CAPE BRETON DEVELOPMENT CORPORATION

ECOLOGICAL ENGINEERING FOR VJ BOGS

and DATA SUMMARY

FINAL REPORT

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SUMMARY

After three growing seasons of experimentation with bogs in the vicinity of the VJCPP several important findings are emerging. The data suggest that the natural vegetation in bogs, dominated by shrubby vegetation like the Leatherleaf on the elevated parts (hummocks and hollows) of the bog, is not tolerant to acid mine drainage. Weedy species, such as cattails and sedges colonize the New Bog which was previously killed by the AMD diverted into the New bog from the ditches of the Lifting and Banking Centre. The same species colonize the depressions (hollows) in the old bog, the bare substrates (test cells).

Ecological Engineering methods were developed to assist the recovery of acid-stressed bogs and to produce conditions which could facilitate the amelioration of acid mine drainage. The first steps in this direction have been taken by adding organic amendments to depressions in the old bog. The vegetation in the depressions (hollows) vegetation has been killed by AMD. Hummock vegetation, however, is surviving in the bogs. The rationale of adding amendment to the dead hollows was to generate alkalinity in the root zone to assist the recovery of hummock vegetation. Data taken from test cells in the Experimental Bog indicate that non-amended and amended cells are both improving rapidly. Both root zone and surface pHs have increased on the average about 2 units.

Although improvements of pH are evident in both bogs and recovery of a new vegetation cover is in progress, several challenges lay ahead before a close-out scenario can be achieved. For example, LBC run-off water and seepages at the coarse waste rock pile have different AMD characteristics. There is little doubt that the vegetation in Smith's Bog, receiving the AMD from the Coarse waste rock pile will die. The recolonization by more tolerant species such as cattails should be encouraged with Ecological Engineering measures. Smith's Bog has no similar input of fresh water from Grand Lake and the AMD characteristics are more severe than those of the LBC. It is therefore necessary, as a first step, to improve the seepage characteristics with the same techniques as used in the Experimental Bogs. The results of the three years of experimentation suggest that existing bogs will respond to Ecological Engineering measures. These measures, will assist in the transformation necessary for a bog which will be tolerant to the AMD seepage and reduce acid loading to downstream.

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1.0 INTRODUCTION

The control and amelioration of the acid mine drainage (AMD) associated with coal mining and coal processing is an integral part of resource management. In particular, it is important for a corporation to have an overall environmental concept in place, which considers the long-term implications of waste water treatment. Treatment plants in association with coal dumps may have to be operated in perpetuity, making acid mine drainage an environmental liability for many generations.

In search of alternatives to the conventional chemical treatment technology, Boojum Research Limited has been developing Ecological Engineering techniques. Ecological Engineering is a holistic approach to environmental management combining a number of natural processes in wetlands and sediments which ameliorate AMD.

The location of the Victoria Junction Coal Processing Plant (VJCPP) is ideally suited to testing and developing an Ecological Engineering approach, as the facility is surrounded by bogs. These bogs or wetlands receive AMD of different characteristics by aerial transport of coal dust and seepages from a coarse waste rock pile, run-off of mine coal stockpiles, product stockpiles, and general site run-off.

The bogs around the VJCPP exhibit various degrees of environmental stress due to AMD exposure. Ecological Engineering techniques, based on processes which naturally occur in wetlands, should be able to: a) assist these bogs to recover from AMD stress, and b) transform them in such a way, that they can be used to ameliorate future AMD produced by the facility.

1.1 Objective

The primary objectives of the project were to: a) determine the health status of the bogs surrounding the VJCPP with respect to AMD stress; b) establish a bog test area, in which Ecological Engineering methods could be applied to the recovery of the bogs stressed by AMD; and c) take appropriate measures which would allow the bogs to function as Ecological Engineering systems, ameliorating AMD from the facility during operations and after closing.

The ultimate goal in the short- and long-term is to protect the local watershed. Devco has several facilities within the Bridgeport drainage basin which could potentially contribute to the deterioration of local streams (Map 2.1). An overview of the relative importance of the VJCPP and the associated historic or presently operating waste depositories is given to provide the framework for a long term environmental protection strategy for the watershed.

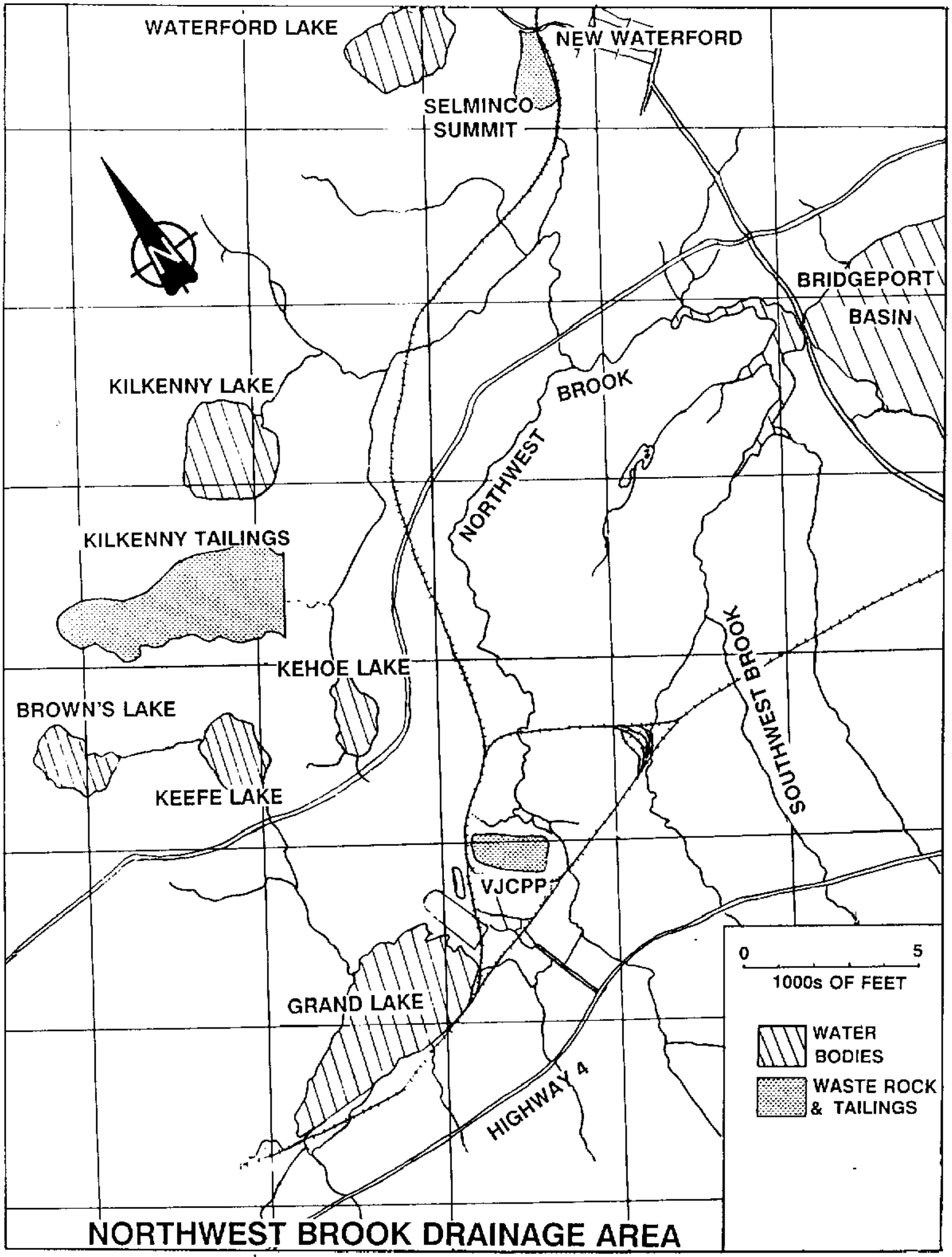
2.0 WATER SHED AND PROJECT DESCRIPTIONS

The VJCPP, VJ Fine Tailings Basin, inactive old coal tailings dumps at Selminco Summit and Gardiner Mines are all located within the Bridgeport drainage basin (MAP 2.1). This watershed is composed of 4 sub watersheds: the Northwest Brook; the Southwest Brook; the streams draining the area on the north side and those draining the south side of the basin. Victoria Junction tailings basin at Kilkenny Lake and Selminco Summit are in the watershed feeding Northwest Brook. This brook is considered a valuable salmonid stream. The Gardiner Mine Dump is located on a small stream which flows directly into the Bridgeport basin.

2.1 The VJCPP Facility

The drainage of the VJCPP flows in three directions, all eventually reaching Northwest Brook. The headwaters of Northwest Brook are in Grand Lake. The southern area of the LBC drains into a ditch entering Northwest Brook just below Grand Lake (PLATE 2.1).

The area to the north of the LBC in the region of the H-Track or old Met bank, is drained to the north through Smith's Bog and Smith's Brook. Smith's Brook enters Northwest Brook just north of the VJCPP. Portions of the VJCPP have been in operation since 1976. The facility was designed to clean and process a total of 4.3 million tonnes of coal per year. The coal washed at the plant comes from the Lingan and Phelan Collieries, which produce coal of different grades and hence different acid generation potentials. Prince Colliery coal also reports to VJ but is directly blended with washed Lingan and Phelan coal on the adjacent Lifting and Banking Centre, which began operation in 1983 (LBC).



MAP 2.1: Overview of the Northwest Brook drainage area and various Devco operations.

The preparation plant produces metallurgical and thermal grade products. Metallurgical and thermal grade coals destined for overseas markets are stockpiled at the LBC while a blended product for steam generation at Nova Scotia power plants is maintained on what is called the H-Track area (former Met bank). Waste rock from the coal preparation process is relegated to the onsite coarse waste rock pile (CWP) and tailings are piped to the VJ Tailings Basin some 25 km to the north (MAP 2.1). Seepages from the CWP are intercepted, and drained into a pond at the east end of the CWP. The AMD is pumped with tailings from there to the VJ tailings basin.

PLATE 2.1: Overview of the LBC and bogs. Photograph courtesy of F. & L. Baechler.

2.2 Amd Sources at VJCPP

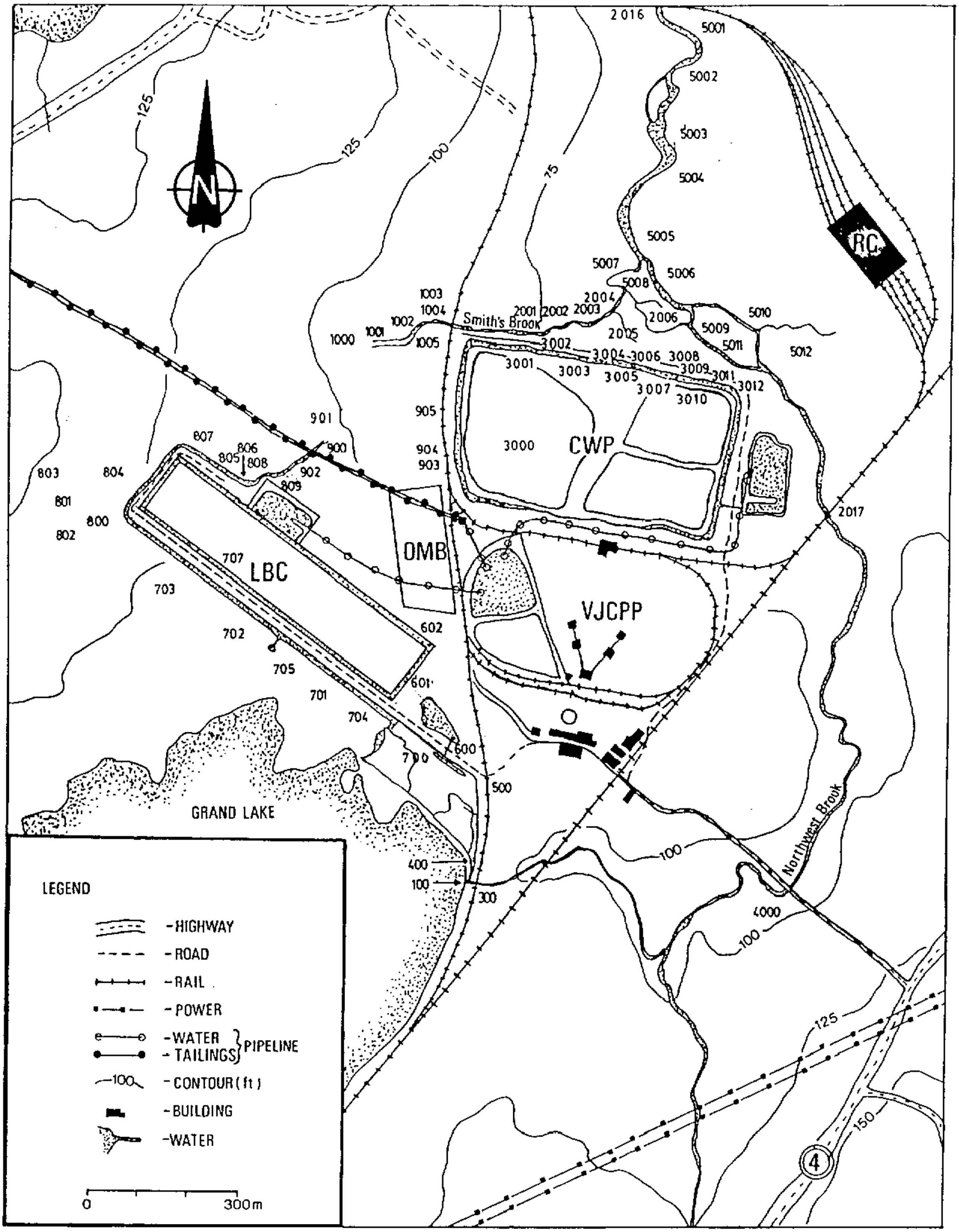
There are three primary sources of AMD at the VJCPP. The blended bank at H-Track, the CWP and the coal stockpiles at the LBC. These three sources create different drainage problems, varying in severity of AMD and metal content.

The coarse waste rock pile has a high pyrite content which oxidized to produce AMD. Seeps along the base of the CWP produce the worst AMD on site (stations 3000 series; MAP 2.2).

The second source is the old metallurgical bank, which used to store metallurgical grade coal. This area is not contoured, and its run-off and seeps drain northward along the railroad tracks to Smith's Brook. Monitoring stations numbered 903-905 cover the surface drainage from the bank (MAP 2.2).

Smith's Bog is located to the NE of the LBC and west of the CWP. Up to the present time, this bog, fed by Smith Brook, has had only freshwater input. Water monitoring stations 1000-1005 are at the bog outflow where it picks up AMD entering from the old Met Bank area (MAP 2.2).

The third source of AMD at VJCPP is the LBC. The AMD from the LBC should be somewhat reduced as the entire site was prepared with an asphalt-paved subfloor and



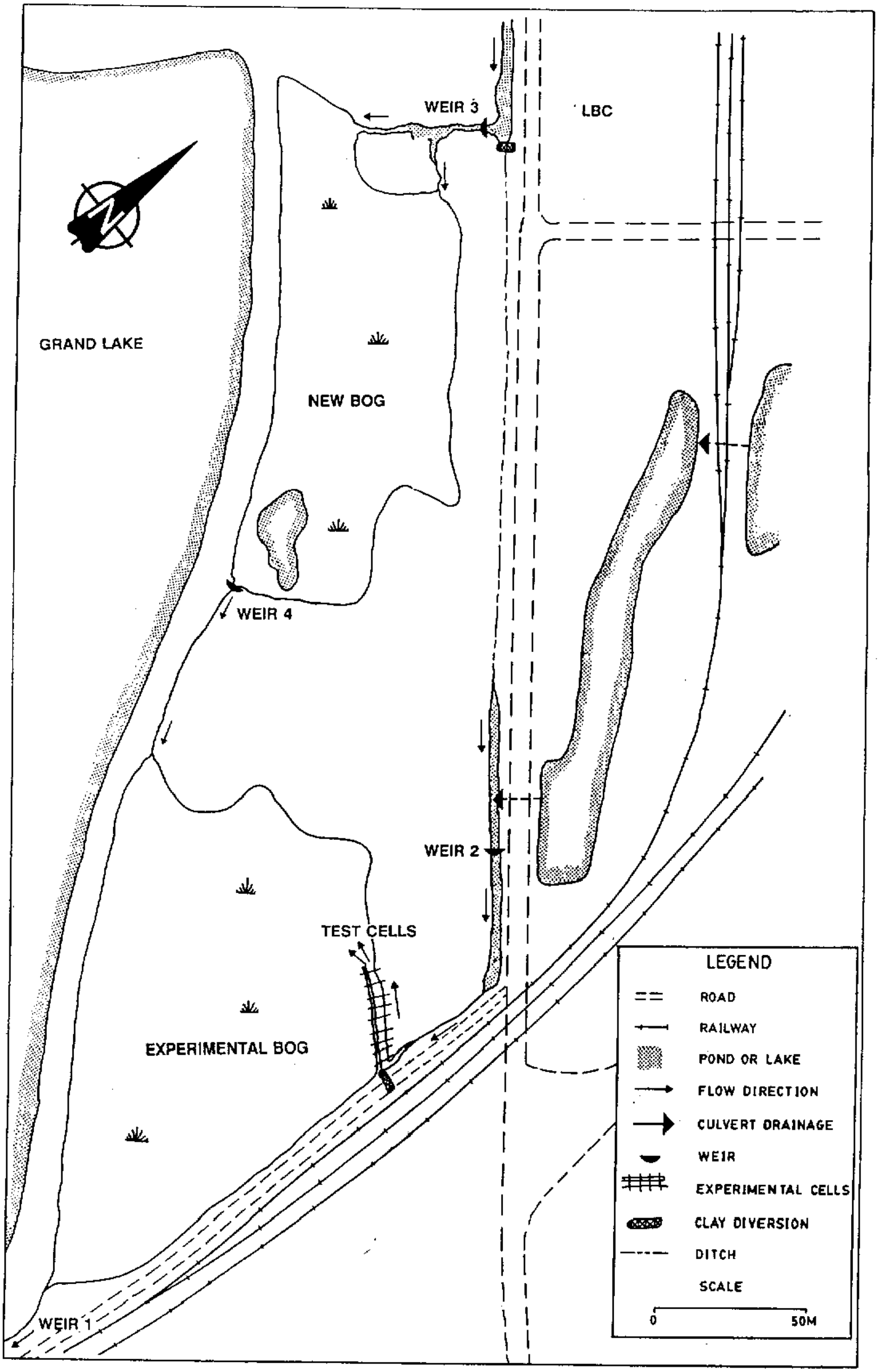
MAP 2.2: VJCPP layout. Numbers are Boojum Research Limited water monitoring stations.

ditch system. Under run-off conditions the water reports to an adjacent settling pond where solids separate out. Pond overflow drains by gravity to a pond # 2 on site at VJ and is subsequently pumped into the VJ Tailings Basin. There is a provision for settling pond overflow directly into Smith's Brook, but there is no record that this has occurred (PLATE 2.1). When the LBC is not properly maintained (i.e. too much inventory), however, run-off from the south side of the LBC is collected by overflow ditches adjacent to the bogs which eventually flow into Northwest Brook (monitoring stations 700s).

2.3 Experimental Site Selection

At the beginning of the project a survey of pH and conductivity was made of the entire site. This survey assessed the different drainage characteristics within the site, and evaluated sites for experimentation. The first bog evaluated, Smith's Bog, has accessability which is essentially limited to the winter season. It was not suited for experimental work.

The area around Smith's Bog which received seepage and run-off from the Met bank, was essentially dead and hence also unsuitable as an experimental area.



MAP 2.3: Experimental bog system at the VJCPP.

Two adjacent bogs on the south side of the LBC were dominated by water from Grand Lake, the headwaters of Northwest Brook. The northern edge of the lake is limited by a dyke. This dyke forms a southern boundary of the two bogs (MAP 2.3). One of these bogs was severely stressed by AMD run-off, and diffuse coal dust. It was selected as the Experimental Bog. The second one was essentially in a pristine state and was referred to as the New Bog. This bog was utilized to investigate the effects of AMD on undisturbed vegetation. These two bogs provided ideal conditions to address the objectives of the project. Further, studies in these two bogs might be applicable to nearby Smith's Bog.

2.4 Project History

In 1987, Boojum Research Limited was requested by the Cape Breton Development Corporation (Devco) to evaluate the potential for application of Ecological Engineering measures at the VJCPP If suitable, Ecological Engineering techniques would be applied to areas with AMD problems at the VJCPP and at other CBDC owned sites.

Water monitoring stations were established at critical areas around the processing plant. These stations were set up to complement those stations already sampled on a regular basis by Devco. The experimental site was selected based on the criteria previously outlined (MAP 2.3). In the first year the hydrological characteristics of the bog were determined. By the end of growing season 1988 it was decided that most of the LBC run-off was short-circuiting along the railroad tracks. Therefore, a diversion ditch which carried AMD from the LBC was dug near station 500, forcing AMD water through the Experimental Bog (MAP 2.3). This diversion ditch was divided up into 10 serial test cells through which ditch water must pass before entering the already severely AMD stressed bog.

The first implementation of Ecological Engineering measures took place in these cells. Based on the results obtained in the test cells, the work was expanded into the area of the bog itself. Amendment was placed in the bog along the major flow channels.

The New Bog was untouched by AMD up to 1988. During that summer, a clay plug was constructed in the LBC ditch which allowed AMD water to be shunted into the New Bog in two directions, along the dyke below Grand Lake and along the edge of the bog between the LBC dyke / ditch and the road (MAP 2.3).

In 1989, both bogs were extensively sampled for pH and conductivity and amendments were applied. The test cells were monitored, and vegetation analyses were carried out with the assistance of funds from CANMET. The initial work on vegetation analysis was summarized in (Kalin and Scribailo, 1989; Kalin et al., 1990).

Trials were also conducted on vegetation nutritional requirements and fertilization strategies. In 1990, more sampling was done in both bogs and fertilizer experiments were continued. Some positive experimental results were finally apparent at the end of the l990 growing season.

3.0 WATER CHARACTERISTICS IN THE DRAINAGE BASIN

The objective of the work is to determine if water chemistry improvements can be achieved through implementation of Ecological Engineering and other measures which assist in bog recovery. In order to determine if the methods used are working, and to protect the existing water characteristics in the Bridgeport watershed, a thorough understanding of background water chemistry of the area is necessary.

Historical water chemistry records are available from the 1970s and early 80s. These data represent a decade of water sampling and adequately characterize the background water characteristics of the Northwest Brook drainage. These records also allow us to define environmental conditions as they pertain to the effluents from the VJCPP.

The pH of naturally acidic bogs is on average between 3.85 and 4 (Larsen 1980). This acidity is due to the production of organic acids by the organic surface layers of the bog. Because healthy bogs are naturally acidic, it is difficult to determine if acid mine drainage is present. While acid mine drainage is acidic, due to the presence of sulphuric acid, it also contains a variety of metals in a number of forms. These metals, often in high concentrations, are one of the major causes of ecological damage. The concentration of metals and impurities in water changes the electrical conductivity. The greater the concentration of impurities, the greater the conductivity.

Since naturally acidic bogs contain only organics, the conductivity of these waters is low, usually less than 500 μmhos/cm. If AMD is present, however, the impurity content can be much higher causing conductivities usually greater than 1000 μmhos/cm. These observations can be derived from FIGURE 3.1 where conductivity is plotted against pH for water samples collected in the Experimental Bog. For the VJ site pH values below 3.5 are generally associated with higher conductivity, likely as a result of AMD. Conductivity is, therefore, a relatively good tool for mapping the extent of AMD damage.

Conductivity is also influenced by ions not present in AMD. One of the major ions present in water leaving the LBC and waste rock pile is chloride. Chloride is one of the major ions in seawater, and because the Devco coal is mined under the sea, seawater is commonly associated with the coal. FIGURE 3.2 graphs chloride ion concentration against pH. The scattered points do not indicate that, at least at station 2016, there is any relationship between chloride ion concentration and pH.

Another AMD indicator is the acidity of water. Acidity is defined as the amount of NaOH necessary to titrate a known volume of water to pH 8.3. Because of numerous interactions between AMD constituents and chemical reactions, the amount of NaOH necessary to buffer AMD water can be quite high. The greater the amount of NaOH required, the more lime must be added and/or more bacterial alkalinity must be generated.

There are very little acidity data available for the site which means it can not be used to determine long term trends. Conductivities, however, have been regularly measured. Since there is no significant relationship between chloride and pH, but a significant one between conductivity and pH, we will use conductivity as the primary indicator in the development of AMD for the sampling stations.

Historical water records are available for 4 monitoring stations along Northwest Brook in the area of the VJCPP (MAP 2.2). Those have been chosen to represent water conditions around the VJCPP. Grand Lake outflow (station 100) sits at the head of the Northwest Brook (MAP 2.2). Station 2017 is sited just to the east of the CWP; station 1004 is located on Smiths' Brook; and station 2016 sits at the railroad tracks some distance downstream from the VJCPP (MAP 2.2). The water characteristics at station 2016 will represent water leaving the VJCPP, and thus integrate the AMD production of the VJCPP, with some freshwater dilution. For some locations data go back to the early 1970s. In others, data have been collected starting in 1977, thus note, that the time axis of the graphs is not always the same.

3.1 pH

The pHs at Grand Lake (station 100) varied between 5 and 7.8 (FIGURE 3.3a). At station 1004 pHs varied between 4 and 7 (FIGURE 3.3b). From 1983-1988, pHs at station 2016 varied from a low of 3.5 in 1986 to a high of 6.5 in 1988 (FIGURE 3.3c). Station 1004 data only extend from 1977 to 1982, but, during this time, the pHs ranged from a low of 4 to a high of 7. There may be a long-term decreasing trend but this method of presentation does not show any seasonal trends in water characteristics. Seasonal trends are important in fully understanding the dynamics of the site. By plotting time of year along the x axis, these seasonal trends become more evident. For example, at stations 100, 1004, 2016, and 2017, there are no seasonal trends in pH (FIGURES 3.4a, 3.4b, 3.4c, 3.4d).

3.2 Conductivity

Conductivity of the water as shown in FIGURE 3.1, can be a useful tool for detection of AMD. Station 100 shows virtually no long-term trends, with the exception of some minor peaks in 1979, 1983, and 1987 in the late summer fall. The average conductivity of the site was 67 μmhos/cm (FIGURE 3.5a). There are no seasonal trends at station 2017 (FIGURE 3.5c), or station 1004 (FIGURE 3.5b). Station 2016, however, shows strong trends, with an increase between days 100 and 250 (FIGURE 3.5d). Conductivities range from 50 to 1400 μmhos/cm. These increases in conductivity could be the result of summer seepages from the CWP and/or from Smith's Bog. The worst years were 1983, 1986 and 1987. A subsurface wall around part of the CWP was completed in 1987. Note the drop in conductivity following installation. No data from these years are available for station 1004.

3.3 Chloride

Samples showing high conductivity levels were noted at station 2016 were further analyzed for the major elements which contribute to the conductivity. These elements are chloride, sulphate, iron, manganese, aluminum, and zinc. For example, chloride levels are low in Grand Lake, between 7 and 28 mg/L (FIGURE 3.6a). Chloride levels in Smith's Brook were similarly low, between 6 and 14 mg/L (FIGURE 3.6b). Station 2017 also shows these background levels, with a range from 7 to 16 mg/L with the exception of two points in 1977, which may be data transcription errors (FIGURE 3.6c).

Chloride levels at station 2016, however, are quite high (FIGURE 3.6d). They range from a low of about 10 to a high of 110 mg/L. After the installation of the cut-off wall in l987 the concentrations dropped drastically. The contribution of the waste rock pile and Smith's brook appears to have been reduced, although the origin can not be traced due to the absence of monitoring data. On a seasonal basis, only station 2016 showed any trends (FIGURE 3.6e). Chloride concentrations seemed to peak during the summer (days 180-250). This is likely due to the lower flows and higher evapotranspiration during the summer months, which would increase chloride concentrations.

Chloride, as a major component of seawater, is also detrimental to bog vegetation. The major adverse effect of soil/water salinity is to reduce the availability of soil/water to plants. This is because the presence of salt in water increases the work that the plant must do to take up clean water. The work involved is against the osmotic potential. The greater the salt content of the water, the greater the osmotic potential. Salinity stressed plants exhibit no distinctive symptoms. The most common effect of salinity stress is a general reduction or stunting of plant growth (Jurinak et al., 1987). This is not easily detected, when plants are already acid stressed. The effects of increased chloride and sodium loadings on bog vegetation in general and VJCPP vegetation in particular are unknown.

3.4 AMD Components

The major components of AMD in general are sulphate, iron, manganese, aluminum and zinc, in order of importance. At DEVCO sodium chloride is an additional component, which will alter freshwater ecosystems to more saline conditions. The concentration of these components is dependent on the severity of the AMD production and the amount of dilution.

3.4.1 Sulphate

Sulphate concentrations follow the chloride pattern. Station 100 has sulphate concentrations which range from a low of 2 to a high of 32 mg/L (FIGURE 3.7a).

Smith's Brook (1004) shows much the same range, from a low of 1 to a high of 23 mg/L (FIGURE 3.7b). Station 2017 ranges from 1 to 15 mg/L (FIGURE 3.7c). Again, the only sampling station on Northwest Brook to show significantly higher levels was station 2016, which had sulphate levels ranging from about 20 to 480 mg/L (FIGURE 3.7d).

On a seasonal basis, station 100 and station 2016 showed late summer increases. At station 100 this seasonal fluctuation was small and occurred only during the years 1983 and 1987. At 2016, the fluctuations were much greater, with major peaks in 1985, 1986 and 1987. The seasonal fluctuations were drastically reduced after 1987 , again a positive effect of the cutoff wall construction. Similar to chloride, sulphate concentrations in the water peaked between day 180 and 250 (June - September), due to the same reasons given for chloride.

3.4.2 Iron

Iron concentrations at station 100 varied between 0.05 mg/L (the detection limit) and 1.2 mg/L (FIGURE 3.8a). At Smith's Brook, the range was a little higher. There, concentrations ranged from 0.05 to a high of 2.3 mg/L (FIGURE 3.8b). At station 2017, iron ranged from 0.05 to about 1.4 mg/L (FIGURE 3.8c), while station 2016 varied between 0.05 and 10 mg/L before the cut-off wall was constructed and varied 0.05 to

3.3 mg/L after 1987 (FIGURE 3.8d). Again, the cut-off wall appears to have had a beneficial effect on the water chemistry at 2016 after 1987.

On a seasonal basis, both stations 100 and 2016 showed significant fluctuations. Iron at stations 100 and 2016 seemed to have a minimum around day 120, which falls in the month of April. The major peaks are between day 150 and 300. The worst years in each case were different. For station 2016 it was 1986, which was pre cut-off wall. For station 100 which represents background, it was 1979, 1982, and 1988. The worst year at station 1004 was 1982.

3.4.3 Manganese

As with iron, manganese concentrations at station 100 varied between 0.05 mg/L (detection limit) and 1 mg/L (FIGURE 3.9a). The higher values appeared in 3 major peaks in 1978, 1983 and 1987. At station 1004, the numbers ranged from a low 0.05 to a high of 7 mg/L (FIGURE 3.9b). The peaks again occurring only rarely in 1979 and 1982. At station 2017, manganese varied between 0.05 and 1.2 mg/L, with major peaks occurring in July of 1981 and 1982 (FIGURE 3.9c). At station 2016, the same trends are evident. The range here is from about 1 to 29 mg/L, with major peaks in 1986 and 1987 between July and September, during the time or cut-off wall construction (FIGURE 3.9d).

3.4.4 Aluminum

Aluminum and zinc are minor components of the Devco AMD. Aluminum concentrations at station 100 varied between 0.05 (detection limit - sometimes 0.04) to a high of 3.5 mg/L, although these may be bad data points (FIGURE 3.10a). At station 1004, only 1 datum was found - 0.4 mg/L ((1980). At station 2016, the values were generally about 10x higher. They ranged from a low of 0.05 to a high of 2.9 mg/L (FIGURE 3.10b). Again, there seems to be a general phenomenon of summer increases in metal concentrations, both in areas where AMD is expected, and where it is not expected.

3.4.5 Zinc

Zinc concentrations were the lowest of all the AMD components. At Grand Lake, they ranged from 0.005 mg/L (detection limit) to about 0.23 mg/L (FIGURE 3.11a). At Smith's Brook, they ranged from 0.005 to 0.08 mg/L (FIGURE 3.11b). We had very few data points for station 2016. The three points ranged from 0.01 to 0.12 mg/L. At station 2017, zinc concentrations ranged from 0.01 to 0.22 mg/L (FIGURE 3.11c).

3.5 Background Water Characteristics

For the most part, the historical data base for Grand Lake does not show any indication of AMD contamination, considering the proximity of the lake to the LBC. Grand Lake is hydraulically upgradient, and samples taken, were above the confluence with bog drainage. Since these data were taken before and after the LBC became operational in 1983, without changing significantly, the fluctuations must be considered natural.

It is interesting to note that there does seem to be a seasonal fluctuation in most of the metals analyzed. Although the concentrations are relatively low, there is a definite summer peak and a minimum in April.

At station 1004, there are some long-term changes in water chemistry. Smith's Bog at station 1004 is influenced by run-off from the Met bank. For the most part, however, the water characteristics of Smith's Bog are similar to those of Grand Lake. With the exception of pH, which may be related to the bog origin of the water, average concentrations of impurities in Smith's Bog are similar to, or less than those in Grand Lake.

Further downstream from Grand Lake, the water characteristics at station 2017 do not appear to be significantly different from those in Grand Lake or Smith's Bog. However, by the time the water leaves the VJCPP at station 2016, the concentrations of metals and impurities have risen. Regardless of origin, the surface water characteristics of water leaving the VJCPP have been altered back as far as 1979, although the greatest changes appeared in 1985, 1986, 1987. This was just before the subsurface cut-off wall around the CWP was completed. As was noted previously, the cut-off wall had beneficial effects on the surface water as the summer increases in concentrations of the relevant AMD characteristics have subsided.

It is not known, if the cut-off wall has effected a overall reduction in AMD seepage, or if the contaminants travel below surface, hence the reduction noted in the surface water.

4.0 WATER CHARACTERISTICS WITHIN THE VJCPP

Monthly pH and conductivity samples have been collected from a large number of stations around the VJCPP. These data are summarized in TABLE 4.1 (station #s are shown on MAP 2.2). The coarse waste rock pile (stations 2000-3000) has several seeps around the northeastern perimeter. These have extremely high conductivities 8000-11000 μmhos/cm, although pH values are at 3.5.

The average conductivity of each group of station numbers presented in TABLE 4.1, was plotted against day of year. The results show that the coarse waste rock pile produces the highest conductivity values (stations 3000 series). The coarse waste rock seeps appear to produce more concentrated AMD during summer (FIGURE 4.1).

The conductivity values of the sampling stations of the 2000 series, which lie just to the east of the 3000 series representing Smith's brook have improved along with the construction of the cut-off wall.

The OMB or H track metallurgical bank drainage area (series 900) has been dry for the past year. In 1988 and 1989, pHs varied between 2.7 and 6.9 and conductivities varied between 510 and 8100 μmhos/cm. The 900 series stations produce a more dilute effluent stream than the seepages from the CWP. These stations have recorded conductivities which average between 1000 and 3000 μmhos/cm. There seems to be no definite seasonal trend in its fluctuations.

A similarly dilute effluent emerges from the LBC run-off (stations 700s). Conductivities range from 1000 to 3000 μmhos/cm. The cleanest areas on site are the 800 series and the 1000 series, which represent the headwaters of Smith brook (Map 2.2 page 7).

4.1. Weirs

In the area around the LBC, monthly water samples have also been taken from 4 weirs (assuming flowing water) on LBC ditches since they were installed in 1988. These weirs were installed on the ditches surrounding the bogs (MAP 2.3). Weir 1 is at the outflow of the Experimental Bog also referred to as the old bog. Weir 2 is at the junction of the sump ditch and road ditch, which is near the entrance to the Experimental Bog. Weir 3 is at the entrance to the New Bog. Weir 4, which is dry most of the time, is at the out/overflow from the New Bog (see MAP 2.3).

Because water at weir 4 is almost never running, data from this weir are sparse and therefore not presented. The water characteristics at Weirs 1, 2 and 3 vary, both from year to year and seasonally (FIGURES 4.2 - 4.10). Much of the difference is due to loading, which can be calculated using data in Figure 4.10. For example, iron concentrations (FIGURE 4.6a) for weir 2 seem to fluctuate in opposition to flow rates (FIGURE 4.10a). This suggests, that high flows are flushing out iron and the rate of acid generation which would solubilize the iron is slow.

Even though both weirs 2 and 3 represent water coming from the LBC, the metal content of the water from each weir is different. Sulphate values (FIGURE 4.5) show a generally increasing trend from October 1989 to December 1989, while sulphate decreases over the same period at weir 3. The second difference is that for the most part, metal concentrations are 2-8 times higher at weir 3 (comparing peak to peak; sulphate - 4x, iron - 7x, aluminum - 5x, manganese - 2x, and zinc - 8x (see FIGURES 4.6-4.8). The only exception is chloride, which is only half as concentrated at weir 3. This may be due to the origin of the chloride, which is not dependent on the rate of acid generation, but is much more mobile with precipitation.

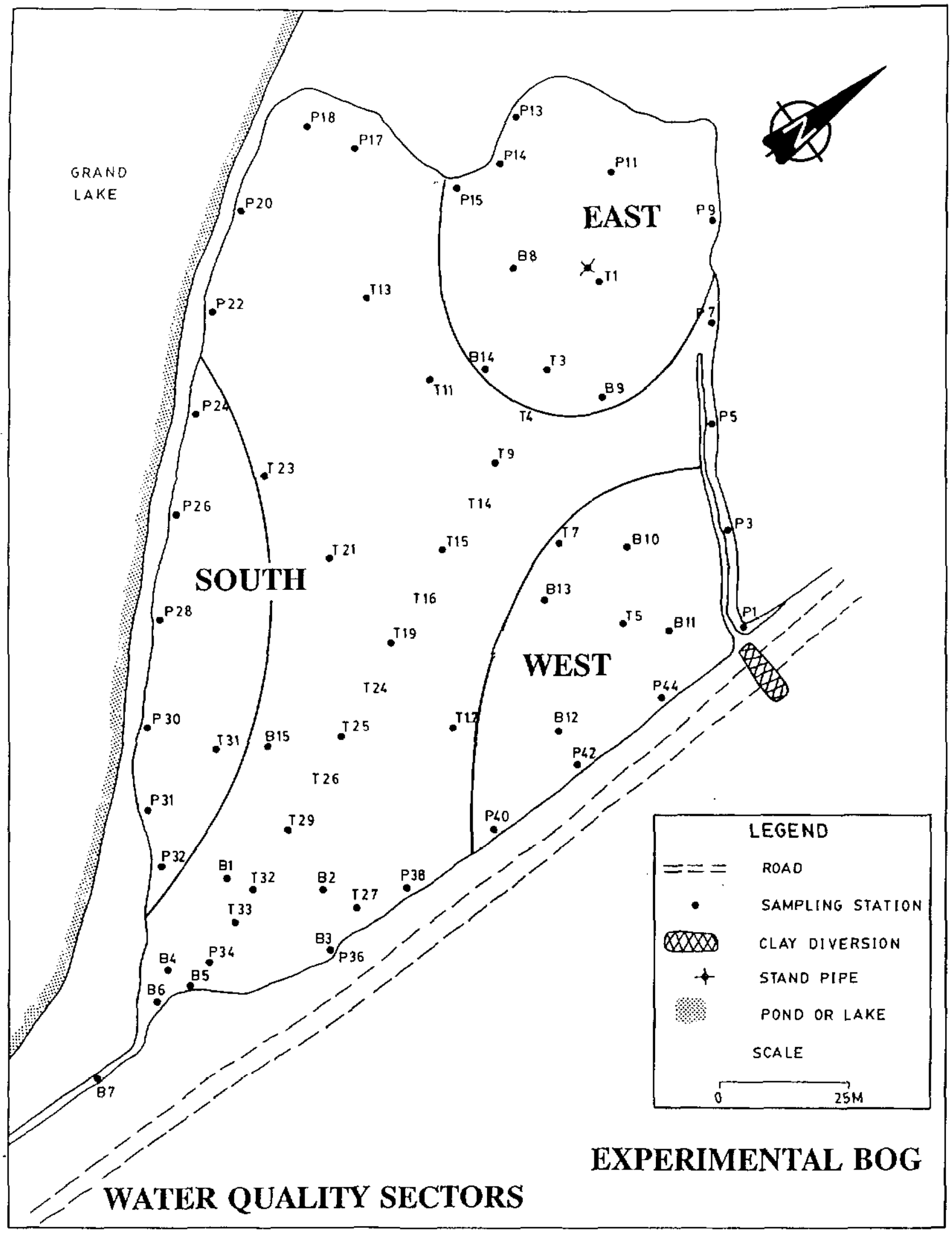
The result is that the effluent characteristics entering the New Bog are different to the composition than that entering the Experimental Bog (through weir 2). Furthermore, the acid-generating material in the collection pond is much more compacted than the coal stored on the LBC, which would also result in differences in the effluents produced.

4.2 Experimental Bog

The Experimental Bogs are located in a hydrologically complex area at the headwaters of Northwest Brook. The bogs receive subsurface freshwater from Grand Lake and AMD from the VJCPP facility.

To characterize the different water sources, permanent monitoring stations were set up in the bogs. P stations were perimeter stations. T stations transected the bog; and B stations are those at which depth profiles have been made. All these stations are shown in MAP 4.1. The hydrology of the Experimental Bog is discussed fully in earlier reports (Kalin and Scribailo 1989). Plate 4.1 gives a general view of the Experimental Bog, looking from the north to the south, across to Grand Lake.

In 1987, the Experimental Bog was receiving diffuse AMD from along the railroad tracks on the eastern border of the bog. Grand Lake water was intruding from the south. In order to follow trends in water characteristics from these areas, water chemistry data from each area were pooled. These areas were: the south side of the bog, which received Grand Lake water through ground water intrusions (MAP 4.1); the eastern area near the junction of the railroad and LBC road; and the western area, which abutted the lifting and banking road along the west side of the bog. After ditch diversion, a fourth area, the test cells, was created. By grouping data from stations in each of the 3 areas, the progressive changes in water characteristics in the Experimental Bog were documented. The area nearest Grand Lake decreased in pH during the initial period after diversion of AMD water into the bogs in 1988 (FIGURE 4.11b). The decrease could have been due to intrusion of AMD into the Experimental Bog or from overflow AMD via the New Bog. (For each date, the highest and lowest pHs recorded and the logarithmic mean of all stations measured are shown.) The pHs have increased since this period and are now at pre-diversion levels.



MAP 4.1: Overview of the Experimental Bog showing permanent water monitoring stations and statistical sectors.

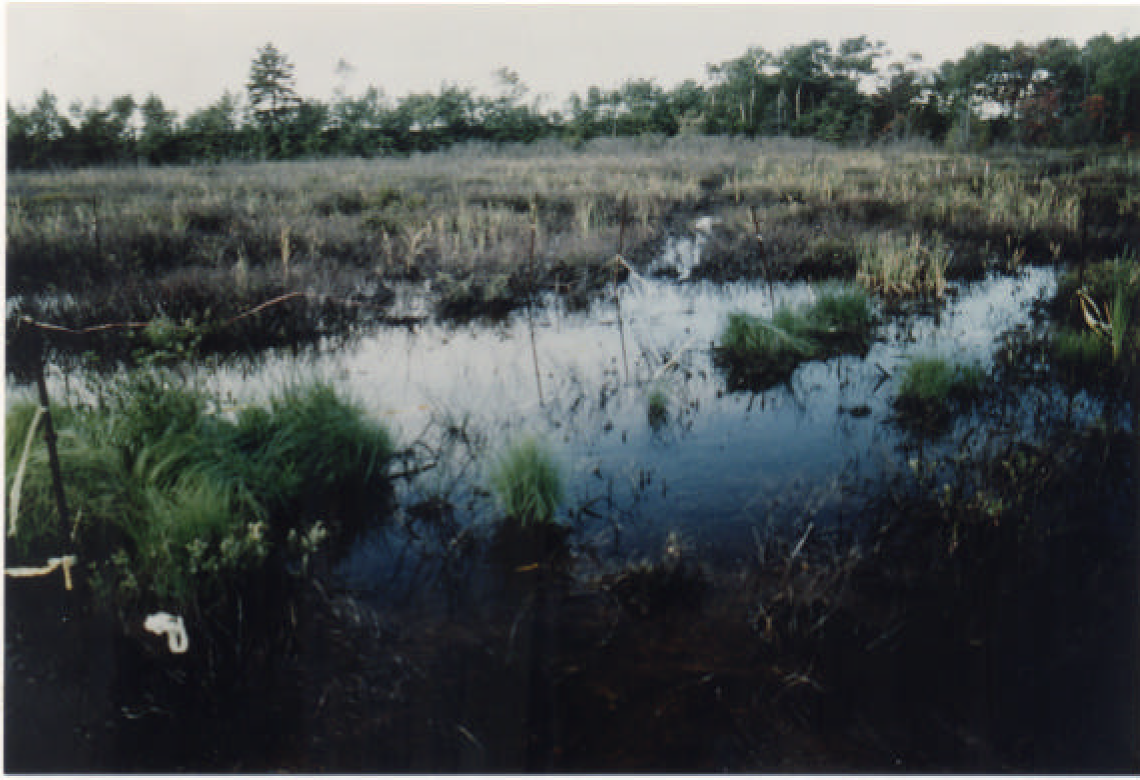


PLATE 4.1: Overview of the Experimental Bog. Fertilizer plot is located in the foreground.

The area nearest the railroad tracks received the most AMD before diversion. Its mean pH was around 2.6 (FIGURE 4.11a). Water in the area has slowly increased in pH to the point that at latest survey (September 1990) showed pHs values which reached 6.5.

The western section of the bog was initially quite variable, with pH ranges from 3 to 5. However, with diversion of AMD into the area in the summer of 1988, the pHs gradually decreased to just over 2. Recent samples from the area, however, indicate that pH may be increasing (FIGURE 4.11c; pH 2.6-4). In July and September 1990, much of the area was covered with jarosite, a mineral surface coating which is indicative of elevated pHs. Extensive cattail and *Juncus* development has also occurred in the area.

Conductivities for the Experimental Bog are shown in FIGURE 4.12. Again, the highest, lowest and mean conductivity are shown for each sampling time in a given sector. The conductivities mirror the pHs. The eastern sector started out with high conductivities, became rather erratic over the next year, and has since improved dramatically (FIGURE 4.12a). Conductivities in the western sector show just the opposite trend (FIGURE 4.12c). During the latter part of 1988 the conductivities were low indicating that the sector was essentially unaffected by AMD. With the diversion ditch, the conductivities increased. The southern sector started out with clean, fresh water and was inundated over much of the next spring, but these values returned to more normal, bog water levels (FIGURE 4.12b).

Since the Experimental Bog was deteriorating under the effects of AMD, some methods were required which would help the bogs to recover. Ecological Engineering techniques were applied to the bog. In general, these techniques involved enhancing natural bacterial populations which generate alkalinity. The primary bacterial populations which were targeted were the sulphate reducers, iron reducers and the methanogenic bacteria. These require anaerobic conditions, an electron acceptor (sulphate, carbon dioxide) a modicum of nutrients and a carbon source. By amending the bogs with an organic carbon source, and controlling the flow of AMD into the bogs, it was hoped that anaerobic conditions would be enhanced. The carbon and nutrients provided by the amendment would foster population increases in these bacteria. The bacteria, in turn, would generate alkalinity as a byproduct of growth.

The Experimental Bog received 196 hay bales, placed primarily in the eastern end of the bog. The bales were placed on straight lines from the northwest to the southeast exit from the bog. Straw was broken up and placed in the hollows. The whole area on the eastern side of the bog also received straw.

In the amended portions of the Experimental Bog, the status of the amendment was also monitored at intervals. By the summer of 1989, very little of the amendment had begun to decompose (see Microbiology section). Water characteristics remained poor. However, by the summer of 1990, areas with slower water flow, or stagnant areas had begun to rise in pH. In these areas, especially near B11, *Typha* (cattail), and *Juncus* (rush) have grown well. In other areas where flows are more rapid, amendment can be seen to be overgrown by *Sphagnum* moss. Cattail growth in these hollow areas is still poor. Only with fertilizer applications have we seen any improvement in hummock grass or brush vegetation (see Fertilizer section). However, when pH data for the area are pooled, it becomes obvious that water chemistry improvement is taking place (Kalin et al. 1990, in appendix).

The vegetation in the Experimental Bog was extensively studied in 1988 and 1989. Several permanent plots were set up and the changes in the vegetation were monitored. These data have been presented in a previous report (Kalin and Scribailo 1989), and further analyzed in a report (Kalin et al. 1990). This report is included in the appendix.

4.3 Test Cells

The diversion ditch into the Experimental Bog was about 2 m wide by 30 m long. It was divided up into 10 serial test cells, separated by wire fencing. The ditch into which the test cell system was placed was completed in July of 1988 and amended with straw (TABLE 4.2).

Water characteristics were monitored at intervals thereafter. The pHs in both the root zone and surface water in the cells is shown in FIGURE 4.13. These data indicate that pHs have been steadily improving since 1989. The primary conclusions from this graph are: 1) pH is increasing; 2) bottom pHs rose faster than surface pHs in 1989; 3) there is currently little difference between amended and unamended cells, and all are high in pH ranging between 4.5 and 6.

Measurements in 1990 show that pHs in the test cells are generally above 6. Concomitant with the increase in pH, an emergent vegetation has flourished. Cattails, rushes, and Bluejoint reedgrass cover most of the surface of the test cell ditch (TABLE 4.2). Even the concentrations of heavy metals have begun to drop in these cells. FIGURES 4.14 - 4.16 show the concentrations of metals as a function of months after diversion. Early data taken just before and just after diversion show that inputs to the system are quite variable. Nevertheless, concentrations since the first year have been consistently low. Probably the most significant data are the acidity data (FIGURE 4.15) which show consistent decreases since the test cells had been installed.

One of the most dramatic changes in the test cells is the replacement of natural bog vegetation with cattails, rushes, and Bluejoint reedgrass. Plate 4.2 shows one of the test cells in July of 1990. These are highly productive, pioneering species which commonly settle into disturbed aquatic areas. Larsen (1980) considers these plants an early successional stage in the development of peatland vegetation. By creating the test cells, a mature ecosystem was removed. The first colonizers are the grasses, reeds, and cattails. These will probably eventually give rise to more *Sphagnum* bog-like vegetation, if conditions in the bog continue to improve. Both cattails and rushes have reputations as weedy species which are capable of tolerating adverse conditions, and accumulating heavy metals. These plants survive and grow well under conditions which are inimical to most bog plants.

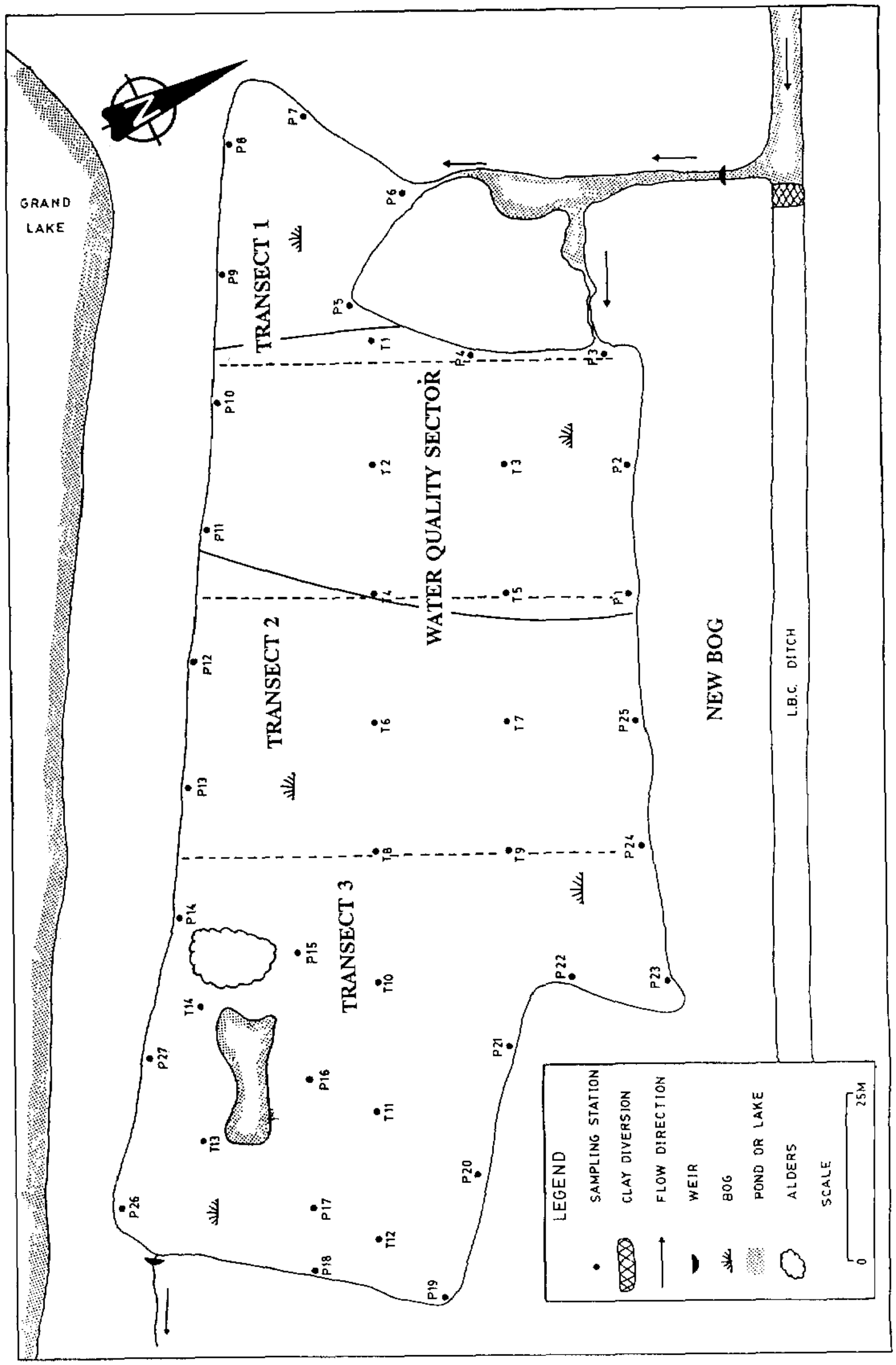
PLATE 4.2: View of Test Cell No. 2 in July 1990.

4.4 New Bog

The New Bog was originally a pristine acidic bog, unaffected by AMD. It is proposed may many workers who address amelioration of AMD with wetland systems, that acidic bogs can be used to ameliorate AMD. It was the contention of Boojum Research that this was not the case. To test this, Boojum Research, with the approval of Devco, diverted AMD into the bog in the summer of 1988. For a more detailed description of the experiment and the bog see Appendix 3.

To follow the water characteristics of the New Bog, a number of water and vegetation monitoring stations were marked permanently, labelled, T for transects and P for perimeter of the bog. P stations are perimeter stations and 3 transverse transects T stations are part of permanent longitudinal transects. These stations are shown in MAP 4.2. To analyze the data points located in various regions are summarized in the outlined section (MAP 4.2). Plate 4.3 shows a view across the New Bog from the northeast to the southwest, in the first year after diversion of AMD into the bog.

PLATE 4.3: Overview of the New Bog. Photograph shows bog centre, looking southeast.



MAP 4.2: Overview of the New Bog showing permanent water monitoring stations and statistical sector. Three tranverse transects are also shown.

Overall, in the New Bog, the pHs were initially quite normal for an acidic bog (FIGURE 4.17a). Data ranged from about 3.6 to 5.6 with a mean around 4.5. As AMD was shunted into the bog, the pHs became more erratic. By the end of 1988, the lowest pHs were 2.9. In 1989, the pHs were much more stable, between 2.2 and 3.1. By 1990, however, there was some pH improvement in the bog. Bulk water samples from the root zone in amended areas reached pHs close to 4.0.

The conductivity in the New Bog mirror the pHs values (FIGURE 4.17b). Conductivities were initially low, indicating that the bog was clean. By the latter part of 1988, however, some measurements were as high as 3000 μmhos/cm. In 1989 the conductivities remained high, sometimes as high as 4300 μmhos/cm. However, during the summer of 1990, the numbers dropped dramatically. The highest recorded conductivity was 1800 μmhos/cm, while the lowest was 500 μmhos/cm.

The New Bog got a total of 113 bales of hay placed primarily along the probable path of the greatest water flow, down the middle from the northwest to the southeast. There were also a number of bales placed along the north side of the bog, especially around P24. A total of 12 bales were placed in the incoming water ditch near the weir. An additional 4 bales were placed just inside the bog around station P3.

In 1989, surveys of the bog vegetation determined that everything in the path of the AMD was dead (Kalin and Scribailo 1989). A resurvey in 1990 showed some surprising but cattails had returned to the bog. The survey in July counted an average of 1.4 cattails/m^2 along the southern edge of the bog, with concentrations even higher towards the centre of the bog (in one location, 3.6 /m^2 (FIGURE 4.18). The distribution of cattails in the bog in 1990 shows the major path of the AMD is not south around the island but to the north of the island (see FIGURE 4.18).

Water flow rates through the bog are important, not only because of AMD loading, but because anaerobic conditions require low or non-existent flow. To measure the low flows in bogs we have modified a method used in marine systems. Diffusion cubes (plaster of Paris) slowly dissolve at a rate determined by the water flow rates. Initial tests of this method were carried out in the New Bog during the summer of 1990. Briefly, the cubes dissolved at different rates in the bog. The dissolution rates appeared to represent different rates of water movement within the bog, i.e. there was more dissolution in areas where we expected greater flow. Absolute rates of flow can only be calculated if the system is calibrated. We are currently attempting to do this now. Original data are presented in the appendix.

5.0 FERTILIZATION EXPERIMENTS

The two requirements for Ecological Engineering are an increased residence time and proper nutrient loading. To satisfy these requirements, we first must define the flow patterns and AMD residence times in the bogs. Ways must be found to use this information to enhance anaerobic conditions in the root zone. The second requirement is to find the proper nutrient mix for ARUM (Acid Reduction Using Microbiology) and vegetation. Major nutrients needed for the growth bacteria is carbon and vegetation requires nitrogen, phosphorus and potassium.

Most bogs are characterized as being nutrient-limited. Generally, N and P availability decline at pH levels below 6. Mineralization, the breakdown of organic matter, including fresh residue, supplies much of the N and P needed by plants. Also, as acidity increases, solubility of some nutrients decreases, as does the activity of some N-fixing bacteria (Tucker et al., 1987). A critical pH level is difficult to define because some species tolerate lower fertility conditions better than others (Tucker et al., 1987).

Acidic conditions thus control nutrients both through locking them up in the vegetation, and reducing solubility of mineralized nutrients. Water chemistry data from the Devco bogs and surrounding areas confirm that these bogs are nutrient-poor. Virtually no nitrate or ammonium could be found in tested bog water.

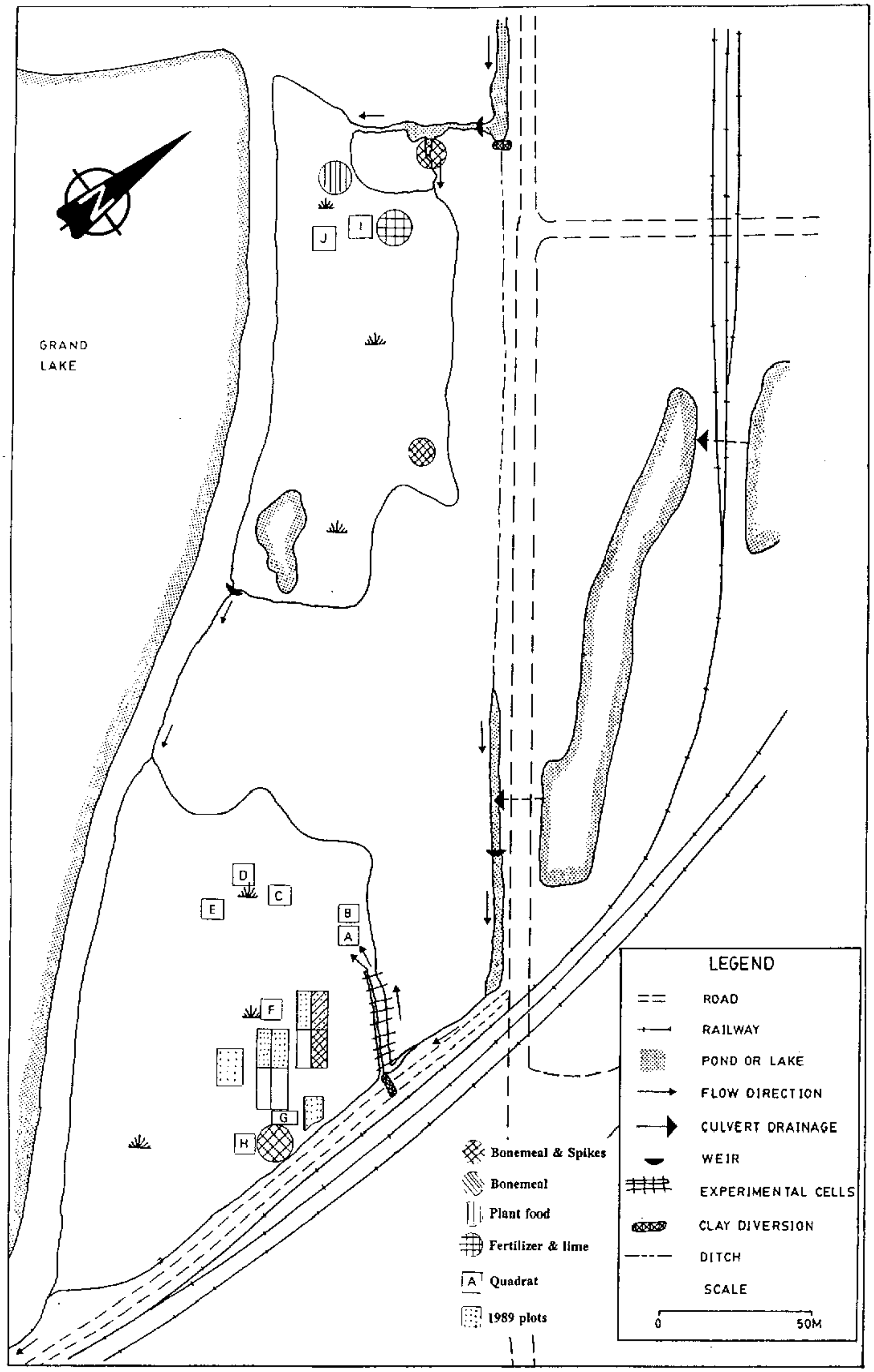
The bacterial alkalinity-generating process which we have tried to enhance in the bogs by carbon addition is probably also under nutrient stress. Nutrients, especially nitrogen, are also required for bacterial growth. Enhancement of certain bacterial populations through manipulation of nitrogen source is also possible. Once alkalinity has been generated through bacterial growth, the decreased acidity will make more of the locked up nutrients available for vegetation growth. The fertilization experiments were therefore aimed at bacterial and vegetation populations.

Nitrogen source is also an important consideration. Nitrate is an anion which must be reduced to be utilized by plants. Certain bacteria, denitrifiers, can utilize nitrate as an electron acceptor and produce as a byproduct N_2 gas and OH^- ions. Further, vegetation assimilation of nitrate requires that the plants also release hydroxyl ions. Assimilation of ammonium ions (a cation) does the opposite. Plants which utilize ammonium, release hydrogen ions. Since fertilization is clearly indicated, we initially felt that it would be best to fertilize bog vegetation without dealing with the acidic water. This could be accomplished by using foliar fertilizers. We then began a series of nutrient application experiments to see if we could enhance vegetation growth in the Experimental and New Bogs.

5.1 Foliar Fertilizers

In May of 1989, fertilization plots were set up in the Experimental Bog. These consisted of 4 defined areas where different combinations and dilutions of foliar fertilizer could be tested. MAP 5.1 shows the locations of these plots. Experiment 1 used a foliar application of 4:18:6 (N:P:K) at dilutions of 1:20 and 1:2000 in three different areas of the bog. Experiment 2 used a foliar application of 14:4:6 (N:P:K) at a dilution of 1:20. All experimental plots were fertilized several times during 1989.

The results of the foliar application of fertilizer were inconclusive. No improvement in vegetation colour or growth was noticed. This has also been the case at other sites where the foliar fertilizer was tested during the same period. However, significant improvement in root health using 4:18:6 foliar fertilizer at other sites has been noticed (Kalin and Scribailo 1989). It is not surprising that root growth was enhanced the most using a high phosphate fertilizer. Phosphate is known to enhance root growth in most plants.



MAP 5.1: Location of all fertilizer experiments in 1989 and 1990.

5.2. Slow-Release Fertilizers & Bone Meal

Based on the results of the 1988 and 1989 work, we decided to try a different method of fertilizing the root zone. The problem with foliar fertilizers is that they may be too quickly diluted and lost. A more efficient method provides plants with nutrients close to the roots, in small doses over time. Slow-release fertilizers fill this prescription. Accordingly, in 1990, we began testing several slow-release fertilizers, including Wilson fertilizer spikes (10:8:7) and an encapsulated, slow-release fertilizer (Nutricote 14:14:14 T100). The tree spikes were designed for soil applications not submergence. They dissolved in a few weeks. Observations on the encapsulated beads confirmed their slow-release. Fertilizer was still present at least 2 months after application.

The encapsulated fertilizer has a balanced N:P:K ratio and a release time of 100 days under normal soil conditions. A medium high nitrogen fertilizer releasing over 3 months should affect the growth of the native plants, and, it was hoped, also provide a nitrogen source for bacterial populations (see Microbiology section).

During the summer of 1990, several experimental plots were also fertilized with bone meal ($CaPO_4$; FIGURE 5.1). Bone meal application has two functions. First, it is a source of immediate alkalinity generation. This will initially ameliorate water conditions in the zone around application. The second function is to deliver high phosphate concentrations to the root zone.

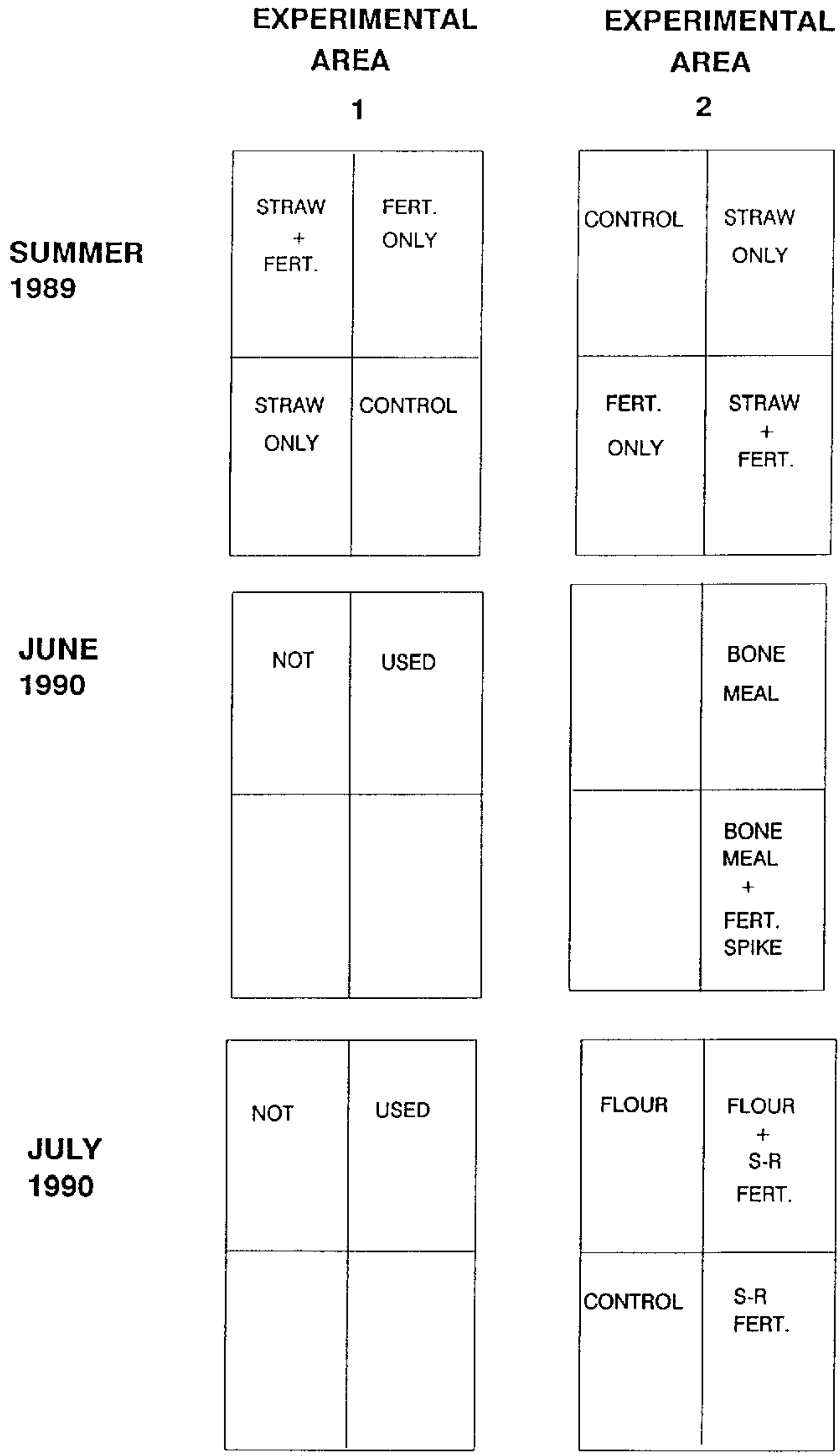


FIGURE 5.1: Setup of the fertilizer plots in the Experimental Bog.

As shown in MAP 5.1 and FIGURE 5.1, we spread bone meal, spikes, and Nutricote (slow-release pellets) in various combinations at several locations in the Experimental and New Bogs. The results of these experiments were generally positive. PLATE 5.1 shows the general trend. After 2 months, fertilizer application areas were considerably greener than areas outside. *Sphagnum* moss was much greener and overgrowing much of the straw amendment (PLATE 5.2). In one place (near P2) in the new bog which receives the brunt of the incoming AMD, grass was growing in the amendment. Nowhere else in that area of the New Bog have we seen grass growing. However, no differences in plant survivability or growth could be seen with just the application of bone meal. Areas with bone meal and fertilizer and areas with only fertilizer showed the most improvement.

In other experiments at several different mine sites we have found that slow-release fertilizer has a dramatic effect on cattail growth. Further, in combination with bone meal, the results are even more promising. The combination of nitrogen for plant shoot development and phosphate for root development are synergistic.

The second reason for applying nitrogen fertilizer was to try to enhance denitrifying bacteria which might be essential to alkalinity generation. These results will be discussed in the next section with the microbiology.

PLATE 5.1: Fertilizer plot in Experimental Bog, showing enhanced grass growth.

PLATE 5.2: Fertilizer plot in Experimental Bog, showing moss coverage of amendmer

6.0 MICROBIOLOGY

Ecological Engineering techniques utilized by Boojum Research Limited to ameliorate AMD depend on ARUM. ARUM is an acronym denoting Acid Reduction Using Microbiology. This means the acidity created by AMD is counteracted by using microbes which generate alkalinity. The microbes utilized are those naturally found in local bogs. These microbes fall into four categories. The first class is iron reducers which use iron as an electron acceptor under anaerobic conditions liberating alkalinity. A second class is the sulfate reducers which utilize sulfate in the water under anaerobic conditions. A third group is called the ammonifiers. These bacteria utilize organic nitrogen, converting it to ammonia. A fourth class is the denitrifiers. These bacteria utilize nitrate under anaerobic conditions and liberate hydroxyl ions which give alkalinity.

Growth of these bacteria requires: a) a carbon source, b) nutrient source, and c) anaerobic conditions. Carbon, with a small amount of nutrient, can be readily provided by using common forage materials, such as hay. Depending on the concentrations of inorganic nutrients in the bog and AMD water, nutrients may have to be added to enhance bacterial growth. Experiments of this nature have been ongoing since 1989. Anaerobic conditions in the bog are very much related to water flow. The greater the flow of water through the bog, or water table fluctuations, the less chance that anaerobic conditions will establish.

To follow the microbiological development of alkalinity in the bogs, amendment samples were collected for microbial analysis. To assure that microbial changes in the samples closely resemble those of the field, the analysis were initiated within two days of sample arrival at the laboratory.

6.1 ATP Analyses

Analyses included ATP assays (Adenosine Triphosphate) using the firefly luciferase method. Measurement of the ATP level of samples gives an indication of the total micro-organism population numbers (see TABLE 6.1).

6.2 Bacterial Enumeration

Samples were also taken for enumeration of specific kinds of bacteria. Bacteria were plated onto Postgate B, E and F media for enumeration of sulfate reducers. Casein medium was used for ammonifiers. Iron reducing bacteria were enumerated in a minimal salt medium containing Fe III and a mixture of peptone, yeast extract and lactate - a carbon source. Denitrifying bacteria were counted by endpoint dilution in medium containing KNO_3 and nutrient broth as per Tiedje (1982). Enumeration data are presented in TABLE 6.1.

6.3 Laboratory ARUM Testing

To obtain more detailed information about the amendments used in the bog and the processes which take place in the test cell system a series of experiments were carried out. Water samples from the root zone in test cells 7 and 9 were placed in small vials and supplemented with: 1) nothing i.e control; 2) alfalfa; 3) barley; 4) cooked meat; 5) glucose; 6) bran; 7) flax.

In the small vials, all six amendments and the control generated alkalinity and brought the pH of water above 6. The differences were in the rate of pH increase. The slowest rate was observed in the control vial. Here, pHs did not rise significantly until day 120. The highest rate was observed in the vials where cooked meat was added, followed by those with alfalfa. These data support the contention that bog water contains ammonifiers (ammonifiers degrade meat to ammonia), and that nitrogen may be limiting (alfalfa is a high N forage material). After two month when the pH had increased to about 5.5 or 5, new AMD was added and it became clear, that the microbial activity was continuing (Figure 6.1a and 6.1b).

6.4 Amendment Degradation Analyses

In this set of experiments, samples of amendment from a number of sites at Devco were subjected to serial extractions. The idea was to find out how much of the amendment (hay bales placed into the bogs) had naturally broken down into simpler carbon products available to bacterial populations. Extraction in acetone removes most of the volatile fatty acids. Extraction in HCl measures that fraction which has been partially degraded and will rapidly be available for bacterial use. Extraction in H_2SO_4 gives the percentage of organic amendment which will eventually be extractable by bacterial populations.

Volatile fatty acids are a breakdown product of cellulose and are a common energy source for a number of methanogenic and ARUM bacteria. The results of the serial extractions are plotted in FIGURE 6.2. From the graph it can be seen that the easily usable volatile fatty acids (VFA) are a very small percentage of the amendment. This percentage seems to be independent of the time of amendment placement or the pH of the amendment/water. For example, E 2.5 (amendment sample from the Experimental Bog with a field pH of 2.5) has 6% VFA and E 6 (amendment sample from the Experimental Bog with field pH 6) has 7.2% VFA. The percentage of rapidly usable material is also consistent between these samples (41% vs. 43%). Very little of the carbon in the amendment appears to be utilized, based on the sequential extraction results. If the amendment were being degraded by bacteria we would expect to see a shift in the percentages toward the top, i.e. larger percentages in more readily usable carbon. This however is not the case. Further studies of the decomposition of the organic amendments are underway.

7.0 CONCLUSIONS

Background data for Northwest Brook watershed indicate that for the most part Grand Lake and Smith's Bog water represent background water quality. The historical water chemistry trends presented in this report for station 2016 shows the greatest evidence of water deterioration, from l983 to 1987. The cause of the deterioration is mainly due to the seepages from the coarse waste rock pile , and drastic improvements have been noted since the constructions of the subsurface cut-off wall in l988 by which time it was completed. The cut-off was completed in the summer of 1987. Further, The stations 2017 just upstream from the coarse waste rock pile does not seem to be affected by the contaminants produced by the pile.

AMD is produced at 3 locations on the VJCPP: H-Track, CWP, and LBC. AMD from the CWP produces the highest effluent with respect to conductivity. Of the waste water produced by the LBC, that which overflows through weir 2 is cleaner than that which flows through weir 3. Weir 3 water was therefore diverted into the New Bog.

The Experimental and New Bogs which have been receiving direct AMD for 2 years amd show signs of pH improvement in root zone water in areas with restricted water flow. In the Experimental Bog, this means a large area in the northeast corner of the bog which has pHs in excess of 6. In the New Bog, an area near P24 is also showing definite signs of improvement.

The bogs have also been receiving sodium and chloride loadings from the LBC run-off. Increased saltwater loadings on bog vegetation may be a factor which will become increasingly more important with time.

The test cells in the Experimental Bog improved significantly in pH since 1988, and are now above pH 5. Cells without amendment are now improving as well as the amended cells, indicating that all water flowing through the cells is being treated. The greatest change is in the diversity and quantity of the vegetation which has colonized the disturbed areas. Cattails, rushes and Canada bluegrass are the dominant vegetation which grow in the test cells. These plants are typical pioneering species, restarting the evolutionary cycle of peatland development.

As conditions in the bogs continue to improve, these pioneering species will move out into the bog. Already we are seeing that cattails have returned to the New Bog. A 1989 census of the bog indicated that no cattails survived the AMD intrusion in 1988. Yet, in July of 1990, 1.4 cattails/m^2 (of bog with cattails) were counted in the New Bog.

The improvement in root zone pH and concomitant colonization by new vegetation are probably a result of several factors. First, microbial alkalinity generations is taking place in areas with reduced flow. Secondly, water entering the bog appears to be cleaner, which is further assisting the recovery of the bogs. Thirdly, the new vegetation types are less sensitive to AMD, and more weedy.

Fertilizer studies in 1990 demonstrated the beneficial effects of adding slow-release NPK fertilizer together with bone meal. In test plots in the Experimental and New Bogs, the plants appear greener. Experiments with foliar fertilizers demonstrated enhanced root production, but could not demonstrate any affect on growth as noted in greener, healthier plants.

Amendment testing in the laboratory indicates that ammonifiers, iron reducing bacteria, denitrifiers, and sulphate reducing bacteria are present in the Devco bogs. Ammonifiers are probably the most predominant. Most of the amendment samples tested had over 100,000 bacteria per ml of interstitial water.

Test of microbial activity in small vials in the laboratory with different addition of substrates, produced alkalinity regardless of the amendment. The control vials, without amendments produced eventually produced alkalinity thus the amendments increased the microbial activity, measured by the rate of pH increases. Best results were obtained by additions of meat. Meat (protein/amino acids) is the substrate for ammonifying bacteria. followed by those amendments with high nitrogen content. This suggest that nitrogen may be the most limiting nutrient.

Nutritional analysis of material placed into the bogs was also carried out. Amendments were divided up into volatile fatty acids, HCl-soluble material, and sulphuric-acid-soluble materials. These are also categorized as available, easily extracted, and least extractable materials, respectively. The results were inconclusive with respect to the amount of organic carbon which had been degraded since placement.

In summary, the key components required to maintain the bogs around the VJCCP have been determined and should be incorporated into the overall decommissioning concepts for the site.

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9.0 FIGURES AND TABLES

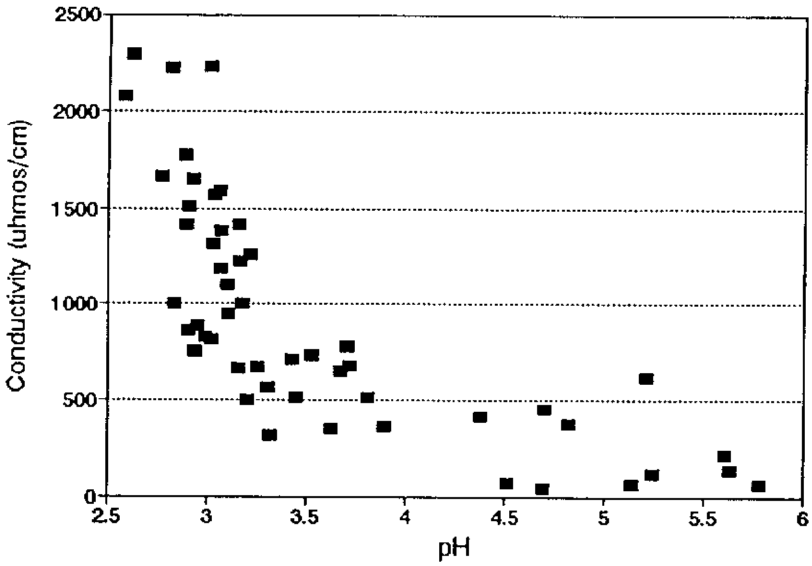


FIGURE 3.1: pH vs. conductivity for data from the Experimental Bog in 1988.

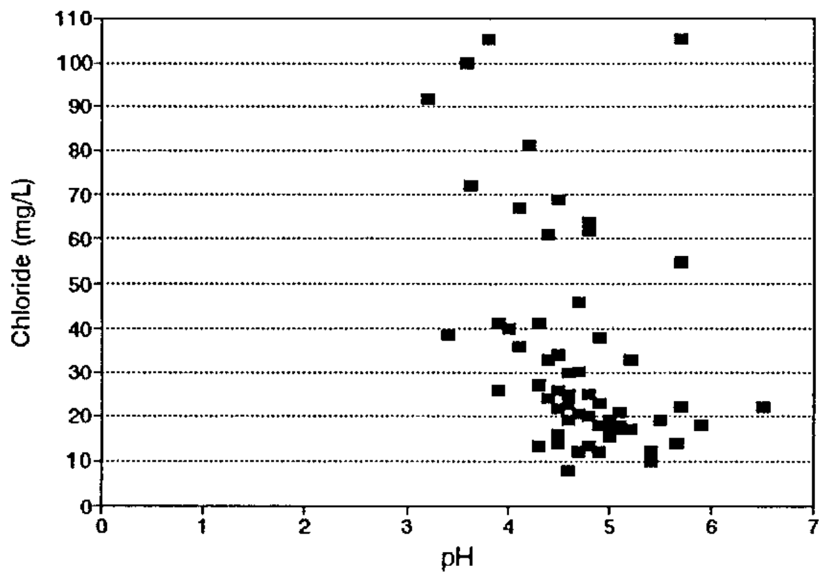


FIGURE 3.2: pH vs. chloride at station 2016.

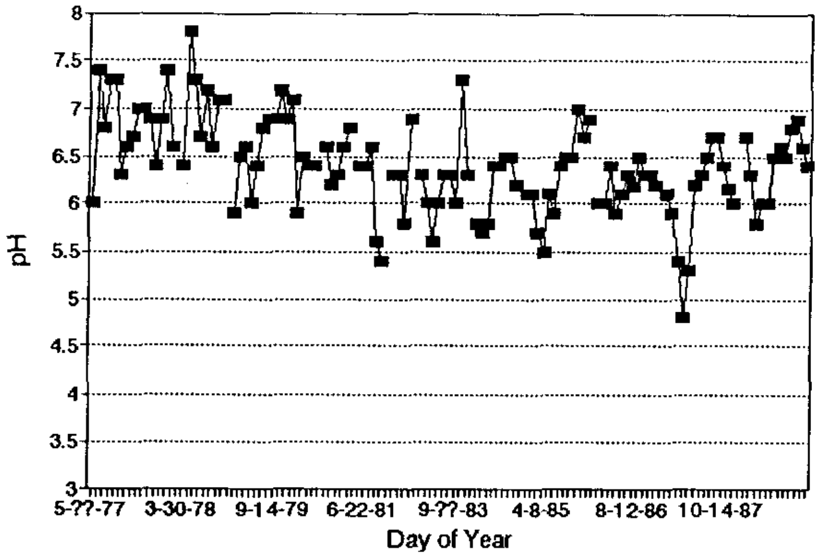


FIGURE 3.3a: pHs at station 100 (Grand Lake). Data extend from 1977 to 1988.

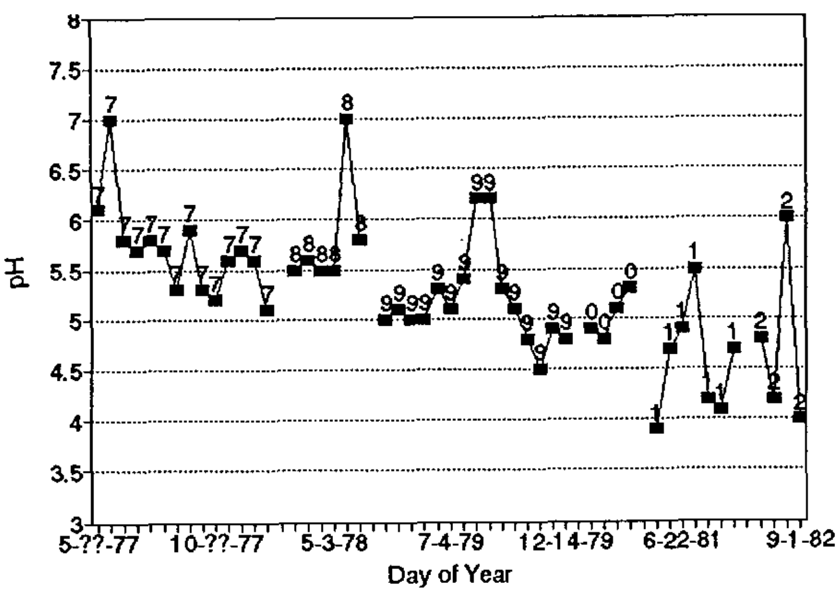


FIGURE 3.3b: pHs at station 1004 (Smith's Brook). Data extend from 1977 to 1982.

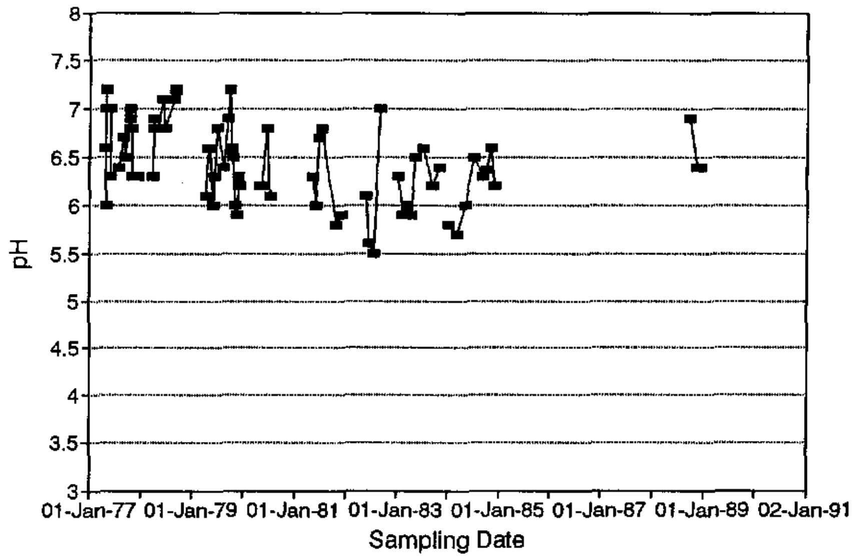


FIGURE 3.3c: pHs at station 2017 (Northest Brook). Data extend from 1981 to 1988.

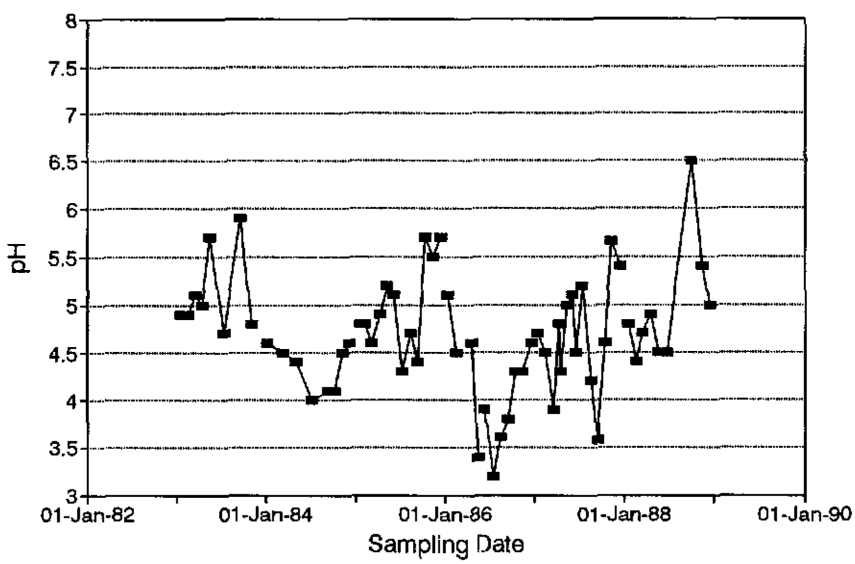


FIGURE 3.3d: pHs at station 2016 (Northwest Brook). Data extend from 1983 to 1988.

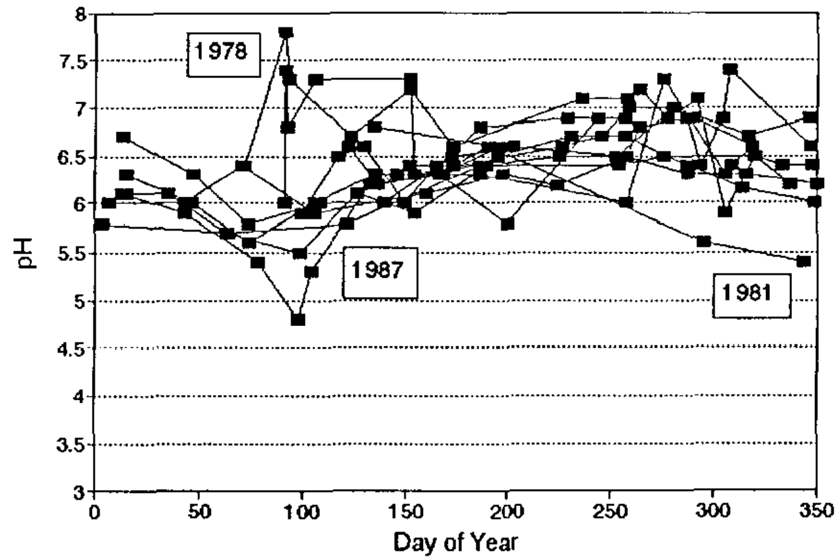


FIGURE 3.4a: Seasonal variation in pH at station 100. Outlying data points are marked with year of occurrence.

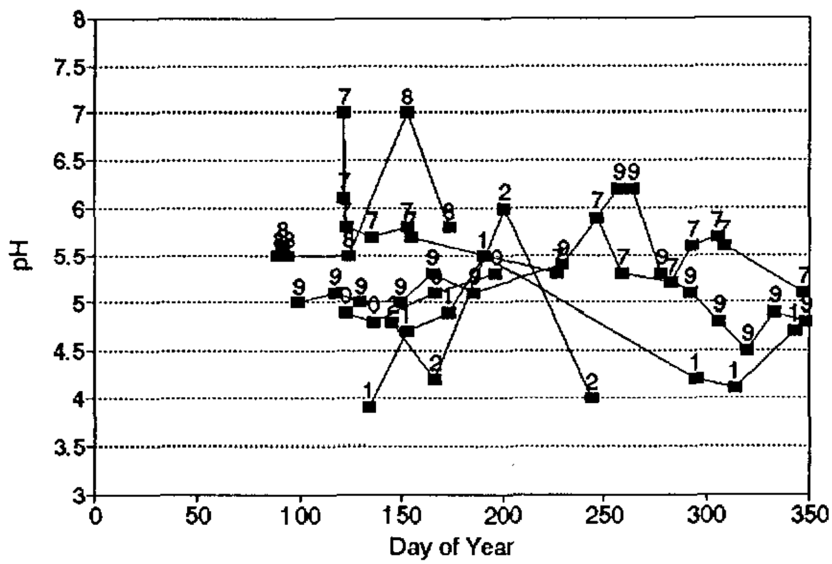


FIGURE 3.4b: Seasonal variation in pH at station 1004. Outlying data points are marked with year of occurrence.

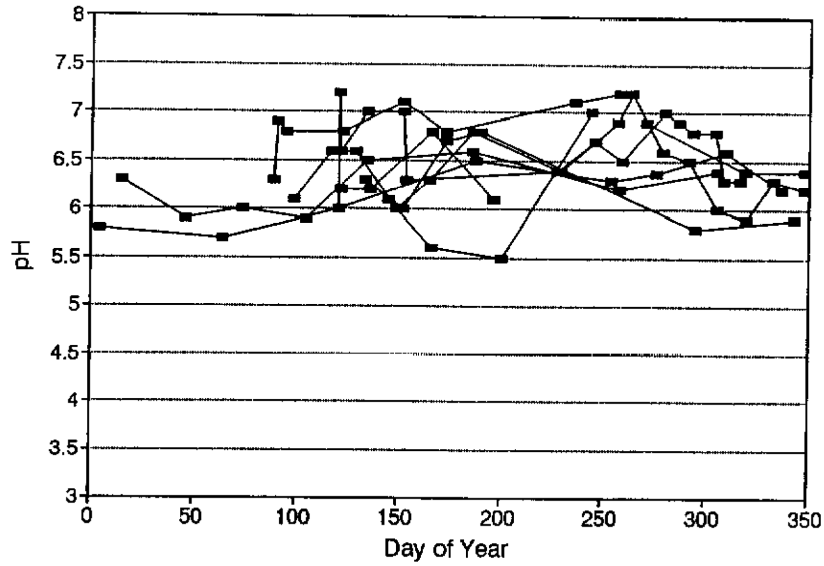


FIGURE 3.4c: Seasonal variation in pH at station 2017. Outlying data points are marked with year of occurrence.

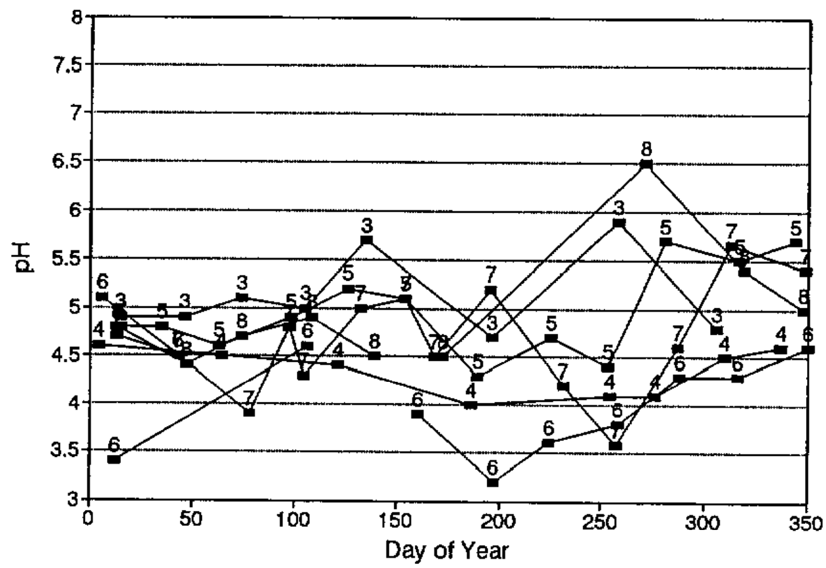


FIGURE 3.4d: Seasonal variation in pH at station 2016. Outlying data points are marked with year of occurrence.

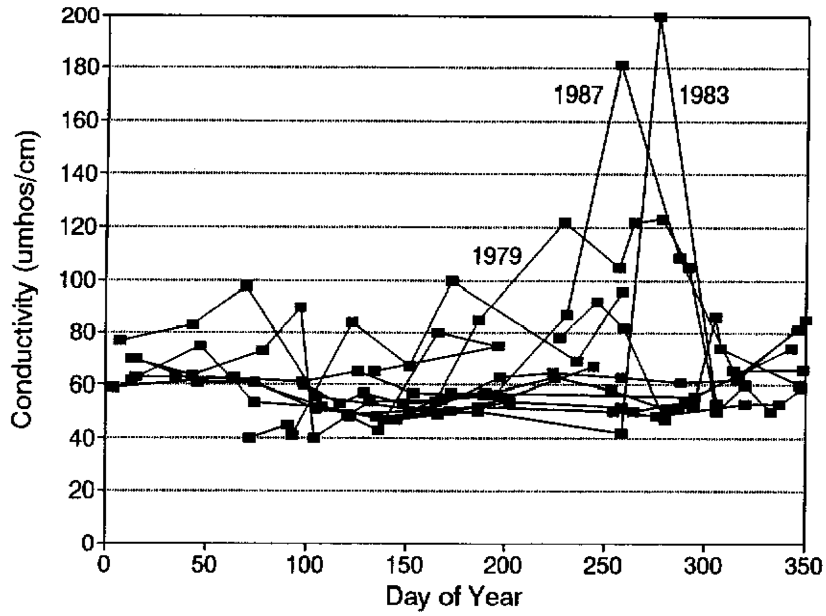


FIGURE 3.5a: Seasonal variation in conductivity at station 100. Numbers identify year of occurrence.

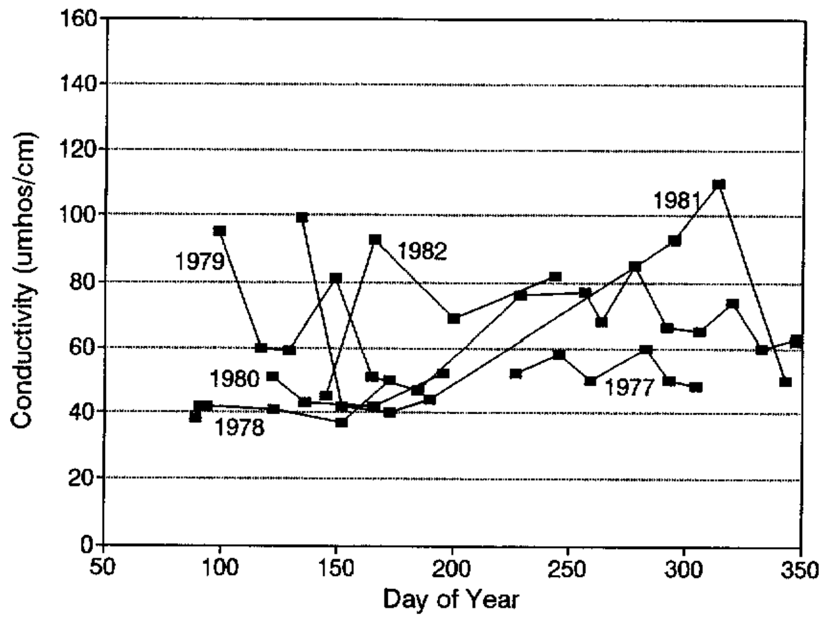


FIGURE 3.5b: Seasonal variation in conductivity at station 1004. Numbers identify year of occurrence.

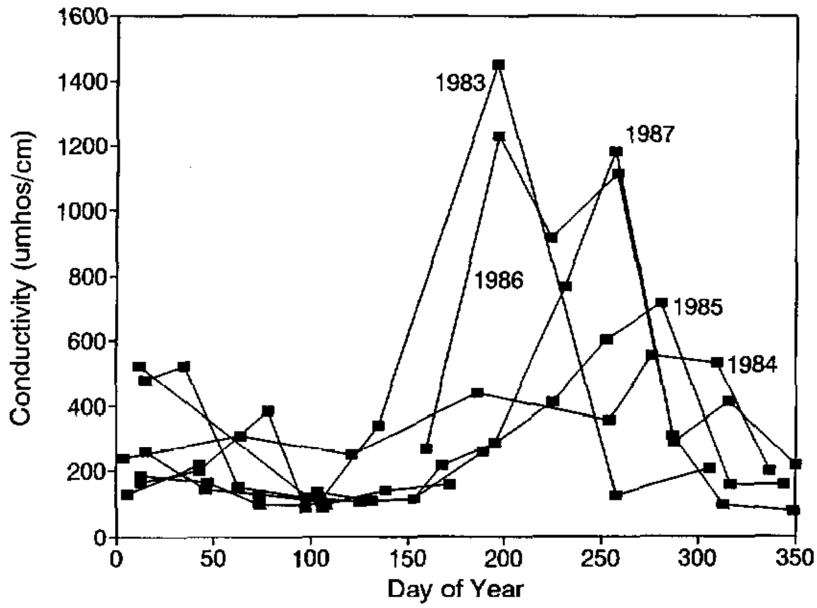


FIGURE 3.5c: Seasonal variation in conductivity at station 2016. Numbers identify year of occurrence.

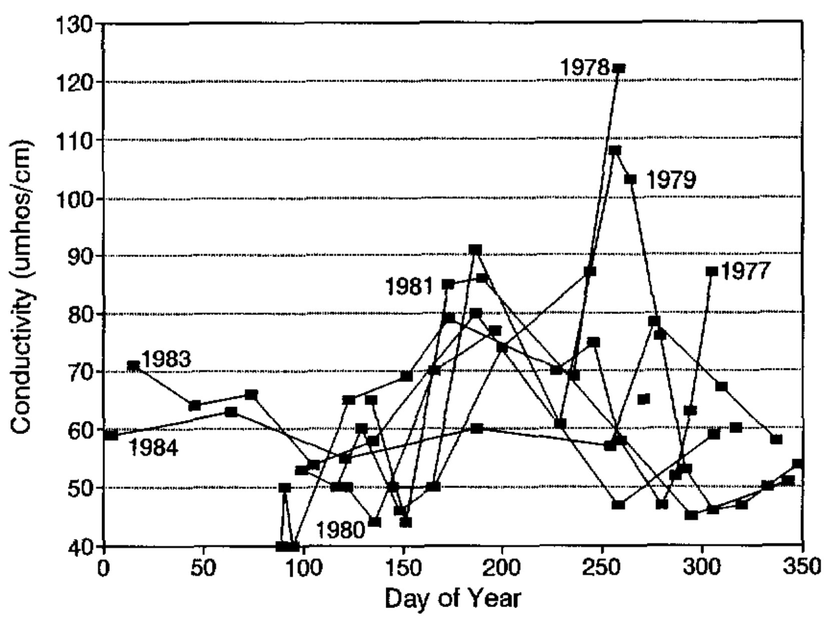


FIGURE 3.5d: Seasonal variation in conductivity at station 2017. Numbers identify year of occurrence.

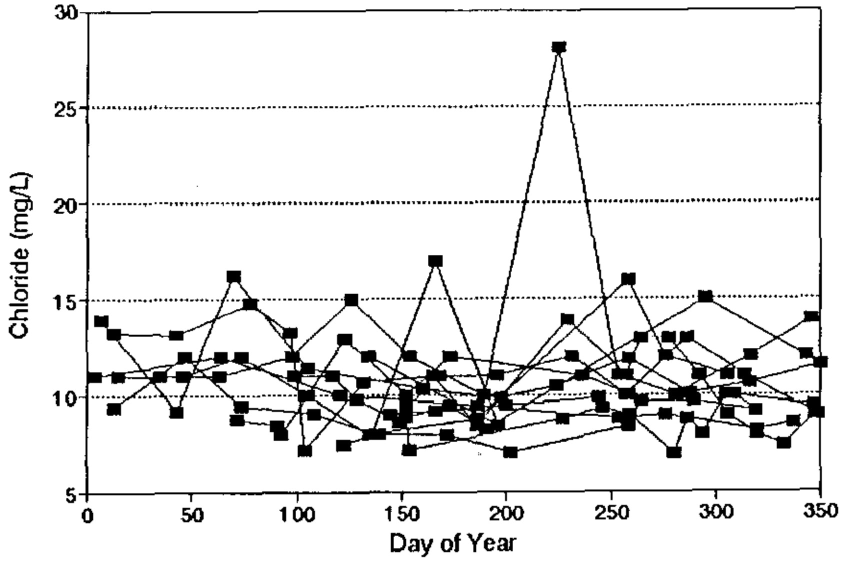


FIGURE 3.6a: Seasonal variation in chloride concentrations at station 100.

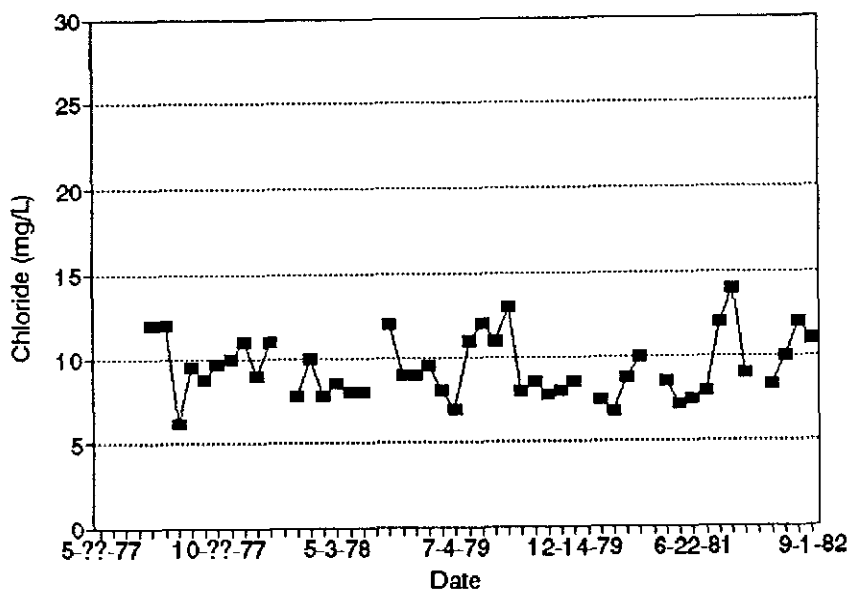


FIGURE 3.6b: Seasonal variation in chloride concentrations at station 1004.

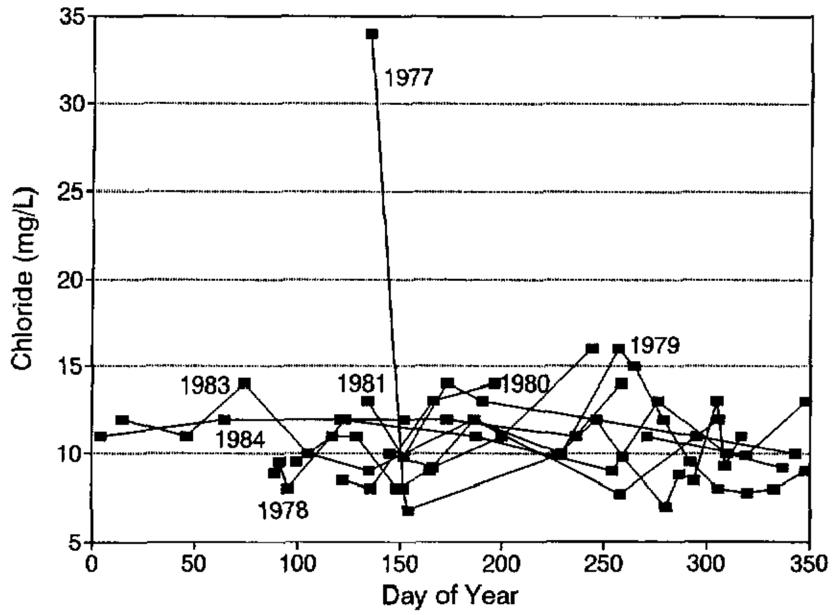


FIGURE 3.6c: Seasonal variation in chloride concentrations at station 2017. Numbers identify year of occurrence.

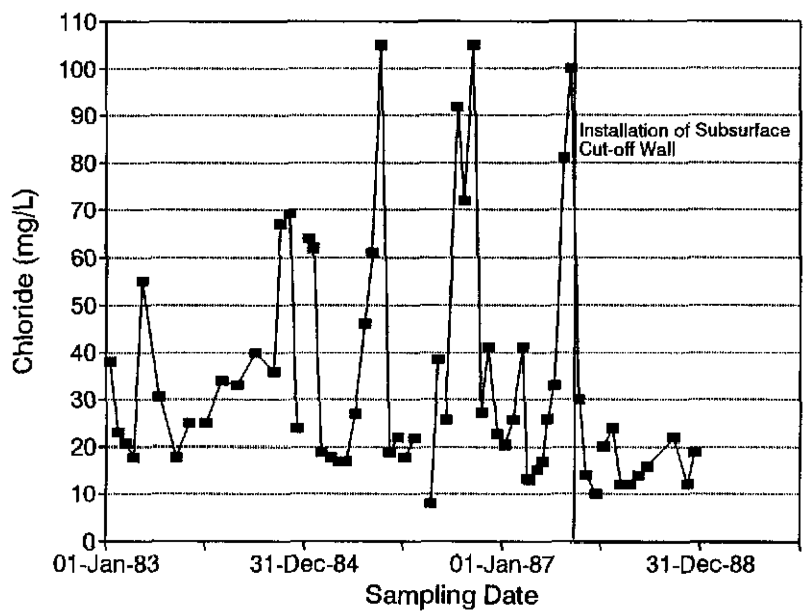


FIGURE 3.6d: Historical chloride concentrations at station 2016, from 1983 to 1990. Note significant summer drop since 1988.

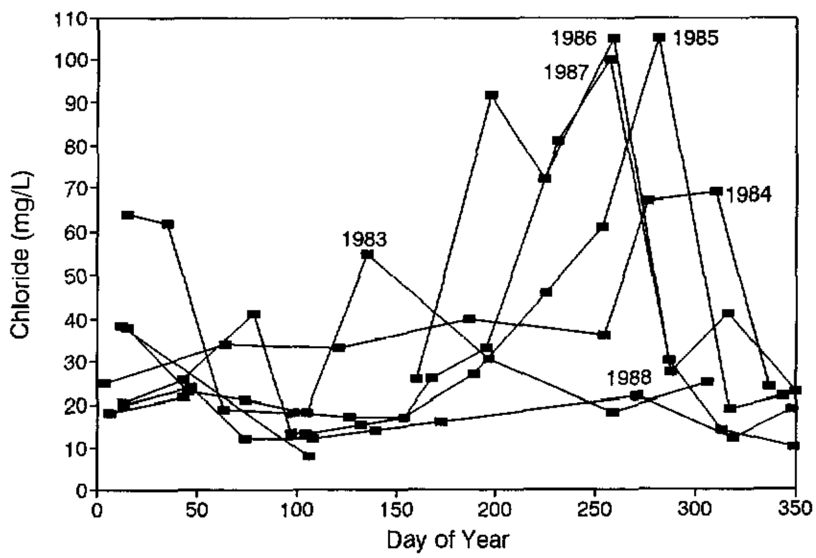


FIGURE 3.6e: Seasonal variation in chloride concentrations at station 2016. Numbers indicate year of sampling. Note significant summer rise in concentration.

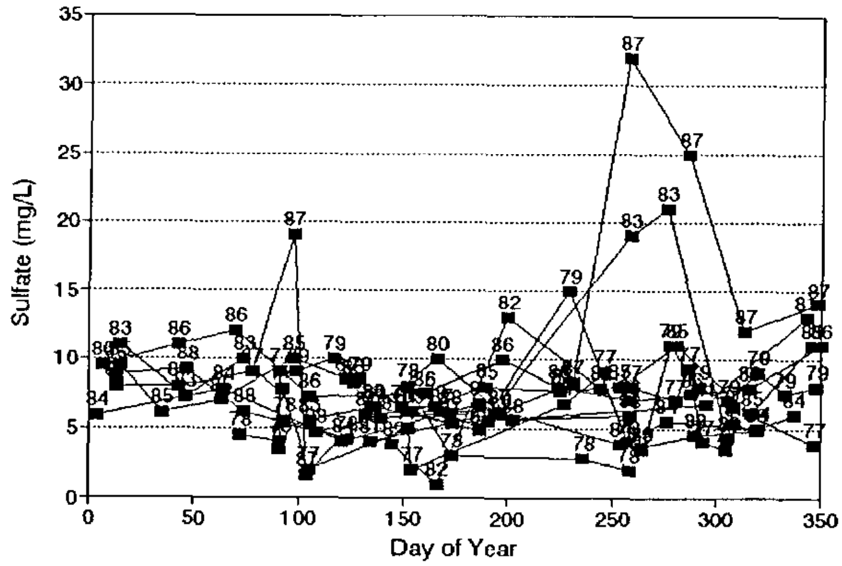


FIGURE 3.7a: Seasonal variation in sulfate concentrations at station 100. Numbers indicate year of sampling.

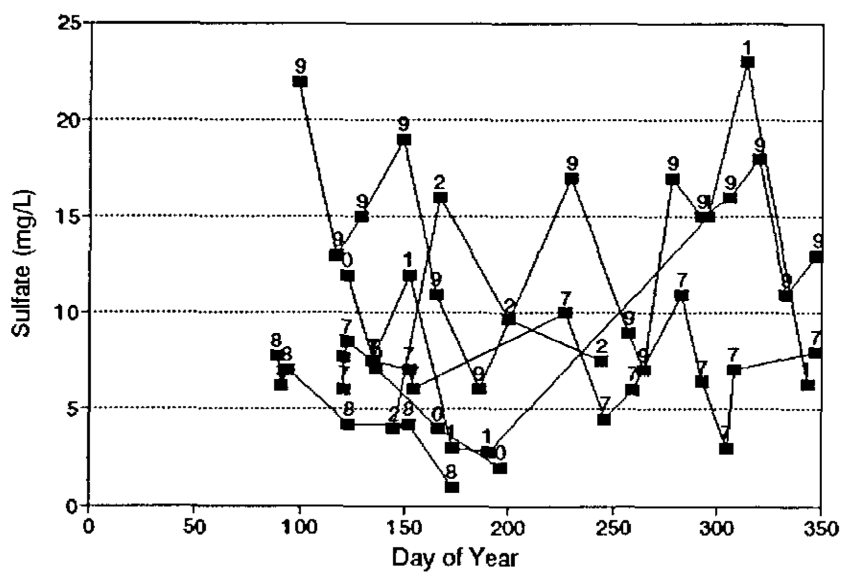


FIGURE 3.7b: Seasonal variation in sulfate concentrations at station 1004. Numbers indicate year of sampling.

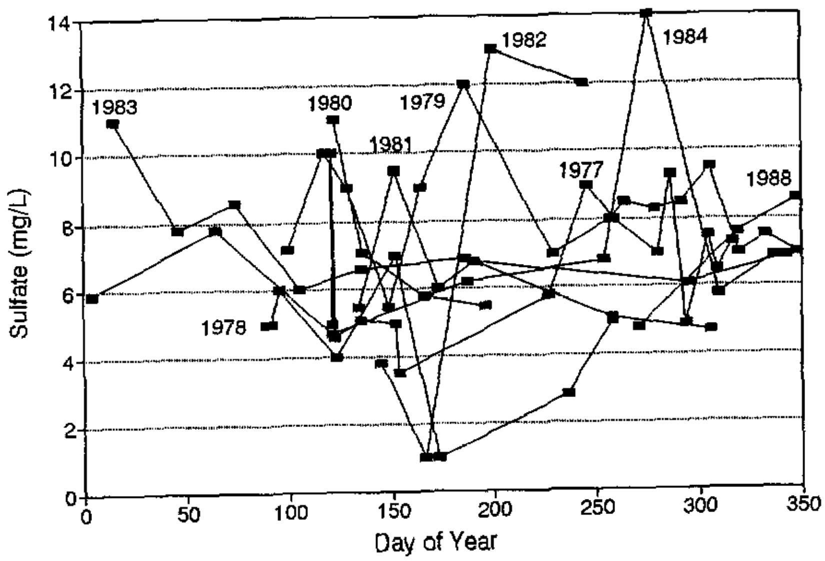


FIGURE 3.7c: Seasonal variation in sulfate concentrations at station 2017. Numbers indicate year of sampling.

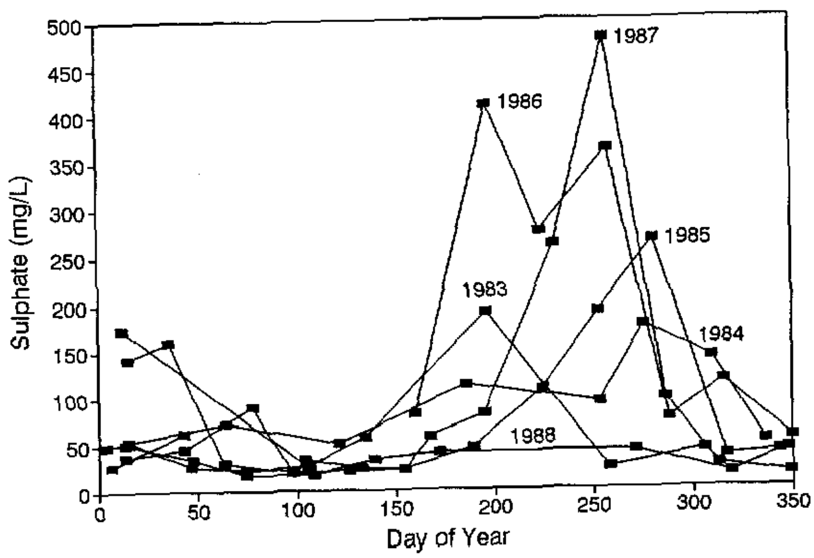


FIGURE 3.7d: Historical sulfate concentrations at station 2016. Data extend from 1983 to 1990.

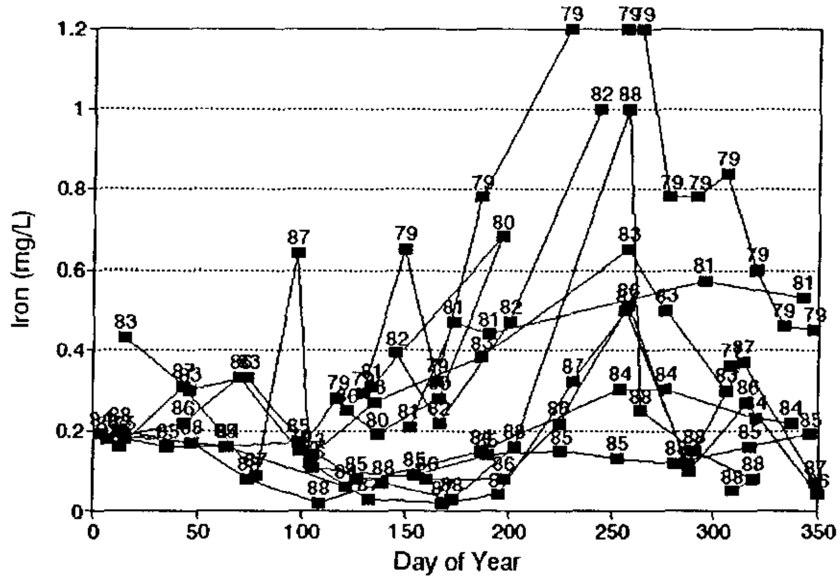


FIGURE 3.8a: Seasonal variation in iron concentrations at station 100. Numbers indicate year of sampling.

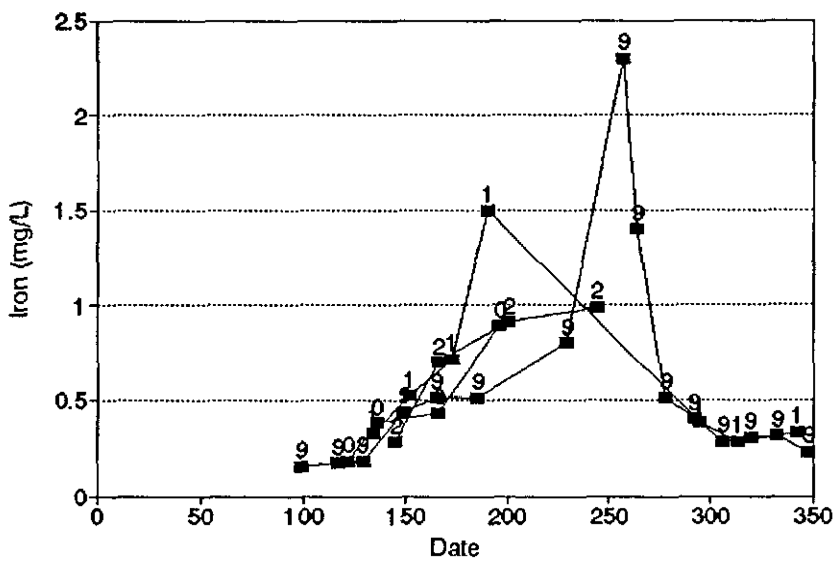


FIGURE 3.8b: Seasonal variation in iron concentrations at station 1004. Numbers indicate year of sampling.

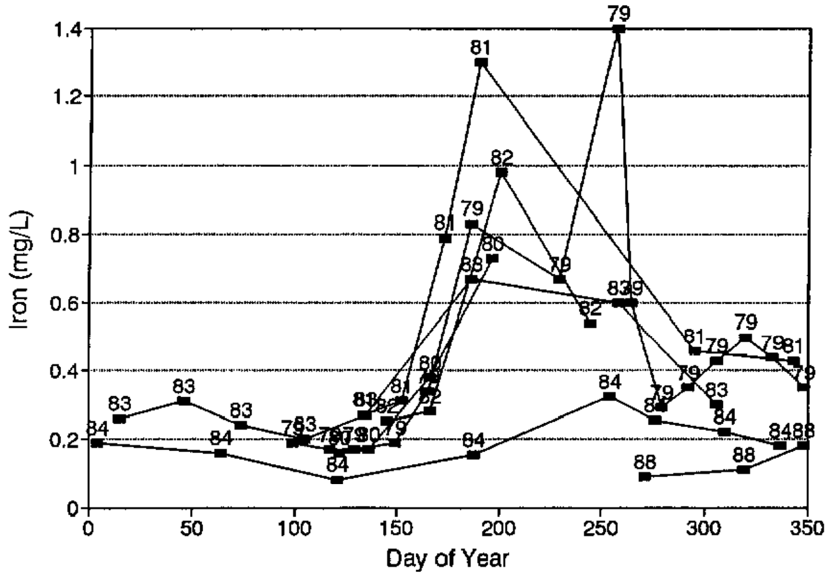


FIGURE 3.8c: Seasonal variation in iron concentrations at station 2017. Numbers indicate year of sampling.

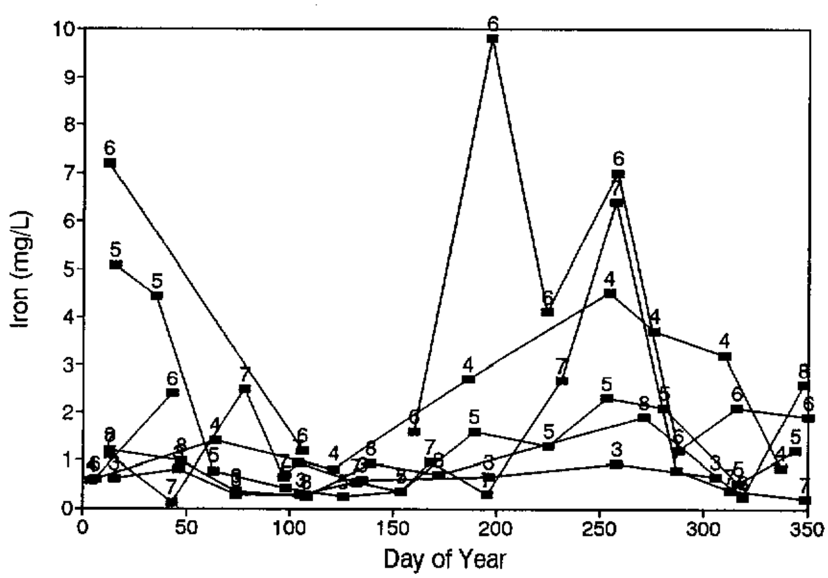


FIGURE 3.8d: Seasonal variation in iron concentrations at station 2016. Numbers indicate year of sampling.

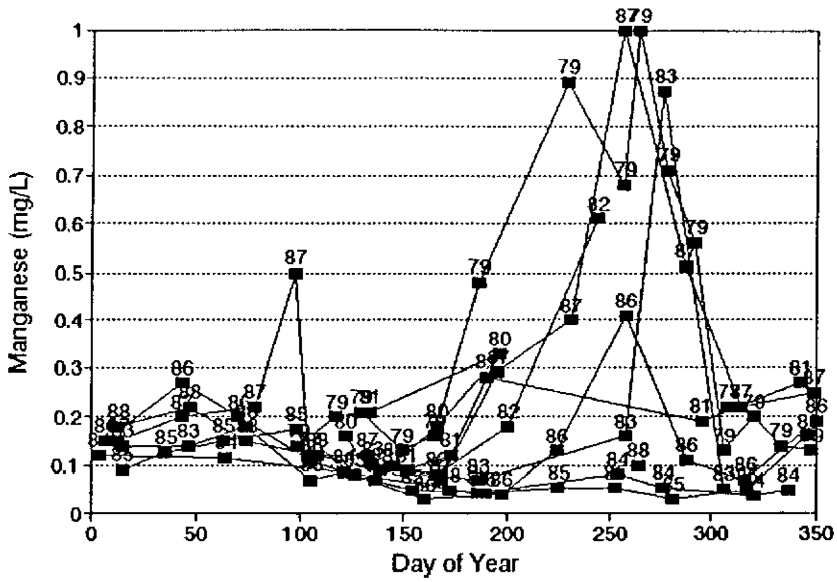


FIGURE 3.9a: Seasonal variation in manganese concentrations at station 100. Numbers indicate year of sampling.

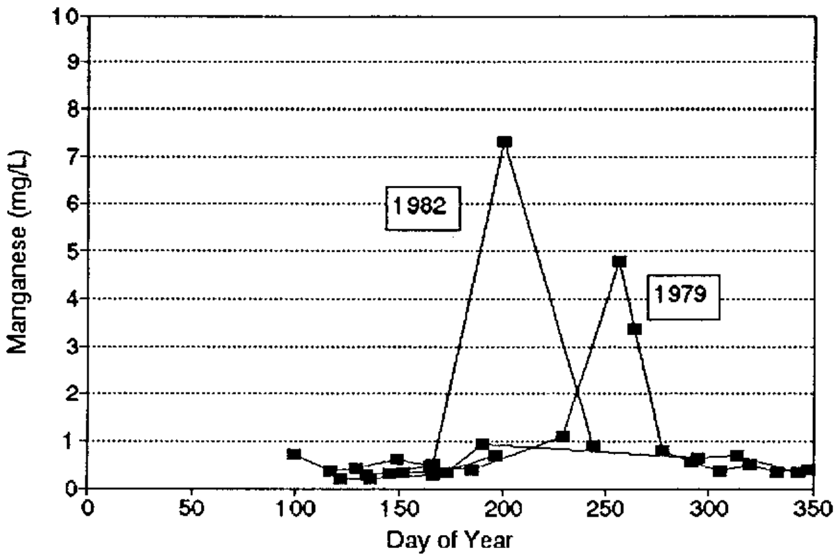


FIGURE 3.9b: Seasonal variation in manganese concentrations at station 1004. Outlying years are identified.

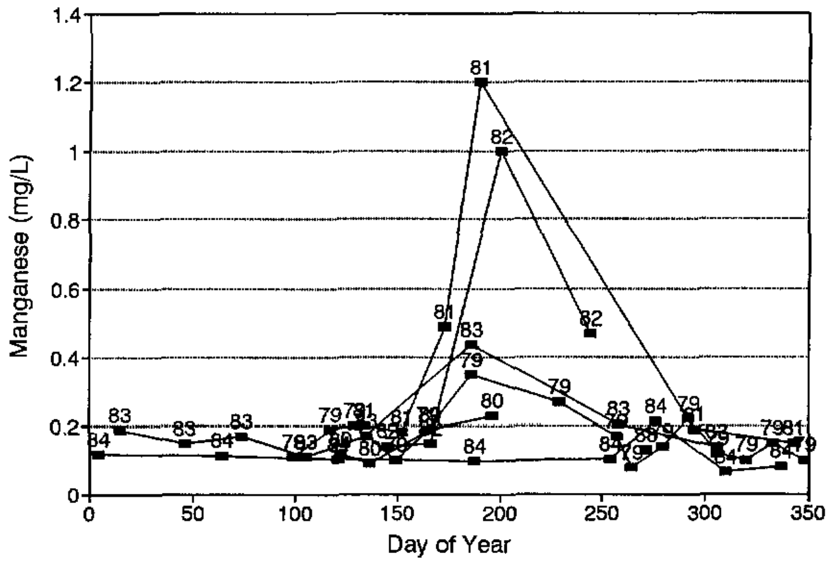


FIGURE 3.9c: Seasonal variation in manganese concentrations at station 2017. Numbers indicate year of sampling.

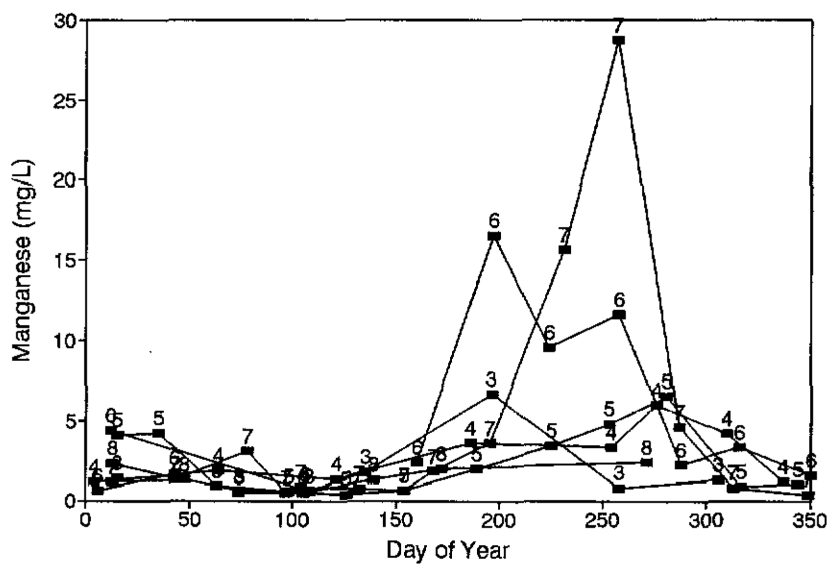


FIGURE 3.9d: Seasonal variation in manganese concentrations at station 2016. Numbers indicate year of sampling.

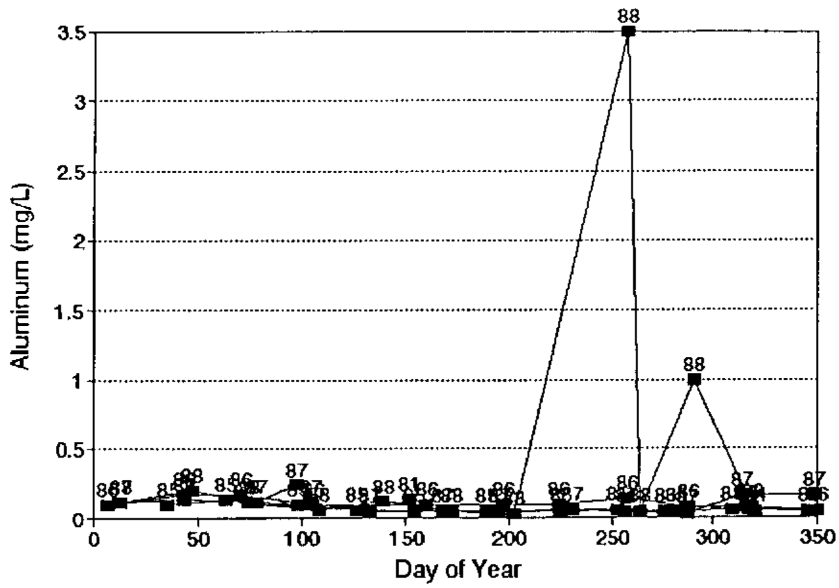


FIGURE 3.10a: Seasonal variation in aluminum concentrations at station 100. Numbers indicate the year of sampling.

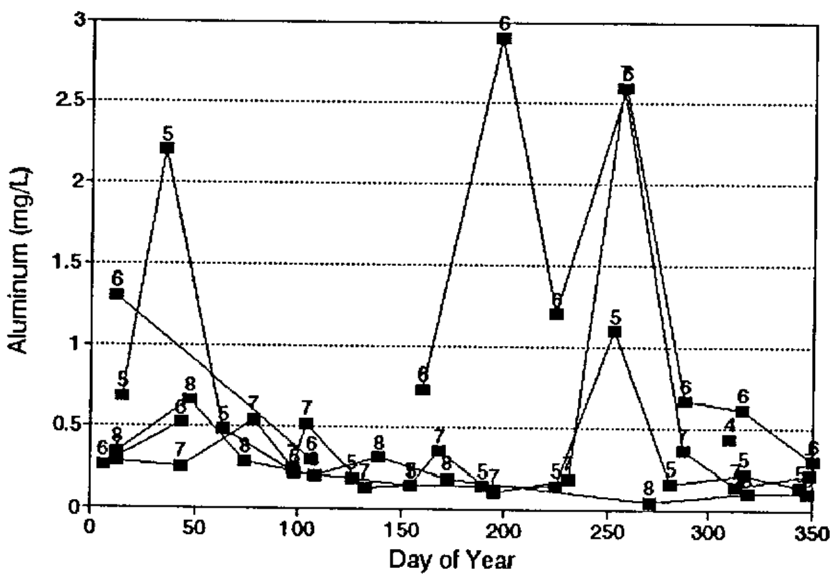


FIGURE 3.10b: Seasonal variation in aluminum concentrations at station 2016. Numbers indicate the year of sampling.

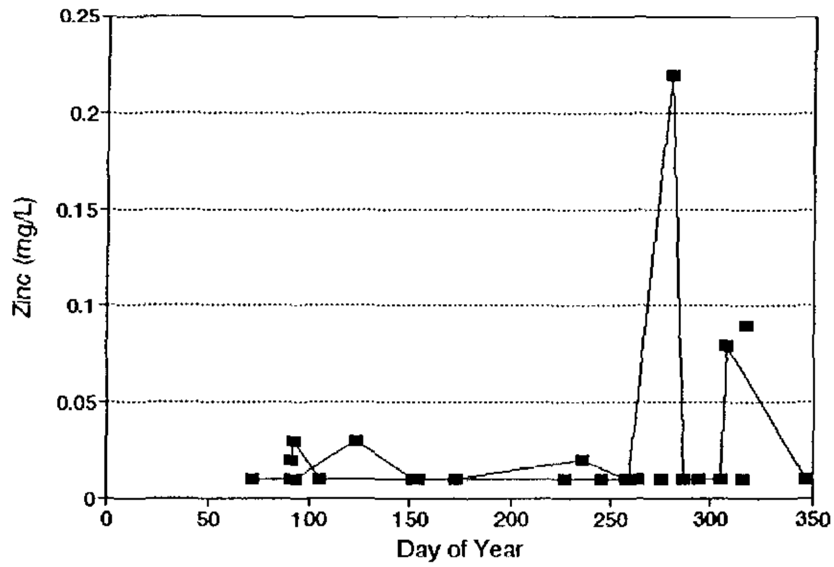


FIGURE 3.11a: Seasonal variation in zinc concentrations at station 100.

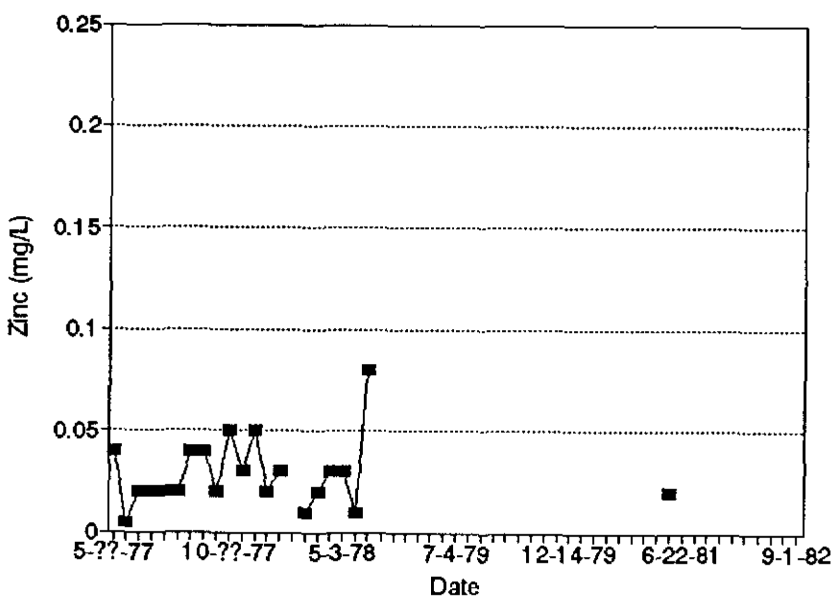


FIGURE 3.11b: Historical sulfate concentrations at station 1004. Data from 1977 to 1982.

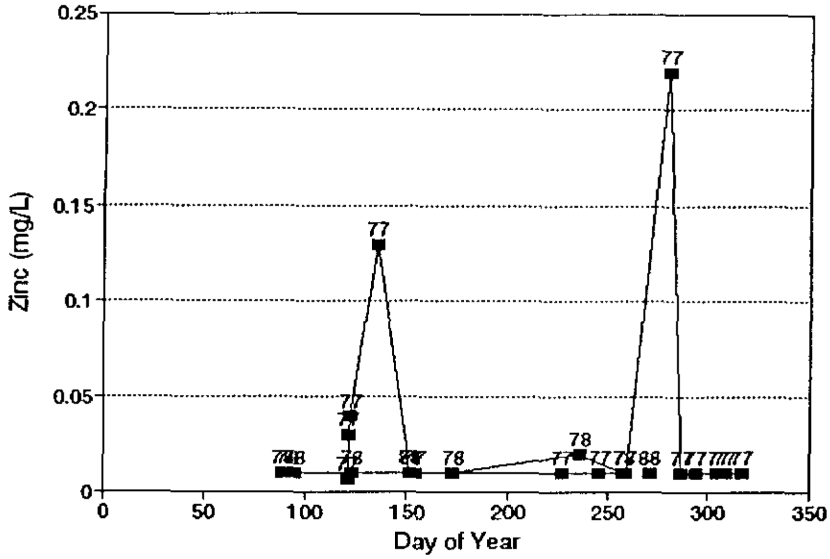


FIGURE 3.11c: Seasonal variation in zinc concentrations at station 2017. Numbers indicate the year of sampling.

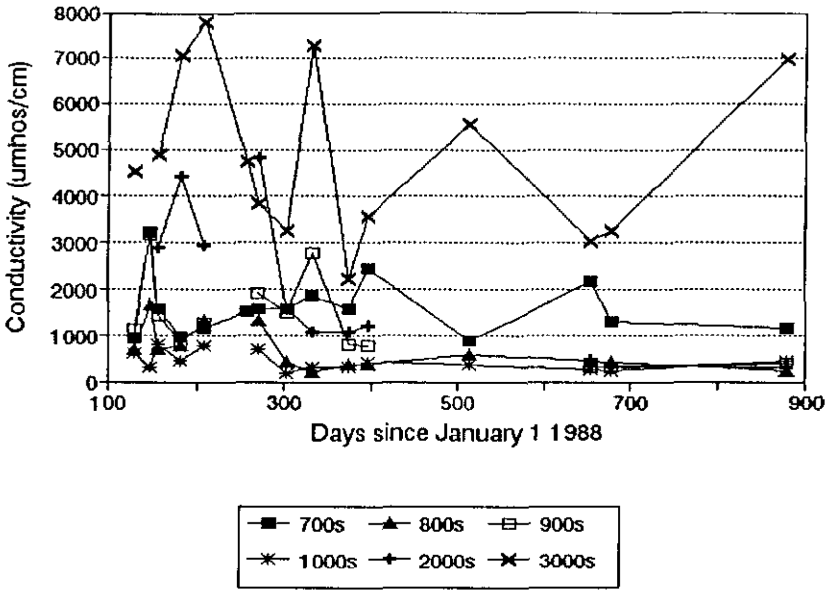


FIGURE 4.1: Mean water conductivities for each group of monitoring stations. Data from Table 4.1.

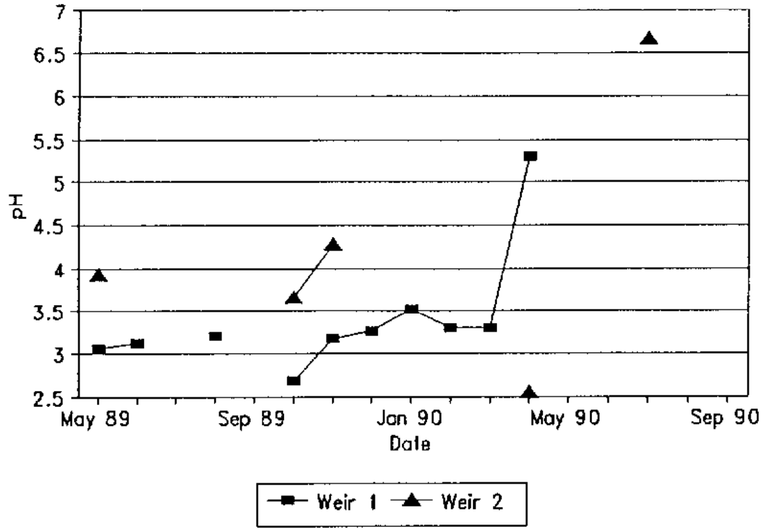


FIGURE 4.2a: Historical pH values at weirs 1 and 2 near the LBC.

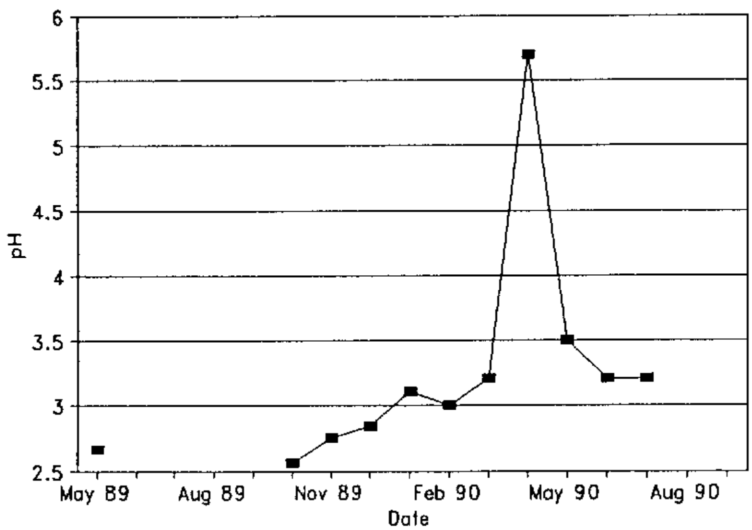


FIGURE 4.2b: Historical pH values at weir 3 near the LBC.

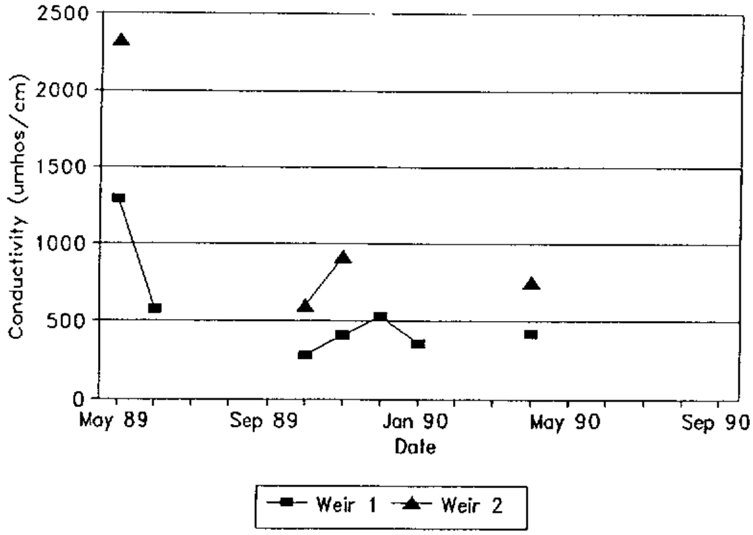


FIGURE 4.3a: Historical conductivity levels at weirs 1 and 2 near the LBC.

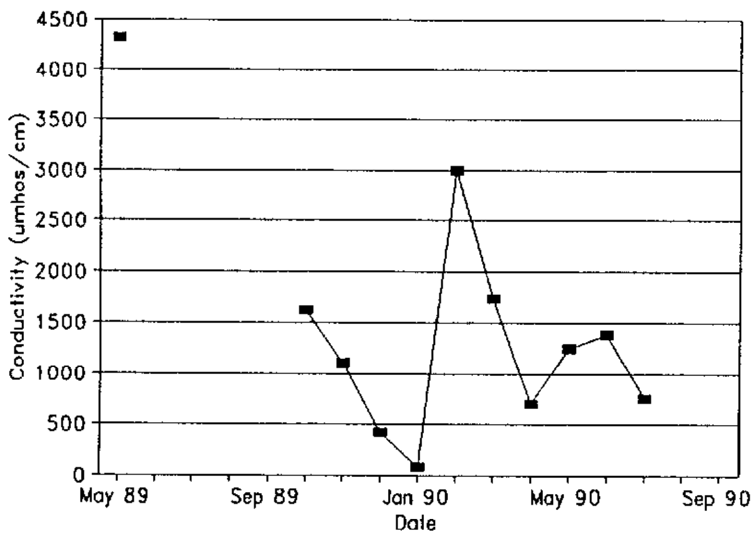


FIGURE 4.3b: Historical conducitivity levels at weir 3 near the LBC.

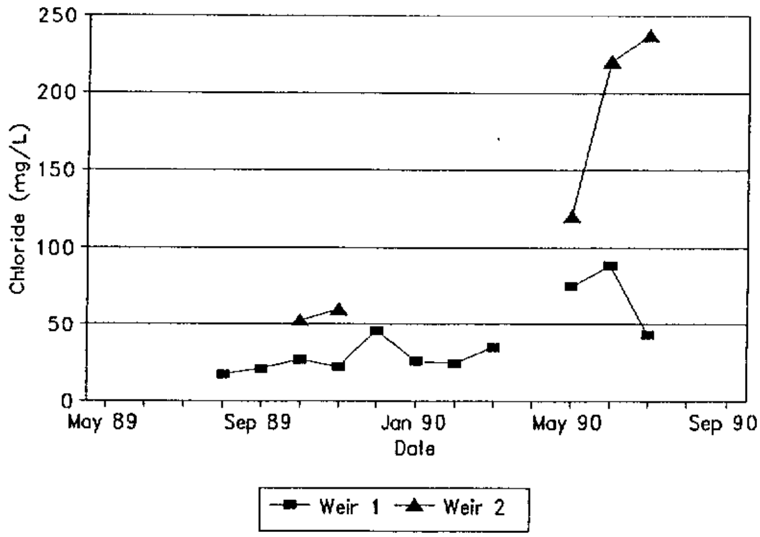


FIGURE 4.4a: Historical chloride concentrations at weirs 1 and 2 near the LBC.

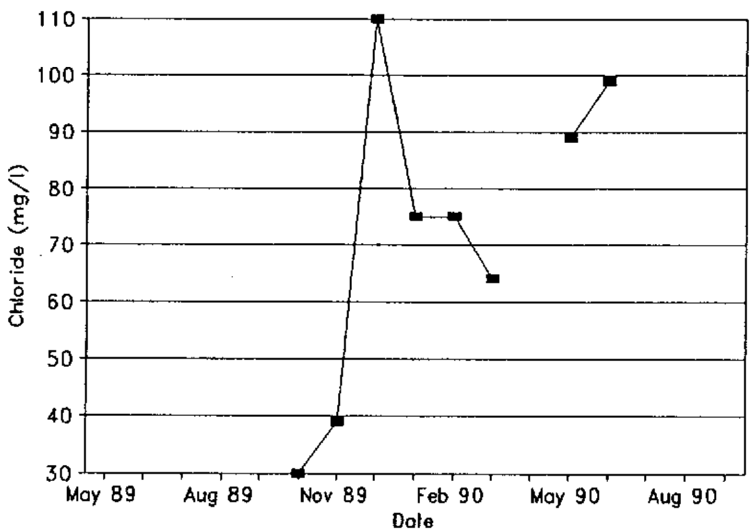


FIGURE 4.4b: Historical chloride concentrations at weir 3 near the LBC.

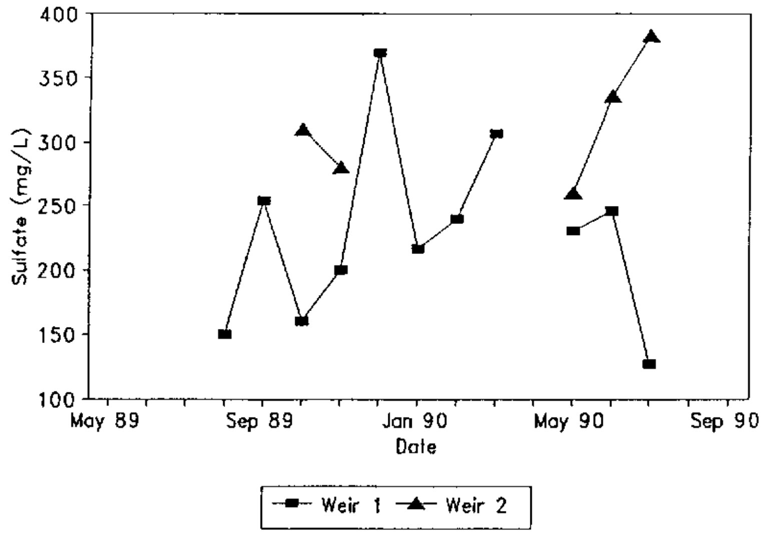


FIGURE 4.5a: Historical sulfate concentrations at weirs 1 and 2 near the LBC.

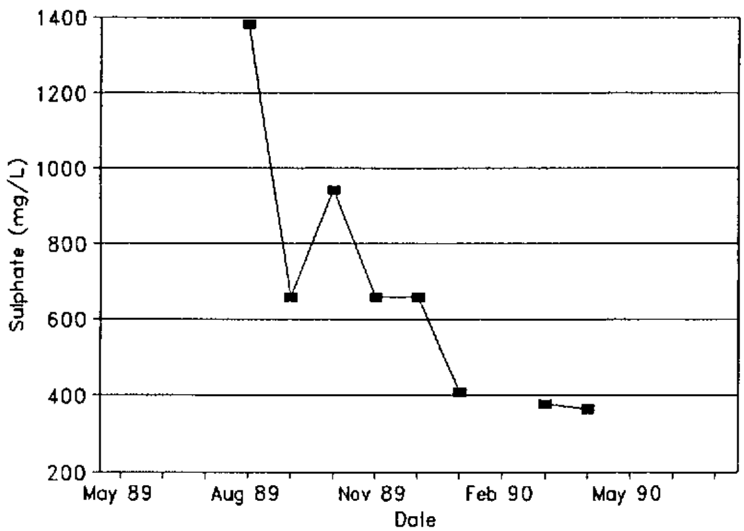


FIGURE 4.5b: Historical sulfate concentrations at weir 3 near the LBC.

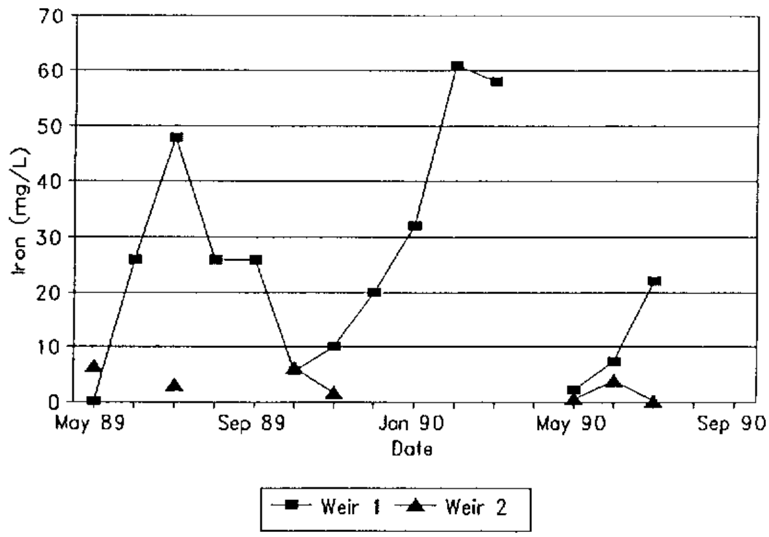


FIGURE 4.6a: Historical iron concentrations at weirs 1 and 2 near the LBC.

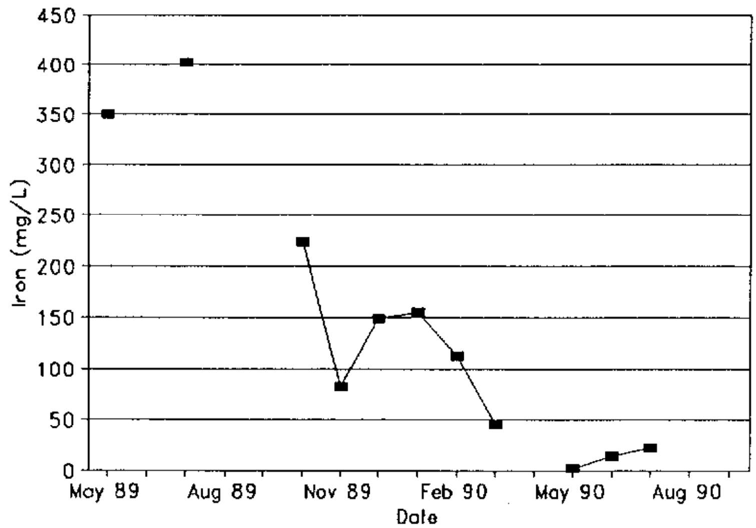


FIGURE 4.6b: Historical iron concentrations at weir 3 near the LBC.

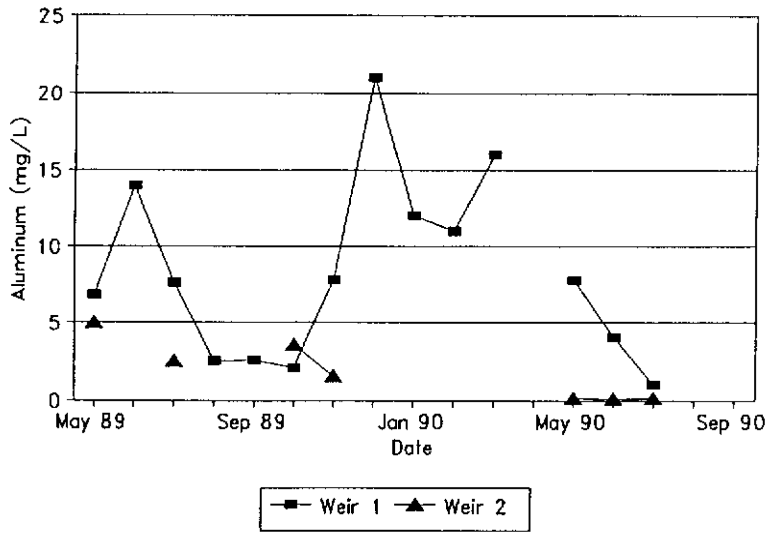


FIGURE 4.7a: Historical aluminum concentrations at weirs 1 and 2 near the LBC.

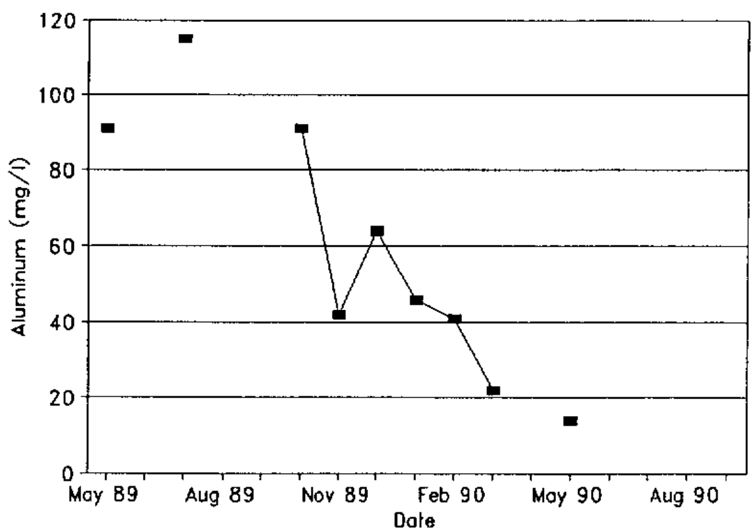


FIGURE 4.7b: Historical aluminum concentrations at weir 3 near the LBC.

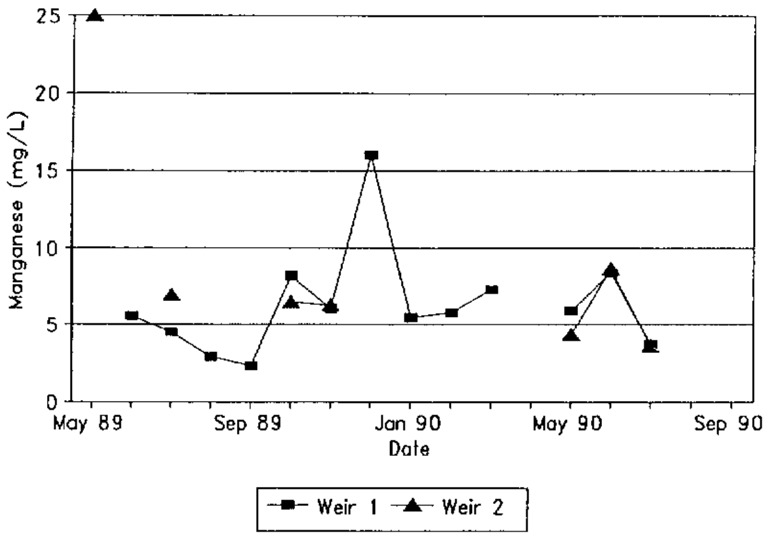


FIGURE 4.8a: Historical manganese concentrations at weirs 1 and 2 near the LBC.

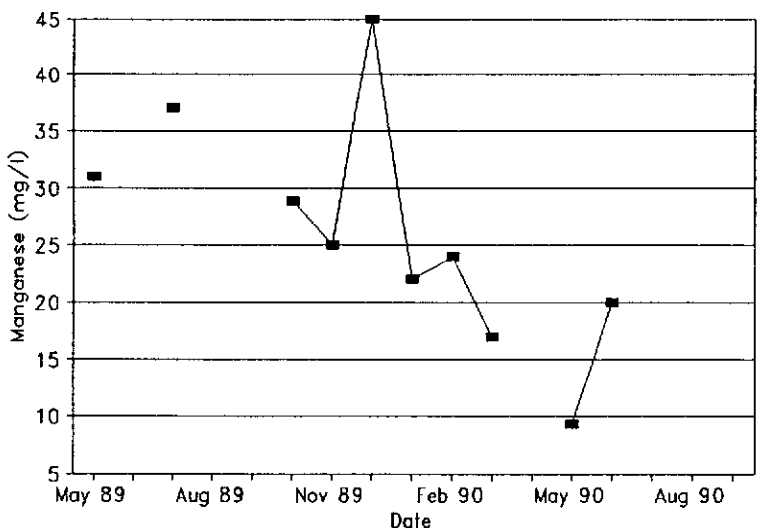


FIGURE 4.8b: Historical manganese concentrations at weir 3 near the LBC.

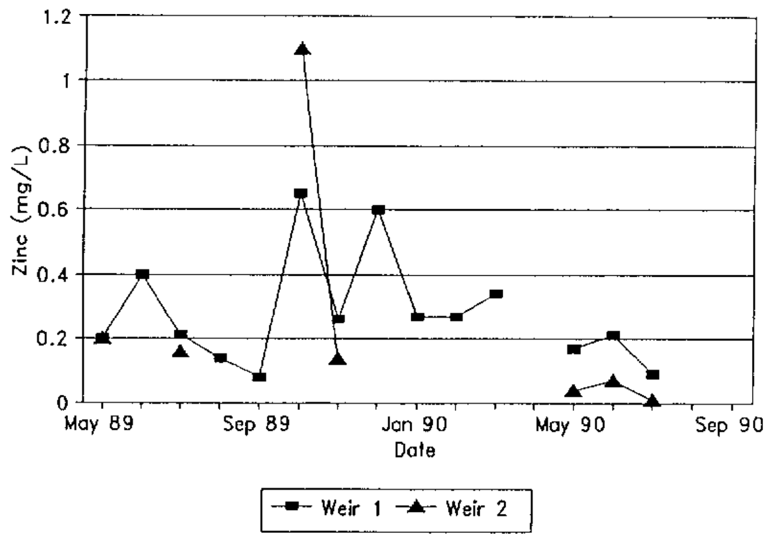


FIGURE 4.9a: Historical zinc concentrations at weirs 1 and 2 near the LBC.

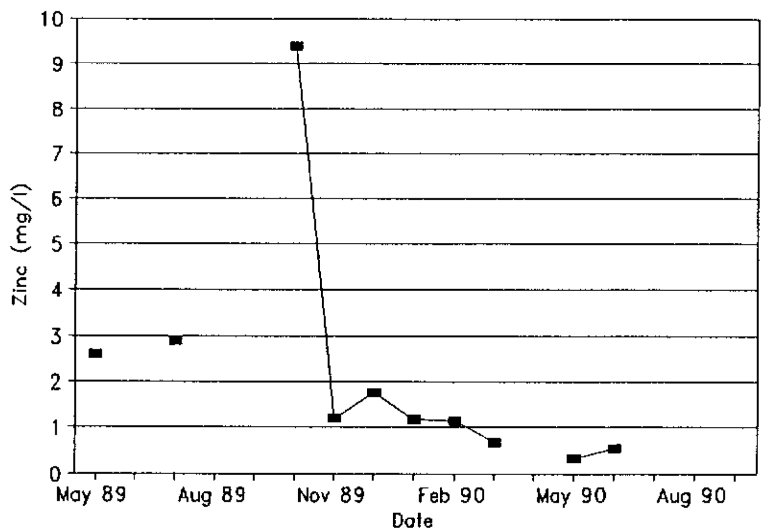


FIGURE 4.9b: Historical zinc concentrations at weir 3 near the LBC.

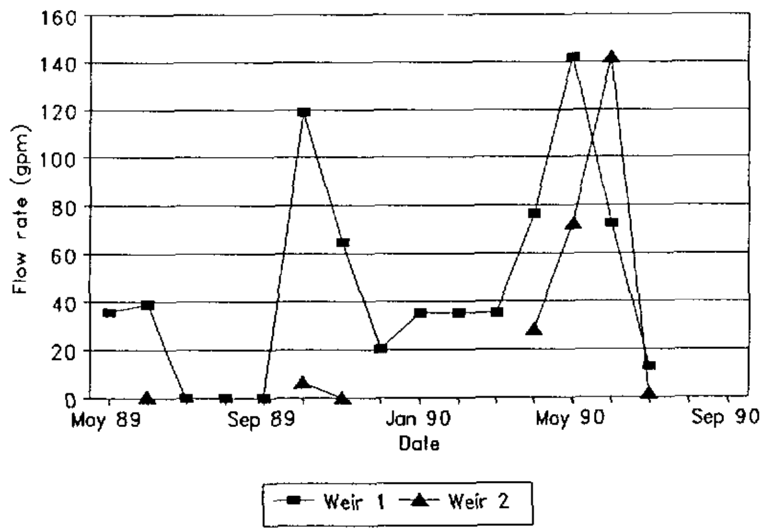


FIGURE 4.10a: Flow rates at weirs 1 and 2 near the LBC.

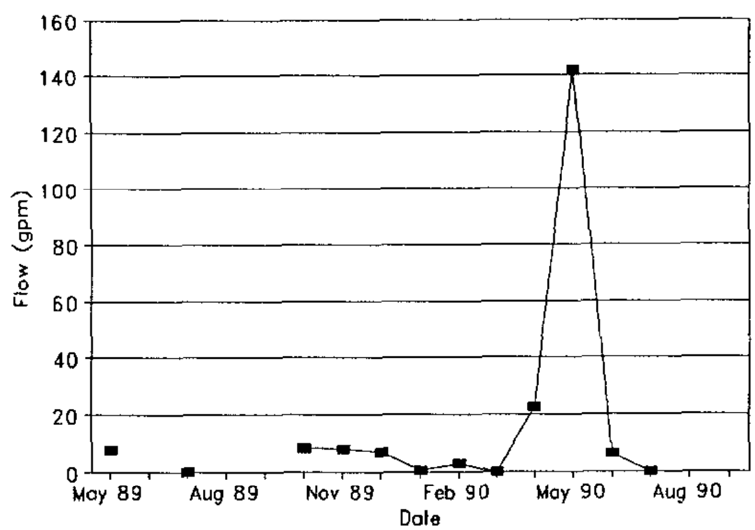


FIGURE 4.10b: Flow rates at weir 3 near the LBC.

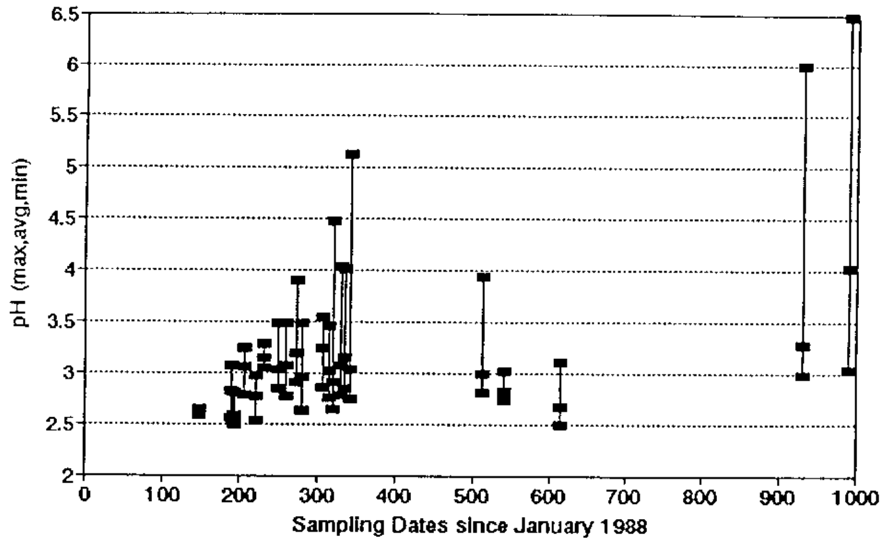


FIGURE 4.11a: Historical pHs at the Experimental Bog. High, low and logarithmic mean of pHs are shown for each sampling date. Data are summarized from the eastern statistical section.

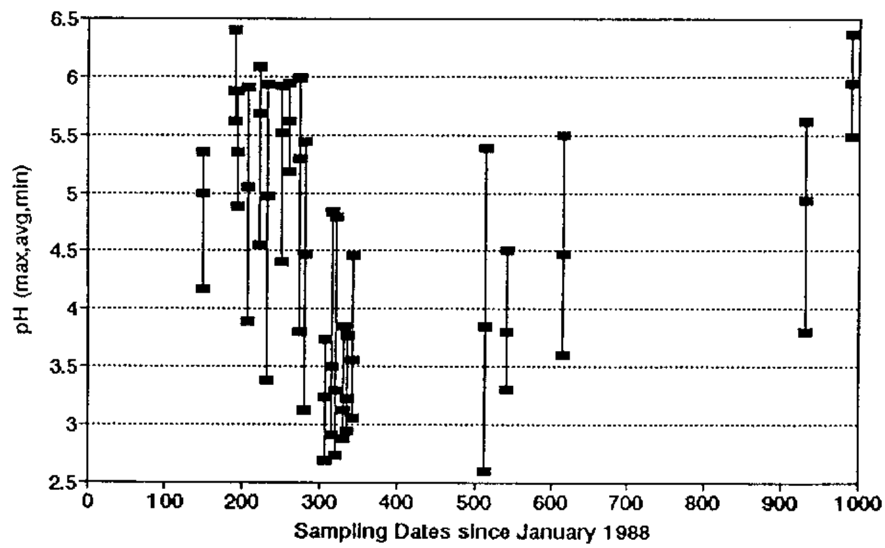


FIGURE 4.11b: Historical pHs at the Experimental Bog. High, low and logarithmic mean of pHs are shown for each sampling date. Data are summarized from the southern statistical section.

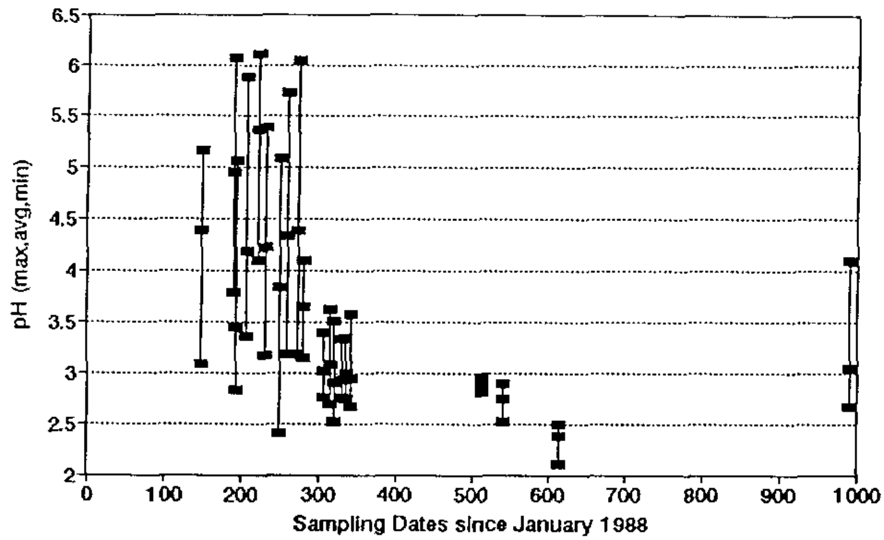


FIGURE 4.11c: Historical pHs at the Experimental Bog. High, low and logarithmic mean of pHs are shown for each sampling date. Data are summarized from the western statistical section.

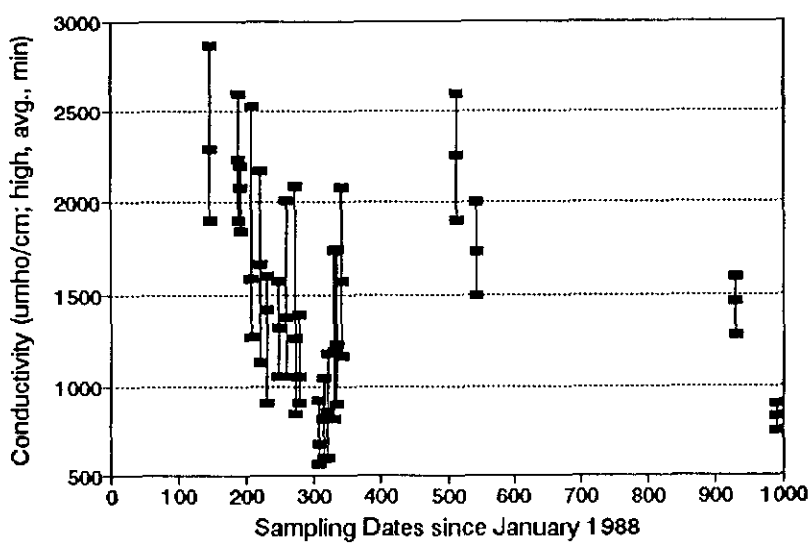


FIGURE 4.12a: Historical conductivities at the Experimental Bog. High, low and mean are shown for each sampling date. Data are summarized from the eastern statistical section.

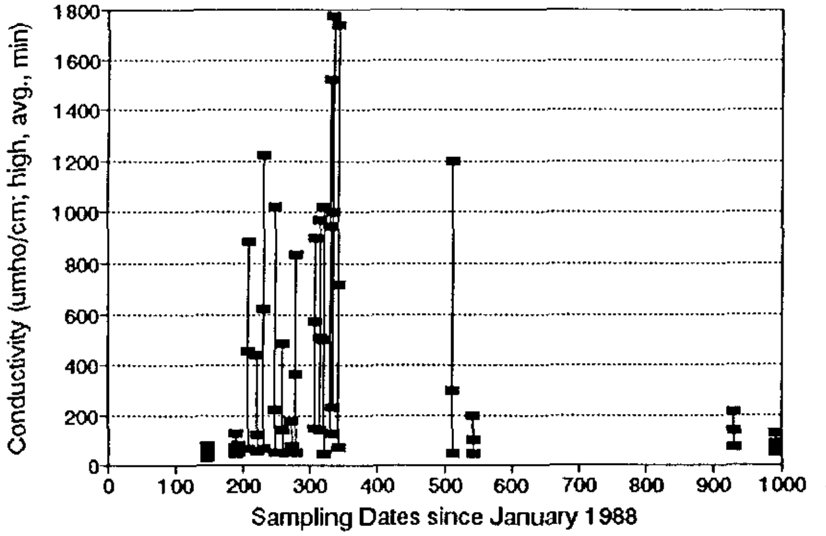


FIGURE 4.12b: Historical conductivities at the Experimental Bog. High, low and mean are shown for each sampling date. Data are summarized from the southern statistical section.

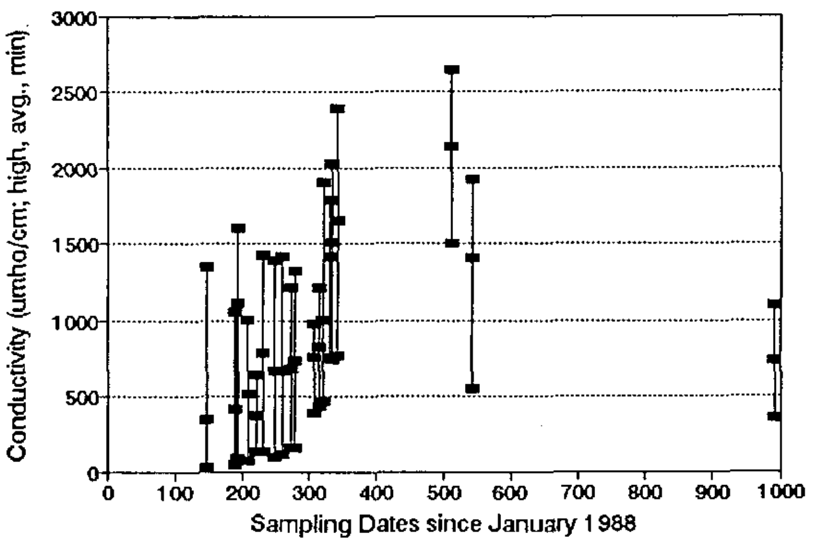
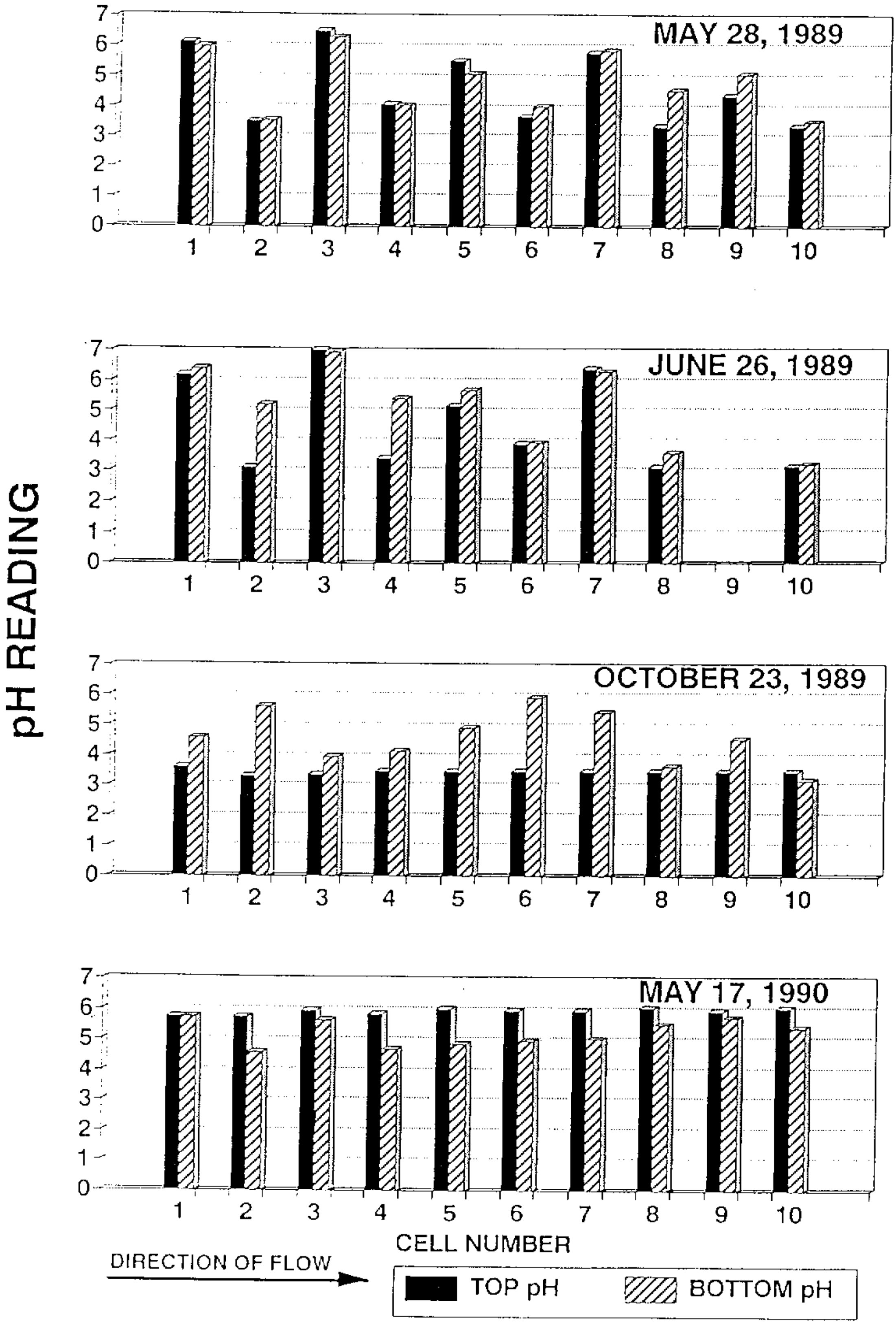


FIGURE 4.12c: Historical conductivities at the Experimental Bog. High, low and mean are shown for each sampling date. Data are summarized from the western statistical section.

FIGURE 4.13: pH readings in the test cells from both surface and root zone.



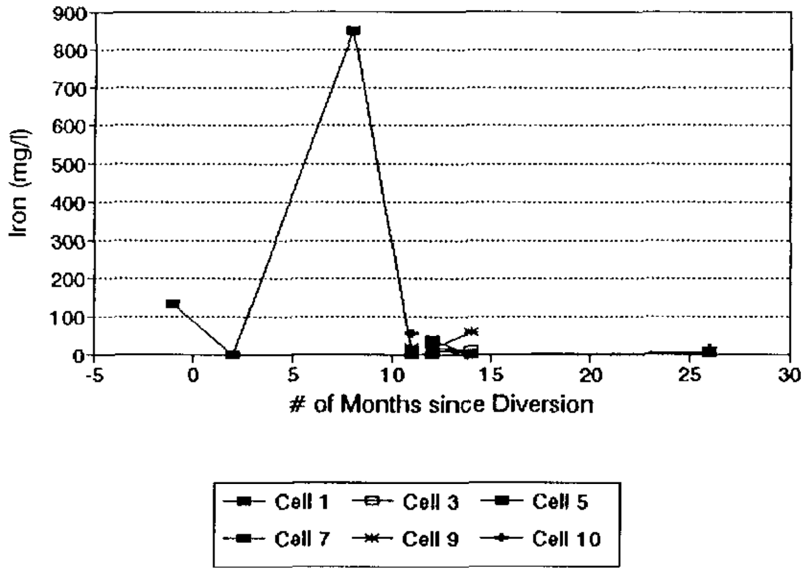


FIGURE 4.14a: Historical variation in iron concentrations sampled from different test cells.

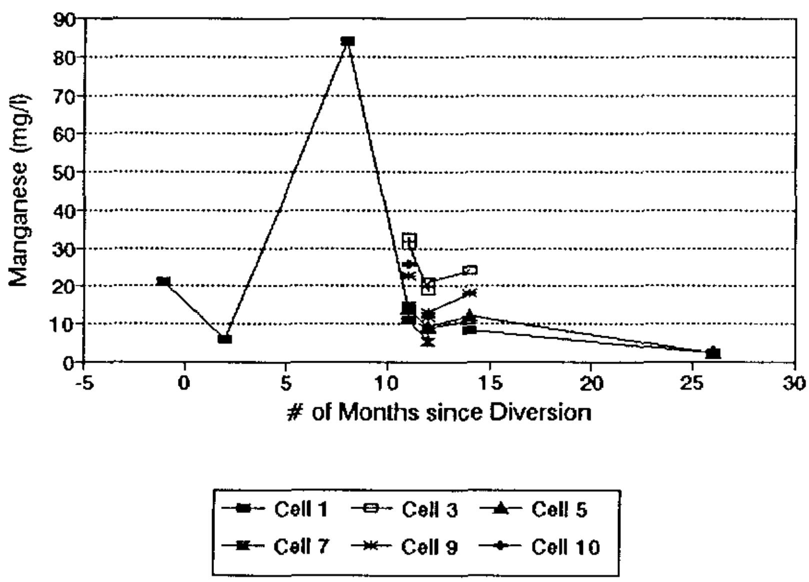


FIGURE 4.14b: Historical variation in manganese concentrations sampled from different test cells.

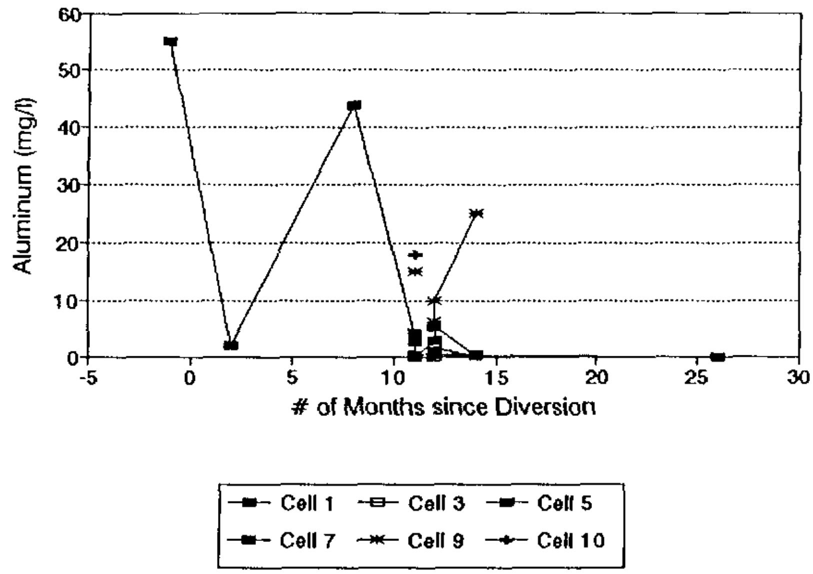


FIGURE 4.14c: Historical variation in aluminum concentrations sampled from different test cells.

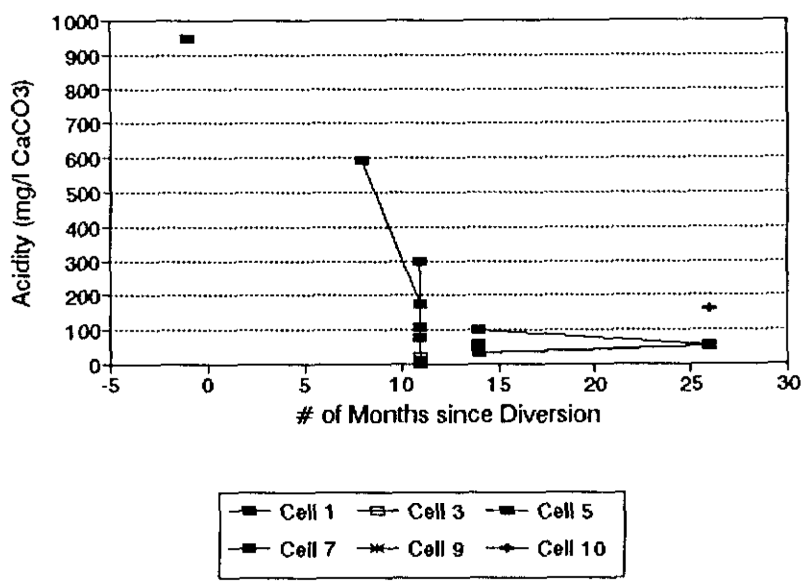


FIGURE 4.15a: Historical variation in acidity concentrations sampled from different test cells.

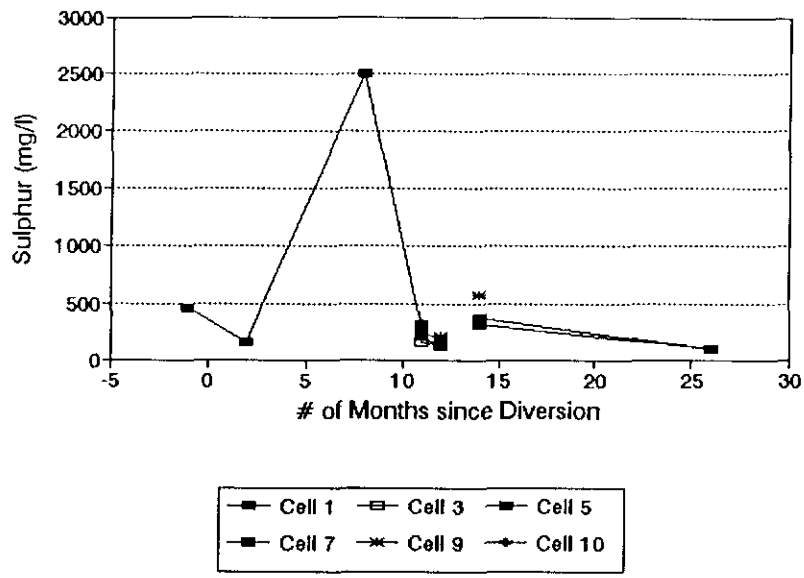


FIGURE 4.15b: Historical variation in sulfur concentrations sampled from different test cells.

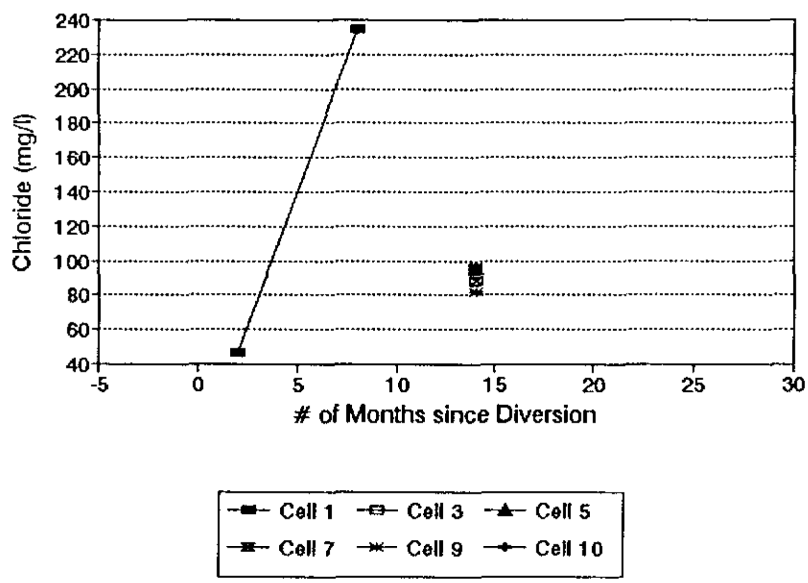


FIGURE 4.15c: Historical variation in chloride concentrations sampled from different test cells.

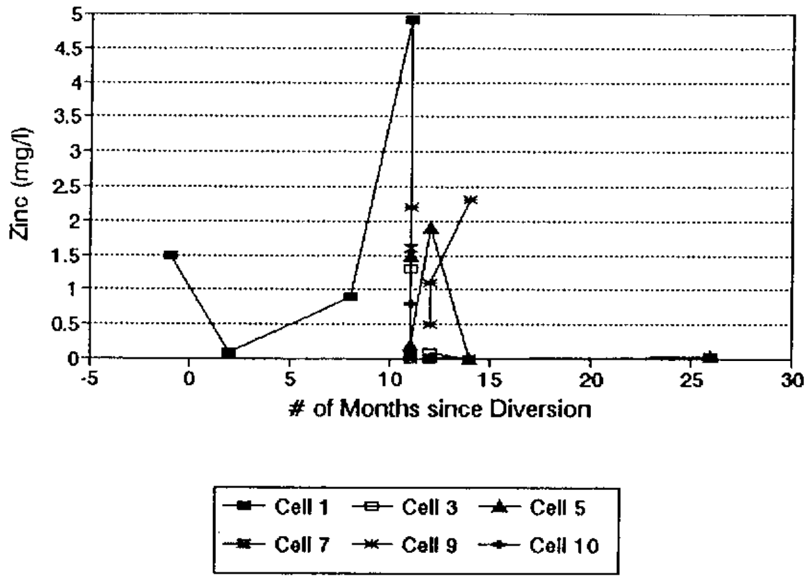


FIGURE 4.16a: Historical variation in zinc concentrations sampled from different test cells.

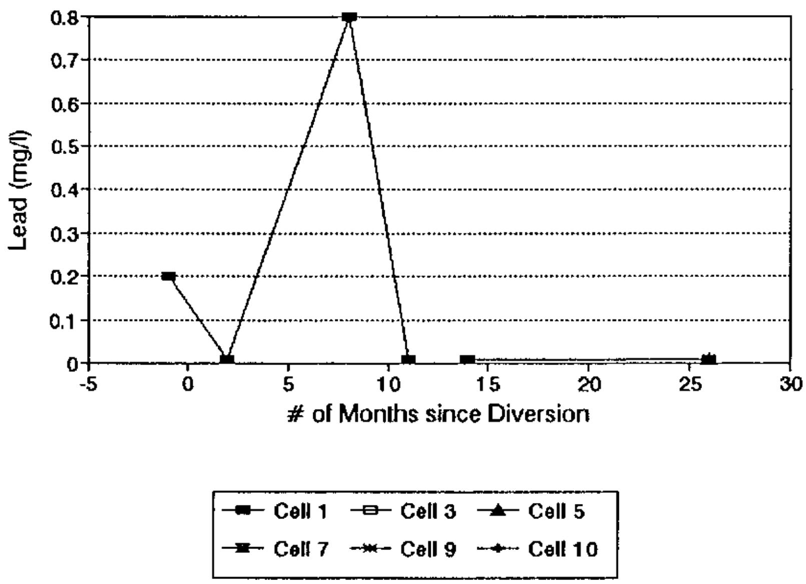


FIGURE 4.16b: Historical variation in lead concentrations sampled from different test cells.

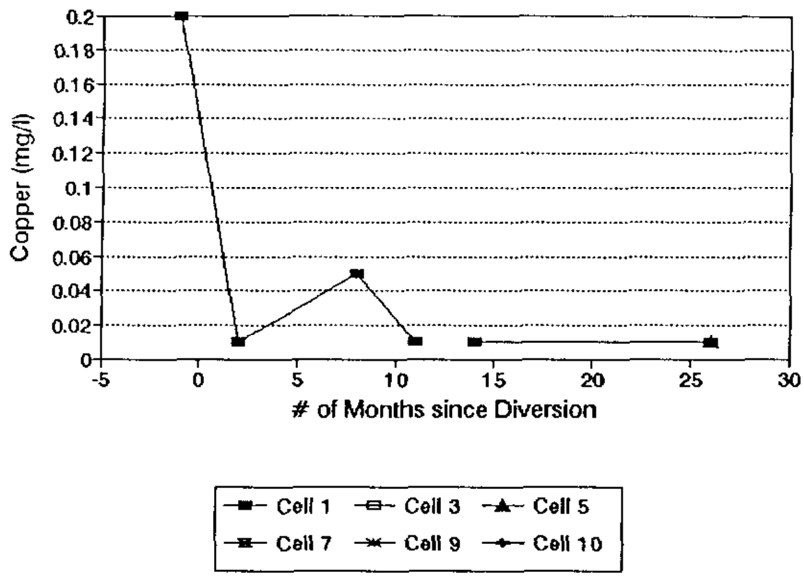


FIGURE 4.16c: Historical variation in copper concentrations sampled from different test cells.

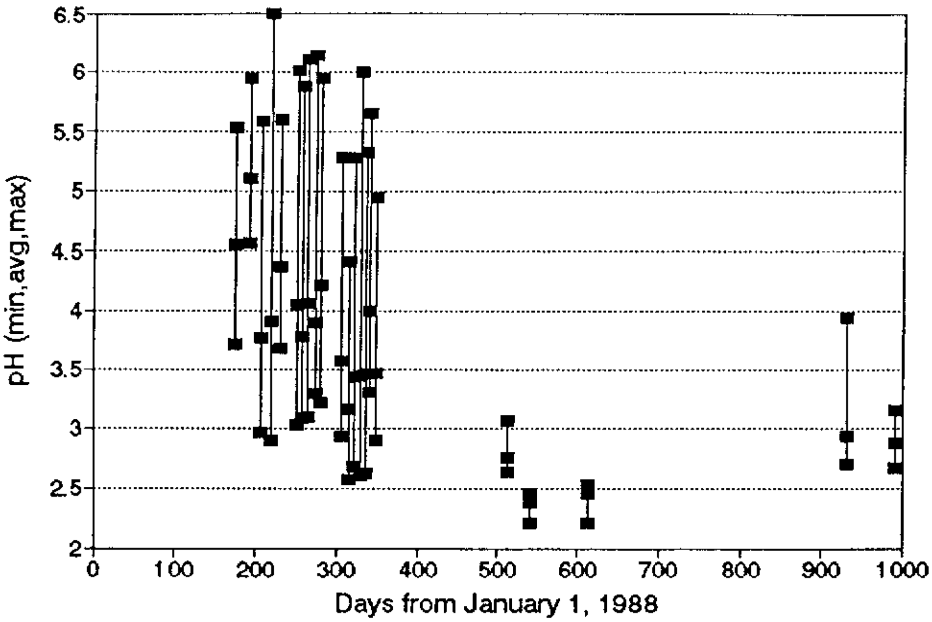


FIGURE 4.17a: Historical pHs in the New Bog. High, low, and logarithmic mean of pH are shown for each sampling date.

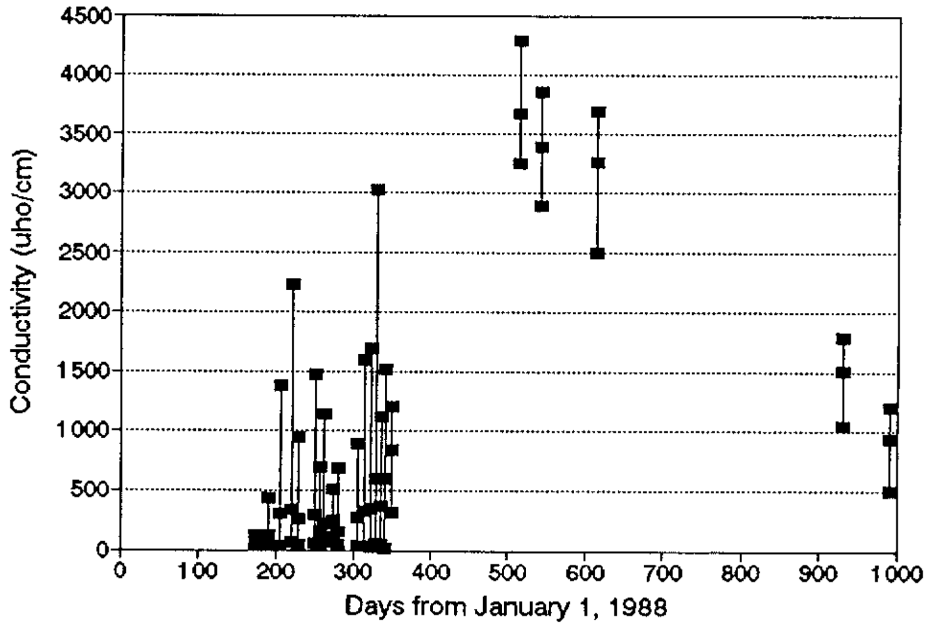


FIGURE 4.17b: Historical conductivities in the New Bog. High, low, and mean are shown for each sampling date.

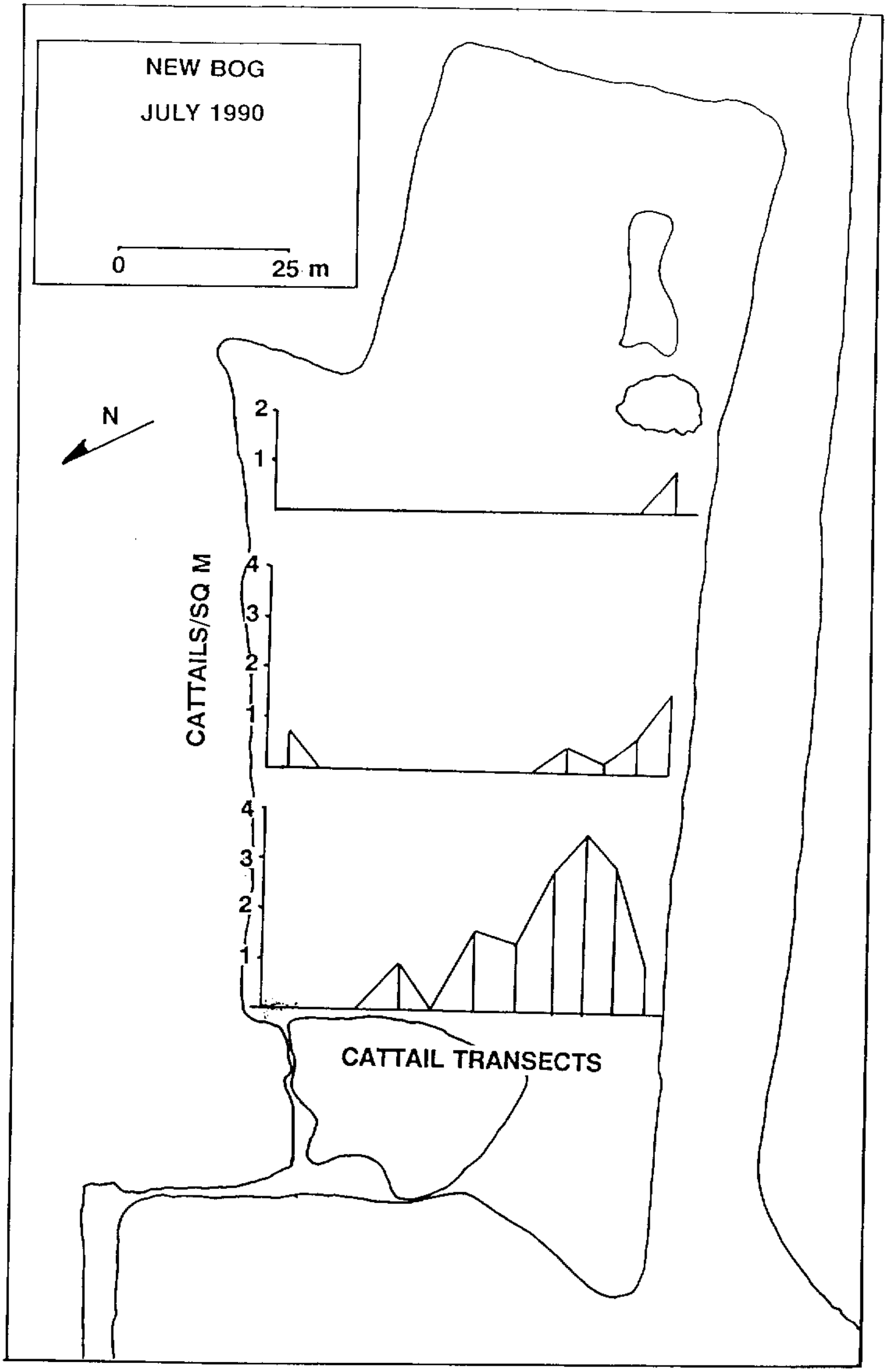


FIGURE 4.18: Distribution and densitites of cattails on three transects across the New Bog in July 1990.

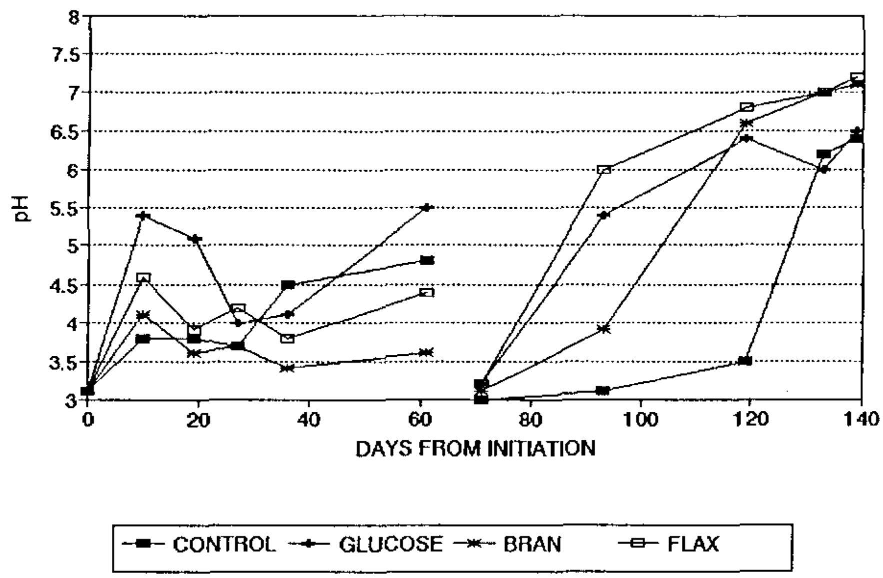


FIGURE 6.1a: Bacterial alkalinity-generation using different organic amendments.

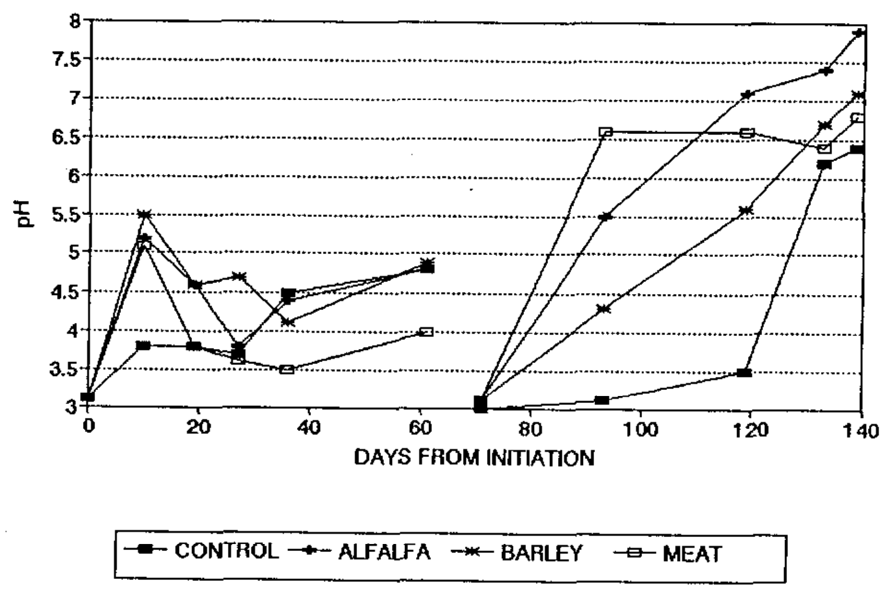


FIGURE 6.1b: Bacterial alkalinity-generation using different organic amendments.

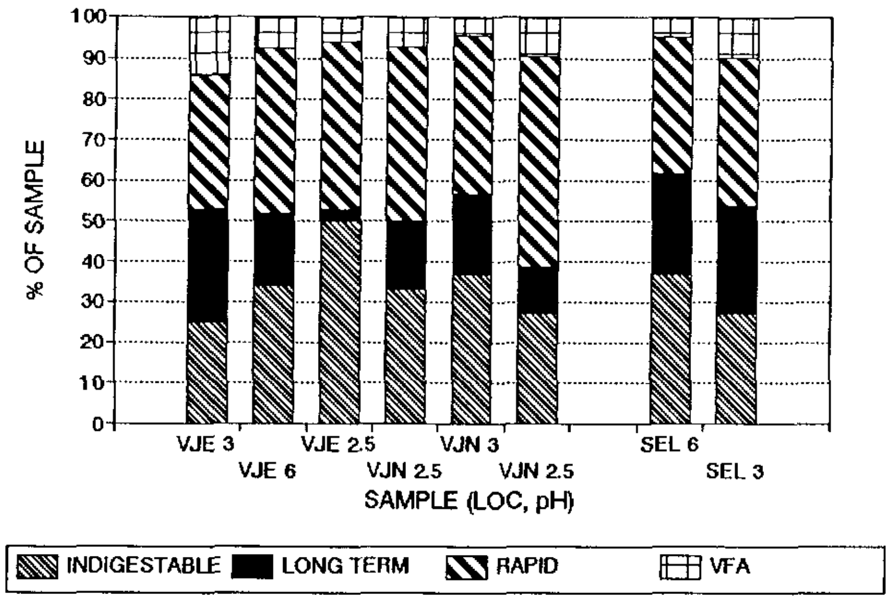


FIGURE 6.2: Degradation/nutrition analyses of Devco bog water and amendment. See Table 6.1 for explanation of locations.

TABLE 4.1a: Historical water pHs at Boojum Research Limited monitoring stations around the VJCPP, stations 100-1005.

STATION	pH 05/10/88	05/28/88	06/06/88	06/30/88	07/28/88	09/15/88	09/29/88	10/31/88	11/30/88	01/09/89	02/01/89	05/28/89	10/17/89	11/09/89	05/28/90
100		5.76	6.2	6.05	6.57		5.91	6.8	6.67	5.27	5.78	5.93	6.48	6.48	6.23
200		6.52	6.4	6.47	6.77		5.46	6.6	6.43	5.66	6.1		DRY	DRY	6.49
300		4.99	3.84	4.74	6.24		6.02	6.5	4.71	3.84	5.68		5.88	6.11	5.9
400		3.1		4.06	3.5		4.04		2.98	3.15	3.08		2.94	3.17	3.12
500	2.86	2.76	2.73	3.25	3.36		3.73	5.7	5.76	5.58	FROZEN		DRY	DRY	6.47
600	2.91	2.95	2.8	3.41	3.32		3.89	6.06	6.17	5.75	FROZEN		3.57	DRY	7.01
700	2.92	2.78		3.41	4.05		3.88	5.94	6.23	5.78	6.85		3.5	4.28	6.39
701	2.9	2.6	2.81	3	2.89		2.83	2.85	2.73	FROZEN	FROZEN		2.48	2.87	3
702	2.75	2.67		3.09	4.03	2.6	2.9	2.53	2.68	FROZEN	2.56		2.49	2.79	2.8
703	4.6		4.3	4.08	3.91		3.95	3.05	3.22	2.88	2.66	3.22	DRY	3.18	3.99
704	4.27		3.98	3.25	2.87		2.83	2.9	2.65	2.54	2.65		2.46	2.89	3.1
705	4.74		4.42	4.28	4.03		3.83	3.22	3.86	4.24	3.82		2.48	2.87	2.78
800	6.58	6.86	5.86	6.68	6.4		5.38	5.01	5.71	4.98	4.45		3.31	5.73	6.09
801	4.62		4.56	5.06	5.23		DRY	4.88	4.92	4.7	4.8		4.41	5.15	5.35
802	4.72		4.89	4.87	5.2		5.35	5.1	5.3	4.84	4.86		4.44	5.18	4.93
803	4.65		4.55	5.24	5.16		5.4	4.98	4.94	4.87	4.86		4.55	5.19	4.57
804	6.9		6.4	6.63	4.68		5.98	6.54	5.88	5.51	5.66		3.69	5.11	5.93
805	6.32	7.01	5.83	6.72	6.18		6.32	6.6	5.85	5.59	5.76		4.72	7.64	6.41
806	6.65	6.68	6	5.64	6.23		6.03	6.36	5.86	FROZEN	5.9		4.95	7.44	6.44
807	6.6		6.15	6.67	6.2		6.18	6.91	5.89	6.05	6.53	6.39	4.15	7.58	6.22
808	5.5		5.86	6.53	6.21		6.1	6.02	5.92	5.59	5.71		4.92	7.36	6.4
809	6.2		6.28	6.64	6.25		6.1	6.2	5.89	5.63	5.77	3.56	5.37	7.27	6.44
900	6.43	6.8	6.34	6.24	6.47		6.37	6.34	5.79	5.6	5.87		5.76	7.16	6.16
901	6.44	6.79	6.35	6.4	6.57		6.46	6.31	5.84	5.63	5.71		5.8	7.13	6.23
902	6.66		6.48	6.13	6.58		6.38	6.22	5.87	5.74	6.05		5.91	7.2	6.08
903	4.7	4.31	3.96	3.46	3.14		3.2	6.1	6.06	6.26	5.35		DRY	DRY	DRY
904	4.7	5.05	5.19	5.5	4.92		DRY	4.53	6.85	5.37	5.9		DRY	DRY	DRY
905	2.5		DRY	;DRY	DRY		DRY	DRY	2.64	2.68	FROZEN		DRY	DRY	DRY
1000	4.83	5.02	4.45	4.65	4.66		5.75	4.79	4.73	4.21	4.78		4.74	7.11	4.77
1001	4.8	5.02	4.5	4.62	4.65		5.76	4.77	4.74	3.94	4.63		4.76	7.12	4.8
1002	4.75	4.98	4.5	4.59	4.64		5.63	4.74	4.74	4.05	4.71		4.65	7.12	4.57
1003	4.5	4.72	4.42	4.59	4.61		5.98	4.84	4.58	3.51	4.79		4.44	7.19	4.6
1004	4.57	4.84	4.43	4.64	4.66		5.43	4.52	4.46	3.91	4.43	4.93	4.57	7.18	4.51
1005	2.6	3.68	2.75	3.89	3.8		2.97	4.22	3.48	3.17	4.05		DRY	DRY	2.5

TABLE 4.1b: Historical water pHs at Boojum Research Limited monitoring stations around the VJCPP, stations 2001-4000 (CWP seepages).

STATION	05/09/88	05/28/88	pH 06/08/88	06/30/88	07/28/88	09/15/88	09/29/88	10/31/88	11/30/88	01/09/88	02/02/89	05/28/89	10/17/89	11/09/89	05/29/90
2001			3.88	4.09	3.85		3.7	3.82	4.14	4.07	4.14		4.08	7.1	4.23
2002			4.74	4.02	3.66		3.62	3.94	5.05	4.96	5.18		4.14	7.1	4.09
2003			2.66	2.86	3.09		2.91	3.46	3.52	FRZ/DRY	FROZEN		4.07	7.12	4.07
2004			2.75	3.16	3.19		3.04	3.52	3.57	FRZ/DRY	FROZEN		3.28	7.12	4.22
2005			2.9	2.86	3.26		6.78	5.38	3.65	FRZ/DRY	FROZEN		3.54	7.12	4.15
2006			3	3.67	4.07		6.78	4.42	4.3	FRZ/DRY	FROZEN		4.21	7.08	4.14
2017												6.2	5.94	7.04	5.75
3001	2.88		2.95	2.66	4.07		DRY	DRY	DRY	FRZ/DRY	FROZEN	DRY	DRY	DRY	2.9
3002	4		3.7	4.35	2.84	DRY	6.79	3.54	3.63	FRZ/DRY	4.36	3.85	DRY	DRY	3.39
3003	4.4		4.58	5.24	3.39	3.44		4.56	5.86	FRZ/DRY	5.79	DRY	DRY	DRY	2.75
3004	3.8		3.1	2.71	4.94	3.15		3.6	5.71	FRZ/DRY	5.58	5.8	3.1	DRY	2.89
3005	5.32		3.8	5.75	3.8	2.46		3.2	5.12	5.54	5.76	6	3.77	DRY	2.98
3006	5.83			5.68	4.4	2.83		5.5	5.56	5.56	5.98		4.54	7.07	3.23
3007	3.55		3.5	3.49	5.41	5.34		3.32	3.78	FRZ/DRY	FROZEN		4.13	7.06	3.05
3008	5.5		4.69	5.53	3.31	DRY		5.6	5.64	5.81	5.92	5.84	4.47	7.04	DRY
3009			2.9	2.94	5.39	5.3		DRY	3.14	FRZ/DRY	FROZEN		4.44	7.06	DRY
3010			3.29	3.71	5.39	2.91		3.48	3.64	FRZ/DRY	FROZEN		3.72	7.05	3.33
3011	3.45		3.76	4.32	3.31	3.31		3.44	3.43	4.18	4.54		3.49	7.05	3.14
3012	2.95		3.05	3.05	3.98	3.37		2.95	3.18	FRZ/DRY	FROZEN		3.55	7.03	3.09
4000					3.08	2.75							5.98	7.03	5.87

TABLE 4.1c: Historical water conductivities at Boojum Research Limited monitoring stations around the VJCPP, stations 100-1005.

STATION	Conductivity (umhos/cm) 05/10/88	05/28/88	06/06/88	06/30/88	07/28/88	09/15/88	09/29/88	10/31/88	11/30/88	01/09/89	02/01/89	05/28/89	10/17/89	11/09/90	05/29/90
100		51	37	48	53		53	40	43	90	63	50	51	47	45
200		113	115	148	184		138	118	173	189	158				115
300		50	90	63	58		59	45	80	220	68		55	45	50
400		1366		1205	582		234		1342	1090	1245		445	410	600
500	1600	3490	2100	1860	1395		1149	495	1196	850	FROZEN		DRY	DRY	1050
600	1520	3640	2400	1324	1415		1423	600	1260	650	FROZEN		526	DRY	1000
700	1800	3540		1167	1738		1340	700	1295	969	1480		654	916	1250
701	2000	3450	5500	1642	220		1975	1040	2600	FROZEN	FROZEN		3150	1734	1420
702	1120	2700		2180	1922	1550	3530	6000	2800	FROZEN	3950		4200	1587	1190
703	550		450	443	545		603	500	968	1130	2660	900	DRY	656	490
704	119		190	305	2470		1948	900	3410	4150	4100		2350	1286	1295
705	82		175	136	158		198	328	168	84	165		2650	1626	1320
800	208	709	140	667	1700		417	155	107	40	265		1207	856	600
801	30		30	42	37		DRY	40	44	43	59		33	30	40
802	30		30	42	47		40	40	39	36	55		33	35	29
803	30		25	51	40		46	39	43	44	67		57	32	30
804	420		800	612	2090		1120	430	401	937	376		435	416	238
805	3200	2800	3250	2170	3400		1319	400	201	396	548		307	156	173
806	1650	1546	970	2540	2800		4610	1670	410	FROZEN	426		896	1237	229
807	36		45	71	59		799	50	49	45	60	90	256	162	135
808	1050		850	945	2190		2530	1200	409	880	872		780	575	450
809	500		900	830	1089		2640	320	430	911	1070	1100	486	880	400
900	365	1073	550	717	721		1755	330	478	610	797		443	375	390
901	310	1051	600	646	628		1551	800	371	540	950		401	388	387
902	570		950	1278	1247		1651	260	1209	506	1143		146	170	455
903	550	1299	1000	1490	1397		2760	1370	2600	1100	510		DRY	DRY	DRY
904	1280	9220	4150	340	3710		DRY	4800	3960	1210	531		DRY	DRY	DRY
905	3850						DRY	DRY	8120	930	FROZEN		DRY	DRY	DRY
1000	195	425	330	481	481		742	181	320	322	470		324	215	210
1001	195	424	320	462	462		743	180	310	247	454		326	292	215
1002	175	425	330	473	473		742	177	271	299	507		320	292	220
1003	40	49	40	61	61		114	35	58	80	92		86	66	37
1004	140	270	300	473	473		695	165	250	254	458	360	323	304	215
1005	3000	249	3500	750	2780		1229	310	709	618	572		DRY	DRY	1750

TABLE 4.1d: Historical water conductivities at Boojum Research Limited monitoring stations around the VJCPP, stations 2001-4000 (CWP seepages).

	CONDUCTIVITY (umhos/cm)													
STATION	05/09/88	05/28/88	06/08/88	06/30/88	07/28/88	09/15/88	09/29/88	10/31/88	11/30/88	01/09/88	02/02/89	05/28/89	10/17/89	11/09/89	05/29/90
2001			1500	3480	3030		3020	1000	440	504	715		296	260	220
2002			4500	7400	7200		7750	2390	3850	1708	1780		345	340	240
2003			4500	7940	5570		7620	2390	970	FRZ/DRY	FROZEN		495	415	250
2004			1900	1459	1215		2800	900	790	FRZ/DRY	FROZEN		956	456	280
2005			3000	5760	444		5670	2850	360	FRZ/DRY	FROZEN		632	491	410
2006			2000	533	187		2090	165	148	FRZ/DRY	FROZEN		250	120	470
2017												70	52	51	49
3001	9100		7000	8740			DRY	DRY	DRY	FRZ/DRY	FROZEN		DRY	DRY	6100
3002	6400		2500	2320	8810	DRY	7690	3700	8740	FRZ/DRY	6420	7500	DRY	DRY	7500
3003	3650		2000	5490	7990	7000		4000	8510	FRZ/DRY	7100		DRY	DRY	7100
3004			5000	6230	5990	4600		4080	7480	FRZ/DRY	4780	6000	2620	DRY	8500
3005	3800		3600	7780	5500	4800		3800	7220	8200	7880	4500	4060	DRY	8800
3006	3850			6410	7840	7500		2550	4710	5010	4180		7000	5200	8000
3007	3000		5000	6970	6640	5000		4600	8540	FRZ/DRY	FROZEN		1040	5570	9000
3008	3400		3700	6070	10200	DRY		2750	4700	5200	4750	4200	485	5570	DRY
3009			7700	10460	6820	5000		DRY	7880	FRZ/DRY	FROZEN		3660	5670	DRY
3010			4200	7360		3500		4500	10450	FRZ/DRY	FROZEN		6350	6110	11100
3011	3000		7000	8380	9050	7500		4800	10650	8340	7640		5450	5950	10000
3012			5900	8470	9090	7500		4150	8330	FRZ/DRY	FROZEN		5500	4910	7500
4000					8770	7000							53	56	49

TABLE 4.2: Vegetation analysis in the test cells.

Test Cell	Amend 7/88	Amend 10/88	Vegetation Description July '88	Vegetation Description July '90
C1	4B	6B	100 % submerged; < 1% cover of dead grass on LBC side	80% cover; 70% Typha and 10% Juncus and unknown Poaceae
C2	---	---	90% submerged; 60% cover; 50% Juncus with some grass and Alder	80% cover; 40% Juncus, 20% Typha and 20% grass
C3	1B	2B	95% submerged; 5% cover of grass	40% cover; 30% grass, 10% Juncus with a few Typha
C4	---	---	75% submerged; 25% cover of which <5% grass; 20% Alder	100% cover; Calamagrostis and Juncus
C5	1B	2B	90% submerged; 10% cover; 5% Alder < 1% grass	50% cover; 30% Juncus; 10% Typha; 10% Alder
C6	---	---	95% submerged; <10% cover; 5% grass	100% cover of Calamagrostis and Juncus
C7	3.25B	2.5B	30% submerged; 70% cover; 5% grass; 5% Alder	70% cover; 50% Calamagrostis 15% Juncus; 5% Typha
C8	---	---	80% submerged; 20% cover; 10% grass; 1 healthy Alder	80% cover of Calamagrostis and Juncus; some asters and Alder
C9	1.75B	0.25B	90% submerged; 10% cover; 5% grass; some Alder	50% cover of Calamagrostis and Juncus with some healthy Alder
C10	---	---	no description	50% cover of Calamagrostis and Juncus

TABLE 6.1: Enumeration of bacterial populations in Devco bog waters and amendments.

SAMPLE	pH FIELD	pH LAB	ATP (ng/mL)	SRB (#/mL)	NH4-PROD (#/mL)	IRB (#/mL)	N2-PROD (#/mL)
VJE 3	3	3.8	92	1E+03	1E+05	1E+05	1E+05
VJE 6	6	6.2	56	1E+05	1E+05	1E+04	1E+04
VJE 2.5	2.5	3.6	140	1E+03	1E+05	1E+05	1E+05
VJN 2.5	2.5	4.1	45	1E+03	1E+05	1E+05	1E+05
VJN 3	3	5.7	110	1E+05	1E+05	1E+04	1E+05
VJN 2.5	2.5	4	230	1E+03	1E+05	1E+05	1E+02
SEL 4	4	4	84	1E+05	1E+05	1E+05	1E+05
SEL 3	3	3.2	55	1E+03	1E+05	1E+05	1E+01

VJE3 - Near P40 in Experimental Bog
VJE6 - Near P3 on bog side of ditch, Experimental Bog
VJE2.5 - Near P36 on bog side of ditch, Experimetal Bog
VJN2.5 - Near P3 in the New Bog
VJN3 - Near P24 in the New Bog
SEL3 - Near hay dam area of bog, Selminco
SEL4 - Near western edge of bog below dam, Selminco

ACID MINE DRAINAGE AMELIORATION IN NATURAL BOG SYSTEMS

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ABSTRACT

Two naturally acidic bogs were studied in Nova Scotia. One bog had been receiving diffuse AMD from a nearby coal processing plant. The other was untouched by AMD. Diversion of AMD into both bogs caused considerable damage to the vegetation. The damage was worse in the untouched bog. It was concluded that acidic bogs are *not* natural cleansers of AMD. Heavy metal concentrations and extreme pHs kill bogs as easily as other ecosystems. Ecological engineering techniques were applied to the bogs in 1988. Since then some remediation in water quality has become evident. This water quality improvement is probably the result of both ecological engineering and improved waste water management at the coal processing plant.

INTRODUCTION

Acidic bogs are alleged to be tolerant to acid mine drainage (AMD) and to ameliorate this waste water by acidity removal. A coal processing plant in Nova Scotia has provided an ideal system in which to test this hypothesis. Two naturally acidic bogs were found adjacent to one another near a Lifting and Banking Centre (LBC) which produced AMD. One of the bogs (referred to as the Experimental bog) had been slowly deteriorating due to diffuse AMD input and aerial coal dust deposition. An adjacent bog (referred to as the New bog) was untouched by AMD.

To test the hypothesis that natural wetlands (bogs) can tolerate and ameliorate AMD, a ditch with AMD was diverted into the New bog in the summer of 1988. A ditch was also rerouted into the Experimental bog, further contaminating it directly with AMD. This paper describes the condition of the bogs at the time of diversion and follows the effects of recovery measures.

SITE DESCRIPTION

The bogs are located adjacent to a coal processing plant in Sydney, Nova Scotia. The plant sorts, washes and aerates coal from several coal mines in the area. Each mine's coal has a different composition, and therefore susceptibility to AMD production.

The layout of the Victoria Junction Coal Processing Plant (VJCPP) is shown in Figure 1. Ditching around the LBC contains the acid runnoff. During normal operations, the ditch

AMD is pumped into a holding pond where it is treated. However, after rainstorms, the overflow is allowed to leave the LBC, via ditching adjacent to the bogs.

The New bog can be referred to as a moat-bog with a partially developed moat separating the bog proper from the uplands. Bogs of this type are usually quaking and floating at their margins although they may be grounded and raised towards the centre. The presence of cattails, reed grass and rushes indicate seasonal flooding of the bog and the presence of a high water table, particularly in the spring.

Unlike the New bog the hydrology of the Experimental bog is much more complex. Water flows into the bog from the southern side of the bog under the dyke separating it from Grand Lake. Additional inflow occurs from the southeastern corner of the New bog after rains. Throughout the bog, three distinct troughs are noticeable which almost run the length of the bog from the northwest to the southeast.

In grounded bogs, in general, there is only limited movement of water beneath the surface of the bog. Seasonal flooding of the bog can cause extensive standing water areas and result in considerable movement of drainage water. This is especially true in the Experimental bog where considerable movement of water occurs through the lower trough areas. Higher areas probably have very little water movement (see Kalin and Scribailo (1989) for further discussion of the hydrology).

VEGETATION ANALYSIS

An initial survey was undertaken of the vegetation associations at different localities in the Experimental bog and New bog. Plant material of each species was collected for further analysis and identification (Table 1). A control area in nearby Smith's Bog was also studied (Figure 1).

The species assemblage in both bogs is typical of that encountered in dwarf-shrub bogs of the Northeastern regions of the USA and Canada. These bogs are dominated by the leatherleaf, *Chamaedaphne calyculata.* Plant associations in the bogs can be roughly divided into two types. Although there is some overlap in these associations, this distinction is useful because it correlates well with the relative impact of acid drainage on the vegetation cover. These associations are called hummocks and hollows.

Hummocks are characterized by the predominance of *Sphagnum* spp. forming a mound of vegetation that is elevated above ground level. In hummocks, the dominant species present is *Chamaedaphne calyculata.* Other species present include *Vaccinium oxycoccum* (cranberry), *Ledum glandulosum* (Labrador tea), *Scirpus caespitosus* and *Juncus inflexus.* In the southern area of the Experimental bog, where fresh water enters from Grand lake, *Myrica gale* (sweet gale) and *Alnus rugosa* (speckled alder) are also present.

A much greater diversity of species was observed on hummocks than in hollows, as the list in Table 1 shows. In the hollows, the prominent species present were *Juncus canadensis* and *Sphagnum fibriatum*. *Typha latifolia, Calamagrostis canadensis*, and *Scirpus caespitosus* were also present, but less frequently.

The New bog vegetation was similar in species composition to that in the Experimental bog. *Typha* and *Sphagnum* spp. were the most common plant in the bog hollows, with an association of *Chamaedaphne, Myrica, Ledum* spp., and *Larix* quite common on the northern bog edges. *Alnus* was found growing along the southern edge near the dyke. *Larix* was also commonly found in the *Chamaedaphne* zone.

AMD EFFECTS ON VEGETATION

In the Experimental bog, diffuse AMD has been present in the bog since the LBC began operations in 1983. By 1988, bog areas adjacent to AMD zones had begun to show signs of deterioration. Although damage was also observed in the same species in the Experimental bog, the extent of the symptoms were not as severe as those seen in the New bog. As compared to control populations in Smith's Bog, roots and rhizomes tended to show some damage but this was much reduced in comparison to that observed in the New bog. Many shoot tips were also healthy, with prominent lateral buds. In the Experimental bog, extensive variability in health was seen between plants growing in hummocks and hollows. Plants in the hollows showed much greater signs of acid associated damage. The extent of damage observed in plants found in the hollows of the Experimental bog was very similar to that observed overall in the New bog.

After diversion of AMD, the vegetation in the both bogs began to rapidly deteriorate. Large sections of the western sector of the Experimental bog began to die. By the summer of 1989, most of the affected areas of both bogs were essentially dead.

The effects of AMD on New bog vegetation were even more striking. All vegetation in the path of the AMD deteriorated rapidly. There was little variation on a local scale, since little hummock formation was observed. At the edges of the New bog, and towards the southern limit of the bog, some plants survived.

In the New bog, deterioration was most noticeable for *Alnus* and the woody dwarf shrubs *Chamaedaphne, Myrica, Kalmia, Ledum* and *Larix*. Examination of plant parts of these species bolstered this conclusion. In all cases, assessments were made on the basis of comparisons with control plant material. Below ground damage (roots, rhizomes, etc.) was most extensive with many of the plants showing only scattered lateral and adventitious root hair development. Many rhizomes also showed extensive signs of internal damage and death from the cortical tissue inward. Above ground parts of the plants had few leaves and much of the woody older tissue was found to be dead. The majority of shoot tips and lateral buds were also found to be dead, suggesting little hope for recovery of the plants in subsequent years.

AMD EFFECTS ON CATTAILS

In the Experimental bog, the rhizomes of the cattails showed a greatly reduced production of both lateral and adventitious roots. Few newly initiated roots were present on the rhizomes compared to controls. Many of these roots appeared to have been initiated but did not emerge from the rhizome. In anatomical characteristics, both types of roots often failed to show the typical aerenchyma type of development which is characteristic of healthy roots.

Recent studies have indicated that a continuous aeration channel connecting the previous year's stalks with new expanding lateral shoots is essential for the maintenance of healthy growth in the roots (Seago and Marsh 1989). First signs of senescence in the roots occur when their apical regions fail to undergo typical lysigenous development of aerenchyma and instead, differentiate with a solid cortex. This type of development was associated with a proliferation of adventitious roots near the tips of lateral roots shortly before growth ceased. In comparison with control plants, this phenomenon occurred very early in the elongation of lateral roots on plants from the New and Experimental bogs.

The capacity of *Typha latifolia* rhizomes to grow buried deep in anoxic sediments is probably a function of their ability to both transport surface oxygen to growing roots and to metabolic ground tissue starch reserves which provide the building blocks for early structural tissues. This ability "to do without" has likely been an asset which has allowed *Typha* to become such a successful competitor in marsh habitats (Crawford et al. 1989).

Above ground cattail biomass showed signs of considerable stress in the summer of 1989, demonstrating an incapacity to maintain healthy leaves. In most cases observed, the first six to eight leaves produced died, and only the last two to four leaves finished the growing season. This is in contrast to the situation at the control site and in the amended plots where all leaves produced remained photosynthetic. This observation suggests that conditions have possibly improved over the course of the season and it was only towards the latter part of the season, possibly associated with drawdown conditions, that the cattails could expand and maintain their photosynthetic tissue. Death of earlier leaves may indicate an earlier senescence in plants in the Devco bogs versus those seen at the control site. Cattails in acid tailings were also found to senesce somewhat earlier than the control sites (Kalin 1984). This suggests that acid stress shortens the growing season.

Examination of starch reserves present in rhizomes indicated that extensive starch was still present in the ground tissue, despite the fact that most plants had only expanded three or four leaves. Although this indicates that plants may be able to survive and produce further shoots for another year or two, unless a substantial photosynthetic input can be achieved, stored reserves could eventually become exhausted.

Despite the detrimental effect of the acid conditions on the roots and rhizomes of the cattails, most plants produced a lateral bud in the axil of each leaf initiated. Although approximately thirty percent of these were dead, the remaining buds were healthy and had the potential for expansion at some future date. All healthy buds had extensive starch reserves present at their base.

MEASURES TO ASSIST BOG RECOVERY

EXPERIMENTAL BOG

Since the Experimental bog was deteriorating under the effects of AMD, some methods were required which would help the bogs to recover. Ecological engineering techniques were applied to the bog. In general, these techniques involve enhancing natural bacterial populations which generate alkalinity. By amending the bogs with an organic carbon source, and controlling the flow of AMD into the bogs, it was hoped that appropriate conditions for alkalinity generation could be enhanced. The carbon and nutrients provided by the amendment would foster population increases in these bacteria.

Amendment was first placed in the diversion ditch in the Experimental bog. The ditch was about 2 m wide by 30 m long (see Figure 2a). It was divided up into 10 serial test cells, separated by wire fencing. The ditch was completed in July of 1988 and immediately filled with different quantities of amendment. Cell 1 received 4 bales; cell 3 received 1 bale; cell 5 received 1 bale; cell 7 got 3.25 bales; and, cell 9 received 1.75 bales.

The pHs in both the root zone and surface water in the cells is shown in Figure 3a-d for several sampling dates since 1988. The first water samplings were taken in the spring of the 1989 (Figure 3a). These data show clearly the effect of amendment in the odd numbered cells. The pHs in cells 1,3,5,7 were all over 5, while the pHs in cells 2,4,6, and 8 were all less than 5 (usually less than 4). There was also little difference between surface and root zone pHs. In Figure 3d, one year later, the pHs in the root zone in all cells were above 5, with surface water all well above pH 4. Concomitant with the increase in pH, an emergent vegetation has flourished. *Typha, Juncus, Calamagrostis* cover most of the surface of the diversion ditch. Vegetation covers are on the order of 50-80%.

In addition to the test cells, the Experimental bog received 196 bales of amendment placed primarily in the eastern end of the bog (see Figure 2a). The bales were placed on straight lines from the northwest to the southeast exit from the bog, mostly in the hollows. The whole area on the eastern side of the bog also received amendment.

In the amended portions of the Experimental bog, the status of the amendment was also monitored at intervals. By the summer of 1989, very little of the amendment had begun to decompose. Water quality remained poor. However, by the summer of 1990, stagnant areas or areas with slower water flow had begun to decompose, with a parallel rise in pH. In these areas, especially near B11, *Typha,* and *Juncus* have grown well (see Figure 2a). In other areas where flows are more rapid, amendment can be seen to be overgrown by *Sphagnum* spp. Cattail growth in these hollow areas is still poor. Only with fertilizer applications have we seen any improvement in hummock grass or brush vegetation.

To monitor the water quality in the bogs, it was first necessary to monitor the water quality going into the bogs. Figure 4a shows the pH of water flowing into the Experimental bog (Weir 2) over the last 3 years. It shows that during the summer of 1988 the pH of incoming water was low, around 4. Dilution over the winter months brought the pH up to 5.5-6. The following summer (1989) the pH dropped again to between 2.5 and 4. Although data after the summer of 89 are sparse, the trend continues; low pHs in the summer and higher pHs in the winter.

In the Experimental bog, itself, conductivity and pH measurements were made at intervals at fixed stations starting in the summer of 1988 (Figures 5,6). In order to analyze the data, water quality stations were lumped into 3 areas in the Experimental bog (see Figure 2a). The bog was divided into an eastern sector which had been receiving the brunt of the AMD since 1983; a western sector which was originally less affected, but after diversion, received most of the AMD; and the southern sector which received fresh water input from Grand Lake.

The pH data for the Experimental bog are shown in Figure 5a,b,c. For each date, the highest and lowest pHs recorded and the logarithmic mean of all stations measured are shown. These data clearly show the progressive intrusion of AMD into the bog. In the eastern sector which originally received the most AMD, the pHs during summer of 1988 (appx. day 150) were initially quite low (2.5). After diversion, there was a period of about 6 months over the winter when the system was equilibrating, shown by the large variations in pH. During the summer of 1989 (days 500-600), however, the entire bog had restabilized between pH 2.5 and 3.5. By following summer, 1990 (days 900-1000), two years after the initial carbon amendments were added, the pHs had increased significantly. Mean pHs were greater than 3 and some areas had pHs in excess of 6.

In the western section, the pHs were initially quite high. This area was the furthest from the diffuse AMD intrusion, and retained much of the original bog's water characteristics. During the fall and winter 1988 (days 240-400) the diverted AMD mixed with the clean bog water. By the summer of 1989 (days 500-600), the water was stable between 2 and 3. By 1990, however, some elevations in pH were seen. The mean pH had risen to just over 3 and some pockets showed pHs in excess of 4.

The southern section is heavily influenced by intrusions from Grand Lake. The pHs here were moderately acidic for a lake unaffected by AMD. Log mean pH was around 5. Over the rest of 1988, the pH varied considerably as AMD intruded into the bog. The next year, 1989 (days 500-600), the pHs varied from a low of 2.5 to a high of 5.5. In 1990, the pHs still varied widely, but the low was only 3.7 and the highs were above 6.

Water conductivities for the Experimental bog are shown in Figure 6a,b,c. Again, the highest, lowest and mean conductivity are shown for each sampling time in a given sector. The conductivities mirror the pHs. The eastern sector started out with high conductivities, became rather erratic over the next year, and has since improved dramatically. Conductivities in the western sector show just the opposite trend. During the latter part of 1988, the conductivities were low indicating that the sector was essentially unaffected by AMD. With the diversion ditch, the conductivities increased. The southern sector started out with clean, fresh water and was inundated over much of the next spring, but these values returned to more normal, bog water levels.

NEW BOG

The water quality going into the New bog has been consistently low. Figure 4b shows the pH of water flowing into the New bog at weir 3. Data show that since the weir was installed in the summer of 1988, the pHs have remained low, generally between 2.5 and 3. This trend has continued, with the possible exception of a single data point in the summer of 1990.

A pooling of measurmeents from fixed stations at the western end of the bog provide an overall picture of water quality (Figure 2b). In this sector, the pHs were initially quite normal for an acidic bog (Figure 7a). Data ranged from about 3.6 to 6 with a logrithmic mean around 4.5 (days 150-180). As AMD was shunted into the bog, the pHs became more erratic, especially during the fall when rains normally flood the bog. By the following spring (1989; day 500) the bog had been completely inundated with AMD, and the pHs were stable, between 2.2 and 3.1.

As a result of the poor water quality flowing into and through the bog, carbon amendments were also added in the fall of 1988. The New bog received a total of 109 bales placed primarily along the path of the greatest water flow, down the middle from the northwest to the southeast. There were also a number bales placed along the north side of the bog, especially around P24 (see Figure 2b). A total of 12 bales were placed in the incoming water ditch near the weir. By 1990, there was some pH improvement in the bog. Bulk water samples from the root zone in some amended areas reached pHs close to 4.0.

The conductivity numbers in the New bog mirror the pHs (Figure 7b). Conductivities were initially low, indicating that the bog was clean. By the latter part of 1988, however, some measurements were as high as 3000 μmhos/cm. In 1989 the conductivities remained high, sometimes as high as 4300 μhos/cm. However, during the summer of 1990, the numbers dropped dramatically. The highest recorded conductivity was 1800 μhos/cm, while the lowest was 500.

CONCLUSIONS

Natural wetlands do not intrinsically tolerate or ameliorate acid mine drainage. Shunting acid mine drainage into the New bog, killed most of the natural vegetation. The only surviving species appear to be *Typha* and *Sphagnum*. All of the woody species, including *Chamaedaphne, Ledum, Myrica* and *Larix* were killed. As conditions in the bog improve, these woody species are being replaced with grasses like *Calamagrostis* and reeds like *Juncus*.

Water quality improvement in the bogs appears to be related to two processes. The first process is a gradual improvement in the water entering the bog; the second process is alkalinity generation through bacterial enhancement. It is most probable that the improvements in water quality observed are a combination of both processes.

ACKNOWLEDGEMENTS

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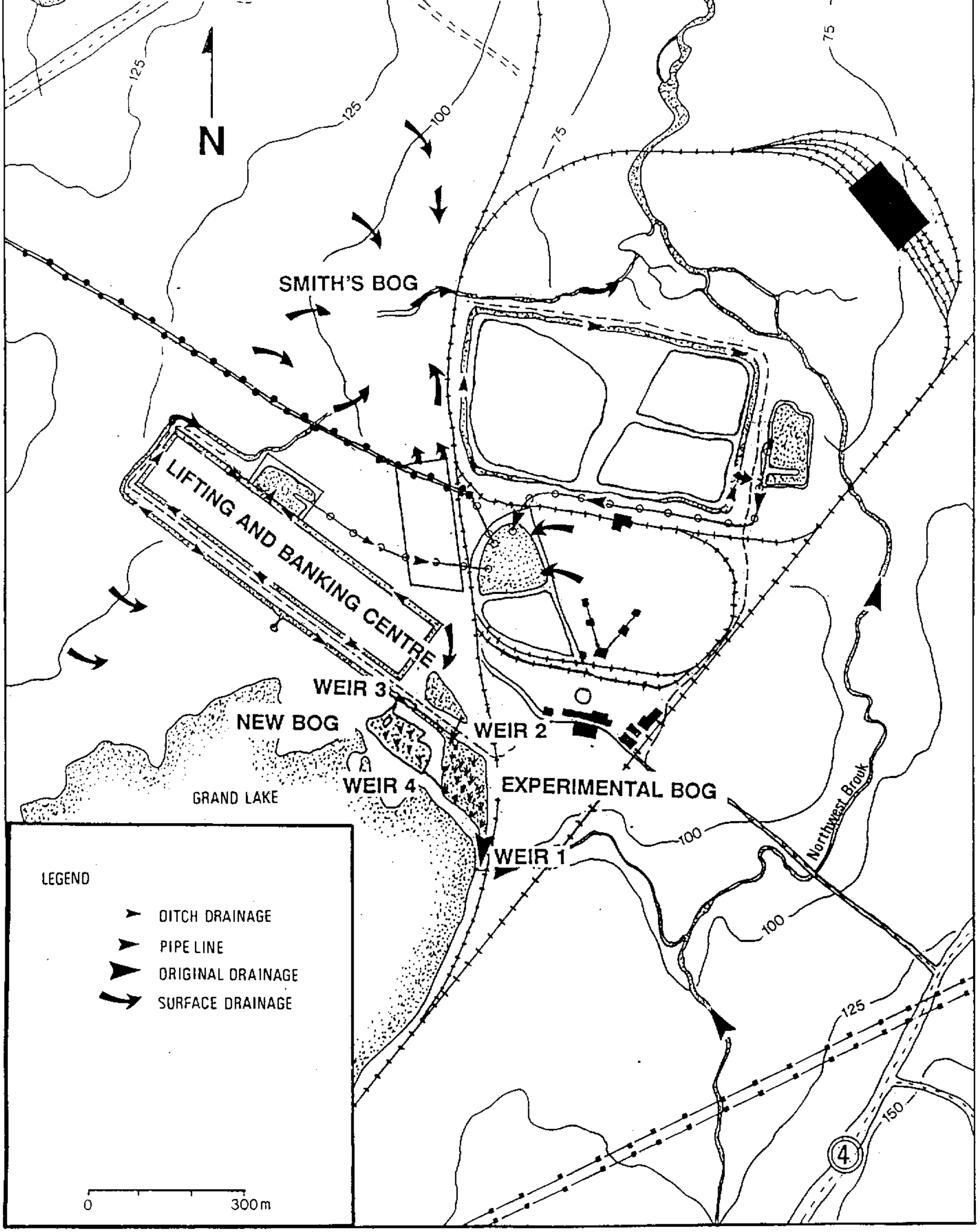
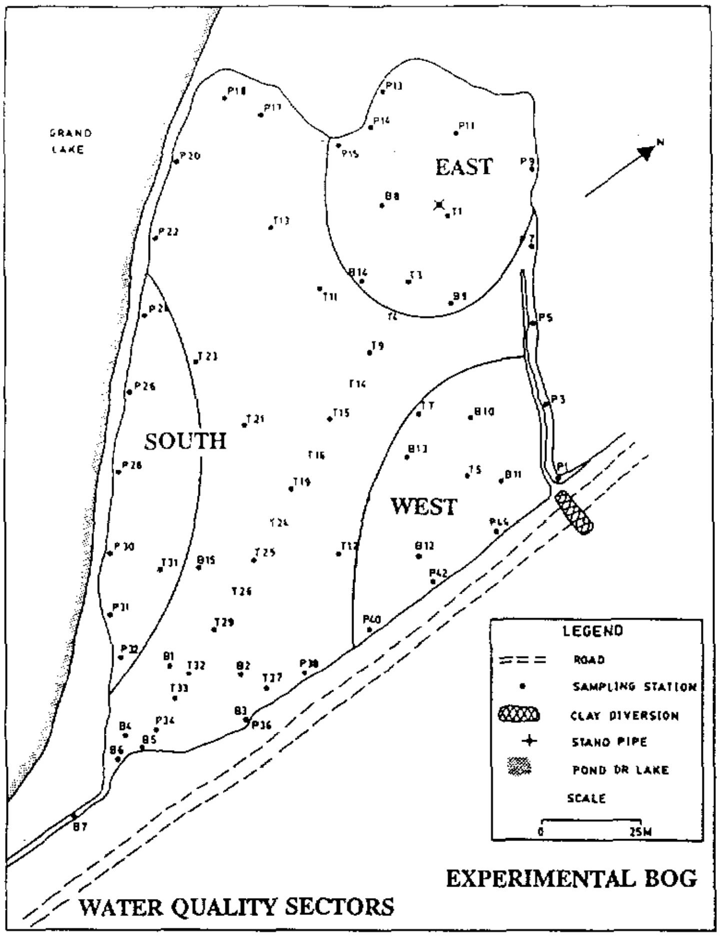
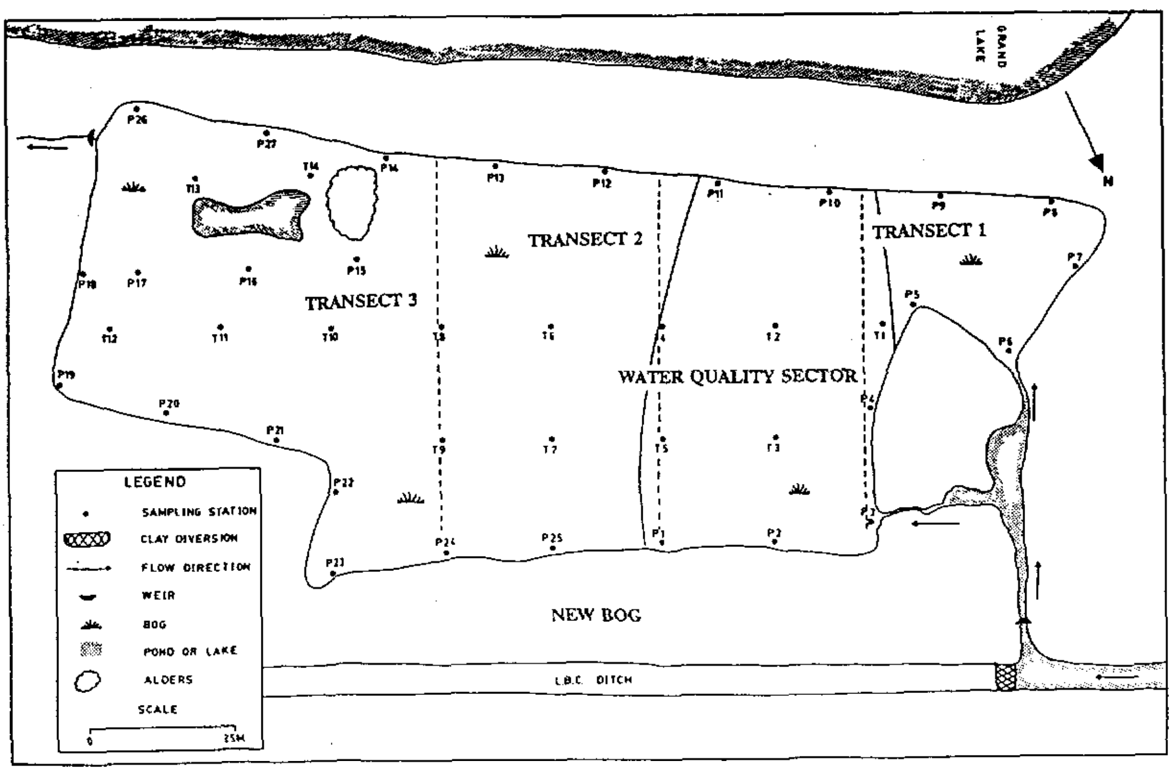
TABLE I. Plant species composition of the Devco Bogs by association.

HUMMOCKS	HOLLOWS
BRYOPHYTA	BRYOPHYTA
Betula pumila	*Cephaloziella sp.*
DROSERACEAE	*Sphagnum fimbriatum*
Drosera angelica	
ERICACEAE	CYPERACEAE
Andromeda glaucophylla	*Scirpus caespitosus*
Chamaedaphne calyculata	JUNCACEAE
Kalmia angustifolia	*Juncus canadensis*
Kalmia polifolia	*Juncus inflexus*
Ledum glandulosum	LILIACEAE
Ledum groendlandicum	*Smilacina trifolia*
Vaccinum oxycoccus	POACEAE
Vaccinum macrocarpon	*Calamagrostis canadensis*
FAGACEAE	TYPHACEAE
Alnus rugosa	*Typha latifolia*
MYRICACEAE	
Myrica gale	
PINACEAE	
Larix laricina	
Picea mariana	
POLYGONACEAE	
Rumex domesticus	

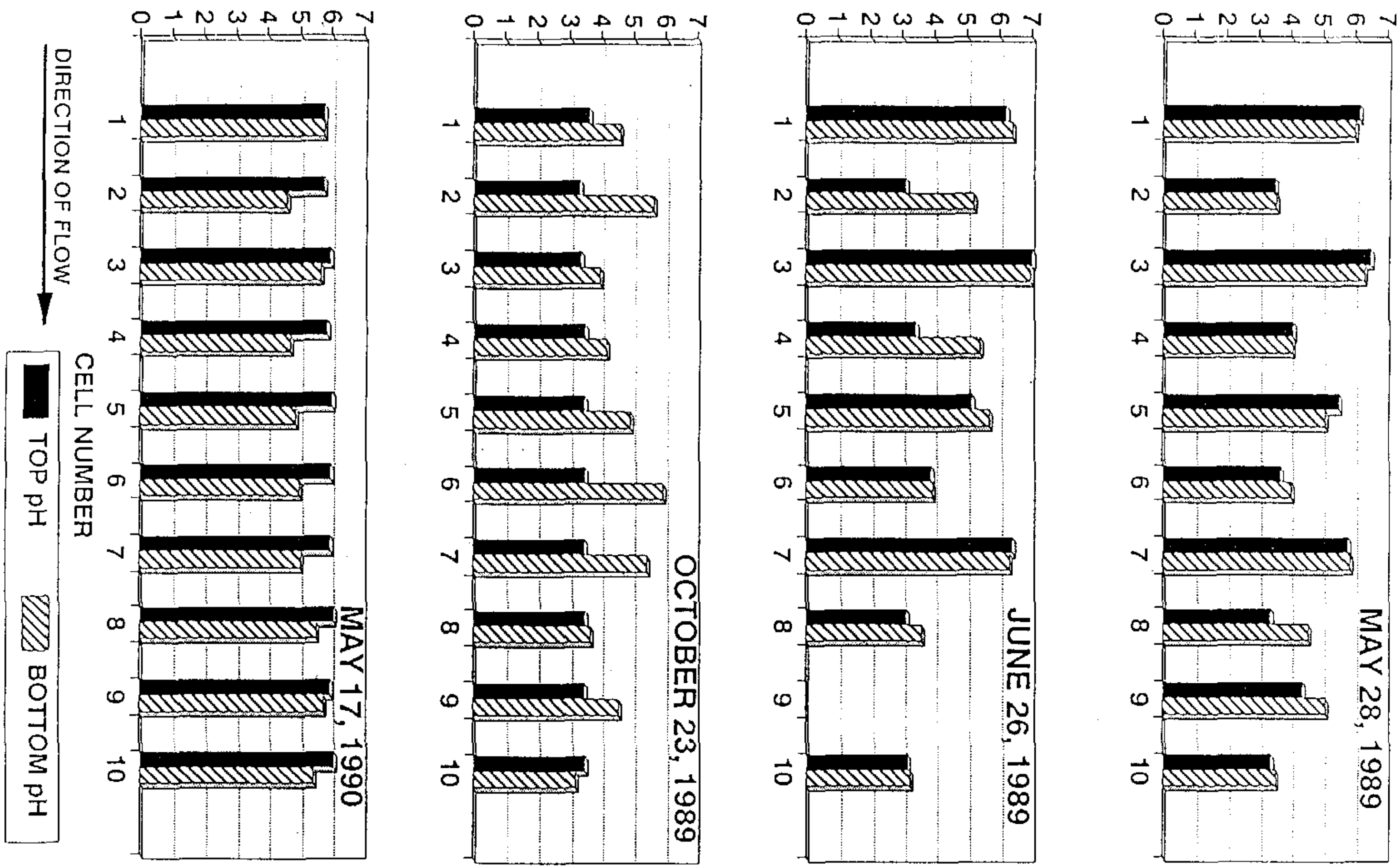
VICTORIA JUNCTION COAL PROCESSING PLANT



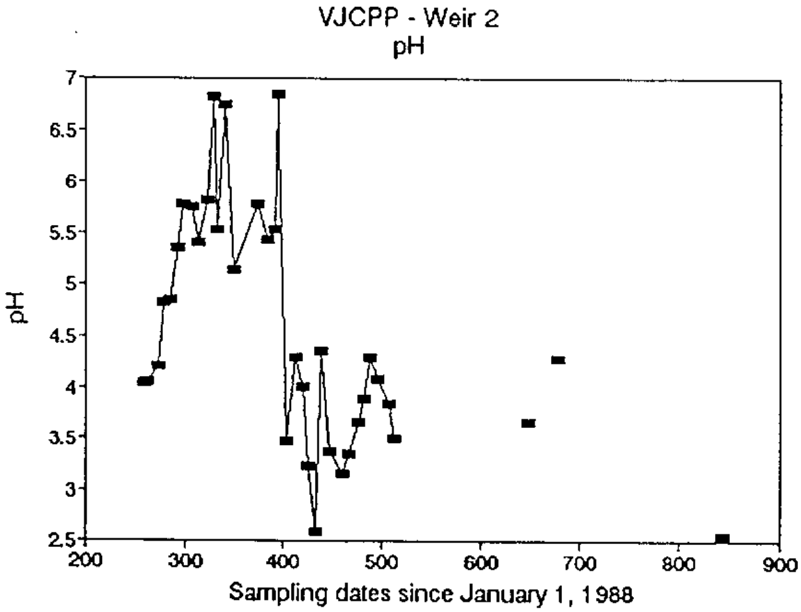

GRAND LAKE
EAST
SOUTH
WEST
N
LEGEND
ROAD
SAMPLING STATION
CLAY DIVERSION
STAND PIPE
POND OR LAKE
SCALE
0
25M
EXPERIMENTAL BOG
WATER QUALITY SECTORS

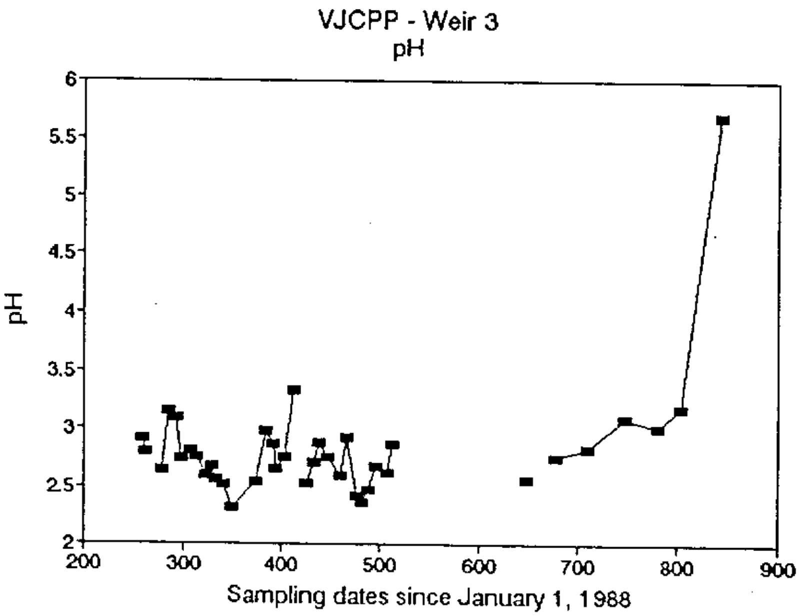

GRAND LAKE
N
TRANSECT 1
TRANSECT 2
TRANSECT 3
WATER QUALITY SECTOR
NEW BOG
L.B.C. DITCH
LEGEND
SAMPLING STATION
CLAY DIVERSION
FLOW DIRECTION
WEIR
BOG
POND OR LAKE
ALDERS
SCALE
0
25M

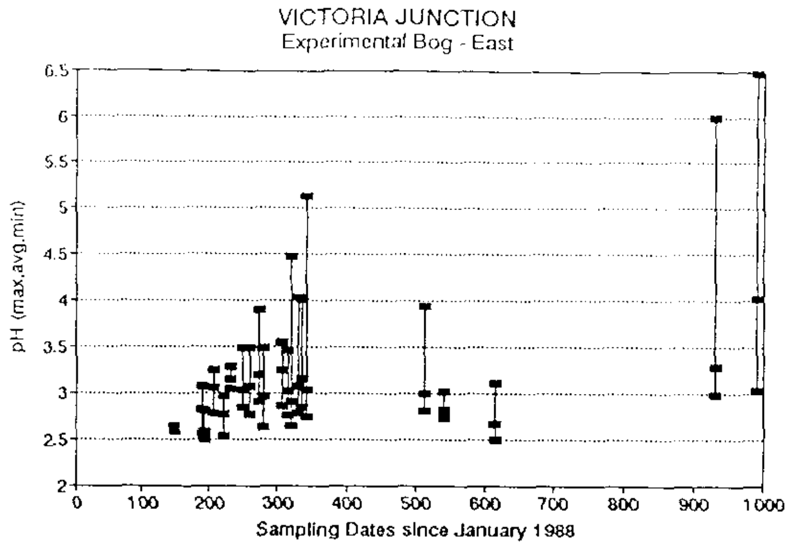
pH READING

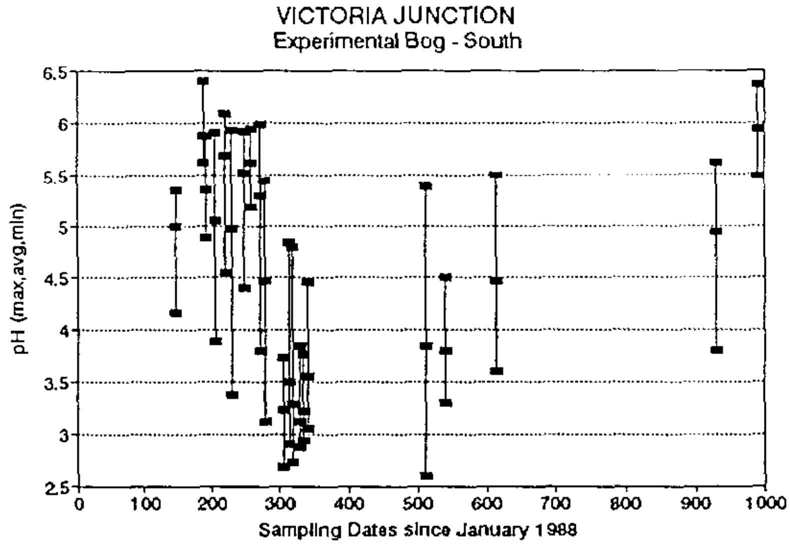


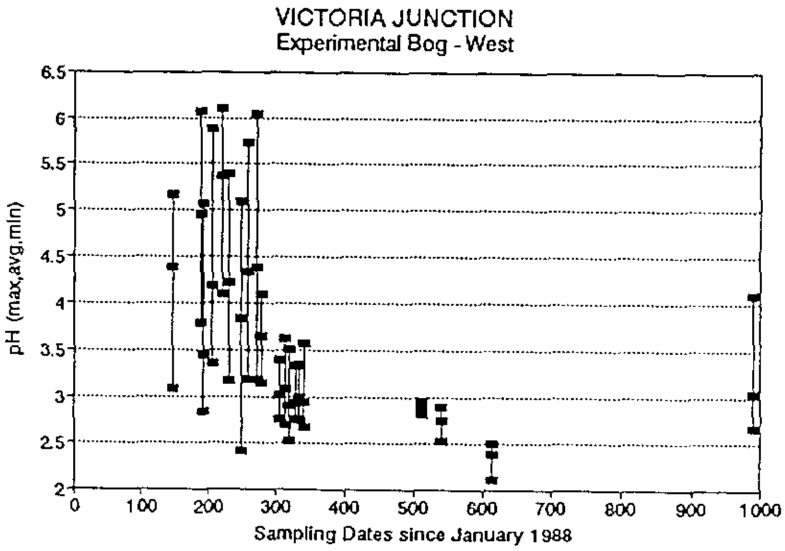
MAY 28, 1989
JUNE 26, 1989
OCTOBER 23, 1989
MAY 17, 1990
CELL NUMBER
DIRECTION OF FLOW
TOP pH
BOTTOM pH

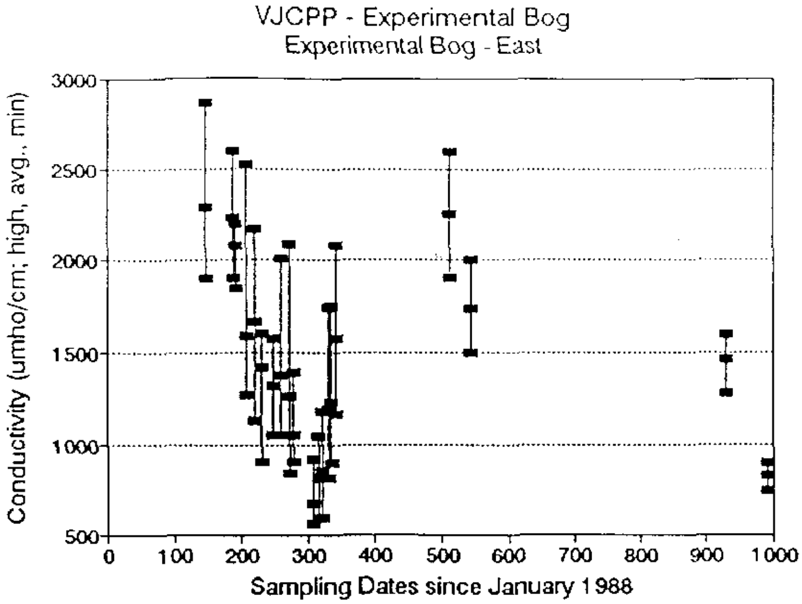

VJCPP - Weir 2
pH
pH
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
200
300
400
500
600
700
800
900
Sampling dates since January 1, 1988

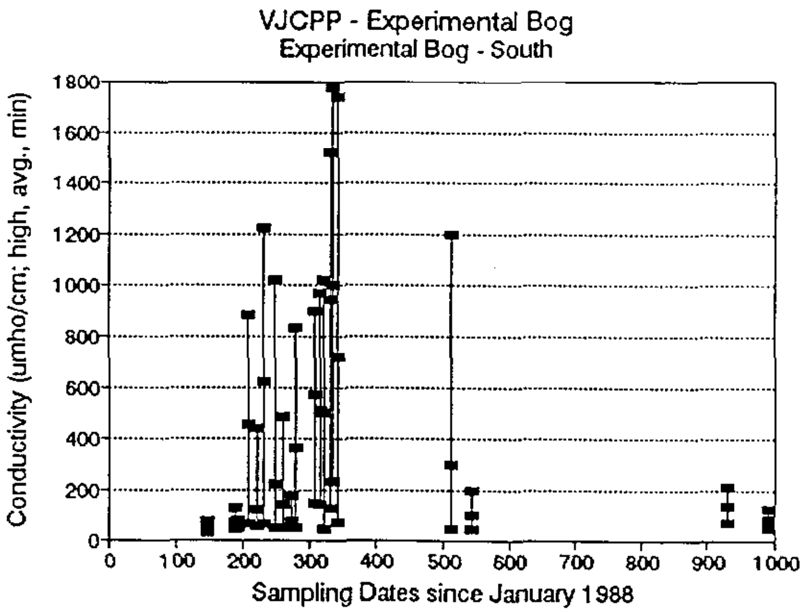

VJCPP - Weir 3
pH
pH
6
5.5
5
4.5
4
3.5
3
2.5
2
200
300
400
500
600
700
800
900
Sampling dates since January 1, 1988

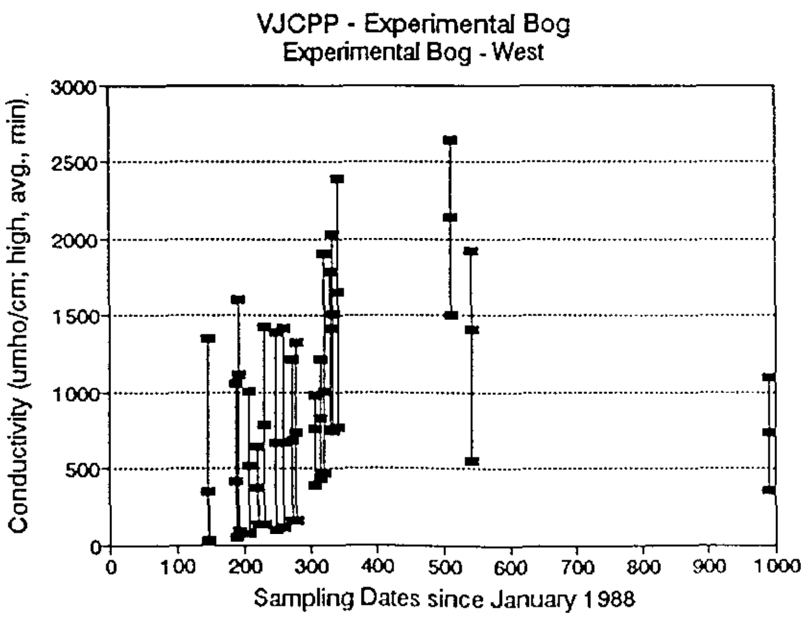

VICTORIA JUNCTION
Experimental Bog - East
pH (max,avg,min)
Sampling Dates since January 1988

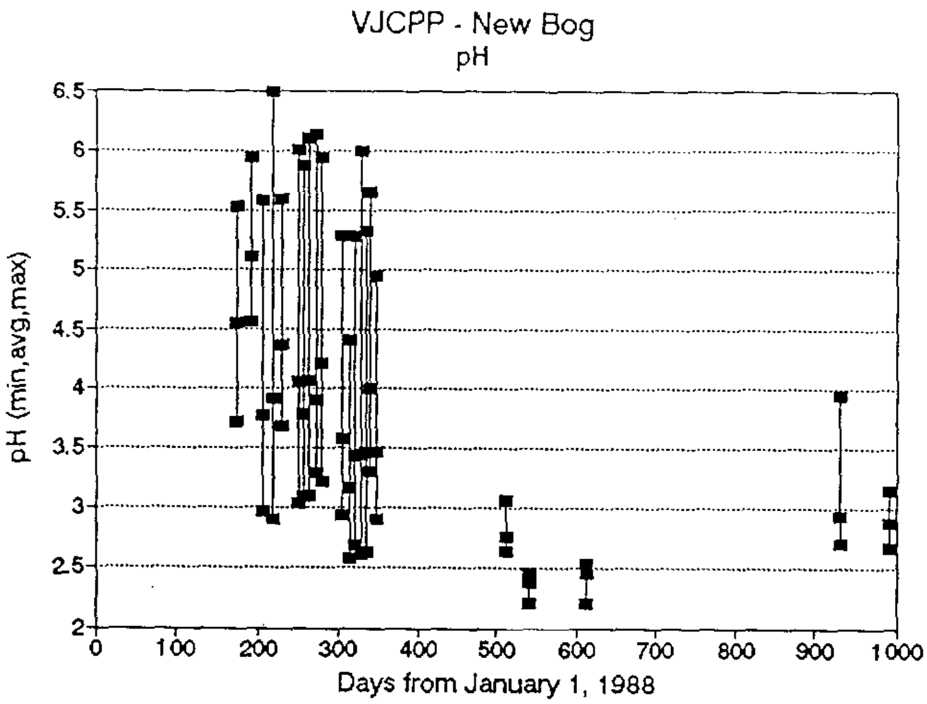

VICTORIA JUNCTION
Experimental Bog - South
pH (max,avg,min)
Sampling Dates since January 1988

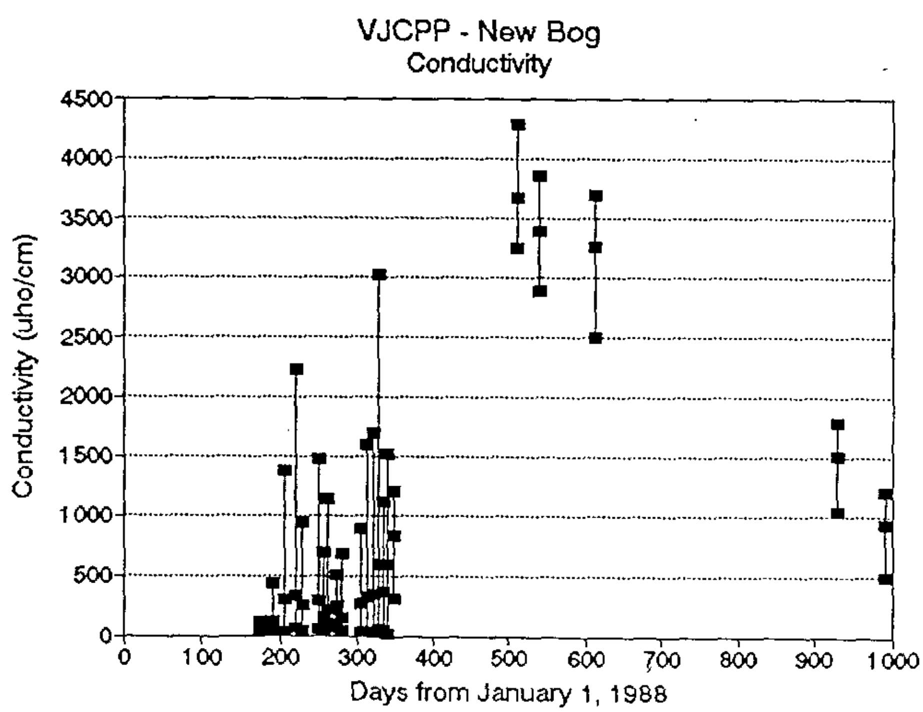

VICTORIA JUNCTION
Experimental Bog - West
pH (max,avg,min)
Sampling Dates since January 1988


VJCPP - Experimental Bog
Experimental Bog - East
Conductivity (umho/cm; high, avg., min)
3000
2500
2000
1500
1000
500
0
100
200
300
400
500
600
700
800
900
1000
Sampling Dates since January 1988


VJCPP - Experimental Bog
Experimental Bog - South
Conductivity (umho/cm; high, avg., min)
1800
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
600
700
800
900
1000
Sampling Dates since January 1988


VJCPP - Experimental Bog
Experimental Bog - West
Conductivity (umho/cm; high, avg., min)
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
900
1000
Sampling Dates since January 1988


VJCPP - New Bog
pH
pH (min,avg,max)
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
0
100
200
300
400
500
600
700
800
900
1000
Days from January 1, 1988


VJCPP - New Bog
Conductivity
Conductivity (uho/cm)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
100
200
300
400
500
600
700
800
900
1000
Days from January 1, 1988

PREPRINT

THE ECOLOGICAL RESPONSE OF A BOG TO ACIDIC COAL MINE DRAINAGE - DETERIORATION AND SUBSEQUENT INITIATION OF RECOVERY

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ABSTRACT

A floating bog in the area of a coal processing plant in Nova Scotia has been studied. The bog was naturally acidic and pristine, prior to the rerouting of acid mine drainage into the northwest corner of the bog. The acidic mine drainage appeared to kill all vegetation. One year after rerouting, there were very few plants alive. Morphological assessments of plant roots and stems indicated the plants were dead. Shortly after the AMD was shunted into the bog, work began on establishing and enhancing alkalinity generating bacteria in the bog. Tests in the laboratory confirmed the presence of ammonifying bacteria, sulphate-reducing bacteria, iron-reducing bacteria, and denitrifiers. Through the addition of carbon amendments, enclosed microbial communities in the laboratory provided alkalinity and raised pH. Forage carbon amendments were then applied to the bog proper. Within two years, pockets of alkalinity have appeared in the root zone of several areas in the bog. Redox measurements have shown reducing conditions on several transects through the bog. Cattails have returned in areas with lower AMD loading. The bog is recovering from the initial acid shock. Carbon amendments and fertilizers appear to have provided some of the necessary conditions for alkalinity generation. Ongoing research is focused on optimizing nutritional requirements for alkalinity-generating bacteria and field testing the results, thereby providing a long-term, stable solution to AMD treatment at the coal processing plant.

Keywords: Bogs, vegetation, bioremediation, cattails, alkalinity-generation, AMD

INTRODUCTION

Wetland bogs exist in a physically constrained environment. Ombotrophic bogs can be quite acidic and oligotrophic (Gore 1983). Humic acids are produced as a partial breakdown product of lignin by micro-organisms (Paul and Clark 1989). The production of these humic substances and other phenolic compounds, such as sphagnol, inhibit further microbial breakdown of peat (Dickenson 1980), thus slowing the natural cycling of carbon, nitrogen and phosphorus, necessary for productive ecosystems. Low mineral input from rainwater and virtually no mineral recycling results in a decline in productivity.

The problem is compounded by the input of acid mine drainage (AMD). AMD adds inorganic acid (sulphuric acid) and heavy metal loadings to the existing humic acids in bog water. Already physically-constrained bog vegetation is further stressed.

Natural wetlands have been described as ecosystems that can process pollutants, including AMD (Smith 1989). However, this has been rarely demonstrated. A coal processing plant in Nova Scotia has provided an ideal system in which to test this hypothesis. A naturally acidic, oligotrophic bog was found adjacent to a coal processing plant which produced AMD. Even though close to the plant, the bog was apparently not previously influenced by AMD.

The object of the work was to test the hypothesis that natural wetlands (bogs) can tolerate and ameliorate AMD. If this particular wetland could not tolerate AMD, then the subsequent deterioration in the bog water characteristics and vegetation would be recorded. If deterioration occurred, the wetland would then be engineered to handle the AMD. Our primary approach has been to develop techniques to generate alkalinity through microbial population enhancement in the bog.

Site Description

The bog is located adjacent to a coal processing plant in Sydney, Nova Scotia. The plant sorts, washes and aerates coal from several collieries in the area. Each colliery's coal has a different composition, resulting in susceptibility to AMD production.

The layout of the Victoria Junction Coal Processing Plant (VJCPP) is shown in Figure 1. Ditching around the LBC contains runoff from the perimeter of the pad. This water eventually flows into the New Bog. During normal operations, AMD from the LBC is drained into a series of holding ponds. From the last of these ponds, it is pumped into the Victoria Junction tailings basin. Runoff from a small uncontrolled portion of the LBC operation flows into an adjacent bog.

The LBC began operations in 1983. Initial description of the bog and microbiological experiments took place in the summer of 1988. In the late summer of 1988, the LBC runoff ditch was shunted into the northwest corner of the bog. The bog was amended with hay in the summer of 1989. During 1989 and early 1990, other microbiological experiments were carried out.

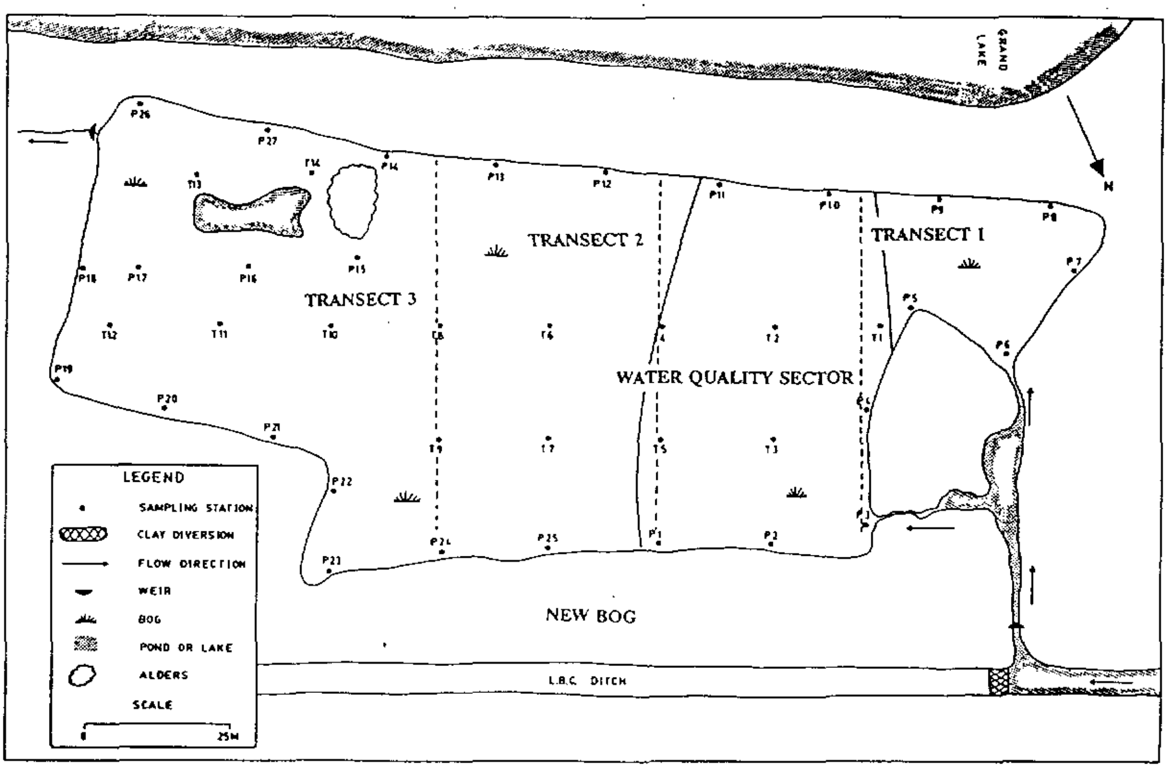

FIGURE 1: Map of the Lifting and Banking Centre bog. Dotted lines are transverse transects. and the solid transverse lines outline the water quality statistical area.

METHODS AND MATERIALS

Bog Water Characteristics

Both pH and conductivity were monitored at fixed stations throughout the bog (Figure 1) to evaluate the extent and severity of the AMD intrusion. Water samples and flow rates were also taken monthly at weirs just outside the bog. Generally, bulk water near the fixed stations was collected and its characteristics measured. Conductivity was measured using a YSI model 33 S/C/T meter. The pH was measured with either Corning model 103 or Orion SA 230 pH meters with Canlab epoxy combination electrodes. Redox (Eh) probes were purchased from Fisher and fitted to the Orion and Corning pH meters.

In 1990, three transects were set up running transversely across the bog. Twice, pH, conductivity, temperature and Eh were measured along these transects at 10 m intervals and at two depths, 0 and 30 cm.

Vegetation was measured using fixed permanent quadrats, and longitudinal transects in the bog. Plants were collected and their morphologies and physiological states were described. The roots were also sectioned for morphological/anatomical assessment. Identifications were made in the laboratory.

In July of 1990, with the reappearance of cattails in the bog, measurements were made of shoot abundance along the Eh and pH transects. All shoots within 1 metre of the transect line were counted.

Remediation Measures

Laboratory Testing

During the summer of 1989, five plastic mesh cages were set up enclosing hay in the channel at the entrance to the bog. The cages and amendment were allowed to incubate under field conditions for the summer. In September, the amendment and surrounding water were removed to the lab. The amendment and water were put into 4.2 L jars and sealed. In other experiments, the interstitial water from the field was mixed with new carbon amendment and sealed in jars. Samples were taken periodically for testing.

Because the bacterial populations in the 4.2 L jars required several months of incubation to produce significant alkalinity generation, picocosms were also set up. A picocosm is simply a sample ecosystem maintained in a small, 15 mL vial. It was hoped that these small systems would react faster to a variety of carbon and nitrogen sources as possible amendments for alkalinity generation.

Water samples from the root zone in an adjacent test area were placed in small vials and supplemented with: 1) control (no amendment); 2) alfalfa; 3) barley; 4) cooked meat; 5) glucose; 6) bran; 7) flax. The micro-organisms in these vials were allowed to develop and pHs were measured periodically.

In another set of experiments, samples of amendment from a number of sites in the bog and a nearby bog were subjected to serial extractions. This was done to ascertain how much of the amendment had naturally broken down into simpler carbon products available to bacterial populations but had not yet been utilized. Amendment, placed in the bog about 10 months earlier, was sampled as described above and returned to the laboratory. Extraction in acetone removed most of the carbon that could be metabolized to volatile fatty acids. Extraction in HCl measured that fraction that had been partially degraded and was available for bacterial use. Extraction in H_2SO_4 gave the percentage of organic amendment which would be eventually extractable by bacterial populations. After 60 days, the medium in each experiment was replaced with fresh bog/AMD water.

Field Implementation

Based on observations made in these and similar laboratory experiments, and on the economics of large-scale amendment application, hay was added to the bog in the fall of 1988 (FIGURE 2). The bog received a total of 109 bales of hay which were placed primarily along the path of the greatest water flow, down the middle from the northwest to the southeast. There were also a number of bales placed along the north side of the bog, especially around P24 (see FIGURE 1), and 12 bales were placed in the incoming water ditch near the weir (FIGURE 2).

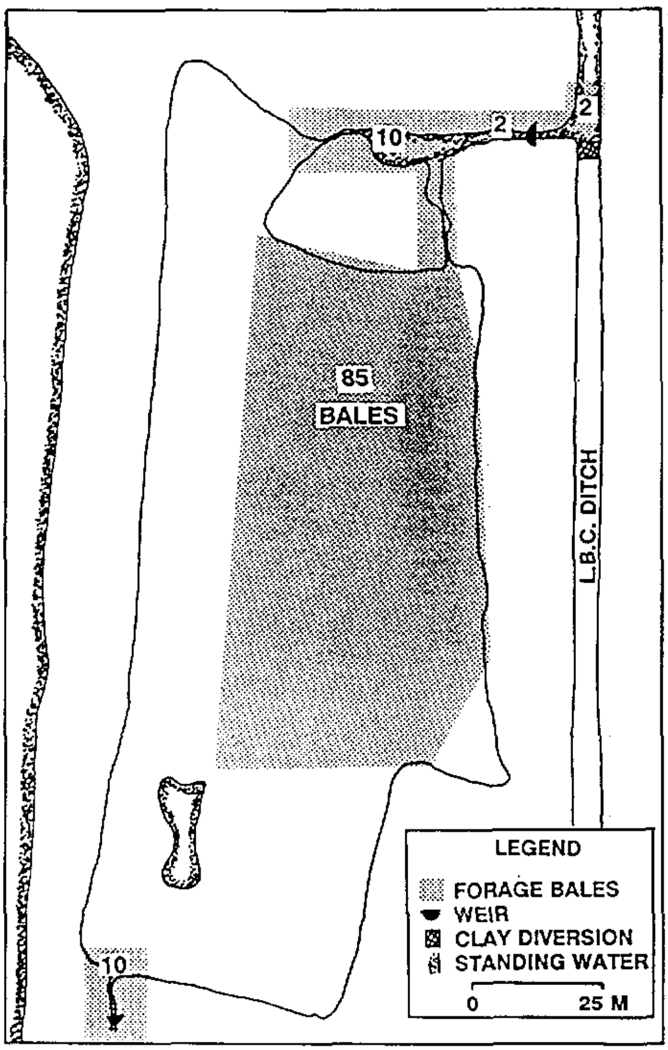

FIGURE 2: Map of the Lifting and Banking Centre bog showing the areas covered with hay amendment. Numbers indicate the number of bales.

Field Monitoring

One of the best field indicators of alkalinity generation is the presence of anaerobic conditions in the root zone at 15-30 cm depth. Anaerobic conditions can be monitored easily by the presence of hydrogen sulphide or by using redox probes. In this case, in the summer of 1990, several redox transects were made across the bog in areas with and without amendment.

To support the redox measurements, microbiological samples were collected in the field. In each case, about 1 litre of material (hay and bog water) were carefully removed from the bog and put in plastic bags. The bags were sealed, and returned to the laboratory for analysis. Analysis usually took place within 72 h of collection. Analyses included ATP assays (Adenosine Triphosphate) using the firefly luciferase method. Measurement of the ATP level of samples gives an indication of the total micro-organism population numbers.

Samples were also taken for enumeration of specific kinds of bacteria. Bacteria were plated onto Postgate B, E and F media for enumeration of sulphate reducers. Casein medium was used for ammonifiers. Iron-reducing bacteria were enumerated in a minimal salt medium containing Fe III and a mixture of peptone, yeast extract and lactate - a carbon source. Denitrifying bacteria were counted by endpoint dilution in medium containing KNO_3 and nutrient broth as per Tiedje (1982).

RESULTS

Water Chemistry

FIGURE 3A shows the pH of water flowing into the bog at weir 3. Data show that since the weir was installed in the summer of 1988, the pHs have remained low, generally between 2.5 and 3. This trend has continued, with the exception of a single data point in the summer of 1990.

Conductivities of weir water are shown in Figure 3B. Conductivities are highest in February of 1990 and lowest in January 1990. The abrupt change between January and February may represent freeze-out. In general, the concentrations vary between 4300 and 100 $\mu hos \cdot cm^{-1}$. Mean conductivities in 1990 were around 1000 $\mu hos \cdot cm^{-1}$.

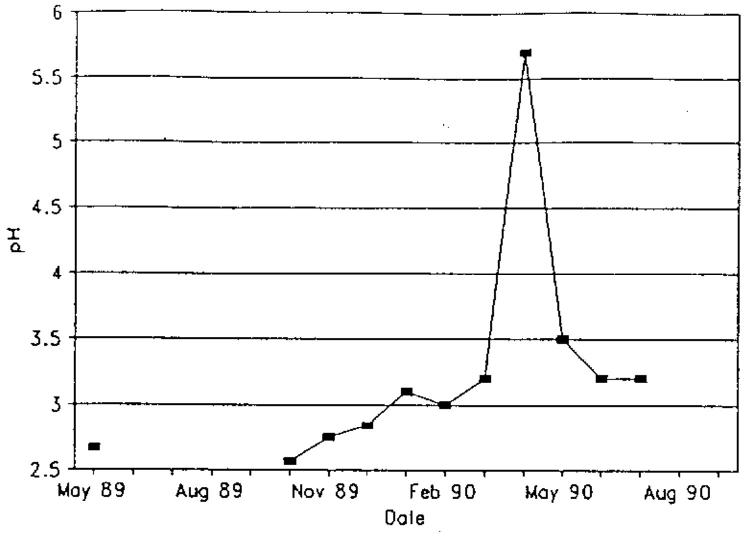

FIGURE 3: A) Water pHs from monthly samplings at weir 3, at the entrance to The bog.

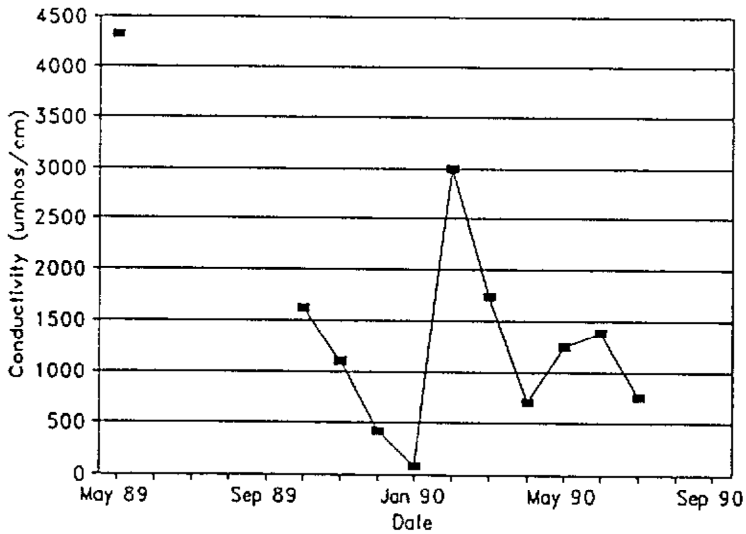

FIGURE 3: B) Water conductivities from monthly samplings at weir 3.

A pool of measurements from fixed stations at the western end of the bog provides an overall picture of water quality (see FIGURE 4A). In this sector, the pHs were initially quite normal for an acidic bog (FIGURE 4B). Data ranged from about 3.6 to 6 with a logarithmic mean around 4.5 (days 150-180). As AMD was shunted into the bog, the pHs became more erratic, especially during the fall when rains normally flood the bog. By the following spring (1989; day 500) the bog had been completely inundated with AMD, and the pHs were stable, between 2.2 and 3.1.

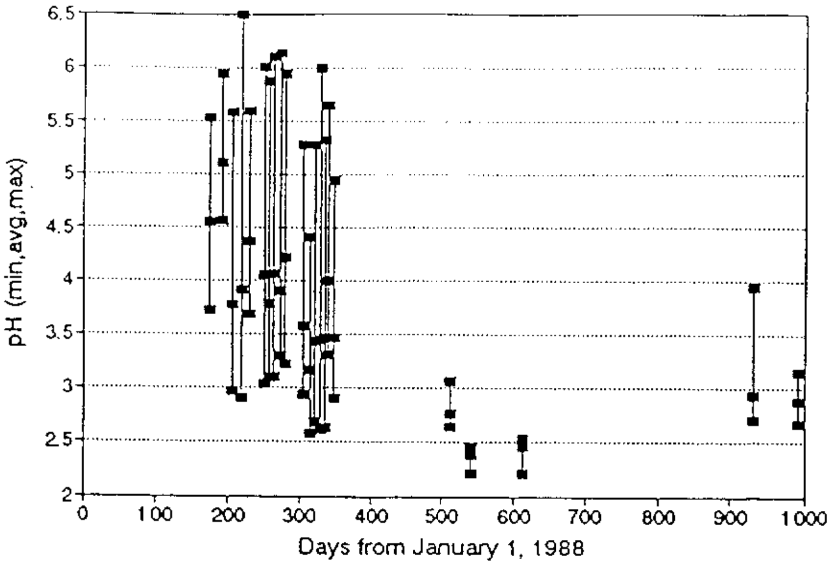

FIGURE 4: A) Water pHs in the bog, compiled from the water quality sector. Each vertical line indicates the minimum, maximum and logarithmic mean of all stations in the water quality sector on a given date.

The water conductivities in the bog mirrored the pHs (FIGURE 4B). Conductivities were initially low, indicating that the bog was initially untouched by AMD. By the latter part of 1988, however, some measurements were as high as 3000 μhos$\cdot$ cm^{-1}. During 1989 the conductivities remained high, ranging up to 4300 μhos$\cdot$ cm^{-1}.

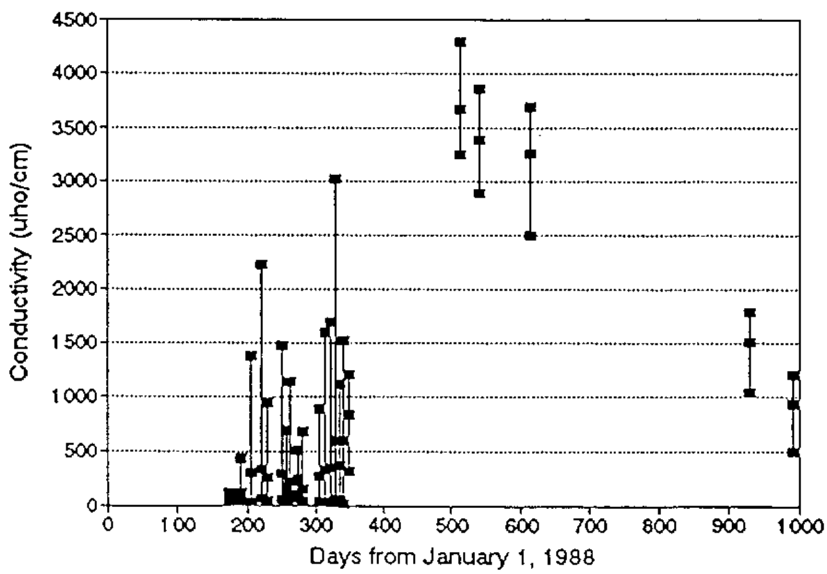

FIGURE 4: B) Water conductivities in the bog. Each vertical line indicates the minimum, mean and maximum conductivity measured from all stations in the water quality sector on a given date.

Vegetation Surveys

Before AMD intrusion, the bog vegetation was similar in species composition to others in the area. *Typha latifolia* and *Sphagnum* spp. were the most common plant in the bog hollows, with an association of *Chamaedaphne calyculata, Myrica gale, Ledum glandulosum* and *L. groendlandicum*, and *Larix laricina* quite common on the northern bog edges. *Alnus rugosa* was found growing along the southern edge near the dyke. *L. laricina* was also commonly found in the *C. calyculata* zone.

The effects of AMD on bog vegetation were striking. All vegetation in the path of the AMD deteriorated rapidly. There was little variation on a local scale, since little hummock formation was observed. At the edges of the bog, and towards the southern limit, some plants survived.

In the bog, after 1 year of AMD intrusion, deterioration was most noticeable for *Alnus* and the woody dwarf shrubs *C. calyculata, M. gale, K. angustifolia and K. polifolia, L. glandulosum and L. groendlandicum* and *L. laricina.* Examination of plant parts of these species bolstered this conclusion. In all cases, assessments were made on the basis of comparisons with control plant material. Below ground damage (roots, rhizomes, etc.) was most extensive with many of the plants showing only scattered lateral and adventitious root hair development. Many rhizomes also showed extensive signs of internal damage and death from the cortical tissue inward. Above ground parts of the plants had few leaves and much of the woody older tissue was found to be dead. The majority of shoot tips and lateral buds were also found to be dead, suggesting little hope for recovery of the plants in subsequent years (Kalin and Scribailo 1989).

Remediation

Amendment Testing - The area near the weir with amendment at pH 2.5 showed no evidence of anaerobic conditions. It also showed the fewest bacteria as shown by the ATP test (TABLE 1). The sample which showed the greatest concentration of ATP was another area near the entrance to the bog near P3 (TABLE 1). It also showed, however, the fewest denitrifiers, and the fewest sulphate-reducing bacteria. The area with elevated pH (near P24) had an intermediate ATP count, but the greatest number of alkalinity generating bacteria. Some hydrogen sulphide production was noticeable at this site. Note also that laboratory pHs taken 72 hours later were considerably higher than field pHs.

If carbon amendment is left in the bog for 3 months, and then sealed in jars, pHs also rise. FIGURE 5 demonstrates that storage in the jars produced both an immediate and a long term effect on pH improvement. Jars sealed with new amendment and old water took longer to incubate. Representative pH values in jars with old and new amendment are shown in FIGURE 5.

TABLE 1: Bog Bacterial Populations.

	VJ-WEIR	VJ-P3	VJ-P24
pH (field)	2.5	2.5	3
pH (lab)	4.1	4	5.7
ATP (ng/mL)	45	230	110
SRB (#/mL)	1E+03	1E+03	1E+05
IRB (#/mL)	1E+05	1E+05	1E+04
NH3 (#/mL)	1E+05	1E+05	1E+05
N2 (#/mL)	1E+05	1E+02	1E+05

SRB - sulphate-reducing bacteria; IRB - iron-reducing bacteria; NH3 - ammonifying bacteria; N2 - denitrifying bacteria

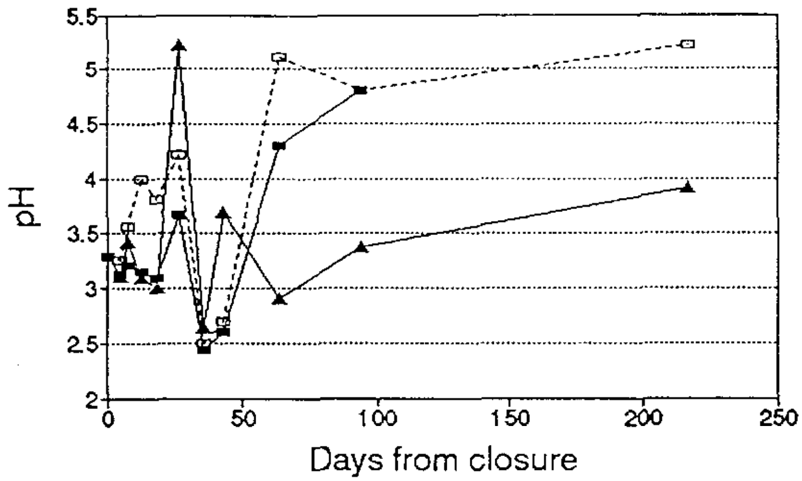

FIGURE 5: Change in pH with time in 4.2 L jars. Jars contained carbon amendment and AMD/bog water. Jar water pHs measured at given dates after closure. Old A (solid squares) and Old B (open squares) indicate that amendment received old amendment water before closure. New (solid triangles) indicates that the jar received fresh AMD/bog water at the time of closure.

By dropping the volume of the ecosystems to the 15 mL picocosms, the incubation process was speeded up. Hydrogen ion content decreased dramatically in just 2 months (FIGURE 6). In the picocosms, six different amendments and the control generated alkalinity and brought the pH of water above 6 in just over 2 months (FIGURE 6). The breach in the middle of FIGURE 6 is due to restarting the reactors with fresh AMD/bog water.

The slowest was the control vial. Here, pHs did not rise significantly until day 120. The fastest was the vial with cooked meat added. The second fastest was alfalfa. These data support the contention that VJ bog water contains ammonifiers (ammonifiers degrade meat protein to ammonia), and that nitrogen may be limiting (alfalfa is a high N forage material).

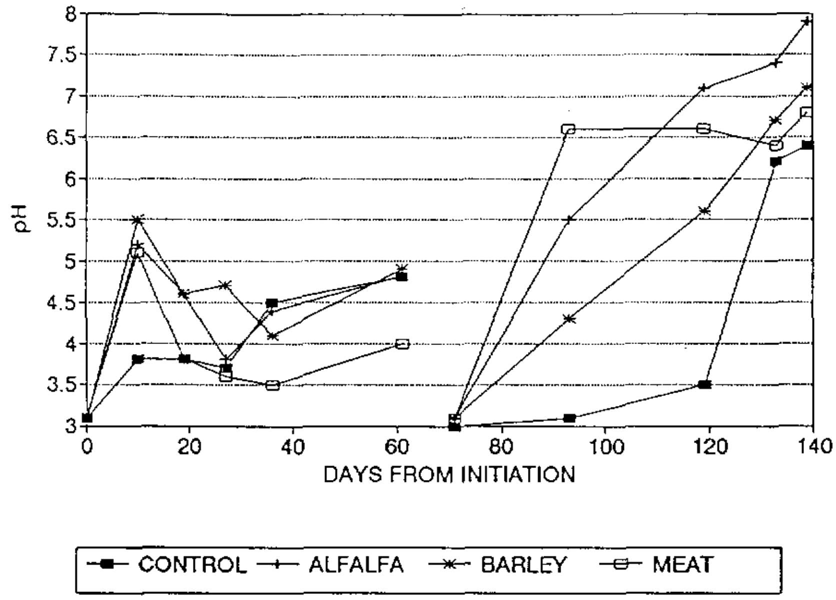

FIGURE 6: Change in pH with time in 15 mL vials. Vials contained AMD/bog water and a variety of carbon amendments. Water in the vials was replaced on day 60 and the vials restarted on day 70.

The results of the degradation analysis are plotted in FIGURE 7. This graph shows that the easily usable volatile fatty acids (VFA) are either a very small percentage of the amendment or they have already been consumed by other bacteria. This percentage seems to be independent of the time of amendment placement or the pH of the amendment/water. For example, VJE 2.5 has 6% VFA and VJE 6 has 7.2% VFA.

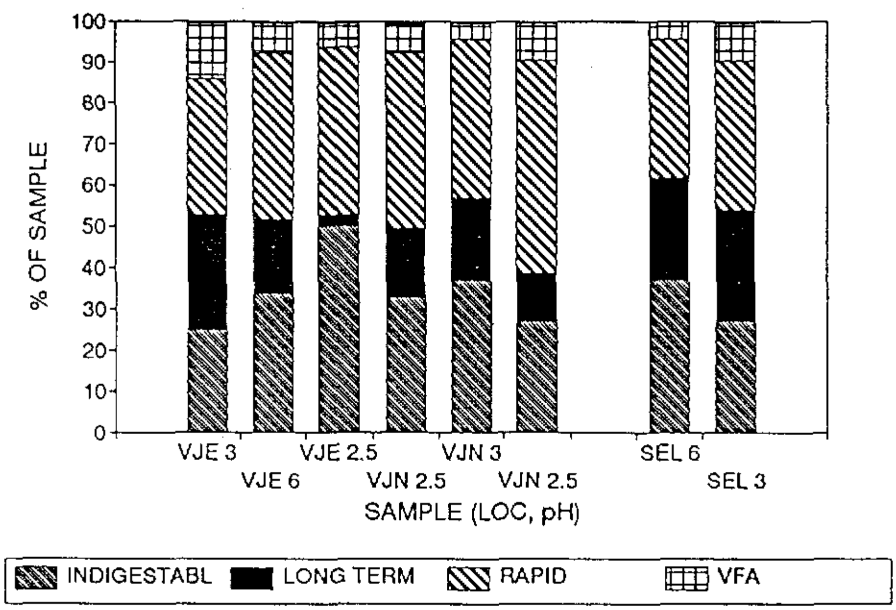

FIGURE 7: Percentage of an amendment sample which is extractable by acetone (VFA), hydrochloric acid (RAPID), and sulphuric acid (LONG TERM). That which is left over is assumed to be INDIGESTIBLE.

The percentage of rapidly usable material is also consistent between these samples (41% vs. 43%). These results suggest that very little of the carbon in the amendment has been used or converted. If the amendment were being degraded by bacteria, a shift toward larger percentages of readily usable carbon would be expected.

Field Implementation

By the summer of 1990, two years after adding the carbon amendment to the bog, there was some improvement in the bog. Water samples from the root zone in some amended areas reached pHs close to 4.0 (data not shown). Other water samples from areas outside the main path of AMD flow showed bulk water pHs greater than 3 (FIGURE 4A). Bulk water conductivities also decreased (FIGURE 4B), although this may be the result of cleaner LBC runoff.

Redox measurements from 3 transects indicated that pockets of reducing conditions existed in the amendment and other parts of the bog (FIGURE 8). A corrected Eh value of less than 300 is considered reducing (Gotoh and Patrick 1974). The second two transects at a root zone depth of 25 cm showed extensive regions with an Eh below 300 mV. Surface water was generally constant just below 600 mV, i.e. oxidized conditions. Only transect 1 (deep) showed an odd datum point at 30 m, where both the deep and surface measurements gave high (oxidized) readings. This may have been due to different mixing in the area. In general, reducing Ehs matched the path of amendment placement in the bog.

Typha latifolia plants were common in the southern parts of the bog in 1988, just before and after the AMD was shunted into the bog. By the summer of 1989, all cattails appeared dead. No new shoots were present in 1989. However, by the late summer of 1990, *T. latifolia* shoots were beginning to repopulate the bog, though only in areas outside the main flow of AMD (FIGURE 9).

DISCUSSION

The amelioration of AMD depends on microbiological alkalinity generation. The acidity in AMD is counteracted by using microbes which generate alkalinity. The microbes utilized are those naturally found in local bogs. These microbes fall into several categories (Mills et al. 1989). Some of the more common alkalinity generators are: iron-reducers, that use iron as an electron acceptor under anaerobic conditions, liberating alkalinity; sulphate reducers, which utilize sulphate in the water under anaerobic conditions; ammonifiers, which utilize organic nitrogen, converting it to ammonia; and denitrifiers, which utilize nitrate under anaerobic conditions and liberate hydroxyl ions. Table 1 shows that sulphate-reducing bacteria, iron-reducing bacteria, ammonifiers and denitrifiers are present in the bog in considerable numbers. The activity of these bacteria may, however, be quite low. Bacterial populations can be present, but not active without the proper substrate (Williams and Crawford 1983).

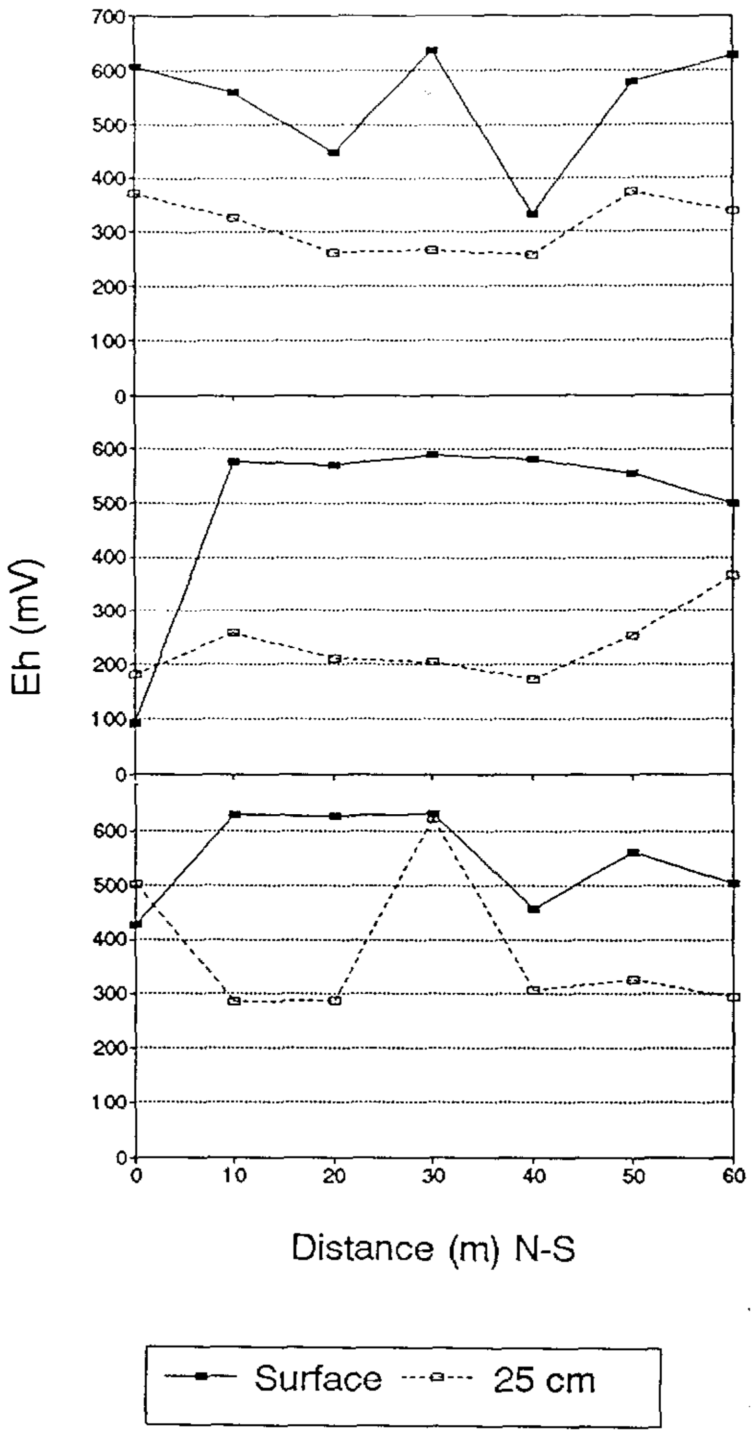

FIGURE 8: Eh transects across the bog. Samples taken at 10 m intervals, both at the surface and at 25 cm.

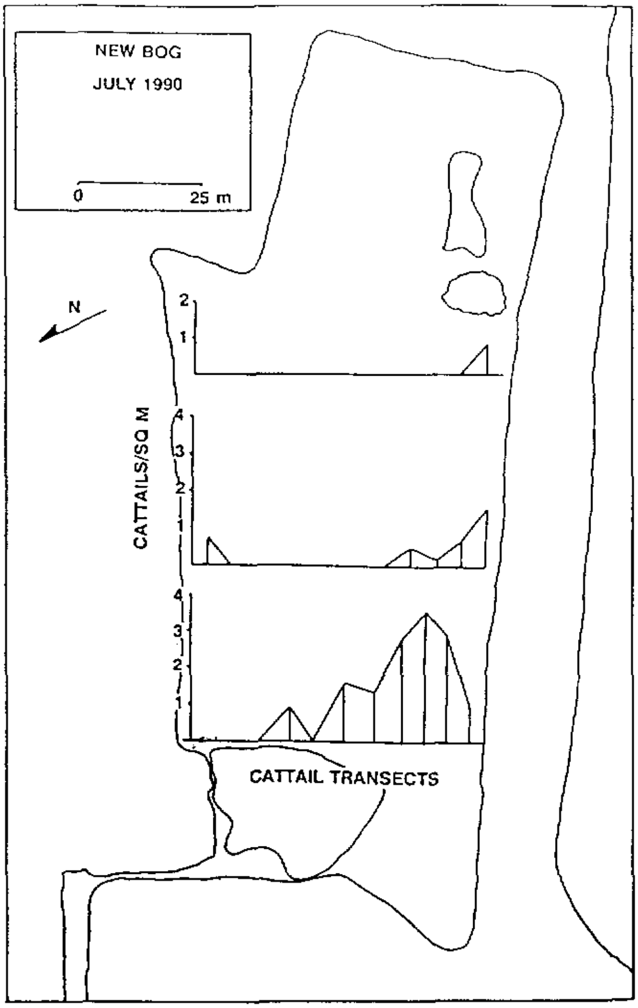

FIGURE 9: Cattail (*Typha latifolia*) transects across the bog. The number of shoots per square meter is shown for each 5 meters along the transect.

Growth of these bacteria requires a readily available and steady supply of carbon and nutrients along with anaerobic conditions. Carbon, with a small amount of nutrient, can be readily provided by using common forage materials. Thus, when forage materials are added to the bog as a carbon amendment, alkalinity can be generated. This was demonstrated in the laboratory and in the field.

Degradation analysis of the amendment indicates that the forage amendment used in the bog is not decaying as rapidly as anticipated. Readily useable forms of carbon are a small percentage of the amendments. It is likely that physical manifestations of bacterial growth (i.e. pH increases) seen in the bog are not the result of amendment breakdown, but rather, are due to the enhancement of other carbon sources, which are in turn being utilized by the bacteria.

Movement of water through the bog helps to determine whether reducing conditions are maintained (Sparling, 1966). Thus, by slowing or controlling the water flow through bogs, it may be possible to enhance alkalinity generation. It is not surprising to find, therefore, that elevated pHs in the bog were only found in areas out of the main flow pattern. Cattails have repopulated the bog, but only in areas of reduced water flow, out of the main AMD channel. Continued research is required to address the problem of water movement through the root zone and its effects on the enhancement of anaerobic conditions and therefore alkalinity generation.

ACKNOWLEDGEMENTS

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