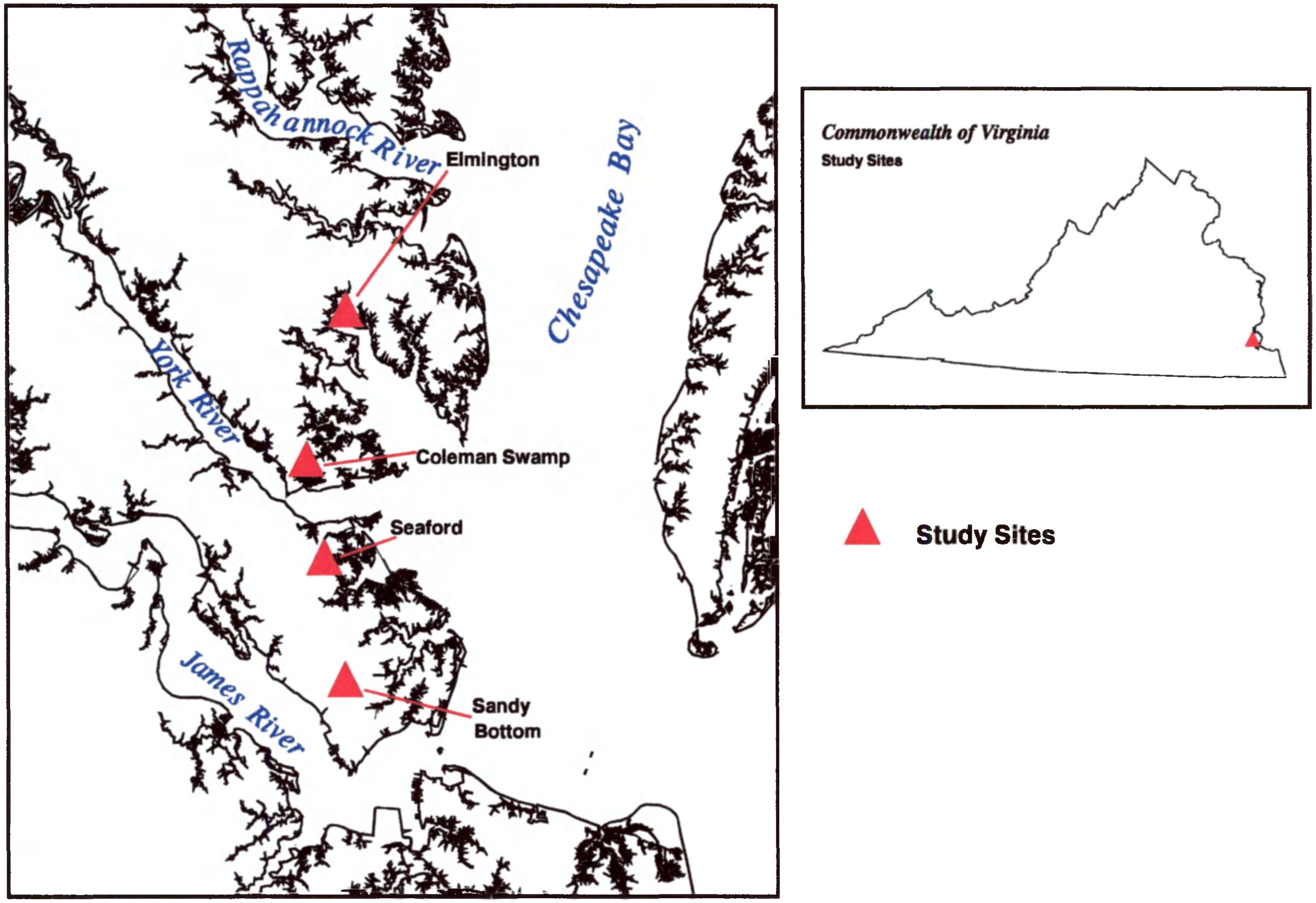


FIGURE 2. Diagram Showing Precipitation Minus Potential Evapotranspiration for Southeast Virginia (Adapted from Virginia State Climatology Office 2003)

Precipitation Minus Potential Evapotranspiration for Southeast Virginia

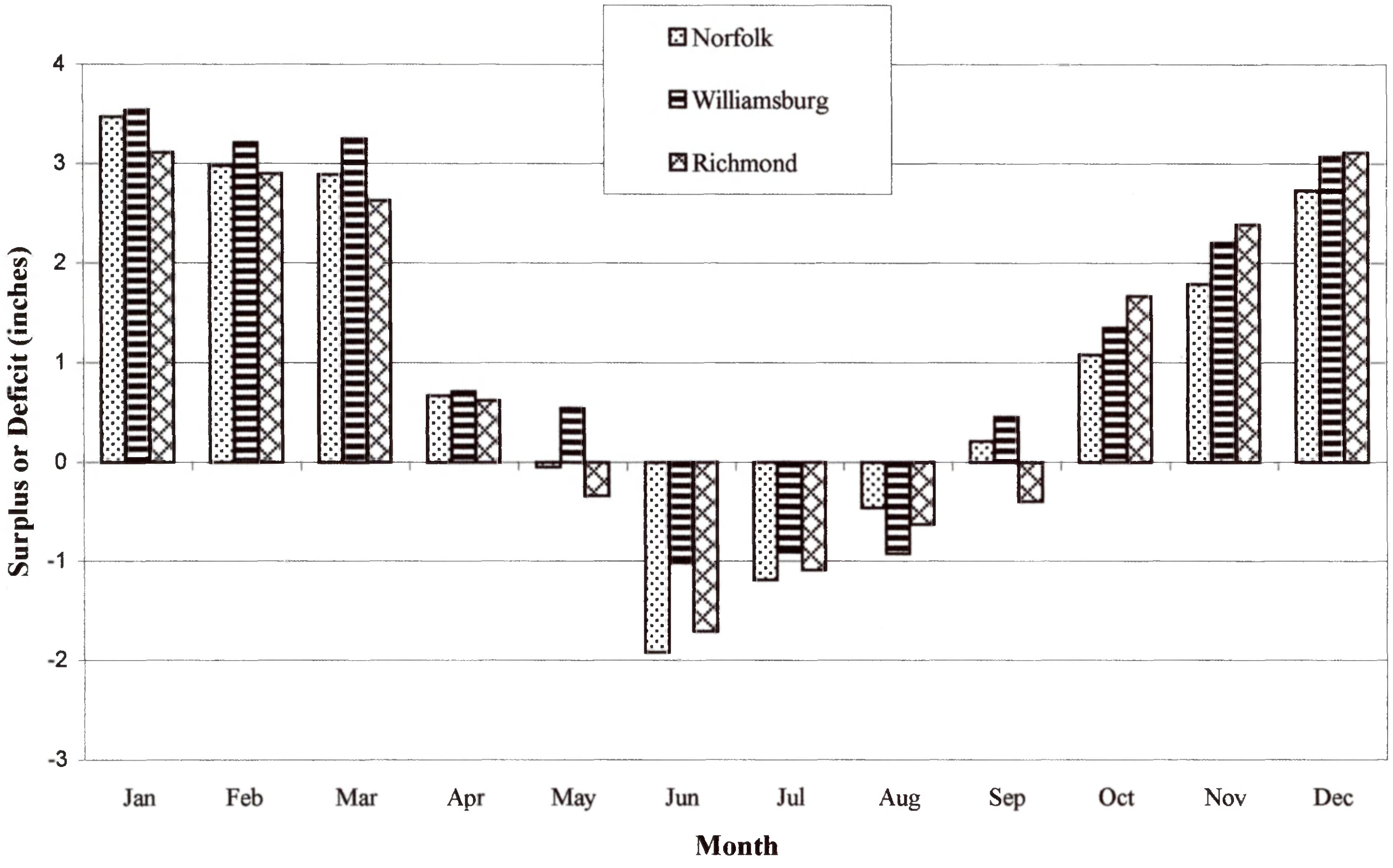


FIGURE 3. An example of the relationship between the air, deep soil, and shallow soil temperatures over the course of a year. The graph shows the air, 10 cm soil, and 50 cm soil temperatures from October 2000 to September 2001 for Elmington.

October 2000 to September 2001 Elmington (EL1)
Air, 10 cm Soil, and 50 cm Soil Temperatures

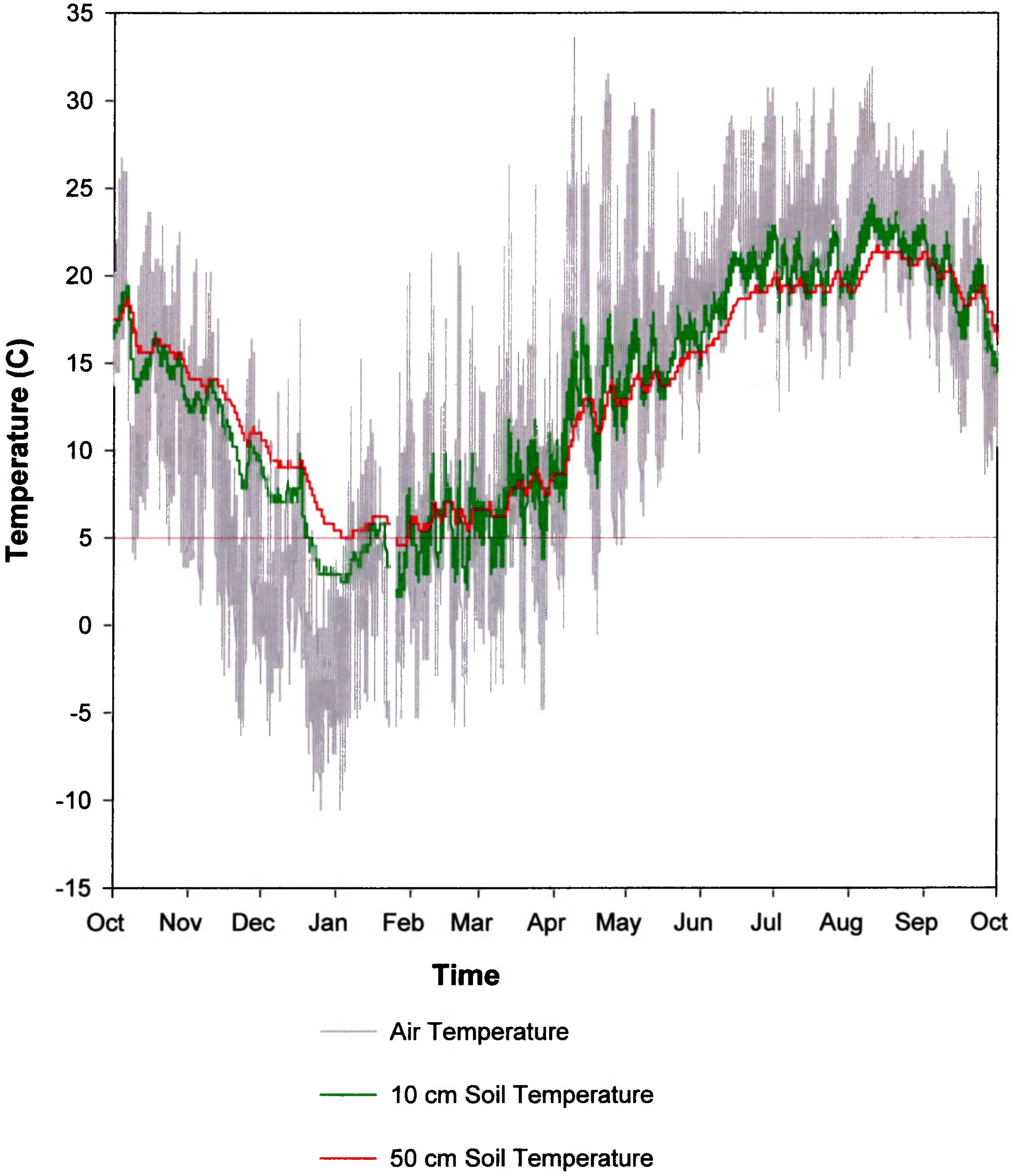


FIGURE 4. Proportion of 10 cm Non-Growing Season with Soil Temperatures ≤ 5°C

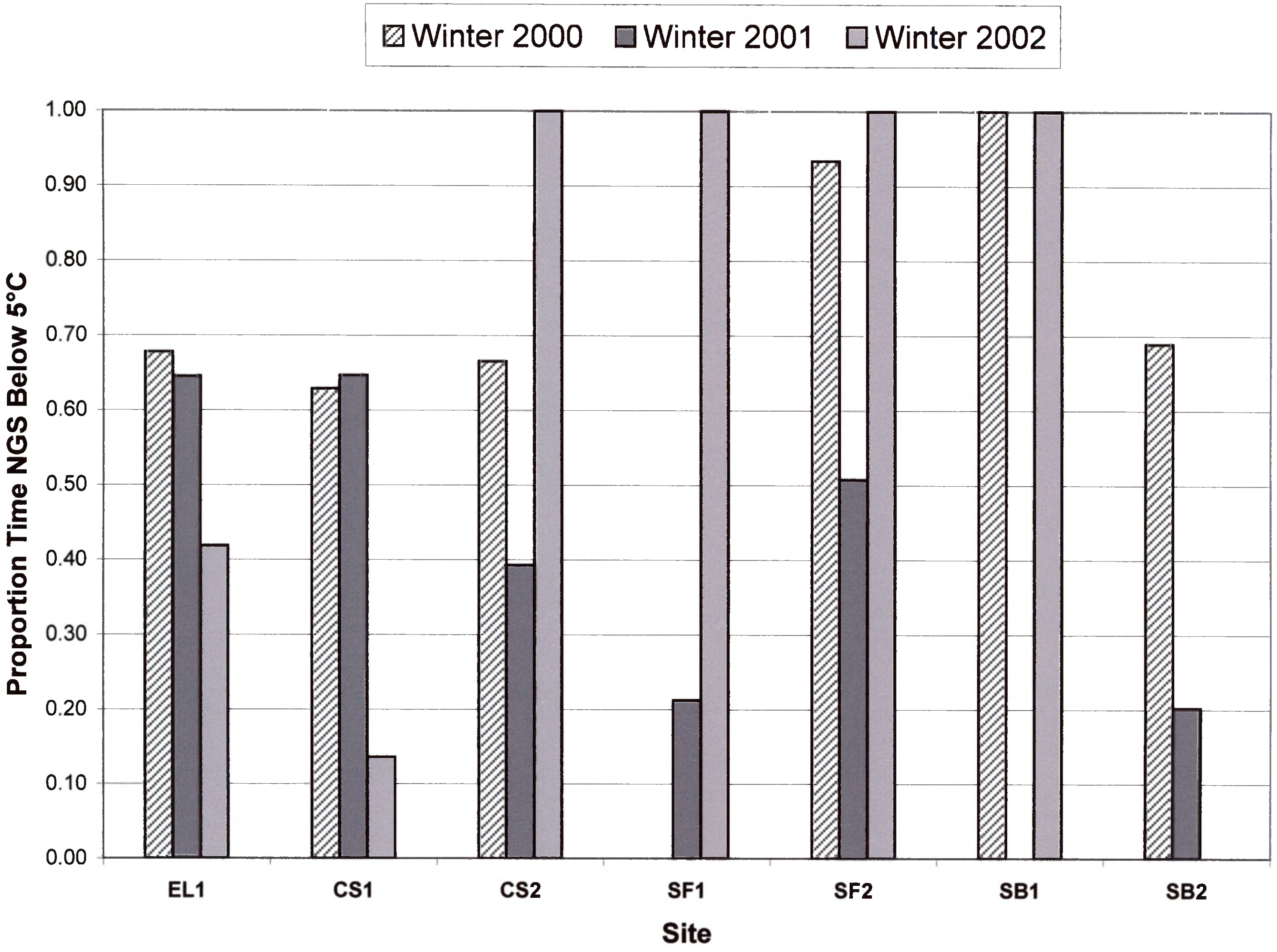

▨ Winter 2000
■ Winter 2001
□ Winter 2002
Proportion Time NGS Below 5°C
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
EL1
CS1
CS2
SF1
SF2
SB1
SB2
Site

FIGURE 5. 1999 to 2002 Measured Growing Season for 10 cm Soil Depth Compared to the Accepted Growing Season

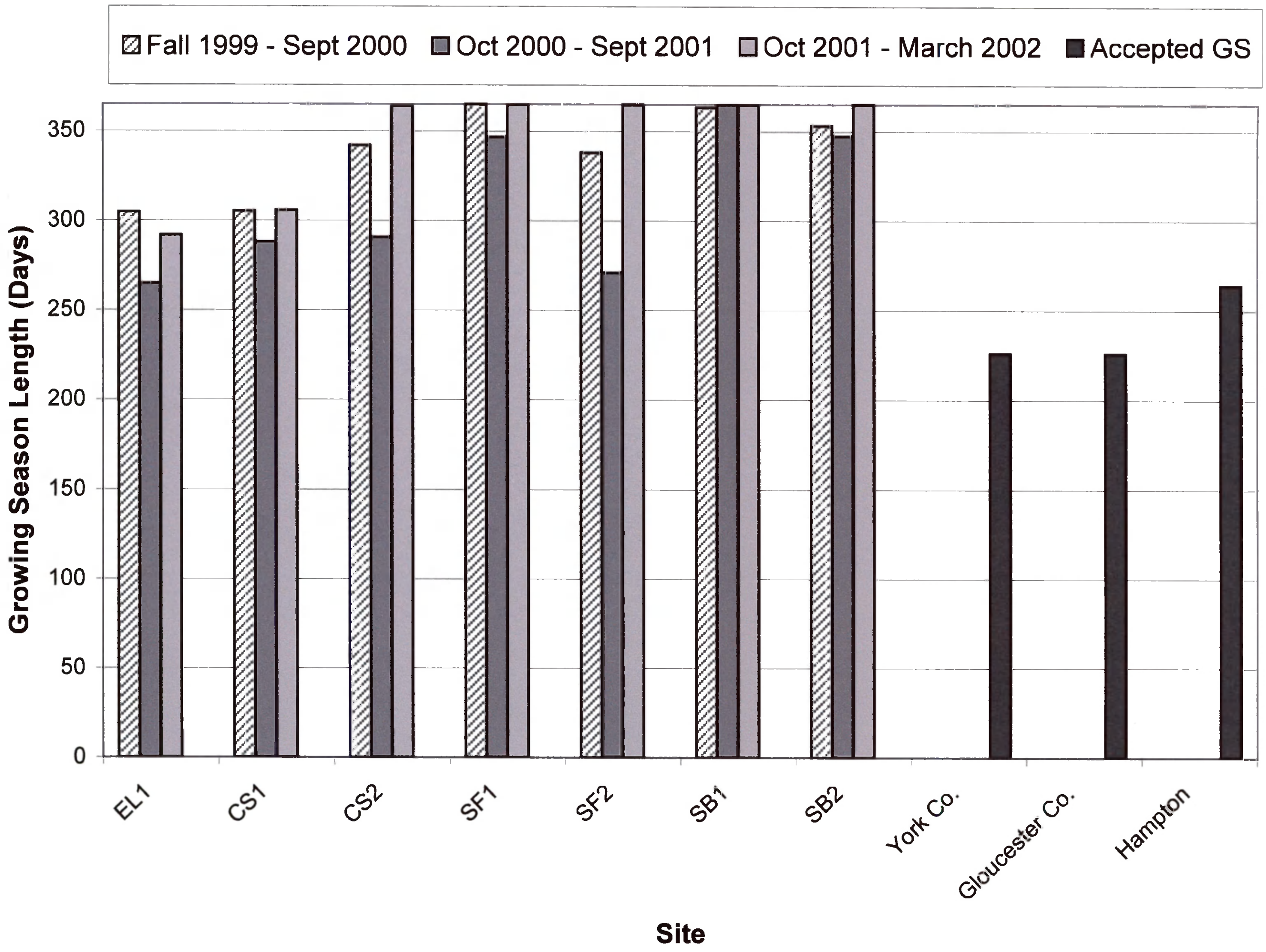

Fall 1999 - Sept 2000
Oct 2000 - Sept 2001
Oct 2001 - March 2002
Accepted GS
Growing Season Length (Days)
0
50
100
150
200
250
300
350
EL1
CS1
CS2
SF1
SF2
SB1
SB2
York Co.
Gloucester Co.
Hampton
Site

FIGURE 6. Proportion of 50 cm Non-Growing Season with Soil Temperatures ≤ 5°C

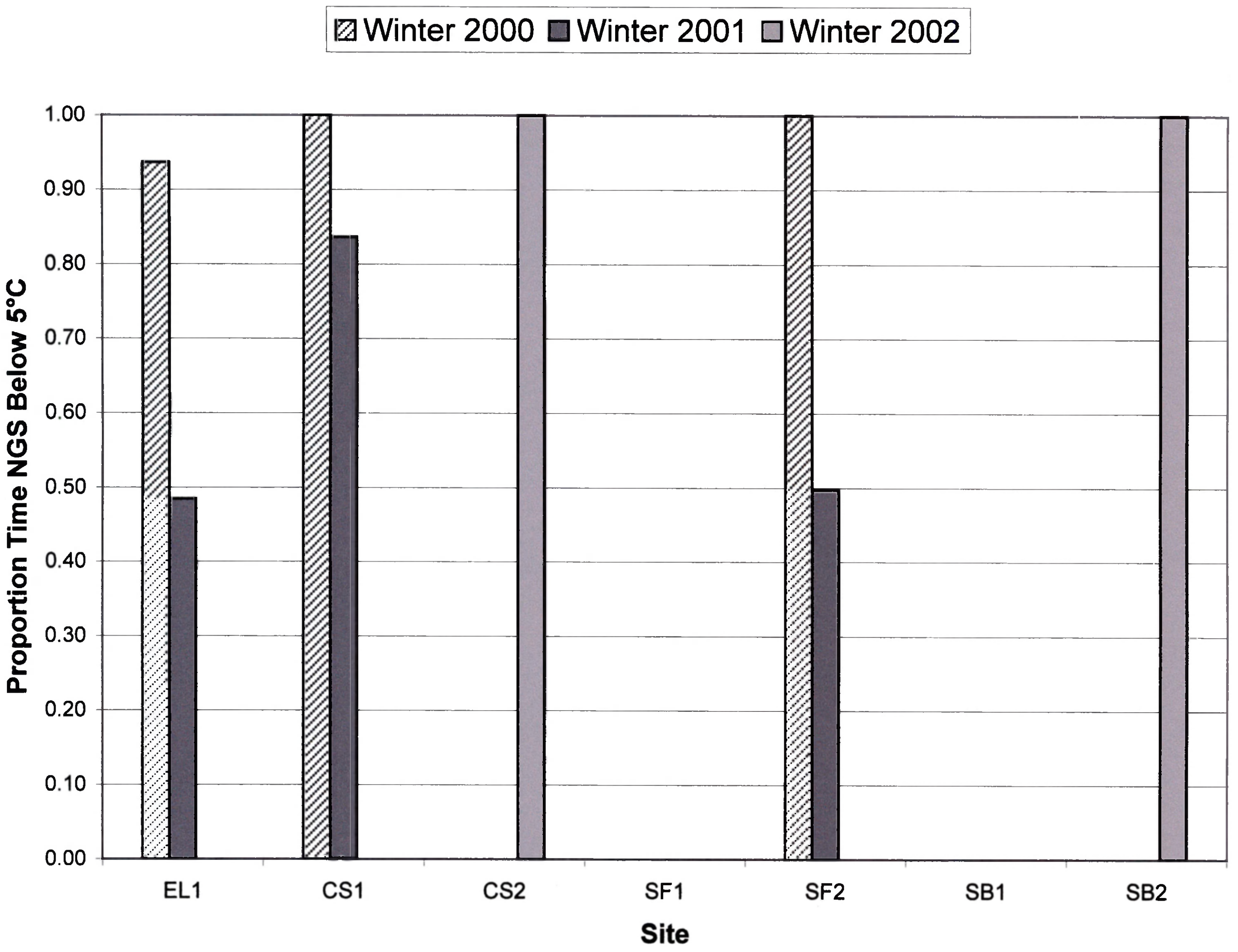
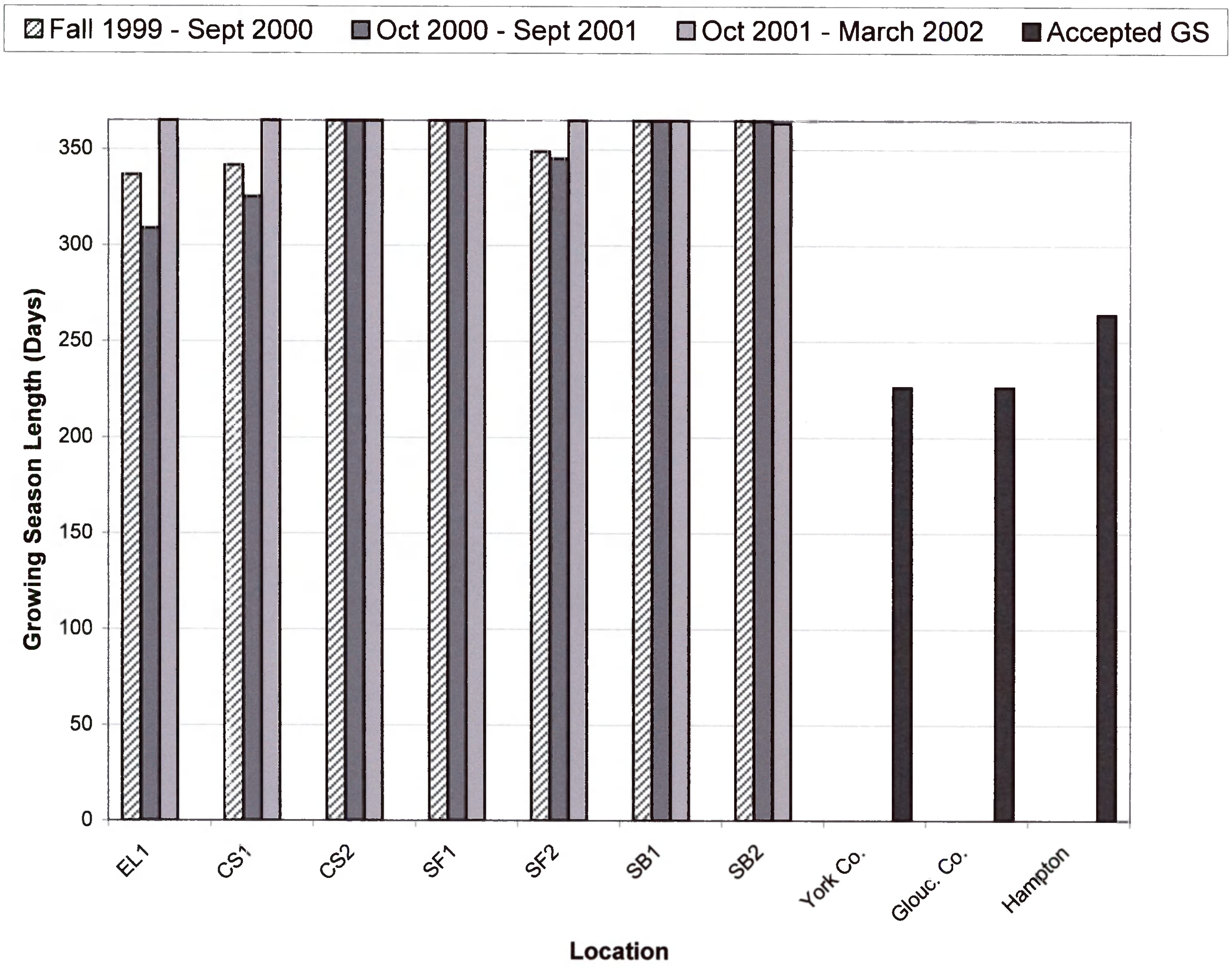

▨ Winter 2000
■ Winter 2001
■ Winter 2002
Proportion Time NGS Below 5°C
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
EL1
CS1
CS2
SF1
SF2
SB1
SB2
Site

FIGURE 7. 1999 to 2002 Measured Growing Season for 50 cm Soil Depth Compared to the Accepted Growing Season



▨ Fall 1999 - Sept 2000
■ Oct 2000 - Sept 2001
■ Oct 2001 - March 2002
■ Accepted GS
Growing Season Length (Days)
350
300
250
200
150
100
50
0
EL1
CS1
CS2
SF1
SF2
SB1
SB2
York Co.
Glouc. Co.
Hampton
Location

FIGURE 8. Norfolk, Virginia Seasonal and Yearly Precipitation Totals for 1998 to 2002 (Data from National Climatic Data Center 2003)

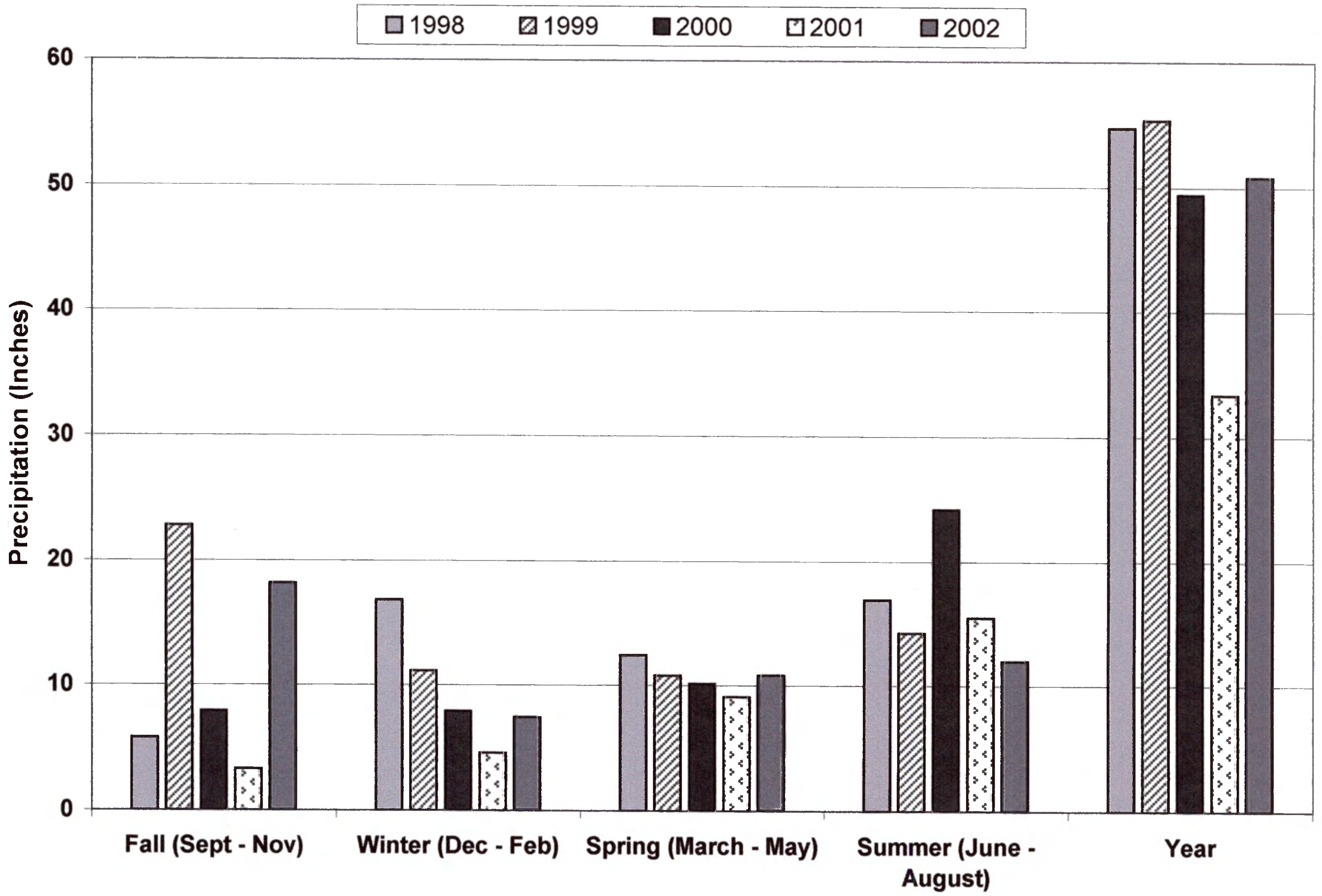

1998
1999
2000
2001
2002
Precipitation (Inches)
60
50
40
30
20
10
0
Fall (Sept - Nov)
Winter (Dec - Feb)
Spring (March - May)
Summer (June - August)
Year

FIGURE 9. Norfolk, Virginia Seasonal and Yearly Precipitation Rankings for 1998 to 2002. Period of Record for Ranks is 1895 to 2003. Low value is drier and high value is wetter. (Data from National Climatic Data Center 2003)

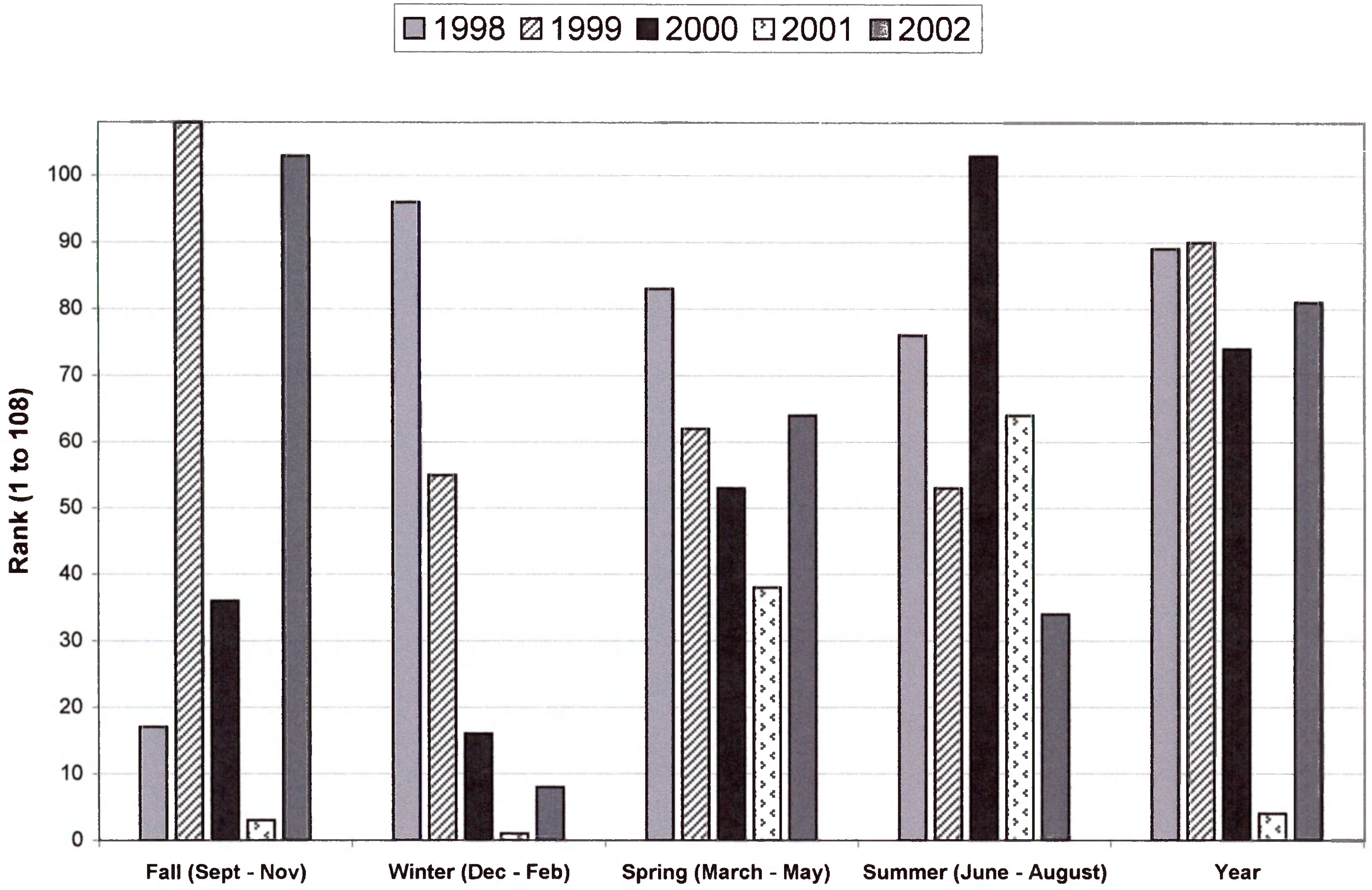

1998
1999
2000
2001
2002
Rank (1 to 108)
100
90
80
70
60
50
40
30
20
10
0
Fall (Sept - Nov)
Winter (Dec - Feb)
Spring (March - May)
Summer (June - August)
Year

FIGURE 10. Norfolk, Virginia Seasonal and Yearly Average Air Temperature (°F) for 1998 to 2002 (Data from National Climatic Data Center 2003)

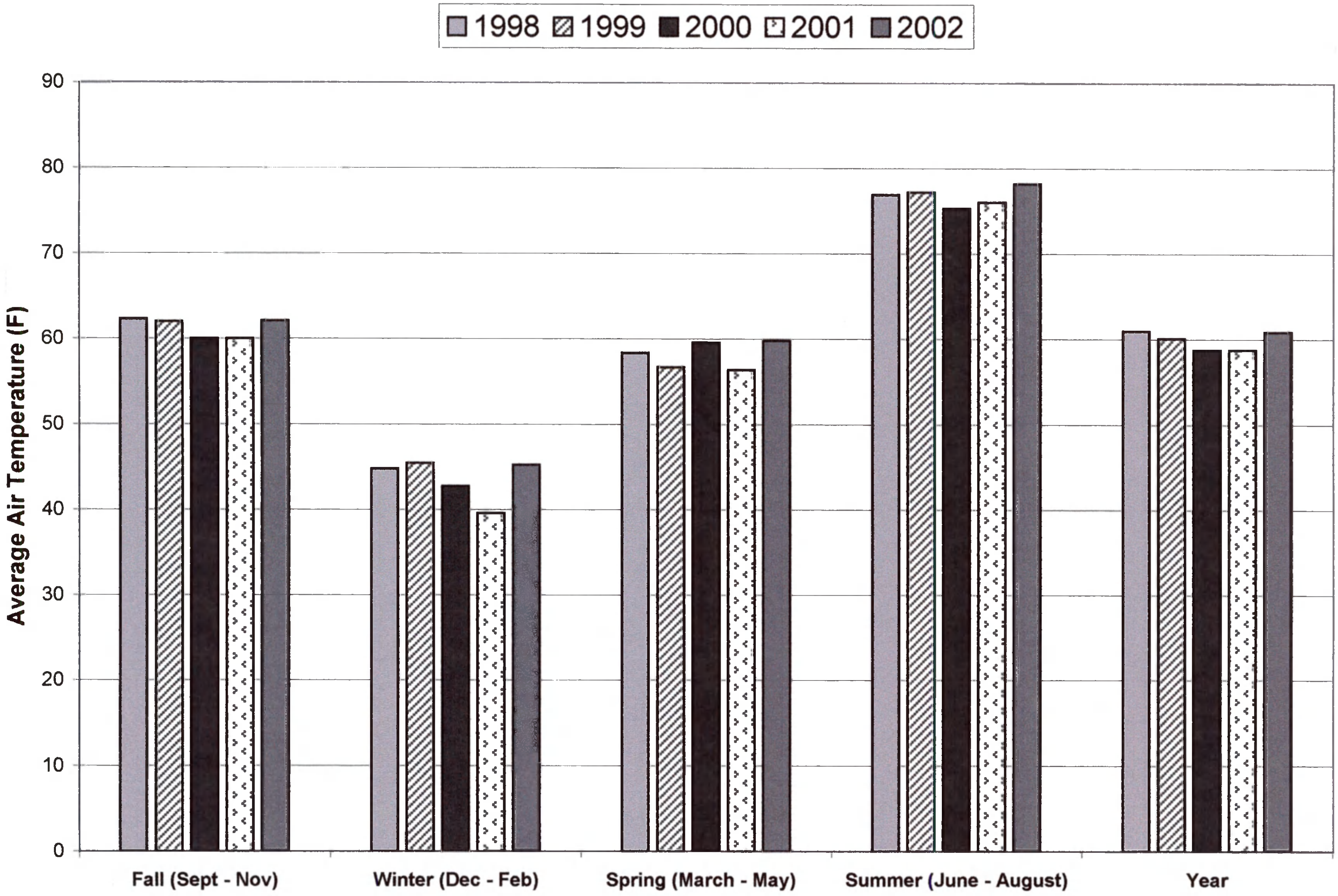

1998
1999
2000
2001
2002
Average Air Temperature (F)
90
80
70
60
50
40
30
20
10
0
Fall (Sept - Nov)
Winter (Dec - Feb)
Spring (March - May)
Summer (June - August)
Year

FIGURE 11. Norfolk, Virginia Seasonal and Yearly Air Temperature Ranks for 1998 to 2002. Period of record for ranks is 1895 to 2003. Low rank is cooler and high rank is warmer. (Data from National Climatic Data Center 2003)

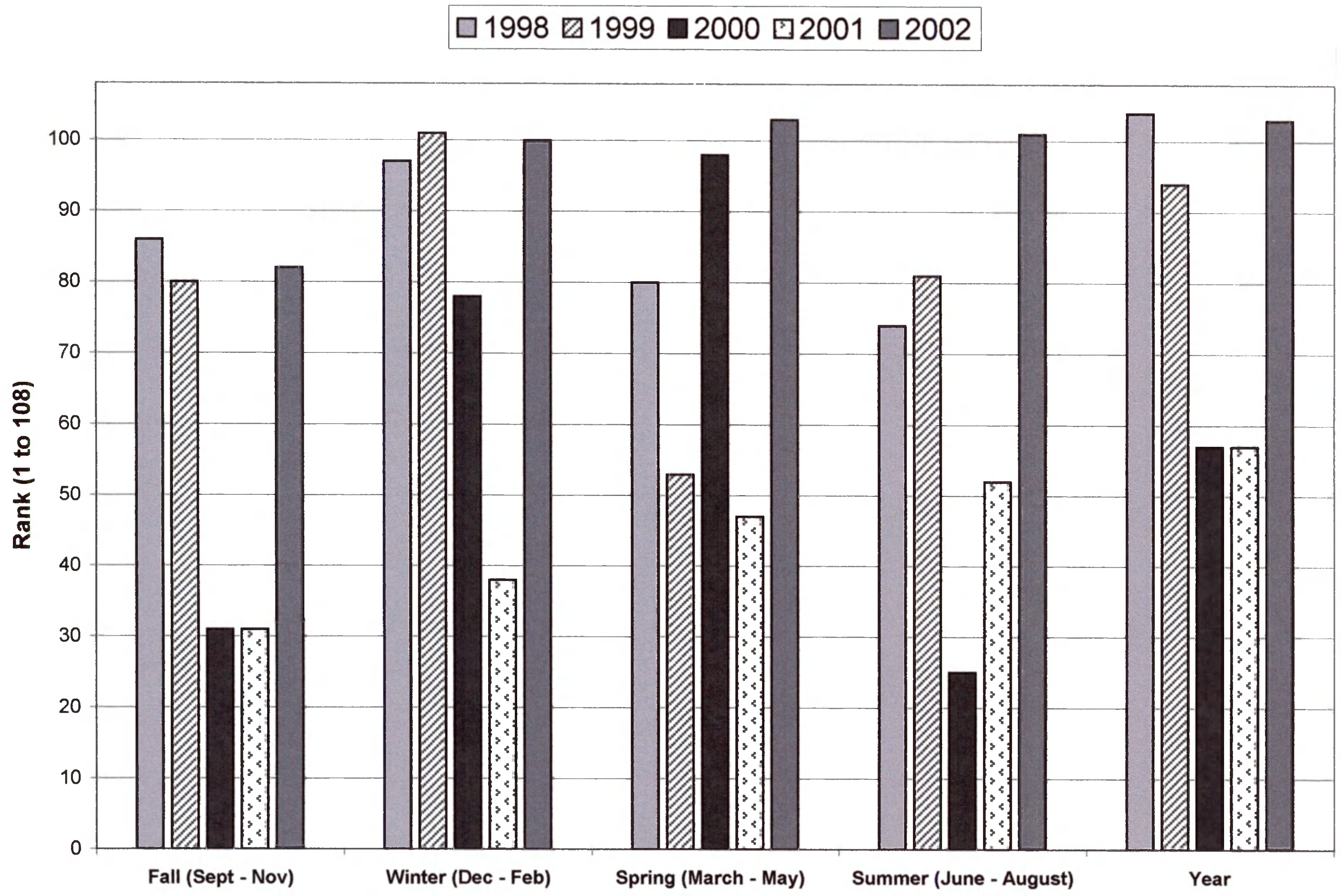

1998
1999
2000
2001
2002
Rank (1 to 108)
100
90
80
70
60
50
40
30
20
10
0
Fall (Sept - Nov)
Winter (Dec - Feb)
Spring (March - May)
Summer (June - August)
Year

FIGURE 12. Diagram of 10 cm and 50 cm Soil Temperature Recorder Deployment. Figure shows position of the soil temperature recorders in the soil. (Diagram not to scale.)

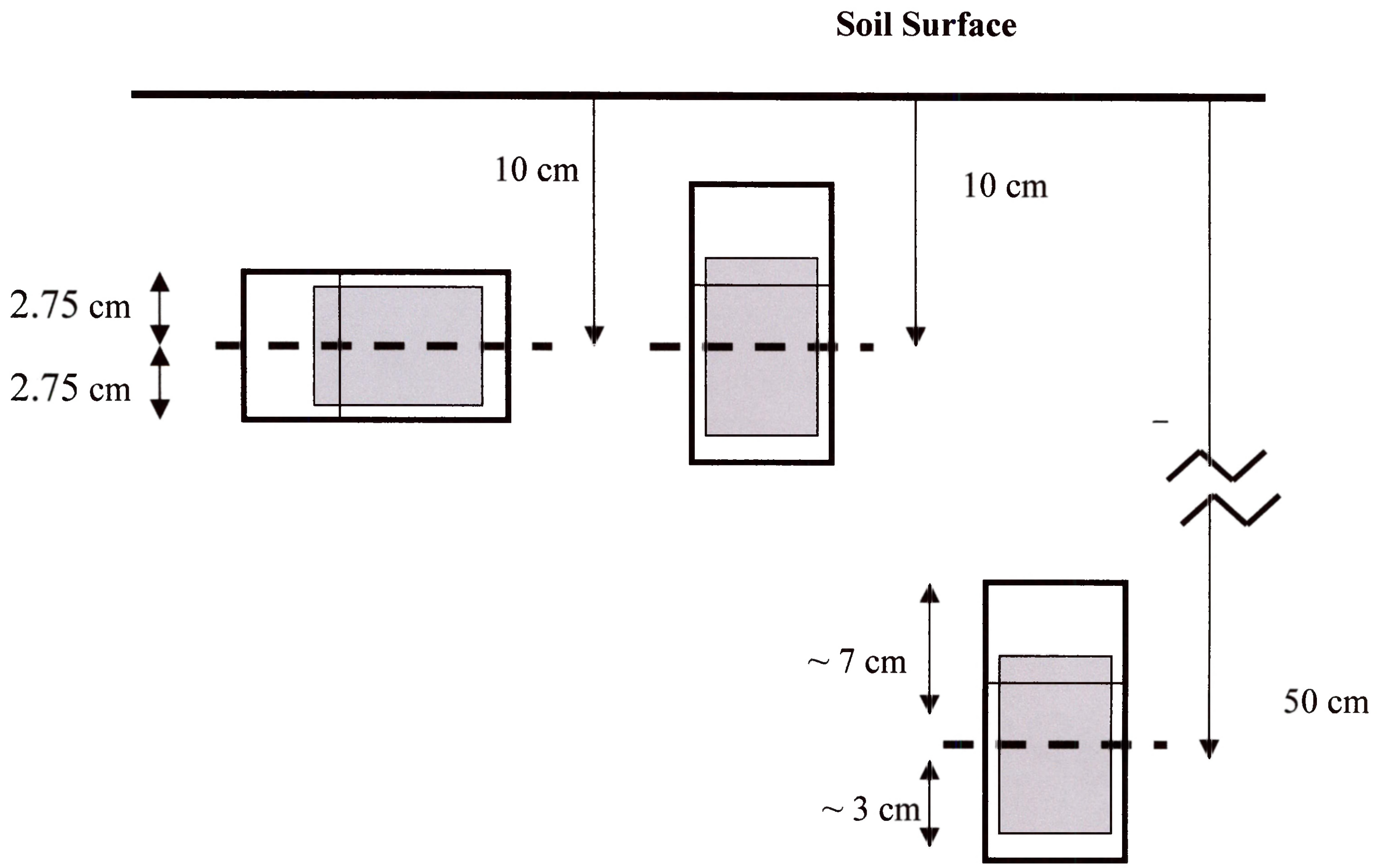

Soil Surface
10 cm
10 cm
2.75 cm
2.75 cm
~ 7 cm
~ 3 cm
50 cm

FIGURE 13. Measured Growing Season (based on 50-cm soil temperatures) vs. Estimated Growing Seasons from Sept 1, 1999 to March 31, 2002 (Green = Growing Season, Black = Non-Growing Season). The currently used growing seasons for the City of Hampton (HamptonGS) and York County and Gloucester County (York/Gloucester GS) are also indicated.

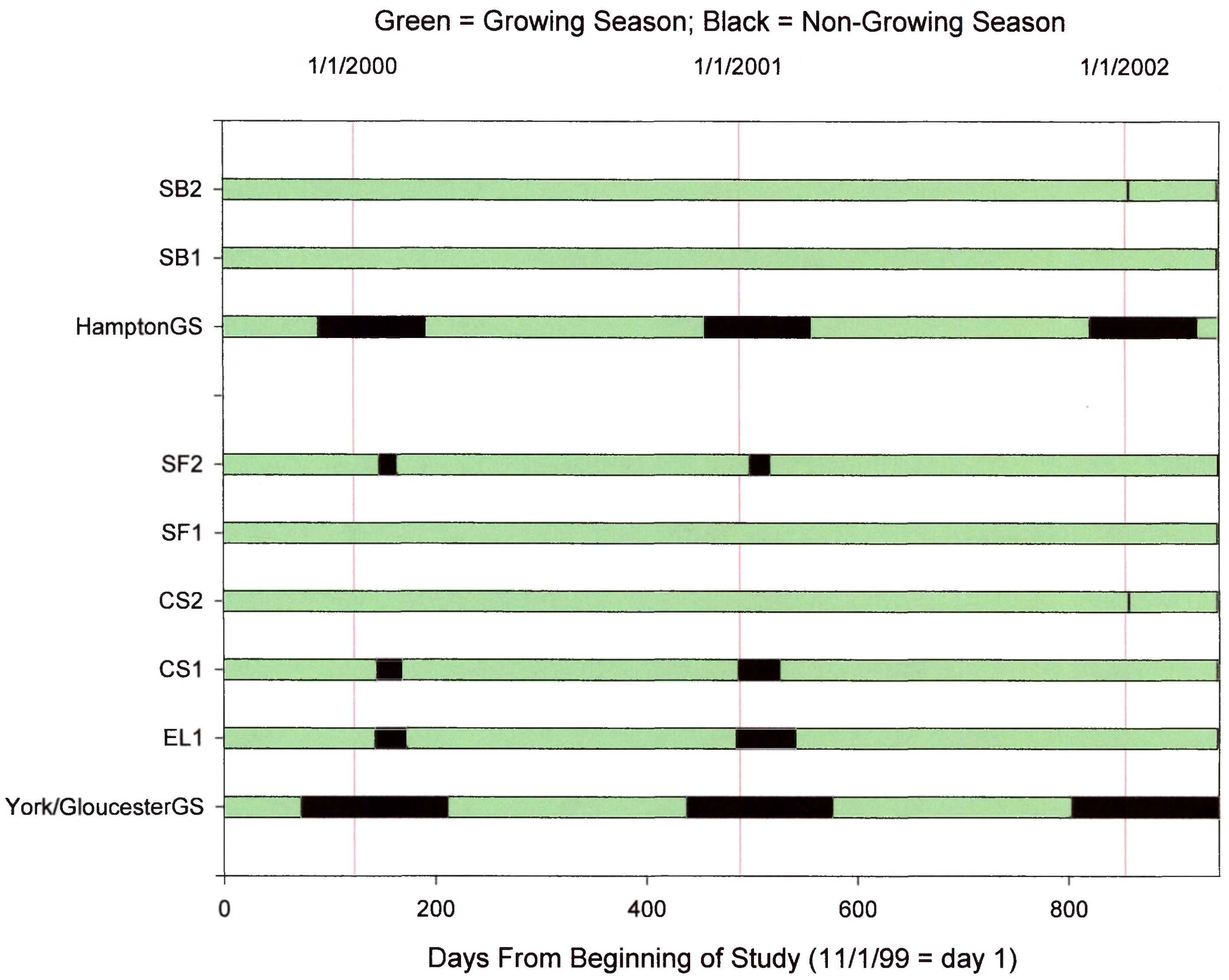

Green = Growing Season; Black = Non-Growing Season
1/1/2000
1/1/2001
1/1/2002
SB2
SB1
HamptonGS
SF2
SF1
CS2
CS1
EL1
York/GloucesterGS
0
200
400
600
800
Days From Beginning of Study (11/1/99 = day 1)

FIGURE 14. Maximum and Minimum 50 cm Depth Soil Temperatures for Each Research Site (for years 2000-2002)

Max and Min 50 cm Soil Temperatures by Site (for years 2000 - 2002)

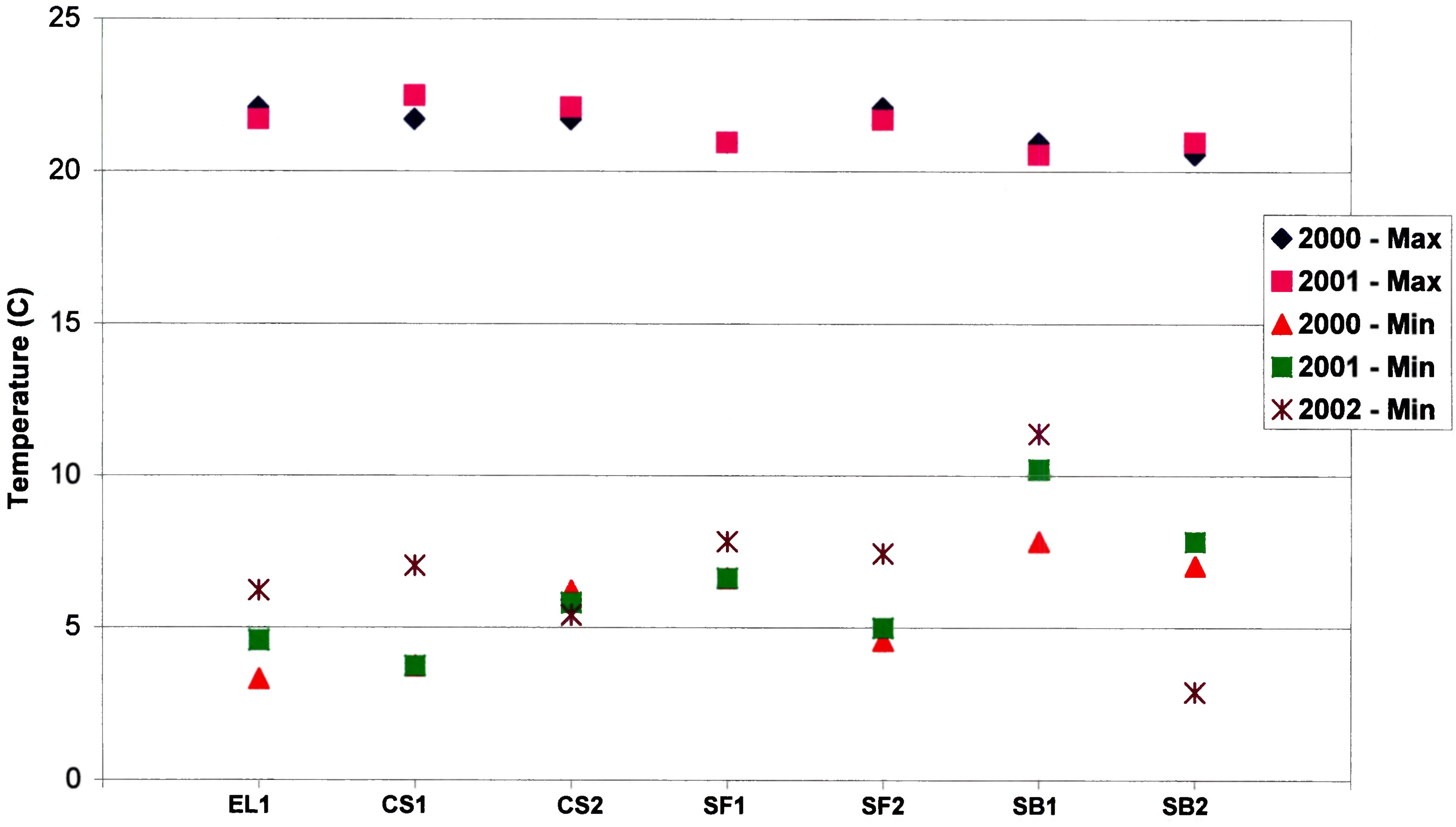


FIGURE 15. Maximum and Minimum 50 cm Depth Soil Temperatures for Research Sites by Year (2000 – 2002)

Maximum and Minimum 50 cm Soil Temperatures by Year

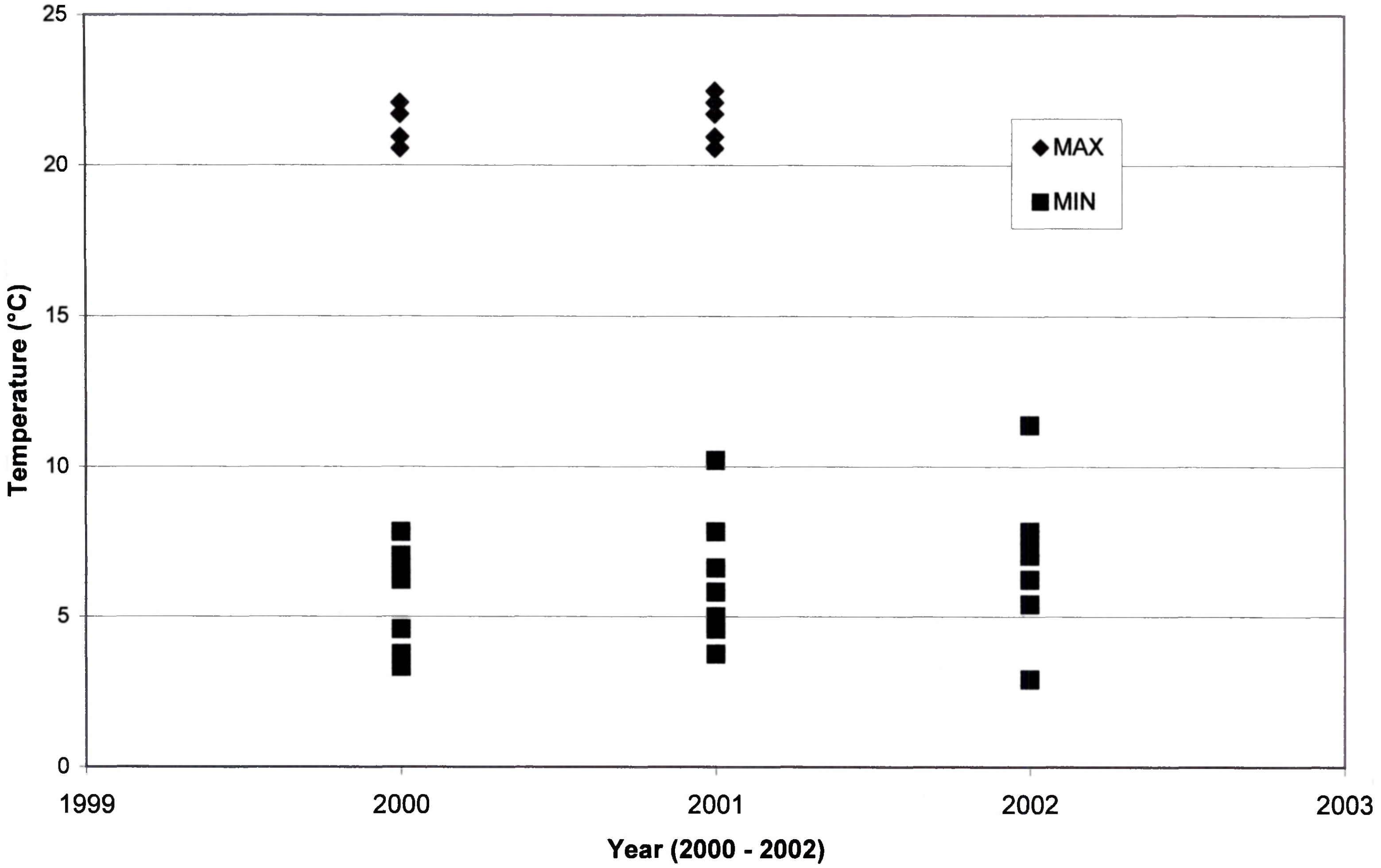


FIGURE 16. Maximum and Minimum 10 cm Depth Soil Temperatures for Each Research Site (for years 2000 - 2002)

Maximum & Minimum 10 cm Depth Soil Temperatures by Site (for years 2000 - 2002)

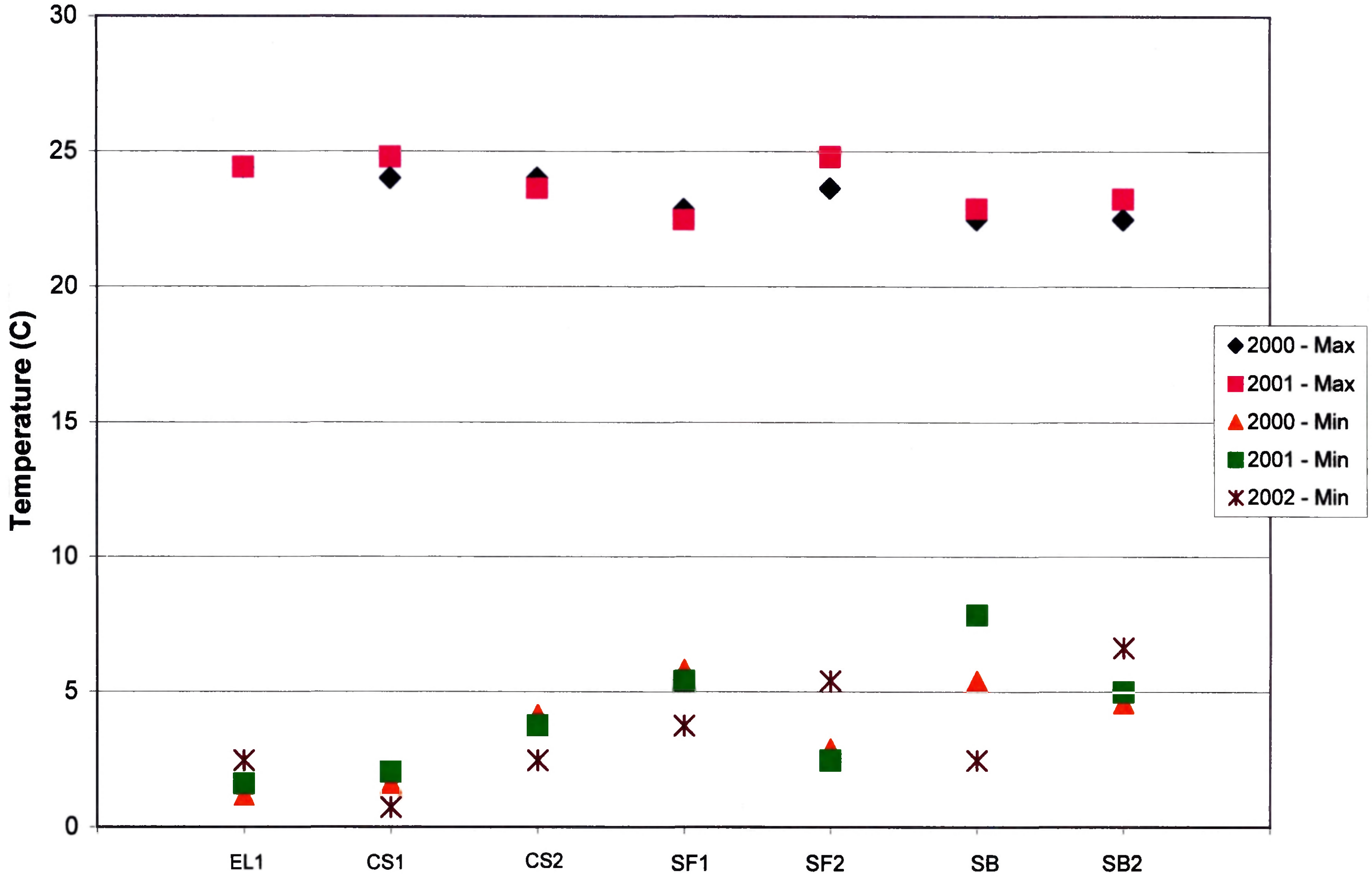


FIGURE 17. Maximum and Minimum 10 cm Depth Soil Temperatures for Research Sites by Year (2000 – 2002)

Maximum and Minimum 10 cm Soil Temperatures by Year

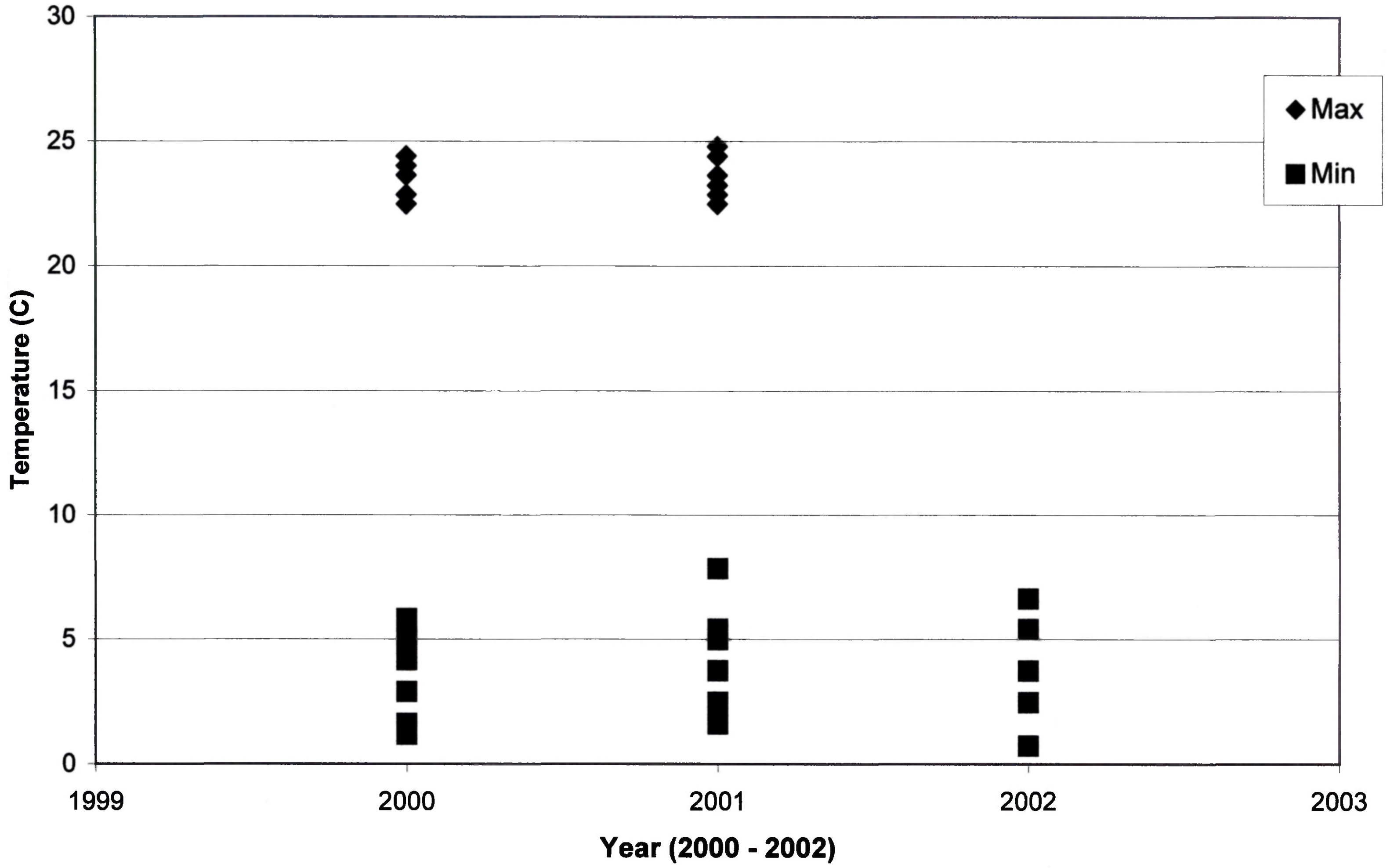


FIGURE 18. Soil Profiles for Each Research Site (Data from Havens et al. 2001)

Soil Profiles

(10 cm and 50 cm soil temperature measurement depths are indicated)

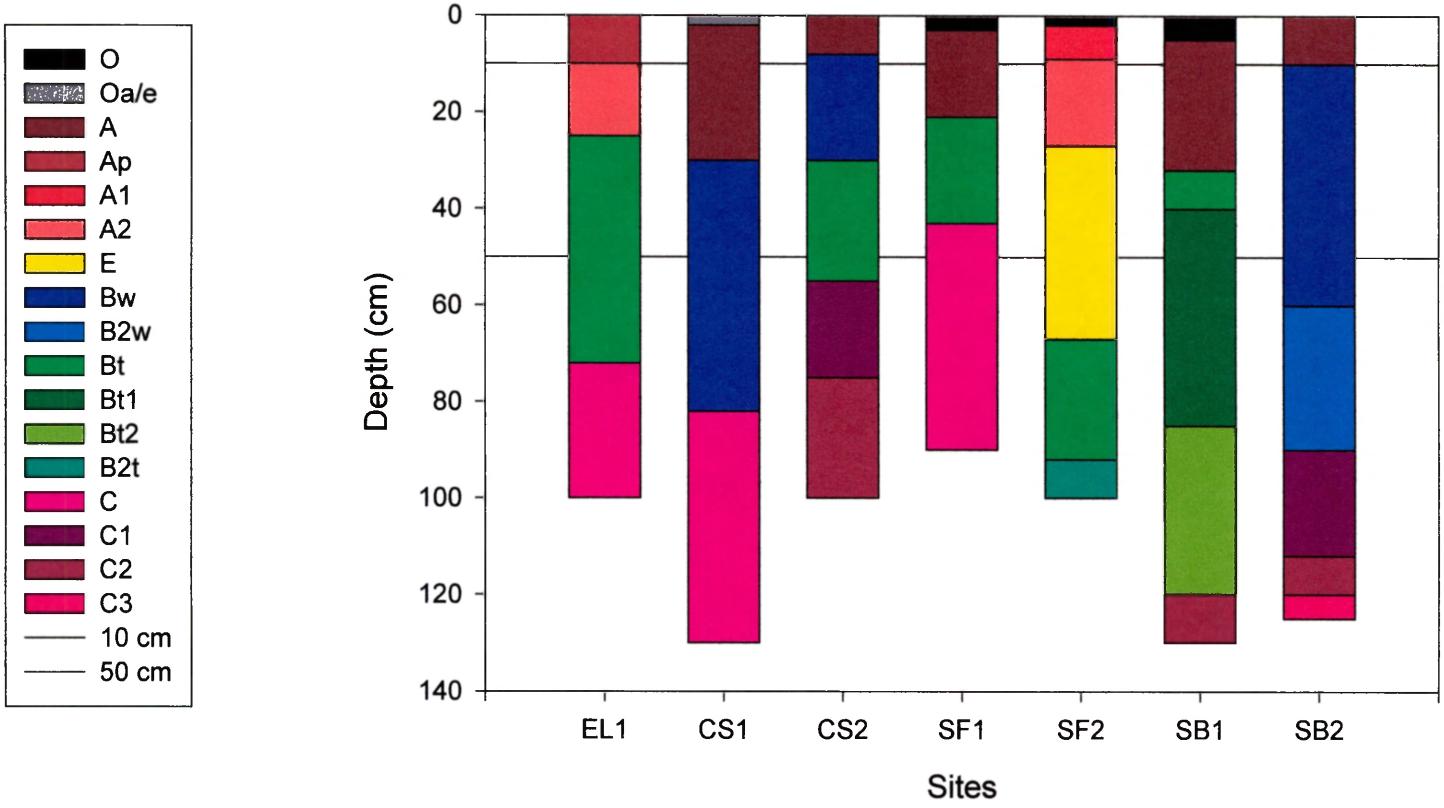


FIGURE 19. Fall Tree and Sapling Leaf Attachment for Red Maple (*Acer rubrum*)

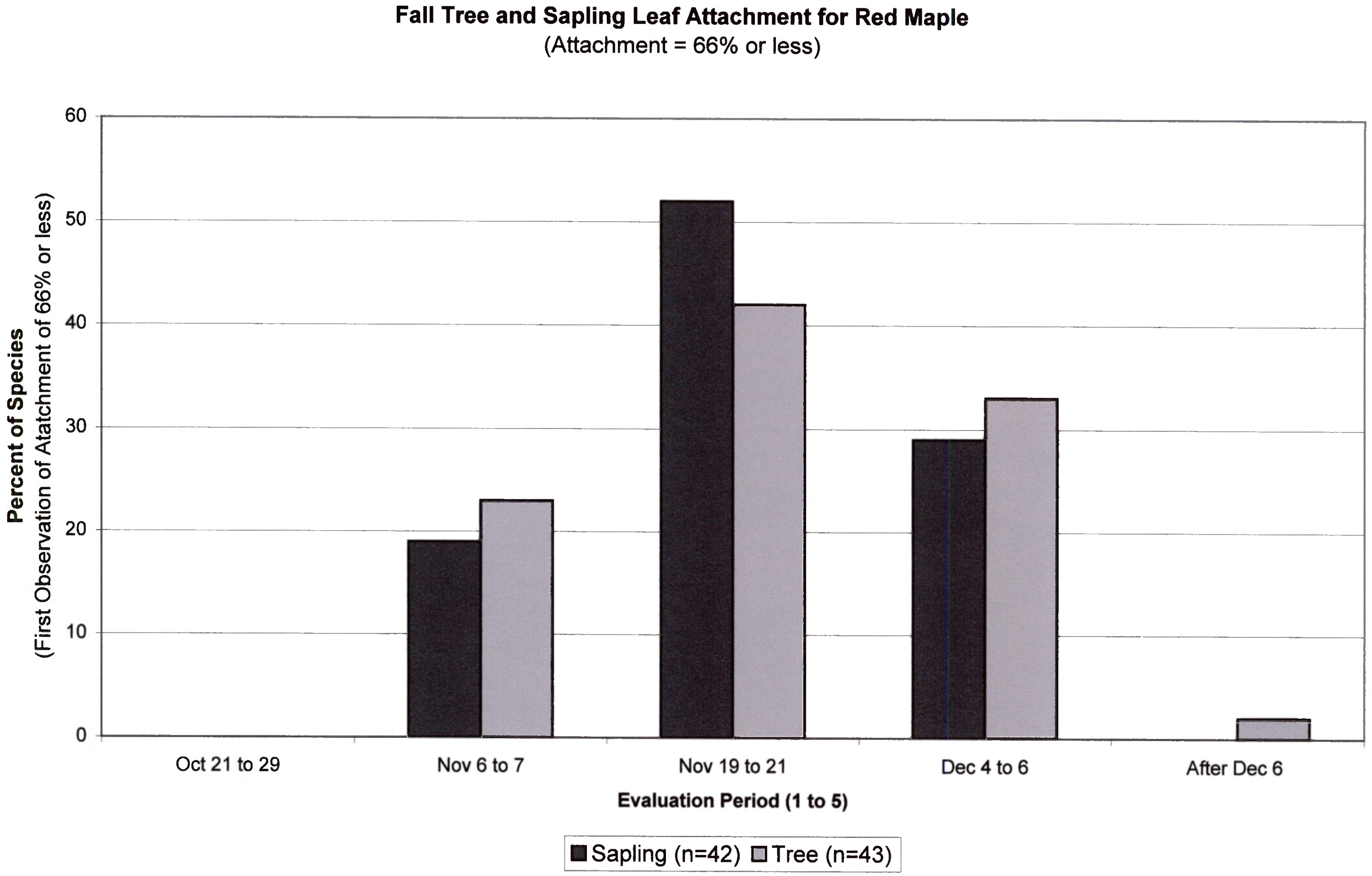

Fall Tree and Sapling Leaf Attachment for Red Maple
(Attachment = 66% or less)
Percent of Species
(First Observation of Atatchment of 66% or less)
60
50
40
30
20
10
0
Oct 21 to 29
Nov 6 to 7
Nov 19 to 21
Dec 4 to 6
After Dec 6
Evaluation Period (1 to 5)
Sapling (n=42)
Tree (n=43)

FIGURE 20. Fall Tree Leaf Color Change and Attachment

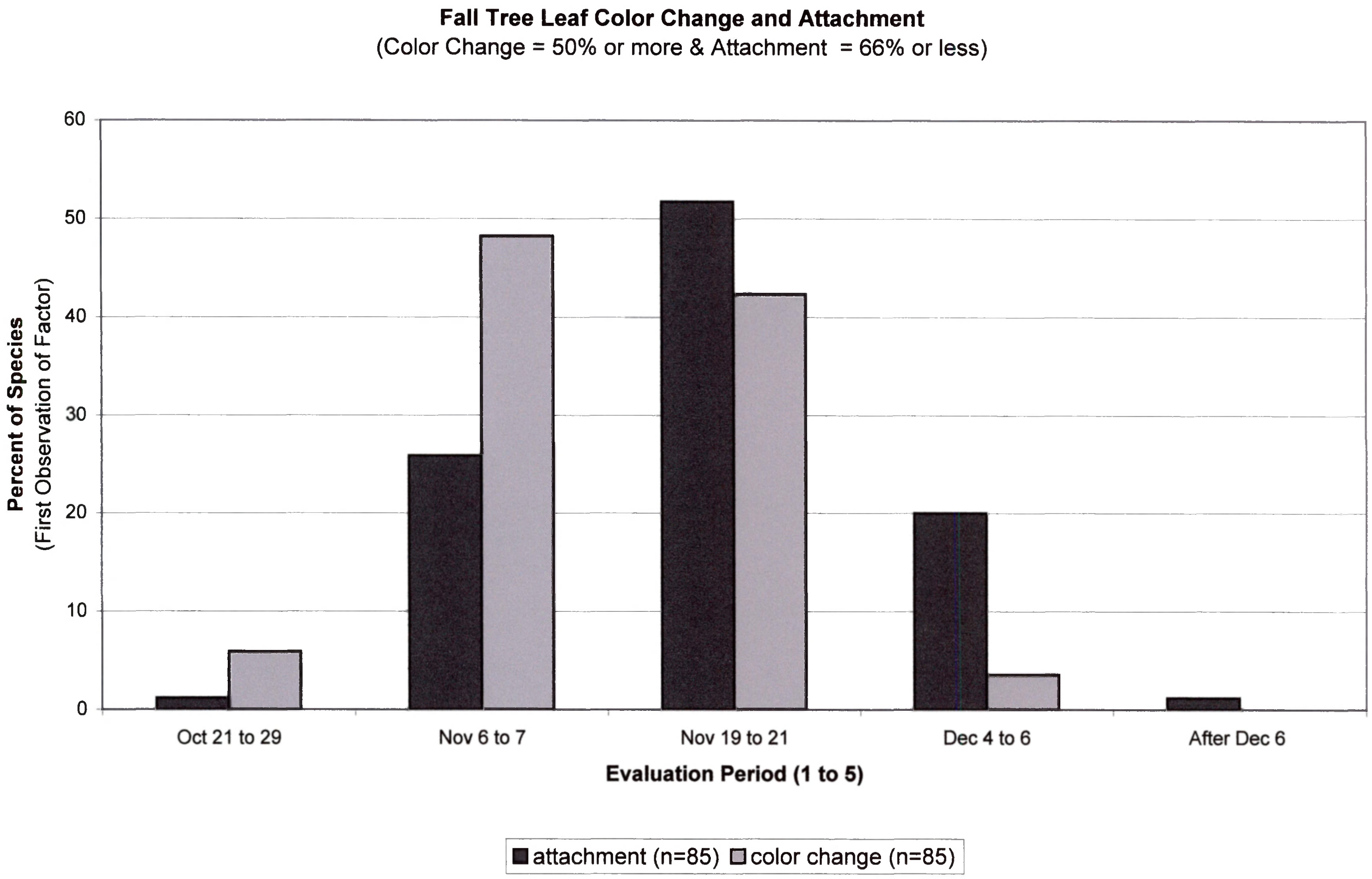

Fall Tree Leaf Color Change and Attachment
(Color Change = 50% or more & Attachment = 66% or less)
Percent of Species
(First Observation of Factor)
60
50
40
30
20
10
0
Oct 21 to 29
Nov 6 to 7
Nov 19 to 21
Dec 4 to 6
After Dec 6
Evaluation Period (1 to 5)
■ attachment (n=85)
□ color change (n=85)

FIGURE 21. Fall Shrub Leaf Color Change by Species

Fall Shrub Leaf Color Change by Species
(First Observation of Color Change of 50% or More)

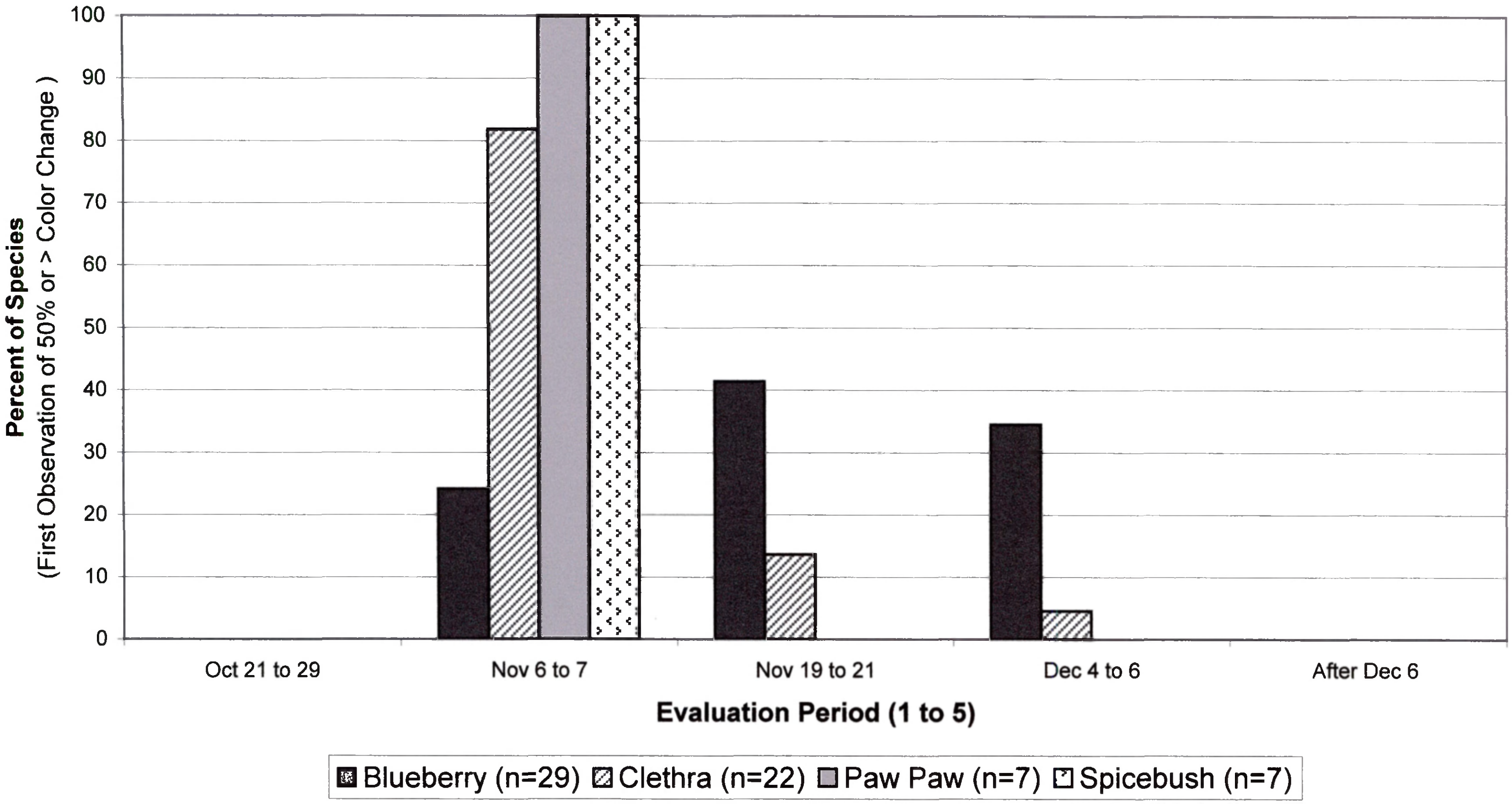


FIGURE 22. Spring Plant Activity – Enlarged Buds (Tree and Sapling Strata)

Spring Plant Activity - Enlarged Buds
Tree and Sapling Strata

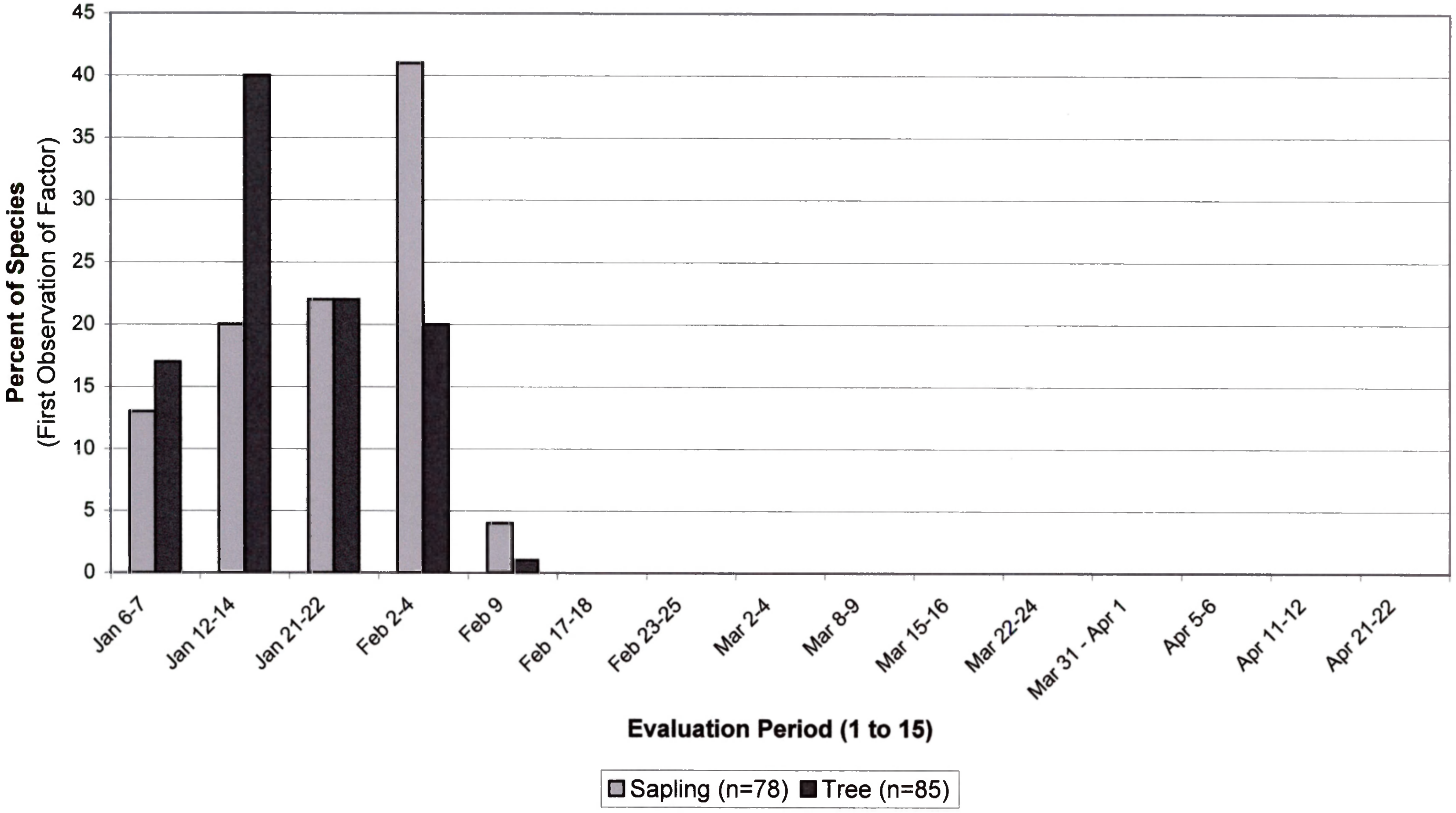


FIGURE 23. Spring Plant Activity – Red Maple (*Acer rubrum*) Flowering and Seed Set (Tree and Sapling Strata)

Spring Plant Activity - Red Maple Flowering and Seed Set
Tree and Sapling Strata

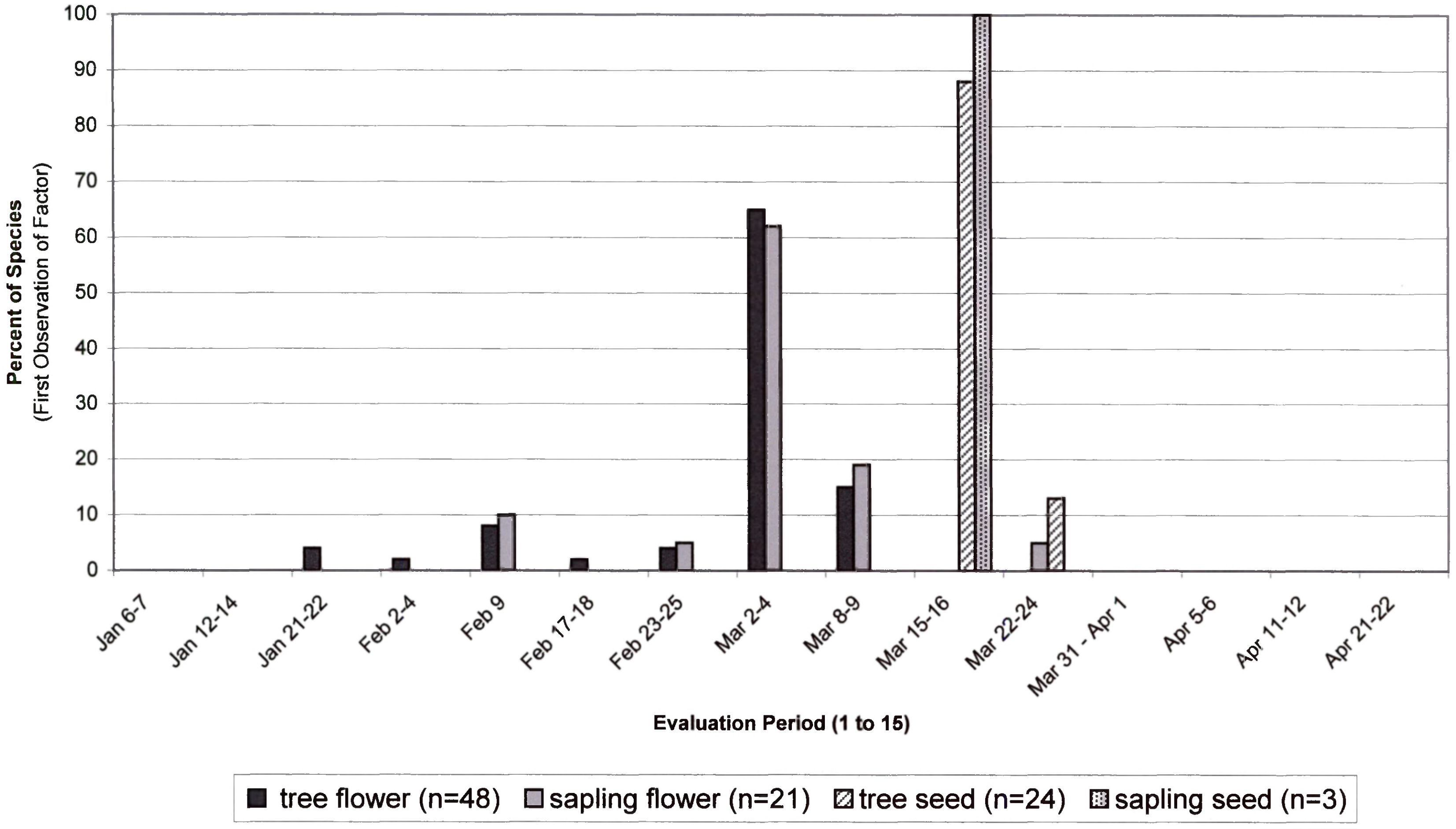


FIGURE 24. Spring Plant Activity: Leaf Out (Tree, Sapling, and Shrub Strata)

Spring Plant Activity: Leaf-Out
Tree, Sapling, and Shrub Strata

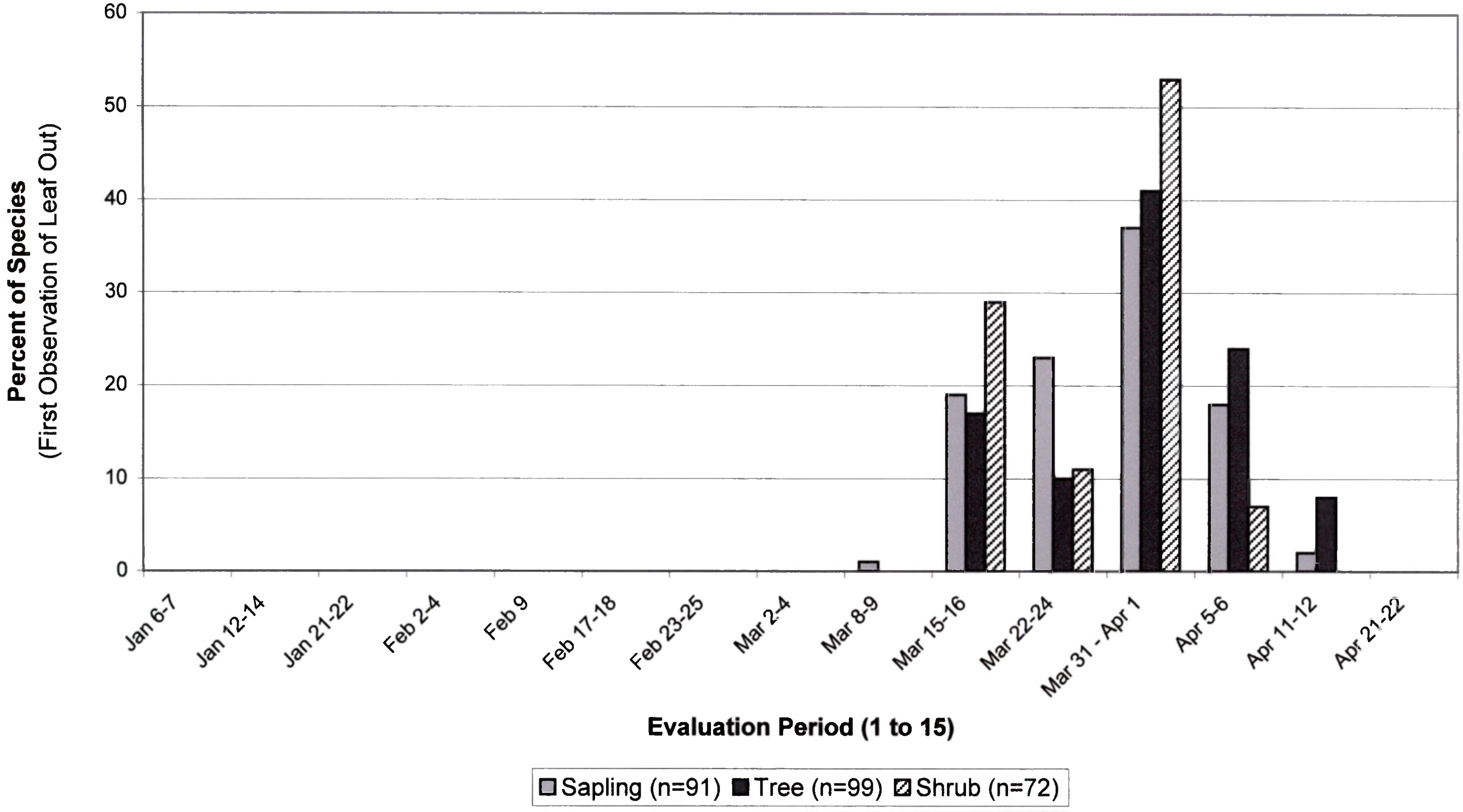


FIGURE 25. Relationship Between Average Groundwater Level and Average Minimum 50 cm Soil Temperatures in December 1999 (Points represent averages calculated for each site.)

December 1999: Average Groundwater Level vs. 50 cm Average Minimum Soil Temperature

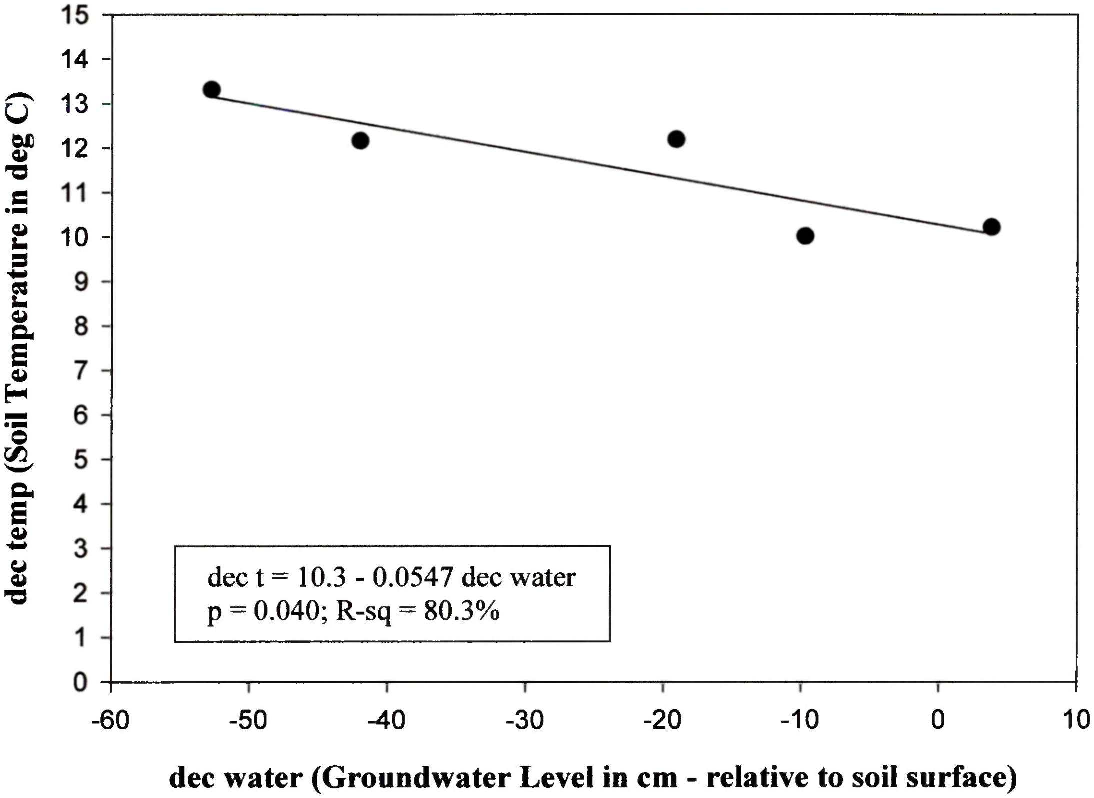


FIGURE 26. Relationship Between Average Groundwater Level and Average Minimum 50 cm Soil Temperatures in January 2000 (Points represent averages calculated for each site.)

January 2000: Average Groundwater Level vs. 50 cm Average Minimum Soil Temperature

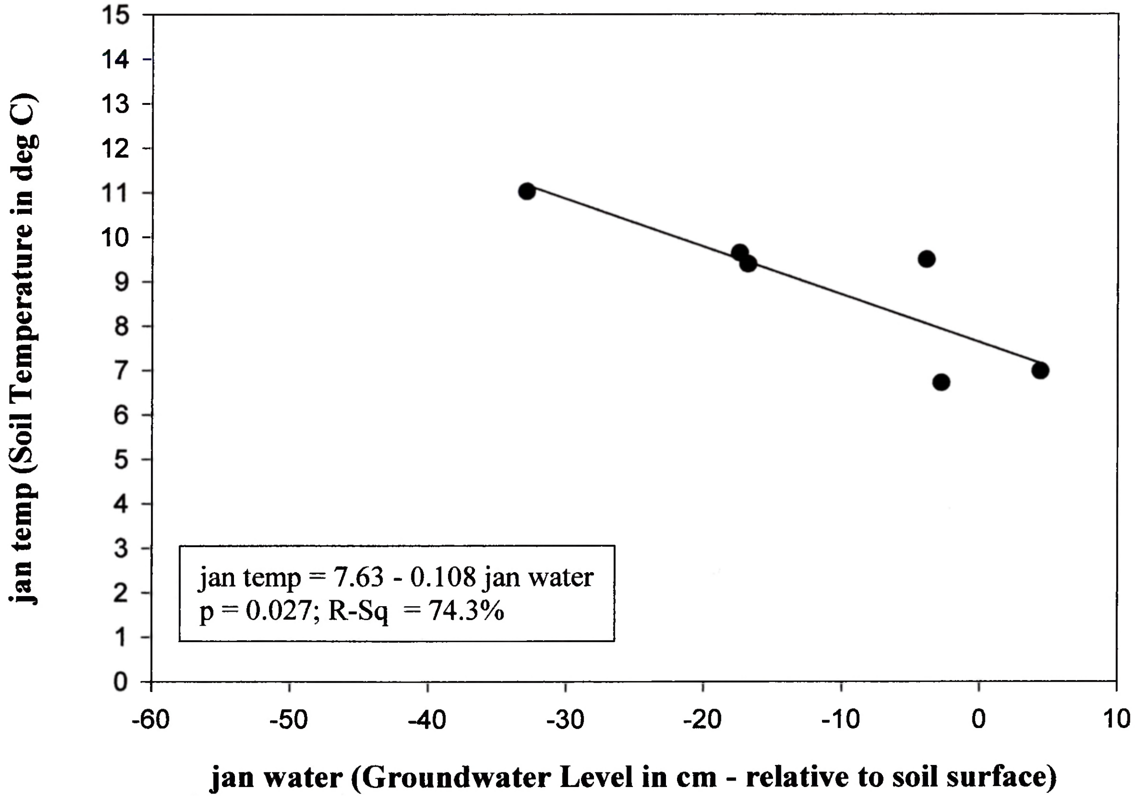
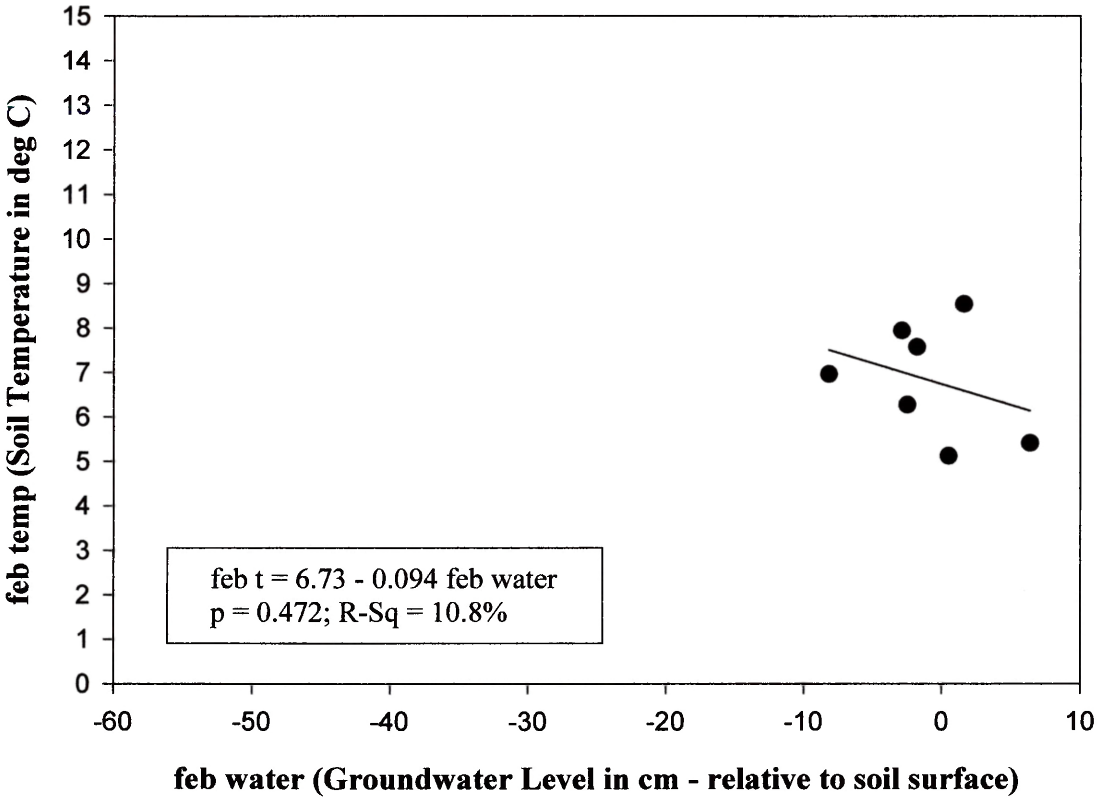


FIGURE 27. Relationship Between Average Groundwater Level and Average Minimum 50 cm Soil Temperatures in February 2000 (Points represent averages calculated for each site.)

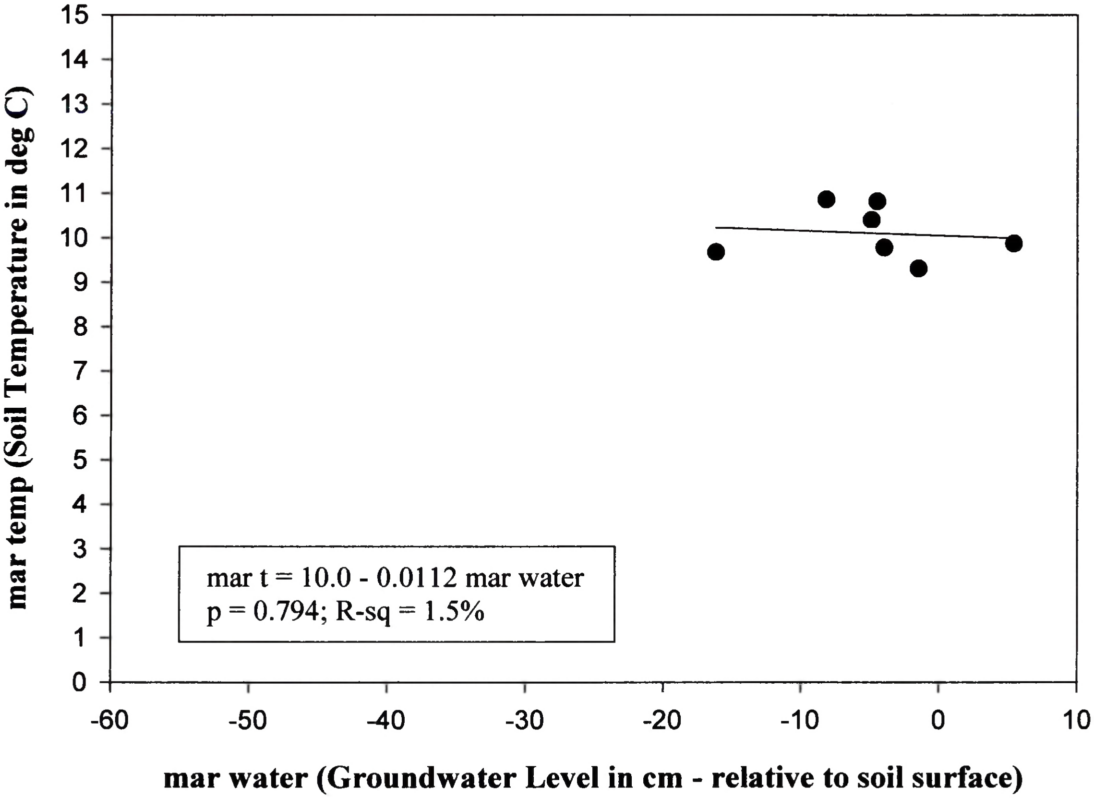
February 2000: Average Groundwater Level vs. 50 cm Average Minimum Soil Temperature



feb t = 6.73 - 0.094 feb water
p = 0.472; R-Sq = 10.8%

FIGURE 28. Relationship Between Average Groundwater Level and Average Minimum 50 cm Soil Temperatures in March 2000 (Points represent averages calculated for each site.)

March 2000: Average Groundwater Level
vs. 50 cm Average Minimum Soil Temperature



APPENDIX A

Vegetation Survey Data

Appendix A (1): Dominant Sapling Species on Each Study Site from October 1999 Survey (10m radius plot method)

Scientific Name	Common name	Species Percent Frequency for Each Site							
		EL1	CS1	CS2	SF1	SB1	SB2	DS1	DS3
Acer rubrum	Red maple	57.9	51.1	38.5	64.3		87.5	42.9	78.3
Carya cordiformis	Bitternut hickory	10.5							
Fraxinus pennsylvanica	Green ash				7.1				
Ilex opaca	American holly				7.1			28.6	
Liquidamber styraciflua	Sweet gum	15.8	22.2	53.8			6.3	14.3	
Nyssa slylvatica	Black gum		13.3		14.3		6.3	14.3	
Pinus teada	Loblolly pine		4.4						
Prunus serotina	Wild black cherry			7.7					
Quercus laurifolia	Laurel leaved oak		4.4						
Quercus lyrata	Overcup oak		4.4						
Quercus michauxii	Swamp chestnut oak								4.3
Quercus velutina	Black oak				7.1				
Ulmus americana	American elm	15.8							17.4

Appendix A (2): Sapling Species on Study Sites from October 1999 Survey (10m radius plot method)

Scientific Name	Common name	Number of Saplings Species per Site								# saplings per species	species % frequency across all sites	proportion of sites with each species
		CS1	CS2	EL1	SF1	SB1	SB2	DS1	DS3			
Acer rubrum	Red maple	23	5	11	9		14	3	18	83	60.6	7 of 8
Carya cordiformis	Bitternut hickory			2						2	1.5	1 of 8
Fraxinus pennsylvanica	Green ash				1					1	0.7	1 of 8
Ilex opaca	American holly				1			2		3	2.2	2 of 8
Liquidamber styraciflua	Sweet gum	10	7	3			1	1		22	16.1	5 of 8
Nyssa slylvatica	Black gum	6			2		1	1		10	7.3	4 of 8
Pinus teada	Loblolly pine	2								2	1.5	1 of 8
Prunus serotina	Wild black cherry		1							1	0.7	1 of 8
Quercus laurifolia	Laurel leaved oak	2								2	1.5	1 of 8
Quercus lyrata	Overcup oak	2								2	1.5	1 of 8
Quercus michauxii	Swamp chestnut oak								1	1	0.7	1 of 8
Quercus velutina	Black oak				1					1	0.7	1 of 8
Ulmus americana	American elm			3					4	7	5.1	2 of 8
	# saplings per site	45	13	19	14	0	16	7	23	(137 total)		

Appendix A (3): Tree Basal Area per Acre Using Bitterlich Method and a BAF=10

		# trees per site								species basal area/acre for each site (feet squared)									
Scientific Name	Common name	CS1	CS2	EL1	SF1	SB1	SB2	DS1	DS3	CS1	CS2	EL1	SF1	SB1	SB2	DS1	DS3	total # trees per species	species basal area/acre for all sites (ft sq.)
Acer rubrum	Red maple	2	4	4	3		4	3	11	20	40	40	30	0	40	30	110	31	38.8
Carya cordiformis	Bitternut hickory			3								30						3	3.8
Liquidamber styraciflua	Sweet gum	2	8	6	2	3	6	2	5	20	80	60	20	30	60	20	50	34	42.5
Nyssa slylvatica	Black gum	2	6			3	2	1		20	60			30	20	10		14	17.5
Pinus teada	Loblolly pine			1	4	1						10	40	10				6	7.5
Quercus falcata	Southern red oak	1								10								1	1.3
Quercus laurifolia	Laurel leaved oak	2				7				20				70				9	11.3
Quercus lyrata	Overcup oak				2	1	1						20	10	10			4	5.0
Quercus michauxii	Swamp chestnut oak				3	1	1						30	10	10			5	6.3
Quercus pagoda	Cherrybark oak				1								10					1	1.3
Quercus phellos	Willow oak	1					1			10					10			2	2.5
Ulmus americana	American elm			2								20						2	2.5
	Totals	10	18	16	15	16	15	6	16	100	180	160	150	160	150	60	160	(112)	(140)

Appendix A (4): Dominant Tree Species from October 1999 Survey (10m radius plot method)

		# trees species per site								total # trees per species	species % frequency per site								species percent frequency across all sites	proportion of sites with each species
Scientific Name	Common name	EL1	CS1	CS2	SF1	SB1	SB2	DS1	DS3		EL1	CS1	CS2	SF1	SB1	SB2	DS1	DS3		
Acer rubrum	Red maple	7	3	5		1	5	7	20	48	38.9	16.7	29.4		8.3	31.3	70.0	74.1	35.8	7 of 8
Carya cordiformis	Bitternut hickory	1								1	5.6								0.7	1 of 8
Liquidamber styraciflua	Sweet gum	8	1	7	2	6	9	1	5	39	44.4	5.6	41.2	12.5	50.0	56.3	10.0	18.5	29.1	8 of 8
Magnolia virginiana	Sweet bay							1		1							10.0		0.7	1 of 8
Nyssa slylvatica	Black gum		2		1	2	2	1		8		11.1		6.3	16.7	12.5	10.0		6.0	5 of 8
Pinus teada	Loblolly pine		2	5	5					12		11.1	29.4	31.3					9.0	3 of 8
Quercus falcata	Southern red oak								1	1								3.7	0.7	1 of 8
Quercus laurifolia	Laurel leaved oak		3			2			1	6		16.7			16.7			3.7	4.5	2 of 8
Quercus lyrata	Overcup oak		6		1	1				8		33.3		6.3	8.3				6.0	3 of 8
Quercus michauxii	Swamp chestnut oak		1		4					5		5.6		25.0					3.7	2 of 8
Quercus pagoda	Cherrybark oak				2					2				12.5					1.5	1 of 8
Quercus phellos	Willow oak				1					1				6.3					0.7	1 of 8
Ulmus americana	American elm	2								2	11.1								1.5	1 of 8
	Totals	18	18	17	16	12	16	10	27	134										

Appendix A (5): Site Shrub Layer Species from October 1999 Survey (10m radius method)

		# of each species per site								total # of each species	species percent frequency for each site								species % frequency across all sites	proportion of sites with each species
Scientific Name	Common name	EL1	CS1	CS2	SF1	SB1	SB2	DS1	DS3		EL1	CS1	CS2	SF1	SB1	SB2	DS1	DS3		
Acer rubrum	Red maple	9	18	24	5	2	5	17		80	11.5	16.8	53.3	16.7	3.0	13.2	5.2		11.3	7 of 8
Amelanchier obovalis	Shadbush/june berry						5			5						13.2			0.7	1 of 8
Arundinaria gigantea	Giant cane							105		105							31.8		14.8	1 of 8
Asimina triloba	Paw paw	7						4		11	9.0						1.2		1.6	2 of 8
Carpinus caroliniana	Ironwood								4	4								28.6	0.6	1 of 8
Carya ovata	Shagbark hickory			1						1			2.2						0.1	1 of 8
Clethra alnifolia	Sweet pepperbush					31	1	80		112					47.0	2.6	24.2		15.8	3 of 8
Diospyros virginiana	Persimmon		1							1		0.9							0.1	1 of 8
Fraxinus pennsylvanica	Green ash				6			3		9				20.0			0.9		1.3	2 of 8
Ilex opaca	American holly	6	2		15			17		40	7.7	1.9		50.0			5.2		5.6	4 of 8
Juniperus virginiana	Eastern red cedar	1								1	1.3								0.1	1 of 8
Leucothoe racemosa	Fetterbush					9		22		31					13.6		6.7		4.4	2 of 8
Lindera benzoin	Spicebush	32								32	41.0								4.5	1 of 8
Lingustrum sinense	Chinese privet	18								18	23.1								2.5	1 of 8
Liquidamber styraciflua	Sweet gum	5	43	15		1	1	39	3	107	6.4	40.2	33.3		1.5	2.6	11.8	21.4	15.1	7 of 8
Lyonia lucida	Fetterbush							10		10							3.0		1.4	1 of 8
Magnolia virginiana	Sweet bay							5		5							1.5		0.7	1 of 8
Myrica cerifera	Wax myrtle		1							1		0.9							0.1	1 of 8
Nyssa slylvatica	Black gum		11			3				14		10.3			4.5				2.0	2 of 8
Persea borbonia	Red bay							6		6							1.8		0.8	1 of 8
Pinus teada	Loblolly pine		1							1		0.9							0.1	1 of 8
Prunus serotina	Wild black cherry			3						3			6.7						0.4	1 of 8
Quercus falcata	Southern red oak			1						1			2.2						0.1	1 of 8
Quercus laurifolia	Laurel leaved oak		8							8		7.5							1.1	1 of 8
Quercus michauxii	Swamp chestnut oak		1							1		0.9							0.1	1 of 8
Quercus phellos	Willow oak			1						1			2.2						0.1	1 of 8
Symplocos tinctoria	Horse sugar						3			3						7.9			0.4	1 of 8
Ulmus americana	American elm								7	7								50.0	1.0	1 of 8
Vaccinium corymbosun	Highbush blueberry		21		4	20	23	22		90		19.6		13.3	30.3	60.5	6.7		12.7	5 of 8
	Totals	78	107	45	30	66	38	330	14	708										

Appendix A (6): Woody Vegetation Measurement Parameters for Survey and Set-up

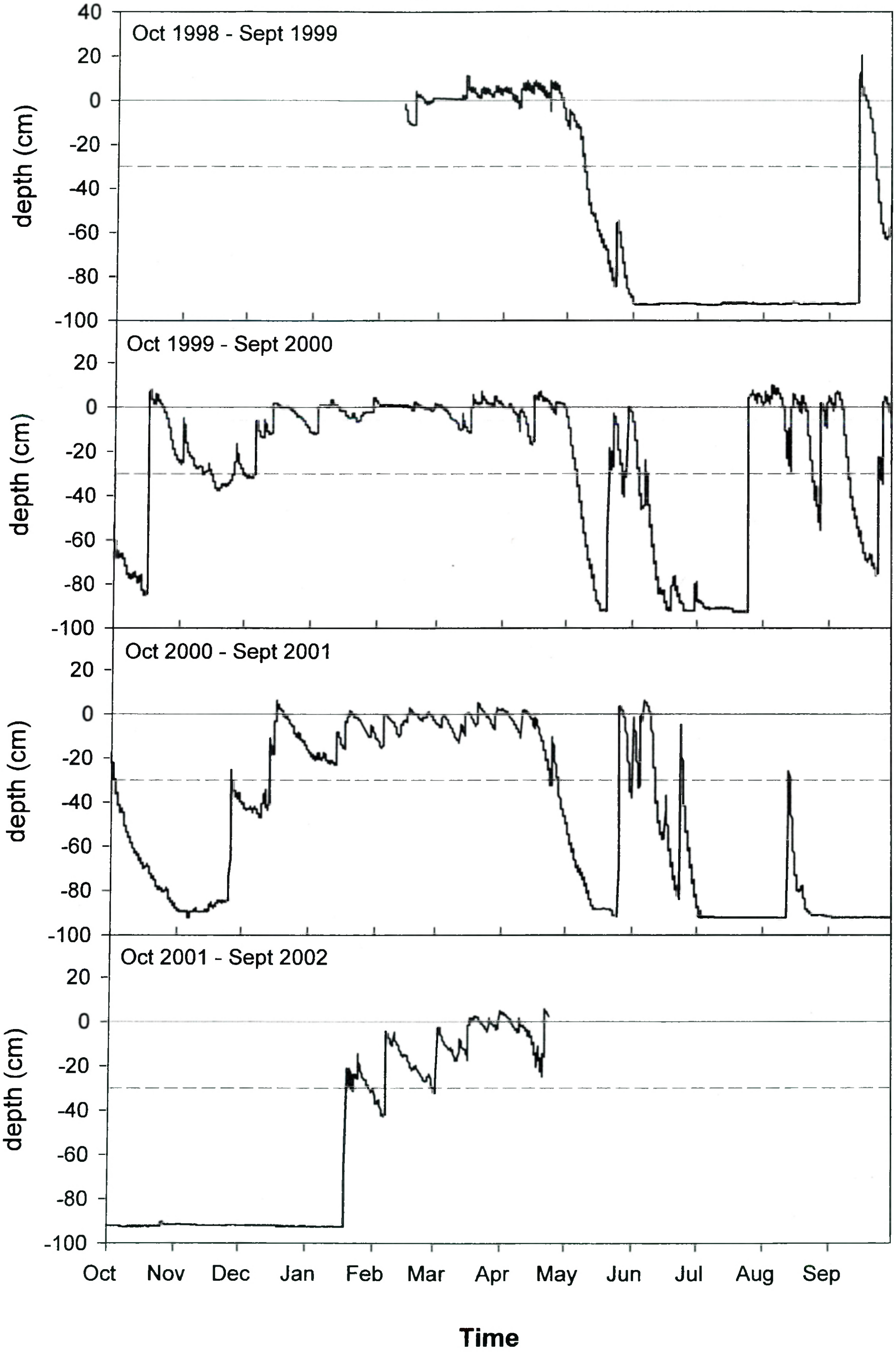
Strata	**1987 manual (1)**	**1989 manual (2)**	**Site Survey (3)**	**Monitoring Set-up (4)**
Tree	Woody, nonclimbing plants with a dbh of > or = 3.0 inches - no height specified.	Woody plants > or = to 20 feet tall and dbh = or > 5 inches.	Woody plants (not vines) > or = 13 cm dbh & > or = 6 meters in height.	Woody plants (not vines) > or = 10 cm and taller than 1 m.
dbh	> or = 3.0 inches (7.6cm)	> or = 5.0 inches (12.7 cm)	> or = 13 cm (approx 5 in)	> or = 10cm (approx 4 in)
height	n/a	> or = 20 feet (6.1m)	> or = 6 m (approx 20 ft)	> 1 m (approx 3.3 ft)
Sapling/Shrub	Woody plants (but not woody vines) with a stem diameter < 3.0 inches, and taller than 3.2 feet.			
stem diameter	< 3.0 inches (7.6 cm)			
height	> 3.2 feet (.98 m)			
Sapling		Young or small trees > or = 20 feet tall and dbh < 5 inches.	Young or small trees < 13 cm dbh and > or = 6 m.	Young or small trees < 10cm dbh and taller than > 1m.
diameter		< 5 inches (12.7 cm)	< 13 cm dbh (approx 5 in)	< 10 cm dbh (approx 4")
height		> or = 20 feet (6.1m)	> or = 6 m (approx 20 ft)	> 1 m (approx 3.3 ft)
Shrub		Woody plants usually between 3 and 20 feet tall, including multi-stemmed, bushy shrubs and small trees below 20 feet.	Woody plants (not vines) generally between 1 and 6 m, and no dbh requirement.	Woody plants/shrubs (not vines) generally > .75 m in height and no dbh requirement.
diameter		n/a	n/a	n/a
height		3 to 20 feet (.91 to 6.1 m)	Approx 1 to 6 m (approx 3.3 to 20 feet)	> .75 m (aprox 2.5 feet)

(1) Federal Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987)
(2) Federal Manual for Identifying and Delineating Jurisdictional Wetlands (Federal Interagency Committee for Wetland Delineation 1989)
(3) Parameters used when collected vegetation data on research sites to determine dominant species.
(4) Parameters used when selecting individual plants for phenology study.

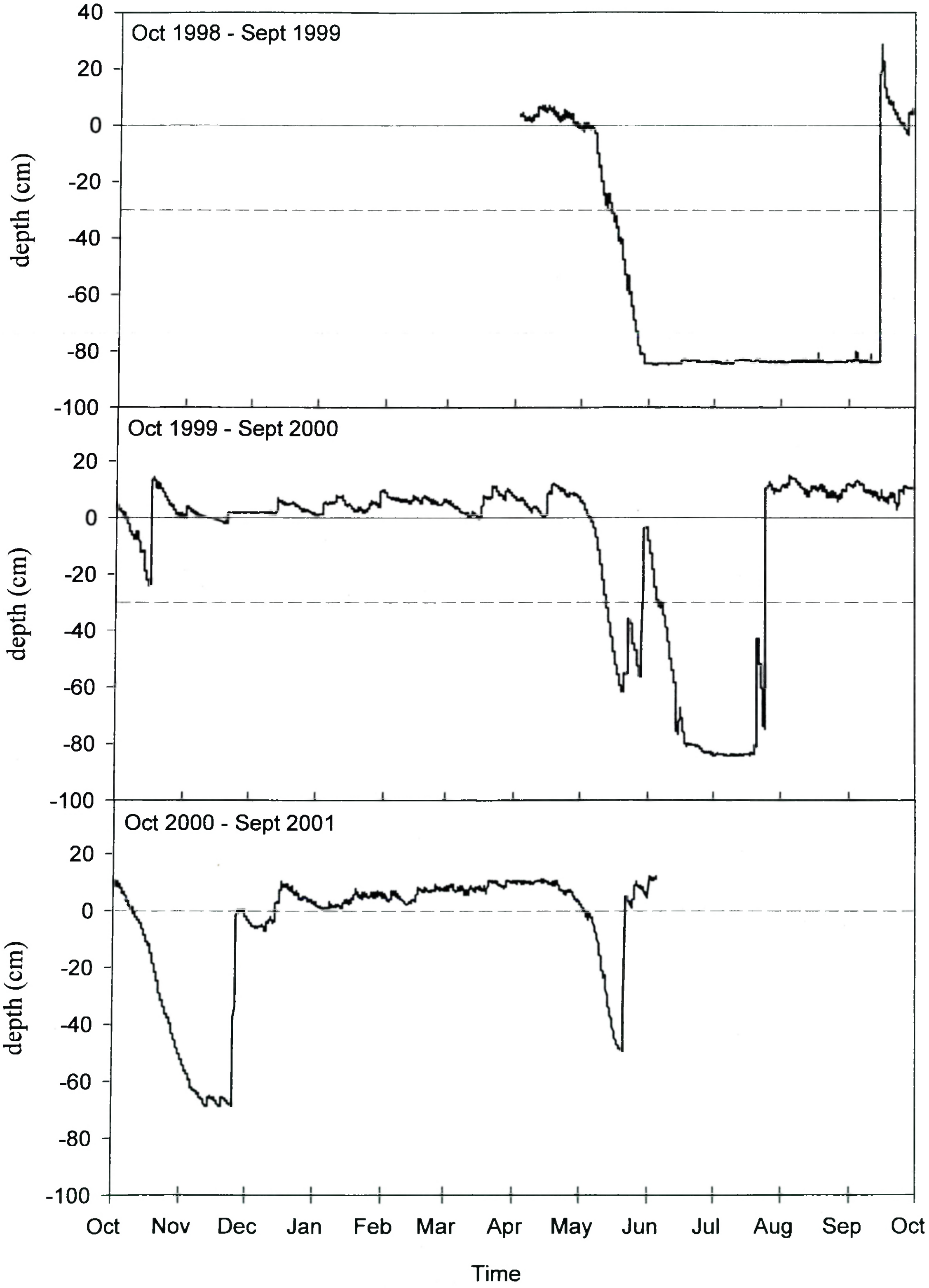
APPENDIX B

Hydrographs

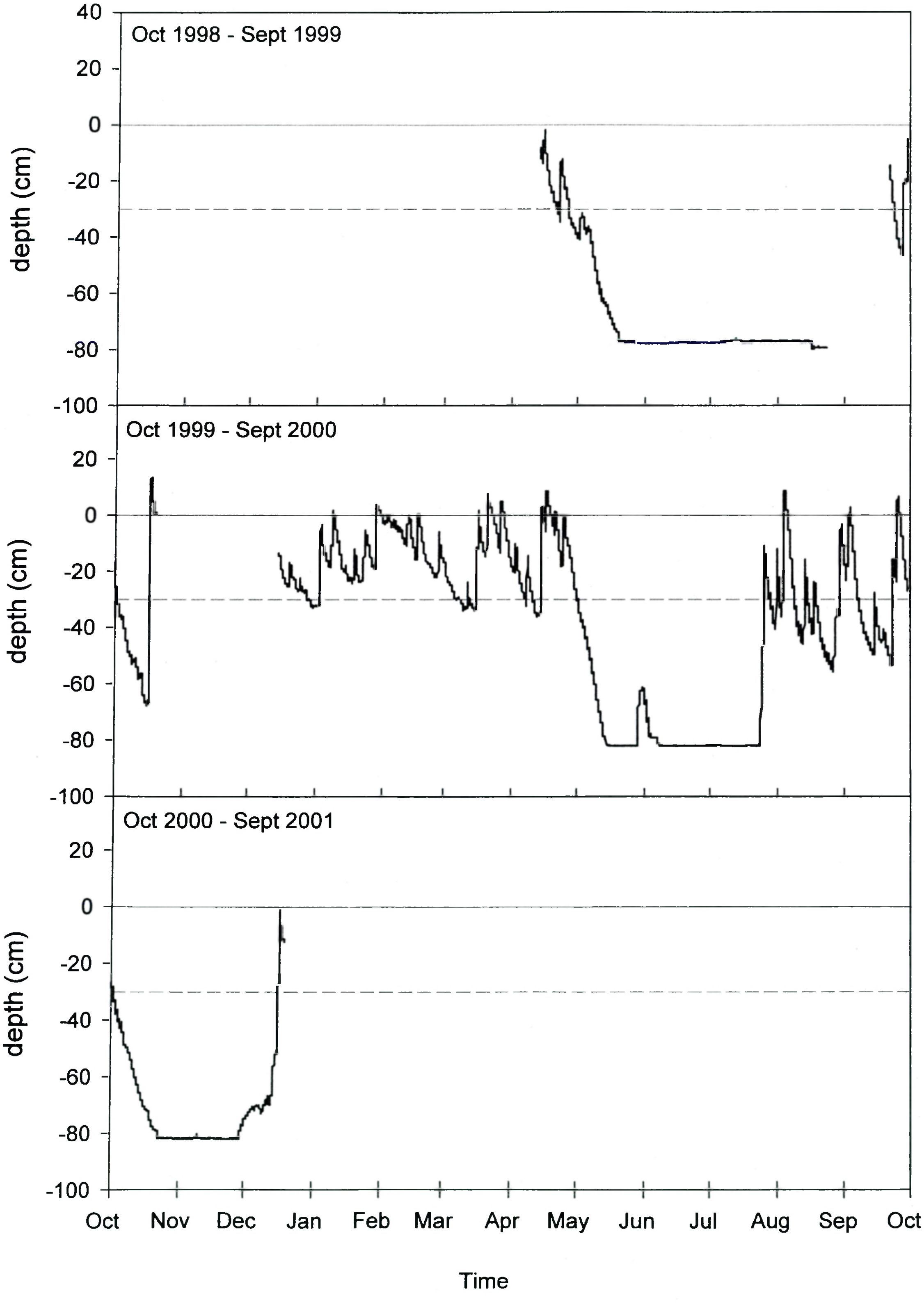
Appendix B (1): Elmington (EL1) Groundwater Levels



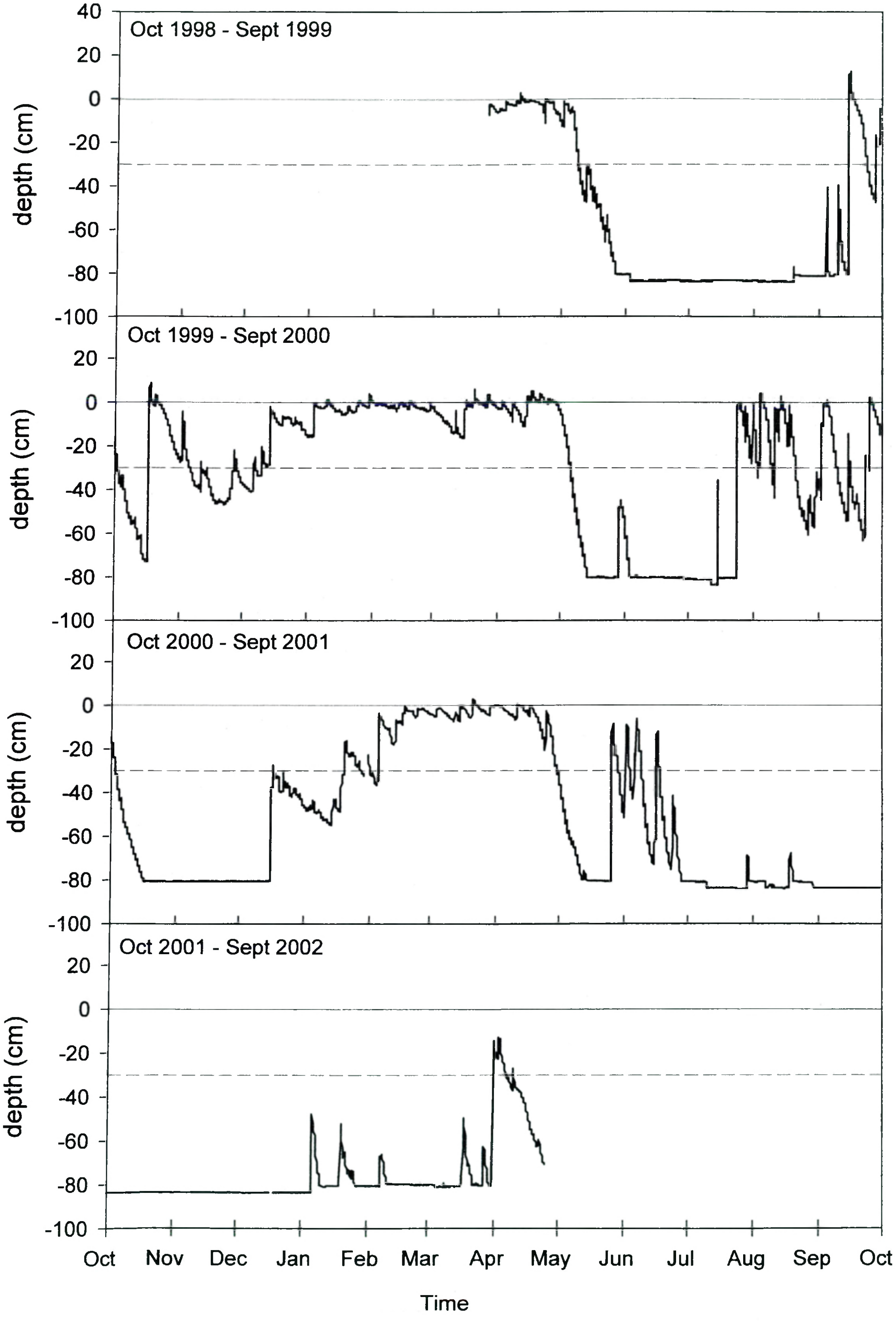
Appendix B (2):
Coleman Swamp 1 (CS1) Groundwater Levels



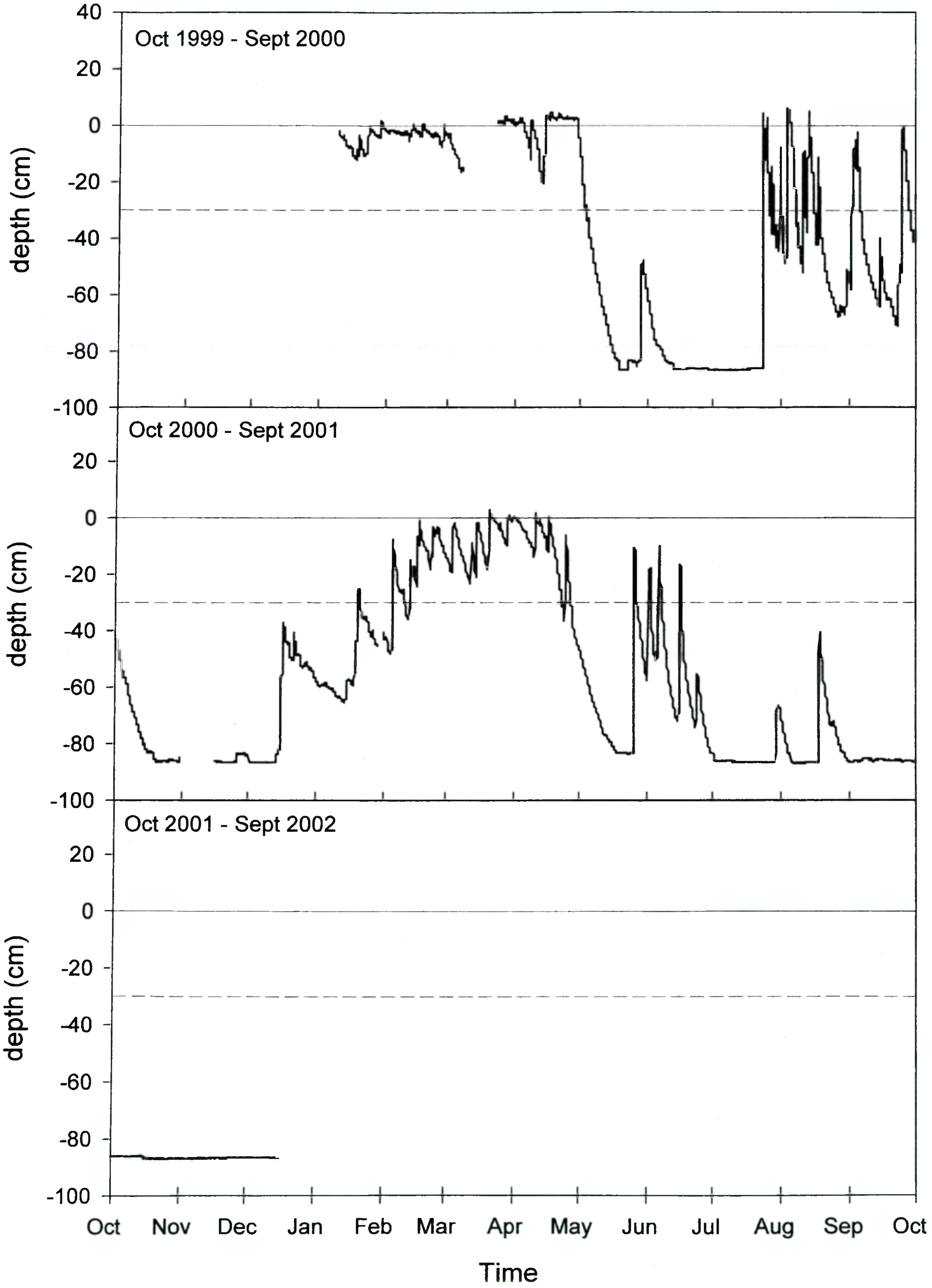
Appendix B (3):
Coleman Swamp 2 (CS2) Groundwater Level



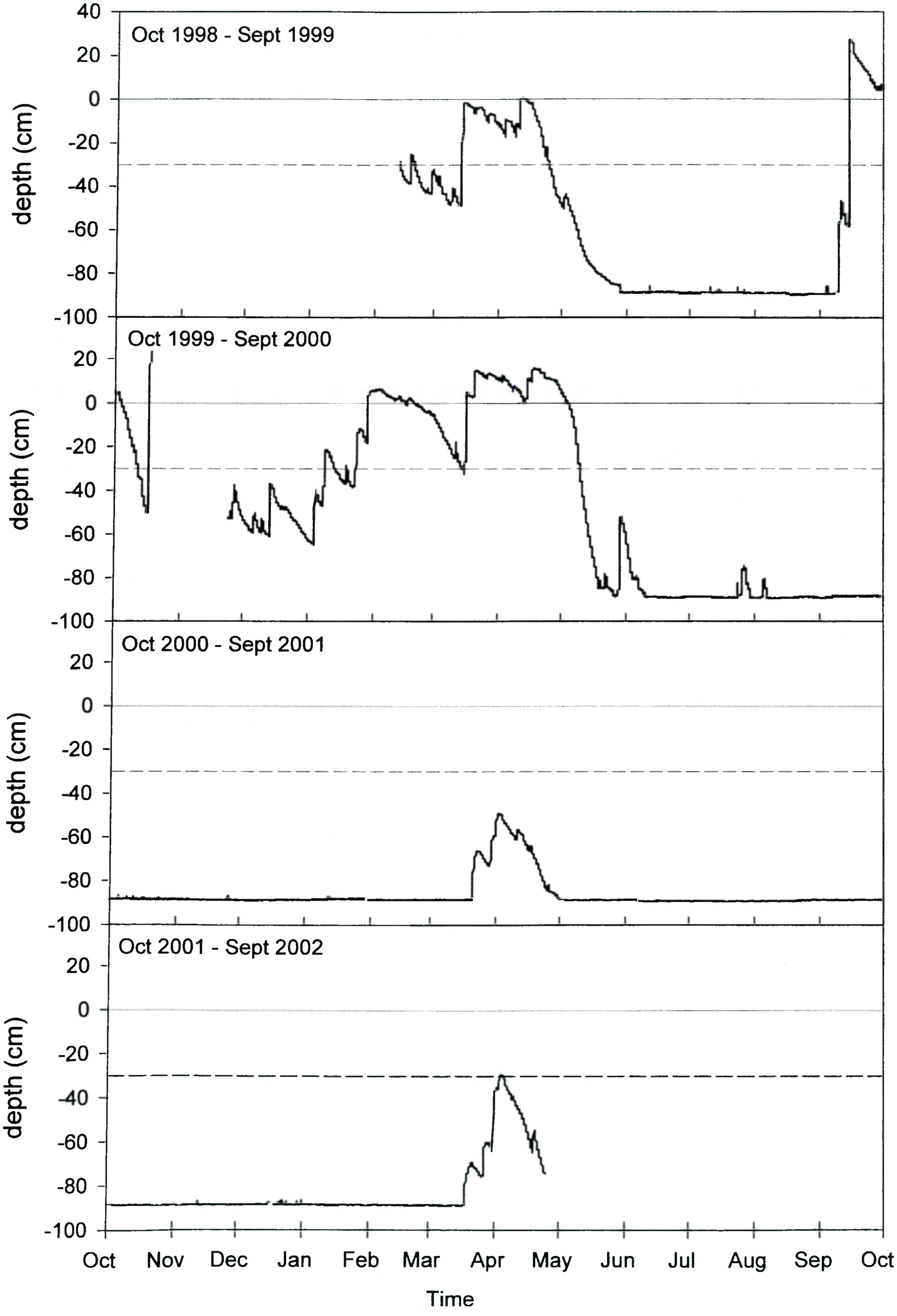
Appendix B (4): Seaford 1 (SF1) Groundwater Level



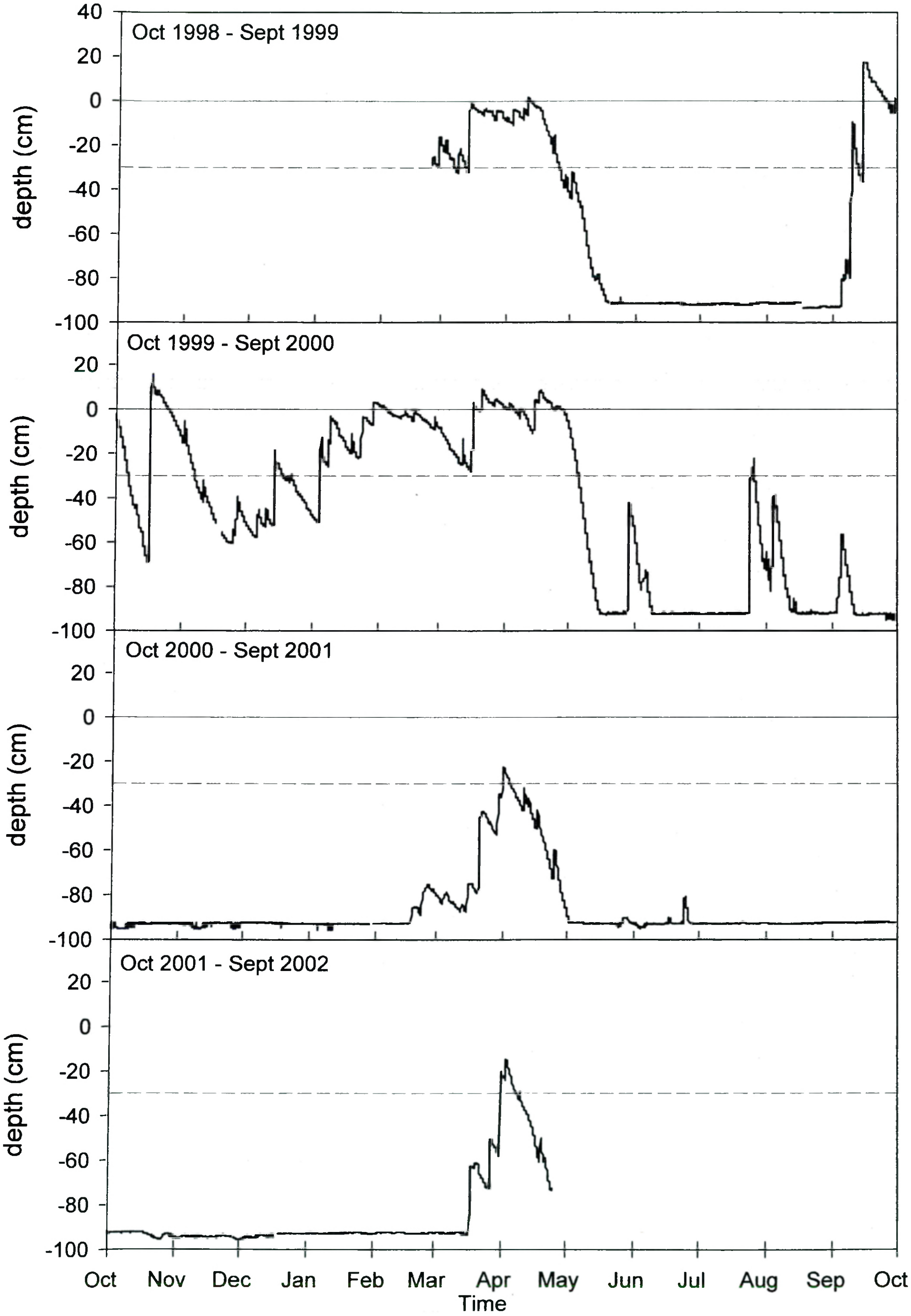
Appendix B(5): Seaford 2 (SF2) Groundwater Level



Appendix B(6): Sandy Bottom 1(SB1) Groundwater Level



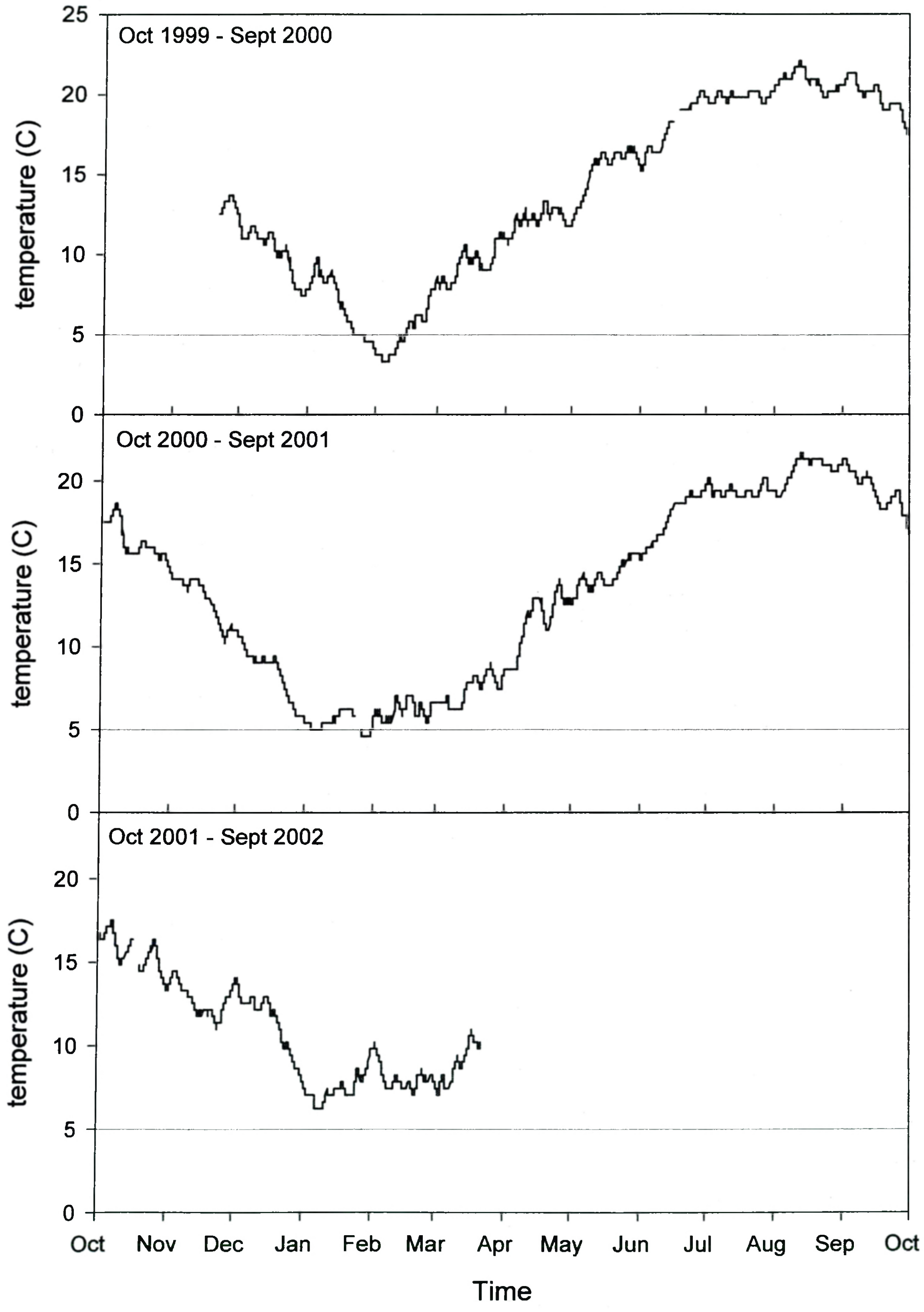
Appendix B (7): Sandy Bottom 2 Groundwater Levels



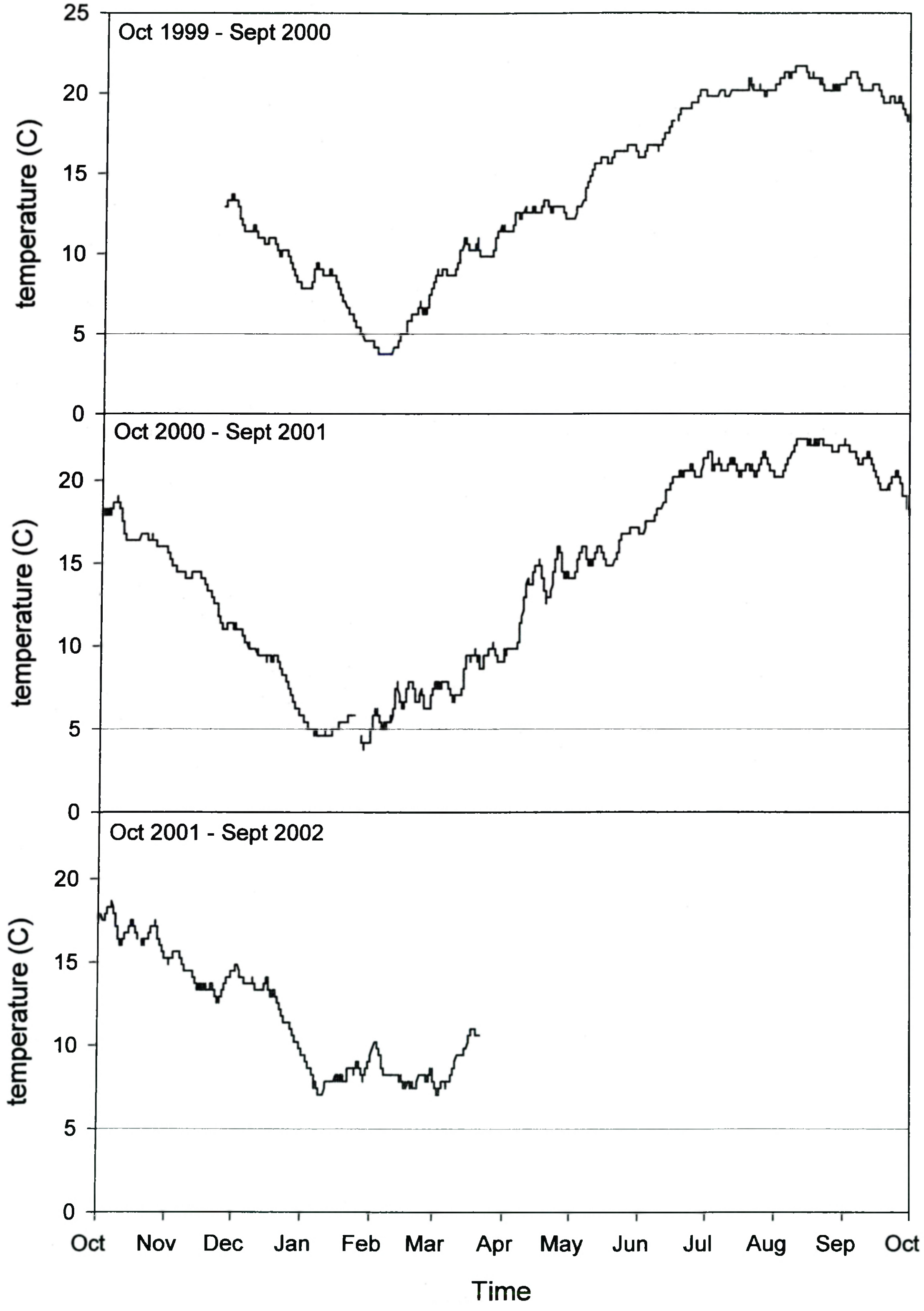
APPENDIX C

50 cm Soil Temperatures

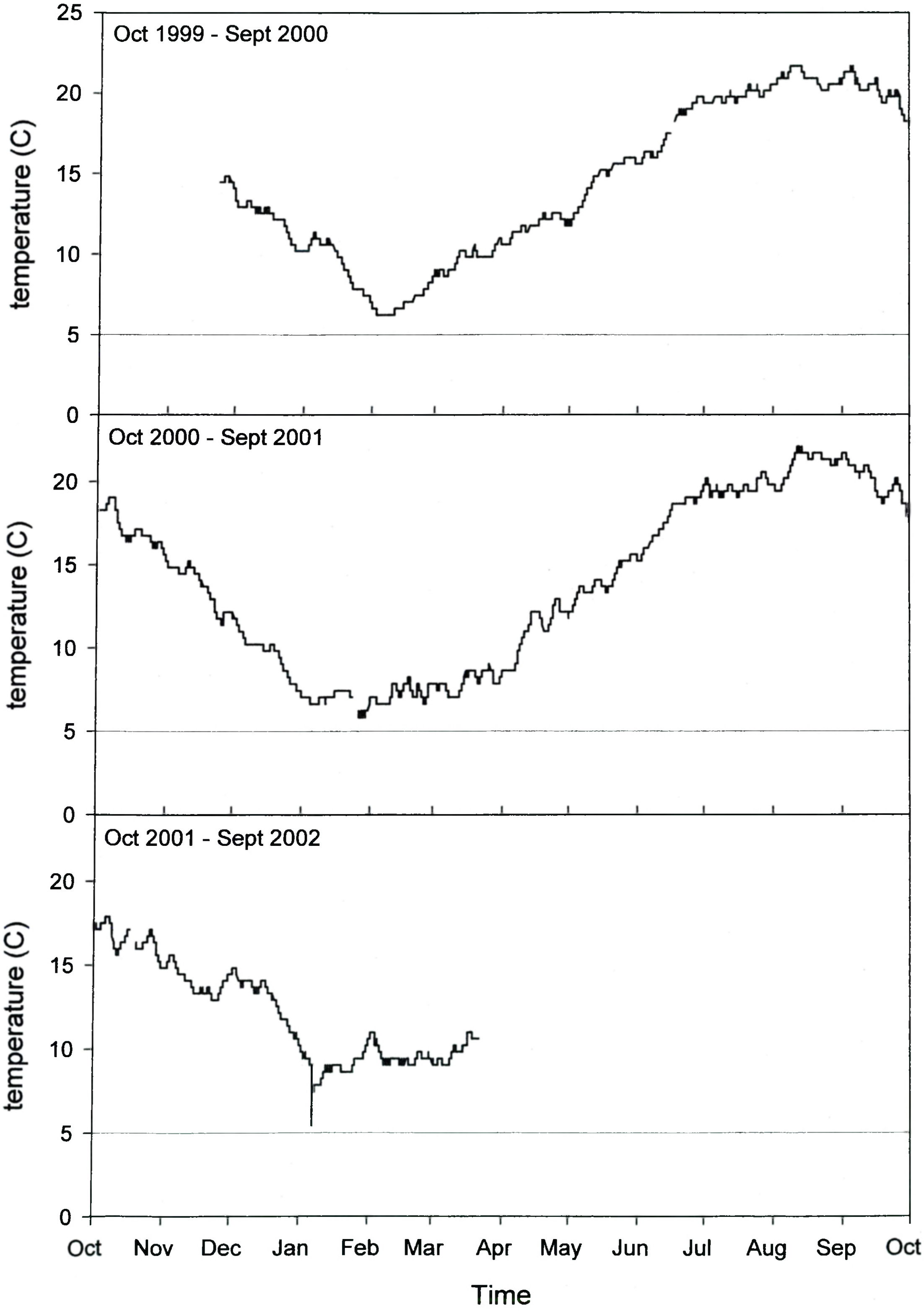
Appendix C (1): Elmington (EL1) 50cm Soil Temperature



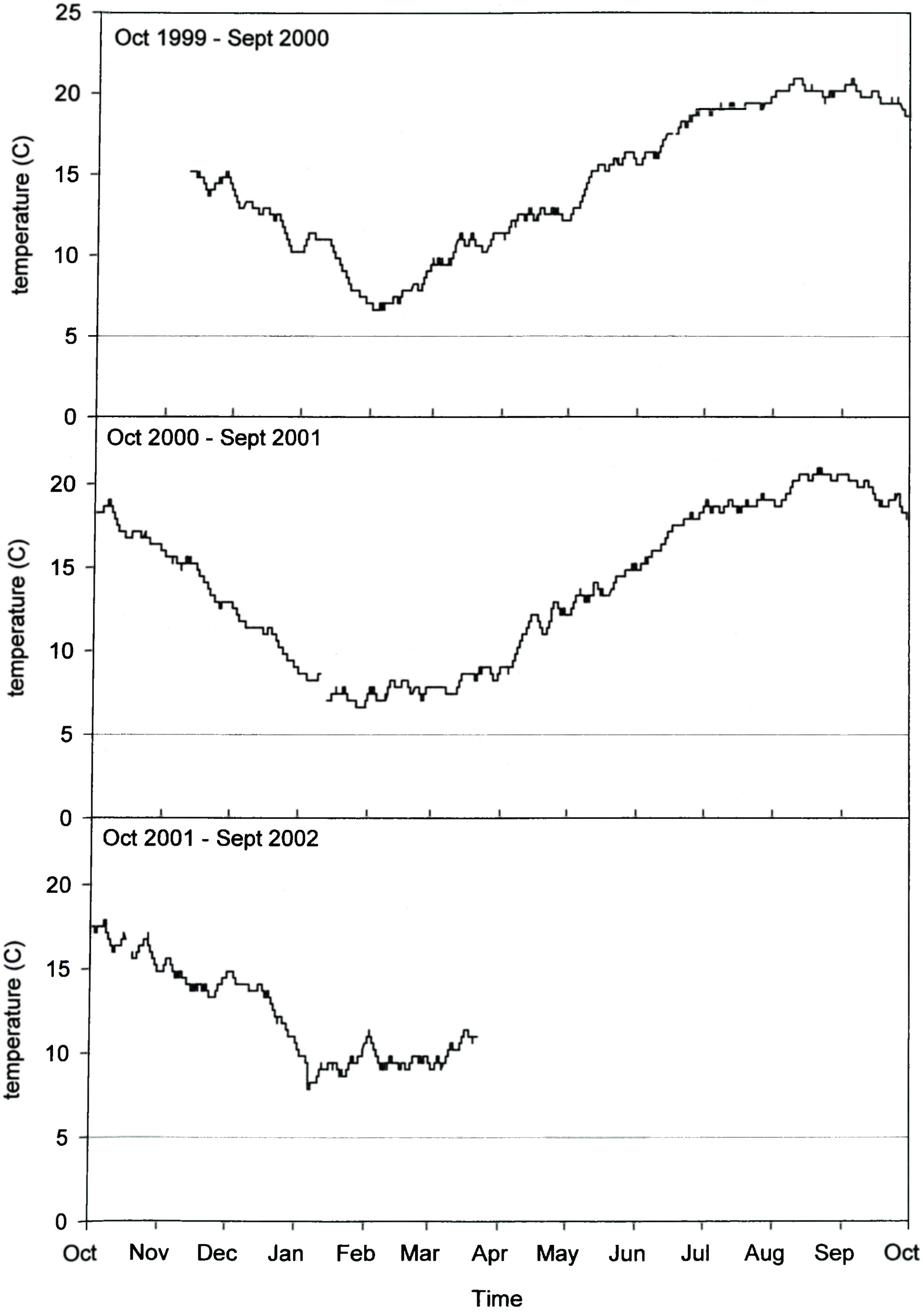
Appendix C (2): Coleman Swamp 1(CS1) 50cm Soil Temperature



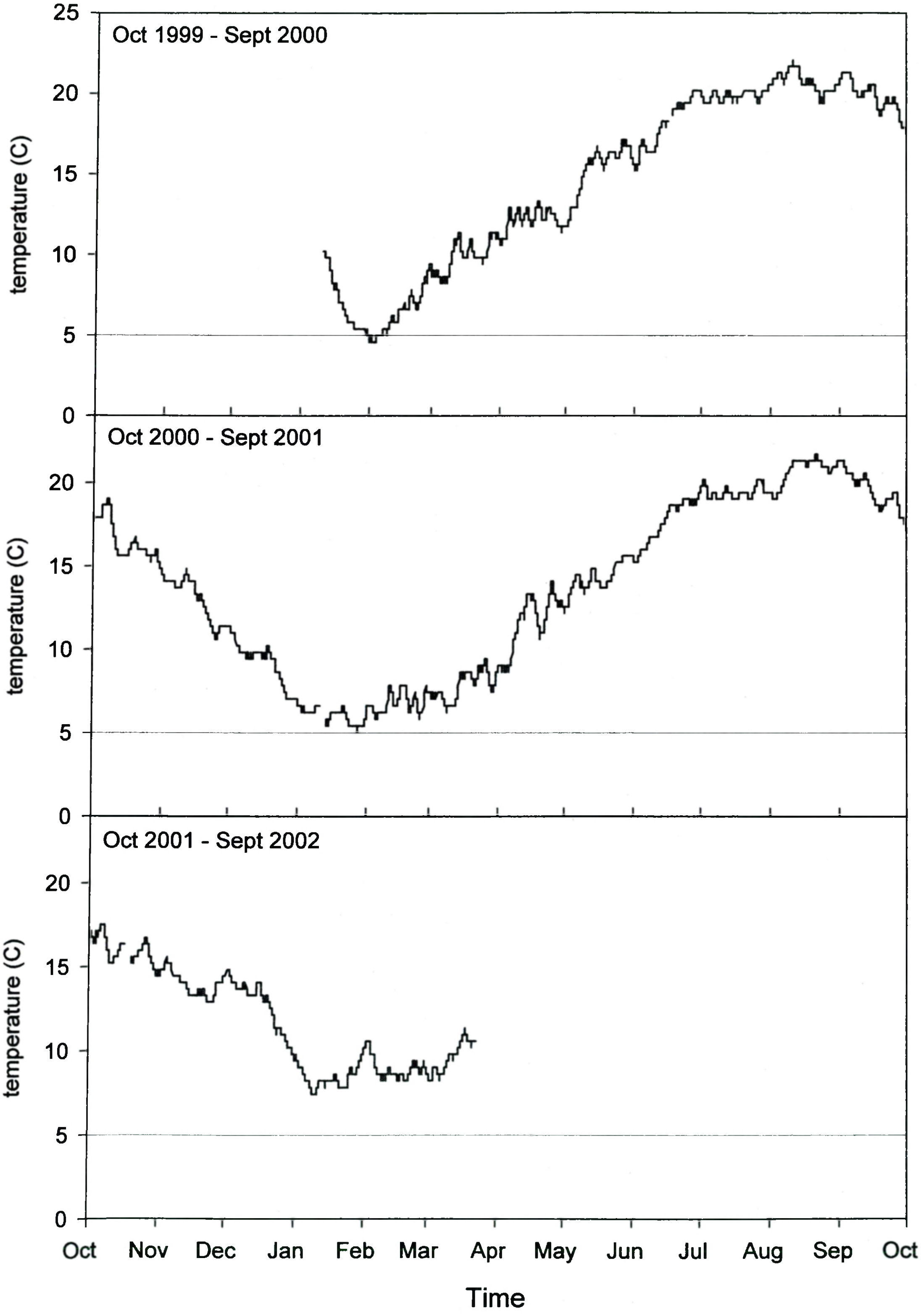
Appendix C (3): Coleman Swamp 2 (CS2) 50cm Soil Temperature



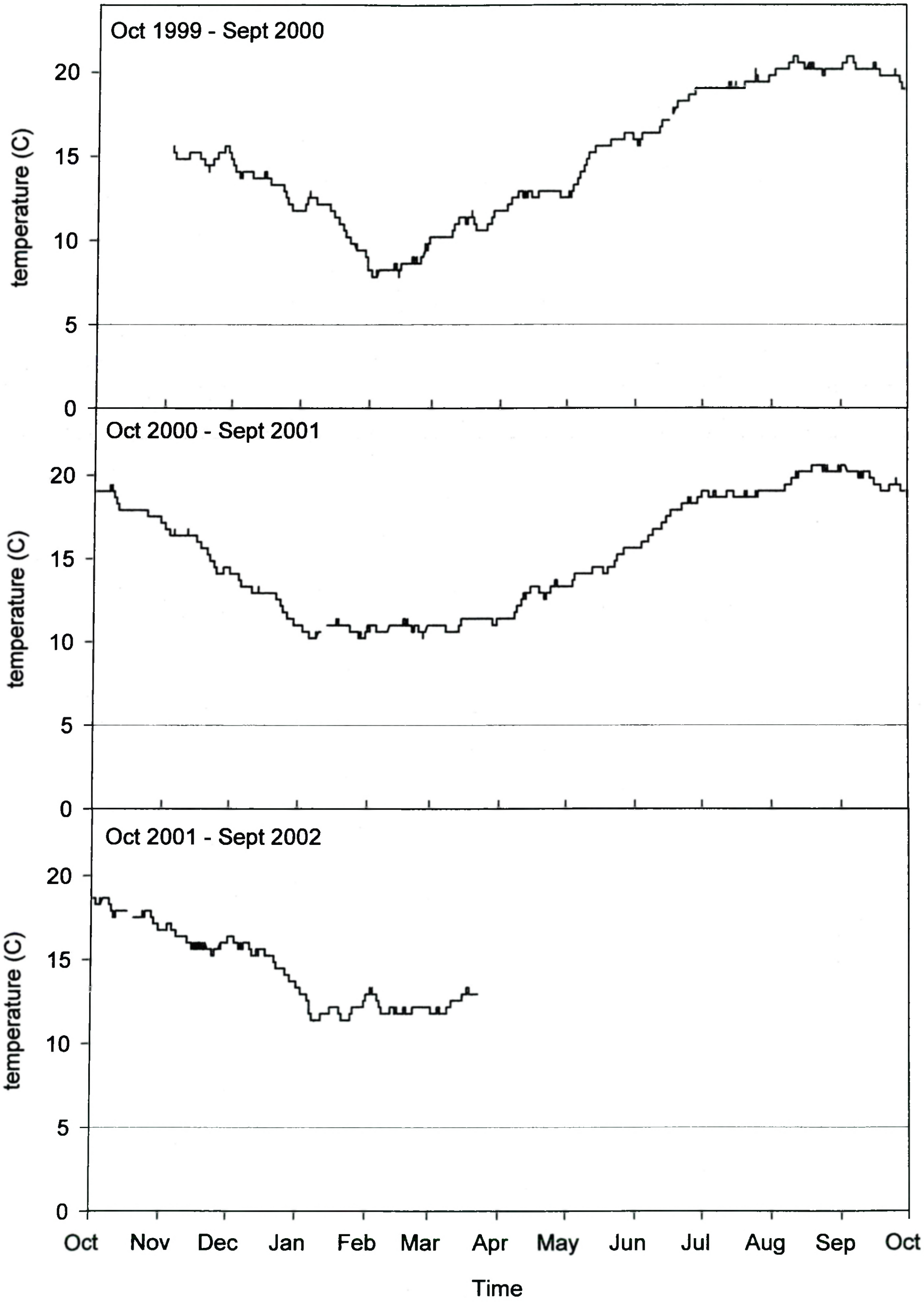
Appendix C (4): Seaford 1 (SF1) 50cm Soil Temperatures



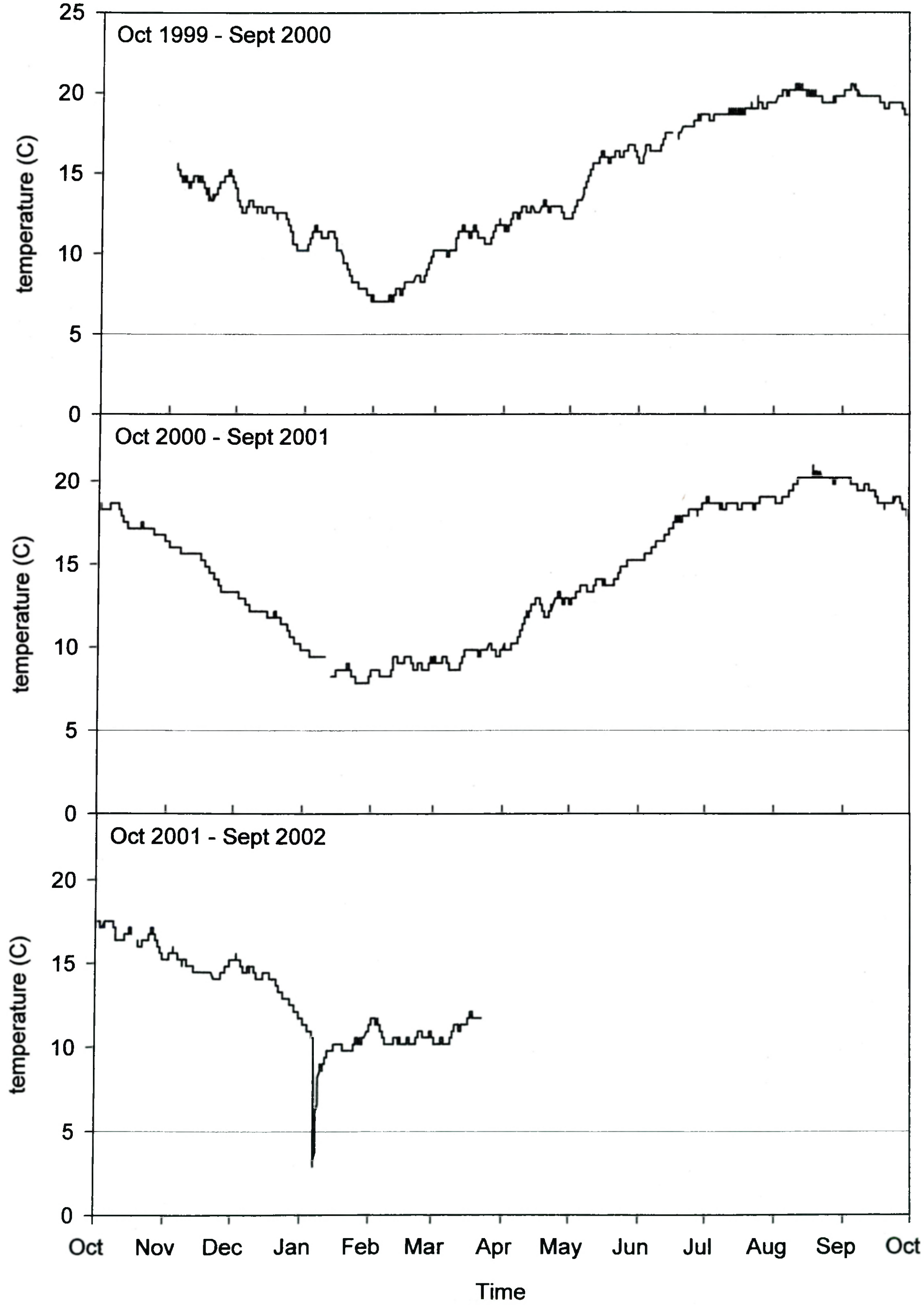
Appendix C(5): Seaford 2 (SF2) 50cm Soil Temperature



Appendix C(6): Sandy Bottom 1 (SB1) 50cm Soil Temperature



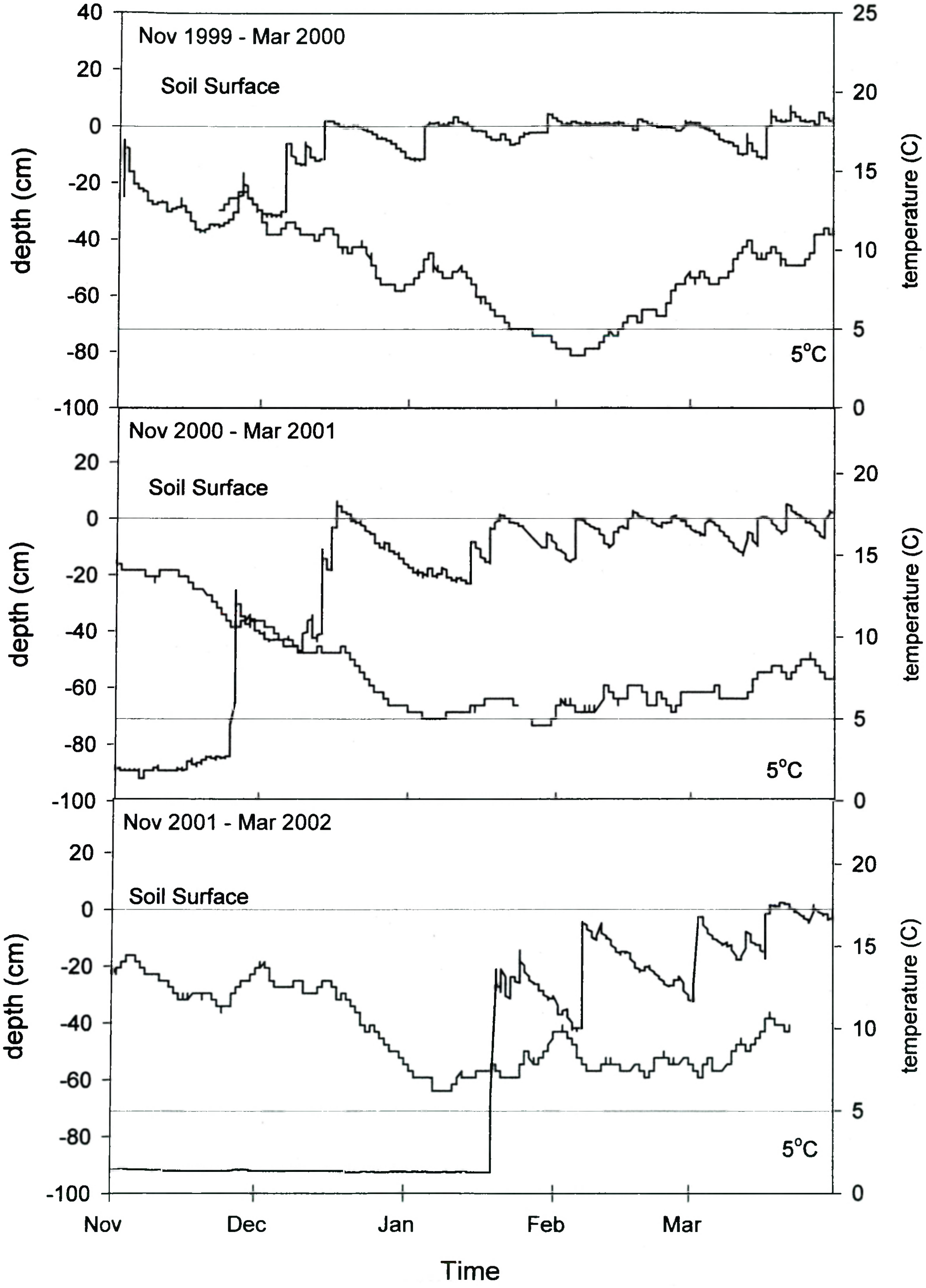
Appendix C (7): Sandy Bottom 2 (SB2) 50 cm Soil Temperature



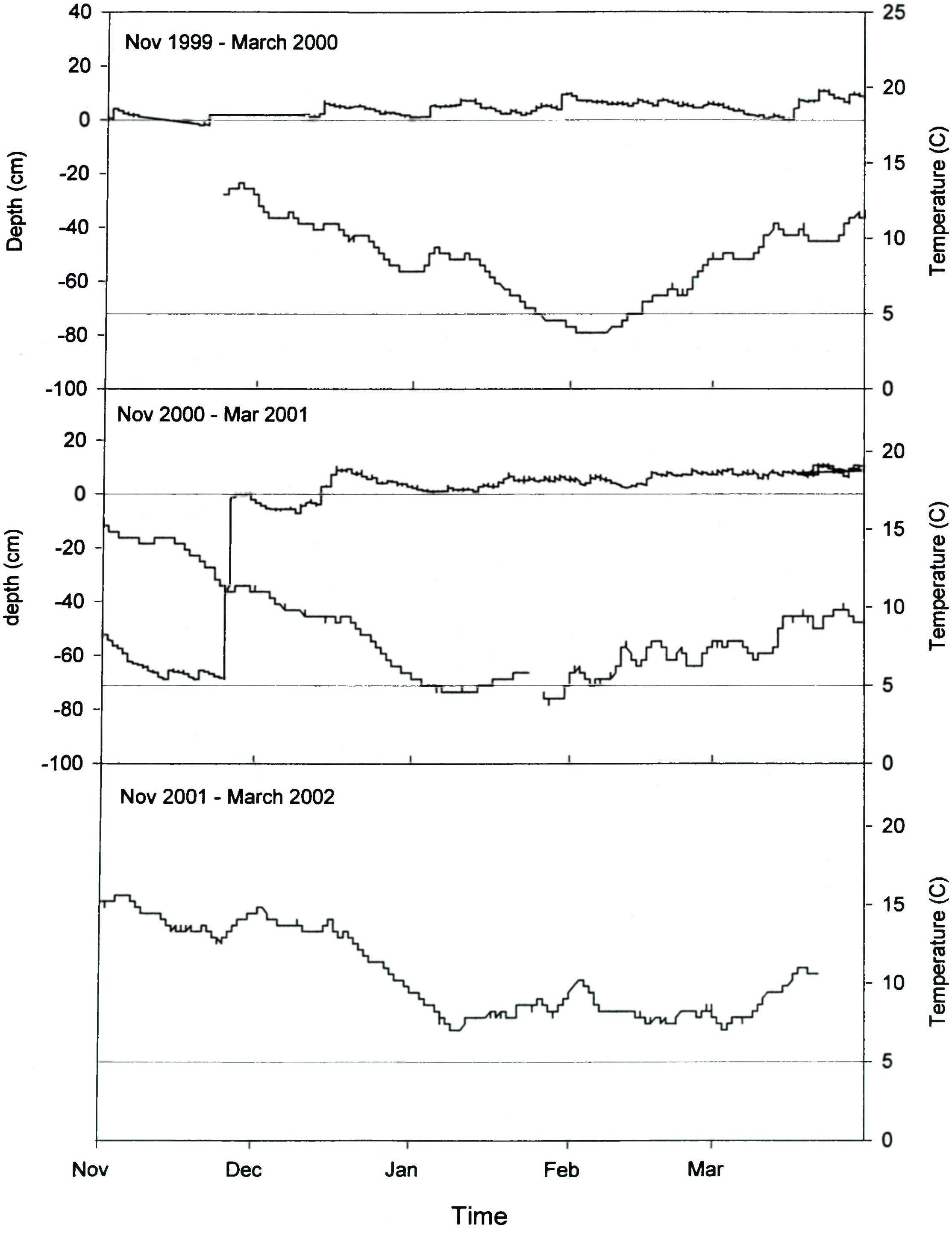
APPENDIX D

November to March
50 cm Soil Temperatures and Groundwater Levels

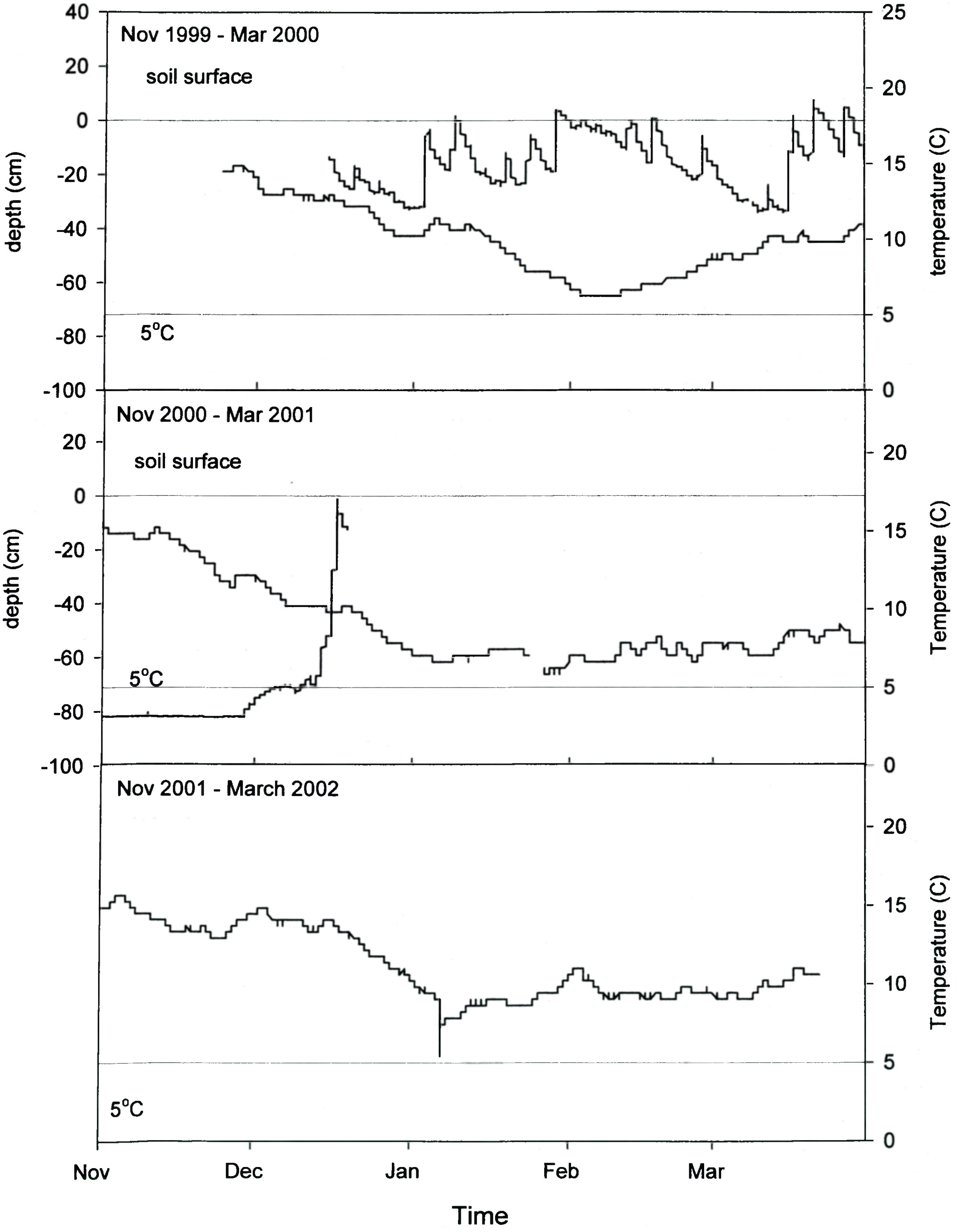
Appendix D (1): November - March
EL1 Groundwater & 50-cm Soil Temperature



Appendix D(2): CS1 Groundwater & 50-cm Soil Temperature
November - March



Appendix D(3): November 1 - March 31
CS2 Groundwater & 50-cm Soil Temperature



Appendix D (4): November - March
SF1 Groundwater & 50-cm Soil Temperatures

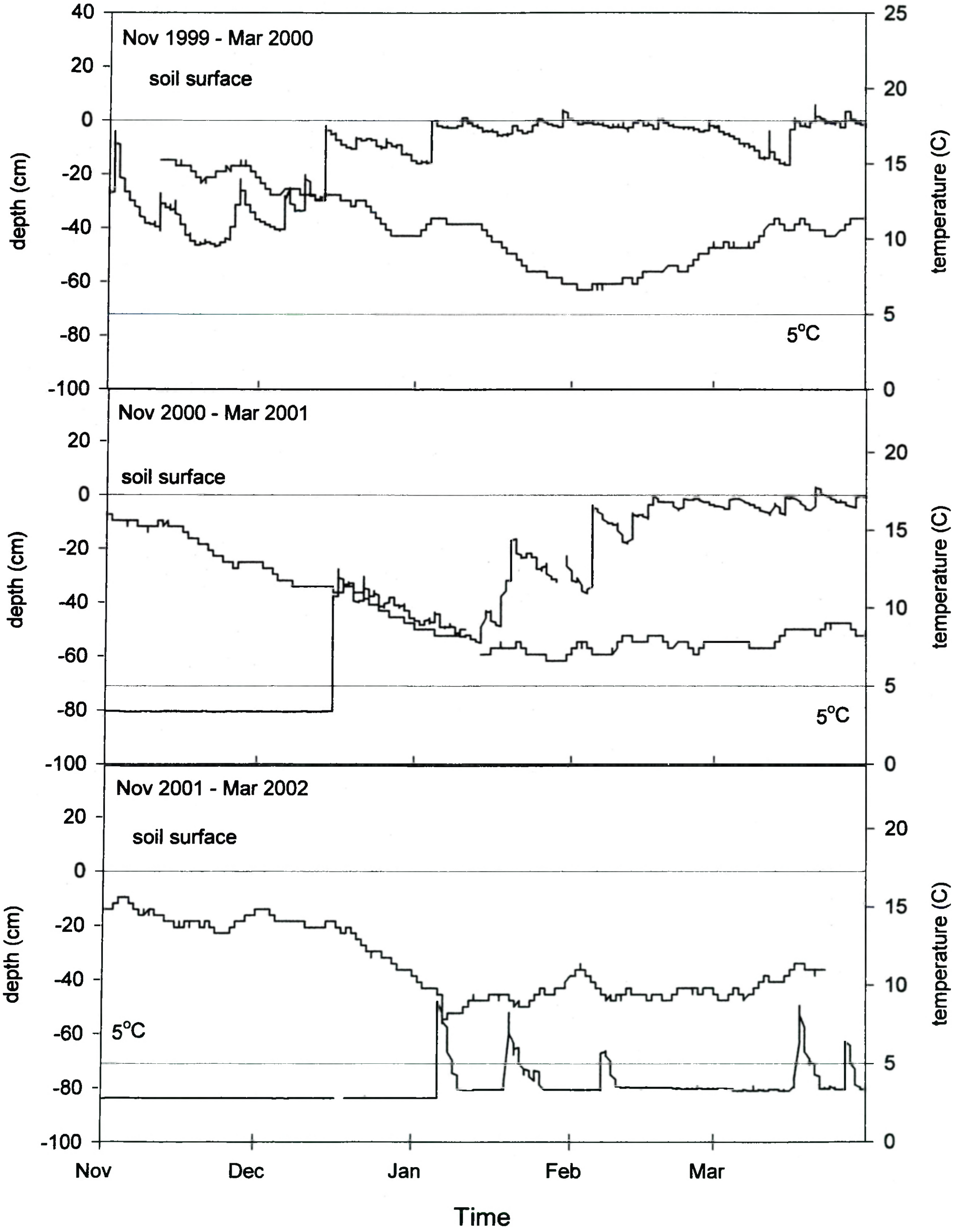
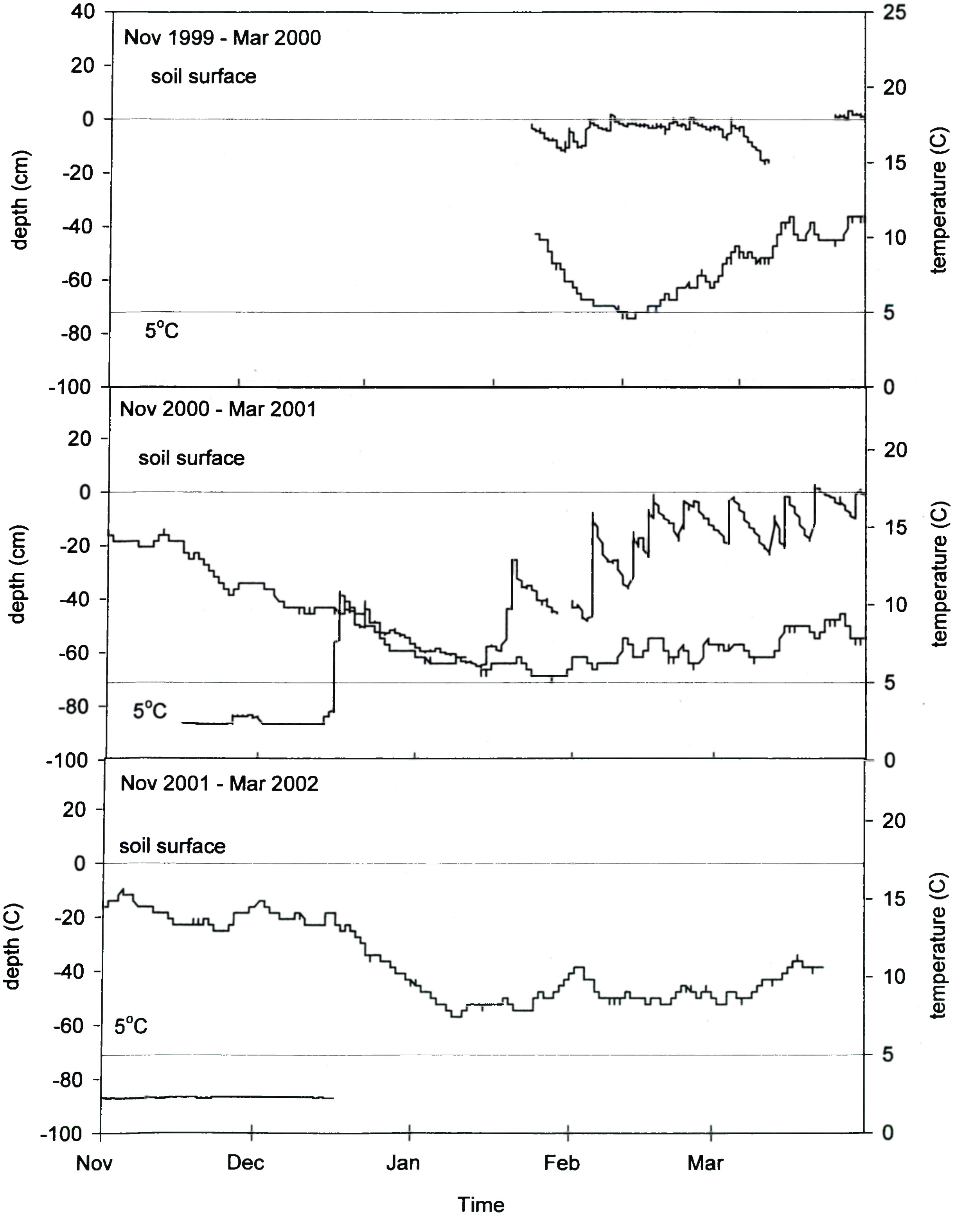
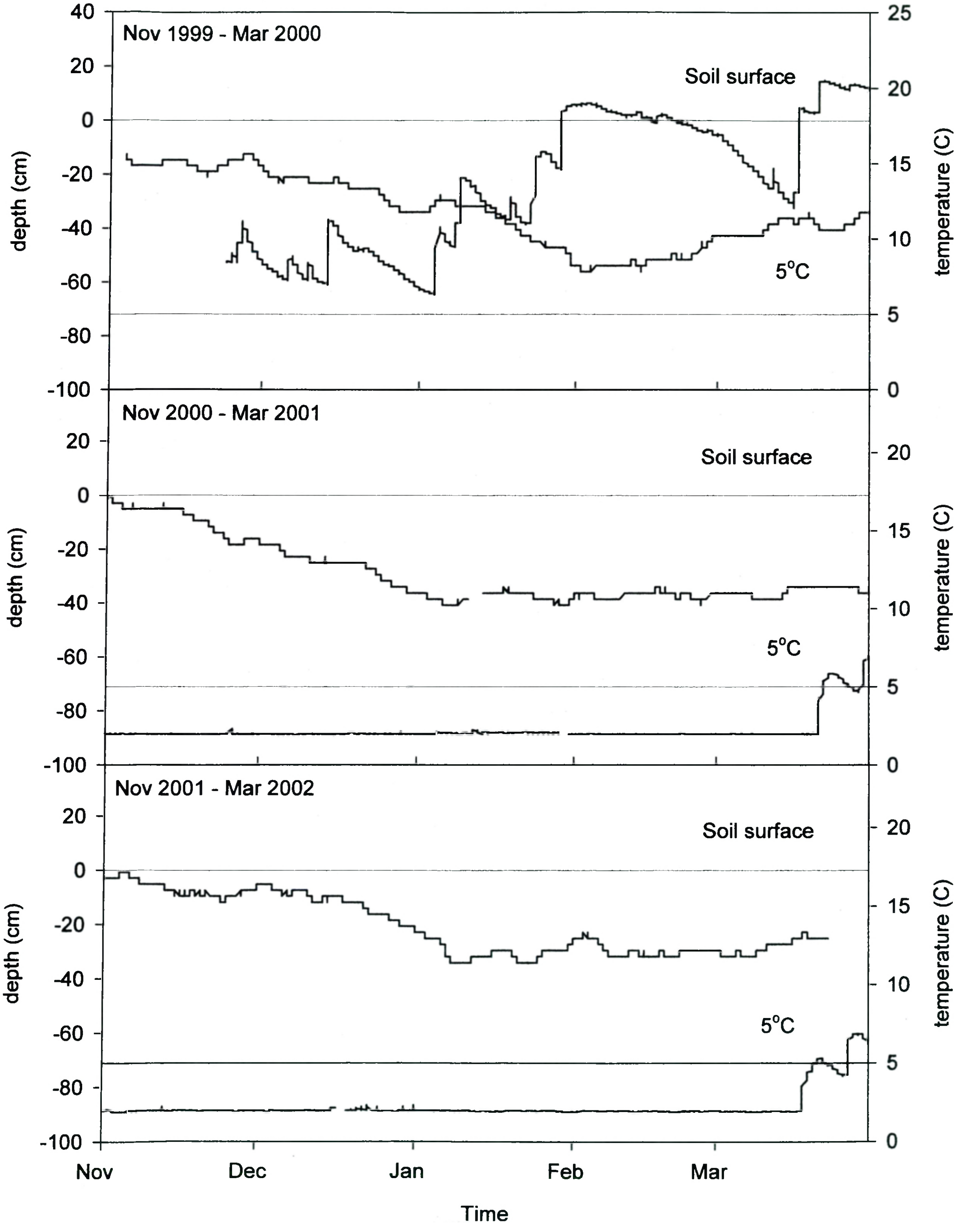


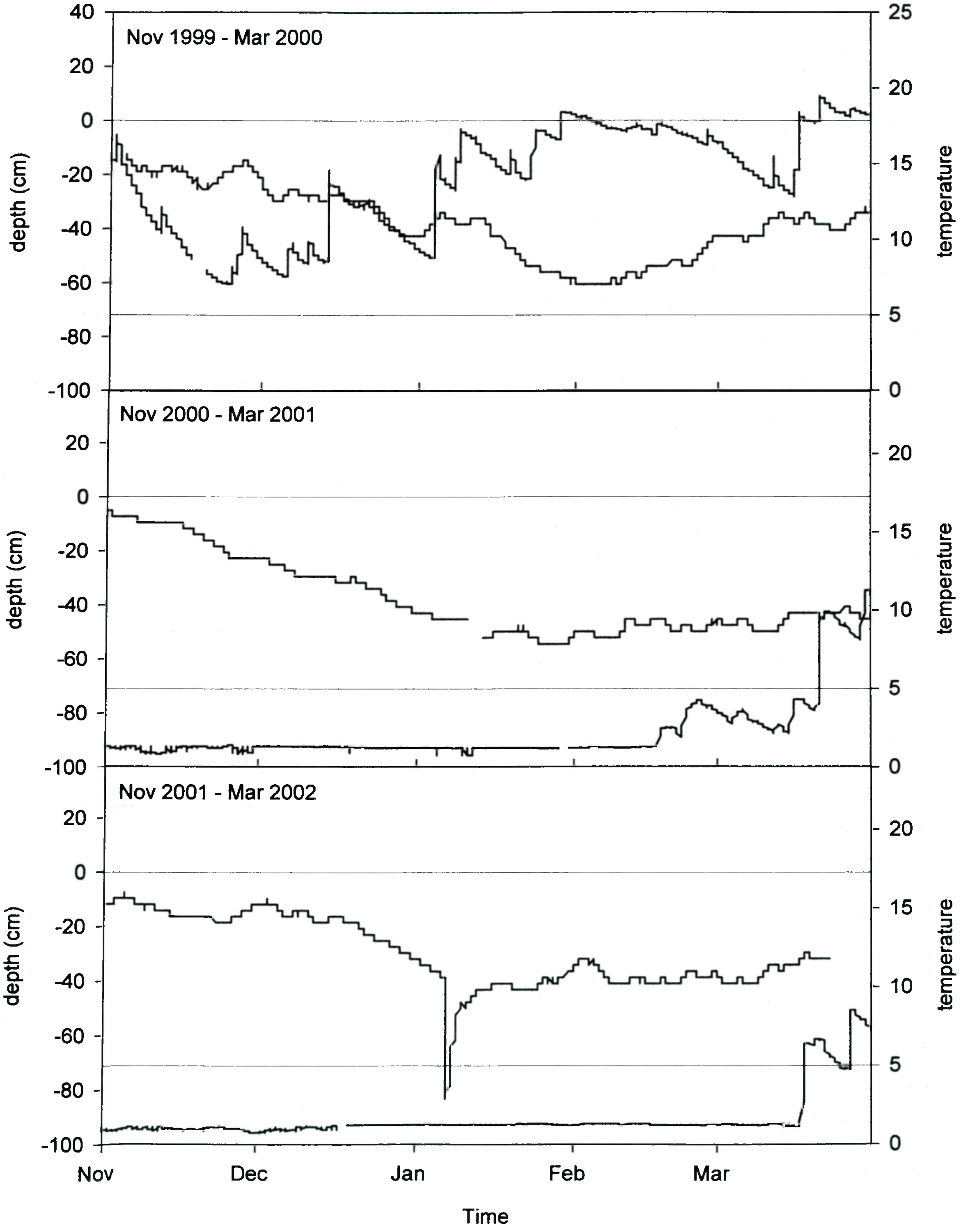
Figure D(5): November - March
SF2 Groundwater & 50-cm Soil Temperature



Appendix D (6): November - March
SB1 Groundwater & 50-cm Soil Temperature



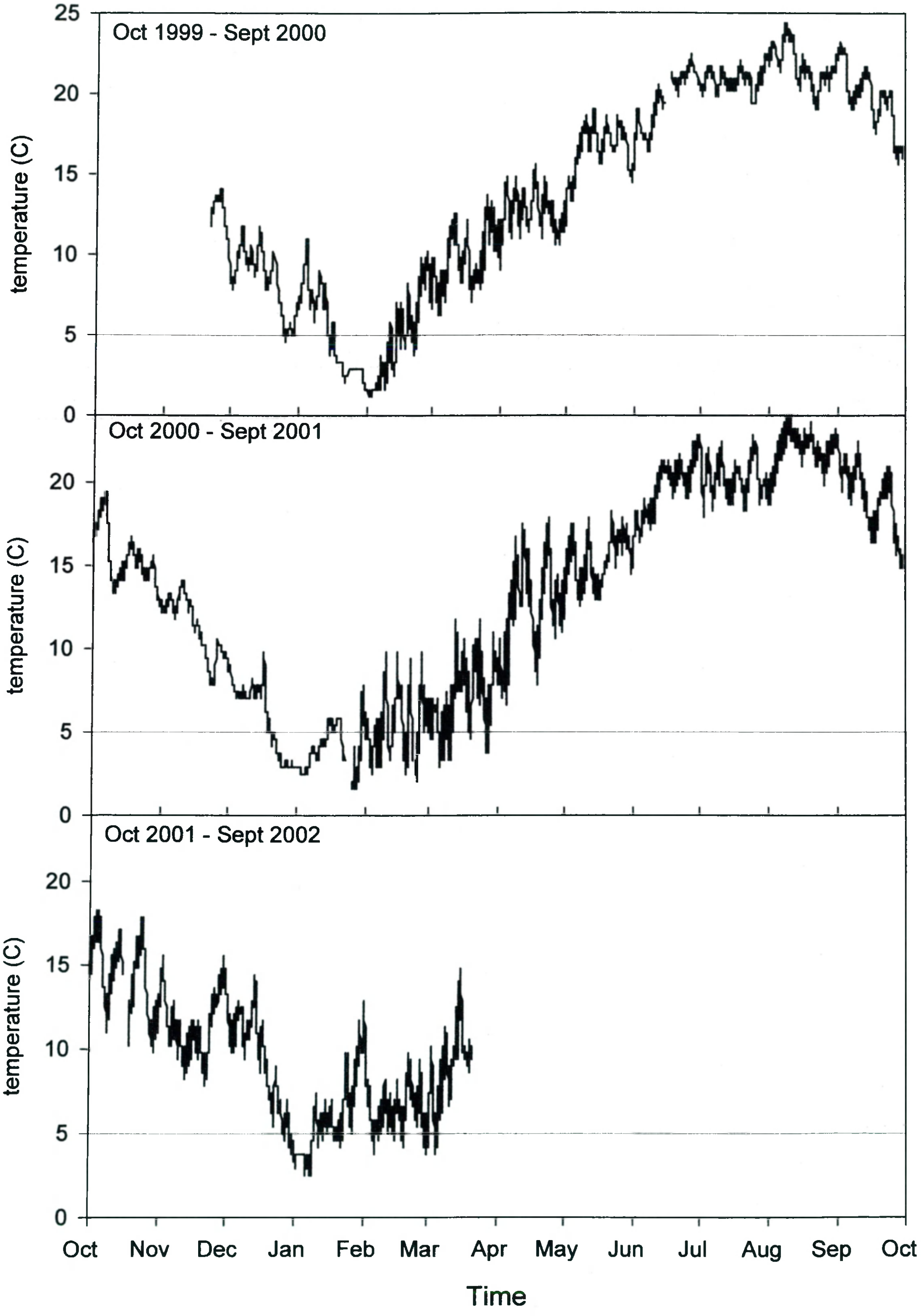
Appendix D (7): November - March
SB2 Groundwater & 50-cm Soil Temperature



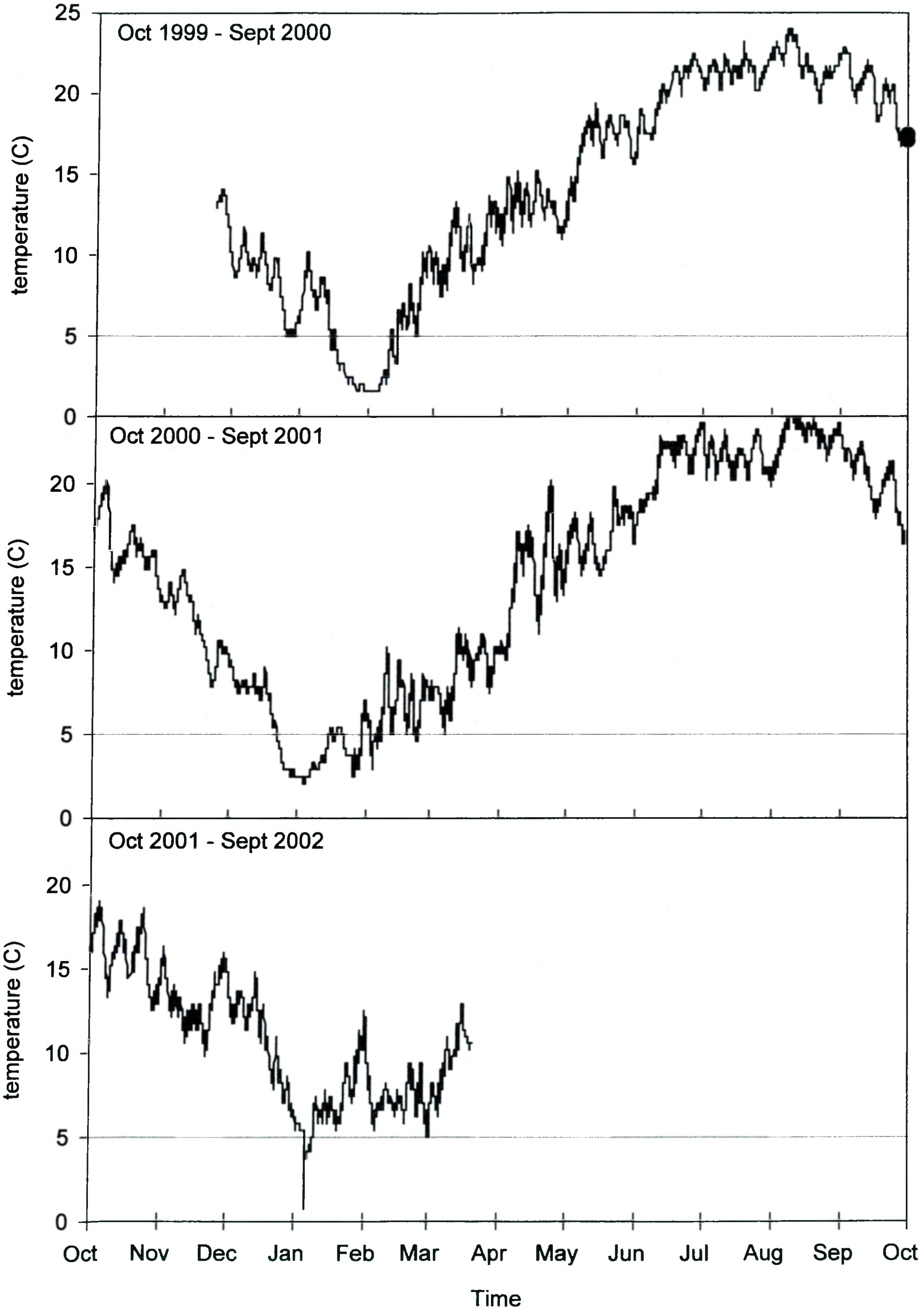
APPENDIX E

10 cm Soil Temperatures

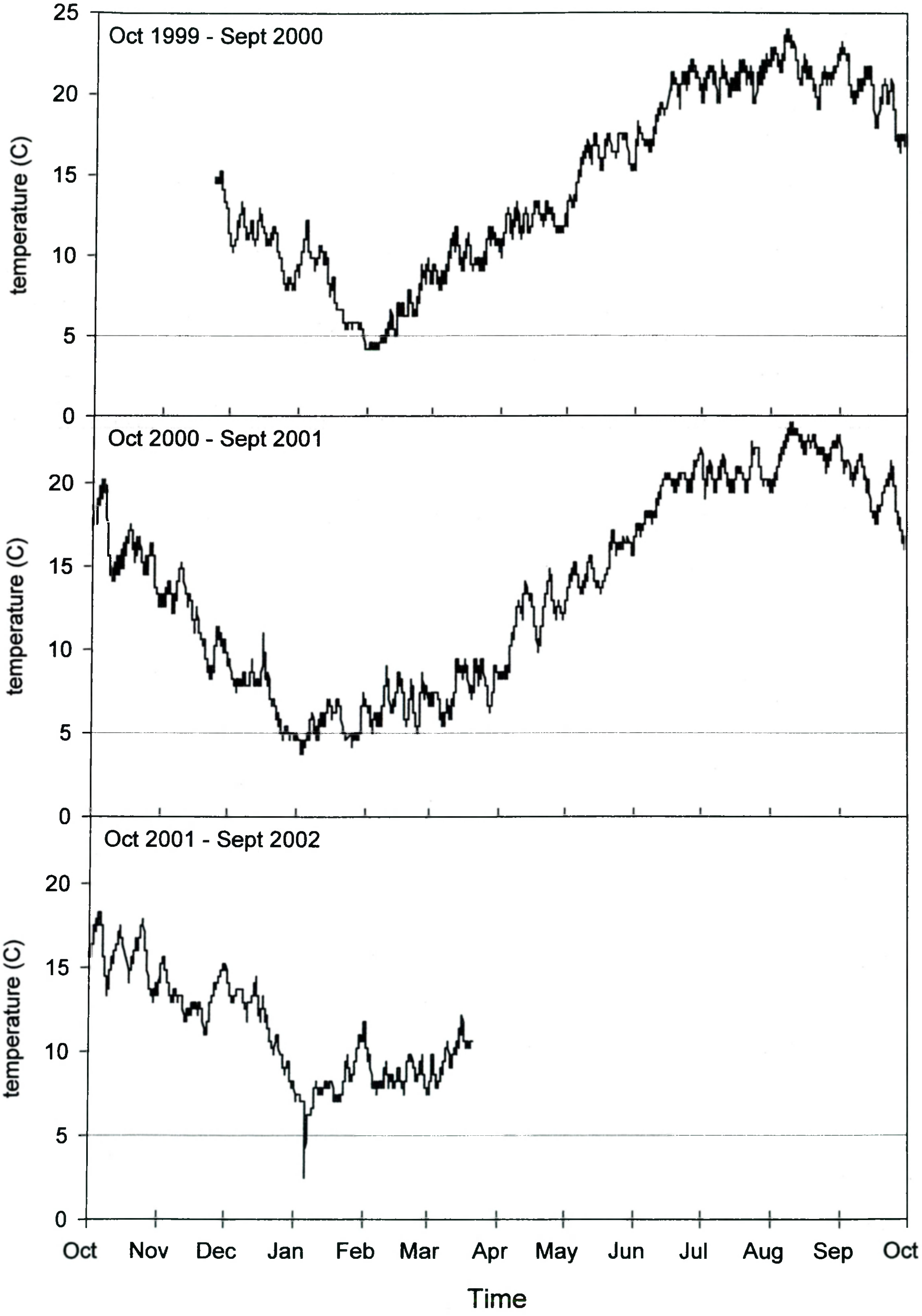
Appendix E (1): EL1 10-cm Soil Temperature



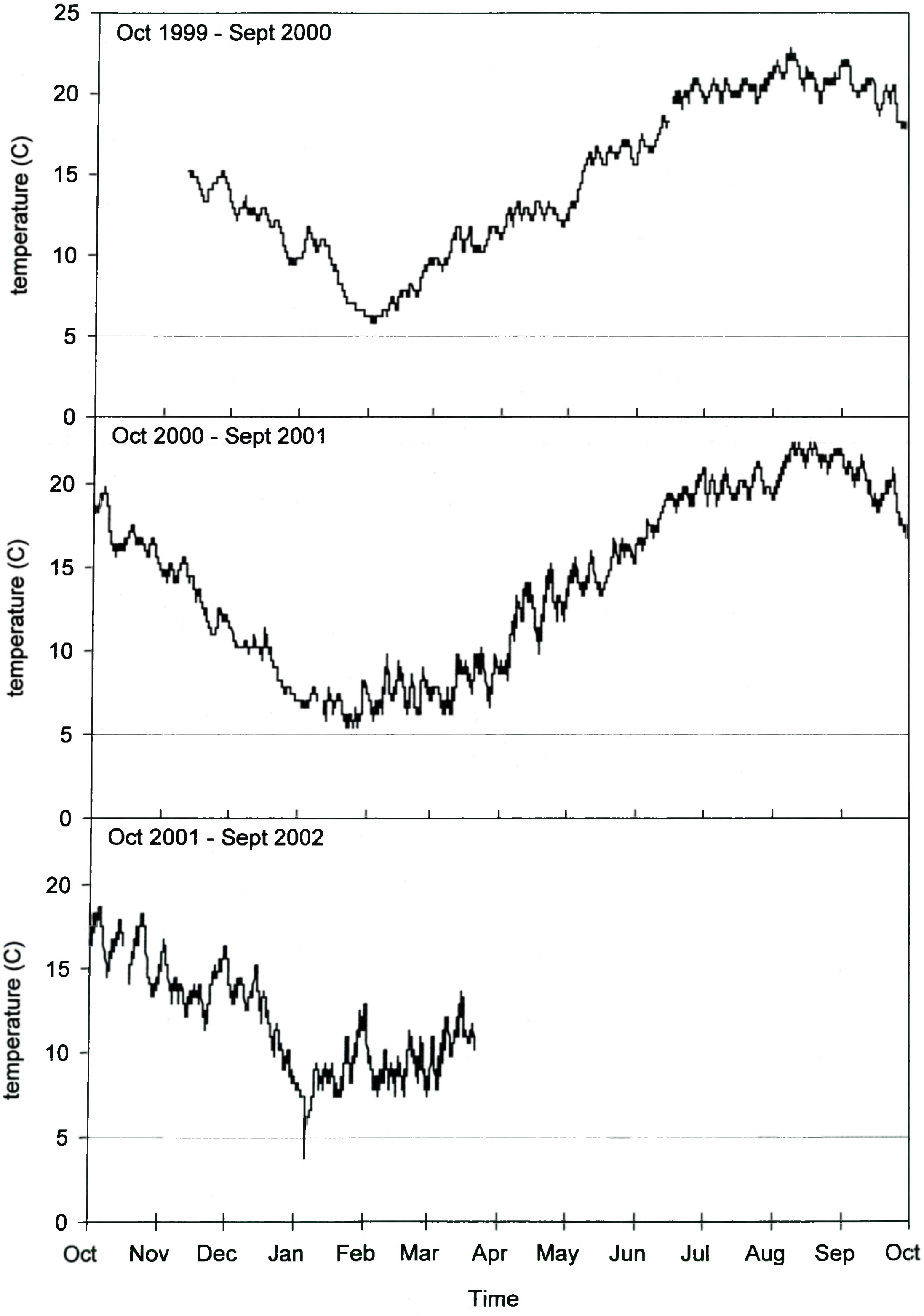
Appendix E (2): CS1 10-cm Soil Temperature



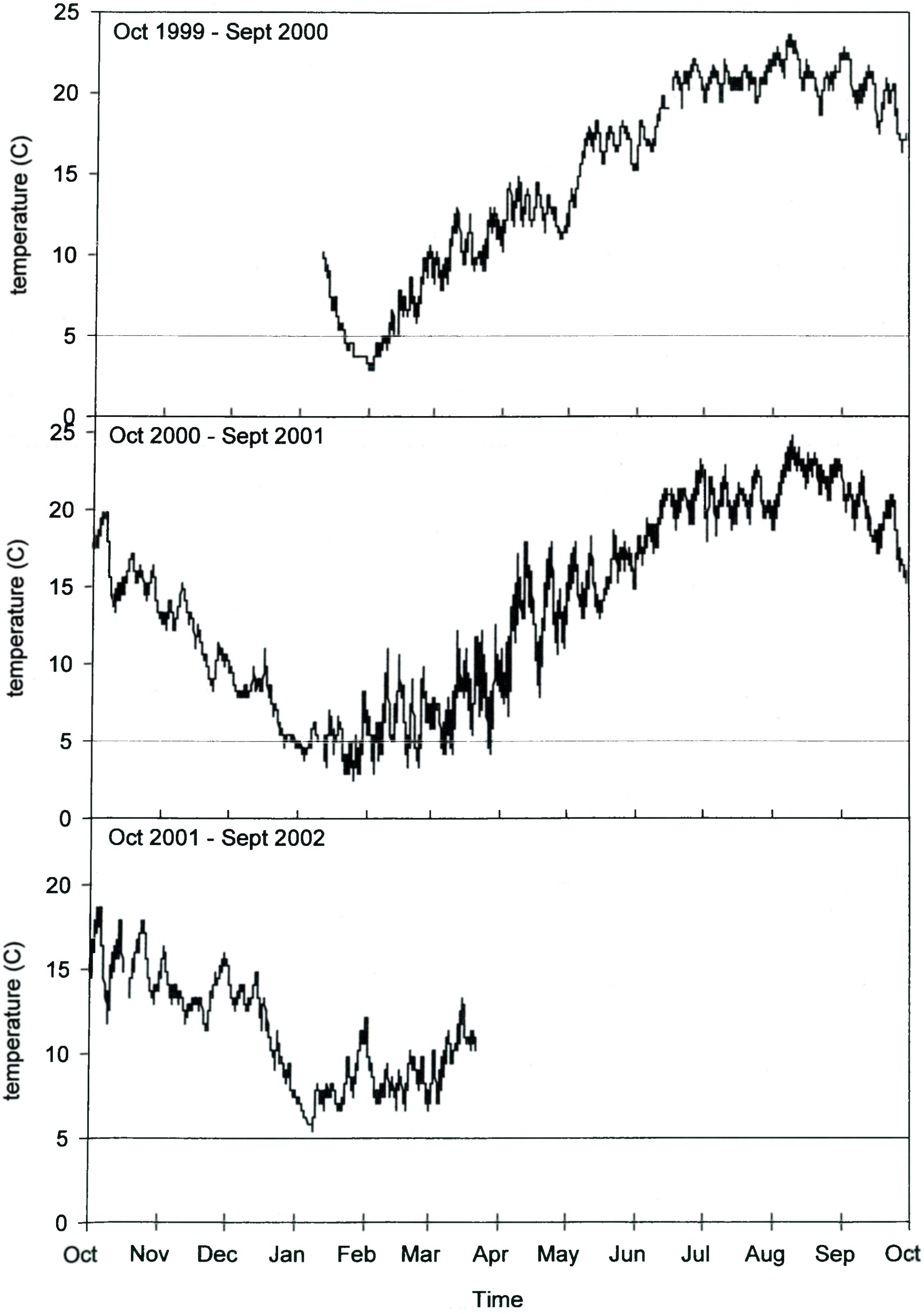
Appendix E (3): CS2 10-cm Soil Temperature



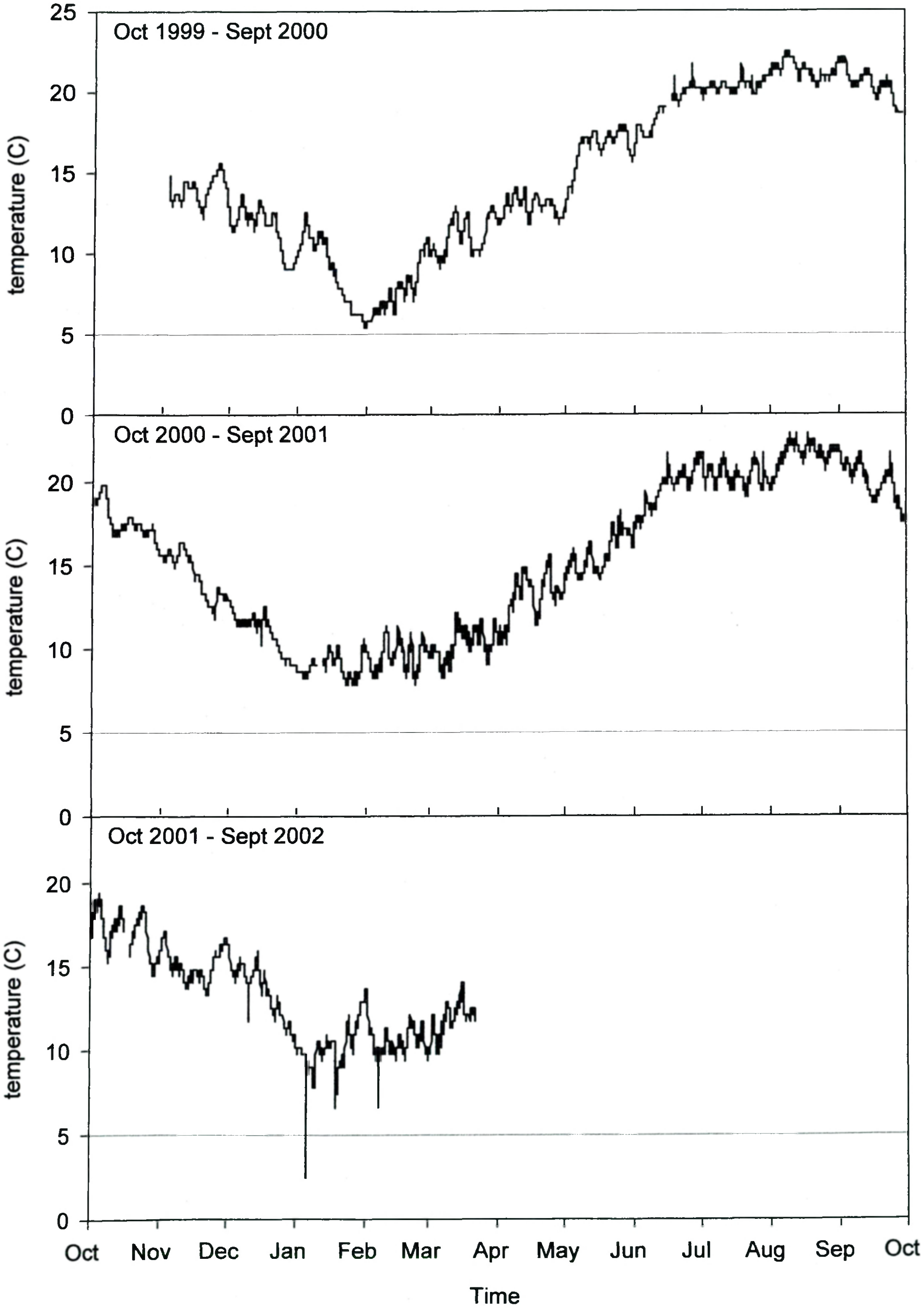
Appendix E (4): SF1 10-cm Soil Temperature



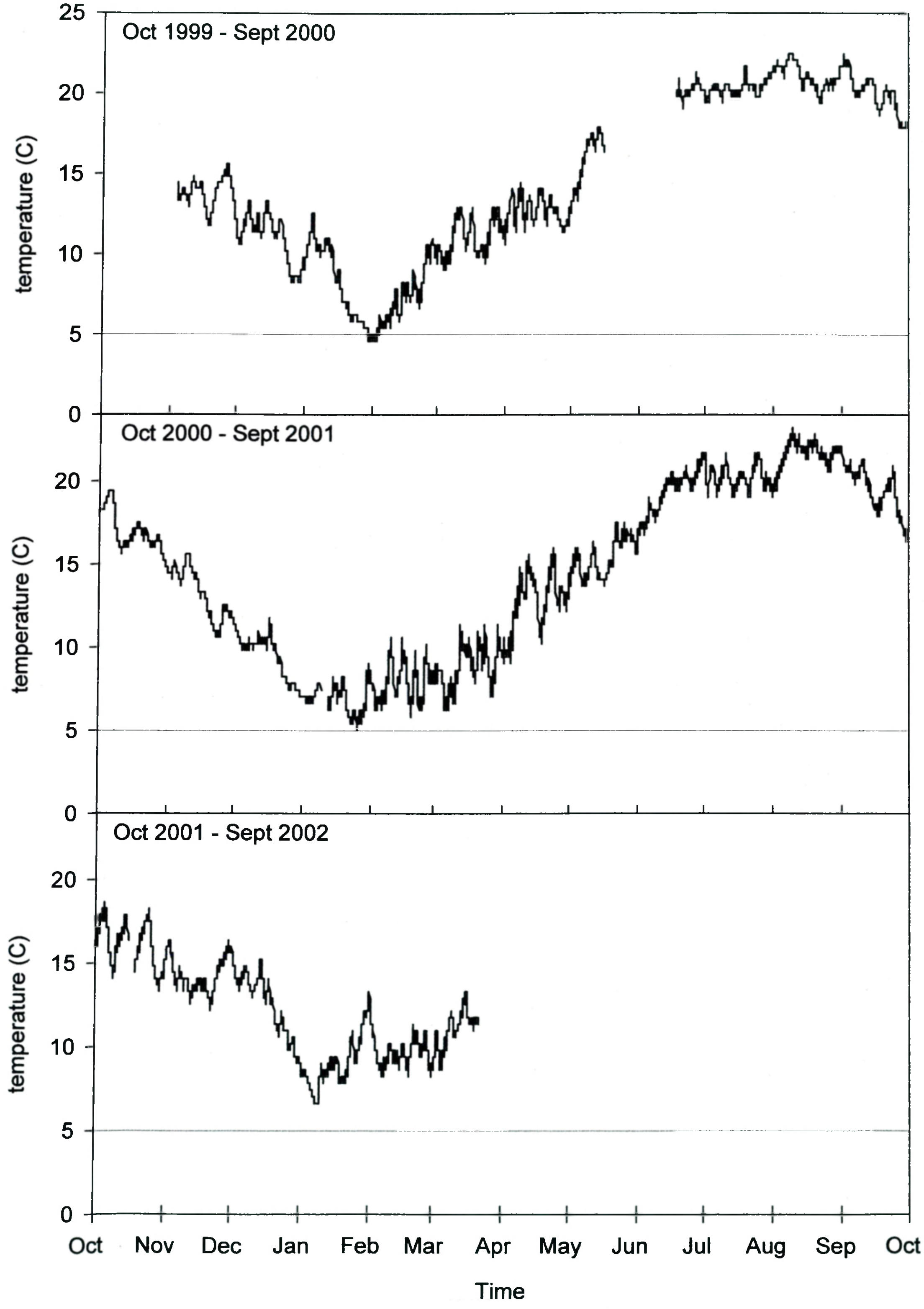
Appendix E (5): SF2 10-cm Soil Temperature



Appendix E (6): SB1 10-cm Soil Temperature



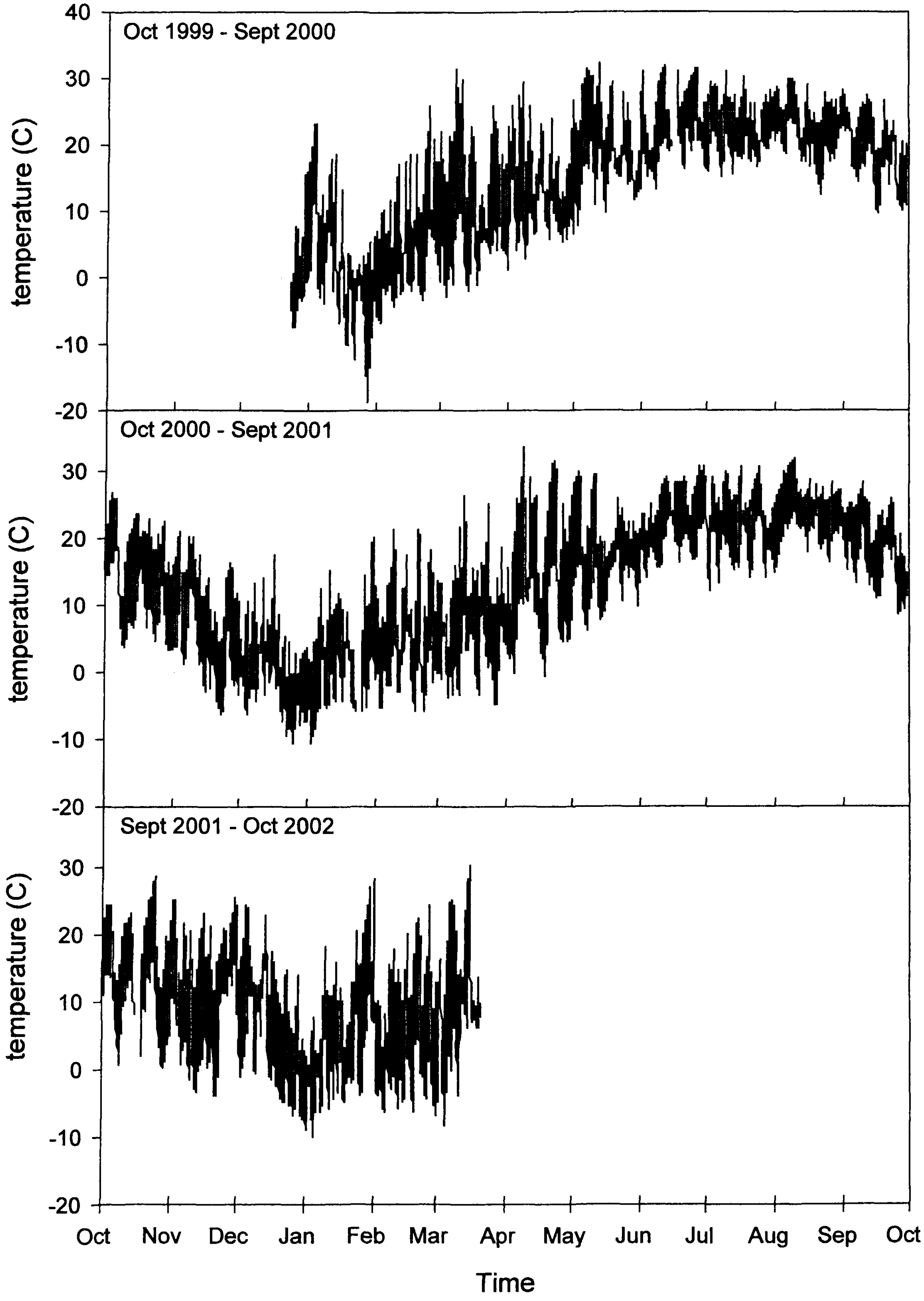
Appendix E (7): SB2 10-cm Soil Temperature



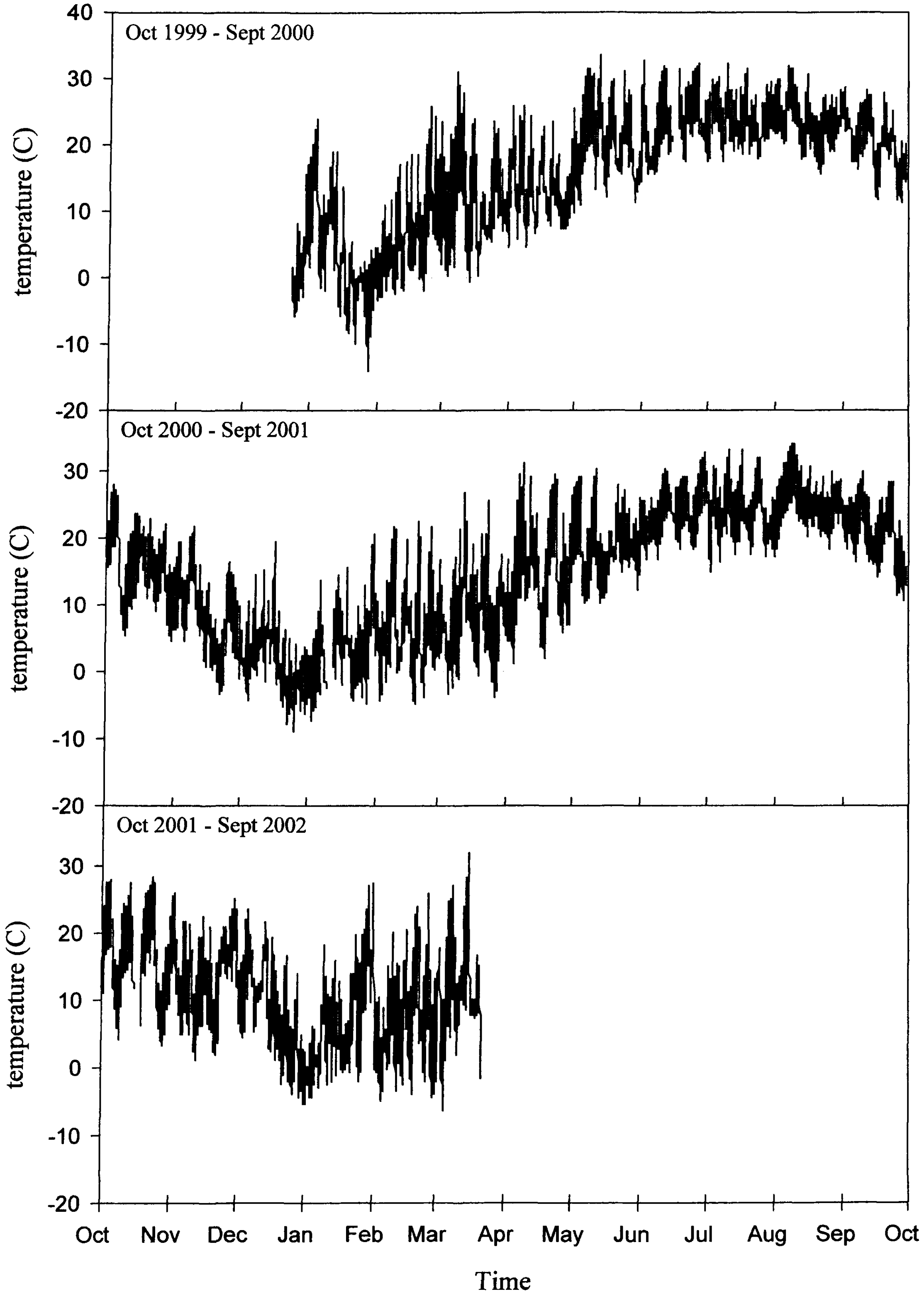
APPENDIX F

Climate/Weather Data

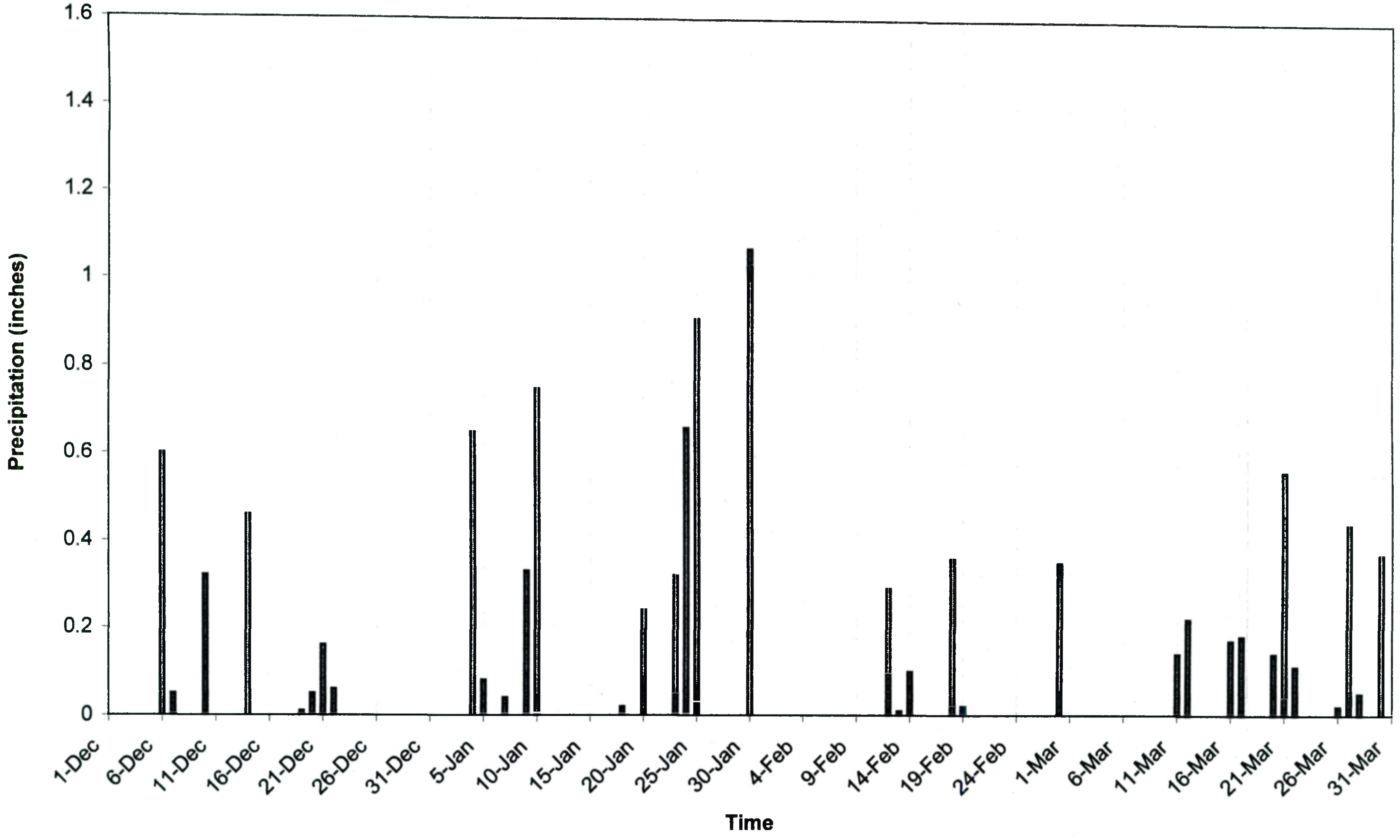
Appendix F (1) -- EL1 Air Temperature



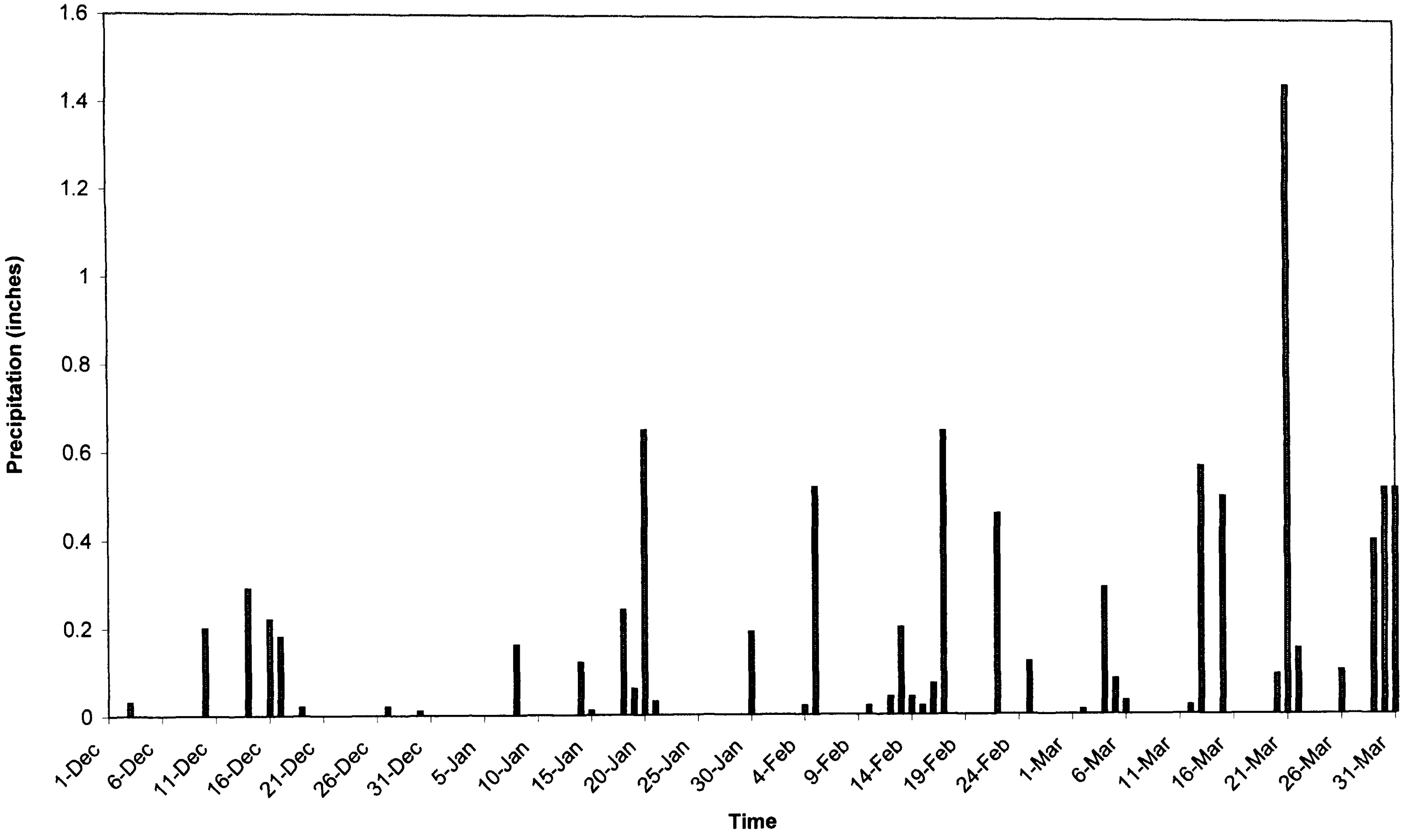
Appendix F (2) -- SB1 Air Temperature



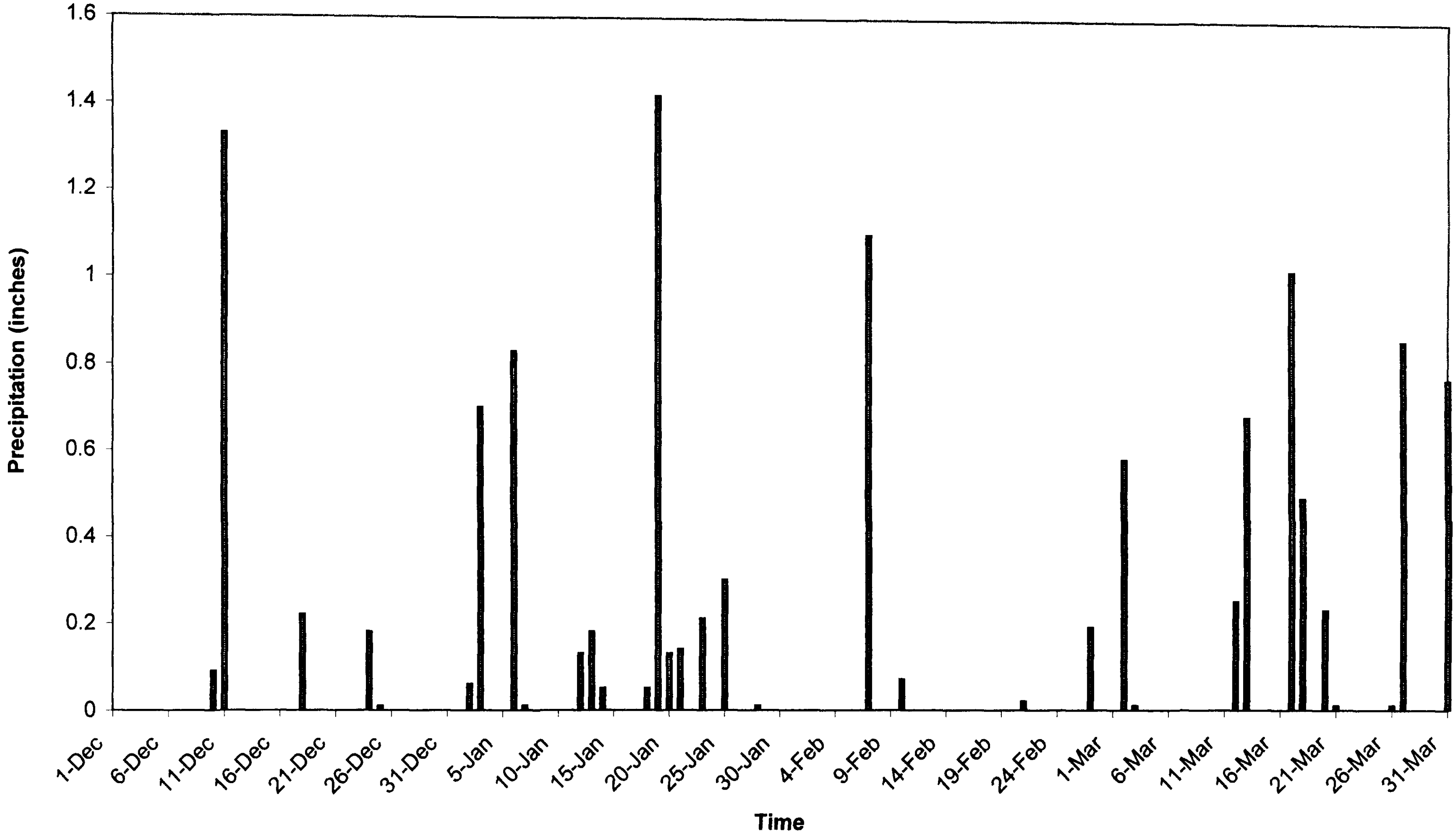
Appendix F (3): Norfolk Precipitation Dec 1999 to March 2000



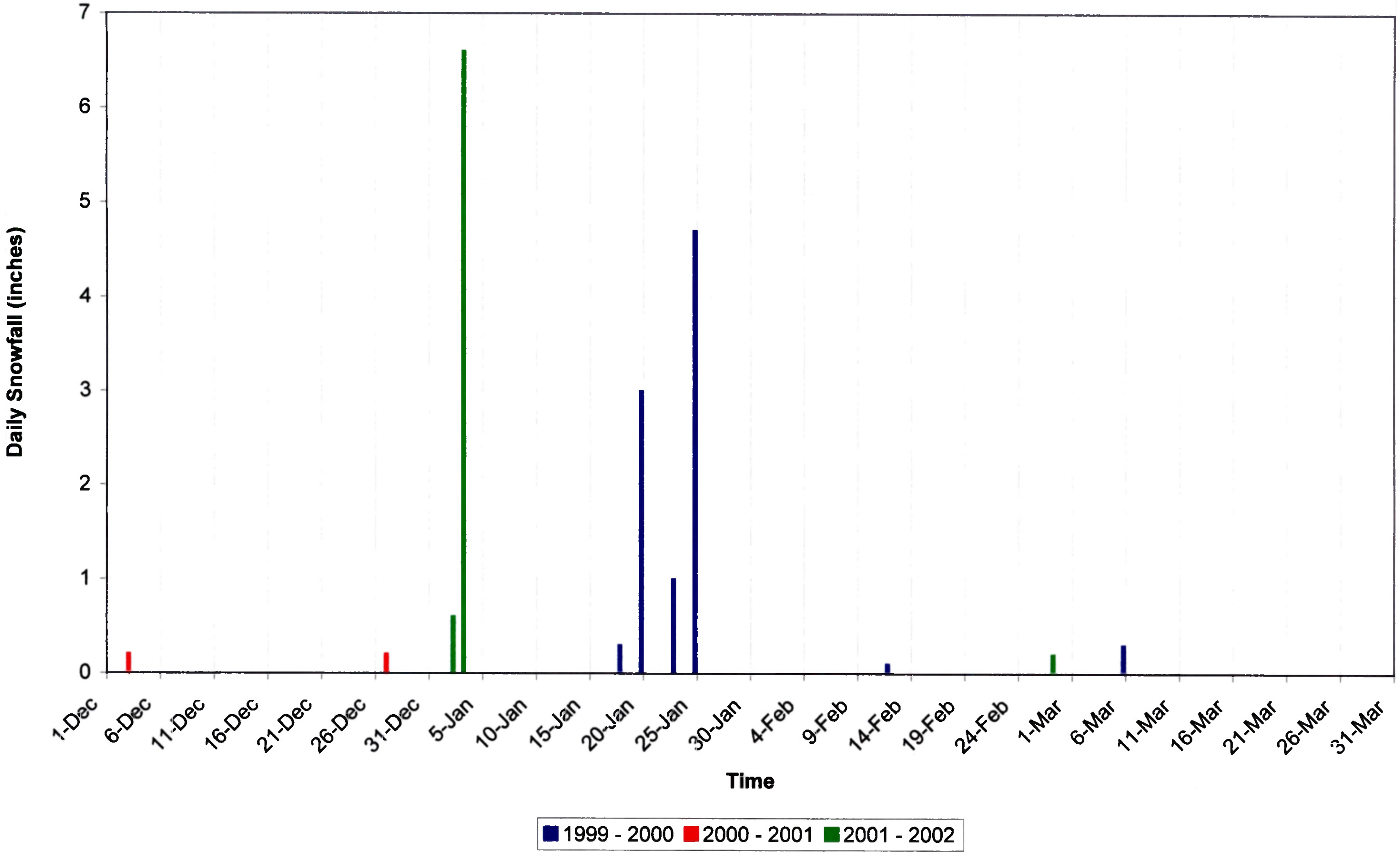
Appendix F (4): Norfolk Precipitation Dec 2000 - March 2001



Appendix F (5): Norfolk Precipitation Dec 2001 to March 2002



Appendix F (6): Norfolk Winter Snowfall Between December and March for 1999 to 2002



DEFINITIONS

Biological zero (Environmental Laboratory 1987):

"Limit of biological activity – With reference to soils, the zone below which conditions preclude normal growth of soil organisms. This term is often used to refer to the temperature (5°C) in a soil below which metabolic processes of soil microorganisms, plant roots, and animals are negligible."

Delineation (Mitsch and Gosselink 2000):

"Technique of determining an exact boundary of a wetland. Used for identifying jurisdictional wetlands in the United States."

Growing season (Environmental Laboratory 1987):

"The portion of the year when soil temperatures at19.7 inches below the surface are higher than biological zero (5°C) (US Department of Agriculture – Soil Conservation Service 1985) For ease of determination this period can be approximated by the number of frost-free days (US Department of the Interior 1970)."

Growing season (Soil Survey Staff 1999b):

"The portion of the year when soil temperatures are above biological zero at 50 cm (19.7")."

Hydric soil (Soil Survey Staff 1999b):

"A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part."

Hydrogeomorphic classification (HGM) (Mitsch and Gosselink 2000):

"Wetland classification system based on type and direction of hydrologic conditions, local geomorphology, and climate."

Hydrogeomorphic wetland class (Smith et al. 1995):

"The highest level in the hydrogeomorphic wetland classification. The seven classes identified by Smith et al. are: depression, lacustrine fringe, tidal fringe, slope, riverine, mineral soil flats, and organic soil flats."

Jurisdictional wetlands (a - Mitsch and Gosselink 2000, b - Smith et al. 1995):

a – "Term used in the United Sates to refer to wetlands that fall under the jurisdiction of federal laws for the purpose of permit issuance or other legal matters."

b – "Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual," or its successor."

Microbial activity season (Megonigal et al. 1996)

"The portion of the year when soils are >5°C at 50 cm."

Mineral soil flats (Rheinhardt et al. 2002):

"Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depression and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, saturation overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage, often due to hardpans, and low lateral drainage, usually due to low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become the class organic soil flats. A pine savanna with hydric soils is an example of a mineral flat wetland."

Thermic (Soil Survey Staff 1996):

"The mean annual soil temperature is 15°C or higher but lower than 22°C, and the difference between mean summer and winter soil temperatures is more than 5°C either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower."

Wetland (Environmental Laboratory 1987):

"Those areas that are inundated or saturated by surface or groundwater at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

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