1997
Bridgham

A Study of Wetland Hydrology in Frog Bog and Brown Cedar Swamp, Northern Wisconsin

Emily T. Klatte
Department of Biological Sciences
University of Notre Dame
Notre Dame, IN 46556

ABSTRACT

Each type of wetland has unique characteristics which are strongly influenced by its hydrology. This experiment tested two important aspects of hydrology: water chemistry (temperature, pH, conductivity, alkalinity, and dissolved organic carbon) and the recharge-discharge function of wetlands. A series of five piezometer nests was installed in each of two riparian wetlands: Frog Bog and Brown Cedar Swamp, located on or near the UNDERC property. Water samples were collected and analyzed twice at each site, while water levels in the piezometers were measured three times at each site. Trends in water chemistry were definitely evident in the data. Measurements varied with depth, distance from the stream, and changing stream conditions. Furthermore, the bog generally had lower pH, conductivity, and alkalinity values, and higher DOC values. Conversely, the samples from the cedar swamp had higher pH, conductivity, and alkalinity values characteristic of a more minerotrophic environment. These differences were also reflected by the recharge-discharge function of each wetland. The bog was found to have mostly lateral flow of water, while the cedar swamp had a combination of recharging, discharging, and lateral flow sites allowing it to be more influenced by groundwater.

INTRODUCTION

Hydrology is one of the central factors controlling the structure and function of different types of wetlands (Bridgham *et al.* 1996). For instance, the nutrients and cations that are carried in the water have a strong influence on the plant species that are able to survive in each wetland. Because groundwater input is one of the primary means by which wetlands may obtain nutrients, it consequently plays a definite role in determining the surface water chemistry and the dominant types of vegetation communities in bogs and fens or cedar swamps.

In addition to groundwater, precipitation and runoff are also important when studying the water chemistry of bogs and fens. Because bogs are raised higher than fens, it is difficult for runoff water to influence the structure of the peatland. Instead, precipitation serves as the major source of nutrients and mineral salts in bogs, often resulting in a pH of less than 4.2 (Siegel 1992). This acidic environment is very suitable for the growth of Sphagnum moss and spruce trees. Conversely, the Sphagnum influences the water chemistry by lowering the pH through the uptake of calcium and the release of protons (Mitsch and Gosselink 1993). Furthermore, the biodegradation of organic acids and the oxidation of peat also enhance this low pH (Siegel 1992).

Fens and cedar swamps generally have a water chemistry much different than that found in bogs. Fen water is often referred to as minerotrophic, for it has a pH greater than 5.7 and a concentration of dissolved inorganic acids of greater than 50 mg/L (in contrast to the 5 mg/L found in bogs). Furthermore, unlike bogs, fens receive water inputs from runoff, as well as from precipitation and groundwater. This input from surrounding soils gives fens a higher concentration of metallic cations, including Ca^{++}, Mg^{++}, Na^{+}, and K^{+} (Mitsch and Gosselink 1993). At the same time, a slower decomposition rate allows for a higher organic content and an increased buffering capacity. This particular environment is especially suitable for sedges and marsh herbs, in contrast to the Sphagnum typically found in bogs (Siegel 1992). Therefore, it is generally accepted that fens have greater productivity than bogs, for their minerogeneous waters have a higher pH, nutrient availability, and cation concentration (Bridgham *et al.* 1996).

As mentioned above, the pH of the soil and water is clearly a distinguishing characteristic of bogs and fens. Because the pH is often interrelated with the calcium concentration, it is often helpful to examine this variable when studying water chemistry. Not only does calcium influence the vegetation due to its role as a limiting nutrient, but it also seems to control the availability of phosphorous. For instance, under alkaline conditions, calcium ions bind with phosphorous to produce calcium-phosphates. Therefore, peatlands with high alkalinity are often P-deficient, which may result in low productivity (Bridgham *et al.* 1996). Despite its role as a limiting nutrient, calcium is more often associated with the pH of wetlands. For instance, the alkalinity (or acid-neutralizing capacity) of many surface waters is basically a function of bicarbonate, carbonate, and hydroxide concentrations. Therefore, the degree of alkalinity can often be associated with the amount of calcium carbonate in the soil (Owen and Axler 1991-1992).

In addition to its affects on pH, nutrient availability, and community structure, hydrology also influences the degree of moisture in the soils. For instance, some peatlands are waterlogged for prolonged periods, which leads to anaerobic conditions in the soil. While some plants cannot survive with this physiological stress, others have adapted and can therefore tolerate different degrees of flooding. It seems that this would especially be true in wetlands fringing streams, for they would be more likely to experience flooding. Conversely, other peatlands undergo periods of drought when the water tables are far below the surface. Just as with flooding, this lack of water also influences plant communities that develop at different peatlands. For instance, in a study of northern Minnesota peatlands, the degree of waterlogging was correlated with the biomass. Whereas wet soil conditions led to low biomass communities, drier conditions led to high biomass communities with more shrubs and trees (Bridgham 1996). Furthermore, variations in water chemistry and duration of flooding may also affect the animals and microbes native to a certain wetland, which could each conversely affect the chemical composition of the water (Mitsch and Gosselink 1993).

In comparison to flooding patterns, the method of groundwater movement is also influential on the vegetation patterns and surface water chemistry. One concept that is particularly useful in studying fluid mechanics is that of hydraulic head, which describes the energy status of water in flow systems. In accordance with the principles of thermodynamics, water will move in the direction of decreasing energy level, or decreasing hydraulic head (Reeve 1990). Therefore, hydraulic head measurements can be used to determine the direction of water flow in a peatland. This is often accomplished by measuring the elevation of water in a piezometer, which is a narrow pipe that allow water to enter through an opening near the bottom (Siegel 1992).

As long as hydraulic head values throughout a peatland are not equal, water will flow upward or downward depending on the pressure gradient (Reeve 1990). For example, precipitation will move deep into the ground water flow system in the direction of decreasing hydraulic head, or wherever pressure decreases with depth. These areas are referred to as recharge zones. On the other hand, when pressure and hydraulic head increase with depth below the surface, groundwater emerges at the surface and then undergoes evaporation or uptake by plants. This net movement of water upward is referred to as discharge (Siegel 1992). A different situation exists when the hydraulic head values are identical at all depths in the soil, for there is no vertical flow of the water. Under these circumstances, the value of the hydraulic head represents the position of the water table, which is defined as the point where the soil water is at atmospheric pressure (Reeve 1990). This suggests that the long-term recharge by precipitation equals long-term groundwater discharge (Siegel 1992).

Clearly, hydrology has a variety of effects on the characteristics of peatlands, including pH, nutrient availability, degree of flooding, and hydraulic head. It is these differing variables that allow for the distinct qualities of bogs, fens, and cedar swamps. Furthermore, the location of a particular peatland could also affect its water chemistry and flow patterns. For instance, wetlands fringing streams would seem to be affected by the water chemistry of the nearby stream. Therefore, an experiment studying the variation on water chemistry with depth and distance from such streams would be useful in demonstrating the importance of hydrology.

MATERIALS AND METHODS

Because hydrology is a key component of wetland ecology, this experiment attempted to study the hydrology of two wetlands fringing streams on the UNDERC property. The two sites were

Brown's Cedar Swamp located along Brown's Creek, and Frog Bog located along the stream connecting Tenderfoot Lake and Palmer Lake. Because these wetlands should conceivably have different hydrologies, a general hypothesis was stated that water chemistry and water flow patterns should vary with depth, distance from the stream, and changing stream conditions.

Piezometer Installation

First, a series of five piezometer nests were placed in each of the two selected wetlands. Each nest consisted of 6 PVC pipes measuring 3 meters in length and 0.5 inch inner diameter. The bottom of each pipe was capped in order to prevent the entrance of peat into the pipe during installation. An additional modification of the pipe involved sawing a narrow slit into the bottom of the pipe of approximately 3 inches in length. This allowed water to flow into the pipe while keeping most of the peat out of the pipes (methods taken from Amoozegar and Warwick, 1990).

The location of each piezometer nest varied according to distance from the stream fringing the wetland. At Brown Bog, the nests were installed at a distance from the stream of 3, 30.5, 41.5, 61.5, and 74.5 meters. The sites located closest to the stream (labeled sites A and B, respectively) were in a habitat characterized mostly by the abundance of Alder bushes and other small vegetation, whereas the nests farther from the stream (C, D, and E, respectively) were surrounded by larger cedar trees. At Frog Bog, the location of the nests with respect to the stream was .5, 9.5, 20.5, 45.5, and 77.5 meters. Sites were labeled A - E, with site A being the closest to the stream. This site was surrounded by several small shrubs, whereas the sites further from the stream had more Sphagnum and Tamaracks.

The series of six pipes in each piezometer nest was divided into three sets, with each set consisting of two replicates. Pipes 1 and 2 were installed deepest into the peat, usually with a depth equal to that of the mineral surface contact. If this was deeper than 3 meters, the pipes were placed at a depth of 2.75 meters. The depth of pipes 1 and 2 was then divided into three increments, and two of the remaining four pipes were installed at each of these respective shallower depths.

Next, water was collected from the pipes for a total of three times at Brown's Cedar Swamp and two times at Frog Bog. Water that had collected in the pipes since installation or previous sampling was first pumped out of all pipes using the Mityvac Hand Pump. After allowing them to quickly refill, the fresh water samples were collected in plastic bottles, labeled appropriately for each pipe. During each sampling period, a bottle of stream water was also collected for later comparison with the water samples collected from the peatland.

Water Chemistry

A second component of this experiment involved several water chemistry tests which were performed on all water samples. Immediately after collection of the samples in the field, the temperature of each sample was recorded. Samples were then transported back to the laboratory where pH and conductivity were measured using a meter with appropriate standards. In order to properly analyze conductivity, a temperature coefficient was calculated as being 2.44. Next, the alkalinity of each sample was measured using the Hach Kit. Specifically, six drops of the indicator Bromcresol Green Methyl Red were added to 50 ml of each sample. A 0.20 N solution of sulfuric acid was then used for titrating the samples. Alkalinity (mg/L) was calculated from the milliliters of sulfuric acid added, and then multiplying this value by 20. Next, a sub-sample of approximately 25 ml was set aside in a plastic vial (film canisters) and placed in the freezer for later analysis at Notre Dame.

After performing these tests, each sample was filtered using a Buchner funnel and glass fiber filter paper. Filters were first acid washed, and all glassware was washed in a 10% hydrochloric acid bath between each sample. After soaking the plastic bottles in the acid bath, the filtered samples were re-collected. The dissolved organic carbon content (DOC) of each sample was then measured using the Spectrophotometer. A 5 ml cuvette and a wavelength of 325 nm were used when determining DOC. Two film canisters were then filled with 25 ml of each filtered sample, along with a 0.02 mmol sodium azide solution in a sample : preservative ratio of 200:1.

Water Table Measurements

In addition to studying water chemistry, the water level in each piezometer was determined for a total of three times at each site. Measurements were initially made using an electrode which buzzed upon contact with water. The height of the pipe extending above the ground was subtracted from the length of the wire used in order for the electrode to reach the water surface. In many cases, however, the ion concentration was too low to initiate the buzzing sound. Therefore, a small fishing weight was attached to fishing line and used to measure the water level. The length of the wire needed to reach the water in the pipes (indicated by the sound of the weight hitting the water surface) was measured. These measurements were used to determine whether the peatland is recharging or discharging at each piezometer nest.

RESULTS

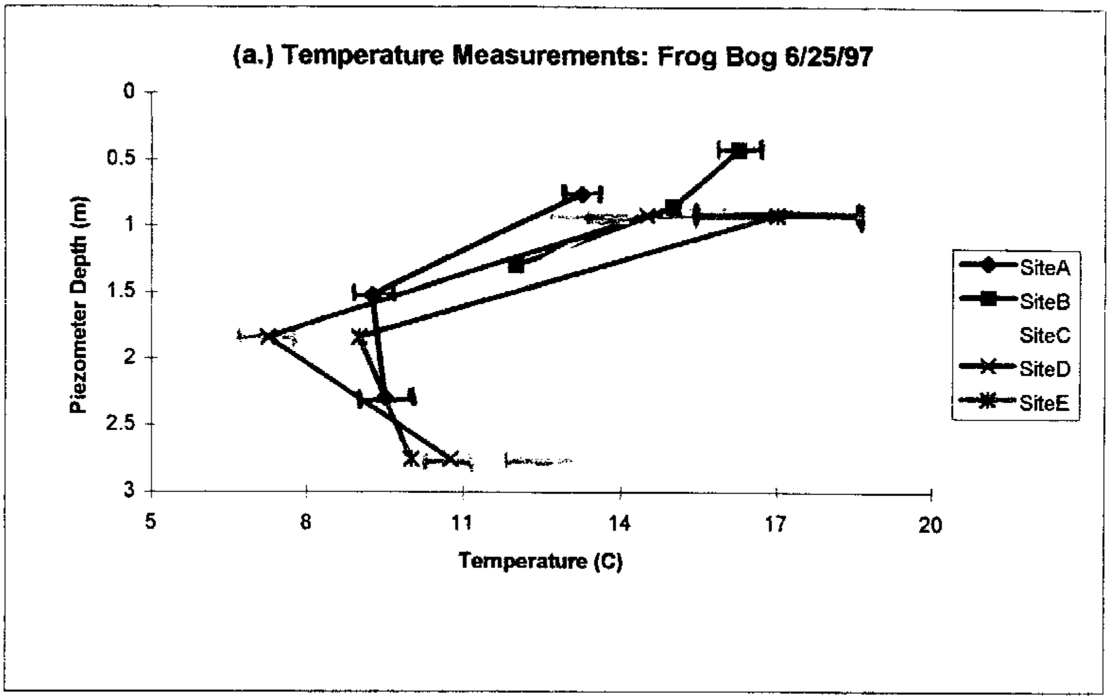
General trends in data supported the hypothesis that water chemistry in riparian wetlands varies with depth, distance from the stream, and wetland type. The results of temperature measurements were similar in both the bog and cedar swamp. Temperature decreased with depth, and was generally higher in the piezometer nests closer to the stream (Figures 1 and 2). Furthermore, when the temperature of stream water increased or decreased (Tables 1 and 2), the water sample temperatures tended to vary accordingly, even if only slightly. This trend was especially apparent at sites closest to the stream.

Unlike the data involving temperature, the pH values varied for the bog and cedar swamp. The pH values for the water samples in the bog were generally in the range of 5 - 6.5, with a few exceptions above and below this range. The pH values tended to increase with depth for all piezometer nests (Figure 3). At the cedar swamp, however, the pH ranged from 6.5 - 7, again with a few exceptions. In contrast to the bog, data did not show a uniform increase in pH with depth, but were instead rather variable (Figure 4). Finally, the pH did seem to be affected by changing stream conditions, especially at nests closer to the stream (Tables 1 and 2).

Conductivity and alkalinity values, which were both an indication of the ion concentration or buffering capacity of the water samples, also differed between the bog and cedar swamp. Frog Bog showed a much wider range in conductivity and alkalinity values: approximately 25 - 310 uS/cm and 0 - 150 mg $CaCO_3$/L as seen in Figures 5 and 7, respectively. The ranges of conductivity and alkalinity values found in Brown Cedar Swamp were rather narrow: 140 - 210 uS/s and 75 - 105 mg $CaCO_3$/L (Figures 6 and 8). There was not a strong relationship between the conductivity and alkalinity of the stream water and the water samples, as was seen for temperature and pH (Table 1).

Absorbance readings, corresponding to the amount of dissolved organic carbon, definitely differed between the bog and cedar swamp. The range of absorbencies at 325 nm were approximately 0.5 - 2.5 in the bog (Figure 9), while they were 0.25 - 1.5 in the cedar swamp (Figure 10). Furthermore, the amount of DOC definitely decreased with depth in Frog Bog, while a trend was more difficult to discern at Brown Cedar Swamp. As was seen with conductivity and alkalinity, there was not an obvious relationship between the absorbency readings of the water samples and stream water (Tables 1 and 2).

Finally, repeated measurements of the water levels in the piezometers indicated that Frog Bog and Brown Cedar Swamp differed in their water flow patterns (Figures 11 and 12). Water movement through the bog was concluded to be lateral. Flow through the bog, however, was variable for each piezometer nest, creating conditions of recharge, discharge, and lateral flow. Finally, distance from the stream may have had some effect on the water levels at site A in the bog (Figure 11a), but was otherwise not clearly a factor influencing water flow patterns through the wetlands.



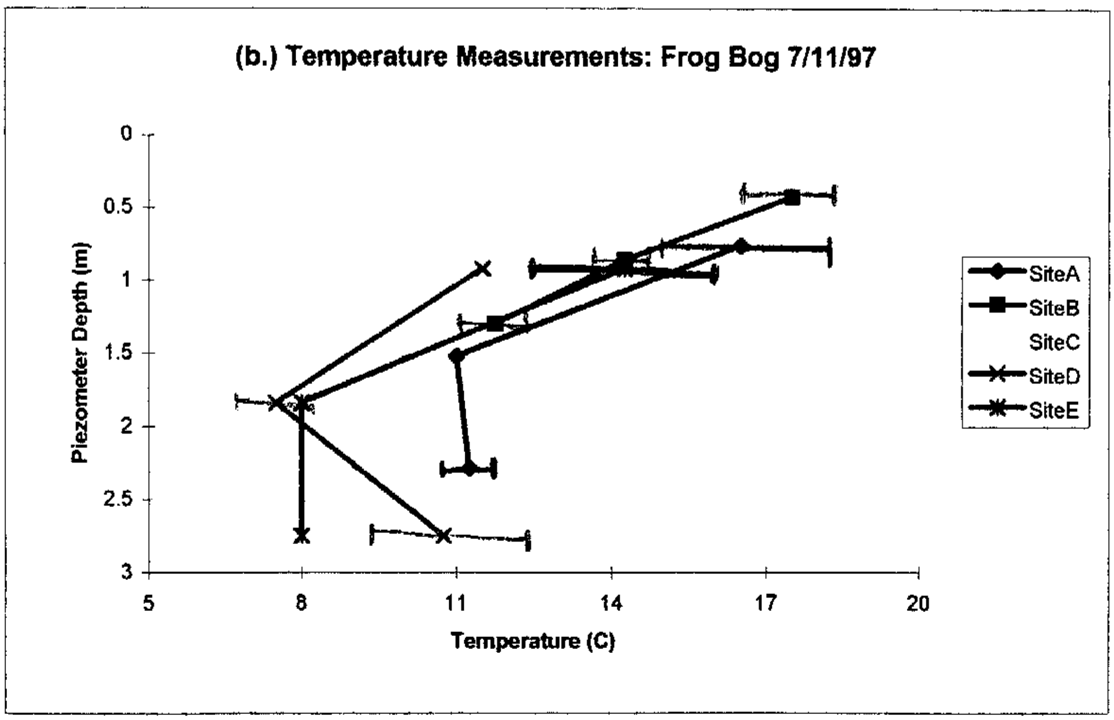
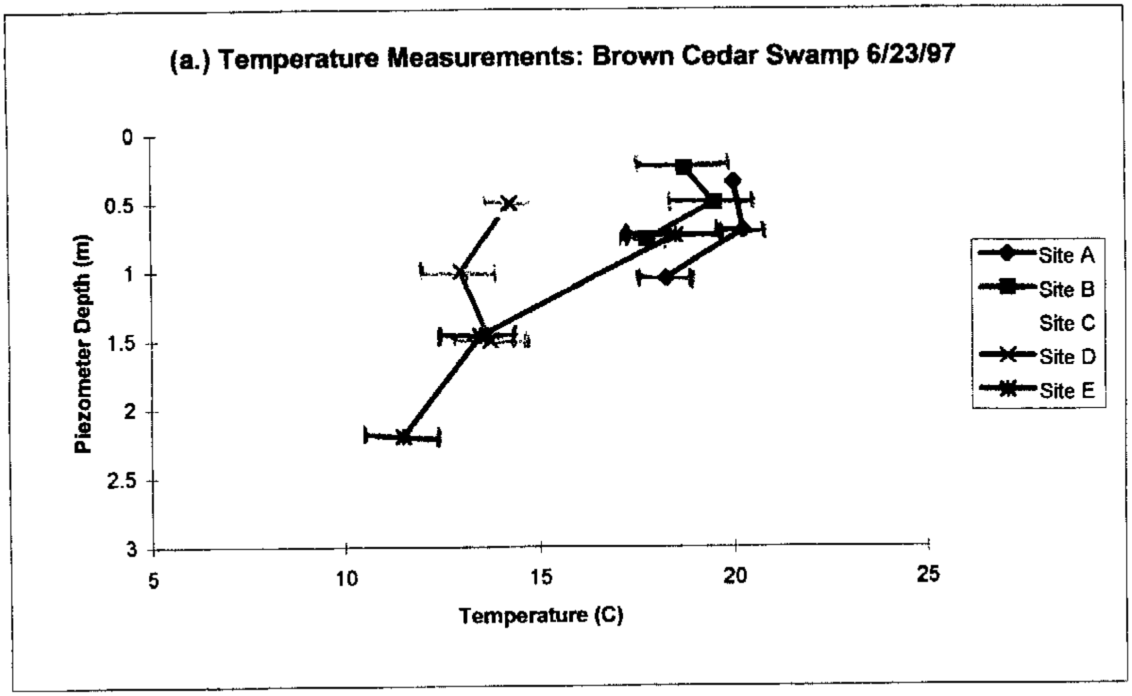


Figure 1: Temperature Measurements at Frog Bog
Values plotted above represent mean temperature values for both sampling periods at Frog Bog, in figures 1a and 1b, respectively. Error bars represent standard deviation on the means for each set of pipes of equivalent depth in each nest. A clear trend is obvious in the data - temperature decreased with depth. Temperatures at each site also varied slightly between the first and second sampling dates.



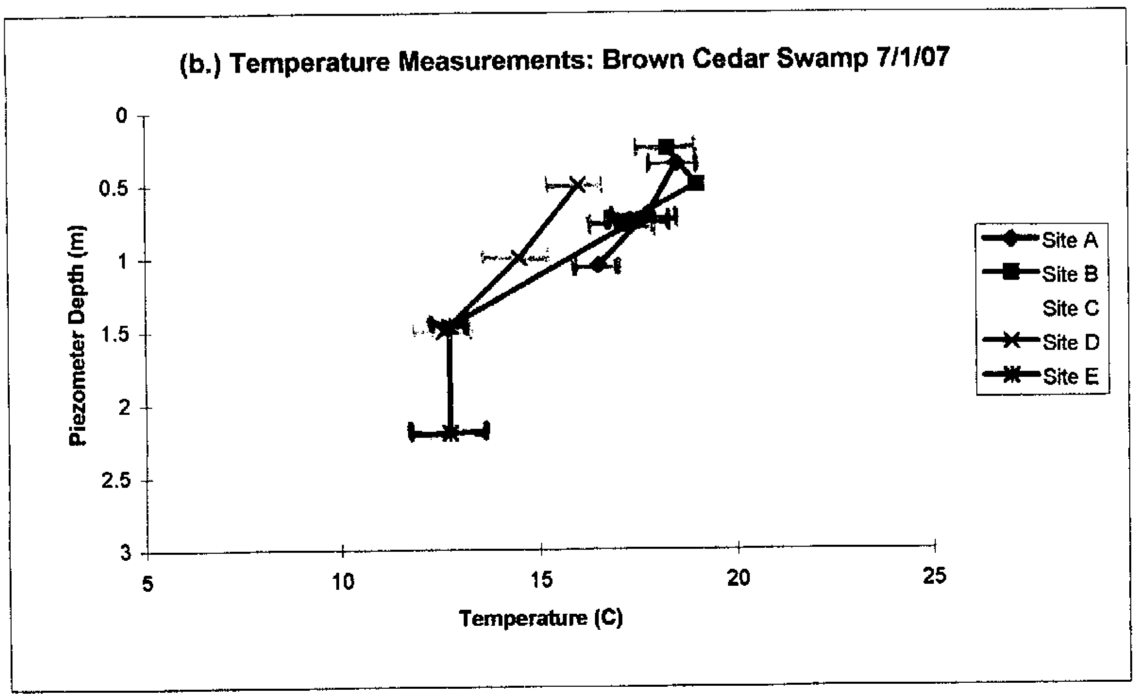


Figure 2: Temperature Variation at Brown Cedar Swamp
Temperature trends are shown for Brown Cedar Swamp for the first and second sampling periods, in Figures a and b, respectively. Sites A-E represent the individual piezometer nests, with A being located closest to the stream. Error bars represent the standard deviation on the means for pipes of identical depth at each nest. Data clearly indicate that temperature decreases with depth for each sampling period.

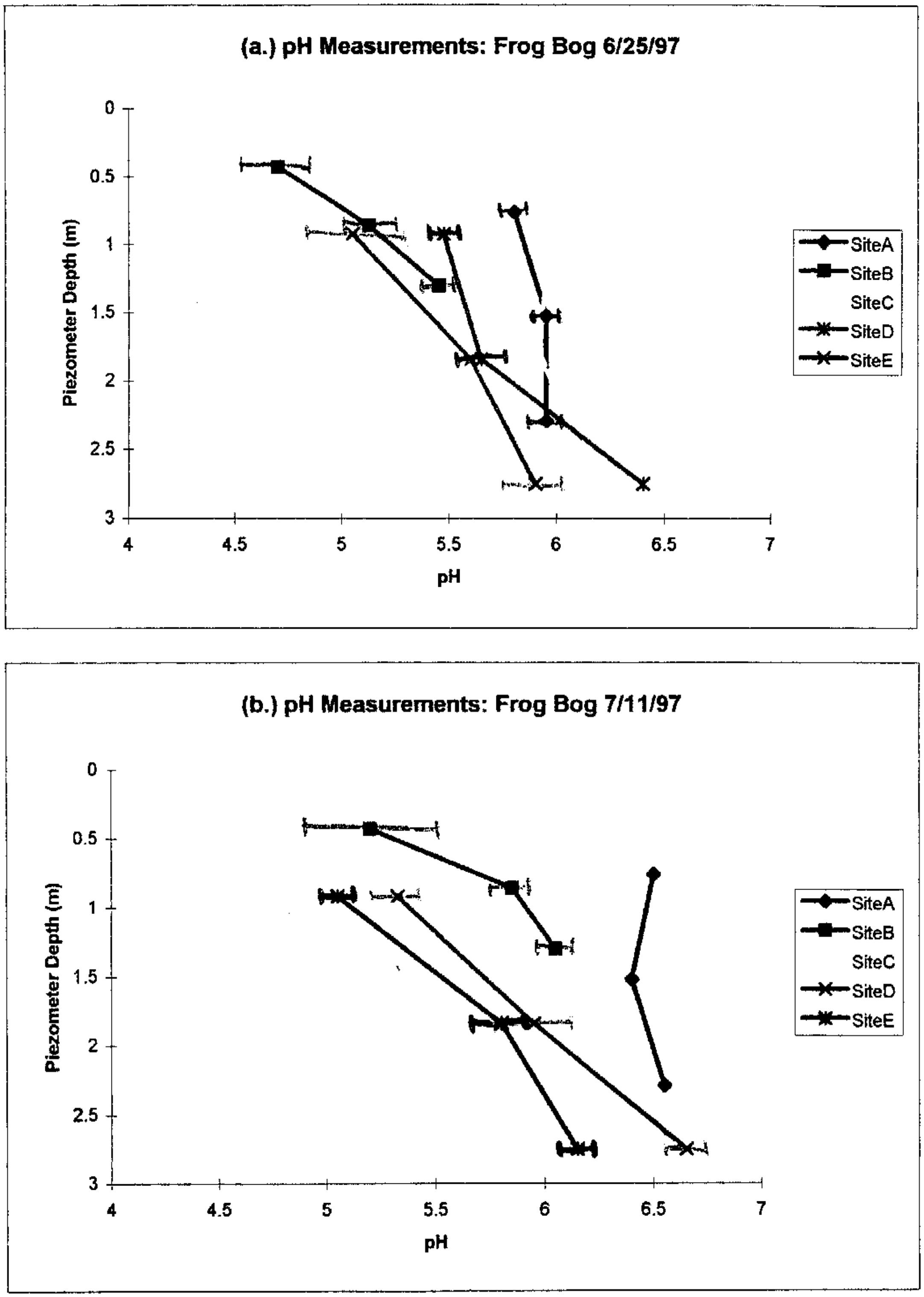


Figure 3: Variation in pH at Frog Bog
Plotted above are pH values, along with standard deviation on the means. Trends are similar for both sampling periods - pH increased with depth for all piezometer nests. As with temperature, there was slight deviation in the pH values of several sites in respect to sampling date.

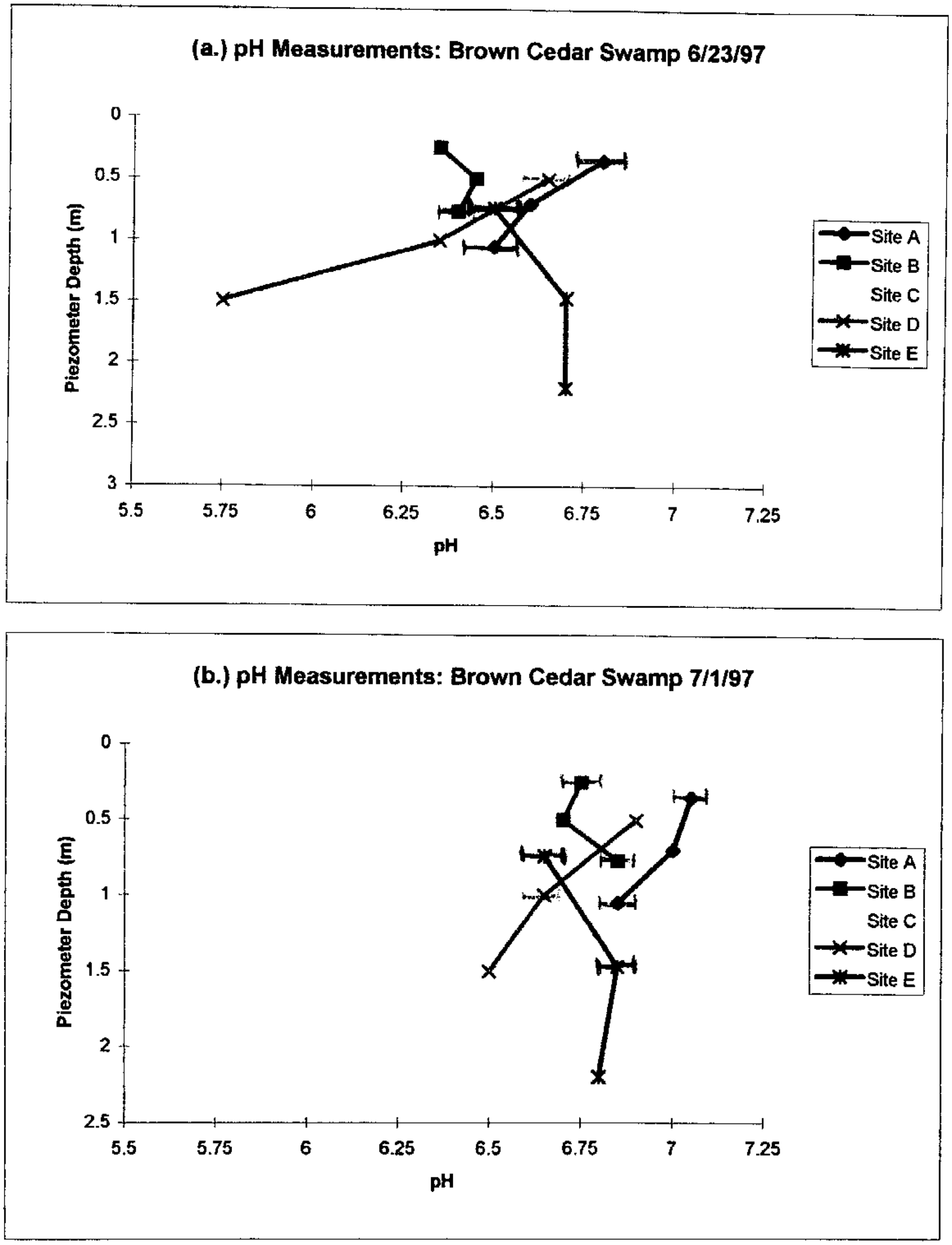
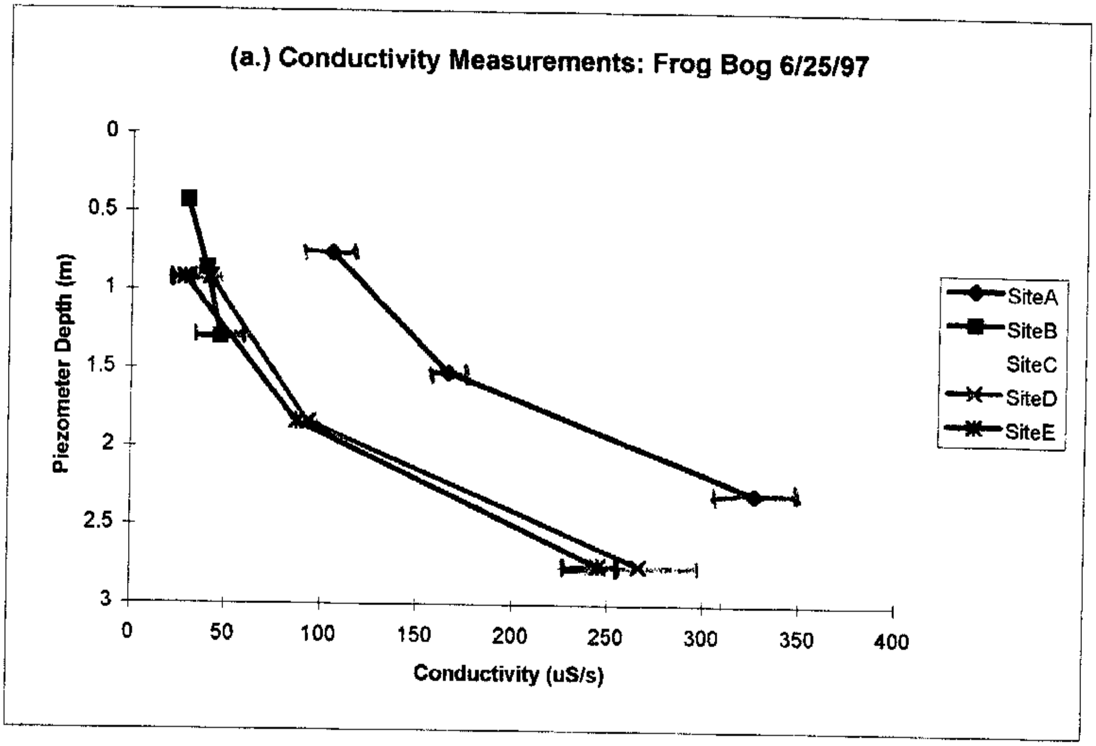


Figure 4: Variation in pH Measurements at Brown Cedar Swamp
The variation in pH with depth is shown for both the first and second sampling periods in figures 4a and 4b, respectively. Values tended to vary with depth at each site, but overall pH values were consistently in the range of 6.25 - 7, with few exceptions, for both sampling periods.



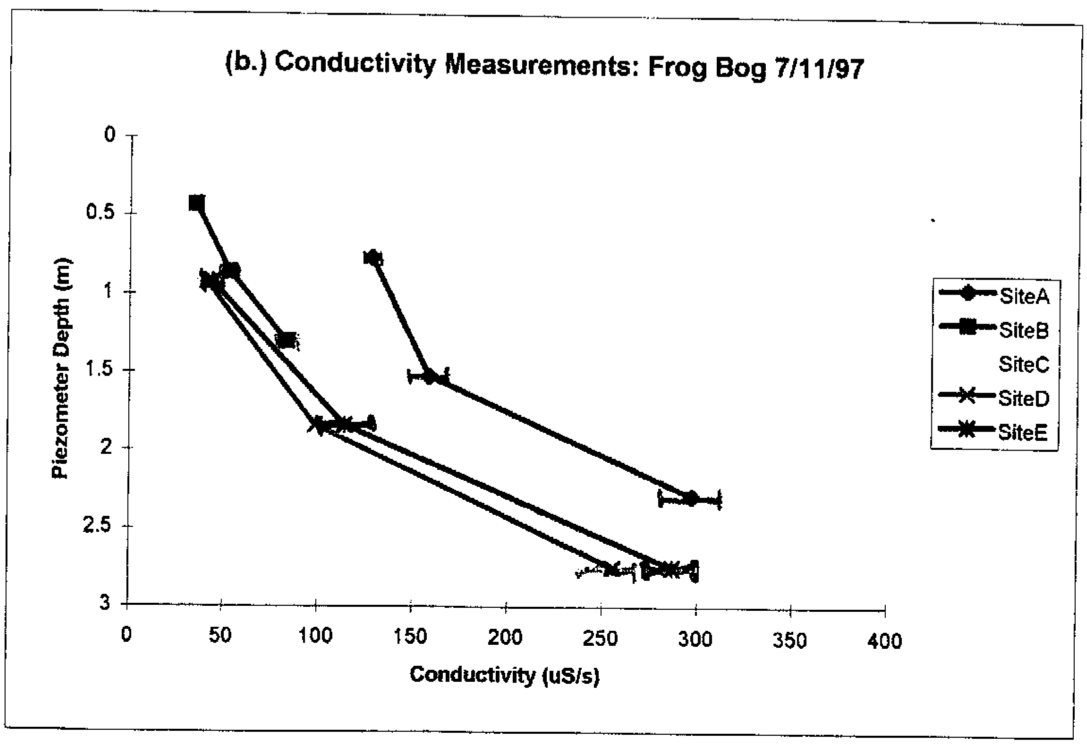
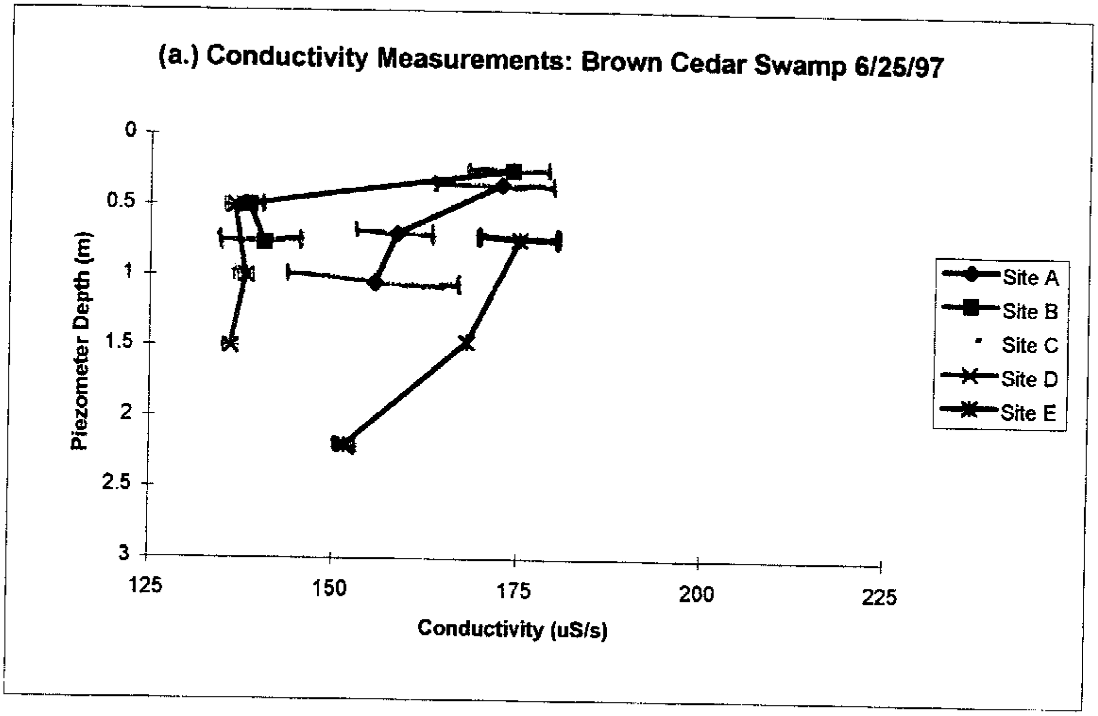


Figure 5: Conductivity Measurements at Frog Bog
The above graphs show conductivity values for both sampling periods, along with standard deviations. Plotted conductivity values have been corrected for hydrogen ion concentration. Trends are obvious for both sets of samples - conductivity increased with depth for all piezometer nests.



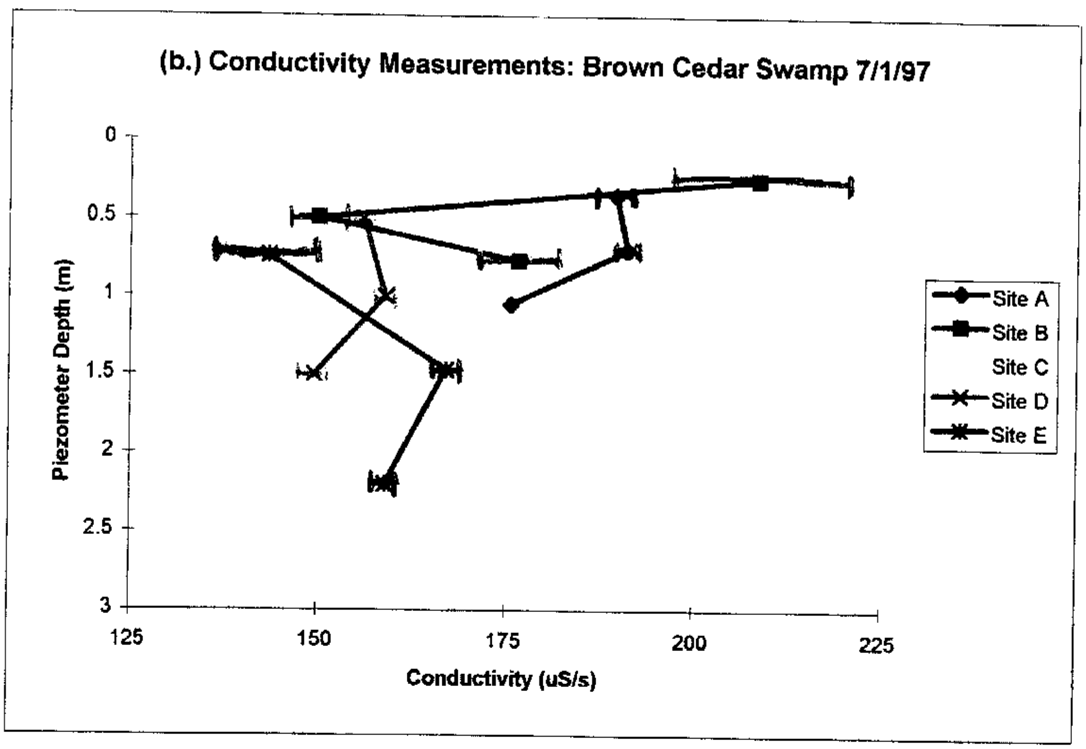
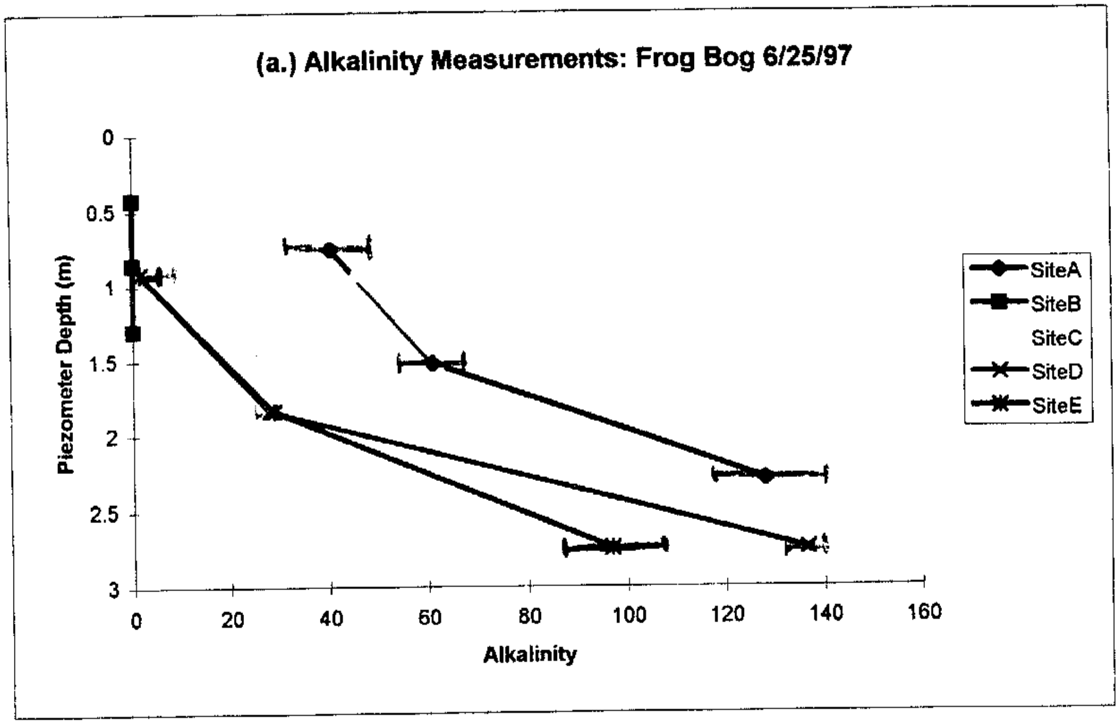


Figure 6: Variation in Conductivity at Brown Cedar Swamp
The values plotted above, along with standard errors, represent the mean conductivity values for each piezometer nest. Conductivity was rather variable with depth for both the first and second sampling periods, as seen in figures 6a and 6b. Plotted conductivity values have been corrected for hydrogen ion concentration.



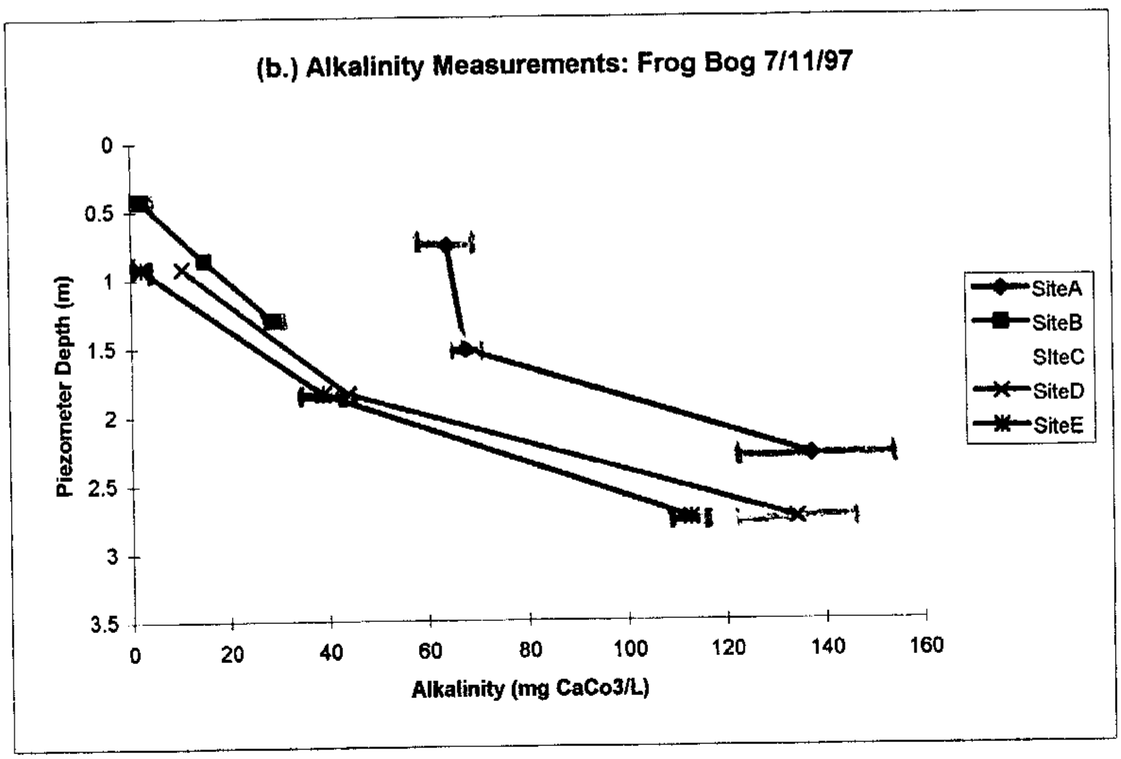
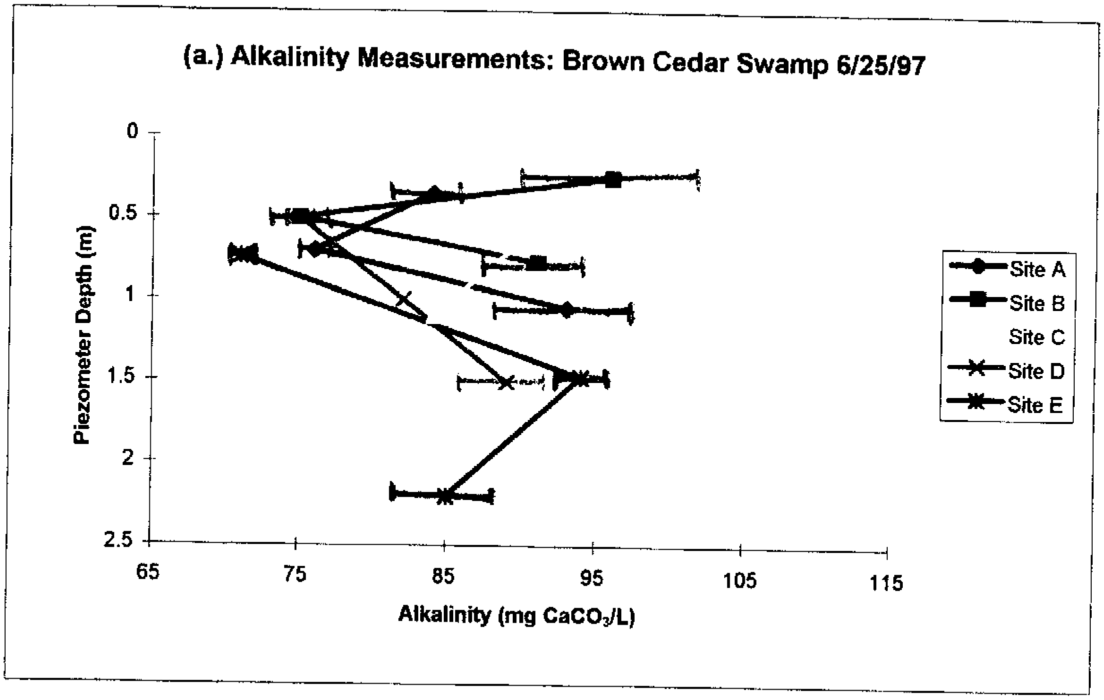


Figure 7: Variation in Alkalinity at Frog Bog
Alkalinity values, along with standard deviation on each mean, are plotted above. Clearly, alkalinity decreases with depth for both sampling periods. Also, much like conductivity, alkalinity values vary slightly between sampling periods.



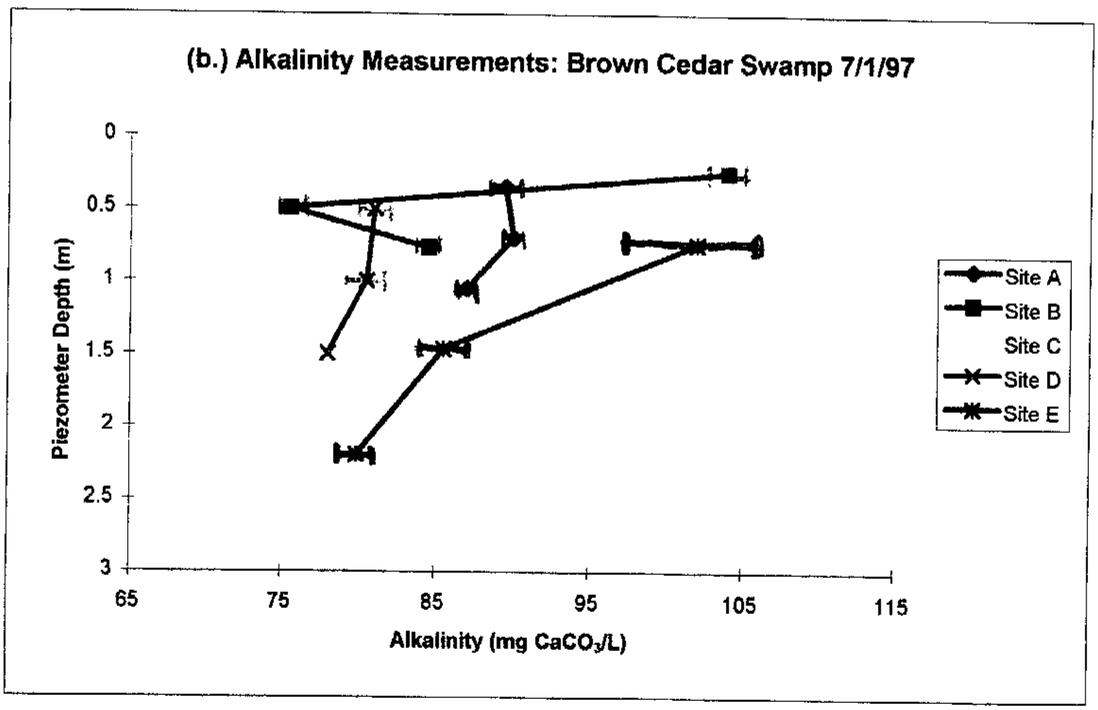
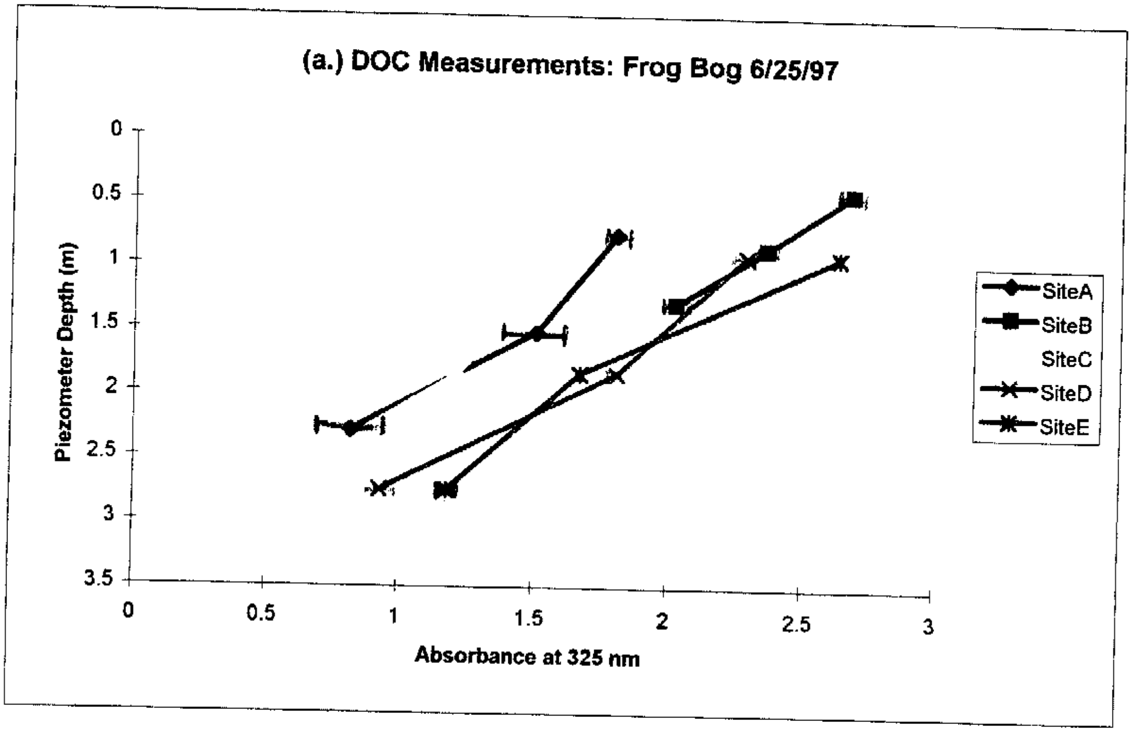


Figure 8: Alkalinity Measurements for Brown Cedar Swamp
The above plots indicate that alkalinity was variable with depth in the cedar swamp for both sampling periods, as was conductivity. The range of overall alkalinity values is similar for both sampling periods.



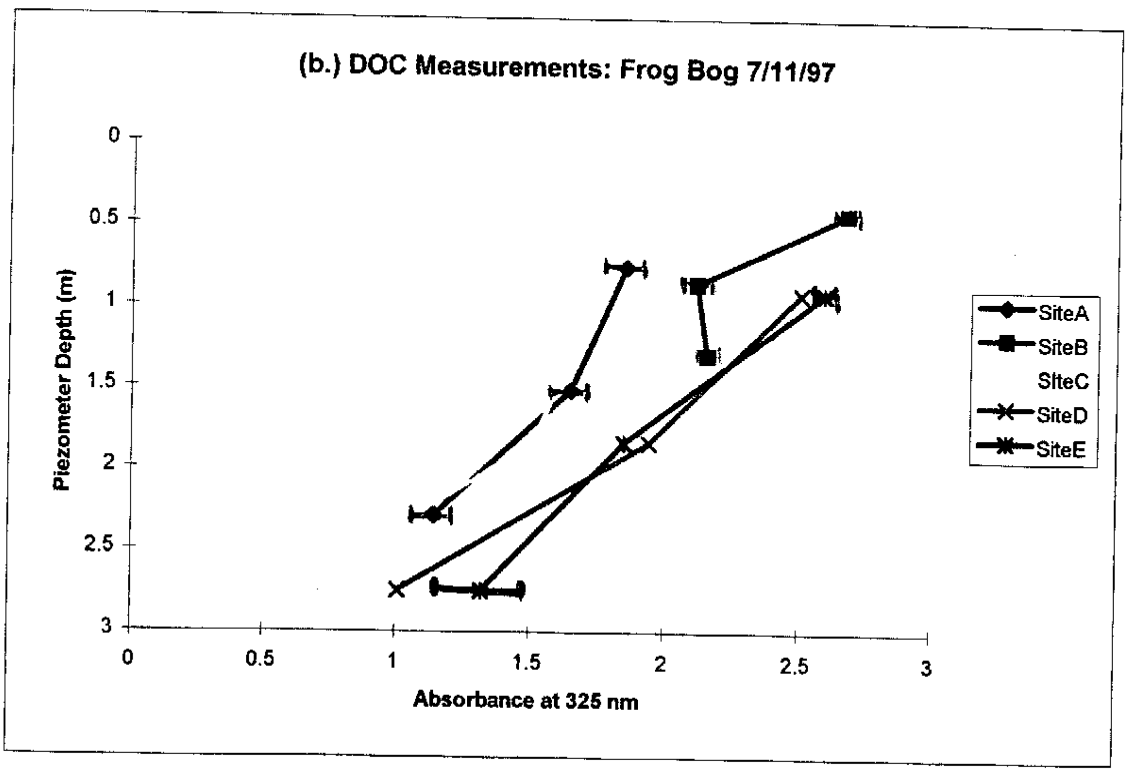
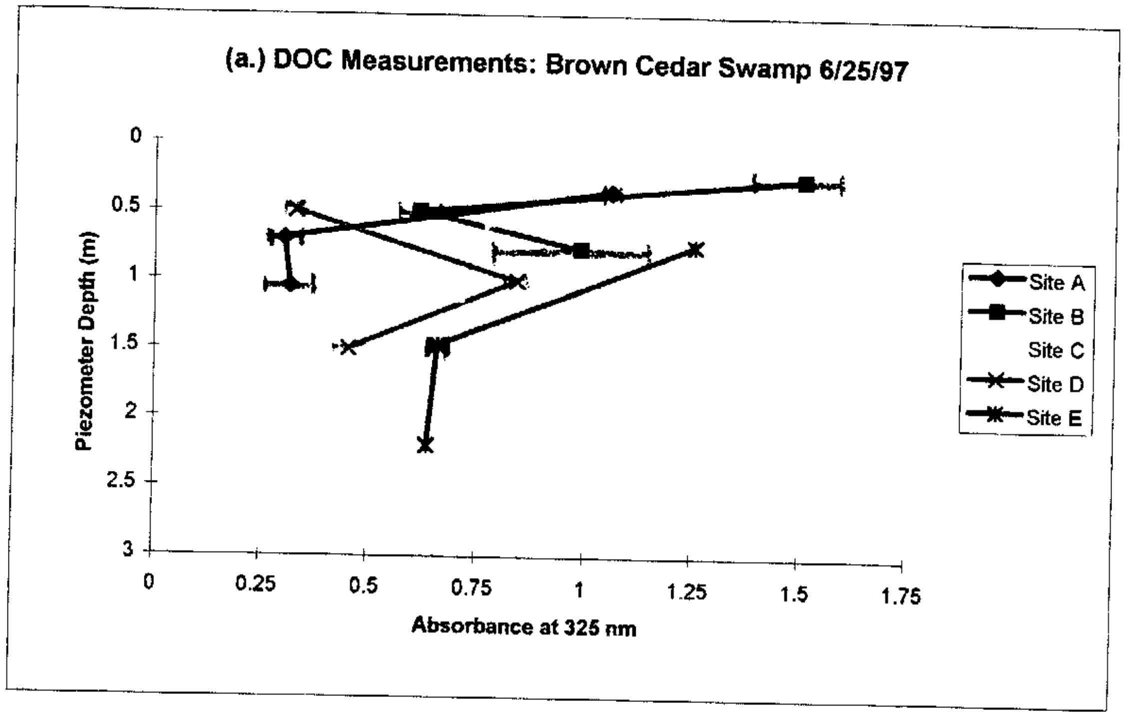


Figure 9: Variation in DOC at Frog Bog

Dissolved organic carbon values, and standard deviations, are plotted above. DOC clearly decreases with depth for both sampling periods and varies slightly between the first and second sampling periods, in figures 9a and 9b, respectively.



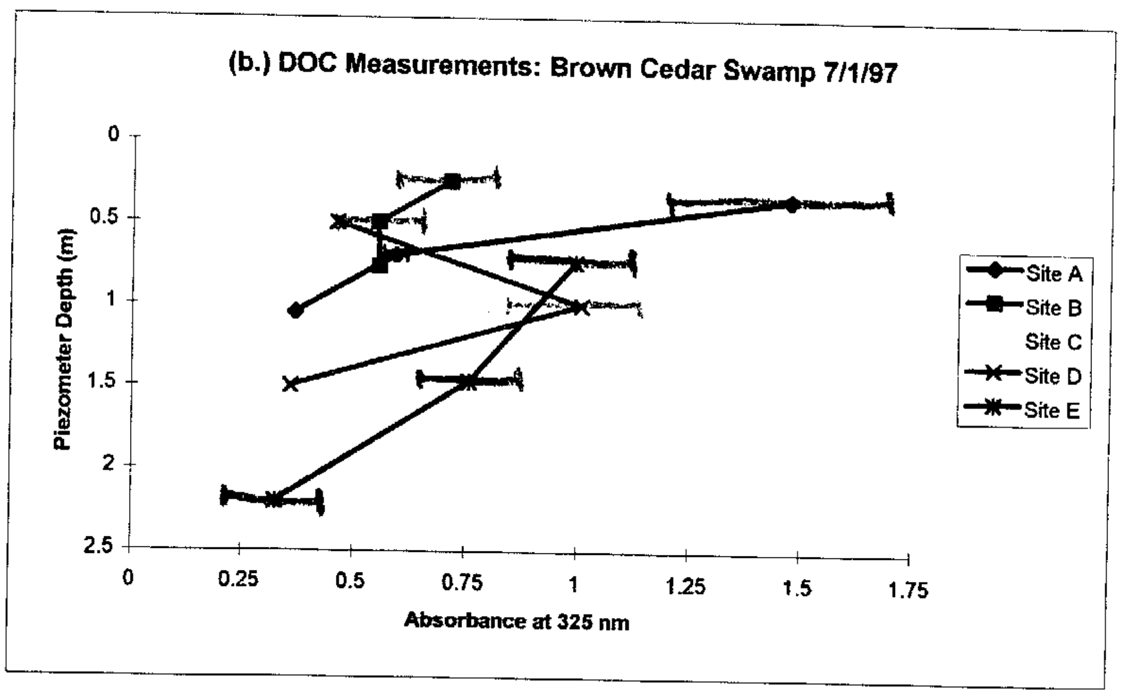


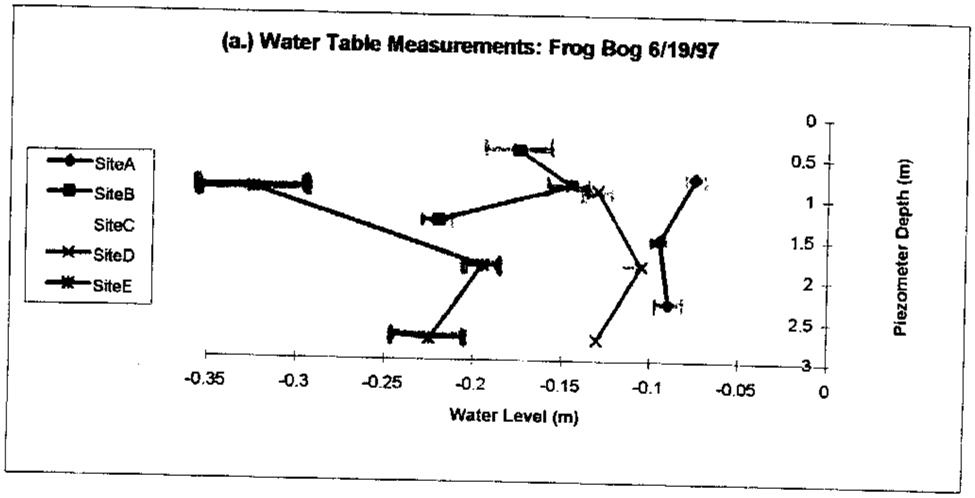
Figure 10: Variation in DOC at Brown Cedar Swamp
Using the spectrophotometer, absorbency values were measured at 325 nm. Higher absorbency values correspond with a greater amount of dissolved organic carbon. Trends were variable with site and depth for the first and second sampling periods, as seen in figures 10a and 10b respectively.

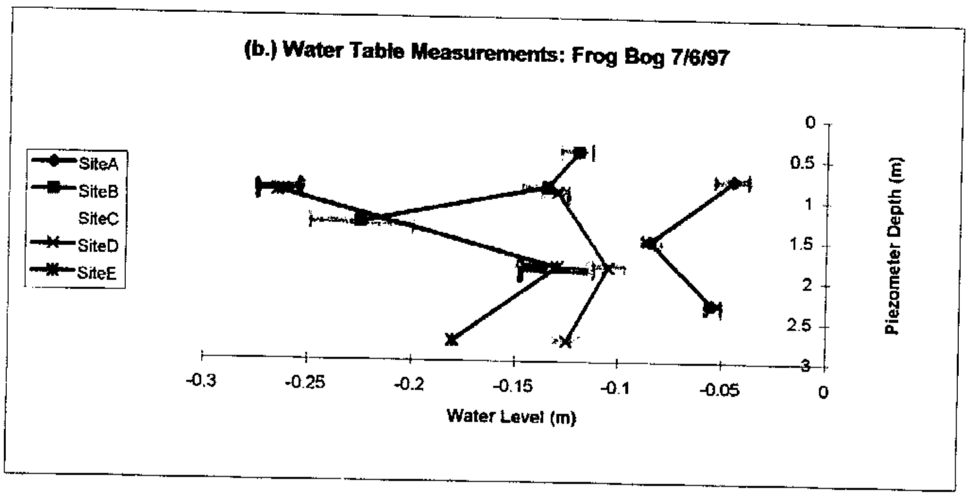
Table 1: Water Chemistry in Stream Fringing Frog Bog

Date	6/25/97	7/11/97
Temperature (C)	23	24
pH	6	7.3
Conductivity (uS/cm)	75	76.6
Alkalinity (mg $CaCO_3$/L)	24	34
Absorbance at 325 nm	0.724	0.695

Table 2: Water Chemistry in Stream Fringing Brown Cedar Swamp

Date	6/23/97	7/1/97
Temperature (C)	26	22.5
pH	6.9	6.8
Conductivity (uS/cm)	106	85.2
Alkalinity (mg $CaCO_3$/L)	46	46
Absorbance at 325 nm	0.641	0.852





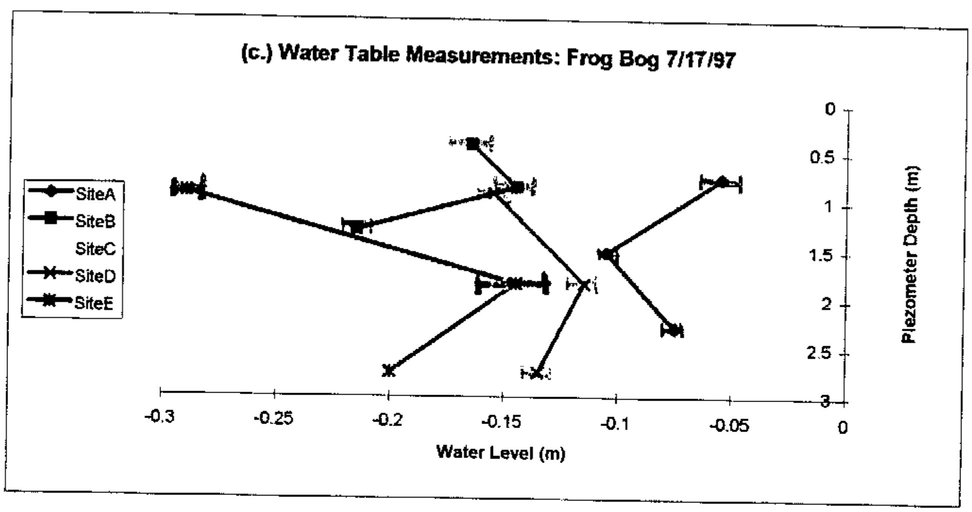


Figure 11: Water Flow Patterns in Frog Bog
Values plotted above represent the mean water levels for each set of piezometers of similar depths, along with the standard deviation calculated for the means. Data is shown for three sampling dates, in figures 11a, 11b, and 11c respectively. The water levels at each nest was below ground level, in the range of 0.05 to 0.3 meters. The change in water level in respect to date was used to determine the recharge/discharge function of individual piezometer nests.

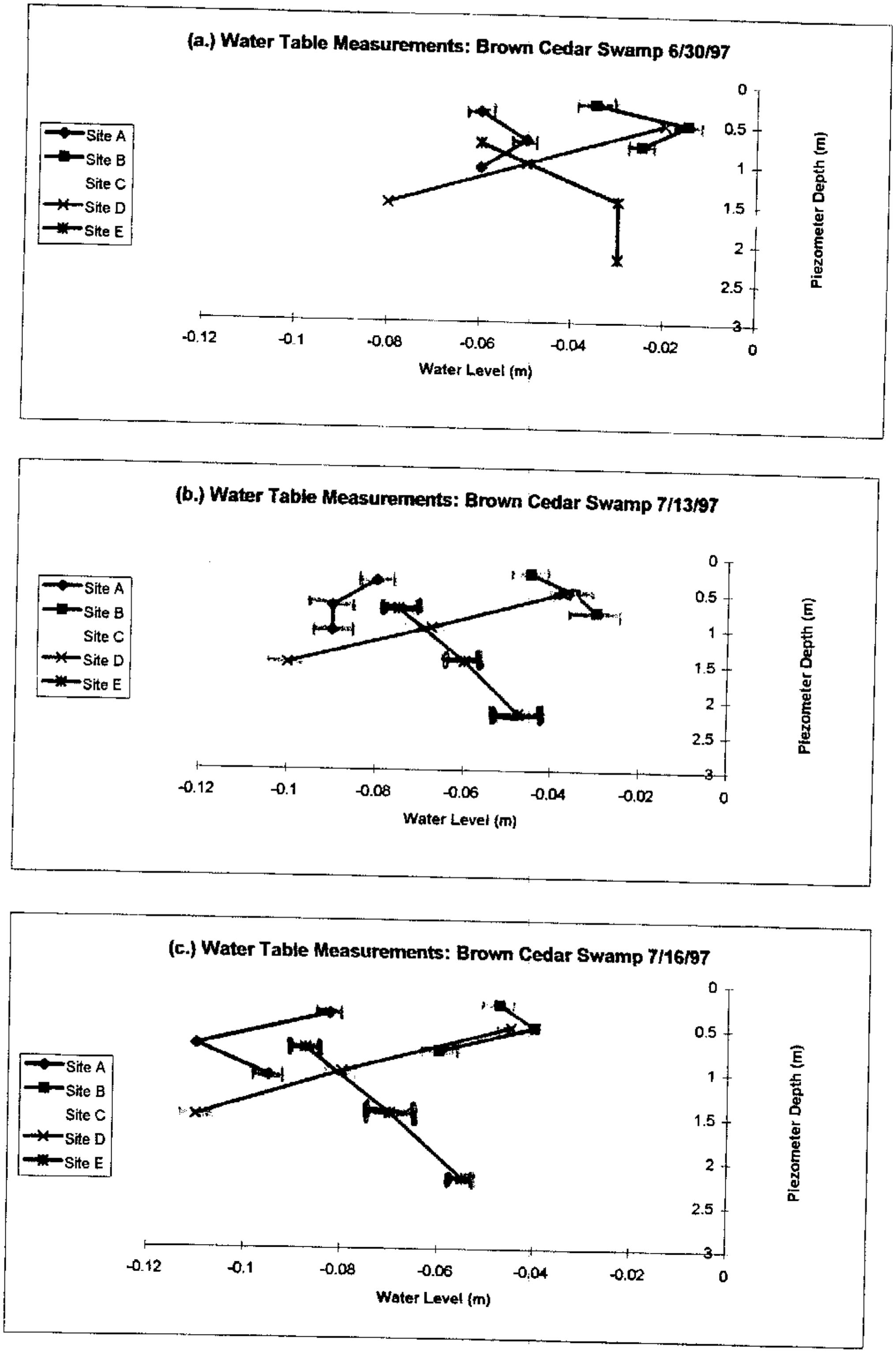


Figure 12: Water Flow Patterns in Brown Cedar Swamp
Values plotted above are the mean water levels in each piezometer. At Brown Cedar Swamp, all water levels were between 0.02 and 0.12 meters below the ground. Variation in water level in respect to depth was used to determine the direction of water flow, or the recharge/discharge function, of each piezometer nest.

DISCUSSION

Variation in Temperature

As indicated by the graphs, temperature is dependent on both depth and distance from the stream. As could be expected, temperature decreased with depth at both the bog and cedar swamp (Figures 1 and 2). This is logical, for the deeper water would not only receive less heat input from the sunlight, but may also be influenced more by the cooler groundwater, for groundwater temperatures tend to be lower than air temperatures during the summer months (Ward 1967).

Unlike its variation with depth, temperature was higher at piezometer nests closer to the stream. This was especially obvious at Brown Cedar Swamp (Figure 2a and 2b). This suggests that wetland characteristics, namely temperature, are affected by fringing streams. This may be due to the fact that the mineral surface contact, and therefore pipe depths, at sites A and B were generally not as deep as those further from the stream. However, it seems more likely that the higher temperatures at sites A and B were due to decreased shading, for unlike the other three nests at Brown, A and B were not surrounded by tall cedar trees. It is also possible that the stream was influencing the temperatures, for even at equivalent depths, the temperatures at sites A and B were generally higher. In other words, more of the stream water was able to flow near the piezometers adjacent to the stream, while the piezometer nests farther from the stream are influenced more by the groundwater, thus the cooler water sample temperatures at this site. The higher temperatures at sites A and B may have also been due to decreased shading resulting from the lack of large cedar trees at these two sites.

Furthermore, the changing conditions of the stream seem to suggest that it was indeed influencing the water temperature of nearby piezometer nests. For instance, the temperatures at Brown Cedar Swamp seem to be slightly higher for the first sampling on June 23. This reflects the higher temperature of the stream during this sampling period in comparison to its temperature on July 1 (Table 2). It is therefore possible that rainwater and the degree of sunlight may affect sites A and B more so than the sites further from the stream. In other words, the sites A and B may be more influenced by stream water inputs and environmental conditions, while sites C, D, and E are influenced more by groundwater inputs. Because groundwater is often associated with rocks for long periods of time, it is generally has a higher ion concentration and less variability than surface waters (Allan 1995). This explains the decreased variability in temperatures at the sites further from the stream.

Although both sites displayed similar trends, there was a slight variation in the range of water temperatures at each site. For instance, the samples at Brown Cedar Swamp were typically between 10 and 20 degrees Celsius, while those at Frog Bog were ranged from 7-18 degrees. Because the mineral surface contact at the bog was generally lower than that at the fen, the piezometers were placed deeper into the soil at the bog. This could be one explanation for the difference in temperature range at each site. However, there also seem to be other factors involved. For instance, Figures 1a and 1b show a slight variation in the trend of decreasing temperature with depth: at sites C, D, and E, the temperature of the water in the deepest piezometers increased. While this is probably due to groundwater influence, it is also possible that certain components of the peat at a given depth act as a better insulator, causing a decrease in the water temperature. For instance, if the peat has a high percentage of clay, the water may be cooler in these areas. Furthermore, despite the relatively small error bars, the variations in temperature may be due to human error. Although the fresh water samples were measured as quickly as possible, it is likely that even a brief lapse in time may have caused the temperature to increase by a couple degrees.

Variation in pH

As expected, the pH was higher for the more minerotrophic cedar swamp than in the ombrotrophic bog (a general pH range of 6.5 - 7 verses 4.5 - 6.5, respectively, as seen in Figures 3 and 4). Slight variations in this trend, such as the low pH for site D (Figure 4a) are probably due to human error. Furthermore, there was a definite decrease in pH with depth at Frog Bog. This is logical due to a decreased rate of decomposition with depth, as well as an increase in cations due to the influence of groundwater. However, the pH of the water sample in the deeper piezometers at the bog are slightly higher than would be expected. This may be indicative that the bog was at one time more fen-like. Although Sphagnum usually contributes to the low acidity of bogs, it may not be present in the decomposed peat at these greater depths for it would not have grown in a typical fen environment. Therefore, the pH values are truly acidic only near the surface where the Sphagnum is more abundant, creating the visible bog-like conditions. This theory was is also supported by the relatively higher pH values at site A, for it was surrounded by less Sphagnum than were the other nests at Frog Bog.

A similar trend describing the variation of pH with depth was not as obvious at Brown Cedar Swamp (Figures 4a and 4b). In fact, while the pH values of site E and possibly site B increased with depth, the pH values at sites A, C, and D actually decreased with depth. It may be expected that groundwater would have more influence at greater depths, resulting in a greater buffering capacity and a higher pH. However, as will be explained shortly, the recharge/discharge status of a peatland may be an important influence on its water chemistry, and can therefore explain this seemingly unusual trend in pH. Furthermore, an argument similar to that used to explain why acidity increased with depth in the bog may be used to explain the decrease of acidity with depth in the cedar swamp. It is possible that Brown Cedar Swamp was once more bog-like than it appeared to be during the sampling periods. However, bogs tend to be rather stable systems in that they are less resistant to changes in water balance and peat accumulation (Mitsch and Gosselink 1993). Therefore, it seems more likely that succession would result in the formation of a bog from a fen, rather than the reverse process. Regardless, the unique composition of peat at each depth may be a cause of this variation of pH with depth, even in the cedar swamp. Despite these possible explanations for the variability on pH, the measured values are nevertheless reasonable for this type of peatland.

Just as water temperature seemed to be influenced by the fringing stream the pH also seemed to show a similar dependency on the stream, especially at Frog Bog. For instance, the measured pH value at the first sampling period was considerably lower than that of the second sampling period (Table 1). Accordingly, the pH values of the water samples also seem to reflect this increase during the second sampling period, especially in sites A and B (Figures 3a and 3b). For example, the pH of site A was generally around 6.0 for the first sampling period, while it increased to 6.5 during the second sampling. The dependency of pH on stream water pH at sites C, D, and E is less obvious as that for sites A and B. Therefore, sites further from the stream seem to be more influenced by groundwater in regard to both temperature and pH. There are certainly exceptions to this trend, such as the decrease in pH for the deepest piezometer at site E during the second sampling period compared to the first sampling period. However, this may be due to factors other than stream influence, including experimental error and natural variation in water conditions. Therefore, the data from Frog Bog again supports the hypothesis that water chemistry of the peatland will vary with distance from the stream and quality of the stream water.

This hypothesis was also supported by the results from Brown Cedar Swamp, although the trend is not as strong as that seen in Frog Bog. For instance, the pH values are slightly higher for the first sampling period for the majority of the piezometer nests. This reflects the higher pH of the stream water for this sampling, in comparison to the second sampling (Table 2). However, because there is only a slight change in stream water pH, this apparent trend may also be due to experimental error.

Variation in Conductivity

As can be seen in figures 5 and 6, there are general trends in conductivity measurements with both peatland type and depth. For instance, the conductivity values greatly increased with depth at Frog Bog. As with pH, this can be explained by both increased groundwater inputs and more fen-like conditions at greater depths. Because the measured conductivity values were corrected for hydrogen ions, it is clear that the higher conductivity values in the shallower piezometers are due solely to fen-like conditions. Likewise, the lower values represent a decreased amount of ions, with the exception of hydrogen, where the peatland is less minerotrophic.

Although depth trends are not as obvious in Brown Cedar Swamp, the overall conductivity values are higher at this site, reflecting its minerotrophic environment (Figures 6a and 6b). Furthermore, the values are similar to those in the deeper piezometers at Frog Bog, again reflecting the fen-like qualities at these depths. Although conductivity does not clearly increase or decrease with depth, this is probably due to the recharge/discharge function of each piezometer nest in the peatland, which would definitely influence its ion concentration.

There is also evidence of stream influence on conductivity values, although the trend is not as strong as those seen with temperature and pH. For example, as seen in Table 1, the conductivity of the stream bordering Frog Bog varied from 75 uS/cm to 76.6. Because these values are so similar, it would be assumed that the water samples in the piezometers would also display similar conductivity values for the two sampling periods. Indeed, this seems to be the case (Figures 5a and 5b). Although there are slight deviations, this is probably due to experimental error, namely difficulty in obtaining stable conductivity readings.

Likewise, Brown Cedar Swamp does not seem to be influenced by the stream water. The obvious decrease in conductivity during the second sampling period (Table 2) does not correspond with the overall slight increase in conductivity ranges for the second sampling period (136-185 uS/cm) in comparison to the first sampling period (136 - 185 uS/cm). This is obvious from Figures 6a and 6b, namely sites A, B, and D. This may indicate that the water in the cedar swamp is more dependent on groundwater influence for conductivity, and thus its buffering capacity, rather than the stream water input. For instance, like the conductivity values, the pH was generally higher during the second sampling period. Because this would result in fewer hydrogen ions, the molecules involved in the buffering mechanism would be in their ionic form, rather than protonated. Therefore, the conductivity would be higher. This could also explain the obvious dependency of the bog on stream water in respect to its pH. The pH of the bog would be more likely to increase along with the pH of the stream, simply because it does not have a strong buffer system to neutralize the hydrogen ions.

Variation in Alkalinity

Because alkalinity is also a measure of the compounds which collectively shift the pH into the alkaline range, the data regarding this variable should be rather similar to that for the corrected conductivity measurements. In the cedar swamp, this was indeed the case for the July 1 sampling period (Figures 6b and 8b). For both conductivity and alkalinity, sites A, C, D, and E decreased with depth, while site B was rather variable. The similarity between conductivity and alkalinity for the June 23 sampling was not as obvious, but this may be due to inaccuracy in measuring these two variables. The change of alkalinity with respect to depth may again be due to the recharge/discharge function of the wetland, which will be described shortly.

The conductivity and alkalinity data for Frog Bog were very similar for both sampling periods (Figures 5 and 7). Like the conductivity, the alkalinity increased with depth, which may again reflect the fen-like character of the bog at these depths. Surprisingly, these values were even higher than those measured for the cedar swamp. Nevertheless, the alkalinity values of water in the shallow piezometers where conditions were clearly bog-like were significantly lower than any of the values found at Brown. Therefore, a definite distinction may be made between the alkalinity of bogs and fens or cedar swamps. A similar conclusion can be drawn regarding conductivity.

Stream influence may or may not be a factor contributing to variation in alkalinity. The measurements of stream alkalinity at Brown Cedar Swamp did not vary significantly between sampling periods (Table 2). This is clearly reflected in Figures 8a and 8b, for the overall ranges of alkalinity are similar for both sampling periods (approximately 75-105 uS/cm). However, the obvious variation between each site in respect to sampling dates indicated that factors other than stream influence are contributing to the alkalinity of the cedar swamp. These factors may include groundwater input, the buffering system, and error in measurement. Stream alkalinity at Frog Bog was slightly higher during the second sampling period (Table 1). There is also a trend, although rather weak, in Figures 7a and 7b which supports this observation. The alkalinity at each site are slightly higher for the second sampling, although this more obvious for Site A, and especially Site B. Once again, this indicates that the sites closer to the stream may be affected more by its input. As distance from the stream increases, however, the sites become less dependent on stream water inputs. This is logical, for bogs are usually not very dependent on surface water inputs.

Variation in Dissolved Organic Carbon

As would be expected, the amount of dissolved organic carbon (DOC) was higher in Frog Bog, reflecting its abundance of Sphagnum and higher rate of decomposition. Furthermore, the decreased rate of decomposition with depth characteristic of bogs is reflected by the decrease in absorbency, and therefore decrease in the amount of DOC at greater depths. This also further supports the theory that Frog Bog was at one time more minerotrophic (Figures 10a and 10b).

The amount of DOC also decreased with depth at Brown Cedar Swamp, with the exception of site D which was fairly variable. This variation may be due to differences in plant composition in the peat at different piezometer nests, or differences in rate of decomposition due to degree of waterlogging.

The conductivity values at Frog Bog seemed to be weakly correlated with stream conditions, while the measurements taken from Brown Cedar Swamp were generally independent of stream inputs. According to Figure 9, there is very little variation between the two sets of absorbency measurements at Frog Bog, although amount of DOC in the stream at the second sampling period was slightly higher (Table 1). The slight difference in stream data, however, may be an error due to difficulty in obtaining stable readings of the absorbency. Therefore, it seems likely that both the stream and peatland showed fairly consistent readings for DOC.

In Brown Cedar Swamp, however, there was a greater difference in the two stream absorbency readings (Table 2). The data in Figures 10a and 10b do not reflect this change. If the stream was truly influencing the amount of DOC in the bog, it would be expected that the amount of DOC would have been higher for the second sampling. Instead the general range of absorbency readings is similar for both sampling times: roughly 0.25 - 1.5. Because the readings of individual piezometers vary, however, it is evident that the cedar swamp is a dynamic system. This variation of DOC, and all other variables tested, may be due to several factors other than stream influence, such as the degree of waterlogging due to the amount of rainfall, the type of plant species present in a given area, and groundwater inputs. Furthermore, it is understandable that the DOC readings for the bog were less variable than that in the fen, for the bog has a constant souse of Sphagnum to contribute to the total amount of DOC.

The Recharge/Discharge Function of Frog Bog and Brown Cedar Swamp

Aside from water chemistry, the water table data was also useful in describing the unique characteristics of each peatland. Figures 11 and 12 are of special importance in that they indicate whether each piezometer nest is a site of recharge, discharge, or lateral flow. It was concluded that the water movement in Frog Bog consisted mainly of lateral flow, despite some variability in results. For instance, the water levels varied very little with depth, with the possible exception of Site E, at which the water level was possibly lower closer to the surface. According to Reeve, these measurements may define the location of the water table in the bog, for where there is not net vertical movement of water, the values of hydraulic head represent the position of the water table (1990). However, this conclusion is uncertain since the actual depth of the water table was not directly measured. A second conclusion that can be drawn is that water is consistently closer to the surface at Site A during all three measuring periods. This may be due to increased inflow of stream water or flooding, which would both tend to have the greatest effect on sites closest to the stream. Although water levels at each sampling period were fairly consistent, slight can be caused by several factors, including the amount of rainfall, evaporation, and even changes in barometric pressure (Ward 1967).

Brown Cedar Swamp definitely shows more variation in its water flow patterns. Water movement at sites A and B seems to consistently move in the lateral direction (Figure 12). As distance from the stream increases, however, the flow of water becomes more dynamic. Site D seems to be a recharge site, for the water level was higher in the shallow piezometers. In contrast, Site E and possibly Site C seem to be discharge sites. Because water levels are lower in the deeper pipes, there is a definite pressure forcing water towards the surface, which is characteristic behavior of a discharge zone. These discharge sites are usually more common bogs, for the expelled groundwater serves to maintain high water tables and wetland habitat, characteristic of a minerotrophic environment (Siegel 1988). This variability in recharge-discharge function is probably due to changing water flow systems beneath the surface of the peat. For instance, groundwater would tend to move downward under raised bogs, while it would increase with depth under fens and cedar swamps (Siegel 1992). Although the flow in Frog Bog was characterized as being lateral, there definitely seems to be a unique water flow pattern similar to that described by Siegel existing in the cedar swamp.

The method of groundwater movement had obvious effects on the water chemistry in both the bog and the cedar swamp. The variation in pH, conductivity, and alkalinity at Frog Bog were rather self-explanatory when considering its once fen-like conditions and the input of groundwater. In other words, the water chemistry of the bog was not strongly influenced by groundwater discharge since the flow of water was determined to be lateral.

This was not the case for Brown Cedar Swamp. The variability of pH, conductivity, and alkalinity are more accurately interpreted after considering the recharge-discharge function of this wetland. For instance, if a certain piezometer nest is discharging ground water, the water samples and surface water should have qualities similar to that of the discharged water: a higher pH, conductivity, and alkalinity. This generally seems to hold true for the discharge sites, with a few exceptions for Site E, such as the alkalinity on June 25. Furthermore, Site D also behaved as a discharge site, especially in regard to pH (Figure 4), which tends to discount the influence of the recharge/discharge function of wetlands. Nevertheless, the water chemistry of Brown Cedar Swamp is definitely variable, and can probably be contributed to the combination of recharge, discharge, and lateral flow conditions indicate that exist at this site.

There is further evidence that groundwater discharge is indeed affecting the water chemistry of Brown Cedar Swamp. On occasion, measurements of surface water pH were taken at both wetland sites. Those at Frog Bog were consistently in the range of 3.6 - 4.1. These values are significantly lower than those recorded for the subsurface water samples (Figure 3). The pH of the surface water at the cedar swamp, however, ranged from 6.9 at Site B to 7.1 at sites further from the stream. These values correspond to the higher pH of the water samples taken from this wetland (Figure 4). This supports the conclusion that groundwater is moving laterally at Frog Bog. If this wetland was discharging water, the pH of the surface water would be higher due to groundwater inputs. On the other hand, the cedar swamp is probably discharging groundwater as indicated by measurements of water level on the piezometers. The high pH of the surface water reflects the high pH and buffering capacity of the groundwater. Therefore, it can be concluded that groundwater does indeed play a role in structuring the water chemistry and vegetation of wetlands.

CONCLUSIONS

It is evident that the water chemistry and groundwater flow patterns play an important role characterizing different types of wetland. As suggested in the hypothesis, all variables studied as a component of the water chemistry portion of this experiment differed in respect to site, distance from the stream, and depth. From these data, one could easily draw distinctions between bogs and fens or cedar swamps. Frog Bog was clearly more acidic and therefore had fewer ions which resulted in a lower conductivity and alkalinity. Furthermore, the bog had higher dissolved organic carbon values, which is not unusual for a bog due to the abundance of Sphagnum and degree of decomposition. Brown Cedar Swamp, which is a more minerotrophic peatland, had a higher pH due to increased buffering capacity and groundwater inputs. This led to higher conductivity and alkalinity values than were found in the bog.

Depth trends were also useful in distinguishing between the environment of the bog and fen. As expected, temperature decreased, while the pH, conductivity, alkalinity, and DOC varied in respect to the type of peatland. In Frog Bog, the pH, conductivity, and alkalinity increased with depth, which is a reflection of groundwater inputs at greater depths. This also indicated that this bog evolved from a fen. Although groundwater was important to bog water chemistry only at increased depths, it was more influential in the cedar swamp. Unlike the bog water flow patterns, which were generally lateral, the cedar swamp also consisted of recharge and discharge sites. Therefore, groundwater was able to influence water chemistry at several depths, which accounts for the variability seen in Figures 4, 6, and 8.

Clearly, bogs and fens have unique environments that are preserved through the interaction of many factors. For instance, the abundance of Sphagnum contributes to the low acidity characteristic of bogs. Furthermore, the primary water source near the surface of bogs is precipitation, rather than groundwater. This results in the production of many organic acids which serve to buffer the bog near a pH of 4, and therefore provide an environment suitable for the growth of Sphagnum and other plant species unique to the bog (Trettin, *et al.* 1997). A comparable situation exists in the cedar swamp, where the pH resulting from a greater buffering capacity supports the growth of completely different plant species than are found in a bog. Therefore, this experiment clearly demonstrated that hydrology is indeed an important factor in maintaining the environments unique to different types of wetlands.

ACKNOWLEDGMENTS

I wish to thank several individuals for their assistance with this project: Dr. Scott Bridgham, for his continual guidance and input; Dr. Hellenthal, for his aid in obtaining PVC pipes; Laurie and Peter, for helping me with materials and equipment; Jeff Runde, for his patience and assistance; and all members of the UNDERC class, especially Karen Cardinal, Molly McCracken, and Noah Grey for their help in the field.

LITERATURE CITED

Allan, David J. Stream Ecology: Structure and Function of Running Waters. London: Chapman and Hill, 1995.

Amoozeger and Warwick. "Piezometry Method." Methods of Soil Analysis: Physical and Mineralogize Methods. 2nd ed. Ed. Arnold Klute. Madison: American Society of Agronomy, Inc. and Soil Science of America, Inc., 1990. 743-749.

Bridgham, Scott. D, John Pastor, Jan A. Janssens, Carmen Chapin, and Thomas J. Malterer. "Multiple Limiting Gradients in Peatlands: A Call for a New Paradigm." Wetlands. 16 Mar. 1996: 45-65.

Mitsch, William J. and James G. Gosselink. Wetlands. 2nd ed. New York: Van Nostrad Reinhold, 1993.

Owen, C.J. and Dr. R.P. Axler. Analytical Chemistry and Quality Assurance Manual. Duluth: Natural Resources Research Institute, 1991-1992.

Reeve, R.C. "Water Potential: Piezometry." Methods of Soil Analysis: Physical and Mineralogize Methods. 2nd ed. Ed. Arnold Klute. Madison: American Society of Agronomy, Inc. and Soil Science of America, Inc., 1990. 545-561.

Siegel, Donald I. "The Recharge-Discharge Function of Wetlands Near Juneau, Alaska: Part I. Hydrogeological Investigations." Ground Water. 26 Jul.-Aug. 1988: 427-433.

Siegel, Donald J. "Groundwater Hydrology." The Patterned Peatlands of Minnesota. Ed. H.E.
Wright, Jr., Barbara A. Coffin, and Norman E. Aeseng. Minneapolis: University of Minnesota Press, 1992. 163-171.

Northern Forested Wetlands: Ecology and Management. Ed. Trettin, Carl C. and Martin F. Jurgensen, David F. Grigal, Margaret R. Gale, and John K. Jeglum. Boca Raton: Lewis Publishers, 1997.

Ward, R. C. Principles of Hydrology. London: McGraw-Hill Publishing Company Limited, 1967.