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EVALUATION OF PEAT FOR THE TREATMENT OF ACID MINE DRAINAGE

by

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ABSTRACT

Maximum potential cation exchange capacity (CEC) and permeability characteristics were used in this investigation as criteria for the initial evaluation of seven samples of raw commercial peats as media for the treatment of acid mine drainage. The average CEC values of the peats were in the range of 0.13 to 1.05 meq/g dry peat. Vertical and horizontal flow rates differed by 10 to 120 percent for each peat. Vertical flow rates increased with increasing head pressure in five of the seven peats. Maximum vertical flow rates measured were in the range of 0.08 to 0.47 gallons per minute. Horizontal flow rates were in the range of 0.04 to 0.24 gallons per minute. Metal ion removal efficiency as a function of pH and metal ion concentration was used as the criterion for the final evaluation of four of the seven peats. Variations in the apparent removal efficiency of Fe^{3+}, Mn^{2+} and Zn^{2+} from synthetic multi-metal ion solutions were observed, although the percent removal of total metals exceeded 90% by all four peats.

Hypothetical treatment systems were designed using the experimentally determined CEC values and flow rates. The results showed that due to the low CEC values, extremely large volumes of each peat would be necessary to provide one year of drainage treatment, if cation exchange is relied upon as the sole treatment mechanism. Other mechanisms, such as filtration and sorption, however, may provide considerable treatment in addition to that provided by cation exchange, thereby reducing the required volume of peat.

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Acknowledgments

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CHAPTER I: INTRODUCTION

Acid mine drainage issuing from an estimated 10,000 abandoned and inactive metal mines presents the most difficult, perpetual, point source of pollution to control and abate in the state of Colorado (McLaughlin Industrial Wastes Engineers, 1981). Iron hydroxide coating of stream channels and high concentrations of acidity and dissolved metal ions in the discharges that are toxic to fish and other aquatic organisms have rendered 450 stream-miles barren of aquatic life. Treatment of the discharges using conventional techniques is unfeasible due to the number of drainage sites requiring treatment, limited access to the sites particularly during winter months, and lack of available funds. Given these economic and physical constraints, there exists a great need in the state of Colorado for low-cost, low-maintenance pollution abatement techniques that will provide adequate on-site treatment. One such alternative technique may be the use of artificial peat bogs.

Acid mine drainage flowing through natural peatbogs and bog-like environments has been observed to undergo reductions in metal and acidity concentrations. These observations led to the belief that artificial peat bogs might serve as an effective means of addressing the abandoned mine discharge problem (Holm, 1983) and for the treatment of acid mine drainage in general (Huntsman, et al, 1978, Anon., 1983, PEER Consultants, Inc. 1984). Installation of a bog at the discharge point could conceivably provide year-round, at-source pollution abatement without the need of frequent maintenance or elaborate equipment.

Commercial peat, i.e. peat that has been harvested and packaged, might provide an economic and efficient material with which to construct artificial peat bogs. It is readily available and relatively inexpensive. Commerical peat moss and various types of peats have been shown experimentally to be effective in removing Ag, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Sb and Zn species from various types of wastewaters (Coupal and Lalancette, 1976, Chaney and Hundermann , 1979, Lapakko and Eger, 1981).

Peat is an extremely heterogeneous material, however, and peats from different bogs are likely to possess different physical and chemical characteristics. Characteristics such as permeability, cation exchange capacity and metal ion removal efficiency may significantly influence the effectiveness and design of a peat-based treatment system. A prior evaluation of these characteristics, however, could conceivably reduce the possibility of over- or under-designing a system, or choosing a peat that is unsuitable for the conditions under which it is to be used.

The objective of this investigation was to develop a simple testing methodology for the evaluation of raw commercial peats from different sources. Cation exchange capacity, permeability characteristics and metal ion removal efficiency were chosen as the criteria by which the peats were to be evaluated and laboratory analyses were devised or selected for the evaluation. The results of the various types of analyses were then used to form the basis of a testing methodology for future evaluations.

A final note on the use of the term "peat" is included here for the purpose of clarification. According to H. A. Lavarin of the Canada Department of Mines and Resources (1946), the term peat moss refers to unhumified Canadian peat products, unhumified meaning the dead, slightly humified moss of Sphagnum mosses. Hypnum peat refers to "the residue of the moss hypnum" (Lavarin, 1946). The American Society for Testing and Materials (1969) uses the terms sphagnum moss peat or peat moss and hypnum moss peat in reference to what appears to be the same materials as those of the Canadian description. In this thesis, the term "peat" has been used in reference to the commercial products labeled "peat moss" (Sphagnum and hypnum). The terminology used to describe the materials used by cited authors reflects the authors' choices of terminology.

CHAPTER II: BACKGROUND

Peat is a general term applied to the complex mixture of organic and inorganic materials that represent the various stages of decomposition of plant and animal matter. The organic matter in peat is chemically classified into nonhumic substances (composed of chemically recognizable compounds) and humic substances (high molecular weight, acidic, amorphous compounds). The humic substances, which represent the bulk of the organic matter in peat, are composed of humic acids, fulvic acids and humins. The humic fractions differ in solubility as a function of pH, molecular weight and functional group content, although they all contain an abundance of carboxyl (-COOH) and phenolic hydroxyl (-OH) functional groups that are capable of chemically reacting with dissolved metal ions and hydrous oxides. The mechanisms whereby this chemical reaction takes place, however, have been the subject of much speculation. Cation exchange, surface adsorption, and complexation/chelation are the mechanisms most frequently cited (Schnitzer and Khan, 1972).

Cation exchange and complexation/chelation mechanisms are closely related in that they both appear to involve the displacement of the H^+ ions of the acidic functional groups present in humic acids. Evidence favoring this hypothesis is the reduction in pH (increased H^+ion concentration) of solutions containing various cationic species passed through the peat accompanied by a proportional loss of the cations from the solution. Complexation and cation exchange reactions are pH-dependent, the extent of reaction increasing with increasing pH, with an optimum range of pH 3 to pH 6-8. At low pH values (3.0), metals are leached from the peat (reverse exchange); at pH values above 6, humic acids are soluble and the peat begins to disaggregate. The total exchange capacity of a peat is dependent upon its humic acid content and the concentration of functional groups present (Manskaia, et al., 1956, Szalay, 1964, Ibarra, et al., 1979). Carboxyl group contents of 1 meq/g dry peat and 3.7 meq/g humic acid have been reported (MacCarthy, 1977, Ibarra, et al., 1979). Total exchange capacities reported by Given and Dickenson (1975) are 20-200 meq/100 grams of dry peat. Fuchsman (1980) reported hydrogen exchange capacities of 170.0, 286.3 and 400 meq/100 grams of humic acid at pH values of 4.5, 6.4, and 8.1, respectively.

Ong and Swanson (1958), however, found that the metal fixation ability of peat and lignite increased after the humic acids had been extracted, and concluded that the primary removal mechanism was surface adsorption between positively charged ions (in solution) and a negatively charged surface (the peat). The surface is believed to be negative because anions are not removed by peat. Removal of the humic acids appeared to increase the available surface area and thus increase the capacity of the peat to adsorb cations. Reduction in surface area caused by compaction during metamorphism was cited as further evidence of this mechanism when the sorption capacities of peat, lignite, and bituminous coal were found to decrease in order of increasing coalification. Since coalification is a reduction process which results in the loss of oxygen, however, a reduction in the carboxyl group content of the organic material with increasing coalification might also have been responsible for this apparent trend.

Prediction of adsorption preference from multi-metal ion solutions was correlated by Ong and Swanson (1958) to the ionic potential of the aqueous metal ions present in the solution. Ionic potential is the ratio of the ionic charge (Z) of the metal cation to its radius (r), Z/r. The greater the ionic potential the greater the preference for adsorption. In a multi-metal ion solution, adsorption sites will be filled in order of decreasing ionic potential until all sites are saturated. The concentrations of the individual ions may also be a factor. This also applies to cations already adsorbed onto the peat surface, which can be replaced by ions of greater ionic potential in the solution. According to Ong and Swanson, this explains the cation exchange phenomena. At pH values less than 3, however H^+ is predominantly adsorbed over all other cations in solution.

The sorption characteristics (sorption implying both chemical and physical processes) of a particular peat are expressed by several authors (Ibarra, et al., 1979, Szalay, 1964, and others) by its sorption capacity and its geochemical enrichment factor (GEF). Sorption capacity and GEF are obtained from the plot of metal ions adsorbed vs equilibrium concentrations of aqueous metals. These curves generally rise very steeply at dilute concentrations and flatten out as concentrations continue to increase (Figure 1). The point at which the curve ceases to rise is the maximum sorption capacity. The GEF is the equilibrium ratio of adsorbed to aqueous ions in dilute solutions at pH 4.5-5. It is derived from the tangent of the curve at its steepest point.

The efficacy of peat moss and peat as wastewater treatment media have been evaluated from the treatment of

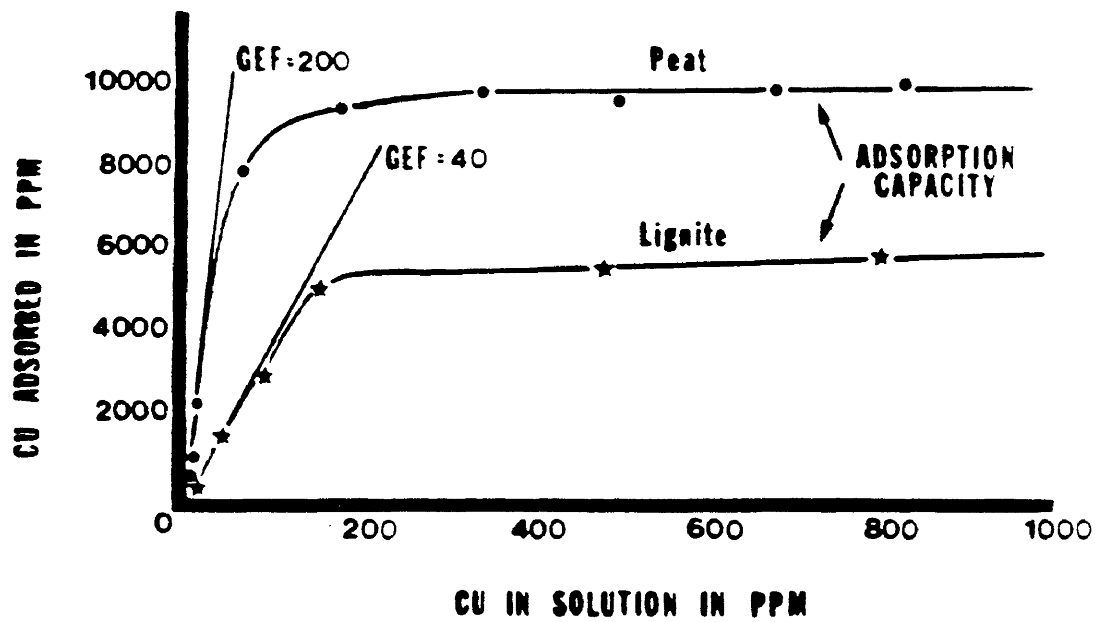


Figure 1. Derivation of the geochemical enrichment factor and adsorption capacity for copper on peat and lignite from graph of equilibrium concentration of Cu^{2+} adsorbed onto organic matter against the equilibrium concentration of Cu^{2+} in solution after adsorption at pH 4.5. (Taken from Ong and Swanson, 1958)

electroplating wastewaters (Chaney and Hundermann, 1979) and runoff from mine tailings stockpiles (Lapakko and Eger, 1981). Columns of commercial sphagnum peat reduced dissolved Cd concentrations by approximately 90% from synthetic cadmium cyanide solutions (simulated electroplating wastes) initially containing 100 mg/l Cd. Particulate Cd was also effectively removed from solution by filtration through the peat. Permeability of the peat was sufficiently high to allow rapid infiltration of the influents. The pH of the effluents, however, was depressed from initial values of 7.5-10.5 to a final range of 3.2-4.1. Peat collected from a black spruce bog in northeastern Minnesota reduced Ni, Co, Zn, and Cu concentrations by 92% from synthetic multi-metal ion solutions and tailings pile runoff samples (Lapakko and Eger, 1981). (Results were expressed as a reduction in CEU, where CEU = copper equivalent units = [Cu] + [Co] + 0.1([Ni] + [Zn]). CEU is an expression of the combined toxicity of the four metals.) Permeability of the peat was enhanced by the addition of sand or tailings. The pH of the effluents was depressed by peat alone; the addition of tailings to the peat columns, however, alleviated the problem. Apparently the buffering capacity of the tailings was sufficient to neutralize the acidity of the peat.

Investigations by Matsuda, et al. (1975) and Lanlancette (1976) indicate that peat also provides an efficient means of removing Hg, Fe, Cr^{6+}, Cr^{3+}, Ag, Pb, and Sb from wastewaters.

The use of peat and peat moss as a means of treating acid mine drainage thus appears justified. Commerical peats (or peat mosses), those which have been harvested and packaged, are particularly attractive since a wide variety of peat types are readily available at low cost and they are easily transported to the drainage site. The considerable variability in the physical and chemical characteristics of peat mosses from different sources, however, requires that an evaluation of the various peats available be conducted prior to selecting a particular peat for incorporation into a treatment system.

CHAPTER III: DEVELOPMENT OF THE TESTING METHODOLOGY

The objective of this investigation was to develop a simple testing methodology whereby different peats could be evaluated as media for the treatment of acid mine drainage. Data derived from the evaluation would facilitate the selection of the most suitable peat sample from a variety of available peats and would also provide the basic information necessary for designing an efficient treatment system that would incorporate the final peat selection.

The primary function of peat in an acid mine drainage treatment system is to remove metal ions from the waste stream. For the system designer, this function therefore requires that both the mechanical (or physical) and chemical properties of the peat be examined. The peat must be sufficiently permeable to accomodate the flow rates of the waste stream in a fashion that will provide a stable, uniform distribution of the stream through the bog, i. e. without floating of the peat or channelizing of the waste stream. A uniform distribution of the stream through the peat will provide the most efficient use of the peat and the most efficient treatment of the drainage. The permeability characteristics of a peat must therefore be well known prior to the construction of the "bog". Permeability characteristics described in the literature are based upon observations of flow through peat columns - i.e. the vertical permeability of peat in a closed system under pressure (head pressure) (Chaney and Hundermann, 1979; Lapakko and Eger, 1981). Observations of flow through peat in an open system where the dominant flow pattern was horizontal (parallel to the open surface), however, strongly indicated that the permeability of peat may well be a function of the type of flow to which it is subjected in addition to such factors as bulk density and degree of compaction (Guertin, et al., 1985). Determination of the permeability characteristics in one type of system may or may not be representative of the peat's permeability under a different set of flow conditions. Therefore the permeability characteristics of the peat samples in both types of systems (vertical/closed and horizontal/open) were examined in this evaluation.

The ability of peat to remove metal ions from the waste stream is also crucial to the design process and the ability of the treatment system to meet treatment objectives. Cation exchange capacity (CEC) was chosen as a means of obtaining an initial estimate of a raw peat's <u>potential ability</u> to remove metal ions from solution.

An estimate of the maximum potential CEC of each peat was obtained by titrating a water-slurried sample of the peat with a strong base. This titration is a simple test wherein the available H^+ ions present in the peat are neutralized by the base. The concentration of H^+ ions determined by the titration is taken as an estimate of the concentration of available exchange or complexation sites (the carboxyl and hydroxyl functional groups) in the peat.

Sites that are occupied by cations other than H^+ ions do not participate in the neutralization reaction, although sites occupied by Na^+, for example, would be available for exchange with Fe, Mn or Zn species in acid mine drainage.

For the purpose of endorsing this technique as a part of the testing methodology, the titration-determined CEC's of some of the raw test peats were compared to their H^+form CEC's. An increase in the CEC following conversion to the H^+-form would strengthen the assertion that the titration-determined CEC was a reliable indication of the concentration of available exchange sites, and thus an initial estimate of a raw peat's potential ability to remove metal ions from solution. Further confirmation of the technique was to be provided by analyzing the eluates from the H^+-form peats and by comparing the ash contents of the H^+-form peats to those of the raw peats.

Routine chemical analyses of the peat samples considered to be representative of the peat samples used in the investigation were obtained from the various suppliers. These analyses indicated that Fe, Mg and Ca were the dominant metal cations present in the various peat samples. The acid eluates were therefore analyzed by atomic absorption spectroscopy for their Fe, Mg and Ca contents.

The presence of cations other than Fe, Mg and Ca and other inorganic materials may also affect the CEC of a peat. Presumably, the higher the inorganic content of the peat, the lower its CEC as estimated by titration with NaOH. Acid-washing alone, however, cannot indicate the total inorganic content of a peat. This was determined by ashing the raw and acid-washed peat samples and comparing the results with the sorption capacity and Fe, Mg and Ca contents previously determined.

The metal ion removal characteristics of a peat cannot be extrapolated from the acid-base titration because the titration reveals only the approximate quantity of available exchange sites and not the "quality" or nature of the sites. (Different sites react or bond differently to different metals; bonding ability or strength is also influenced by the chemical environment of the exchange site.) (Irving and Williams, 1948; Kitchener, 1961). While the determination of the nature and environment of the exchange sites in peat far exceeds the scope of both this investigation and the proposed testing methodology, the metal ion removal characteristics of individual peats can be simply and empirically determined.

Because of the importance of this characteristic to the ability of the treatment system to meet treatment objectives, the determination of metal ion removal efficiency was included in the testing methodology as the criterion for the final evaluation of peats.

CHAPTER IV: EXPERIMENTAL DESIGN

Materials

The proposed testing methodology was applied to a series of six commercial sphagnum peats. Sphagnum peat was chosen because live Sphagnum shows the highest CEC of any recorded plant (Clymo, 1963). Since the high CEC of the live plant is retained after the death of the plant (Bell, 1959, Clymo, 1964), pure sphagnum peat seemed the logical choice. Hypnum peat, a peat formed in alkaline environments, was included in the investigation for comparative purposes (Table 1). The peat samples were purchased from commercial suppliers in the metropolitan Denver area. The samples used in the testing procedure were taken directly from the bags and used in their raw forms without pretreatment of any kind.

Table 1. Brand names and suppliers of peat samples used in this investigation.

Peat	Supplier
Alberta Rose	Hood Mfg. Enterprises, LTD Edmonton, Alberta, Canada
Beaver	Fisons Western Corp. Seba Beach, Alberta, Canada
Emerald	Saskatchewan Minerals Peat Moss Division Carrot River, Saskatchewan Canada
Garden O'Plenty	(same as Emerald)
Premier	Premier Brands, Inc. New York, NY (mined in Winnipeg, Manitoba, Canada)
Sunshine	Fisons Western Corp. Vancouver, B.C., Canada
Repeat (hypnum)	Eli Colby Co. Lake Mills, Iowa

Determination of Peat Permeability for Aqueous Solutions

Vertical permeability characteristics were initially observed using the apparatus shown in Figure 2a. The time required for the top of the 12-in. column of water to reach the top of the upper gravel layer was recorded and used as the basis of the comparison of the vertical permeabilities of the seven samples. Each test was repeated 10 times with the same sample of peat to assess the susceptability to compaction of the peat in the column.

Vertical flow rates for each of the seven peat mosses were recorded using the apparatus shown in Figure 2b. Head pressures were varied by varying the height of the column of water above the peat from 0 inches to 48 inches in increments of 12 inches. Water was supplied to the column via a 5/8-inch diameter garden hose connected to a water tap. Flow measurements for each head pressure level were recorded after the head had been maintained for 1 hour. The head pressure at each level was maintained by a series of one-inch diameter holes drilled into the column, one hole at each of the twelve inch increments. Any excess flow into the column was thus released from the column through the appropriate outlet. The excess flow out of the column was projected away from the collection basin (at the bottom of the column) by forcing it through

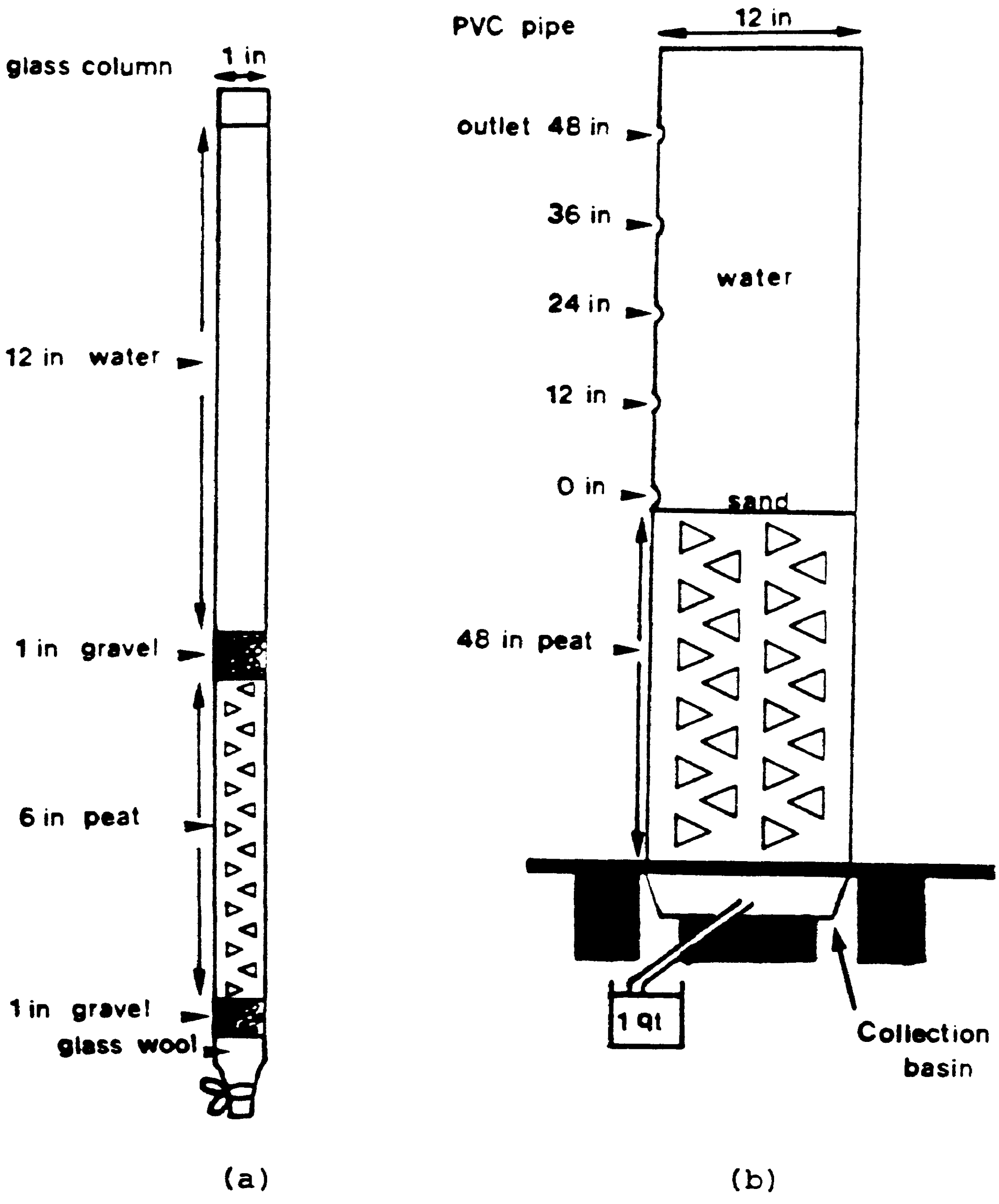


Figure 2. Apparatus for observing vertical permeabilities and flow rates.

an eight inch length of half-inch diameter Tygon tubing. The tubing was held in place (approximately normal to the wall of the column) by inserting it through a one inch diameter rubber stopper placed in the outlet. When the height of the water column was increased to the next level, the lower hole was closed with a solid rubber stopper. Water flowing through the peat column flowed into a collection basin, and into a calibrated collection vessel. The time required to collect 1 quart of water was recorded at each level and converted to gallons per minute (gpm).

Horizontal flow rates were determined using the apparatus shown in Figure 3. The trough was inclined at a 5.45° angle from the horizontal, which was the minimum angle required to establish actual flow through the water-saturated peat. No flow could be established when the trough was in the horizontal position. The peat was allowed to equilibrate in the trough for several hours, at which time the flow rate was determined by the timed collection of 1 quart of water.

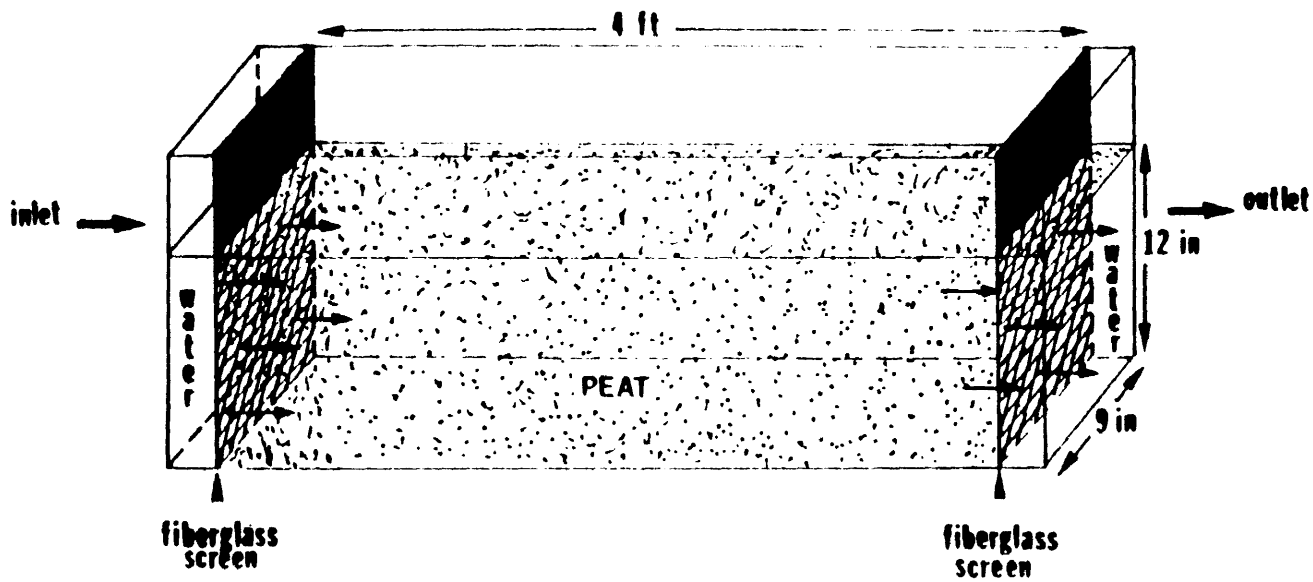


Figure 3. Apparatus for observing horizontal flow rates. Trough was inclined at an angle of 5.45 degrees.

Determination of Raw-form Cation Exchange Capacity

Approximately 100 grams of raw peat were roughly homogenized by stirring with a glass stirring rod in a large beaker. From the homogenized sample, one 5-gram and four 2-gram samples were weighed into glass beakers. The 2-gram samples were dried to constant weight at 70°C and the moisture content calculated. The 5-gram sample was saturated with sufficient deionized water to produce a slurry. The slurry was titrated with a standardized 0.1N NaOH solution to a pH of 10. The slurry was gently stirred with a magnetic stirring bar for 1 minute and allowed to rest for 1 minute before the pH of the slurry was recorded. pH values were obtained using an Orion research analog pH meter, model 301, equipped with a KCl-gel-filled conventional combination electrode, model 91-05. Successive aliquots of NaOH were made immediately after recording the pH. The CEC was calculated over a range of pH values from a plot of pH vs ml NaOH added for each titration. A sample titration curve and calculations are shown in Appendix 1.

Determination of H^+-Form Cation Exchange Capacity

A 30-cm long, tared glass column, 1-cm in diameter, was filled with homogenized, raw, dry peat and weighed. The peat was held in place by a small plug of glass wool inserted into the bottom of the column. A stopcock was attached to the column using a 1-in. length of Tygon tubing. The sample was then thoroughly saturated with deionized water, followed by 100 ml of 3M HCl, passed through the sample at approximately 1 ml per minute. This was followed by repeated rinsing with deionized water until the effluent showed no trace of chloride as determined by the addition of HNO_3 and $AgNO_3$. The acid eluate and washings were collected, brought to a known volume and saved for analysis. The acid-washed peat was removed from the column, slurried in a beaker with deionized water and titrated with 0.1N NaOH as previously described. The CEC was calculated from the titration curve and compared to the capacity of that peat in its raw form.

Determination of Ash Contents

The ash content of the raw peat was determined by weighing four 5-gram samples of homogenized peat into tared porcelain crucibles, drying at 70°C for approximately 8 hours to constant weight (for determination of moisture content) followed by ignition at 550°C in a muffle furnace for approximately 12 to 15 hours to constant weight (A.S.T.M., 1979). Acid-washed samples were prepared as previously described, with the exception of placing the prepared samples into tared crucibles rather than slurried in beakers. The samples were then ashed to constant weight at 550°C.

Determination of Metal Ion Removal Characteristics

The metal ion removal characteristics of four of the seven peat samples were examined as a function of pH and total metal ion concentration using multi-metal ion solutions of Fe^{3+}, Mn^{2+} and Zn^{2+}. The concentrations used are shown in Table 2. Fe, Mn and Zn were chosen because they represent the major constituents in the acid mine drainage in the Front Range mining districts (Ramirez, 1976). Stock solutions of 0.1<u>M</u> Fe^{3+} and 0.01 <u>M</u> Zn^{2+} were prepared by dissolving the appropriate weight of each metal nitrate salt in deionized water and diluting to 1 liter. A 0.01 <u>M</u> Mn^{2+} stock solution was prepared from a 50% (w/w) liquid reagent of $Mn(NO_3)_2$. The Zn and Mn stock solutions were

Table 2. Concentrations of Fe^{3+}, Mn^{2+} and Zn^{2+} in experimental multi-metal ion test solutions.

	Moles/Liter			Meq/Liter			mg/Liter (ppm)		
Solution	(Fe)	(Mn)	(Zn)	(Fe)	(Mn)	(Zn)	(Fe)	(Mn)	(Zn)
a*	0.02	0.002	0.002	60.0	4.0	4.0	1120.0	110.0	130.0
b*	0.01	0.0001	0.001	30.0	2.0	2.0	560.0	55.0	65.0
c*	0.001	0.0001	0.0001	3.0	0.2	0.2	56.0	5.5	6.5
a	0.01	0.003	0.003	30.0	6.0	6.0	560.0	165.0	195.0
b	0.001	0.0003	0.0003	3.0	0.6	0.6	56.0	16.5	19.5

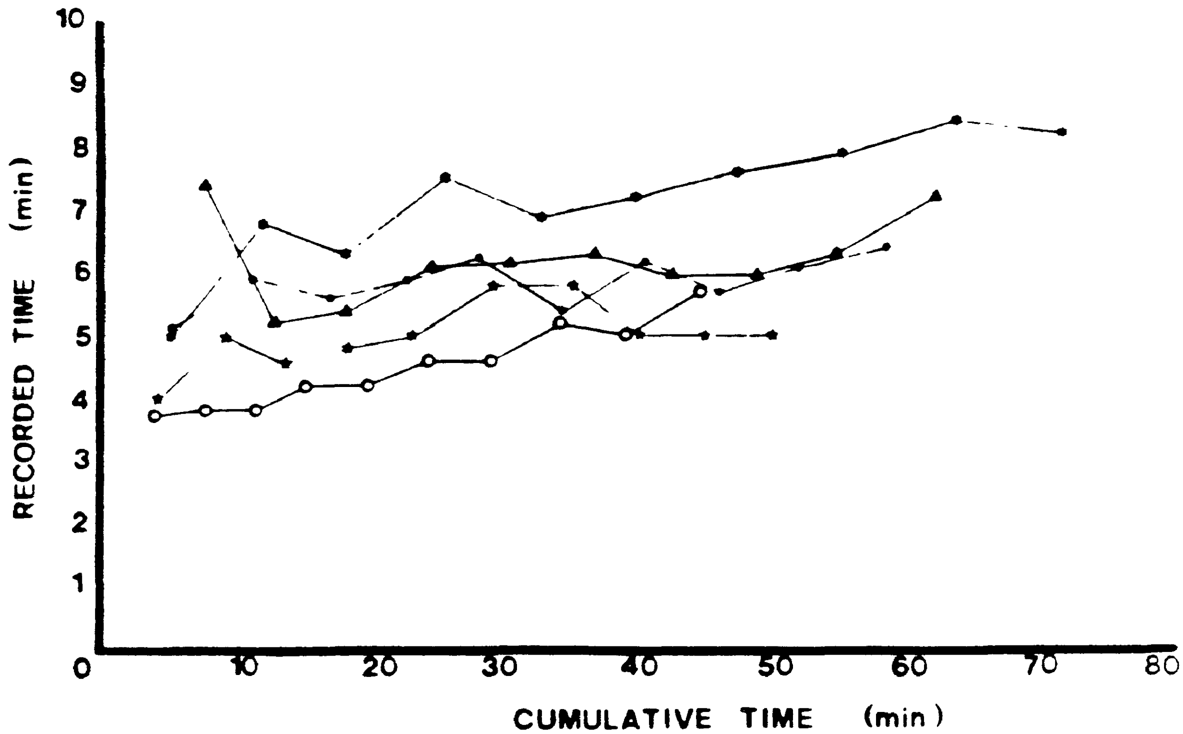
* Used on Premier only.

standardized by ion exchange (Ansted, 1982). The Fe stock solution was standardized using a slightly modified version of the method outlined by MacCarthy (1971). (A muffle furnace was used in place of the Meker flame called for in the MacCarthy technique). 25.00 ml of the Fe stock solution were pipetted into a weighed, dried porcelain crucible, evaporated to dryness under an infra-red lamp, and ignited to constant weight in a muffle furnace at 450°C. A factor of 0.69944 was used to convert Fe_2O_3 to Fe^{3+}. The multi-metal ion test solutions shown in Table 2 were made up by pipetting the appropriate amount of each metal stock solution into a volumetric flask and diluting to the required volume. pH adjustments were made using HNO_3 and NaOH. The amount of peat used in each experiment was determined by calculating the wet weight of peat necessary to provide a 7-fold excess of exchange sites (based on the titration data) over the total number of equivalents of metal ions in the strongest (highest concentration) test solution. (See Appendix 2.) Each test solution was passed through the peat immediately followed by rinsing with deionized water. The effluent and rinsings were collected, filtered through Whatman 40 ashless filter paper, brought to known volume in a volumetric flask and acidified with HNO_3 to a pH of approximately 2. The concentrations of Fe, Mn, and Zn in the treated effluents were determined by flame atomic absorption spectroscopy. The A.A. analyses were performed by CSMRI-Analytica, Inc. with a Perkin-Elmer 5000 spectrophotometer. No attempt was made to regulate the flow rate of the solutions through the peat column.

CHAPTER V: RESULTS

Peat Permeability

The results of the initial vertical permeability observations are shown in Figure 4. The curves were developed by plotting the recorded time required for the top of the 12-in. column of water to reach the top of the upper gravel layer in the 1-in. diameter column (Figure 1) against the sum of the recorded times for that peat (cumulative time). The data were plotted in this manner so as to provide uniform, continuous axes on which the peats could be statistically analyzed. Figure 4 shows that the seven peats can be separated into two groups. Shorter recorded times were observed for five of the peats (3.68 - 8.42 min.) and longer times for the remaining two (10.92 - 23.62 min.).



Curve	Peat
●	Alberta Rose
▲	Beaver
☆	Garden O'Plenty
*	Premier
O	Sunshine

Figure 4. Recorded time vs cumulative time for vertical permeability observations in 1-in. diameter column (Figure 2a). See Table 3 for linear regression analysis of data. See Appendix 3 for raw data.

(a) Plots for Alberta Rose, Beaver, Garden O'Plenty, Premier, Sunshine

(b) Plots for hypnum and Emerald

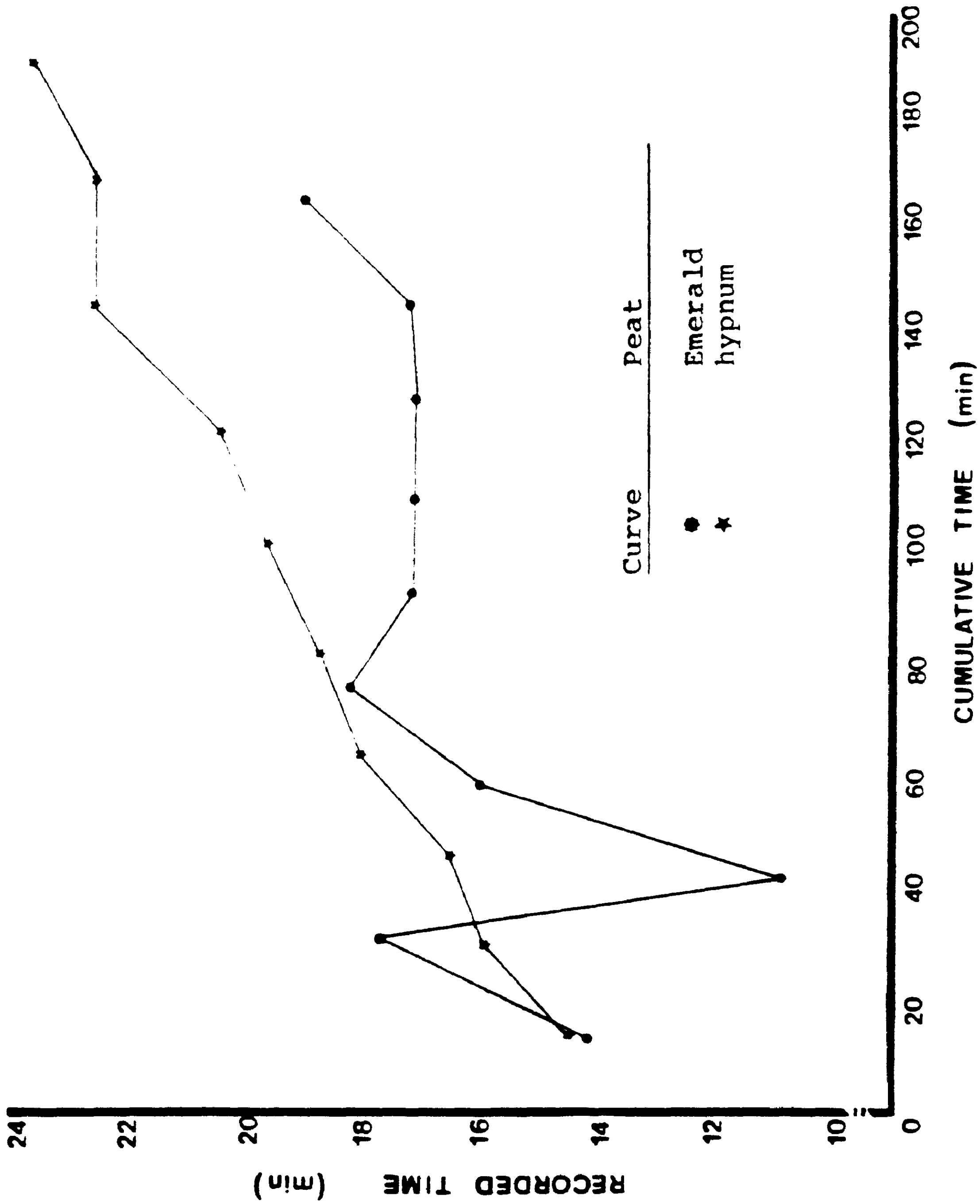


Figure 4. (b) Plots for hypnum and Emerald.

Table 3. Linear regression analysis of vertical permeability data shown in Figure 4. Slope is statistically equal to zero when F is less than 5.32 (at the 95 percent confidence level). r represents the correlation coefficient. (Ambrose and Ambrose, 1981)

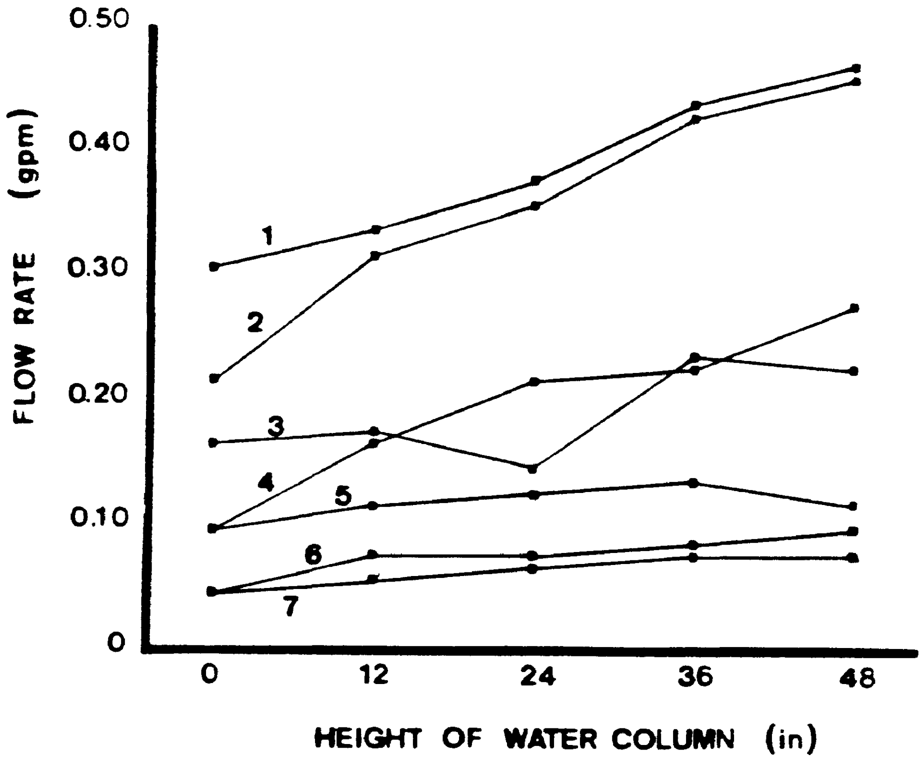
Curve	Peat	Y-intercept (min)	Slope	F	r
★	hypnum	14.27	0.05	263.48	0.99
⬢	Emerald	14.10	0.03	5.03	0.59
✱	Premier	5.70	0.04	27.92	0.88
▲	Beaver	5.87	0.01	0.57	0.26
•	Alberta Rose	5.43	0.01	3.01	0.61
☆	Garden O'Plenty	4.49	0.02	3.40	0.53
○	Sunshine	3.40	0.05	-1576.00	0.97

Hypnum, the non-sphagnum peat used for comparative purposes, displayed the longest recorded times in 9 out 10 trials. A comparison of the relative permeabilities of the seven peats (based on the y-intercept for each peat) implies that Sunshine peat has the highest vertical permeability, followed by Garden O'Plenty, Alberta Rose, Beaver, Premier, Emerald and hypnum. The susceptibility of the permeability of peat to change as a function of time under flow conditions was assessed by a simple linear regression analysis of the data. The analysis indicated that an approximately linear relationship exists between the recorded time and the cumulative time for only two of the peats (hypnum and Premier). The positive slopes of these curves implies that the vertical permeability of hypnum and Premier peat continually decreased over the cumulative time of the experiment, which is taken as an indication of susceptibility to compaction in these two peats within the limits of the experiment. The vertical permeabilities of the remaining five peats did not change with time (statistically, $b=0$). The correlation coefficients (r) of these data, however, were fairly low ($r < 0.65$) with the exception of $r=0.97$ for Sunshine peat.

The vertical flow rates determined for each of the seven peats as a function of head pressure in the 12-in.

diameter column are shown in Figure 5. A positive, approximately linear relationship exists between head pressure and flow rate for five of the seven peats. Flow rates thus appear to increase with increasing head pressure. Emerald was the only peat that displayed no linear relationship in either of the two vertical permeability tests. The correlation coefficients for these data were quite high ($r>0.93$). A comparison of the flow rates of the seven peats, again based on y-intercepts, shows that Garden O'Plenty peat had the highest flow rate, followed by Alberta Rose, Beaver, Sunshine, Emerald, Premier, and hypnum.

The horizontal flow rates determined for each peat are shown in Figure 6. The range of flow rates was from 0.24 gpm to a low of 0.04 gpm in the following decreasing order: Alberta Rose, Emerald, Beaver, Garden O'Plenty, Sunshine, and Premier. Hypnum was the only peat in which a uniform, horizontal flow of water could not be established under the conditions of the experiment. This peat continually formed two layers in the trough - an upper layer consisting of 8-10 inches of chunks of wood and matted grasses, and a lower layer consisting of 2-3 inches of silty muck that coated the bottom of the trough and outlet screen. The water flowed between the two



Curve	Peat
1	Garden O'Plenty
2	Alberta Rose
3	Beaver
4	Sunshine
5	Emerald
6	Premier
7	hypnum

Figure 5. Vertical flow rate vs height of water column above 4-ft. column of peat in 12-in. diameter column (Figure 2b). See Table 4 for linear regression analysis of data. See Appendix 4 for raw data.

Table 4. Linear regression analysis of vertical flow rate data shown in Figure 5. Slope is statistically equal to zero at the 95 percent confidence level when F is less than 10.13. r represents the correlation coefficient. (Ambrose and Ambrose, 1981)

Curve	Peat	Y-intercept	Slope	F	r
1	Garden O'Plenty	0.30	3.50×10^{-3}	220.50	0.99
2	Alberta Rose	0.24	4.92×10^{-3}	86.84	0.98
3	Beaver	0.16	1.50×10^{-3}	3.38	0.73
4	Sunshine	0.12	3.50×10^{-3}	55.12	0.97
5	Emerald	0.11	5.00×10^{-3}	2.08	0.64
6	Premier	0.06	9.17×10^{-4}	18.99	0.93
7	hypnum	0.05	6.67×10^{-4}	48.00	0.97

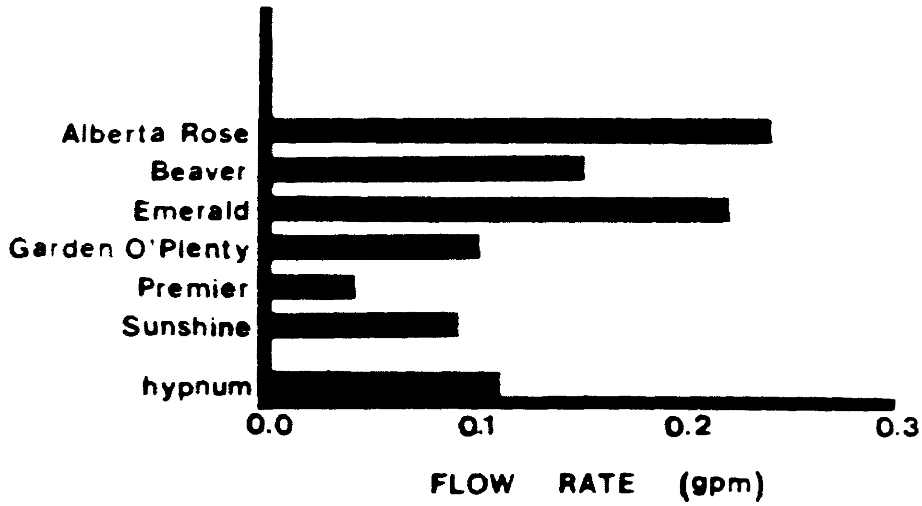


Figure 6. Flow rates of water through peats in the open/horizontal system shown in Figure 3. See Appendix 5 for raw data.

layers. The particulate components of the upper layer could not be sufficiently saturated with water to prevent them from floating, thus causing the separation of the two particle-size fractions. The flow rate shown for hypnum in Figure 6 is a measure of the flow between the two layers through the muck-clogged screen.

The design of the trough used to measure horizontal flow rates appears to have solved previously encountered difficulties in establishing uniform flow through peat in a horizontal/open system (with the exception of hypnum) (Guertin, et al., 1985). It is believed that the solution lies in changing the influent source from a line source which produces turbulence in the peat at the inlet to an area source which evenly distributes the influent through the entire cross section of the peat bed and by providing an outlet well to prevent draw-down at the downstream end of the bog.

Cation Exchange Capacity

The average maximum potential CEC's of the raw peats as estimated from the titration data are shown in Figure 7. The range of CEC values for the sphagnum peats was from 0.18 meq/g dry weight (Alberta Rose) to 1.05 meq/g

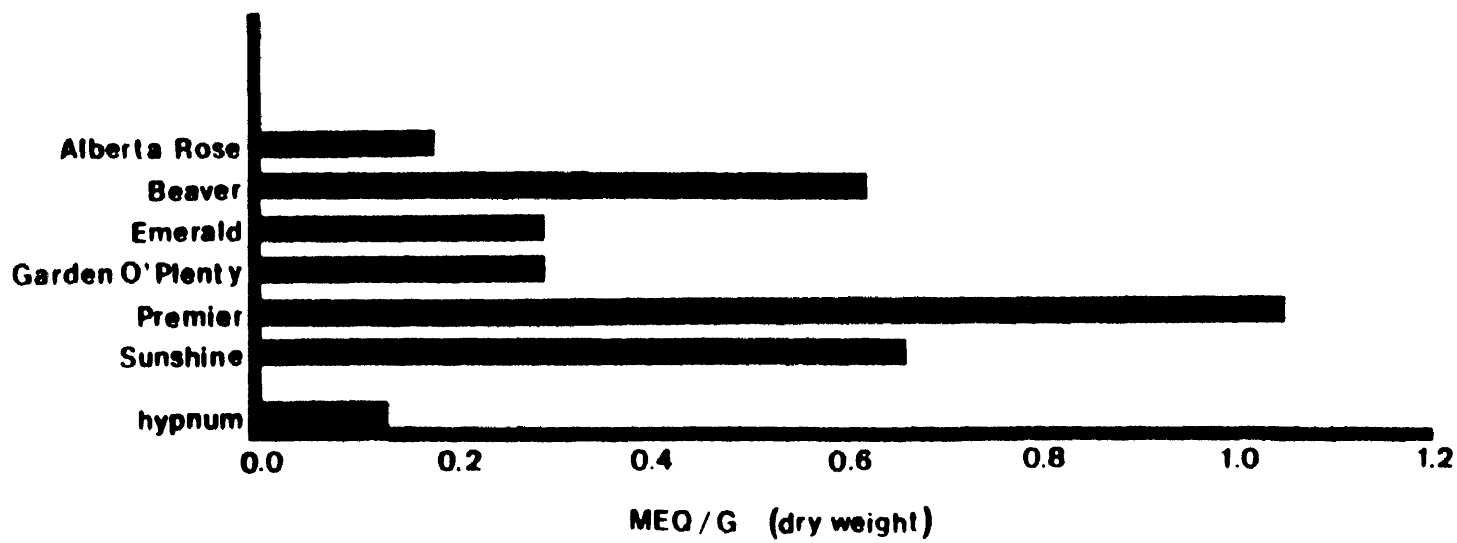


Figure 7. Average maximum potential cation exchange capacities of raw peats determined by titration. See Appendix 6 for raw data.

dry weight (Premier). The CEC of hypnum was 0.13 meq/g dry weight - the lowest of all samples. The data were statistically compared using the Kruskal-Wallis non-parametric test for the determination of significant differences between means. (Ambrose and Ambrose, 1981). The analysis showed that the data can be separated into two groups that are significantly different from one another. Thus the CEC values of Alberta Rose, Emerald, Garden O'Plenty and hypnum peats are significantly different from those of Sunshine, Beaver and Premier peats. The CEC values of the peats within each group, however, are not significantly different from one another.

Conversion to the H^+-form increased the CEC values of all of the four peats tested (Figure 8). Hypnum and Alberta Rose, both of which displayed the lowest CEC's in the raw state, had an 84.7 and 84.2% increase, respectively, in their CEC values following acid washing. Premier, which had the highest raw CEC, had the smallest increase (7.89%) in CEC after acid washing. The CEC values of the four peats tested were significantly different prior to the acid treatment, but were statistically similar to one another afterwards at the 95 percent confidence level using the Kruskal-Wallis test.

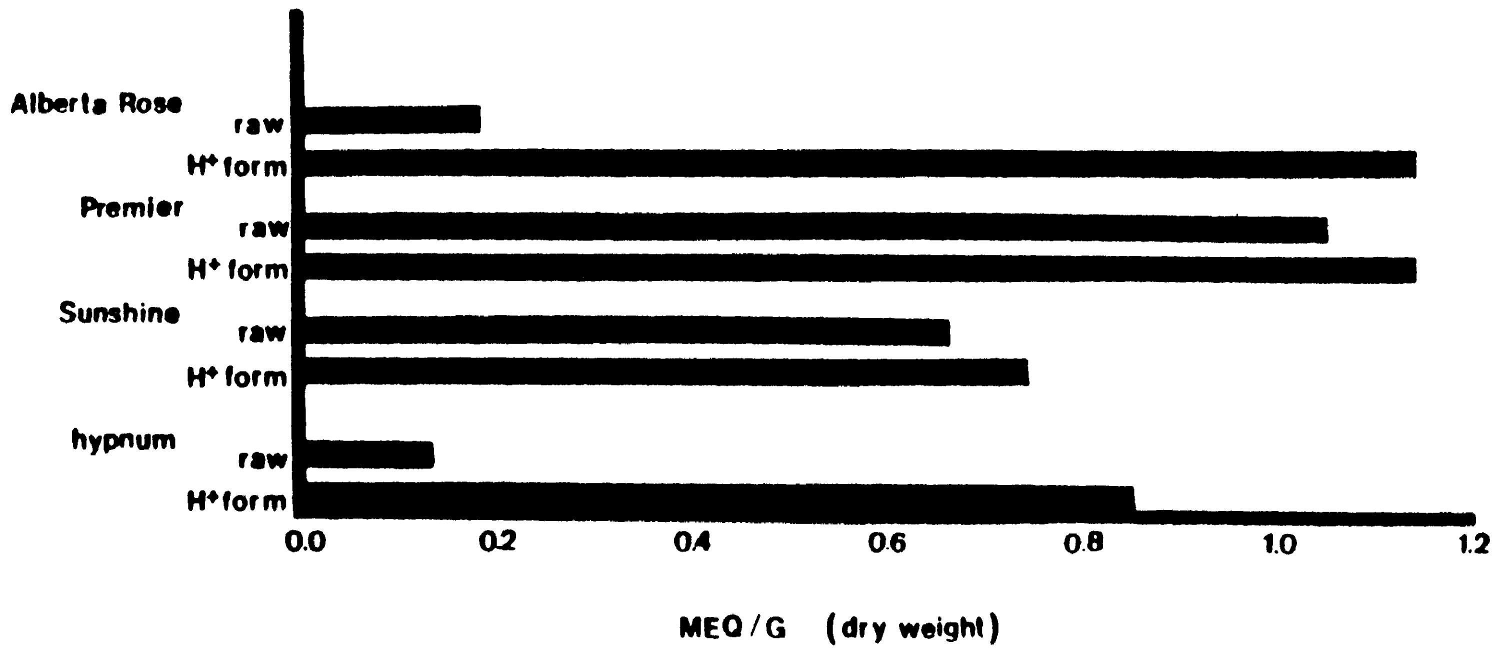


Figure 8. Maximum potential cation exchange capacities of peats before and after washing with 3M HCl. See Appendix 7 for raw data.

The ash contents of the raw and H^+-form peats are shown in Figure 9. Hypnum showed the highest ash content both before and after treatment (25.6 and 17.3% respectively), while Premier peat had the lowest (3.61 and 2.95% respectively). The ash content of all four of the peats decreased by washing with acid.

Concentrations of Ca, Mg, and Fe in the eluates from the acid-washed peats are shown in Figure 10. The total number of meq of metals released by acid washing was highest for hypnum (3.02 meq) and lowest for Premier (0.17 meq), which corresponds well with the changes in CEC and ash contents of the peats as the result of acid washing.

Metal Ion Removal Characteristics

The results of the metal ion removal investigations are shown in Figures 11 through 14. The average percent removal of metals for all four peats under all conditions was high. Fe, Mn and Zn concentrations were reduced by 97.3 to 98.5%, 89.2 to 95.5% and 83.2 to 96%, respectively. Alberta Rose and hypnum peats showed the highest overall reductions, followed by Sunshine and Premier peats. Total metal ion removal (Fe + Mn + Zn) exceeded than 90% for all four peats under all conditions tested.

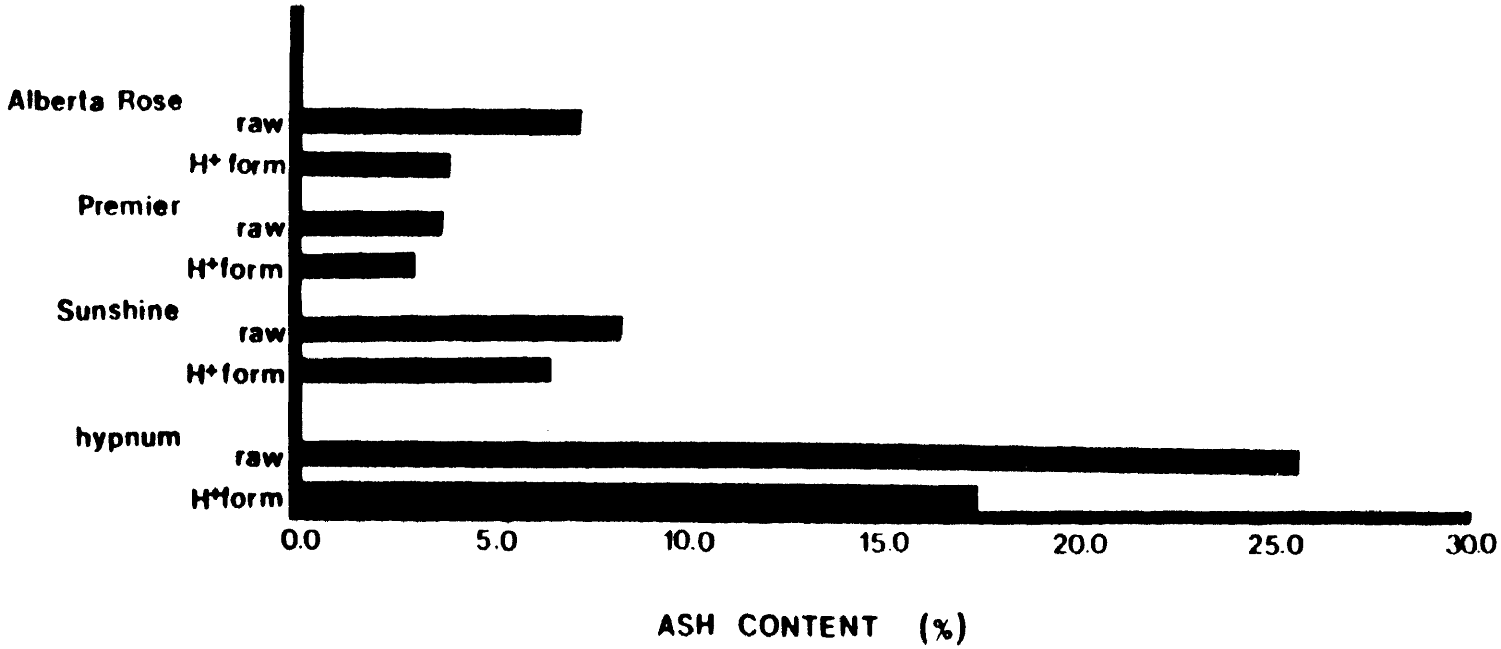


Figure 9. Ash contents of various peats before and after washing with 3M HCl. See Appendix 8 for raw data.

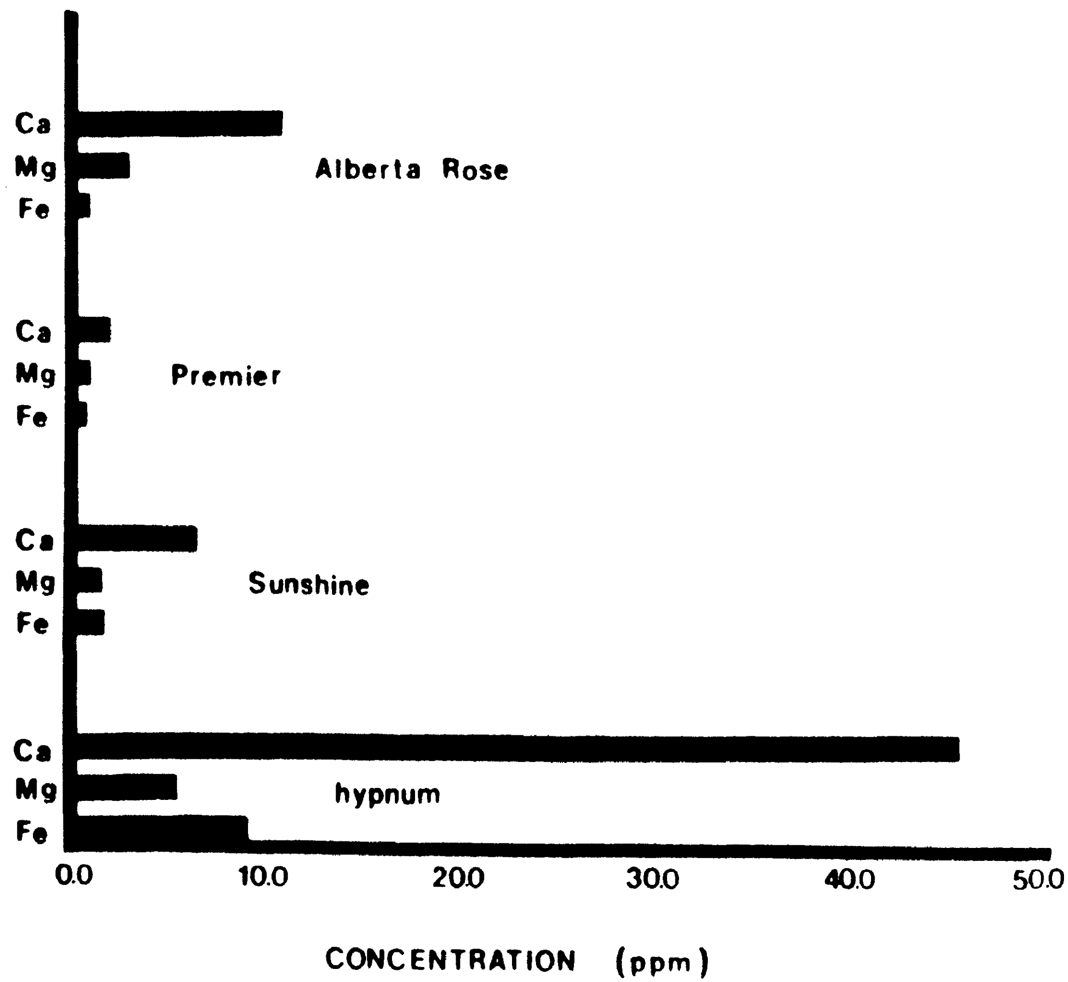


Figure 10. Concentrations of total Ca, Mg and Fe in eluates from acid-washed peats. See Appendix 9 for raw data.

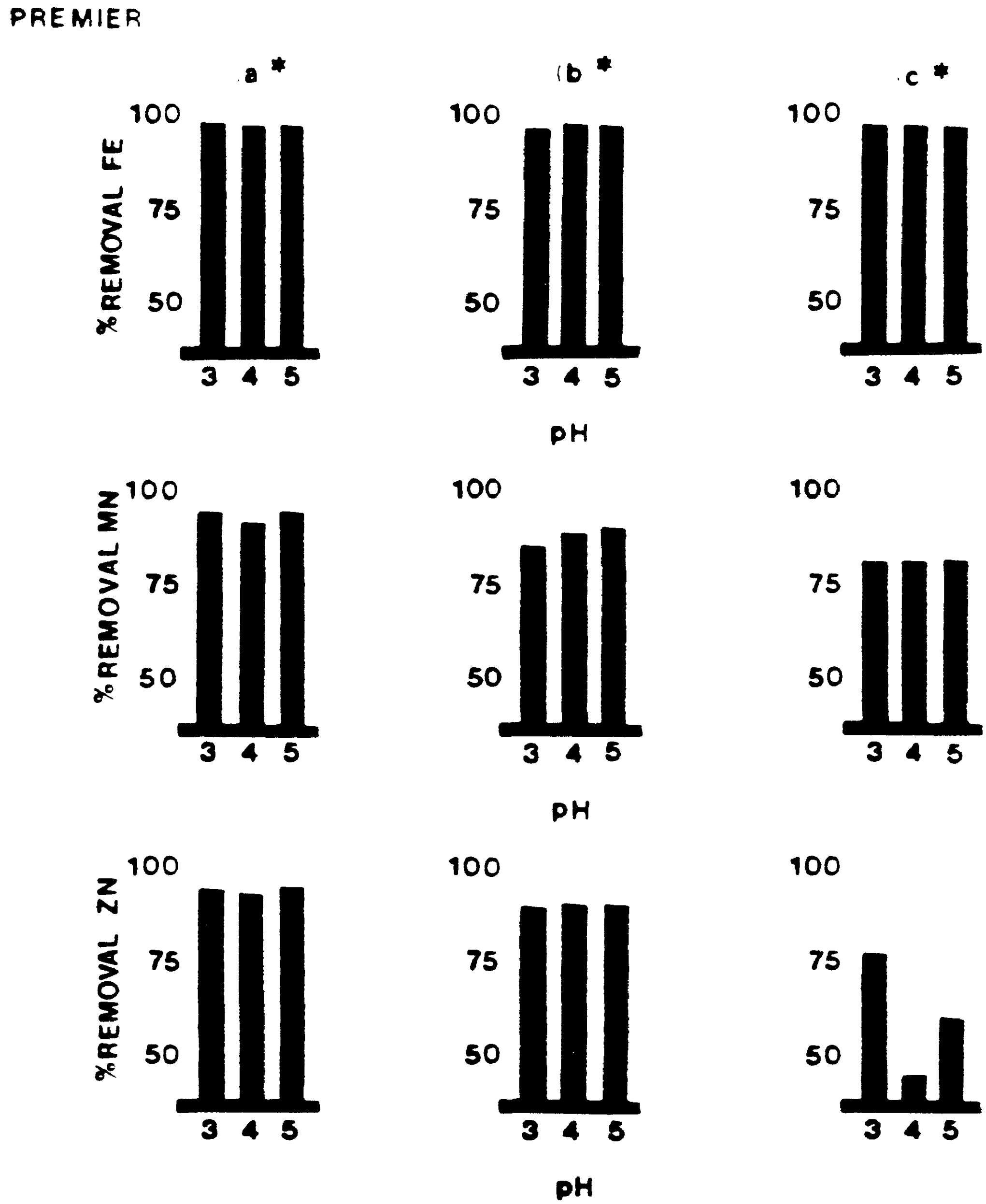


Figure 11. Metal ion removal by Premier peat. See Table 2 for a*, b* and c* solution concentrations. See Appendix 10 for raw data.

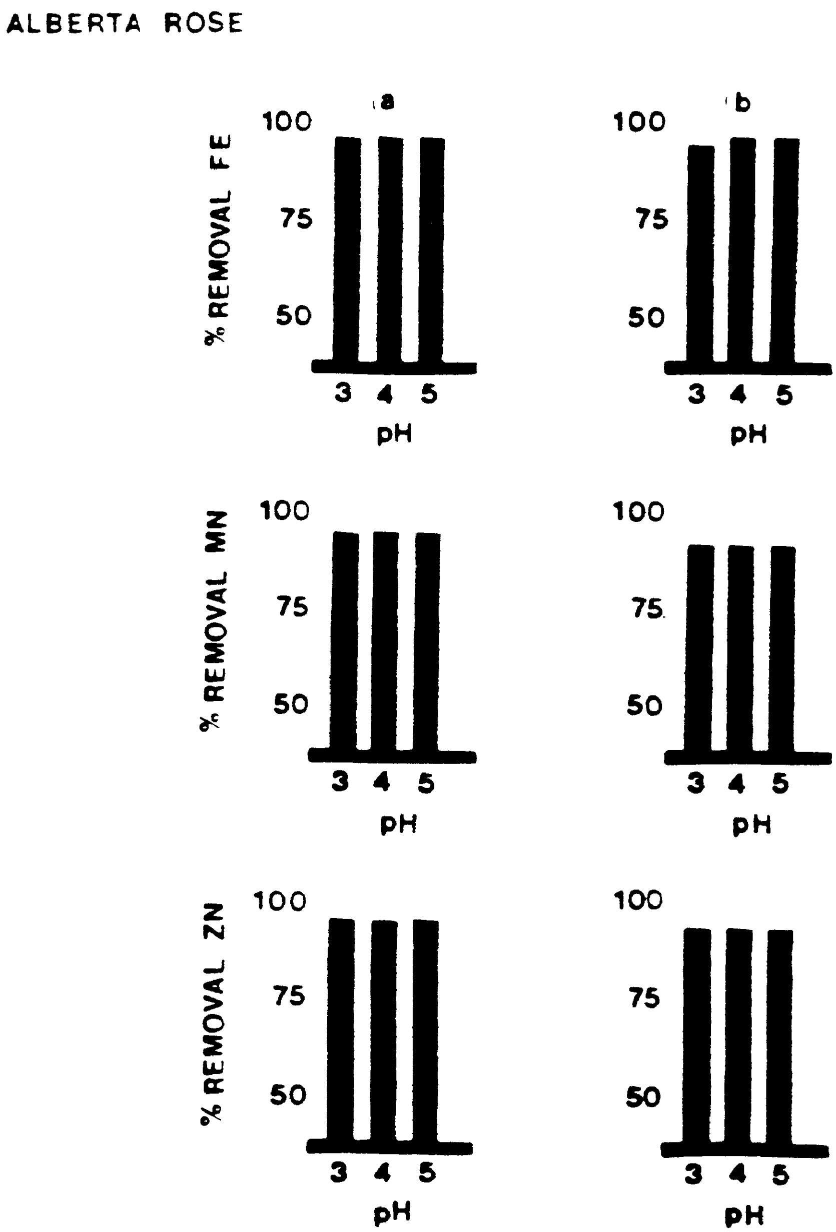


Figure 12. Metal ion removal by Alberta Rose. See Table 2 for a and b solution concentrations. See Appendix 11 for raw data.

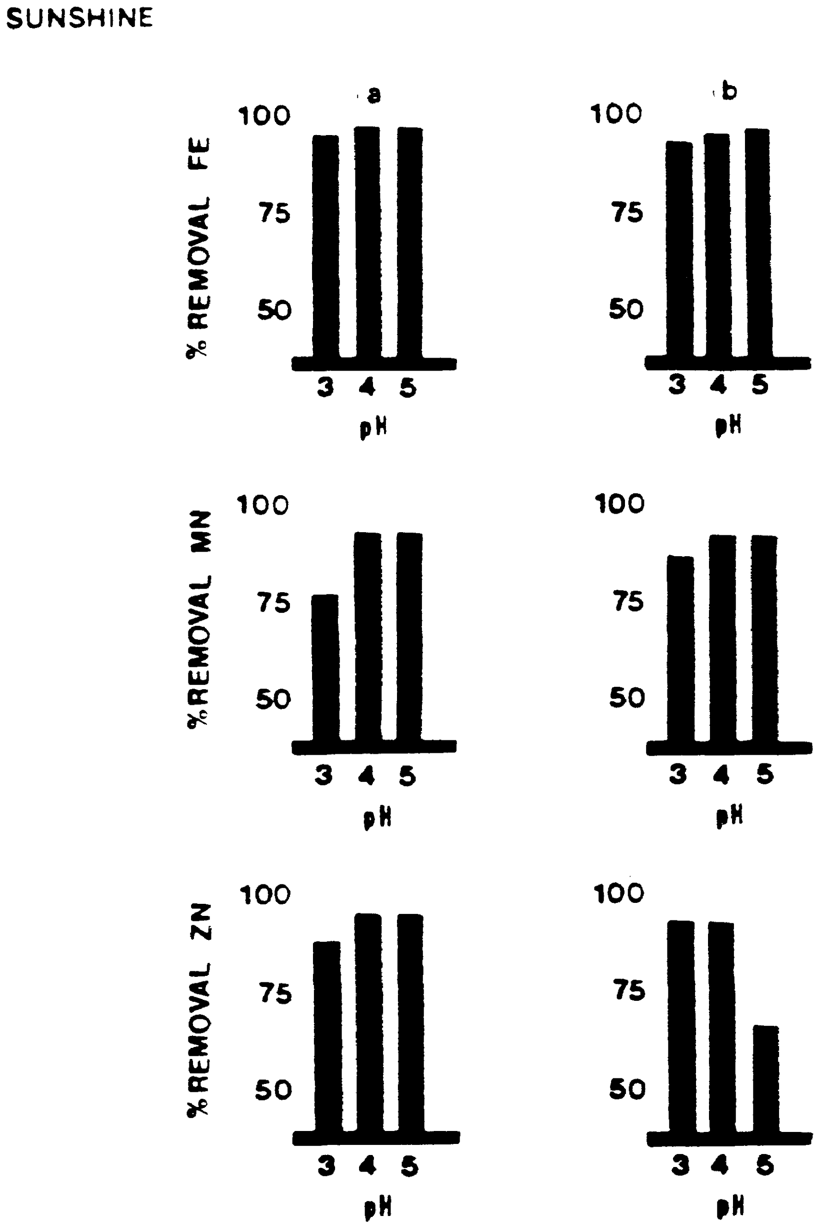


Figure 13. Metal ion removal by Sunshine peat. See Table 2 for a and b solution conentrations. See Appendix 12 for raw data.

HYPNUM

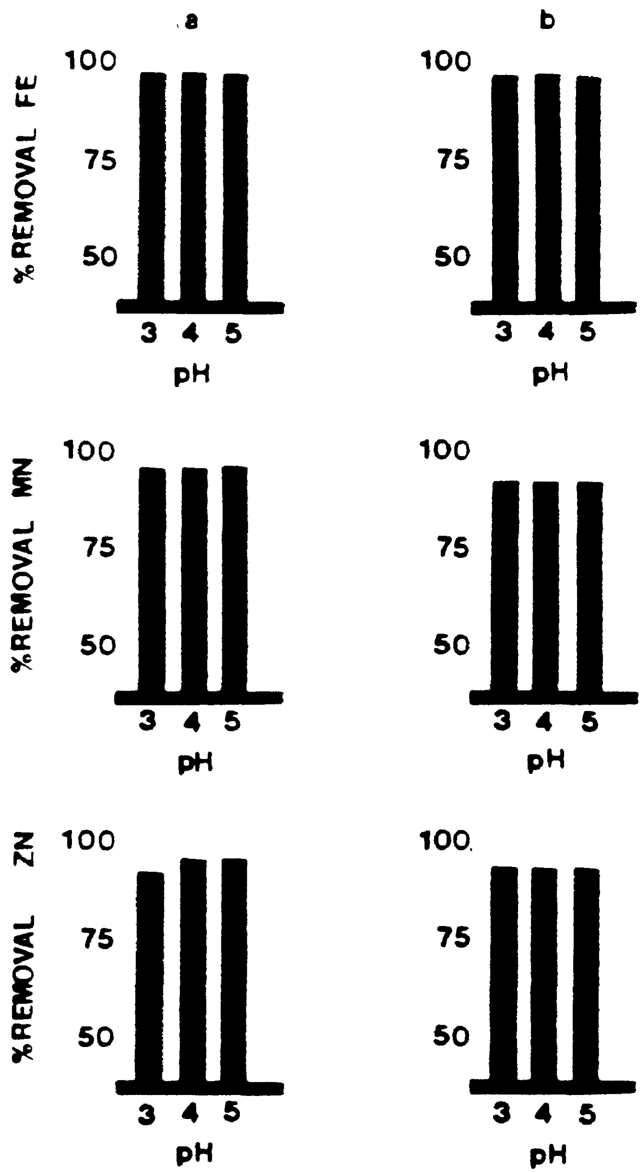


Figure 14. Metal ion removal by hypnum peat. See Table 2 for a and b solution concentrations. See Appendix 13 for raw data.

Changes in the pH of the test solutions had little or no effect on the removal of metal ions by any of the peats. Fe and Mn removal was increased only slightly with increasing pH for the three sphagnum peats. The pH appeared to have no measurable on Fe and Mn removal in hypnum under the conditions studied. The percent removal of Zn increased by 1.5 to 3.5% between pH 3 and 4 with hypnum and Sunshine peats, but decreased by 11% with Premier peat and remained unchanged with Alberta Rose. An increase in pH from 4 to 5 showed an increase in the percent removal of Zn of 5.5% with Premier, a decrease of 13.5% with Sunshine, and no change with either hypnum or Alberta Rose peats.

Metal ion removal generally decreased when metal concentrations were reduced by one-half under all conditions for all four of the peats tested. The reduction in Fe removal was in the range of 0.5 to 4.5%. Mn removal was reduced by 1.0 to 9.5%, while Zn removal was reduced by 1.0 to 50.0%. Zn and Mn removal in Premier and Sunshine appeared to be more strongly influenced by decreasing metal concentrations than either hypnum or Alberta Rose peats.

CHAPTER VI: DISCUSSION

The evaluation of the seven commercial peats illustrated their heterogeneity and confirmed the need for such evaluations prior to designing peat-based low-maintenance treatment systems. As an illustration of the utility of these data in the system design process and the influence of the CEC and permeability characteristics of each peat on the actual system design, two hypothetical treatment systems (one horizontal, one vertical) were designed from the experimental results. The systems were designed for the treatment of the water from a mine near Idaho Springs, Colorado. The mine water contains 180 mg/l Fe, 23 mg/l Mn, and 2.4 mg/l Zn. The water is to be pumped from the shaft to a storage pond, and then from the pond to the treatment system at a rate of 10 gpm. The volume of dry peat required to remove the metals from the stream for a period of 1 year was calculated for each peat using the average CEC value for that peat in its raw form. In this example, no excess of exchange sites was provided. A bulk density of 0.1×10^6 g/m^3 was assumed for each peat (Rock, et al, 1984). The dimensions of each horizontal system were determined using the calculated volume of peat required and the horizontal flow rate determined experimentally for each peat. In calculating the bog dimensions, it was assumed that due to the physical nature of peat, the measured horizontal flow rates could only be extrapolated to systems in which the ratios of depth to width and cross-sectional area to flow rate were maintained. The bench scale apparatus (See Figure 3) in which the flow rates were measured had a ratio of depth to width of 0.75 and a cross-sectional area of 0.75 sq. ft. The dimensions of the hypothetical "bog" can thus be determined from the calculated volume of peat required and the desired flow rate. (See Appendix 14 for calculations.) The results, shown in Table 5, show that the size and shape of each "bog" are uniquely defined by the CEC and horizontal flow rates of each peat. The low CEC values of each peat are responsible for the extraordinarily large volumes of peat necessary to provide the treatment.

Similar calculations were performed to determine the number of columns that would be necessary to provide the same treatment in a vertical system. Each column contained 7.85 ft^3 of peat, which corresponds to a 10-ft. column of peat in a 12-in. diameter column. (See Appendix 15 for calculations.) The results, shown in Table 6, again illustrate the significant difference in the size of each system (the number of columns), and also

Table 5. Hypothetical treatment systems designed for treatment of a stream containing 180 mg/l Fe^{3+}, 23 mg/l Mn^{2+} and 2.4 mg/l Zn^{2+}. Volumes represent treatment for one year with no excess provided. Stream flow = 10 gpm. (See Appendix 14 for calculations.)

Horizontal Systems

Peat	Volume (cu. ft.)	Bog Dimensions (ft.) Length	Width	Depth
Alberta Rose	414774.3	13265.8	4.84	6.46
Beaver	120418.4	2411.3	6.12	8.16
Emerald	257446.1	7548.8	5.06	6.74
Garden O'Plenty	257446.1	3432.6	7.50	10.00
Premier	71104.2	378.2	11.90	15.80
Sunshine	113120.3	1363.7	7.90	10.50

hypnum (excluded due to undesirable horizontal permeability caharacteristics.)

Table 6. Hypothetical treatment systems designed for treatment of stream described in Table 5. (See Appendix 15 for calculations.)

Vertical Systems

Peat	Volume (cu.ft.)	No. of Columns
Alberta Rose	414774.3	52837.5
Beaver	120418.4	15339.9
Emerald	257446.1	32795.7
Garden O'Plenty	257446.1	32795.7
Premier	71104.2	9057.8
Sunshine	113120.3	14410.2
hypnum	574059.0	73159.6

the extremely large number of columns that would be necessary to contain all of the peat.

The results of these experiments show that if cation exchange is the sole mechanism relied upon to provide treatment, then the low CEC values of these peats render them impractical for use as an acid mine drainage treatment medium due to the large volumes of peat that would be necessary. Other mechanisms such as sorption and filtration, however, may also provide significant treatment in addition to that provided by cation exchange. This would result in a smaller volume of peat being required.

The results also clearly illustrate that the development of a testing methodology whereby CEC and permeability characteristics can be determined is well justified.

In this investigation, laboratory analyses were selected or devised with the development of a testing methodology as the primary objective. A comparison of the results from the various analyses led to the acceptance or rejection of each technique.

The results of the permeability tests in which vertical and horizontal flow rates were measured confirm the assertion that peat permeability in a vertical/closed system is different from that in an horizontal/open system. Only two of the seven peats (Alberta Rose and hypnum) showed less than a 10% difference between the horizontal and vertical flow rates. The remaining five peats showed variations of 25 to 120% between the flow rates in the two systems. The testing methodology must therefore include a procedure by which the flow rate can be measured in the appropriate system.

It was originally believed that the simple test of observing the time required to pass 12 in. of water through 6 in. of peat in a 1-in. diameter column would be a valid method for evaluating the permeability of different peats. The results of the various permeability tests, however, indicate that this method is of limited value. The results from the 1-in. and 12-in. columns were compared by converting the data to units of flow per unit of cross-sectional area of peat (gpm/in^2). The results of the 1-in. column test were higher than those of the 12-in. column test by 62 to 86%. (Table 7) This indicates that the results of a 1-in. column test should probably not be used to predict the flow rate of the same peat in a larger, vertical system.

A similar comparison was made between the data from the 1-in. column test and the horizontal flow rates.

Table 7. Recorded times (Appendix 3) and vertical and horizontal flow rates (Appendices 4 and 5) converted to units of flow per unit of cross-sectional area of peat (gpm/in^2) for the purpose of comparing the various permeability tests.

Peat	1-in. Column	12-in. Column	Percent* Difference	Horizontal	Percent** Difference
Alberta Rose	0.008	0.003	62.5	0.002	75.0
Beaver	0.008	0.002	75.0	0.001	87.5
Emerald	0.003	0.001	70.6	0.002	41.2
Garden O'Plenty	0.010	0.003	70.0	0.0009	91.0
Premier	0.005	0.0007	86.0	0.0004	92.0
Sunshine	0.014	0.002	85.7	0.0008	94.3
hypnum	0.003	0.0005	83.3	0.001	66.7

* ((1-in. - 12-in.)/1-in.)x100

** ((1-in. - horizontal)/1-in.)x100

Again, the results of the 1-in. column test were consistently higher than the horizontal flow rates by a range of 41 to 94%.

The peats were then ranked in order of decreasing permeability for each permeability test. For each peat, the difference in rank between the 1-in. column test and the vertical flow rate test was computed. The same was done for the 1-in. column and the horizontal flow rate test. The differences were then averaged for each comparison. The average difference in rank between the 1-in. test and the vertical flow rate test was 0.57. It was 2.60 for the average difference between the 1-in. column and horizontal flow rate test. This implies that the 1-in. column test might be an acceptable means of comparing the vertical permeability characteristics between several peats, but it would not be a valid method for discerning horizontal permeability characteristics.

Titrating raw peat with a strong base appears to be a reliable method for determining concentrations of available exchange sites in the raw samples. The results of the experiment in which the CEC's and ash contents of four of the peats before and after washing with a strong acid appear to uphold this conclusion. These data also suggest that, for these four peats, CEC was strongly influenced by the percent base saturation of the raw peats, since conversion of the peats to their H^+-form removed the significant difference that existed between their exchange capacities in the pre-washed state. If the percent base saturation were not the dominant influence, then acid washing would probably not have produced the increased CEC's and reduced ash contents observed. Since the percent base saturation in a peat is in part a function of the ionic content of the water in the bog from which the peat was harvested, it is logical to assume that the CEC values of peats from different bogs are likely to have significantly different CEC's in their raw state.

The importance of incorporating the CEC of a peat into the treatment system design process has already been demonstrated in the previous discussions. The use of supplier values and CEC data provided by the manufacturer is not recommended unless the data apply directly to the peat in question and the conditions under which the data were obtained are known. Premier Brands, Inc., for example, reported a CEC of 1.2 meq/g which is in close agreement with the CEC determined for Premier in this investigation (1.5 meq/g). Saskatchewan Minerals, suppliers of Emerald and Garden O' Plenty peats, however, reported CEC values of 0.66 and 0.59 meq/g. The exchange capacities of these peats determined in this investigation were 0.29 meq/g for both peats, a difference of 51 to 56%.

The results of the metal ion removal experiments show that some variation in metal ion removal efficiency did exist between the four test peats. This upholds the assertion that the CEC of a peat cannot be taken as an indication of its ability to remove metal ions. The exchange capacity determined by titration is a maximum potential CEC, i.e. the conditions under which it is determined are not representative of the conditions in an actual treatment system. Furthermore, the titration data give no indication of either the chemical environment of the exchange sites themselves, both of which factors will exert an influence on the metal ion removal efficiency of a particular peat. The determination of metal ion removal efficiency should, therefore, be included in the testing methodology. The validity of the results derived from the use of synthetic solutions was not tested in this investigation and thus it is unknown whether synthetic solutions are representative of actual acid mine drainage.

CHAPTER VII: CONCLUSIONS AND RECOMENDATIONS

Commercial peats from different sources will have significantly different CEC values and permeability characteristics in their raw form, although they appear to be equally efficient in their ability to remove ions from solutions of varying ionic concentrations and pH values. The effectiveness of a commercial peat-based treatment system will depend upon the incorporation of the peat's physical and chemical characteristics into the treatment system design. An effective evaluation of these characteristics can be obtained by determining the cation exchange capacity, permeability, and metal ion removal efficiency. A simple titration of a water-slurried sample of the peat with NaOH provides a reliable estimate of the concentration of available exchange sites in the raw peat. The volume of peat required to achieve treatment objectives can be calculated from this CEC. Peat permeability, when determined as the flow rate obtained in the flow regime in which the peat is to be used (column or bog), provides the basis on which the treatment system is to be designed. Difficulties in establishing uniform flow through peat in horizontal/open systems appear to be overcome when the influent is changed from a line source to an area source in combination with an outlet well. Metal ion removal efficiency can be estimated using synthetic, multi-metal ion solutions under varying conditions of pH and metal-ion concentrations.

The low CEC values of the peats examined in this evaluation dictate the use of extremely large volumes of peat, thus rendering them impractical for use in acid mine drainage treatment. The necessary volume of peat may be reduced, however, when contributions to the treatment process made by sorption and filtration are taken into account.

The results of this investigation were derived from lab and bench scale apparatuses (with the exception of the 12-in. column test) and synthetic solutions. A final evaluation of the testing methodology will only be possible when it has been applied to the design of a full scale system and the results obtained using actual acid mine drainage.

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APPENDICES

Appendix 1.

Calculations for determination of maximum potential cation exchange capacities of Premier at pH 7, 8, and 9 from titration curve.

CEC at pH 7.0

no. ml NaOH added at pH 7.0 = 18.5 ml

$$\text{no. meq NaOH at pH 7.0} = 18.5 \text{ ml} \times 0.097 \frac{\text{meq}}{\text{ml}}$$
$$= 1.79 \text{ meq}$$

$$\text{CEC} = \frac{1.79 \text{ meq}}{2.42 \text{ g}} = \underline{0.742} \frac{\text{meq}}{\text{g}} \text{ (dry weight)}$$

CEC at pH 8.0

no. ml NaOH added at pH 8.0 = 25.5 ml

$$\text{no. meq NaOH at pH 8.0} = 25.5 \text{ ml} \times 0.097 \frac{\text{meq}}{\text{ml}}$$
$$= 2.47 \text{ meq}$$

$$\text{CEC} = \frac{2.47 \text{ meq}}{2.42 \text{ g}} = \underline{1.02} \frac{\text{meq}}{\text{g}} \text{ (dry weight)}$$

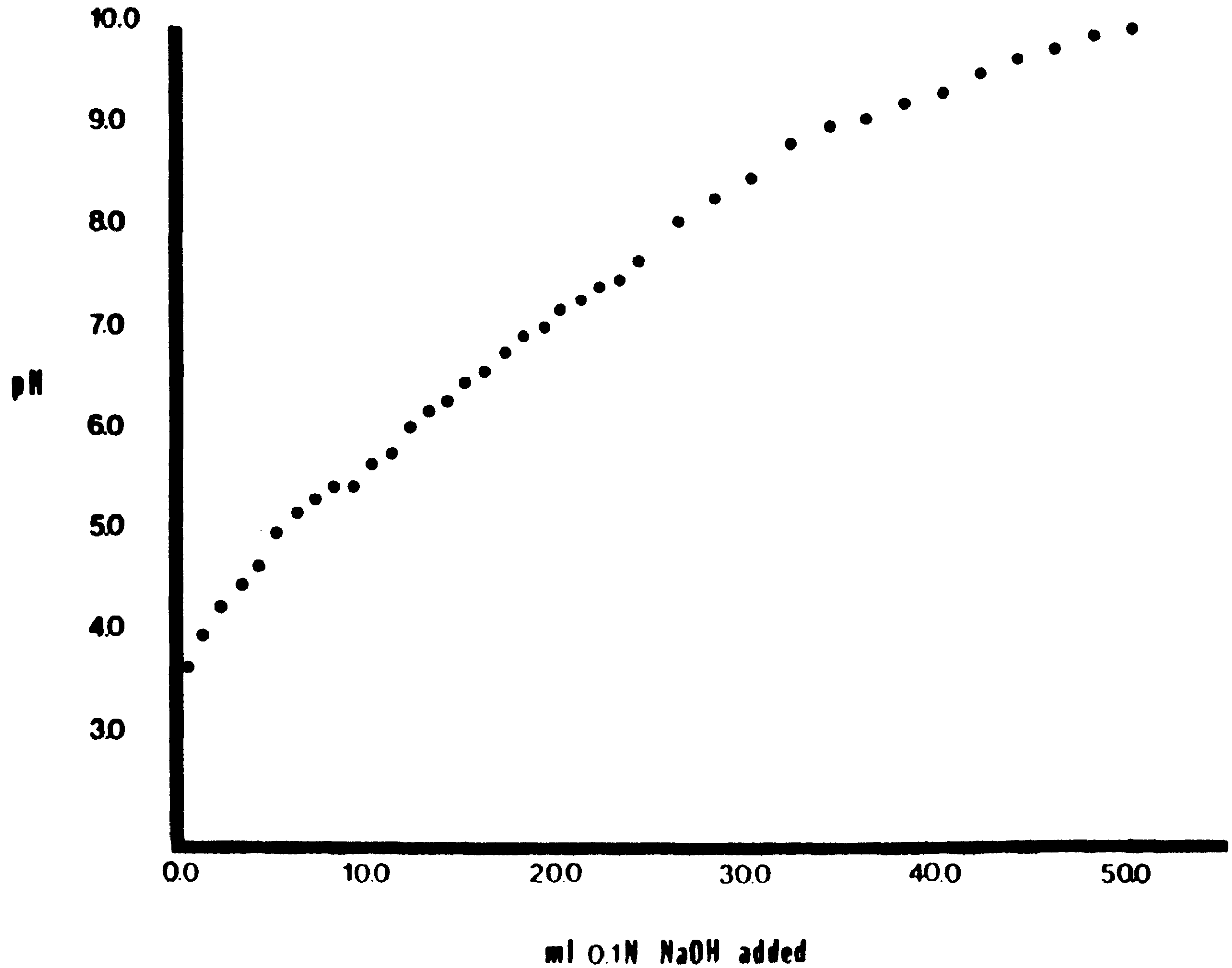
CEC at pH 9.0

no. ml NaOH added at pH 9.0 = 34.0 ml

$$\text{no. meq NaOH at pH 9.0} = 34.0 \text{ ml} \times 0.097 \frac{\text{meq}}{\text{ml}}$$
$$= 3.30 \text{ meq}$$

$$\text{CEC} = \frac{3.30 \text{ meq}}{2.42 \text{ g}} = \underline{1.36} \frac{\text{meq}}{\text{g}} \text{ (dry weight)}$$

Appendix 1. Cont. Titration curve for Premier peat.
Dry weight of sample = 2.42 g.



Appendix 2. Calculations for determining weight of wet peat required for metal ion removal experiments.

Peat sample: Premier

Metal ion concentrations: $Fe^{3+} = 0.02\underline{M}$

$Mn^{2+} = 0.002\underline{M}$

$Zn^{2+} = 0.002\underline{M}$

$$\frac{\text{meq } Fe^{3+}}{\text{liter soln}} = 0.02\ \frac{\text{moles}}{\text{liter}} \times 3\ \frac{\text{eq}}{\text{mole}} \times 1000\ \frac{\text{meq}}{\text{eq}} = 60\ \frac{\text{meq } Fe^{3+}}{\text{liter}}$$

$$\frac{\text{meq } Mn^{2+}}{\text{liter soln}} = 0.002\ \frac{\text{moles}}{\text{liter}} \times 2\ \frac{\text{eq}}{\text{mole}} \times 1000\ \frac{\text{meq}}{\text{eq}} = 4\ \frac{\text{meq } Mn^{2+}}{\text{liter}}$$

$$\frac{\text{meq } Zn^{2+}}{\text{liter soln}} = 0.002\ \frac{\text{moles}}{\text{liter}} \times 2\ \frac{\text{eq}}{\text{mole}} \times 1000\ \frac{\text{meq}}{\text{eq}} = 4\ \frac{\text{meq } Zn^{2+}}{\text{liter}}$$

$$\frac{\text{Total meq metals}}{\text{liter soln}} = 60 + 4 + 4 = 68\ \frac{\text{meq metals}}{\text{liter}}$$

$$\frac{\text{grams of dry peat}}{\text{liter soln}} = 68\ \frac{\text{meq metals}}{\text{liter}} \times \frac{1\text{ g peat}}{1\text{ meq exch. sites}}$$

$$\times\ \frac{1\text{ meq exch. sites}}{1\text{ meq metal ions}} \times 7\text{-fold excess}$$

$$= \frac{476\text{ g dry peat}}{\text{liter soln}}$$

$$\frac{\textbf{grams of wet peat}}{\textbf{liter soln}} = 476\text{g} + (476 \times 40\%\text{ moisture})$$

$$= \frac{666\text{ g wet peat}}{\text{liter soln}}$$

$$666\ \frac{\text{g peat}}{\text{liter}} = 66.6\ \frac{\text{g peat}}{100\text{ ml}} = 6.66\ \frac{\text{g peat}}{10\text{ ml}}$$

Appendix 2. Cont.

For practicality, use 10 ml solution on 6.66 g of wet peat. Rinse with approximately 90 ml of deionized water and bring to volume in a 100 ml volumetric flask. This will result in a 1:10 dilution of 10 ml of untreated test solution (worst case). Determine the detection limits for each metal ion in 10 ml of untreated, diluted solution. The detection limit of the Perkin Elmer 5000 flame atomic absorption spectrophotometer is 0.5 ppm (CSMRI Analytica, Inc.).

Fe $0.02\underline{M}\ \text{Fe} \times 56\ \frac{\text{g}}{\text{mole}} \times 1000\ \frac{\text{mg}}{\text{g}} = \underline{1120\ \text{ppm}}$ Fe in untreated soln

by 1:10 dilution, $\frac{1120}{10} = 112.0$ ppm, untreated, diluted

% Removal at detection limit = (1-(0.5/112.0)) x 100

= $\underline{99.6\%}$

Mn $0.002\underline{M}\ \text{Mn} \times 55\ \frac{\text{g}}{\text{mole}} \times 1000\ \frac{\text{mg}}{\text{g}} = \underline{110\ \text{ppm}}$ Mn in untreated soln

by 1:10 dilution, $\frac{110}{10} = 11.0$ ppm, untreated, diluted

% Removal at detection limit = (1-(0.5/11.0))x100

= $\underline{95.4\%}$

Zn $0.002\underline{M}\ \text{Zn} \times 65\ \frac{\text{g}}{\text{mole}} \times 1000\ \frac{\text{mg}}{\text{g}} = \underline{130\ \text{ppm}}$ Zn in untreated soln

by 1:10 dilution, $\frac{130}{10} = 13.0$ ppm, untreated, diluted

% Removal at detection limit = (1-(0.5/13.0))x100

Appendix 2. Cont.

Zn (cont.)

% Removal at detection limit = 96.2%

These figures are within acceptable limits of detection and practicality. Experiment is thus carried out using 6.66 g of wet peat and 10 ml of test solution at the concentrations indicated. The wet weight of peat required for solutions b* and c* (Table 2) was determined in a similar fashion, as were the weights of all other peats used in the metal ion removal experiments.

Appendix 3. Raw data from vertical permeability tests conducted in 1-in. diameter column (Figure 2a).

<u>Alberta Rose</u>	<u>Recorded Time</u> (min)	<u>Cumulative Time</u> (min)
	5.12	5.12
	5.90	11.02
	5.62	16.64
	5.90	22.54
	6.25	28.79
	5.42	34.21
	6.18	40.39
	5.68	46.07
	6.12	52.19
	6.38	58.57
<u>Beaver</u>	5.20	5.20
	5.42	10.62
	6.12	16.74
	6.15	22.89
	6.30	29.19
	5.93	35.12
	5.95	41.07
	6.28	47.35
	7.38	54.73
<u>Emerald</u>	14.20	14.20
	17.70	31.90
	10.92	42.82
	16.02	58.84
	18.22	77.06
	17.15	94.21
	17.13	111.34
	17.30	128.64
	17.22	145.86
	18.98	164.84

Appendix 3. Cont.

Garden O'Plenty	Recorded Time (min)	Cumulative Time (min)
	3.92	3.92
	5.03	8.95
	4.55	13.50
	4.78	18.28
	4.92	23.20
	5.78	28.98
	5.83	34.81
	4.92	39.73
	5.03	44.76
	5.02	49.78
Premier	4.97	4.97
	6.78	11.75
	7.55	25.58
	6.90	32.48
	7.20	39.68
	7.63	47.31
	7.88	55.19
	8.42	63.61
	8.22	71.83
Sunshine	3.68	3.68
	3.78	7.46
	3.78	11.24
	4.18	15.42
	4.22	19.64
	4.57	24.21
	4.57	28.78
	5.20	33.98
	4.92	38.90
	5.67	44.57

Appendix 3. Cont.

hypnum	Recorded Time (min)	Cumulative Time (min)
	14.52	14.52
	15.90	30.42
	16.53	46.95
	17.92	64.87
	18.70	83.57
	19.57	103.14
	20.35	123.49
	22.47	145.96
	22.47	168.43
	23.62	192.05

Appendix 4. Vertical flow rate data from 12 inch diameter column.

(a) Time (in minutes) to collect 1 quart of water from the base of the column at each of the water column height levels.

	Height of Water Column (in)				
	0"	12"	24"	36"	48"
Peat	Time (min)				
Alberta Rose	1.10	0.78	0.69	0.58	0.54
Beaver	1.58	1.42	1.61	1.02	1.07
Emerald	2.36	2.14	1.90	1.76	2.12
Garden O' Plenty	0.80	0.73	0.65	0.57	0.53
Premier	4.62	3.20	3.15	2.87	2.58
Sunshine	2.36	1.52	1.15	1.07	0.09
hypnum	5.27	4.07	3.63	3.22	2.98

(b) Flow rate of water through peats at each water column height level, obtained by conversion of above recorded times to gallons per minute: gpm = 0.25 gal / recorded time.

Peat	Flow Rate (gpm)				
Alberta Rose	0.23	0.32	0.36	0.43	0.46
Beaver	0.16	0.18	0.16	0.24	0.23
Emerald	0.10	0.12	0.13	0.14	0.12
Garden O' Plenty	0.31	0.34	0.38	0.44	0.47
Premier	0.05	0.08	0.08	0.09	0.10
Sunshine	0.10	0.16	0.22	0.23	0.28
hypnum	0.05	0.06	0.07	0.08	0.08

Appendix 5. Flow rate data from determination of horizontal flow rate of water through peats using apparatus shown in Figure 3.

Peat	Recorded Time* (min)	Flow Rate (gpm)
Alberta Rose	1.03	0.24
Beaver	1.71	0.15
Emerald	1.13	0.22
Garden O'Plenty	2.40	0.10
Premier	7.00	0.04
Sunshine	2.82	0.09
hypnum	2.23	0.11

* Time required to collect 1 quart of water from outlet end of trough.

Appendix 6. Titration data for the determination of maximum potential CEC values of raw peats.

Alberta Rose

(1) 1.93 g dry wt.

pH	ml NaOH
5.70	0.00
6.95	0.50
7.50	1.00
7.90	1.50
8.10	2.00
8.35	2.50
8.45	3.00
8.60	3.50
8.70	4.00
8.80	4.50
8.90	5.00
9.00	5.50
9.05	6.00
9.10	6.50
9.10	7.00
9.15	7.50
9.20	8.00
9.25	8.50
9.30	9.00
9.35	9.50
9.40	10.00
9.45	10.50
9.50	11.00
9.60	12.00
9.65	13.00
9.70	14.00
9.80	15.00
9.90	16.00
9.95	17.00
10.00	18.00

(2) 2.20 g dry wt.

pH	ml NaOH
5.60	0.00
6.05	0.15
6.40	0.25
6.70	0.45
6.90	0.65
7.10	0.85
7.25	1.05
7.30	1.25
7.45	1.45
7.65	1.65
7.70	1.85
7.80	2.05
7.85	2.25
8.00	2.45
8.00	2.65
8.05	2.85
8.10	3.05
8.15	3.25
8.20	3.45
8.40	3.85
8.60	4.35
8.70	4.85
8.95	5.35
9.05	5.85
9.10	6.35
9.15	6.85
9.20	7.35
9.25	7.85
9.30	8.35
9.40	8.85
9.40	9.35
9.45	9.85
9.50	10.35
9.55	10.85
9.65	11.85
9.70	12.85

(2) Cont.

pH	ml NaOH
9.80	13.85
9.90	14.85
9.95	15.85
10.00	16.85

(3) 3.91 g dry wt

pH	ml NaOH
5.3	0.00
5.55	1.00
5.90	2.00
6.30	3.00
6.60	4.00
6.95	5.00
7.15	6.00
7.40	7.00
7.65	8.00
7.80	9.00
7.95	10.00
8.10	11.00
8.35	12.00
8.50	13.00
8.65	14.00
8.85	15.00
8.95	16.00
9.05	17.00
9.10	18.00
9.15	19.00
9.25	20.00
9.50	25.00
9.70	30.00
9.90	35.00
10.00	37.00

Appendix 6. Cont.

Beaver

(1) 4.20 g dry wt.

pH	ml NaOH
3.70	0.00
3.80	1.0
4.45	2.00
4.50	3.30
4.90	4.30
5.20	5.30
5.40	6.30
5.55	7.30
5.70	8.30
6.05	9.30
6.85	11.70
6.90	14.70
7.15	16.70
7.35	18.70
7.65	20.70
7.70	22.70
7.95	24.70
8.10	26.70
8.30	28.70
8.35	30.70
8.80	35.70
9.00	36.70
9.45	43.70
9.75	49.70

(2) 3.35 g dry wt.

pH	ml NaOH
3.65	0.00
3.70	1.00
4.10	2.00
4.35	3.00
4.95	4.00
5.05	5.00

(2) Cont.

pH	ml NaOH
5.00	6.00
5.15	7.00
5.70	8.00
5.90	9.00
6.10	10.00
6.20	11.00
6.35	12.00
6.60	13.00
6.75	14.00
6.85	15.00
7.00	16.00
7.20	17.00
7.30	18.00
7.40	19.00
7.55	20.00
7.65	21.00
7.95	22.00
8.25	24.00
8.45	26.00
8.70	28.00
8.90	30.00
9.10	32.00
9.15	34.00
9.30	36.00
9.40	38.00
9.65	42.00
9.80	46.00
9.90	48.00

(3) 2.74 g dry wt.

pH	ml NaOH
3.70	0.00
4.25	1.00
4.70	2.00

(3) Cont.

pH	ml NaOH
5.10	3.00
5.35	4.00
5.60	5.00
6.00	6.00
6.10	7.00
6.25	8.00
6.50	9.00
6.70	10.00
6.90	11.00
7.00	12.00
7.20	13.00
7.30	14.00
7.40	15.00
7.55	16.00
7.65	17.00
7.60	18.00
7.90	20.00
8.00	21.00
8.15	22.00
8.25	23.00
8.40	24.00
8.50	25.00
8.60	26.00
8.70	27.00
8.85	28.00
8.95	29.00
9.00	30.00
9.10	31.00
9.25	33.00
9.40	35.00
9.60	37.00
9.70	39.00
9.85	41.00
9.95	43.00

Appendix 6. Cont.

Emerald

(1) 0.71 g dry wt.

pH	ml NaOH
6.00	0.00
7.20	0.50
7.78	1.00
8.05	1.50
8.43	2.00
8.70	2.50
8.98	3.00
9.15	3.50
9.25	4.00
9.38	4.50
9.45	5.00
9.59	5.50
9.65	6.00
9.75	6.50
9.83	7.00
9.90	7.50
9.99	8.00
10.00	8.50

(2) 0.72 g dry wt.

pH	ml NaOH
5.30	0.00
5.83	0.20
6.60	0.40
7.03	0.60
7.40	0.80
7.70	1.00
7.70	1.20
7.95	1.40
8.12	1.60
8.22	1.80
8.39	2.00
8.50	2.20
8.65	2.40

(2) Cont.

pH	ml NaOH
8.72	2.60
8.83	2.80
8.90	3.00
8.99	3.20
9.00	3.40
9.05	3.60
9.19	4.00
9.35	4.50
9.45	5.00
9.55	5.50
9.65	6.00
9.75	6.50
9.80	7.00
9.95	7.50
10.00	8.00

(3) 1.69 g dry wt.

pH	ml NaOH
5.20	0.00
7.10	1.00
7.75	2.00
8.30	3.00
8.50	4.00
8.60	5.00
9.05	6.00
9.15	7.00
9.30	8.00
9.40	9.00
9.50	10.00
9.60	11.00
9.75	12.00
9.85	13.00
9.90	14.00
10.00	15.00

Garden O'Plenty

(1) 2.98 g dry wt.

pH	ml NaOH
4.95	0.00
4.95	1.10
5.25	2.10
5.60	3.10
6.00	4.10
6.40	5.10
6.85	6.10
7.10	7.10
7.55	8.10
8.10	9.10
8.35	10.10
8.55	11.10
8.70	12.10
8.90	13.10
9.05	14.10
9.10	15.10
9.10	16.10
9.15	17.10
9.35	18.10
9.50	19.10
9.60	20.10
9.70	21.10
9.85	22.10
9.90	23.10
10.00	25.30

(2) 3.02 g dry wt.

pH	ml NaOH
5.10	0.00
5.30	1.00
5.70	2.00
6.25	3.00
6.65	4.00
7.10	5.00

Appendix 6. Cont.

Garden O'Plenty (cont.)

(2) Cont.

pH	ml NaOH
7.70	6.00
8.00	7.00
8.30	8.00
8.50	9.00
8.70	10.00
8.95	11.00
9.00	12.00
9.10	13.00
9.25	14.00
9.30	15.00
9.40	16.00
9.55	17.00
9.60	18.00
9.70	19.00
9.75	20.00
9.80	21.00
9.90	22.00
9.95	23.00
10.00	24.00

Premier

(1) 2.42 g dry wt.

pH	ml NaOH
3.60	0.00
3.75	1.00
4.05	2.00
4.35	3.00
4.70	4.00
4.90	5.00
5.10	6.00
5.30	7.00
5.90	8.00
6.00	9.00

(1) Cont.

pH	ml NaOH
6.15	10.00
6.30	11.00
6.65	12.00
6.80	13.00
6.90	14.00
6.95	15.00
7.15	16.55
7.60	20.55
8.35	24.55
8.65	28.55
9.10	32.55
9.20	36.55
9.35	40.55
9.45	44.55
9.55	48.55
9.60	52.55
9.70	56.55
9.80	60.55
9.90	64.55
10.00	68.55

(2) 2.57 g dry wt.

pH	ml NaOH
3.50	0.00
3.70	1.00
3.90	2.00
4.10	3.00
4.40	4.00
4.60	5.00
4.80	6.00
5.05	7.00
5.25	8.00
5.40	9.00
5.55	10.00
5.75	11.00

(2) Cont.

pH	ml NaOH
5.90	12.00
6.10	13.00
6.20	14.00
6.35	15.00
6.50	16.00
6.65	17.00
6.75	18.00
6.90	19.00
7.05	20.00
7.15	21.00
7.20	22.00
7.35	23.00
7.40	24.00
7.75	26.00
8.05	28.00
8.25	30.00
8.45	32.00
8.65	34.00
8.90	36.00
9.05	38.00
9.10	40.00
9.25	42.00
9.40	44.00
9.50	46.00
9.65	48.00
9.75	50.00
9.85	52.00
9.95	54.00
10.00	56.00

(3) 2.42 g dry wt.

pH	ml NaOH
3.70	0.00
4.00	1.00
4.30	2.00

Appendix 6. Cont.

Premier (cont.)

pH	ml NaOH
4.50	3.00
4.70	4.00
5.00	5.00
5.20	6.00
5.35	7.00
5.45	8.00
5.50	9.00
5.70	10.00
5.80	11.00
6.05	12.00
6.20	13.00
6.30	14.00
6.50	15.00
6.60	16.00
6.80	17.00
6.95	18.00
7.05	19.00
7.20	20.00
7.30	21.00
7.45	22.00
7.50	23.00
7.70	24.00
8.10	26.00
8.30	28.00
8.50	30.00
8.85	32.00
9.00	34.00
9.10	36.00
9.25	38.00
9.35	40.00
9.55	42.00
9.70	44.00
9.80	46.00
9.90	48.00
10.00	50.00

Sunshine

(1) 4.55 g dry wt.

pH	ml NaOH
3.95	0.00
3.85	1.00
3.95	2.00
4.20	3.00
4.45	4.00
4.60	5.00
4.70	6.00
4.90	7.00
5.05	8.00
5.25	10.00
5.45	12.00
5.95	14.00
6.20	16.00
6.45	18.00
7.00	20.00
7.30	22.00
7.65	24.00
7.85	26.00
8.05	28.00
8.20	30.00
8.30	32.00
8.50	34.00
8.55	36.00
8.70	38.00
8.90	40.00
9.05	42.00
9.15	44.00
9.25	46.00
9.35	48.00
9.50	50.00
9.55	52.00
9.70	54.00
9.75	56.00
9.85	58.00
9.95	60.00
10.05	62.00

(2) 4.84 g dry wt.

pH	ml NaOH
3.75	0.00
4.10	1.00
4.40	2.00
4.65	3.00
4.75	4.00
5.05	5.00
5.15	6.00
5.40	7.00
5.45	8.00
5.60	9.00
5.70	10.00
5.85	11.00
6.00	12.00
6.10	13.00
6.25	14.00
6.35	15.00
6.45	16.00
6.50	17.00
6.60	18.00
6.75	19.00
6.90	20.00
7.05	21.00
7.10	22.00
7.20	23.00
7.30	24.00
7.70	26.00
7.85	28.00
8.05	30.00
8.20	32.00
8.35	34.00
8.50	36.00
8.65	38.00
8.85	40.00
8.95	42.00
9.00	44.00
9.10	46.00
9.20	48.00

Appendix 6. Cont.

Sunshine (cont.)

(2) Cont.

pH	ml NaOH
9.30	50.00
9.40	52.00
9.50	54.00
9.60	56.00
9.70	58.00
9.75	60.00
9.85	62.00
9.90	64.00
10.00	66.00

hypnum

(1) 3.11 g dry wt.

pH	ml NaOH
5.35	0.00
6.65	1.00
7.45	2.00
8.05	3.00
8.40	4.00
8.65	5.00
8.95	6.00
9.05	7.00
9.10	8.00
9.30	9.00
9.40	10.00
9.50	11.00
9.60	12.00
9.70	13.00
9.75	14.00
9.85	15.00
9.95	16.00
10.00	17.00

(2) 3.97 g dry wt.

pH	ml NaOH
5.60	0.00
6.25	1.00
7.00	2.00
7.45	3.00
7.85	4.00
8.25	5.00
8.45	6.00
8.60	7.00
8.85	8.00
8.90	9.00
9.00	10.00
9.15	11.00
9.30	12.00
9.40	13.00
9.50	14.00
9.60	15.00
9.70	16.00
9.75	17.00
9.85	18.00
9.90	19.00
9.95	20.00
10.00	20.50

Appendix 6. Cont.

Average maximum potential CEC values of raw peats as shown in Figure 5.

pH	Alberta Rose	Beaver	Emerald	Garden O' Plenty	Premier	Sunshine	hypnum
7.00	0.06	0.36	0.13	0.18	0.70	0.42	0.05
8.00	0.15	0.58	0.22	0.25	0.99	0.60	0.10
8.50	0.22	0.70	0.32	0.32	1.18	0.72	0.14
9.00	0.31	0.83	0.48	0.42	1.34	0.88	0.22
Average	0.18	0.62	0.29	0.29	1.05	0.66	0.13

CEC values are shown as meq/g dry wt.

Appendix 7. Maximum potential CEC values of various peats in their H^+-form as shown in Figure 8.

pH	Alberta Rose	Premier	Sunshine	hypnum
7.0	0.78	0.85	0.41	0.64
8.0	1.09	1.12	0.71	0.82
8.5	1.24	1.25	0.87	0.92
9.0	1.46	1.36	0.97	1.02
Ave.	1.14	1.14	0.74	0.85

Appendix 8. Ash contents of various peats before and after washing with 3M HCl as shown in Figure 9.

	Ash Contents (%)	
Peat	Before	After
Alberta Rose	7.19	3.84
Premier	3.61	2.95
Sunshine	8.18	5.91
hypnum	25.55	17.27

Appendix 9. Concentrations of Ca, Mg and Fe in eluates from acid-washed peats as shown in Figure 10.

Peat		Ca (ppm)	Mg (ppm)	Fe (ppm)
Alberta Rose		13.9	2.83	<0.50
		13.4	2.71	1.04
	Ave.	13.65	2.77	<0.77
Premier		1.44	0.80	0.63
		2.26	0.80	0.61
	Ave.	1.85	0.80	0.62
Sunshine		5.09	1.04	1.02
		7.22	1.51	1.64
	Ave.	6.16	1.28	1.33
hypnum		38.1	4.43	5.46
		52.3	5.88	12.20
	Ave.	45.2	5.16	8.83

Appendix 10. Metal ion removal data from Premier peat as shown in Figure 11.

Element	Solution*	pH	Results (ppm)**	% Removal
Fe^{3+}	a*	3.0	< 0.85	> 39.9
	b*		2.45	95.5
	c*		< 0.58	> 97.8
	a*	4.0	< 0.50	> 99.5
	b*		< 0.50	> 99.1
	c*		< 0.50	> 98.2
	a*	5.0	< 0.50	> 99.5
	b*		< 0.50	> 99.1
	c*		< 0.50	> 98.2
Mn^{2+}	a*	3.0	< 0.50	> 95.8
	b*		0.80	86.5
	c*		< 0.50	> 83.0
	a*	4.0	0.64	94.6
	b*		< 0.58	> 90.0
	c*		< 0.50	> 83.0
	a*	5.0	< 0.50	> 95.4
	b*		< 0.50	> 95.4
	c*		< 0.50	> 83.0
Zn^{2+}	a*	3.0	< 0.50	> 96.0
	b*		< 0.60	> 91.2
	c*		< 0.70	> 79.1
	a*	4.0	< 0.70	> 94.8
	b*		< 0.50	> 92.0
	c*		1.70	45.9
	a*	5.0	< 0.50	> 96.0
	b*		< 0.50	> 92.0
	c*		1.21	61.5

* See Table 2 for solution concentrations.

** Average results obtained by atomic absorption spectroscopic analysis of "treated" test solution.

Appendix 11. Metal ion removal data from Alberta Rose peat as shown in Figure 12.

Element	Solution*	pH	Results (ppm)**	% Removal
Fe^{3+}	a	3.0	< 0.5	> 99.0
	b		0.93	96.4
	a	4.0	< 0.50	> 99.0
	b		< 0.50	> 98.0
	a	5.0	< 0.50	> 99.0
	b		< 0.50	> 98.0
Mn^{2+}	a	3.0	< 0.50	> 97.0
	b		< 0.50	> 93.9
	a	4.0	< 0.50	> 97.0
	b		< 0.50	> 93.9
	a	5.0	< 0.50	> 97.0
	b		< 0.50	> 93.9
Zn^{2+}	a	3.0	< 0.50	> 97.3
	b		< 0.50	> 94.7
	a	4.0	< 0.50	> 97.3
	b		< 0.50	> 94.7
	a	5.0	< 0.50	> 97.3
	b		< 0.50	> 94.7

* See Table 2 for solution concentrations.

** Average results obtained by atomic absorption spectroscopic analysis of "treated" test solution.

Appendix 12. Metal ion removal data from Sunshine peat as shown in Figure 13.

Element	Solution*	pH	Results (ppm)**	% Removal
Fe^{3+}	a	3.0	1.94	96.2
	b		2.30	95.5
	a	4.0	< 0.50	> 99.0
	b		< 0.50	> 98.0
	a	5.0	< 0.50	> 99.0
	b		0.60	97.6
Mn^{2+}	a	3.0	3.45	79.1
	b		0.98	88.1
	a	4.0	0.88	94.7
	b		< 0.50	> 93.9
	a	5.0	0.86	94.8
	b		< 0.50	> 93.9
Zn^{2+}	a	3.0	1.94	89.6
	b		< 0.50	> 94.6
	a	4.0	< 0.50	> 97.3
	b		< 0.50	> 94.6
	a	5.0	< 0.50	> 97.3
	b		2.98	68.2

* See Table 2 for solution concentrations.

** Average results obtained by atomic absorption spectroscopic analysis of "treated" test solutions.

Appendix 13. Metal ion removal data from hypnum peat as shown in Figure 14.

Element	Solution*	pH	Results (ppm)**	% Removal
Fe^{3+}	a	3.0	<0.50	>99.0
	b		<0.50	>98.0
	a	4.0	<0.50	>99.0
	b		<0.50	>98.0
	a	5.0	<0.50	>99.0
	b		<0.50	>98.0
Mn^{2+}	a	3.0	<0.50	>97.0
	b		<0.50	>93.9
	a	4.0	<0.50	>97.0
	b		<0.50	>93.9
	a	5.0	<0.50	>97.0
	b		<0.50	>93.9
Zn^{2+}	a	3.0	<0.50	>97.3
	b		<0.50	>94.7
	a	4.0	<0.50	>97.3
	b		<0.50	>94.7
	a	5.0	<0.50	>97.3
	b		<0.50	>94.7

* See Table 2 for solution concentrations.

** Average results obtained by atomic absorption spectroscopic analysis of "treated" test solutions.

Appendix 14. Calculations for the design of a hypothetical bog (horizontal system) using Alberta Rose peat.

Stream parameters

Stream contains 180 mg/l Fe^{3+}, 23 mg/l Mn^{2+} and 2.4 mg/l Zn^{2+}. Average flow rate is 10 gpm. Thus;

$$10 \text{ gpm} = 14{,}400 \frac{\text{gal}}{\text{day}} = 54{,}504 \frac{\text{liters}}{\text{day}}$$

$$54{,}504 \frac{\text{liters}}{\text{day}} = 9{,}810{,}720 \frac{\text{mg } Fe^{3+}}{\text{day}} \;;\; 1{,}253{,}592 \frac{\text{mg } Mn^{2+}}{\text{day}} \;;$$

$$\text{and } 130{,}810 \frac{\text{mg } Zn^{2+}}{\text{day}}$$

$$9{,}810{,}720 \frac{\text{mg } Fe^{3+}}{\text{day}} = 525{,}570 \frac{\text{meq } Fe^{3+}}{\text{day}}$$

$$1{,}253{,}592 \frac{\text{mg } Mn^{2+}}{\text{day}} = 45{,}585 \frac{\text{meq } Mn^{2+}}{\text{day}}$$

$$130{,}810 \frac{\text{mg } Zn^{2+}}{\text{day}} = 8{,}050 \frac{\text{meq } Zn^{2+}}{\text{day}}$$

Total meq metals per day = 525,570 + 45,585 + 8,050
= 579,205 meq metals per day

Weight of peat needed to provide treatment for one year:

$$579{,}205 \frac{\text{meq}}{\text{day}} \times \frac{\text{g}}{0.18 \text{ meq}} \times \frac{m^3}{0.1 \times 10^6 \text{ g}} = 32.18 \frac{m^3}{\text{day}}$$

$$32.18 \frac{m^3}{\text{day}} \times 365 \frac{\text{days}}{\text{year}} = 11{,}744.99 \frac{m^3}{\text{year}} = 414{,}774.30 \frac{ft^3}{\text{year}}$$

Appendix 14. Cont.

Bog dimensions

Maintain ratios of (1) width to depth (0.75 ft. : 1.0 ft.) and (2) cross-sectional area to flow rate (0.75 ft.^{2} : 0.24 gpm) from experimental trough.

Cross-sectional area of bog:

$$\frac{0.75\ \text{ft.}^2}{0.24\ \text{gpm}} = \frac{\text{area}}{10\ \text{gpm}}$$

$$\text{area} = \underline{31.25\ \text{ft.}^2} \quad \text{or depth x width} = 31.25\ \text{ft.}^2$$

$$\text{depth} = \frac{31.25}{\text{width}}$$

Dimensions:

$$\frac{0.75\ \text{ft.}}{1.0\ \text{ft.}} = \frac{\text{width}}{\text{depth}}$$

$$= \frac{\text{width}}{31.25/\text{width}}$$

$$= \frac{(\text{width})^2}{31.25}$$

$$\text{width} = \underline{4.84\ \text{ft.}}$$

$$\text{depth} = \frac{31.25}{4.84} = \underline{6.46\ \text{ft.}}$$

$$\text{length} = \frac{414{,}774.3\ \text{ft}^3}{(4.84)\ (6.46)} = \underline{13{,}265\ \text{ft.}}$$

Appendix 15. Calculations for the design of vertical treatment systems using Alberta Rose peat. Refer to Appendix 10 for stream and peat parameters.

$$\text{Volume of 10-ft. column of peat} = (3.14)\ \frac{(1\ \text{ft.})^2}{4}(10\ \text{ft.})$$

$$= \underline{7.85\ \text{ft.}^3}$$

Need 414,774.3 ft.^{3} of Alberta Rose peat to provide one year of treatment. Thus;

$$\text{No. of 10-ft. columns} = 414{,}774.3\ \text{ft.}^3 \times \frac{\text{column}}{7.85\ \text{ft.}^3}$$

$$= \underline{52{,}837.5\ \text{columns}}$$