Soil and Surface Water Nutrients in The Everglades Nutrient Removal Project

by

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ACKNOWLEDGEMENTS

Historically, the Everglades ecosystem evolved from peat accumulation under flooded soil conditions driven primarily by atmospheric nutrient inputs. Over the last several decades, anthropogenic activities have modified the nutrient and chemical budget of this system. In an effort to minimize further changes to the nutrient balance of the Everglades, the Everglades Nutrient Removal (ENR) project is being developed to assimilate nutrients from agricultural runoff before reaching the Everglades marshes. Artificially constructed and natural wetlands have been and continue to be used worldwide to assimilate and store nutrients from agricultural runoff and municipal sources. Nevertheless, the retention efficiencies of wetland systems in various geographical areas for different forms of nitrogen (N) and phosphorus (P), are highly variable and difficult to predict. Thus, it is important to understand the biological and physico-chemical factors controlling P and N cycling in the Everglades to predict the efficiency of biological nutrient uptake systems in the Everglades Agricultural Area.

Approximately 95% of all the nutrients in a wetland system are stored in the soils, and approximately 70% of the volume of organic peat soils in the ENR project is water. Therefore, the levels of both total soil and interstitial nutrients were determined in this study. Soil submergence modifies the biological and physico-chemical processes affecting soil nutrient retention and therefore, the release of stored nutrients upon soil flooding was also investigated. Two flooded fallow agricultural fields and one drained field under agricultural production were sampled for surface water and interstitial soluble nutrients and other chemical parameters from August, 1989 to June, 1990. In addition, micro-profiles of ammonium (NH_4^+), soluble reactive P (SRP) and pH were measured at the soil-water interface in 1 cm intervals, September 1990. Soil redox profiles were also determined and soil cores were collected and analyzed for total soil nutrient and mineral content.

Total soil P in the upper 30 cm of the three fields sampled ranged from 289 to 343 $\mu g\ g^{-1}$ and N from 23.22 to 26.29 mg g^{-1}. Mean P and N storage in the upper 30 cm were 276 and 21,967 kg ha^{-1}, respectively, based on bulk densities of 0.298 ± 0.068 g cm^{-3}. Soil P levels in the ENR are within the range reported for rich fens in Newfoundland, peatlands of the northern U.S.A., and the tropical *Papyrus* swamps of Uganda. Regionally, P levels in the upper 30 cm of the ENR soils were similar to the northern area of Water Conservation Area 2A (WCA-2A) and the upper range cited for Water Conservation Area 3 (WCA-3), but was 2 and 9 times higher than southern sites of WCA-2A and the interior of Water Conservation Area 1 (WCA-1), respectively. Total N content of Everglades soils including those from the ENR site, Water Conservation Areas (WCAs), and Everglades National Park (ENP) were within the upper ranges of peatland soils reported in the literature on a dry weight or areal basis. A sub-tropical climate which promotes bacterial and blue-green algal production may contribute to the N accumulation via N-fixation in Everglades soils. Variations in bulk densities have a significant impact on the accumulation of N and P reported for different peatlands. As a result, compaction and desiccation which consolidates the organic material could influence comparative values of nutrient storage.

Total soil N and P in a peatland soil represent the bulk accumulation of nutrients over time and their potential availability. However, it is the recycling of these nutrient pools in the soil environment which determines the biological productivity of wetland ecosystems. At the initiation of the flooding experiment, soluble P in the interstitial waters ranged from 0.043 to 0.539 mg L^{-1} and increased to 0.419 to 3.131 mg L^{-1} after 10 months of soil saturation. Soil porewater NH_4^+ concentrations also increased from < 1.0 mgL^{-1} before flooding to 1.418 to 8.222 mgL^{-1} in June, 1990. Soluble reactive P concentrations found in the ENR soils were an order of magnitude higher than *Typha/Carex* marshes in Canada and Michigan and the interior of WCA-

1 and southern sites of WCA-2A. However, ENR soluble P levels were comparable to those found in the northern areas of WCA-2A.

Biological mineralization of organic P and N appears to be an important factor in the release of inorganic P and N into the interstitial waters upon soil flooding. Sulfate reduction supports approximately 50% of organic matter decomposition in salt marshes and may be important in releasing stored nutrients in soils of the ENR project. Sulfate (SO_4^{2-}) levels are high in the ENR soils compared to most freshwater systems and decreased significantly over the study period. Additionally, soil oxidation-reduction potentials fell within the theoretical range of sulfate reduction. Nitrate was also available seasonally with peak concentrations in the fall and winter within the range of 1.0 to 2.0 mg L^{-1} and would preferentially be reduced by dissimilatory processes before SO_4^{2-} in the breakdown of organic matter.

The chemical form, i.e., organic, inorganic, oxidized, or reduced, of both P and N released into the interstitial water will determine the potential for biological and/or physico-chemical processes to cycle and store these nutrients. Soluble reactive P represented 86% of the total P in the interstitial pool and would be available for assimilation by emergent vegetation in the ENR site. Conversely, dissolved organic N represented a major fraction (74%) of total soluble N in the soils. Organic N would accumulate unless it is broken down further to NH_4^+, the primary form of N taken up by vegetation. This pool of dissolved organic N had a mean concentration at all depths over the entire year of 11.925 ± 3.405 mg L^{-1} in the flooded fields and 8.877 ± 3.405 mg L^{-1} in the drained field, with no significant changes over time. Accumulation of soluble refractory organic N (non-bioavailable) in the interstitial waters could cause high rates of N diffusion into the overlying surface waters. This potential N release from the sediments is suggested by the relatively high dissolved organic N in overlying surface water of the flooded fields, 3.657 ± 1.193 mg L^{-1} compared to total inorganic N, 0.161 ± 0.104 mg L^{-1}.

Although organic N was high in the surface waters, inorganic N and P concentrations in overlying surface waters were low compared to those of the interstitial waters and tended to decrease over time. Average TP and SRP levels in the two flooded fields were highest in August, 1989 at the initiation of flooding, 0.372 and 0.244 mg L^{-1}, and decreased to 0.046 and 0.004 mg L^{-1} in June, 1990. Similarly, NH_4^+ concentrations ranged from 0.260 to 0.040 mg L^{-1} in August, 1989 and decreased in range, 0.038 to 0.024 mg L^{-1} in June, 1990.

Several factors may be controlling surface water nutrient levels despite steep concentration gradients from the soils to the overlying waters. High pH values in the upper soil and water column indicate high benthic algal productivity. This submerged vegetation can be very important in directly assimilating inorganic nutrients and also lowering CO_2 and HCO_3^- concentrations thus, shifting the carbonate equilibrium toward $CaCO_3$ precipitation. Calcium concentrations in the ENR are high, > 100 mg L^{-1}; therefore the inorganic precipitation of P with $CaCO_3$ may be a significant inorganic P uptake and storage mechanism. Oxygen production by benthic vegetation would also cause the oxidation of ferrous iron compounds which are known to co-precipitate available P. A shallow oxidized micro-layer in wetland soils has been shown to control nitrification of NH_4^+ and thereby influence the N_2 removed through nitrification-denitrification processes.

In conclusion, the ENR project has the potential to maintain low inorganic surface water N and P levels in spite of high soil nutrient levels. However, further research is needed on the mineralization of stored inorganic and organic N and P in the soils, N and P assimilation rates and *in situ* flux rates from the soils, the processes controlling the soil-water interface, and the biological availability of soluble organic N and P in the surface waters.

Recommendations for the ENR project based on the present study include:

1) Plan a recirculation system into the construction design for the start-up phase when

nutrients will be released upon flooding agricultural fields. In the future this could also be used as a flushing technique to harvest soil nutrients back into the agricultural area after periods of drought.

    2) Conduct liming addition experiments to determine the effect on co-precipitation of available P with calcium carbonate.

    3) Promote vegetation which would not shade benthic algal mats.

    4) Select for species which have a high resistance to decomposition such as high lignin or silica content.

    5) Control outflows such that only surface waters are exported from the system with a minimum disturbance to the soils thus, minimizing resuspension of soil nutrients into overlying waters.

EXECUTIVE SUMMARY GLOSSARY

Anthropogenic: Involving the impact of man on nature. Induced or altered by the presence and activities of man.

Benthic: Pertaining to aquatic bottom or sediment habitats.

Bulk Density: Is a unit of mass per unit of volume. In this case the weight of the soil within a volume of a soil core ($g\ cm^{-3}$).

Decomposition: Metabolic breakdown of organic materials primarily by microorganisms.

Denitrification: Enzymatic reduction of nitrates by bacteria to nitrogen gas.

Dissimilatory: Catabolism, contrasted with assimilation. In this context, nitrate is reduced to accept electrons not as an assimilative process.

Fens: Open wetland systems that generally receive some drainage from surrounding mineral soils and often covered by grasses, sedges, or reeds.

Interstitial: The pore spaces between lattices. In this context, the pore spaces of un-decomposed organic material and inorganic matter. In wetland soils this space is primarily occupied by water.

Mineralization: The process of converting or being converted into a mineral or inorganic form.

N-Fixation: The reduction of atmospheric nitrogen to cell nitrogen by microorganisms.

Nitrification: The biological oxidation of ammonia to nitrate.

Physico-chemical: All the non-biologic factors that form a part of the environment for an organism.

Redox Potential: Abbreviation for oxidation-reduction potential. A composite measure of the compounds present which are either being used as electron acceptors or electron donors in the soil. A measure of the reducing condition of the soil.

Refractory: A material resistant to corrosion or biological breakdown.

Sulfate Reduction: The enzymatic reduction of sulfate to reduced forms such as sulfide, primarily mediated by microbes.

ABSTRACT

The present study was initiated to investigate soil and water nutrient levels, mineral content, conductivity, pH, and soil redox potentials in the Everglades Nutrient Removal (ENR) project. Changes in soluble nutrient concentrations from persistent soil submergence was also followed for one year to document the potential release of accumulated phosphorus (P) and nitrogen (N). Total P and N storage in the upper 30 cm soil profile were 276 and 21,967 kg ha^{-1}, respectively. Before fields were flooded, interstitial soluble ammonium (NH_4^+) and total P concentrations ranged from 0.130 to 0.976 and 0.043 to 0.539 mg L^{-1}, respectively. After 10 months of soil flooding, ranges increased to 1.418 to 8.222 mg L^{-1} NH_4^+ and 0.419 to 3.131 mg L^{-1} total P. Oxidation-reduction potentials (Eh) were found within the values of sulfate (SO_4^{2-}) instability, approximately -100 mV. Interstitial SO_4^{2-} concentrations, > 100 mg L^{-1}, exceed those found in most fresh water peatlands and decreased throughout the year with persistent flooding. After two months of flooding, mean monthly NH_4^+, total P, and SRP concentrations in the surface water were one to two orders of magnitude lower, 0.048 ± 0.023, 0.091 ± 0.053, and 0.021 ± 0.026 mg L^{-1}, than in the interstitial water. Calcium levels greater than 100 mg L^{-1}, high pH values of 8.0, and benthic vegetation at the sediment-water interface, may have contributed to the low inorganic P levels in the overlying surface waters. The ENR project showed the capacity to maintain low inorganic N and P concentrations in the overlying water. However, the potential for organic nutrient retention, particularly N, may be limited.

Key Words: Phosphorus, Nitrogen, Everglades, Interstitial, Soil

INTRODUCTION

The Everglades Nutrient Removal (ENR) project is being developed to assimilate nutrients from agricultural runoff before reaching the Everglades marshes. Artificially constructed and natural wetlands have been and are being used to assimilate and store nutrients such as nitrogen (N) and phosphorus (P) from municipal and non-point sources in the United States, Germany, Holland, Finland, and other countries (Odum et al., 1975; Tourbier and Pierson, 1976; Tilton et al., 1976; for review see Godfrey et al., 1985). Several different wetland types including freshwater marshes, northern peatlands and, forested swamps, have been found to function as nutrient sinks (Grant and Patrick 1970, Kitchens et al., 1975; Kadlec 1976; Fetter et al., 1978; Verry and Timmons, 1982). The capacity for wetlands to store nutrients may be limited, however, by seasonal variability in nutrient retention, particularly in regions where freezes occur, and the inability of different wetland types to assimilate various forms of N and P (Whigham and Simpson, 1976; Mitsch, 1977; Simpson et al., 1978; Richardson et al., 1978; Kadlec, 1979; Dolan et al., 1981; Nessel and Bayley, 1984; Kemp and Day, 1984).

Wide discrepancies in P retention efficiencies are found in the literature from different wetland types and within various geographical regions (Richardson and Davis, 1987; Mitsch and Gosselink, 1986). As an example, retention capacities of total P have been reported to be 87 % to -27 % efficient from loadings of 0.9 to 16.8 g P m^{-2} yr^{-1} from sites in Florida and Michigan (Boyt et al., 1977; Knight et al., 1985; Tuschall et al., 1981; Nessel, 1978; Kadlec 1981, 1983). Nitrogen removal efficiencies have been reported to be more consistent than P and average approximately 75% retention under various loading rates (Richardson and Davis, 1987). Richardson and Davis (1987) report variability in the N species wetland systems can assimilate and a decrease in N uptake for some forms of N over time. Thus, it is important to understand the biological and physico-chemical factors controlling P and N cycling in the Everglades to predict the efficiency of biological nutrient uptake systems in the EAA.

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In addition to a wide range of nutrient removal efficiencies reported for wetlands, our knowledge on nutrient dynamics in wetland peats is primarily based on low pH bogs and fens in temperate regions (Pollett, 1972; Kadlec, 1979; Kadlec and Kadlec, 1979; Richardson et al., 1976, 1978; Verhoeven, 1983; Etherington, 1983; Koerselman et al., 1988) or riverine freshwater marshes with a high mineral content (Whigham and Simpson, 1976; Sloey et al., 1978; Klopatek, 1978). Very little information exists to date on the mechanisms controlling nutrient cycling in organic histosols in the Everglades, particularly under various hydrological conditions. The Everglades Nutrient Removal (ENR) project is also unique compared to many other ongoing and proposed flowway systems for three reasons:

1) The location of this project in a sub-tropical peatland allows for a year-round growing season. Continued growth of vegetation with high nutrient availability directly enhances biological nutrient uptake (Richardson et al., 1976; Klopatek, 1978; Tilton and Kadlec 1979). The indirect effects of vegetation on nutrient cycling may be more important, particularly changes in the physico-chemical environment of the soils through oxidation of the rhizosphere or area surrounding the roots (Ponnamperuma, 1965; Armstrong, 1978; Good and Patrick, 1987). These processes which affect soil nutrient dynamics are important because, approximately 90% of the TP, and TN in wetlands is stored in the soils (Richardson et al. 1976; Verhoeven, 1986).

2) Weather patterns are highly variable and include periods of extreme drought. Therefore, the ENR project must be intensely managed hydrologically, to avoid soil desiccation, subsequent oxidation (Stephens, 1984) and the release of stored nutrients (Richardson et al., 1978; Kadlec and Kadlec, 1979; Worth, 1983).

3) The concentrations of nutrients, P in particular, are low in the inflow waters of the ENR project (< 0.20 mg TP L^{-1};) compared to waste water effluents treated in managed wetlands (> 1.0 mg TP L^{-1}; frequently > 10 mg L^{-1}). These low P concentrations must be reduced to even lower levels in the outflow to achieve net P uptake from the system.

Phosphorus is an important limiting nutrient in the Everglades (Steward and Ornes, 1975; Swift, 1981; Swift and Nicholas, 1987; Scheidt et al., 1987) and other freshwater wetlands including, freshwater marshes (Klopatek, 1978), northern bogs (Heilman, 1968), and Southern swamps (Mitsch et al., 1979). Therefore the emphasis for nutrient removal within the ENR project and nutrient studies in the Everglades has been focused on P. A conceptual design of the P dynamics in the ENR project is illustrated in Figure 1. Six general P pools are identified: 1) surface water, 2) above-ground macrophytic and epiphytic (attached) vegetation, 3) benthic algal biomass (macro and microscopic), 4) below-ground biomass of roots, 5) detritus and associated microbial community active in cycling and mineralizing the organic and inorganic P forms, and 6) buried soil below the active biological layer which acts as a permanent inorganic and organic P storage unless a dramatic event occurs (e.g. a deep peat burn).

The major transformations and fluxes of P are represented by letters **a** through **j** in Figure 1. As P enters the system through surface water inflows (**a**) it can be taken up by submerged aquatic vegetation (Littlefield and Forsberg, 1965; McRoy et al., 1972), epiphytic growth on macrophytes (**b**; Toth, 1972), and benthic algal mats (**c**; Gleason, 1972; Swift and Nicholas, 1987). Although vegetative uptake represents a sink for P, macrophytes can act as conduits for soluble P from the soils to the water column (Klopatek, 1975) and rapid turnover rates of benthic algae could act as an additional P source to the water column. The oxygen production of this benthic algal mat is extremely important in maintaining the depth of the aerobic/anaerobic microzone of the water/soil interface (Belanger et al., 1989) which can directly and indirectly control the flux of soluble soil P to the water column (Syers et al., 1973; Patrick and Khalid, 1974). Fluxes **d** and **e** represent the accumulation of organic P known to be important for P storage in enriched areas of the Everglades (Koch and Reddy, in review). This P pool (5) is a

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Phosphorus Pools and Cycling

Precipitation/Canal P

2. Above-ground Macrophyte/Epiphytic P

B

A

3. Benthic algal P

C

G

1. Surface water P

Aerobic

Soil - Water Interface

Anaerobic

5a. Interstitial P

D

E

F

5. Surface soils/biogeochemically active P

4. Below-ground live biomass P

5c. Adsorbed/co-precipitated P

5b. Organic P

H

I

6. Organic Peat/Inorganic P (Storage)
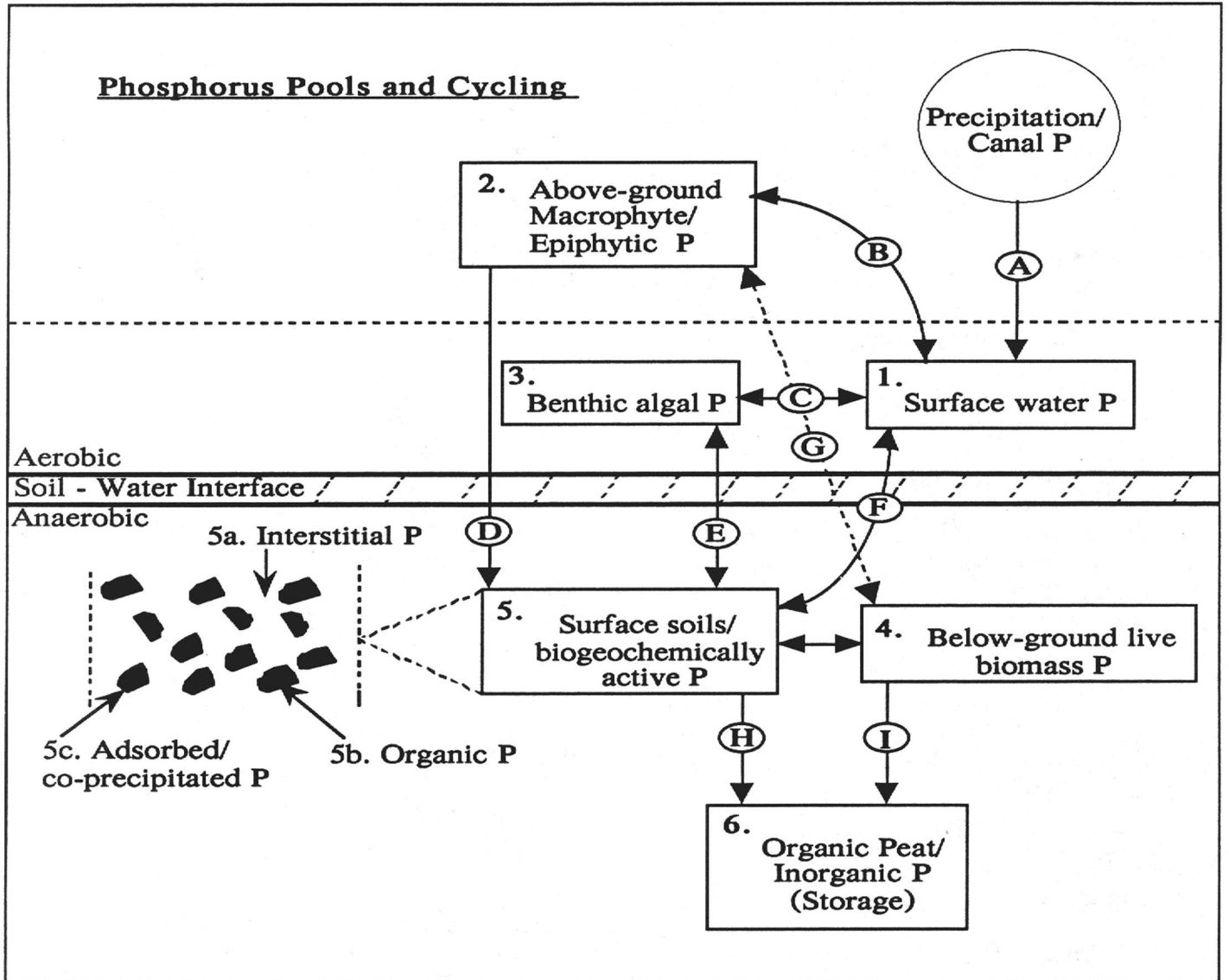
Figure 1   Schematic illustration of the major phosphorus pools listed 1 through 6 and arrows depicting phosphorus flows, **a** through **j**, in the Everglades Nutrient Removal Project

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combination of detritus (dead biological material) with associated microflora (Reeder and Davis, 1983). Detritus increases in P content over time under nutrient enrichment in northern peatlands, fresh water tidal marshes (Whigham and Simpson, 1976), and Everglades peat (Davis, 1982). A fraction of this soil P may be adsorbed or co-precipitated with organic colloids (Harter, 1969; Jervis, 1969) and inorganic material (Otsuki and Wetzel, 1972; Wetzel, 1983). The P which is assimilated or precipitated will accumulate if stored below the active surface layer (h,i). Otherwise, resuspension and diffusive fluxes (f) may cause the soils to become a source of P to the surface waters.

Since the bulk density of decomposed peats are reported to be between 0.2 and 0.3 g cm^{-3} (Brady, 1974), the same range found at the ENR site, a large volume of the soil, 70 to 80% is interstitial water. This can be compared to 45 to 55% pore space volume for inorganic mineral soils (Patrick, 1981). The present study was initiated to determine the concentrations of soluble P and N within the pool of interstitial water and how these nutrient levels may affect surface water nutrient concentrations. Total soil N and P levels were also measured and compared to other freshwater peatlands. In addition, changes in soluble nutrient concentrations from continuous soil submergence were followed for one year to document the potential release of stored P and N due to the flooding of agricultural fields.

MATERIALS AND METHODS

Study Site

The ENR project is located 26°39' latitude and 80°25' longitude on the western edge of the L-7 canal and Water Conservation Area-1 (WCA-1) southeast of Lake Okeechobee in the S5-A drainage basin (Figure 2). The 3,700 acre area presently encompasses 16 agricultural fields which are labelled A through P. Fields A and B were flooded along with O and P in August, 1989. Remnant cane from one year of being left fallow was growing but died back through out the year with continual

submergence. Staff gauges were installed in the center lateral canal in fields A and B and at the intake canal where an auxiliary pump (G-210) was located along the L-7 levee (Figure 2). The auxiliary pump was used to supply supplemental water in periods of low rainfall to keep fields A, B, O and P flooded. Rainfall recorded at the S-5A pumping station, approximately one mile from the ENR site, was 91 cm (35.9 inches) through the period of study (August, 1989 to June, 1990). A water budget was not within the scope of this study because preliminary muck berms with high seepage rates were used to isolate flooded fields. However a water budget will be an integral component for the nutrient budget in the larger scale 3,700-acre ENR project.

Soil Nutrients

Soil cores were collected in September, 1989 at the initiation of the study from all five sites in each field. A plastic (PVC) core (10 cm in diameter and 70 cm in height) was driven into the peat with a sledge hammer causing minimum compaction, < 2.0 cm. Soil cores were transported to the District laboratory and sectioned into 0-15, 15-30, 30-45, and 45-60 cm depths. Soils were air dried, weighed, digested with sulfuric acid and analyzed for total P using the molybdate blue method (Method 365.4; EPA, 1979). Total Fe, Al, and Ca were determined according to EPA method 6010 (EPA, 1986). Total C and N were analyzed using a 1-240C Perkin Elmer Elemental Analyzer.

Surface Water and Interstitial Nutrients

Monthly sampling - Three fields, A, B, and C were chosen to measure changes in surface water and interstitial nutrient concentrations and other chemical parameters for one year (Figure 2). Fields A and B were kept flooded for one year and field C remained drained and in sugar cane production. Water samples were collected and water levels at each site were recorded in August, September, October, November, February, April, and June. Soil solution samplers (Wagner, 1962) were installed one meter apart at five randomly

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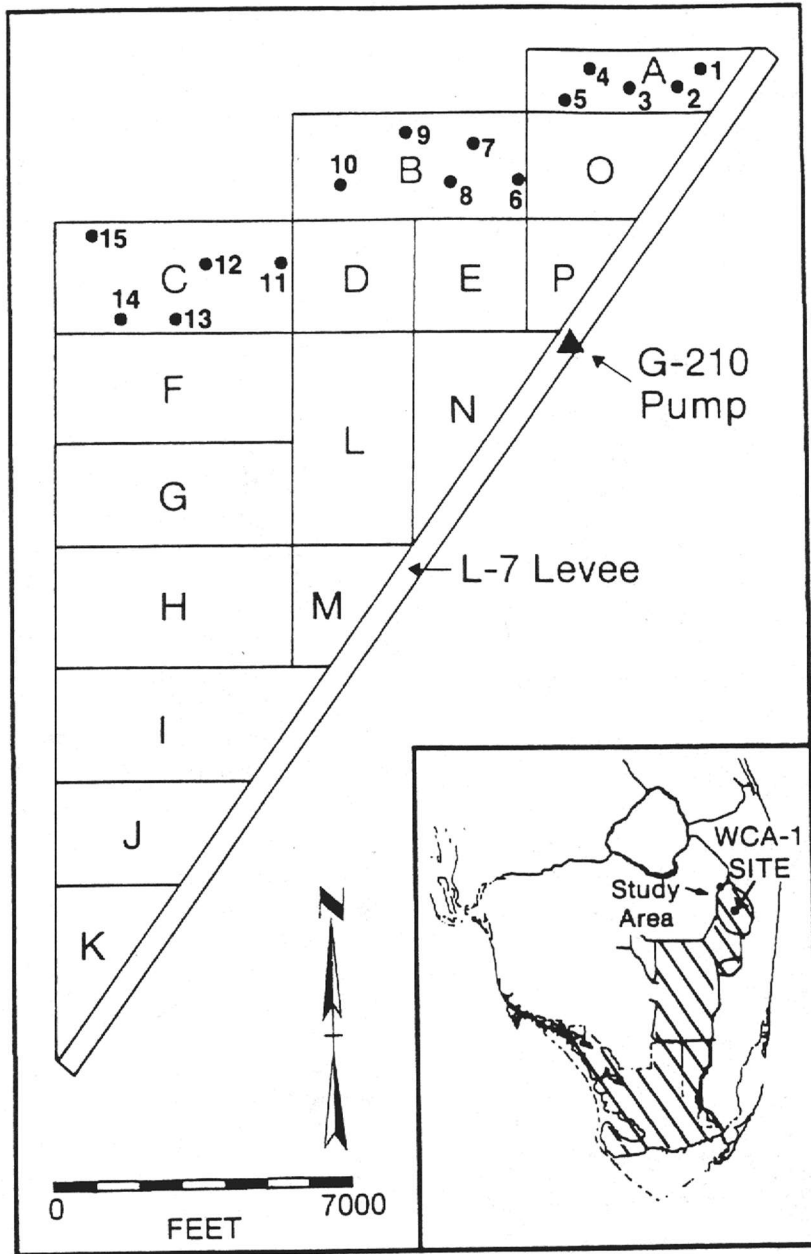
Figure 2. Study area is shown in relation to the Everglade marshes (shaded bar). Agricultural fields included within the Everglades Nutrient Removal Project area are labelled A through P. The five sites in field A, B, C and control site in WCA-1 are shown with blackened circles. Location of the auxiliary pump, G-210 and the L-7 levee are identified.

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chosen sites in each field at 15, 30, 45, and 60 cm depths (Figure 2). Interstitial soil solution samplers were allowed to equilibrate for one month in the soil and two liters of water were drawn through the porous ceramic cup to reduce the effect of absorption of PO_4^{3-} and NH_4^+ (Hansen and Harris, 1975). Ceramic cup samplers (n=5) were also compared to plastic well points with slits in the PVC (n=5). For this test, each sampler type was alternately placed and spaced one meter apart to a depth of 30 cm in field A.

During each sampling event, wells were emptied (n=60) and 40 decibars of vacuum applied. After 24 hours, approximately 500 ml of water was collected from each well. A surface water sample was also collected in a non-disturbed area in close proximity to the wells. Samples were immediately put on ice and transported back to the District laboratory. Unfiltered samples were analyzed without acidification for specific conductance (EPA, 1979). Samples to be analyzed for total Kjeldahl nitrogen (TKN; EPA, 1979) and total phosphorus (TP; APHA, 1985) were acidified with sulfuric acid (H_2SO_4) to pH 2.0. Samples analyzed for iron (Fe; APHA, 1985), manganese (Mn; EPA, 1979), and mercury (Hg; EPA, 1979) were acidified with nitric acid (HNO_3) to pH 2.0. Samples analyzed for soluble reactive phosphorus (SRP; APHA, 1985), nitrite (NO_2^-; APHA, 1985), sulfate (SO_4^{2-}; EPA, 1979), chloride (Cl^-; APHA, 1985), and silicate (SiO_2; APHA, 1985) were filtered using a Millipore Swinnex 47 mm filter holder containing a 0.45 µM Poretics polycarbonate filter and a fiberglass prefilter before analysis. Nitrate plus nitrite ($NO_3^- + NO_2^-$; APHA, 1985), ammonium (NH_4^+; APHA, 1985), total dissolved Kjeldahl nitrogen (TDKN; EPA, 1979) and total dissolved phosphorus (TDP; EPA, 1979) were also filtered as described previously and acidified to pH 2.0 with H_2SO_4. Calcium (Ca^{2+}; APHA, 1985), magnesium (Mg^{2+}; APHA, 1985), sodium (Na^+; APHA, 1985) potassium (K^+; APHA, 1985) , and manganese (Mn; EPA, 1979) were also filtered as

described above and acidified to pH 2.0 with 50% hydrochloric acid (HCl).

Micro-profile sampling - In addition to monthly interstitial water sampling, the micro-profile of SRP, NH_4^+, $NO_3^- + NO_2^-$, and pH of the interstitial and overlying waters were measured. Soil porewater was sampled using equilibrators (60 X 7 X 2 cm) with thirty 8 mL cells equally spaced at 1.0 cm intervals (Hesselin 1976). Equilibrators were installed at five sites in field A and an interior control site in WCA-1 (Figure 2) September 1990 in collaboration with the Department of Soil Science, University of Florida (Reddy and Graetz 1991). Prior to installation, cells were filled with deionized deoxygenated (gassed with N_2) water and covered with a 0.2 µM nucleopore polycarbonate membrane with a protective 1 µM sectra/mesh nylon membrane cover. The equilibrators were then put into a storage case and gassed with deoxygenated deionized water for 24 hours before being transported to the field. Cells were allowed to equilibrate for 14 days in the field after which they were retrieved and immediately sampled. A syringe was used to pierce the membrane and remove the water sample which was immediately acidified to pH 2 with H_2SO_4 in a 20 mL scintillation vial. The last 5 mL of sample was kept in the syringe which was then stuck into a rubber stopper to prevent degassing for pH determinations within 24 hours of returning to the Soil Science Department, Wetland Soil Laboratory, University of Florida. Water samples were analyzed for SRP, NH_4^+, and $NO_3^- + NO_2^-$ using a Technicon Auto Analyzer II (APHA, 1985).

Soil Oxidation-Reduction Potential (Eh)

Soil Eh (mV) was measured at 5 sites in field A and a control site in the interior of WCA-1 September, 1990 (Figure 2). In anaerobic soils Eh is used as an indicator of soil reduction because oxygen tension is low and O_2 readings are unstable. After oxygen is consumed by microbes, other oxidized compounds i.e., NO_3, Mn^{4+}, Fe^{3+}, SO_4^{2-}, and CO_2 and are

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reduced to N_2, NH_4^+, Mn^{2+}, Fe^{2+}, H_2S, and CH_4, respectively. During microbial respiration, this reduction follows a sequential pattern and the redox-couples present, measured in mV, are an indication of soil anaerobic conditions (Patrick 1964; Connell and Patrick, 1968; Turner and Patrick, 1968; Ponnamperuma, 1972) as illustrated in Figure 3.

Platinum redox probes constructed with copper wire laser welded to a 1.0 cm length platinum wire (18 gauge) were used for mV readings with a Cole-Parmer model 5985-80 pH, temperature, mV meter. All platinum probes were rinsed with dilute HCl and distilled water and checked with quinhydrone in pH buffer 4.0 (+218 mV) before being installed in the field. All probes were accurate within 8 mV of the standard (range = +210 to +218 mV). Measurements were taken in the soil at 2.0 cm intervals from 1 cm to 15 cm depth after a 30 minute equilibration period, at which time readings were stable. Eh values were corrected by subtracting the potential of the calomel reference electrode, -244 mV, from the mV reading.

Statistical Analysis

Regression, analysis of variance, t-tests, correlation analysis (Pearson correlation coefficients), multiple mean range testing (Duncan's multiple range test), means, standard errors, standard deviations, and coefficient of variation were performed using SAS (SAS, 1988). All means are presented with ± standard error of the mean. Means are significantly different at the $P < 0.05$ level, unless otherwise stated.

RESULTS
Water Levels

Precipitation and pumping of water into the study area achieved a continuous flooding treatment in field A and B (Figure 4). However, micro-topographical differences in elevation caused variability in water levels between the five sites in field A and B. Water levels at sites 1, 2, and 3 in field A fell below the soil surface during February and April, and at site 10 in field B in April. Data are presented in this report for field A and B separately, not
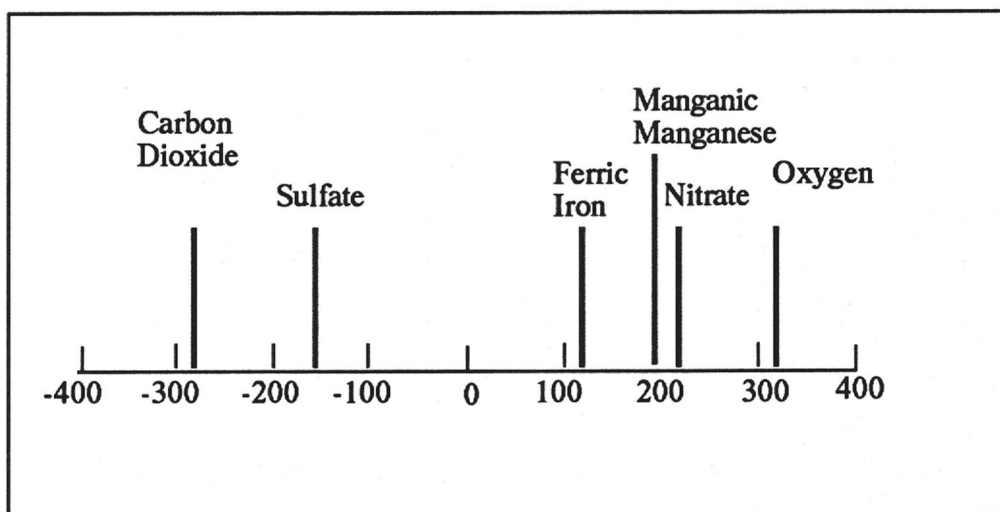
Figure 3. Theoretical ranges in Eh (mV) where important oxidation-reduction systems become unstable at pH 7. Modified from Gambrell and Patrick (1978).

Field A
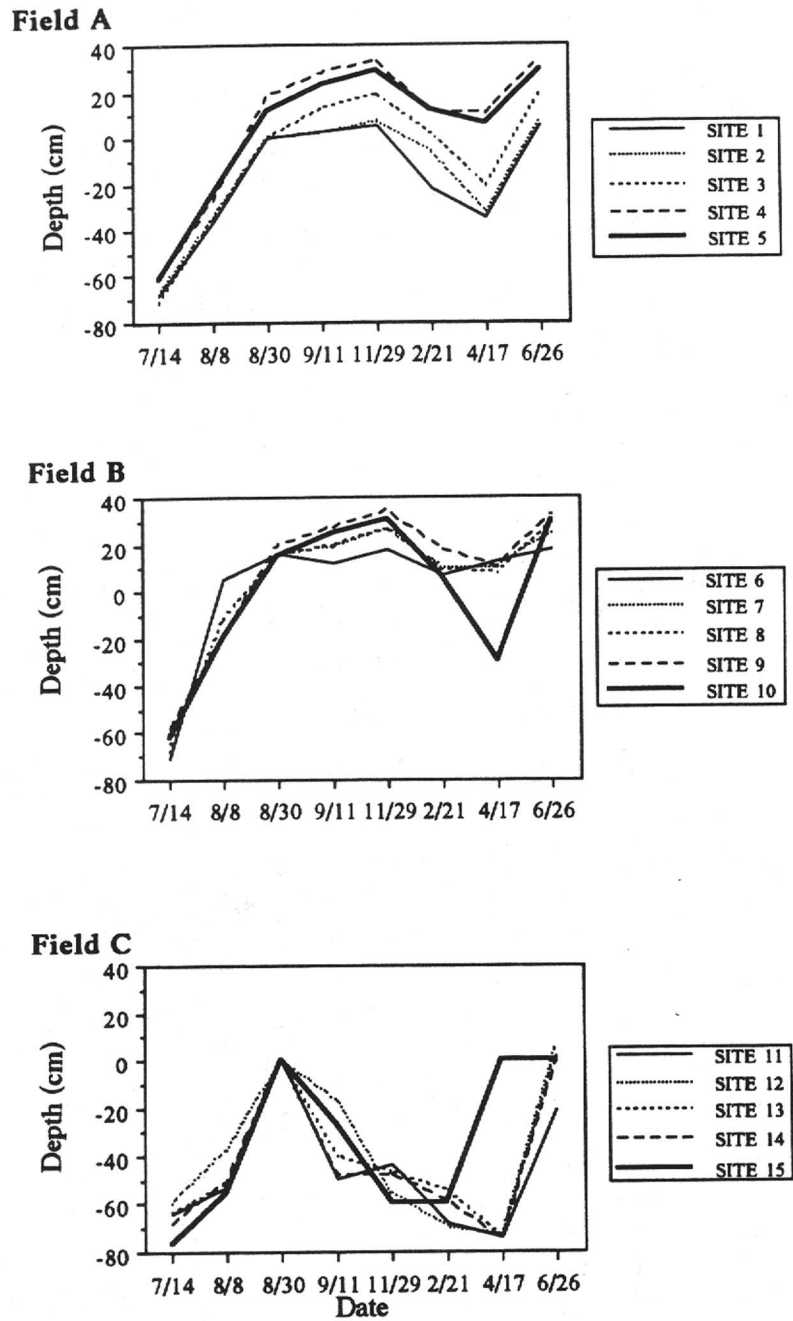
Field B

Field C

Figure 4. Water levels (cm) relative to the soil surface at each site in field A, B, and C from July, 1989 to June, 1990.

as replicate flooded fields, due to hydrological variations in sites for each field.

Hydrology in field C was controlled by Knight's Farm and was only monitored during water sampling events. In this field, water levels remained approximately 50 cm below the soil surface except in August and June when heavy rains caused the water table to rise quickly (Figure 4).

Soil Nutrients

Total soil P concentrations ranged from 102 to 378 μg g^{-1} and TN levels ranged from 18.859 ± 3.929 to 32.154 mg g^{-1} for all three fields (Figure 5). No significant differences in TP and TN were found between the three fields at the 0-15 and 15-30 cm depth. However, total P concentrations were higher in field C (278 ± 51 μg g^{-1}) than field B (151 μg g^{-1}) at the 30-45 cm depth. Both TP (156 μg g^{-1}) and TN (30.195 mg g^{-1}) levels were higher at the 60 cm depth in field C than field B (102 μg g^{-1} and 18.859 mg g^{-1}, respectively).

Total N levels in the soil did not change with depth. Conversely, TP decreased with depth in all three fields: field A slope = -5.04, $P < 0.01$, $r^2 = 0.60$; field B slope = -5.46, $P < 0.01$, $r^2 = 0.53$ and C slope = -4.64, $P < 0.01$, $r^2 = 0.58$.

Interstitial and Surface Water Nutrients

Interstitial water samplers - No significant differences in mean N and P concentrations were found between the ceramic cup and PVC well point samplers based on t-tests (Table 1). Thus, the ceramic porus cup samplers did not interfere with interstitial nutrient results in these agricultural organic soils. Spatial variability in the interstitial P levels in samples taken from replicate (n=5) ceramic cup and PVC well point samplers was high. The coefficient of variability (standard error as % of mean) of the soluble P species was ~ 45% compared to N species ~ 12%.

Monthly Sampling

Phosphorus - Before field A and B were flooded in August, interstitial SRP levels, including all depths, ranged from 0.011 ± 0.005 mg L^{-1} to 0.332 ± 0.226 mg L^{-1} in field A and from 0.055 ± 0.013 mg L^{-1} to 0.481 ± 0.192 mg L^{-1} in field B (Figure 6a). After 11 months of flooding, soil-bound P was released and the ranges in SRP concentrations increased to 0.374 ± 0.207 mg L^{-1} to 1.085 ± 0.529 mg L^{-1} in field A and 0.555 ± 0.068 mg L^{-1} to 2.740 ± 0.566 mg L^{-1} in field B. A similar increase in TP levels was observed, ranging from 0.043 ± 0.017 mg L^{-1} to 0.348 ± 0.214 mg L^{-1} in field A and 0.093 ± 0.021 mg L^{-1} to 0.539 ± 0.230 mg L^{-1} in field B in August and in June increased to 0.419 ± 0.223 mg L^{-1} to 1.688 ± 0.625 mg L^{-1} in field A and 0.619 ± 0.068 mg L^{-1} to 3.131 ± 0.652 mg L^{-1} in field B (Figure 6b).

Soluble interstitial P concentrations responded differently upon flooding at the four depths investigated (15, 30, 45, and 60 cm). Soluble reactive P, TDP, and TP concentrations significantly increased from August to June in Field A at the 30 and 45 cm depths and in field B at the 15, 30 and 45 cm depths (Figure 6a-c). No significant change over time was measured for SRP, TDP, or TP at 60 cm for either of the flooded fields.

Soluble P levels in field C were less than 0.60 mg L^{-1} until November when fields were fertilized (Figure 6a-c). Fertilizer application resulted in an increase in soluble P through the soil profile to 60 cm and extremely high localized SRP, TDP, and TP levels were found at the 15 cm depth, 32.3 ± 19.7 mg L^{-1}, 30.6 ± 18.7 mg L^{-1}, 32.3 ± 19.2 mg L^{-1}, respectively (Figure 6a-c). These mean SRP, TDP, and TP concentrations had a high coefficient of variation, 171%, and values ranged from 0.395 to 106.5 mg L^{-1}, 0.429 to 101.8 mg L^{-1}, and 0.494 to 104.5 mg L^{-1}, respectively. Thus, these mean values should be recognized as the average of highly localized nutrient enrichment not equally distributed throughout the entire field. The banding of fertilizer along furrows next to sampling wells probably accounted for the high mean P concentrations found in this field. No data

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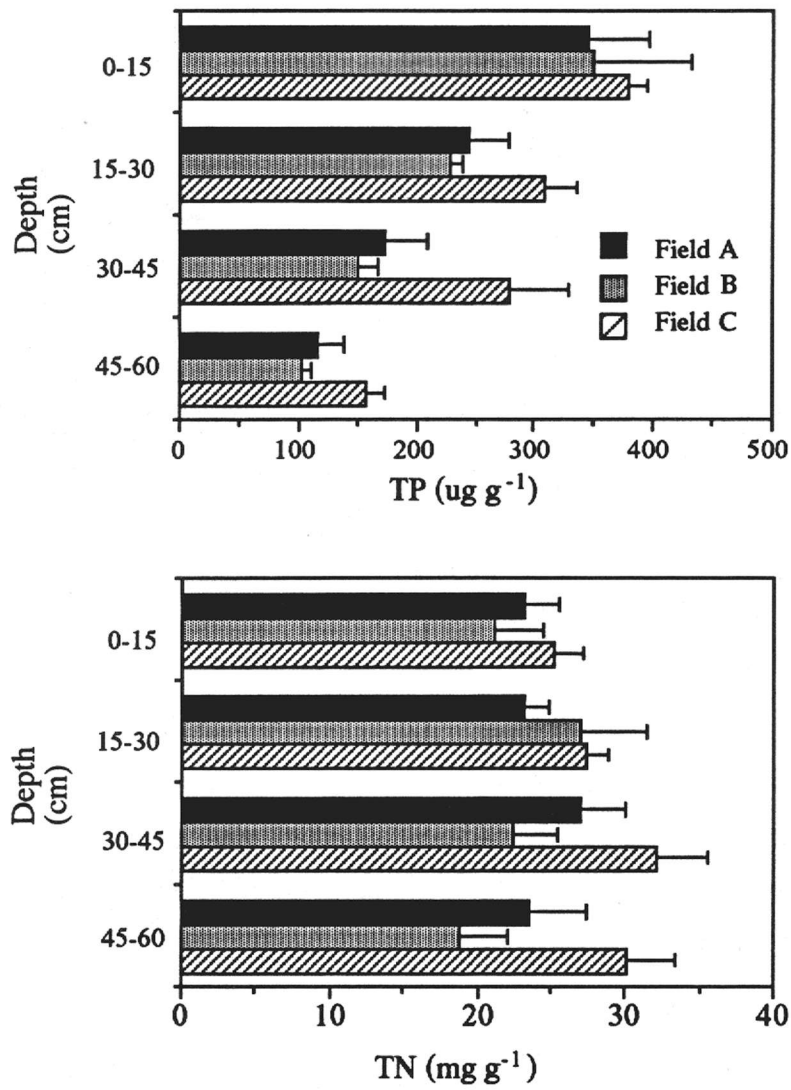
Figure 5. Total soil P (ug g^{-1}) and soil N (mg g^{-1}) levels at 0-15, 15-30, 30-45, and 45-60 cm in field A, B, C in August, 1989. Means are given with $\pm$ standard error (n=5)

TABLE 1. Inorganic phosphorus and nitrogen concentrations sampled at 30 cm in field A using ceramic and plastic interstitial water samplers.

Sampler Type:	SRP (mg L⁻¹)		TDP (mg L⁻¹)		TP (mg L⁻¹)		NH_4^+-N (mg L⁻¹)		NO_3^- + NO_2-N (mg L⁻¹)	
	C*	P**	C	P	C	P	C	P	C	P
Rep: 1	2.450	3.745	2.575	4.300	2.695	4.440	10.24	10.41	0.040	0.049
2	3.800	2.170	3.955	2.365	4.170	2.550	11.24	9.25	0.041	0.042
3	1.761	1.744	1.765	1.830	1.821	1.976	9.27	8.24	0.033	0.053
4	2.170	1.656	2.215	1.661	2.595	1.798	9.95	8.79	0.034	0.045
5	1.260	1.363	1.234	1.469	1.338	1.641	8.63	7.41	0.034	0.036
Mean	2.288ns	2.136	2.349ns	2.325	2.524ns	2.481	9.866ns	8.82	0.036ns	0.045
S.D	0.957	0.945	1.029	1.153	1.078	1.148	0.990	1.12	0.004	0.007
C.V. (%)	41.8	44.2	43.8	49.6	42.7	46.3	10.0	12.7	11.1	15.6

ns = not significant
* = ceramic cup sampler
** = plastic PVC sampler

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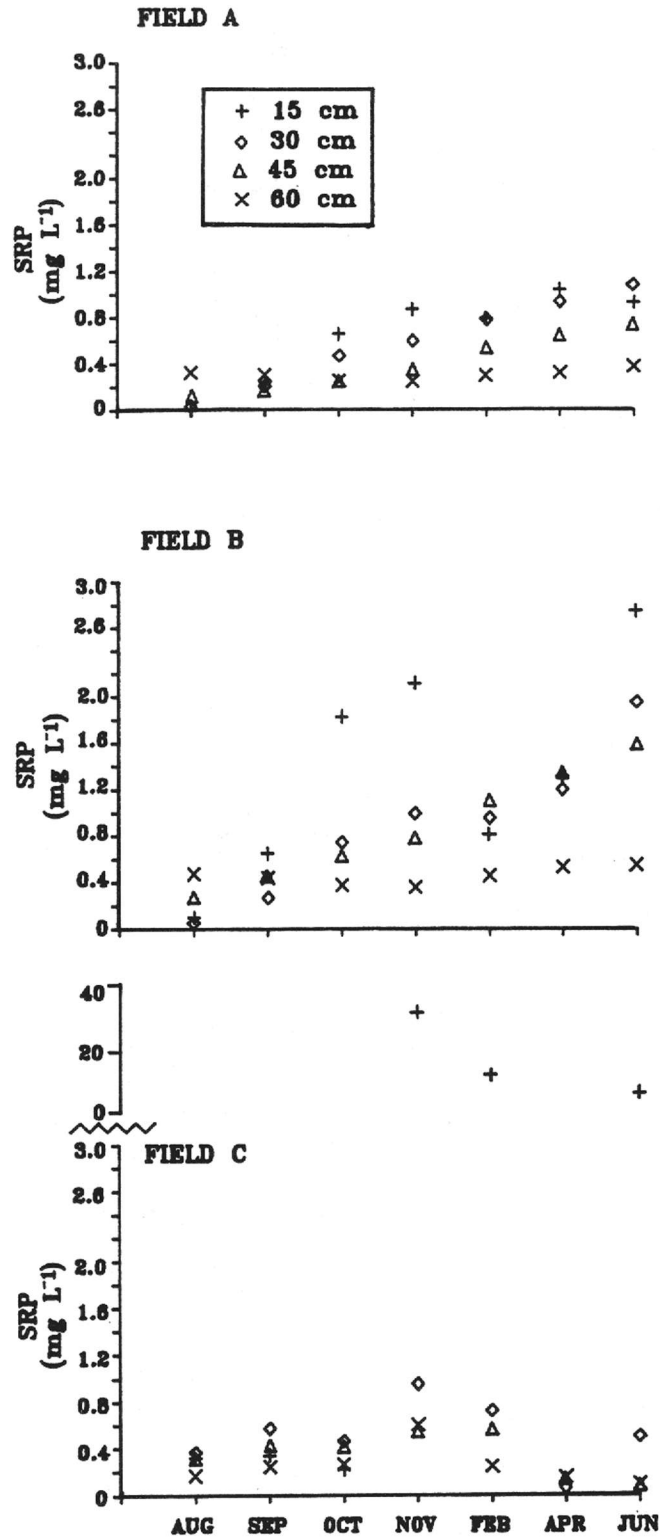
Figure 6a. Interstitial soluble reactive phosphorus (mg L^{-1}) concentrations at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990 (n=5). Note alternate scale in Field C for values at 15 cm.

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Figure 6b. Interstitial soluble total phosphorus (mg L^{-1}) concentrations at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990 (n=5). Note alternate scale in Field C for values at 15 cm.

13
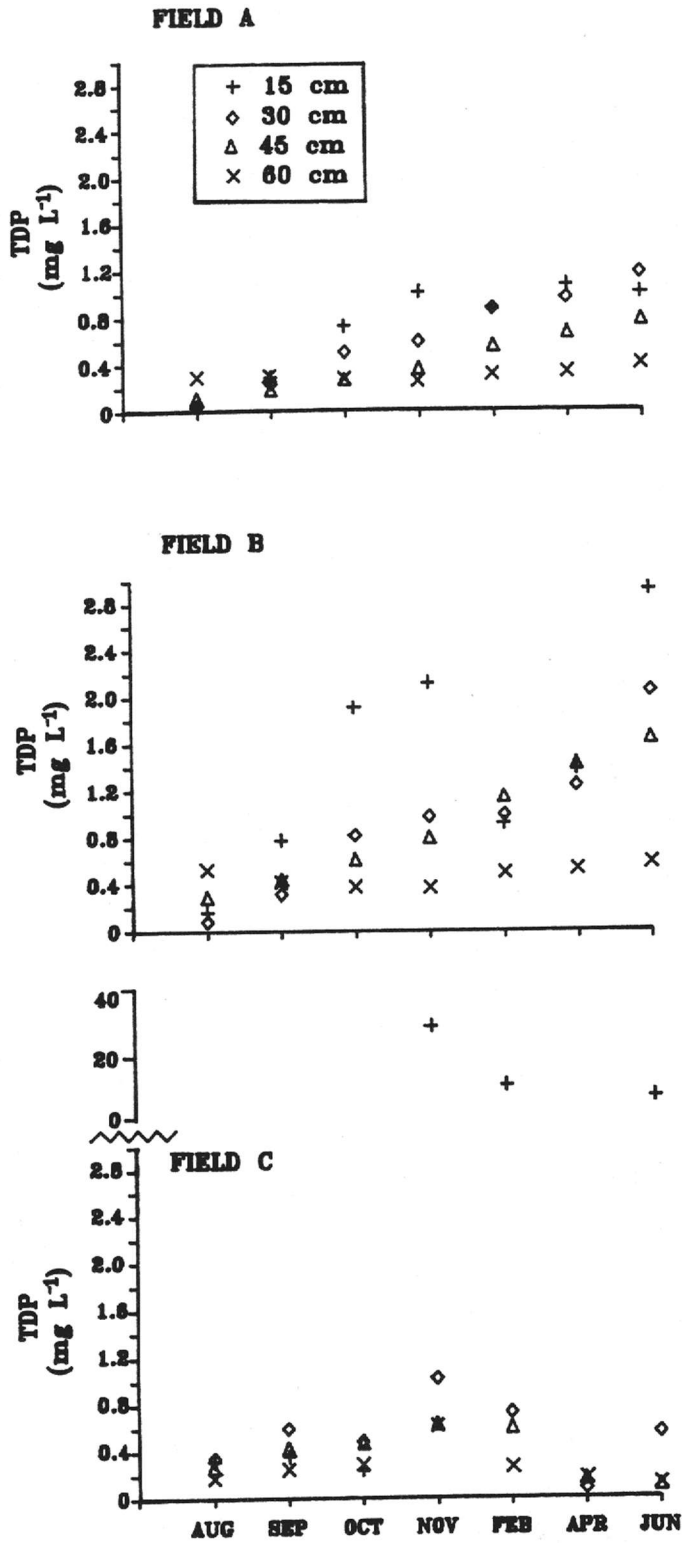
Figure 6c. Interstitial soluble total dissolved 0.45 μM phosphorus (mg L^{-1}) concentrations at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990 (n=5). Note alternate scale used in Field C for values at 15 cm.

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were reported for field C at the 15 cm depth in April, because wells were broken by farm equipment and had to be replaced (Figure 6a-c).

Surface water P concentrations were an order of magnitude lower than those measured in the interstitial waters and decreased over time (Figure 7). Soluble reactive P, TDP, and TP decreased in field A (slope range = -0.017 to -0.024, $P < 0.01$) and SRP and TDP in field B (slope = -0.002, $P < 0.05$ and slope =-0.004, $P < 0.07$, respectively) from August, 1989 to June, 1990. Although an overall decrease in surface water P levels was found from August to June, observations during the month of February were higher than previous months (Figure 7).

Changes in the soluble P concentration occurred over 10 months of flooding but the P speciation was consistent between the surface and the interstitial waters. In the surface waters, the ratio of SRP:TDP was 28 ± 5 % and 32 ± 3 % in fields A and B. In the interstitial waters, the speciation changed with a larger proportion of the TDP in the soluble reactive form (Figure 6a-c). The SRP:TDP ratio at 15, 30, 45, and 60 cm depths, were 70 ± 4 %, 81 ± 3 %, 86 ± 3 %, and 89 ± 3 % in field A and 87 ± 3 %, 90 ± 3 %, 93 ± 2 %, and 94 ± 1 % in field B.

Nitrogen - Interstitial NH_4^+ concentrations increased significantly with persistent flooding (Figure 8a). Release of NH_4^+ to the soil solution over time was more pronounced in the upper depth profile as evidenced by the greater slopes from 15 to 45 cm depths (slope range = 0.215 to 0.599; $P < 0.01$; field A, 15 cm = $P < 0.10$) compared to the 60 cm depth (slope = 0.059 and 0.077; $P < 0.06$ and $P < 0.01$, respectively) from fields A and B (Figure 8a).

Inorganic N as $NO_3^- + NO_2^-$ did not increase linearly with flooding duration (Figure 8b). Interstitial $NO_3^- + NO_2^-$ concentrations were low during August and September in all three fields, increased from October to February and decreased in April and June (Figure 8b). Mean $NO_3^- + NO_2^-$ concentrations from all four depths in field A increased from 0.054 ± 0.013 mg L^{-1} in November to $1.532 \pm$ 0.095 mg L^{-1} in February (Figure 8b). During months where high $NO_3^- + NO_2^-$ levels were found, variation in concentrations between sites was also high. Mean standard deviations (S.D.) of $NO_3^- + NO_2^-$ for all soil depths in field A were higher in February and April, 1.383 to 0.878 mg L^{-1}, compared to August through November, 0.049 to 0.293 mg L^{-1}. Soil soluble $NO_3^- + NO_2^-$ levels in field B followed a similar trend to field A, although concentrations were higher and more variable for $NO_3^- + NO_2^-$ levels in October (S.D. = 1.035 mg L^{-1}) and November (S.D. = 0.985 mg L^{-1}), in addition to February (S.D. = 1.461 mg L^{-1}) and April (S.D. = 1.014 mg L^{-1}).

Total interstitial Kjeldahl N concentrations did not change significantly during several months of flooding in field A or B but, an initial release of TDKN occurred in September at the 15 and 30 cm depths (Figure 8c). The soluble organic N fraction (TDKN - NH_4^+) represented the largest pool of soluble interstitial N. This fraction accounted for $79 \pm 3\%$, $78 \pm 3\%$, $80 \pm 3\%$, and $80 \pm 3\%$ in field A and $48 \pm 13\%$, $73 \pm 4\%$, $78 \pm 2\%$, and $79 \pm 3\%$, in field B of the TDKN at 15, 30, 45, and 60 cm, respectively.

Both the inorganic and organic N concentrations were low in the surface waters compared to the interstitial water of the soils (Figure 9). The ratio of dissolved organic N to total N in the surface waters was $95 \pm 1\%$ in field A and $96 \pm 2\%$ in field B. Thus, the inorganic fractions in the surface waters represent only 5% of the total N compared to 20% in the soils.

The inorganic fraction represented by ammonium in the surface waters was less than $NO_3^- + NO_2^-$ from October through April and concentrations remained at or below 0.10 mgL^{-1} (Figure 9). Surface water $NO_3^- + NO_2^-$ levels were highest and most variable from October to February (Figure 9). Total Kjeldahl N and TDKN both decreased in the surface water in field A and B through the study period (slope = -0.310 to -0.100, $P < 0.01$).

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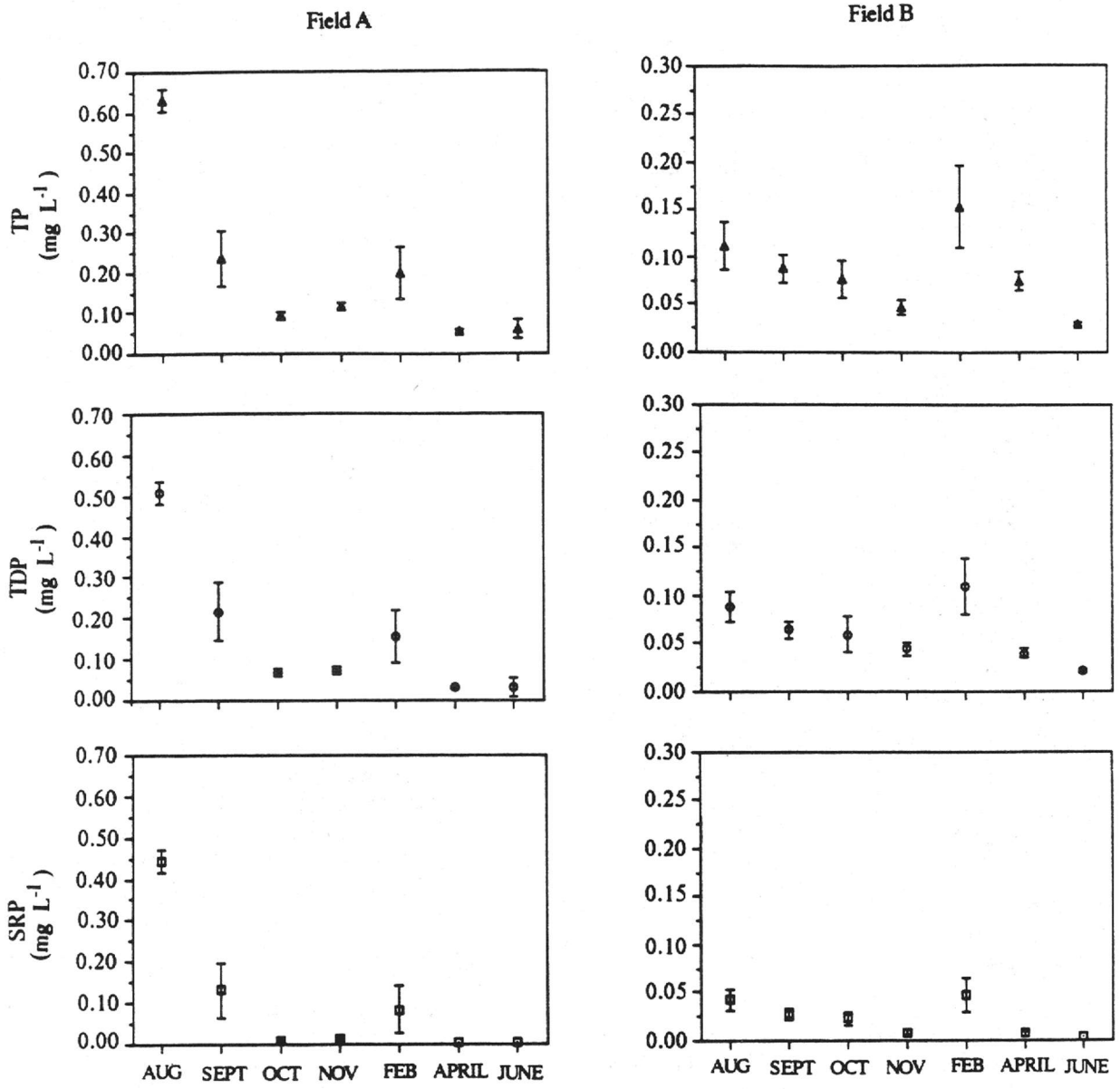
Figure 7. Surface water SRP, TDP, and TP concentrations (mg L^{-1}) in field A and B from August, 1989 to June, 1990. Note scale differences for TP, TDP, and SRP in field A and B. Means are given with ± standard error (n=5).
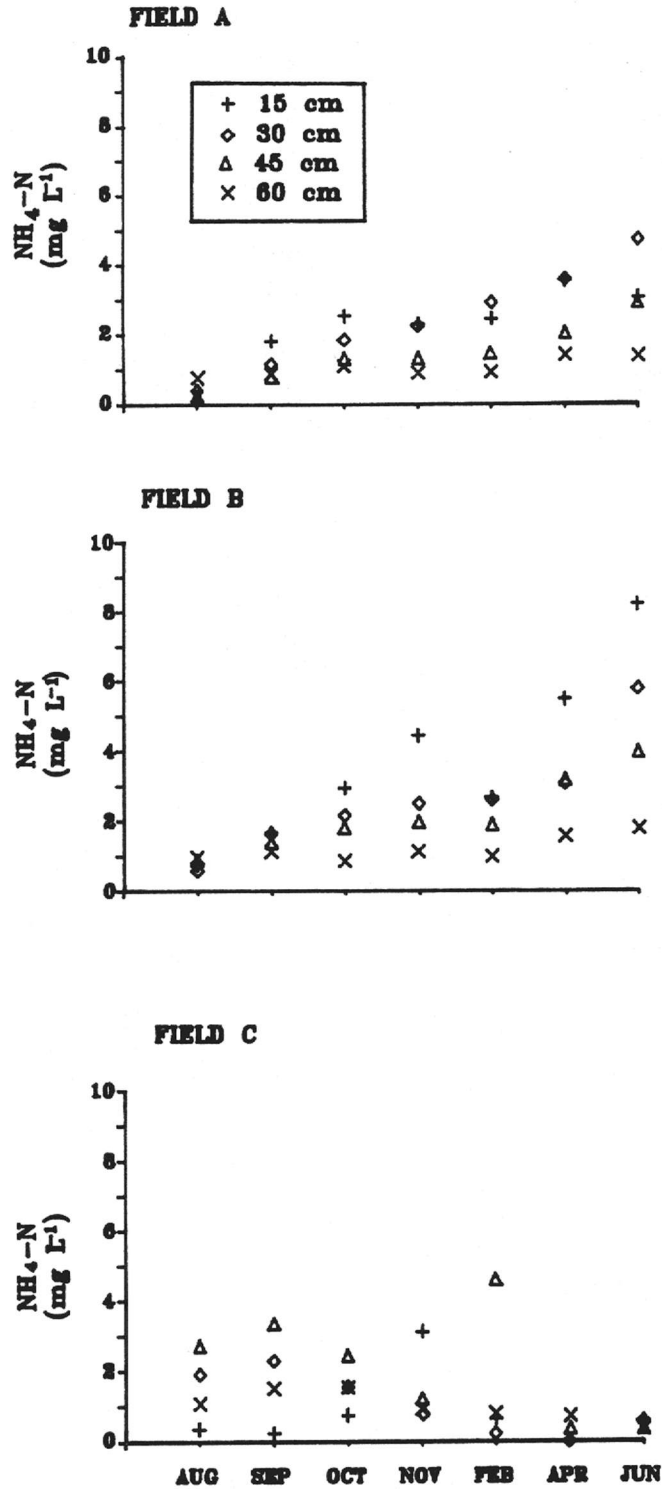
Figure 8a. Interstitial soluble NH₄-N concentrations (mg L⁻¹) at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990.

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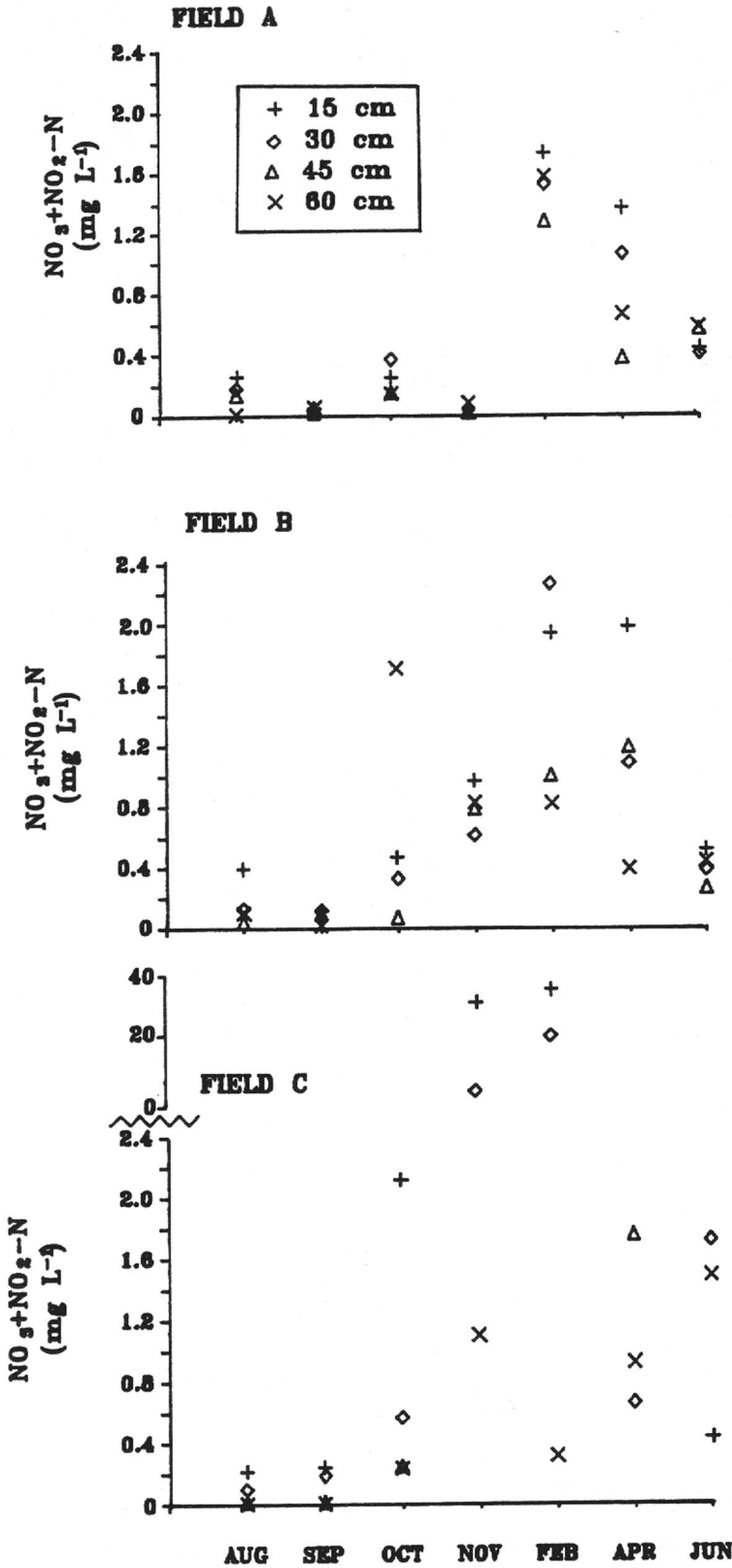
Figure 8b. Interstitial soluble $NO_3 + NO_2$-N concentrations (mg L^{-1}) at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990. Note alternate scale in Field C for $NO_3 + NO_2$-N values at 15 cm.
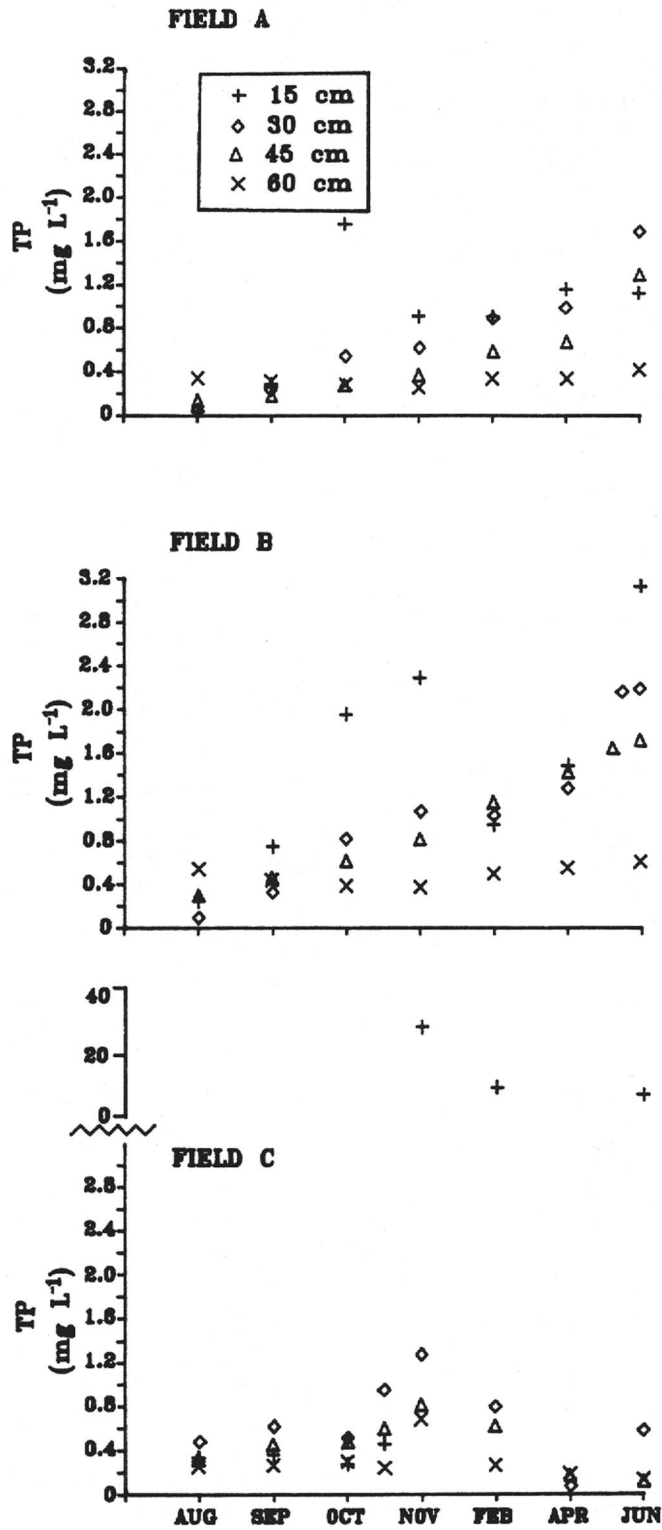
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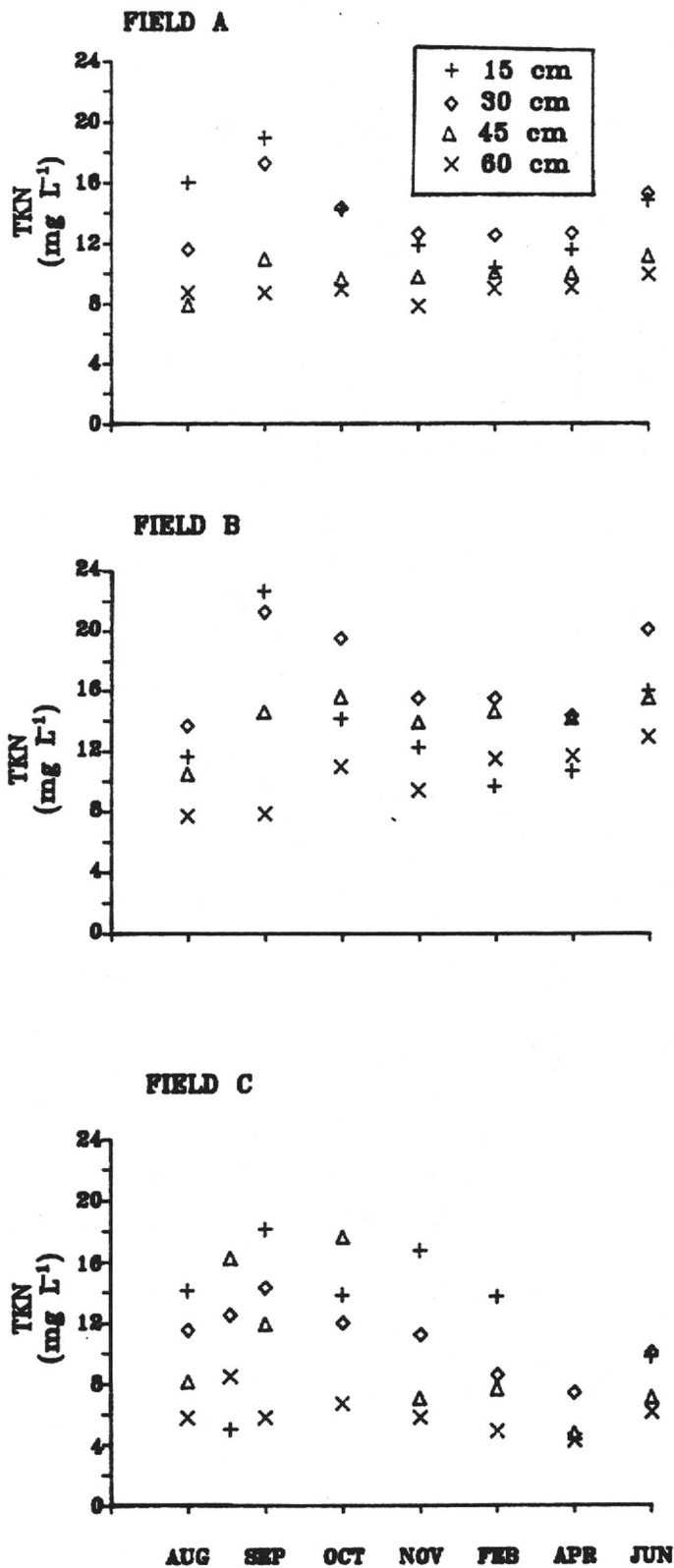
Figure 8c. Interstitial soluble total Kjeldahl nitrogen concentrations (mg L^{-1}) at 15, 30, 45, and 60 cm in field A, B, and C from August, 1989 to June, 1990.

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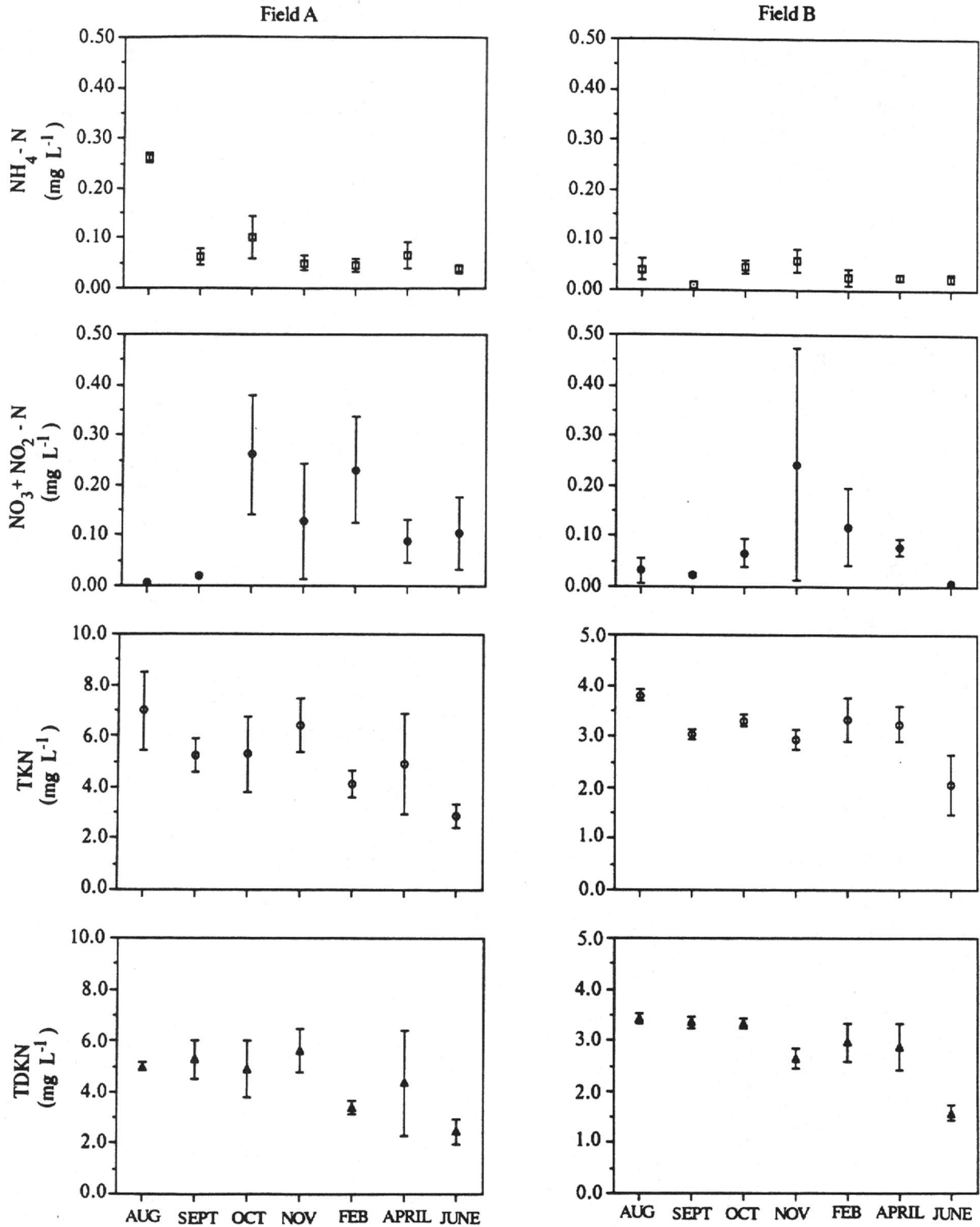
Figure 9. Surface water NH₄-N, NO₃+NO₂-N, TKN, and TDKN concentrations (mg L⁻¹) in field A and B from August, 1989 to June, 1990. Note scale differences for TKN and TDKN in field A and B. Means are given with ± standard error (n=5).

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Chemical constituents - Surface water and interstitial conductivity, Na^+, K^+, Cl^-, Ca^{2+}, Mg^{2+}, SiO_2, SO_4^{2-}, and total Fe, Mn, and Hg concentrations at the initiation of the study (August) and 10 months after flooding (June) are presented in Table 2. Data from sampling in September, October, November, February, and April are included in Appendix A. Conductivity levels were high for a freshwater peatland, greater than 1,000 μmhos cm^{-1} in the surface and interstitial waters. Correlation matrixes are shown in Appendix B for mean concentrations of chemical parameters of all soil depths and surface water samples from all sampling dates. Sodium, Cl^-, Ca^{2+}, and Mg^{2+} were significantly correlated to conductivity in Field A and B (Appendix B). Conductivity in the interstitial waters did not change over time in field A, but decreased in field B along with Na^+, Cl^-, Ca^{2+}, and Mg^{2+} at the 45 and 60 cm depths (Table 2, Appendix A).

Sulfate levels decreased with time in the interstitial waters in both fields with continuous flooding at all but the 60 cm depths (Table 2). Conversely, no significant trends over time were found for the trace metals i.e., total soluble Fe, Mn or Hg. Soil soluble silicate concentrations increased with flooding and were highly correlated to all P species and NH_4^+ (Table 2; Appendix B).

Micro-profile of Soil Nutrients

Soluble reactive P and NH_4^+ concentrations in equilibrium with the soil water solution are within the ranges found in the monthly sampling (Figure 10a). A control site in the interior of WCA-1 had two orders of magnitude less interstitial SRP concentrations compared to those from ENR soils (Figure 10a,b). In contrast the differences in NH_4^+ levels were only 3-fold between the ENR site and WCA-1 (Figure 11a,b).

The micro depth profiles of NH_4^+ and SRP between the 5 sites are variable, but consistent trends are evident. Both NH_4^+ and SRP concentrations are very low in the surface waters and the shallow soil layer which was observed as flocculent detritus in the field (with

the exception of site A1; Figure 10a, 11a). Below the upper 5 cm soil depth a steep concentration gradient was observed for interstitial NH_4^+ and SRP. Similar NH_4^+ gradients were found in the control site, but SRP was low through the soil-water interface (Figures 10 and 11).

Soil pH values were high in the surface waters and shallow soil profile compared to the deeper depths in ENR soils (Figure 12a). Levels of pH in the surface waters were as high as 7.5 to 8.0 compared to 6.5 to 7.0 pH units in the lower depths. In WCA-1 pH values were low, between 5.5 and 6.5 with no significant increase in the surface waters (Figure 12b).

Soil Eh

After 10 months of flooding field A soils were highly reduced compared to a moderately reducing conditions measured in WCA-1 (Figure 13). At all six sites shown in Figure 13, Eh values peaked at the 5 to 10 cm depth, possibly due to root oxidation overlaid by an active surface detrital layer with a high demand for oxidized compounds. Water Conservation Area 1 redox potentials approach the theoretical ranges of NO_3^-, Mn^{4+}, and Fe^{3+} reduction (Figure 3). In comparison, the soils in field A suggest SO_4^{2-} and CO_2 reduction may be the dominant redox couples driving respiration

DISCUSSION

Soil Nutrients

Peatland soils evolve from semi-decomposed plant material under anaerobic (without oxygen) conditions and are characteristically low in nutrient content. Ombrotrophic bogs, primarily fed by rain are nutrient poor compared to nutrient rich fens in direct contact with groundwater (Pollet, 1972). Total P levels in peat soils from the ENR project (Table 3), fall within the range of nutrient rich fens of Newfoundland classified by Pollet (1972) and those reported for the Michigan Houghton Lake fen (Richardson et al., 1978). Total P in the ENR soil are similar

TABLE 2a. Chemical constituents in the surface and interstitial water under drained conditions. Means are given with ± standard error of the mean (n=5).

August (1989)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (μmhos cm^{-1})	1053 ±14	1559 ±314	1505 ±285	1371 ±231	1081 ±117	1013 ±139	1690 ±372	2576 ±379	2414 ±256	2030 ±115	--- ---	1200 ±132	976 ±77	990 ±72	1100 ±67
Sodium (mg L^{-1})	106.60 ±2.90	207.54 ±44.19	211.75 ±43.77	195.08 ±35.95	154.22 ±11.73	93.13 ±12.90	325.32 ±66.55	452.35 ±54.24	388.12 ±48.37	283.07 ±47.12	--- ---	44.97 ±22.18	42.86 ±20.78	39.20 ±18.68	36.14 ±14.68
Potassium (mg L^{-1})	18.40 ±0.05	1.70 ±0.54	2.42 ±1.02	4.40 ±1.47	5.05 ±1.14	16.99 ±1.54	5.56 ±1.54	4.65 ±1.49	5.59 ±1.51	6.26 ±1.48	--- ---	42.47 ±9.66	17.42 ±4.62	13.80 ±4.49	13.97 ±4.30
Chloride (mg L^{-1})	164.8 ±9.8	294.2 ±92.5	311.1 ±94.4	286.5 ±88.2	244.6 ±65.2	138.2 ±20.6	339.4 ±97.6	543.4 ±122.4	1534.0 ±696.4	475.7 ±25.7	--- ---	193.7 ±39.1	124.0 ±24.1	95.0 ±12.6	87.5 ±8.0
Calcium (mg L^{-1})	63.2 ±11.1	132.5 ±21.3	105.0 ±14.1	85.1 ±11.3	89.2 ±15.0	69.5 ±10.8	87.3 ±13.3	116.4 ±25.2	111.6 ±13.9	103.3 ±17.9	--- ---	156.7 ±16.9	135.4 ±17.7	140.8 ±11.9	173.1 ±17.1
Magnesium (mg L^{-1})	21.29 ±0.60	30.39 ±5.59	29.06 ±4.20	25.02 ±3.56	26.79 ±5.13	23.34 ±3.35	23.03 ±3.30	29.83 ±8.15	28.35 ±3.81	28.46 ±6.53	--- ---	29.78 ±4.70	27.69 ±2.27	31.50 ±3.18	33.10 ±3.66
Silicate (mg L^{-1})	34.5 ±4.6	6.6 ±0.9	6.8 ±1.0	11.5 ±2.9	14.7 ±3.1	24.8 ±1.2	21.4 ±2.5	14.1 ±1.8	19.6 ±5.7	35.1 ±8.3	--- ---	16.6 ±3.4	18.6 ±3.5	14.9 ±2.2	15.2 ±2.4
Sulfate (mg L^{-1})	51.3 ±0.6	223.3 ±34.3	184.1 ±37.5	125.5 ±33.7	84.6 ±31.3	56.6 ±7.5	207.6 ±79.4	329.9 ±61.3	198.2 ±52.3	114.6 ±43.7	--- ---	233.8 ±23.5	162.2 ±54.7	112.2 ±34.3	110.0 ±22.8
Iron (mg L^{-1})	0.60 ±0.10	1.60 ±0.58	1.05 ±0.18	0.84 ±0.06	0.90 ±0.06	0.33 ±0.04	1.68 ±0.82	0.73 ±0.22	0.47 ±0.08	0.54 ±0.12	--- ---	0.77 ±0.27	1.27 ±0.35	0.77 ±0.13	0.56 ±0.11
Manganese (μg L^{-1})	245 ±45	246 ±46	242 ±27	<200 ±0	<200 ±0	<200 ±0	230 ±30	232 ±32	<200 ±0	<200 ±0	--- ---	523 ±131	570 ±103	338 ±96	<200 ±0
Mercury (μg L^{-1})	<0.20 ±0.00	0.70 ±0.50	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	--- ---	0.48 ±0.28	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00

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TABLE 2b. Chemical constituents in the surface and interstitial waters after 10 months of flooding in Field A and B. Means are given with ± standard error of the mean (n = 5).

June (1990)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (µmhos cm⁻¹)	476 ±79	1553 ±355	1300 ±261	1177 ±169	1176 ±160	817 ±360	1051 ±84	1152 ±85	1308 ±167	1848 ±259	---	1153 ±252	1192 ±163	1187 ±167	1115 ±171
Sodium (mg L⁻¹)	66.18 ±15.99	226.25 ±60.35	197.42 ±47.02	182.23 ±31.83	171.82 ±17.24	51.40 ±6.37	176.77 ±4.23	249.80 ±27.55	286.20 ±40.70	295.50 ±33.70	---	48.94 ±33.56	54.07 ±27.01	51.46 ±23.95	49.64 ±29.79
Potassium (mg L⁻¹)	8.59 ±1.16	14.38 ±2.36	10.53 ±2.19	7.10 ±0.93	5.34 ±0.97	10.78 ±0.50	13.90 ±3.76	14.74 ±2.22	8.37 ±1.84	6.48 ±1.23	---	91.88 ±61.69	68.57 ±44.64	18.17 ±3.30	16.03 ±6.08
Chloride (mg L⁻¹)	95.0 ±23.8	390.0 ±107.2	378.7 ±90.3	288.0 ±63.9	308.4 ±72.9	72.4 ±7.8	264.0 ±8.5	309.5 ±27.8	351.7 ±64.3	342.5 ±63.2	---	165.3 ±54.5	209.7 ±41.8	197.9 ±38.8	148.2 ±37.9
Calcium (mg L⁻¹)	33.9 ±3.7	121.1 ±28.6	110.3 ±14.3	99.9 ±9.3	108.0 ±12.9	40.7 ±5.7	74.2 ±12.6	68.5 ±7.1	82.5 ±14.0	103.4 ±20.0	---	148.0 ±33.7	198.6 ±29.4	213.0 ±33.9	205.3 ±30.9
Magnesium (mg L⁻¹)	10.90 ±1.10	26.25 ±5.66	29.80 ±4.58	28.38 ±3.01	31.72 ±3.82	12.08 ±0.93	23.72 ±5.40	16.37 ±2.70	18.79 ±3.50	25.94 ±6.00	---	63.06 ±40.48	39.38 ±5.35	46.82 ±9.80	39.92 ±2.73
Silicate (mg L⁻¹)	12.8 ±1.8	33.9 ±5.7	25.9 ±3.7	20.7 ±3.6	14.9 ±1.1	9.7 ±0.8	44.6 ±3.9	37.1 ±5.0	31.2 ±3.2	25.9 ±3.5	---	13.5 ±6.1	7.7 ±1.5	7.7 ±1.0	11.2 ±1.7
Sulfate (mg L⁻¹)	5.2 ±1.2	4.2 ±2.2	7.1 ±3.8	54.7 ±35.5	44.3 ±15.9	27.4 ±3.1	5.0 ±2.8	13.0 ±9.9	53.4 ±30.9	85.6 ±46.9	---	276.1 ±66.4	333.4 ±56.2	301.4 ±88.8	210.5 ±47.4
Iron (mg L⁻¹)	0.21 ±0.04	1.67 ±0.26	1.69 ±0.18	1.11 ±0.31	0.74 ±0.10	0.12 ±0.01	1.82 ±0.27	1.58 ±0.72	1.21 ±0.23	0.83 ±0.10	---	0.88 ±0.11	0.63 ±0.11	0.63 ±0.15	0.53 ±0.06
Manganese (µg L⁻¹)	202 ±2	207 ±8	245 ±24	<200 ±0	<200 ±0	<200 ±0	238 ±24	<200 ±0	<200 ±0	<200 ±0	---	520 ±65	260 ±66	436 ±138	236 ±36
Mercury (µg L⁻¹)	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	0.40 ±0.12	0.70 ±0.44	0.35 ±0.10	0.32 ±0.08	---	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00

Field A
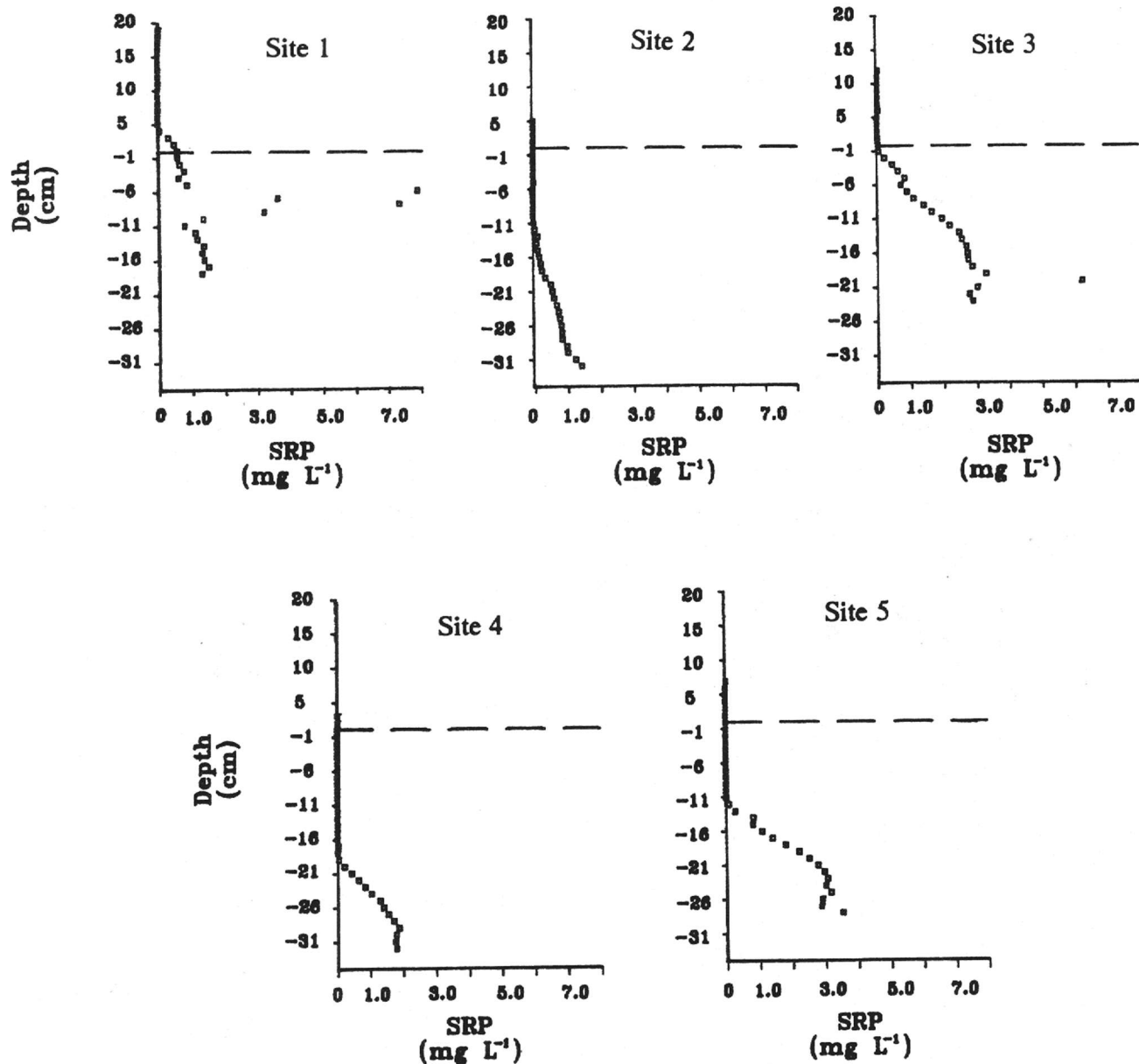
Figure 10a. Soluble reactive phosphorus concentrations (mg L^{-1}) through the surface water-soil interface (dotted line) after 2 weeks of equilibration at site 1-5 in field A.

Water Conservation Area 1
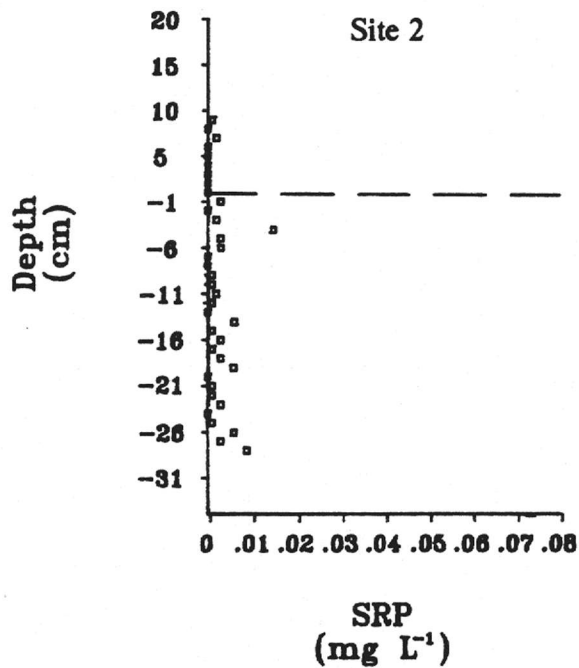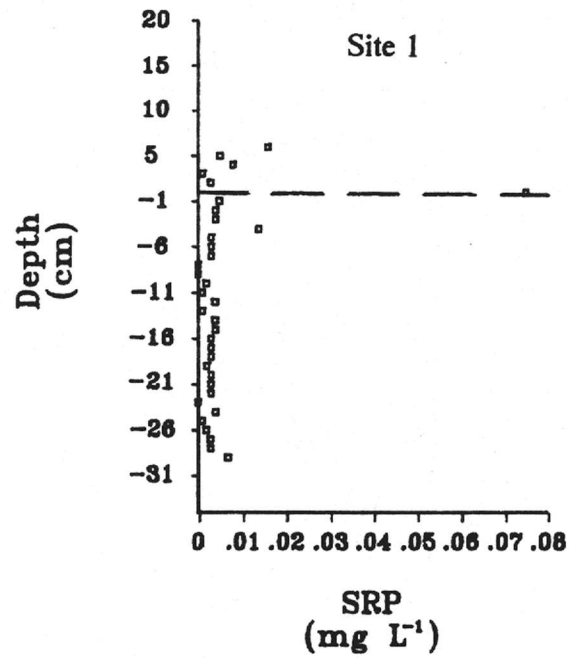
Figure 10b. Soluble reactive phosphorus concentrations (mg L^{-1}) through the surface water soil interface (dotted line) after 2 weeks of equilibration at two control sites in the interior of Water Conservation Area 1.

Field A
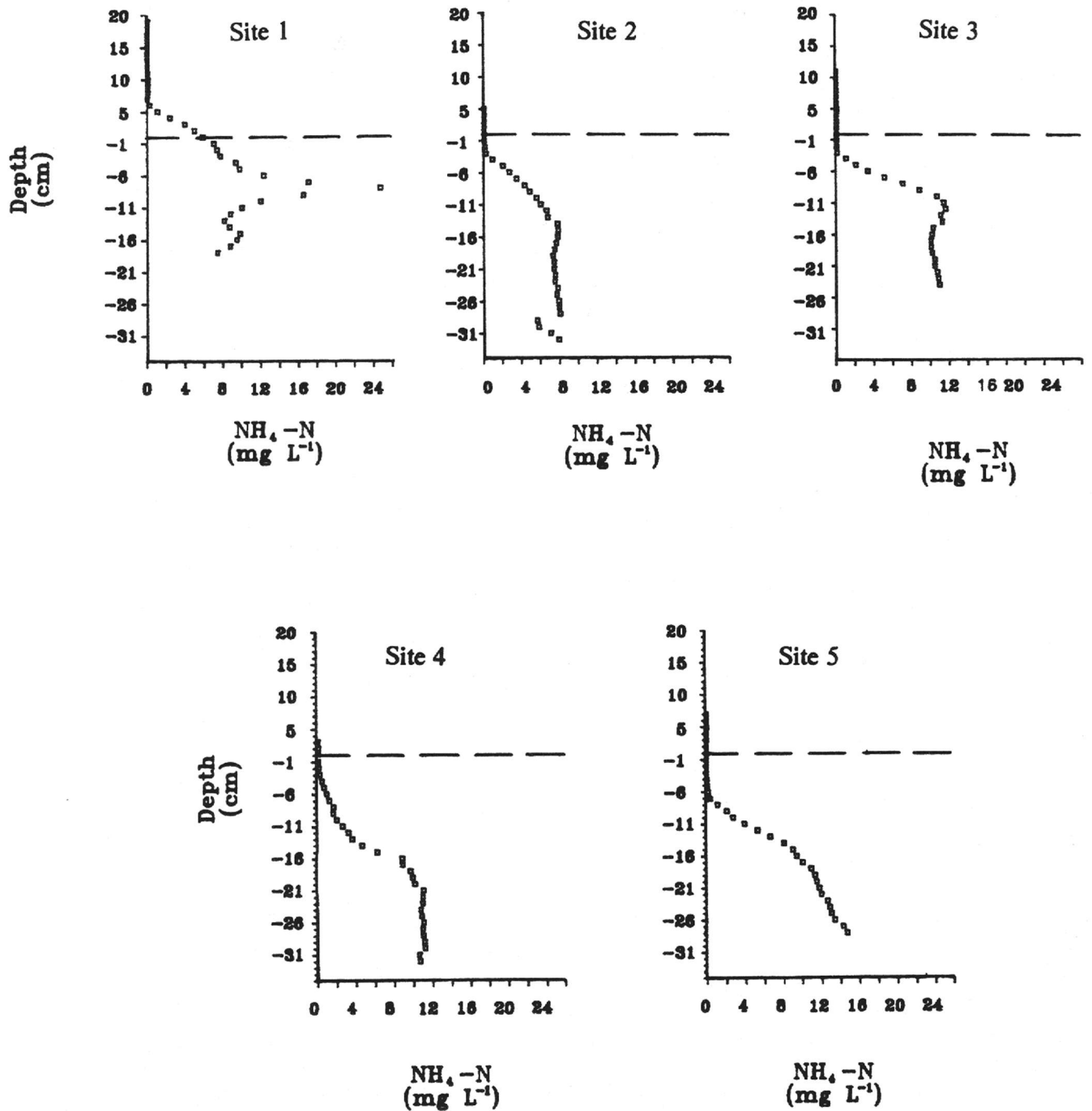
Figure 11a. Soluble NH₄-N concentrations (mg L⁻¹) through the surface water-soil interface (dotted line) after 2 weeks of equilibration at site 1-5 in field A.

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Water Conservation Area 1

Figure 11b. Soluble NH_4-N concentrations (mg L^{-1}) through the surface water-soil interface (dotted line) after 2 weeks of equilibration at two control sites in the interior of Water Conservation Area 1.

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Field A

Figure 12a. Levels of pH through the surface water-soil interface (dotted line) after 2 weeks of equilibration at site 1-5 in field A.

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Water Conservation Area 1

Figure 12b.. Levels of pH through the surface water-soil interface (dotted line) after 2 weeks of equilibration at two control sites in the interior of Water Conservation Area 1.
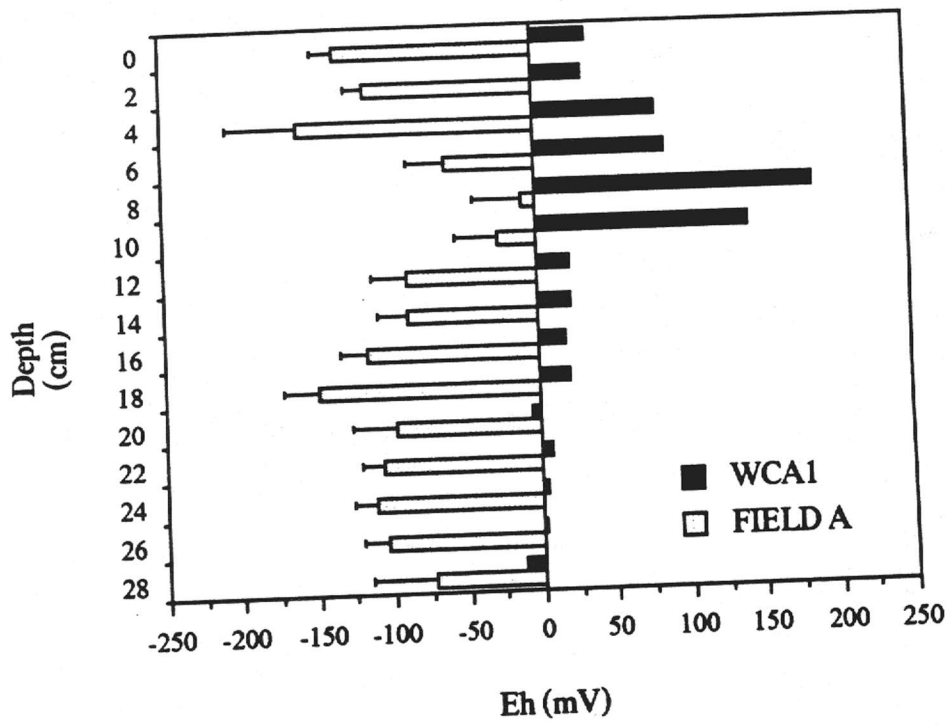
Figure 13. Soil Eh (mV) at 2 cm increments from 0 to 30 cm at site 1-5 in field A and a site in the interior of Water Conservation Area 1.

TABLE 3a. Soil nitrogen, phosphorus and bulk density in the ENR system compared to WCAs and ENP.

Site	Depth cm	n	Bulk Density g cm^{-3}	Phosphorus[†]		Nitrogen[†]		Reference
				µg g^{-1}	kg ha^{-1}	mg g^{-1}	kg ha^{-1}	
ENR								
Field A	0-30	5	0.280 ±0.050	294 ±38	247	23.22 ±4.18	19505	This study
Field B	"	5	0.314 ±0.027	289 ±99	272	24.14 ±8.33	22740	"
Field C	"	5	0.300 ±0.035	343 ±51	309	26.29 ±3.93	23661	"
Field A-P	"	107	0.289 ±0.021	287 ±49	249	28.31 ±1.50	24545	Reddy & Graetz, 1991
WCAs								
WCA-1 Interior Site	"	2	0.048 ±0.002	190 ±0.3	27	32.78 ±0.04	4720	"
WCA-2A Northern site	"	2	0.073 ±0.014	1047 ±148	229	25.99 ±0.36	5692	Koch & Reddy, in review
WCA-2A Southern site	"	2	0.080 ±0.002	421 ±187	101	28.60 ±0.18	6925	"
WCA-3	not given	5	--	--	97-257	27.30-28.20	15272-15792	Steward & Ornes, 1975
ENP								
Pa-hay-okee	0-30	12	--	373 ±67	--	31.42 ±3.847	--	Parsons, 1977

[†] Means given with ± standard deviation.

TABLE 3b. Soil nitrogen, phosphorus and bulk density from peatlands in other geographical regions.

Site	Depth cm	n	Bulk Density g cm^{-3}	Phosphorus[†] µg g^{-1}	Phosphorus[†] kg ha^{-1}	Nitrogen[†] mg g^{-1}	Nitrogen[†] kg ha^{-1}	Reference
Newfoundland								
Ombrotrophic bogs	0-20	669	0.030-0.090*	340-330	28-94	6.7-7.6	370-1590	Pollet, 1972
Minerotrophic fens	"	97	0.070-0.250	540-1030	94-379	16.0-20.9	3100-8910	"
Michigan								
Houghton Lake fen	--	--	--	--	242	--	6830	Richardson et al, 1978
Uganda								
Papyrus swamp	--	--	--	610	265	28.0	12180	Gaudet, 1976
The Netherlands								
floating fens	**	16	0.057 ±0.017	880 ±40	127 ±49	20.2 ±3.1	3350 ±1040	Verhoeven, 1986

[†] Means given with ± standard deviation.

* Bulk density expressed as mg L^{-1}.

** Mats 20-40 cm thick.

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to those found in the northern area of WCA-2A and within the upper limit cited by Steward and Ornes (1975) from WCA-3A (Table 3). These values are 2 times the P storage to 30 cm at southern sites in WCA-2A reported by Koch and Reddy (in review) and 9 fold higher than the interior of WCA-1 (Table 3a).

Variations in the soil P concentrations on a soil weight basis ($\mu g \ g^{-1}$) can be partially normalized on an areal basis (kg ha^{-1}) using the bulk density of the soils. For example, ENR soils have bulk densities that are three times greater than the northern site in WCA-2A, but TP concentrations that are three times lower (Table 3). Therefore, the total soil P storage from 0 to 30 cm is similar for the two sites.

In contrast to the variation of TP, TN content on a soil weight basis (mg g^{-1}) is similar under various loadings in the Water Conservation Areas (Steward and Ornes, 1975; Reddy and Graetz, 1991; Koch and Reddy, in review), Everglades National Park (Parsons, 1977), and the ENR project (Reddy and Graetz, 1991). Since TN concentrations in the soils are similar, variations in bulk density causes significant differences in TN accumulation when extrapolated to an areal basis. For this reason, TN accumulation in the upper soil profile is 3-fold higher at the ENR site compared to WCA-2A (Table 3a). Steward and Ornes (1975) report similar N values in WCA-3 compared to ENR soils, however, bulk densities were not reported and N storage may have been overestimated (Table 3a).

Storage of TN in Everglades soils is higher than those found in other peatlands including 16 fens in The Netherlands, seven major peatland types in Newfoundland, and temperate North American fens (Tables 3a,b). Total N accumulation reported by Steward and Ornes (1975) for WCA-3 and those reported for the ENR have comparable levels to the tropical *Papyrus* swamps of Uganda (Gaudet, 1976). *Scytonema*, along with other species of blue-green algae of the Everglades, have been shown to fix N at high rates (Goldstein et al. 1980), and perhaps this N source could explain the high N accumulation in this subtropical peatland. Bacterial N$_2$ fixation has also been recognized as an important source of N inputs

to minerotrophic (high mineral content) peatlands (Verhoeven, 1986).

The availability of total soil N and P to the surrounding soil matrix or interstitial waters is determined by the mineralization rates or breakdown of organic material. This release of organically bound N and P is primarily controlled by the chemical composition of organic material and factors controlling the microbial activity of the sediments. Physico-chemical changes in the soil can also solubilize inorganically bound P.

Interstitial Nutrients

Freshwater peatland soils are characterized by low soluble nutrients, particularly in Northern bogs. This is due to low atmospheric nutrient loading which is the primary nutrient source and can limit microbial recycling of organically stored nutrients. Everglades soils that have been fertilized in the ENR site from agricultural practices, have an order of magnitude greater soil soluble P concentration (Figure 6a-c) and 2 to 4 times higher NH$_4^+$ levels (Figure 8a) compared to northern peatlands and Everglades soils. Interstitial nutrient concentrations in *Typha/Carex* marshes in Canada and Michigan were < 0.10 mg L^{-1} for PO$_4^{3-}$ and < 1.0 mg L^{-1} for NH$_4^+$ (McGrimmon, 1980; Richardson et al., 1978). Similarly low interstitial SRP concentrations were measured in the southern area of WCA-2A (SRP < 0.07 mg L^{-1}; Koch and Reddy, in review; Koch, in prep) and in the interior of WCA-1 (Figures 10b and 11b); however, NH$_4^+$ levels were 2 and 4 times greater, respectively.

Soluble reactive P and NH$_4^+$ concentrations at the ENR sites (Figure 6a, 8a) are equivalent to northern sites in WCA-2A (SRP = 0.94 to 2.97 mg L^{-1}, NH$_4^+$ = 0.05 to 7.80 mg L^{-1}; Koch and Reddy, in review; Koch, in prep.). These values are also comparable to nutrient enriched fens receiving groundwater from agricultural runoff in The Netherlands (PO$_4^{3-}$ = 0.5 mg L^{-1}, NH$_4^+$ = 3-5 mg L^{-1}; Verhoeven, 1983).

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Interstitial Nutrients and Flooding

The diffusion of oxygen into soils is 10,000 times slower when soils are flooded (Greenwood, 1961). Because of this physical limitation of oxygen supply, wetland soils become anaerobic and other oxidized compounds are used as terminal electron acceptors in microbial respiration which supports mineralization. An increase in SRP and NH_4^+ over time in the ENR soils with continuous soil flooding (Figure 6a, 8a) may have been due to mineralization or physical processes associated with soil anaerobic conditions (Khalid and Patrick, 1974).

A close relationship was found between interstitial SRP and NH_4^+ throughout the flooding experiment (Figure 14) along with a continuous reduction in interstitial SO_4^{2-} concentrations (Figure 15). A positive correlation was also found between SiO_2 and both SRP and NH_4^+ in the interstitial soil (Appendix B). Thus, decomposition potentially supported by SO_4^{2-} reduction and other oxidized compounds, appears to be releasing organically bound P, N, and SiO_2 from the Everglades peat.

Sulfate concentrations in the interstitial waters exceeded other potential reductants i.e., Fe^{3+}, Mn^{4+}, and NO_3^- by several orders of magnitude (Table 2 and Figure 8b). In salt marsh sediments where SO_4^{2-} is abundant, SO_4^{2-} reduction is estimated to mineralize 432 g C m^{-2} yr^{-1} and account for 50% of mineralization (Howes et al., 1981 and 1984). In most freshwater systems SO_4^{2-} concentrations are low. However, the canals associated with the EAA supply connate (of marine origin) groundwater and agricultural drainage which is highly mineralized possesing high conductivity and SO_4^{2-} levels (Gleason, 1974). Evidence for SO_4^{2-} reduction is also shown in the redox profiles measured in field A which are within the theoretical range of SO_4^{2-} instability (Figure 3, 13).

Although redox profile measurements in September, 1990 only showed potential ranges

for denitrification in WCA-1, available NO_3^- would be preferentially reduced before SO_4^{2-} (Figure 3, 13). Denitrification rates in coastal wetlands have been reported to range from 5 to 60 kg N ha^{-1} yr^{-1} (Kaspar, 1982). The dissimilatory reduction of nitrate, made available by soil oxidation, would provide a reductant for decomposition and promote recycling of nutrients upon reflooding. Extremely high NO_3^- levels were available during the course of this study beginning in October for field B and February in field A (Figure 8b).

High NO_3^- levels in the flooded fields may have been the result of soil oxidation from the winter freeze in January, along with lower water levels during the drought (Figure 4). Nitrate is a highly mobile compound, thus could have been transported down to 60 cm as shown in Figure 8b. Oxidation of surface sediments was also evident by the increase in SO_4^{2-} concentrations at 15 cm in both field A and B during the month of February (Figure 15). Soil oxidation during the dry season and during artificial drawdowns in WCA-2A has been shown to significantly increase NO_3^- concentrations in the surface waters as high as 1.7 mg L^{-1} (Worth, 1983) and up to 5.1 mg L^{-1} in the interstitial waters (Koch, in prep.).

In addition to biological nutrient releases under anaerobic conditions, several physico-chemical processes control P solubility under flooded conditions. Phosphorus can be released to the soil solution by: 1) a reduction of oxidized forms of iron (ferric to ferrous) releasing ferric phosphate compounds, 2) hydrolysis of ferric and aluminum phosphates, and 3) release of P adsorbed to clays and hydrous oxides by anion exchange processes (Ponnamperuma, 1972). Although total soil iron and aluminum content is low in the ENR soils (Table 4) compared to mineral soils, the release of Fe and Al bound P could have contributed to the increased soluble P in the interstitial waters (Figure 6a-c). However, no significant increase in interstitial soluble Fe over several months of flooding ENR soils was found in the present study.

Based on preliminary results from Koch and Reddy (in review) in WCA-2A, and the

Field A

$$SRP = 9.16 \times 10^{-3} + 0.26(NH_4^+) \quad r^2 = 0.89$$

SRP (mg L^{-1})

NH$_4^+$ (mg L^{-1})

Field B

$$SRP = 6.80 \times 10^{-2} + 0.34(NH_4^+) \quad r^2 = 0.85$$

SRP (mg L^{-1})

NH$_4^+$ (mg L^{-1})
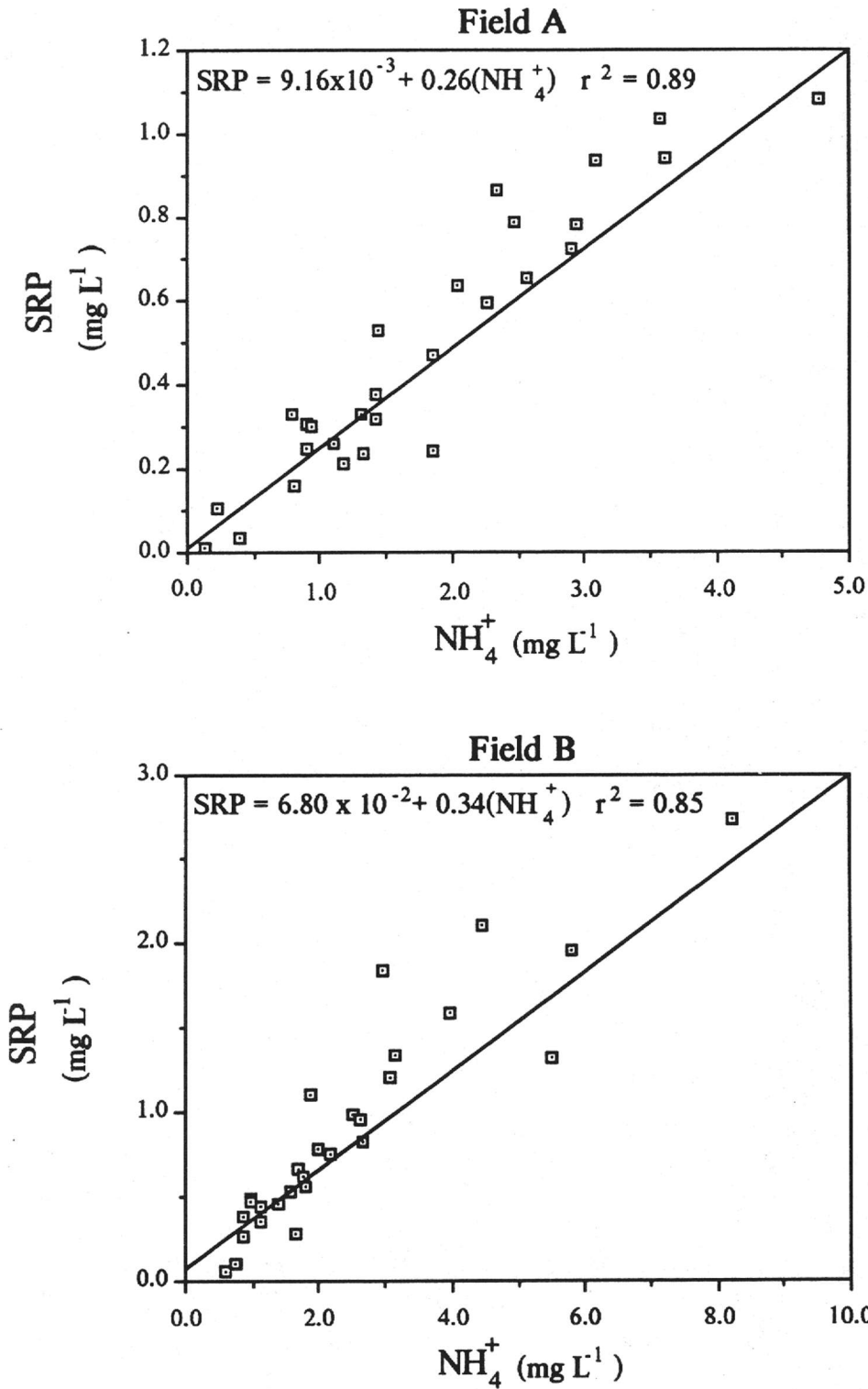
Figure 14.   Relationship of soluble reactive phosphorus and ammonium in the interstitial water (15, 30, 45, and 60 cm depths) from August, 1989 to June, 1990 (n = 140).
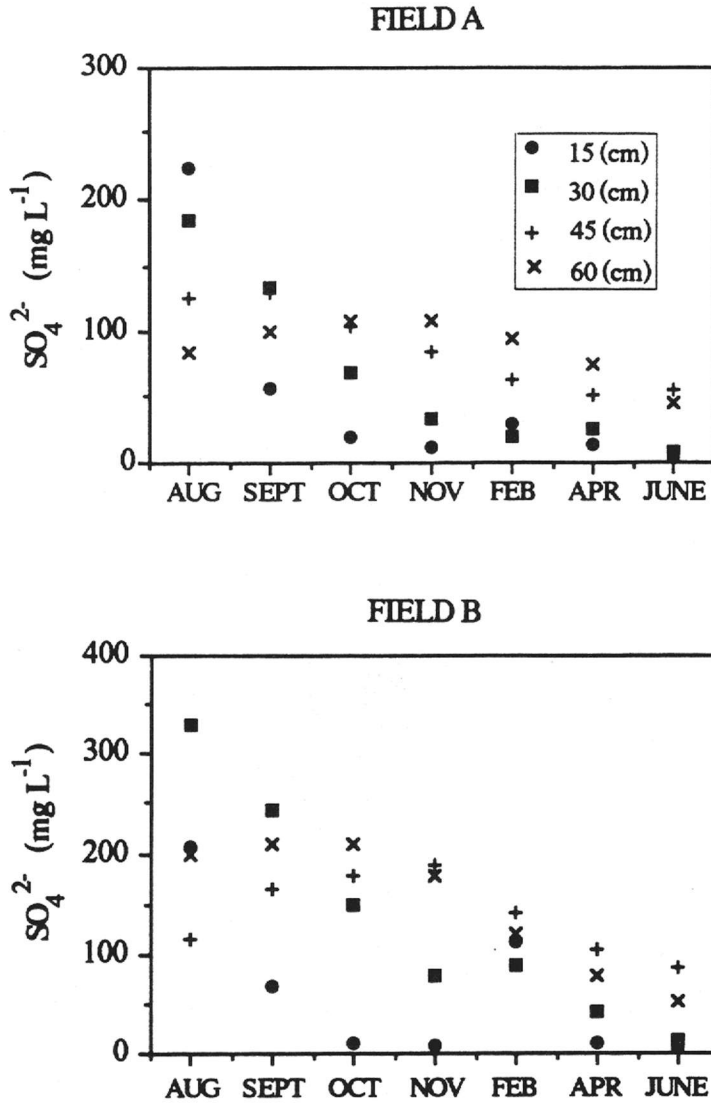
Figure 15.   Changes in sulfate concentrations (mg L^{-1}) in the interstitial water (15, 30, 45, and 60 cm depths) due to soil flooding from August, 1989 to June, 1990. Means are given with ± standard error (n=5).

TABLE 4. Total iron, aluminum, calcium carbonate, and carbon in the ENR soils.

Field

	A Depth (cm)				B Depth (cm)				C Depth (cm)			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Fe (g kg⁻¹)	3.36 ±0.82	2.62 ±0.51	2.56 ±0.84	0.97 ±0.52	3.28 ±0.59	1.84 ±1.13	1.60 ±1.05	1.38 ±0.67	3.74 ±1.14	3.22 ±1.93	3.40 ±3.61	4.16 ±3.66
Al (g kg⁻¹)	4.32 ±1.22	3.58 ±1.02	3.46 ±1.60	1.62 ±1.02	4.06 ±0.71	1.81 ±1.15	2.37 ±1.25	2.21 ±1.55	3.84 ±0.81	3.10 ±1.67	5.78 ±6.90	7.52 ±6.57
Total Ca	44.01 ±14.45	36.45 ±9.46	35.66 ±9.26	18.62 ±10.96	35.50 ±4.15	29.69 ±14.62	41.67 ±19.37	42.02 ±22.27	37.49 ±8.40	28.25 ±9.16	49.98 ±49.36	45.60 ±20.62
Total C (g kg⁻¹)	475.90 ±29.30	510.74 ±14.44	527.97 ±36.98	525.14 ±17.56	487.00 ±12.54	497.70 ±20.68	505.85 ±17.19	524.19 ±22.81	455.70 ±38.23	479.96 ±6.13	479.95 ±19.81	457.93 ±40.40

Means are given with ± standard deviation (n=5).

high calcium levels found in the ENR project (Tables 2,4), calcium may be more important than Fe and Al in the inorganic binding of P once the ENR project is established . Higher pH values were present in the surface soils and overlying water in field A than in lower soil depths (Figure 12a). At these high pH values, 8.0 pH units, calcium precipitation and concomitant phosphate adsorption could contribute to the sequestering of available P (Figure 12a).

Nutrients and the Soil/Water Interface

The soil-water interface is an important boundary due to changes in redox potentials created by anaerobic soil conditions overlain by aerobic surface waters. Benthic vegetation at the soil-water interface not only supplies O_2, but also lowers the partial pressure of CO_2 and therefore promotes Ca precipitation at this boundary. Biological nutrient assimilation capacity in the upper detrital layers of the Everglades has been shown through radioactive tracing studies to be active in removing surface water nutrients even against concentration gradients (Davis, 1982). The dynamic nature of the soil-water interface is depicted in the profiles of SRP, NH_4^+, and pH shown in Figures 10 to 12.

An oxidized microzone in the soil surface can effectively limit high interstitial soluble P from diffusing to the surface waters and may have been important in keeping low surface water nutrient levels during this study. If this oxidized microlayer becomes anoxic, the P diffusion rate would accelerate and a significant amount of soluble P could be transported from the soils to the surface water. This phenomenon has been observed in lakes where soluble P increased more than 100 times in the hypolimnion following reduction at the sediment-water interface (Mortimer, 1941).

Due to the high biological oxygen demand in the anaerobic sediment of enriched soils of the Everglades (Belanger et al., 1989), diurnal oxygen consumption without the balance of photosynthetic O_2, could deoxygenate the soil-water interface and increase the soil P efflux at night or during periods of low autotrophic

activity. As an example of the importance of the aerobic microzone, Lake Apopka soils under anaerobic conditions diffused upward 10 mg P m^{-2} day^{-1} of the 16 mg P m^{-2} day^{-1} that was produced (Reddy and Rao, 1983). The depth of the oxidized soil horizon in wetland soils is limited to a few millimeters in thickness (Ponnamperuma, 1972; Patrick and DeLaune, 1972; Koch et al., in review). In field A, redox profiles indicated this zone was less than 1.0 cm, the length of the platinum on the tips of the probes (Figure 13). Because of the shallow depth of the oxidized boundary layer, any slight turbulence in the overlying water could affect the flux of soil nutrients.

The oxidized soil surface layer is also an important site for both N and P cycling. Ammonium which is the most abundant inorganic N form in wetland soils, diffuses up to this zone where it is oxidized and potentially lost from the system as N_2 through denitrification. Nitrate availability below the thin oxidized surface layer in flooded soils is frequently cited as the limiting step in controlling denitrification rates (Patrick and Reddy, 1976; Oremland et al., 1984; Seitzinger and Nixon, 1985; Koch et al., in review) but would be resupplied from inflow waters in the ENR project. In a constructed biological nutrient uptake system, such as that proposed for the ENR project, denitrification could remove excess inorganic N, but would have to be balanced with mineralization to obtain a net N loss from the system. Nitrification-denitrification and NH_3 volatilization may have been important in maintaining the low NH_4^+ concentrations observed in the surface waters throughout the 10 months of this flooding experiment.

The oxidation status and pH of the upper soil profile can have a significant influence on the cycling of inorganic N and P, however the role of these physico-chemical processes on organic nutrient dynamics is less understood. Flooded organic soils may have a very low potential to buffer the organic forms of N and P in the floodwaters compared to clay loam soils (Reddy, 1983). Dissolved organic P and N represented 70 and 96 %, respectively, of the total P and N in the overlying surface waters in

this study. These data suggest that although inorganic P and N can be assimilated biologically or chemically removed from the available pool in the surface waters, the organic forms may not be sequestered as efficiently. Organic N levels in the interstitial soils reach values up to 20 mg L $^{-1}$ and represent approximately 80% of the total N. Thus, a significant flux of organic N to the overlying water could minimize the net N uptake capacity of the ENR project. Additional information is required on the actual flux rate of the different P and N species from the soils and factors controlling their solubility under flooded anaerobic soil conditions.

CONCLUSION

An initial release of inorganic SRP and NH_4^+ into the interstitial water occurred upon flooding field A and B at the ENR site. Mineralization supported by SO_4^{2-} and NO_3^- reduction or abiotic releases probably accounted for this nutrient flux. Although the interstitial waters of field A and B were high in soluble P and N throughout the period of soil saturation, inorganic nutrient levels in the surface waters remained one to two orders of magnitude lower and decreased with time after inundation. The ENR system tended to maintain low surface water inorganic nutrient levels, however, organic nutrient forms, particularly organic N were less efficiently sequestered in the ENR soils.

The present study provides baseline data on the static condition of nutrients at the ENR project site. Environmental variables that can be managed in the ENR to enhance the nutrient uptake efficiency of the system should be investigated further i.e., hydroperiod, water depth, and vegetation community types. Modelling these environmental variables in relation to P cycling would assist in predicting the efficiency of the ENR project and other water management areas. More detailed physico-chemical data are needed to model the dynamics of nutrient uptake for these organic soils. Factors which should be considered in any future research include: 1) factors controlling *in situ* mineralization rates of

organically and inorganically stored P and N, 2) flux rates of organic and inorganic species of N and P from the soils to the overlying waters, 3) the precipitation kinetics of Fe, Al, and Ca, 4) the role of the soil oxidized micro-zone in diurnal and seasonal predictions of nutrient uptake efficiencies, 5) nitrification-denitrification and NH_3 volatilization contributing to N losses from the sytem, and 6) the effects of soil desiccation during periods of drought on releases of stored nutrients.

RECOMMENDATIONS

1. Design an outflow or recirculation system in the event that water quality standards are not achieved in the outflow during the start-up phase of the system when fields are initially flooded. This will be particularly important because a) the ENR will need to attain a relatively low P (nutrient) outflow concentration, b) the receiving water is particularly sensitive thus, little tolerance for initial release of nutrients will be acceptable, and c) the area may dry out during periods of extreme drought and a release of stored nutrients may occur with initial reflooding.

2. Conduct liming experiments to determine if inorganic P adsorption could be enhanced by additional precipitation of calcium carbonate. This may only be necessary during the start-up phase of the system. A calcium carbonate berm could also be installed in the future at the outflow to lower P concentrations to meet water quality standards.

3. Promote vegetation by planting or altering hydroperiods, such that submerged aquatic vegetation and benthic algal mats could be sustained and not shaded out. This would help maintain a soil surface oxidized layer and thus, provide a barrier to diffusion of inorganic N and P. Aquatic slough communities would provide such a habitat, if they could be sustained and not out competed by less desirable species.

4. Promote vegetation, if possible, which has a high resistance to decomposition (high lignin, silica content etc.) such that a desirable peat

will be formed which will minimize the flocculent material. This would minimize the resuspension of sediment bound nutrients into the surface waters.

5. The present study showed high interstitial nutrient concentrations compared to the surface waters. Therefore, outflows should be designed to bleed off the surface waters and minimize the disturbance to the sediments. Physical disturbance could resuspend interstitial nutrients into the overlying waters, therefore should be limited when operating pumps or sampling water quality.

6. An aeration system may be needed to oxidize organic forms of P and N which could then be removed from the biological system either through denitrification of oxidized N compounds or assimilation of inorganic P.

7. Continue research on the geochemical mechanisms of nutrient cycling in the ENR project and other proposed stormwater treatment areas in the context of possible management options. This information will provide the basis for important management decisions for future nutrient uptake systems.

8. Experimental cells should be used to test, on a reasonable scale, different management scenarios for the ENR site and other stormwater treatment areas.

9. Continue research in the WCAs and ENP on the factors controlling nutrient cycling in the Everglades peat, so that the release mechanisms for P and N causing eutrophication can be better predicted and then controlled.

10. Utilize data from this report and others (Davis, 1982; Reddy and Graetz, 1991; Koch and Reddy, in review; Koch, in prep) to initiate a soil P model. This model can act as an integrator of available information and can be used to understand the processes controlling the efficiency of nutrient uptake systems in the Everglades such as the ENR and other water management area sites.

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Appendix I-A

September (1989)

	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (µmhos cm⁻¹)	938 ±142	1220 ±252	1517 ±328	1585 ±298	1450 ±232	1001 ±79	861 ±247	2008 ±100	2296 ±206	21400 ±109	--- ---	662 ±119	857 ±80	999 ±86	1139 ±79
Sodium (mg L⁻¹)	97.71 ±24.27	150.98 ±39.13	196.22 ±44.08	198.12 ±38.31	159.70 ±13.24	101.99 ±5.17	196.25 ±36.57	367.45 ±25.04	376.92 ±41.66	323.84 ±42.25	--- ---	34.34 ±18.61	42.53 ±21.87	37.94 ±17.52	36.11 ±14.41
Potassium (mg L⁻¹)	16.73 ±2.57	3.47 ±1.03	2.66 ±1.10	3.96 ±1.32	4.77 ±1.08	13.98 ±0.47	7.53 ±1.17	5.04 ±1.64	5.41 ±1.48	7.31 ±1.15	--- ---	30.95 ±8.34	18.33 ±4.38	14.10 ±4.44	14.20 ±4.09
Chloride (mg L⁻¹)	148.4 ±41.5	210.3 ±55.2	274.8 ±87.7	284.4 ±88.3	265.3 ±71.7	152.6 ±7.4	209.7 ±33.2	404.2 ±49.9	529.4 ±61.1	489.6 ±24.9	--- ---	92.6 ±33.1	118.8 ±28.4	111.8 ±13.5	110.6 ±17.6
Calcium (mg L⁻¹)	57.7 ±4.7	88.6 ±12.8	97.5 ±11.6	92.4 ±11.7	97.3 ±17.0	75.7 ±7.9	55.5 ±5.1	87.0 ±5.5	105.9 ±9.6	114.1 ±11.8	--- ---	97.3 ±11.6	118.7 ±9.8	148.0 ±19.3	176.8 ±18.7
Magnesium (mg L⁻¹)	18.35 ±1.40	19.45 ±2.00	26.46 ±3.33	26.78 ±3.59	28.75 ±5.26	24.35 ±1.95	14.68 ±2.64	20.35 ±0.96	26.30 ±2.68	31.62 ±5.11	--- ---	17.88 ±3.16	25.07 ±1.74	32.41 ±3.43	34.66 ±4.80
Silicate (mg L⁻¹)	19.3 ±2.5	21.3 ±1.8	10.9 ±1.4	11.0 ±2.3	12.4 ±2.9	17.1 ±2.4	34.0 ±4.1	20.2 ±2.9	17.8 ±4.6	25.0 ±6.3	--- ---	15.1 ±3.9	19.1 ±3.4	14.5 ±1.6	13.3 ±2.0
Sulfate (mg L⁻¹)	16.4 ±6.5	57.3 ±13.5	132.4 ±32.2	128.6 ±25.9	100.3 ±31.5	54.1 ±7.5	67.5 ±27.3	244.1 ±35.9	209.2 ±67.5	164.6 ±59.0	--- ---	119.6 ±15.3	122.8 ±49.3	114.7 ±55.2	131.1 ±31.6
Iron (mg L⁻¹)	0.38 ±0.03	1.29 ±0.39	1.10 ±0.31	0.66 ±0.16	0.61 ±0.08	0.24 ±0.01	2.40 ±0.76	1.10 ±0.32	0.76 ±0.08	0.56 ±0.06	--- ---	1.24 ±0.15	1.50 ±0.45	1.03 ±0.36	0.52 ±0.13
Manganese (g L⁻¹)	<200 ±0	220 ±8	270 ±33	<200 ±0	<200 ±0	<200 ±0	207 ±7	204 ±4	<200 ±0	<200 ±0	--- ---	475 ±49	575 ±112	362 ±111	<200.0 ±0
Mercury (µg L⁻¹)	0.25 ±0.03	0.25 ±0.02	0.23 ±0.02	0.21 ±0.01	0.21 ±0.01	0.31 ±0.05	0.25 ±0.04	0.25 ±0.04	0.23 ±0.03	0.22 ±0.02	--- ---	0.29 ±0.06	0.36 ±0.05	<0.20 ±0.00	<0.20 ±0.00

Appendix I-A (con't)

October (1989)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (μmhos cm^{-1})	900 ±175	1010 ±166	1162 ±254	1267 ±233	1274 ±184	1002 ±95	1074 ±48	1547 ±133	2050 ±145	2080 ±119	--- ---	846 ±115	1057 ±114	1234 ±125	1414 ±120
Sodium (mg L^{-1}) ±	114.35 ±40.16	139.85 ±35.00	179.00 ±41.54	194.63 ±36.83	165.54 ±13.56	117.24 ±9.29	178.86 ±24.34	319.43 ±32.22	376.56 ±42.64	339.76 ±41.12	--- ---	29.14 ±15.97	39.61 ±21.73	36.84 ±18.27	35.45 ±15.71
Potassium (mg L^{-1}) 1.10	13.06 ±0.45	6.24 ±1.36	3.30 ±1.34	4.05 ±1.45	4.79 ±1.14	13.23 ±0.51	11.68 ±1.37	5.75 ±1.68	5.46 ±1.42	7.03 ±1.10	--- ---	25.15 ±6.81	18.87 ±4.33	14.84 ±4.13	14.75 ±4.01
Chloride (mg L^{-1})	189.18 ±73.39	227.60 ±51.62	238.88 ±78.90	292.76 ±93.09	272.78 ±70.04	169.82 ±15.23	219.86 ±14.85	342.90 ±49.00	482.24 ±71.28	506.62 ±48.14	--- ---	72.14 ±25.09	99.24 ±21.56	111.04 ±7.40	107.00 ±11.73
Calcium (mg L^{-1})	67.78 ±7.63	89.58 ±11.19	89.54 ±10.81	92.74 ±10.80	102.66 ±16.91	84.08 ±10.18	58.48 ±8.58	78.22 ±10.57	108.82 ±10.10	124.74 ±13.41	--- ---	93.82 ±8.58	116.48 ±8.01	151.16 ±20.05	184.38 ±21.12
Magnesium (mg L^{-1})	20.86 ±4.02	19.88 ±1.69	24.09 ±3.32	26.58 ±3.25	30.30 ±4.81	28.04 ±3.44	16.70 ±4.49	17.31 ±1.77	26.63 ±2.85	34.09 ±5.27	--- ---	16.50 ±2.43	23.46 ±1.73	32.00 ±2.66	34.75 ±3.83
Silicate (mg L^{-1})	12.35 ±1.82	26.30 ±1.79	17.46 ±2.37	13.16 ±1.69	11.48 ±2.33	17.62 ±3.20	44.38 ±4.07	28.30 ±4.19	20.68 ±4.81	24.26 ±7.42	--- ---	9.48 ±2.68	20.78 ±2.76	16.14 ±1.51	15.04 ±2.11
Sulfate (mg L^{-1})	13.95 ±3.65	19.08 ±7.24	68.98 ±26.15	103.08 ±30.13	107.14 ±33.12	57.36 ±11.01	9.92 ±5.63	148.08 ±37.31	208.98 ±67.05	178.08 ±51.27	--- ---	104.88 ±10.89	105.12 ±32.51	107.28 ±48.26	130.38 ±32.27
Iron (mg L^{-1})	0.39 ±0.04	1.71 ±0.34	1.32 ±0.36	0.89 ±0.16	0.67 ±0.09	0.32 ±0.03	2.61 ±0.58	1.60 ±0.49	1.00 ±0.12	0.70 ±0.11	--- ---	0.89 ±0.10	1.24 ±0.34	1.05 ±0.37	0.64 ±0.10
Manganese (μg L^{-1})	<200 ±0	232 ±21	256 ±34	<200 ±0	200 ±0	<200 ±0	227 ±27	<200 ±0	<200 ±0	<200 ±0	--- ---	277 ±57	470 ±101	316 ±87	<200.0 ±0
Mercury (μg L^{-1})	0.51 ±0.06	0.54 ±0.08	0.53 ±0.08	0.45 ±0.09	0.41 ±0.04	0.37 ±0.02	0.42 ±0.07	0.47 ±0.03	0.53 ±0.11	0.38 ±0.02	--- ---	0.68 ±0.15	0.69 ±0.24	0.69 ±0.11	0.55 ±0.12

Appendix I-A (con't)

November (1989)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (μmhos cm^{-1})	1395 ±105	1181 ±184	1106 ±218	1241 ±230	1246 ±157	1082 ±35	1129 ±37	1413 ±112	1964 ±129	2114 ±175	--- ---	3653 ±2045	1347 ±193	1128 ±98	1176 ±117
Sodium (mg L^{-1})	201.81 ±22.68	165.43 ±43.24	158.75 ±54.01	199.32 ±39.42	180.96 ±18.77	137.34 ±3.80	168.54 ±18.06	290.33 ±35.95	389.37 ±36.57	301.32 ±70.43	---	118.60 ±25.91	90.67 ±29.83	67.52 ±19.42	67.63 ±17.10
Potassium (mg L^{-1})	17.83 ±2.03	7.95 ±1.87	4.05 ±1.35	4.16 ±1.41	4.74 ±1.11	12.72 ±0.48	12.13 ±1.13	7.55 ±1.35	5.05 ±1.22	6.03 ±0.92	---	461.19 ±379.31	36.51 ±9.18	30.07 ±6.39	17.49 ±3.54
Chloride (mg L^{-1})	259.28 ±50.31	283.82 ±58.11	252.26 ±77.81	268.34 ±81.53	253.02 ±68.77	177.18 ±4.24	194.54 ±4.41	286.32 ±40.69	455.26 ±71.84	485.22 ±65.11	---	1034.94 ±420.27	226.66 ±38.63	166.20 ±10.73	153.40 ±5.43
Calcium (mg L^{-1})	97.30 ±6.01	102.84 ±17.72	82.90 ±11.72	89.62 ±10.60	104.12 ±15.78	79.90 ±1.26	54.64 ±10.34	64.96 ±9.84	108.76 ±13.11	130.0 ±16.80	---	265.93 ±73.14	150.62 ±34.98	110.70 ±27.85	158.36 ±27.94
Magnesium (mg L^{-1})	34.21 ±2.69	22.91 ±3.18	22.90 ±3.43	25.80 ±3.31	30.90 ±4.64	31.69 ±0.49	17.17 ±4.79	15.31 ±1.93	26.01 ±3.28	38.43 ±6.66	---	53.44 ±19.29	28.09 ±4.95	23.08 ±3.50	33.68 ±5.38
Silicate (mg L^{-1})	21.72 ±2.17	24.24 ±2.75	18.88 ±2.95	15.40 ±2.50	10.88 ±1.53	17.54 ±0.60	43.80 ±4.52	33.02 ±3.61	23.36 ±4.00	23.10 ±6.82	---	41.70 ±8.21	14.04 ±1.57	16.36 ±1.84	17.66 ±1.96
Sulfate (mg L^{-1})	44.18 ±8.62	11.92 ±7.42	33.66 ±17.16	83.52 ±33.65	108.82 ±34.09	47.14 ±1.43	7.28 ±2.63	79.42 ±33.05	177.44 ±57.34	189.14 ±46.19	---	236.52 ±33.05	202.30 ±38.81	116.26 ±45.68	114.56 ±48.35
Iron (mg L^{-1})	0.34 ±0.02	1.59 ±0.29	1.35 ±0.32	0.73 ±0.19	0.65 ±0.16	0.19 ±0.01	1.64 ±0.32	1.26 ±0.42	0.86 ±0.11	0.66 ±0.09	---	0.76 ±0.12	0.88 ±0.15	0.61 ±0.10	0.29 ±0.05
Manganese (mg L^{-1})	242 ±26	238 ±22	248 ±21	<200 ±0	<200 ±0	<200 ±0	220 ±20	<200 ±0	<200 ±0	<200 ±0	---	580 ±110	396 ±95	228 ±12	228 ±21
Mercury (μg L^{-1})	0.20 ±0.00	0.21 ±0.01	0.25 ±0.05	0.23 ±0.03	0.23 ±0.03	0.21 ±0.00	0.20 ±0.00	0.23 ±0.03	0.24 ±0.03	0.20 ±0.00	---	0.22 ±0.02	0.25 ±0.04	0.30 ±0.08	0.27 ±0.03

Appendix I-A (con't)

February (1990)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (μmhos cm^{-1})	1055 ±100	1394 ±259	1202 ±243	1225 ±214	1326 ±186	957 ±34	1121 ±45	1276 ±102	1581 ±187	1916 ±169	--- ---	1144 ±231	982 ±172	936 ±100	1017 ±114
Sodium (mg L^{-1})	146.80 ±20.34	186.2 ±43.74	171.13 ±40.86	185.25 ±37.39	174.18 ±13.37	122.86 ±2.31	176.28 ±15.62	243.30 ±26.89	300.42 ±39.53	329.78 ±34.20	--- ---	63.79 ±28.09	39.80 ±22.93	41.18 ±20.56	39.80 ±21.26
Potassium (mg L^{-1})	24.26 ±0.56	10.81 ±2.49	6.14 ±1.58	4.51 ±1.23	4.56 ±1.03	19.93 ±1.88	13.73 ±0.46	10.11 ±1.60	5.98 ±1.19	5.57 ±1.02	--- ---	153.69 ±72.73	42.67 ±12.99	24.15 ±6.16	16.29 ±0.76
Chloride (mg L^{-1})	261.7 ±54.0	333.9 ±72.4	311.6 ±78.1	278.6 ±75.8	258.3 ±71.6	179.6 ±4.3	228.2 ±16.7	287.5 ±34.5	337.7 ±67.6	406.9 ±67.0	--- ---	768.0 ±538.7	131.6 ±26.6	97.4 ±10.1	94.8 ±13.1
Calcium (mg L^{-1})	65.7 ±5.3	110.7 ±22.6	85.7 ±10.1	88.0 ±9.2	106.1 ±15.2	59.8 ±1.8	63.5 ±6.3	58.6 ±6.1	85.4 ±13.7	118.6 ±18.3	--- ---	304.3 ±119.0	134.2 ±32.7	141.1 ±16.2	170.9 ±26.3
Magnesium (mg L^{-1})	22.30 ±1.85	25.32 ±4.25	24.32 ±3.03	26.38 ±3.24	32.58 ±4.45	24.13 ±0.91	20.31 ±3.51	14.03 ±1.45	20.46 ±3.48	31.25 ±6.00	--- ---	66.00 ±35.94	26.78 ±4.58	31.42 ±5.71	34.22 ±5.02
Silicate (mg L^{-1})	7.7 ±1.5	22.5 ±3.9	20.8 ±2.5	16.9 ±2.4	10.9 ±1.5	8.5 ±2.1	31.0 ±4.4	30.0 ±2.8	22.6 ±3.8	17.2 ±4.4	--- ---	33.2 ±8.5	19.6 ±2.7	15.6 ±1.9	11.6 ±2.1
Sulfate (mg L^{-1})	43.2 ±11.9	28.5 ±9.9	19.5 ±9.0	61.8 ±26.3	94.4 ±28.0	53.4 ±3.8	112.0 ±27.2	88.3 ±16.6	120.7 ±43.4	139.9 ±44.6	--- ---	306.5 ±91.9	160.0 ±36.7	118.8 ±54.0	121.5 ±55.9
Iron (mg L^{-1})	0.28 ±0.01	1.36 ±0.32	1.32 ±0.26	0.57 ±0.13	0.51 ±0.09	0.23 ±0.02	1.14 ±0.34	1.43 ±0.50	0.91 ±0.16	0.65 ±0.13	--- ---	0.43 ±0.06	0.40 ±0.05	0.79 ±0.26	0.32 ±0.10
Manganese (μg L^{-1})	<213 ±12	<260 ±27	<264 ±37	<200 ±0	<200 ±0	<200 ±0	<257 ±38.44	<200 ±0	<200 ±0	<200 ±0	--- ---	<225 ±25.0	<210 ±10.0	<345 ±116.9	<200 ±0
Mercury (μg L^{-1})	<0.2 ±0.00	<0.20 ±0.00	0.28 ±0.08	<0.200 ±0.00	<0.20 ±0.00	0.24 ±0.04	0.27 ±0.07	<0.20 ±0.00	0.28 ±0.08	0.24 ±0.04	--- ---	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00

Appendix I-A (con't)

April (1990)	Field A Depth (cm)					Field B Depth (cm)					Field C Depth (cm)				
	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Conductivity (μmhos cm^{-1})	1294 ±326	1739 ±258	1304 ±206	1287 ±191	1344 ±155	1800 ±505	1194 ±37	1811 ±469	1466 ±209	1818 ±220	--- ---	--- ---	721 ±110	937 ±90	1081 ±90
Sodium (mg L^{-1})	183.00 ±58.20	230.38 ±49.48	175.04 ±36.20	188.63 ±34.64	174.94 ±12.40	161.30 ±29.53	170.88 ±7.74	246.08 ±33.73	281.72 ±40.26	312.58 ±37.21	--- ---	--- ---	19.72 ±4.91	33.76 ±16.30	33.33 ±16.73
Potassium (mg L^{-1})	19.85 ±9.37	12.69 ±4.14	6.50 ±1.50	4.59 ±1.01	4.14 ±0.89	13.23 ±1.75	14.22 ±0.37	11.30 ±2.03	6.80 ±1.43	5.02 ±0.93	--- ---	--- ---	15.51 ±6.56	12.03 ±2.18	10.12 ±2.27
Chloride (mg L^{-1})	267.50 ±87.30	385.36 ±78.14	296.7 ±58.19	281.98 ±60.07	270.72 ±57.52	230.23 ±40.47	264.73 ±10.67	295.96 ±24.12	354.00 ±66.11	399.28 ±63.21	--- ---	--- ---	110.28 ±16.63	95.32 ±12.08	93.56 ±11.76
Calcium (mg L^{-1})	69.8 ±11.2	137.9 ±25.9	91.3 ±8.7	91.9 ±9.2	107.5 ±14.0	60.5 ±2.1	70.8 ±11.2	60.5 ±5.9	79.5 ±14.7	107.5 ±20.8	--- ---	--- ---	95.8 ±4.4	139.1 ±12.8	173.6 ±23.5
Magnesium (mg L^{-1})	28.68 ±2.01	30.14 ±4.47	24.93 ±2.77	26.33 ±2.79	31.94 ±3.94	28.71 ±2.21	24.76 ±4.32	14.96 ±2.21	18.90 ±3.70	28.18 ±6.51	--- ---	--- ---	22.90 ±4.18	29.85 ±4.99	35.42 ±3.54
Silicate (mg L^{-1})	19.3 ±1.4	22.4 ±4.8	21.8 ±3.3	17.8 ±2.8	11.3 ±1.4	6.9 ±1.5	35.2 ±4.7	30.9 ±4.2	27.6 ±2.4	24.6 ±4.8	--- ---	--- ---	4.4 ±0.7	10.5 ±2.5	12.9 ±2.0
Sulfate (mg L^{-1})	29.4 ±27.4	14.3 ±7.1	25.1 ±14.7	51.1 ±21.4	73.6 ±21.1	52.3 ±2.8	9.3 ±5.2	41.3 ±12.6	79.6 ±35.5	105.8 ±43.6	--- ---	--- ---	151.1 ±40.8	121. ±47.	104.0 ±37.1
Iron (mg L^{-1})	0.29 ±0.12	1.48 ±0.34	1.59 ±0.30	0.90 ±0.19	0.68 ±0.08	0.23 ±0.04	1.58 ±0.66	1.60 ±0.61	1.24 ±0.27	0.79 ±0.10	--- ---	--- ---	0.43 ±0.08	0.88 ±0.36	0.34 ±0.07
Manganese (μg L^{-1})	215 ±15	260 ±38	305 ±64	<200 ±0	<200 ±0	228 ±17	450 ±60	268 ±39	223 ±23	210 ±10	--- ---	--- ---	<200 ---	328 ±111	202 ±2
Mercury (μg L^{-1})	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	0.22 ±0.02	<0.20 ±0.00	<0.20 ±0.00	<0.20 ±0.00	0.30 ±0.06	0.25 ±0.05	0.24 ±0.04	--- ---	--- ---	<0.20 0.00	<0.20 ±0.00	<0.20 ±0.00

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Correlation coefficients x 100[*]
Surface water (Field A)

	SRP	TP	TDP	NOx	NH4+	TKN	TDKN	TN	SiO2	Na+	K+	Ca2+	Mg2+	Cl-	SO4^2-	COL	COND	TFe	THg
TP	**98**																		
TDP	**99**	**99**																	
NOx	.	.	.																
NH4+	**72**	**70**	**67**	.															
TKN	.	.	.	.	40														
TDKN	.	.	.	.	.	**93**													
TN	.	.	.	.	41	**100**	**93**												
SiO2	47	48	50	.	56	52	47	50											
Na+	.	.	.	.	.	**76**	**74**	**77**	.										
K+	.	.	.	.	.	.	.	.	.	.									
Ca2+	.	.	.	.	.	**64**	.	**66**	.	**82**	45								
Mg2+	.	.	.	.	.	**65**	.	**66**	38	**87**	44	**94**							
Cl-	.	.	.	.	.	55	.	56	.	**81**	.	**60**	**59**						
SO4^2-	.	.	.	.	.	.	.	.	.	**95**	43	54	**60**	.					
COLOR	.	38	40	.	.	.	40	.	.	.	.	.	.	.	.				
COND	.	.	.	.	.	**80**	**79**	**81**	39	.	41	**89**	**90**	**76**	46	.			
TFe	49	53	51	.	**64**	**75**	**69**	**76**	58	.	.	.	.	.	.	**62**	43		
THg	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
TMn	.	.	.	.	.	.	.	.	.	.	.	.	.	47	.	.	38	.	.

. = Correlation not significant
* = Bold values ≥ (r = 0.60)

Appendix B (con't)

Correlation coefficients x 100*
Surface water (Field B)

	SRP	TP	TDP	NOx	NH4+	TKN	TDKN	TN	SiO2	Na+	K+	Ca2+	Mg2+	Cl-	SO4^2-	COL	COND	TFe	THg
TP	**86**																		
TDP	**90**	**96**																	
NOx	·	·	·																
NH4+	·	·	·	52	·														
TKN	42	56	55	·	·														
TDKN	53	59	59	·	·	**79**													
TN	37	52	52	·	42	**97**	**74**												
SiO2	·	·	·	·	·	·	43	·											
Na+	·	·	·	·	·	40	48	44	·										
K+	51	**63**	**60**	·	·	55	58	54	·	34									
Ca2+	·	·	·	·	·	·	43	·	48	53	·								
Mg2+	·	·	·	·	·	·	45	·	·	**85**	·	**86**							
Cl-	·	·	·	·	·	41	52	44	·	**98**	37	54	·						
SO4^2-	·	·	·	·	·	34	50	35	38	54	42	**83**	**75**	**60**					
COLOR	59	58	**62**	·	·	**72**	**88**	**69**	50	·	50	·	·	·	·				
COND	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·			
TFe	49	49	53	·	·	**65**	**79**	**61**	42	·	·	·	·	·	·	**93**	·	·	
THg	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
TMn	·	·	·	·	·	·	·	·	·	44	·	·	·	42	·	·	·	·	·

· = Correlation not significant
* = Bold values ≥ (r = 0.60)

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Correlation coefficients x 100*
Interstitial pore water 0-60 cm (Field A)

	SRP	TP	TDP	NO_x	NH_4^+	TKN	TDKN	TN	SiO_2	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	COL	COND	TFe	THg
TP	**87**																		
TDP	**100**	**87**																	
NO_x	.	.	21																
NH_4^+	**91**	**77**	**90**	.															
TKN	52	48	53	.	56														
TDKN	48	46	49	.	53	**90**													
TN	54	50	55	.	58	**97**	**87**												
SiO_2	**66**	**64**	**66**	21	**64**	25	24	29											
Na^+	-53	-47	-52	.	-47	-53	-51	-52	-29										
K^+	.	.	.	22	.	-27	-27	-22	59	23									
Ca^{2+}	-33	-31	-33	.	-24	-43	-47	-39	.	**60**	40								
Mg^{2+}	-35	-33	-35	.	-27	-55	-56	-50	-25	57	31	**87**							
Cl^-	-37	-31	-36	.	-33	-58	-56	-53	.	**86**	41	73	71						
SO_4^{2-}	-39	-37	-39	.	-38	.	.	.	**-67**	27	-35	.	33	.					
COLOR	.	.	.	-22	.	52	37	44	.	.	.	.	-28	.	.				
COND	-49	-44	-48	.	-41	-58	-57	-56	-25	**90**	29	**79**	**77**	**91**	31	.			
TFe	42	46	44	.	41	59	55	**60**	48	-40	.	-24	-40	-26	-37	.	-40		
THg	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	
TMn	.	.	.	.	24	29	22	32	30	-22	.	.	.	.	.	.	.	40	

. = Correlation not significant
* = Bold values $\geq$ (r = 0.60)

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Correlation coefficients x 100*
Interstitial pore water 0-60 cm (Field B)

	SRP	TP	TDP	NO_X	NH_4^+	TKN	TDKN	TN	SiO_2	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	COL	COND	TFe	THg
TP	**100**																		
TDP	**100**	**100**																	
NO_X	.	.	.																
NH_4^+	**83**	**84**	**83**	.															
TKN	27	28	29	.	23														
TDKN	30	30	32	.	.	**66**													
TN	29	30	31	.	25	**98**	**65**												
SiO_2	**73**	**072**	**73**	.	**65**	.	.	.											
Na^+	-45	-45	-45	.	-47	.	.	.	-54										
K^+	30	30	29	.	43	-32	.	-29	45	-55									
Ca^{2+}	-27	-28	-28	.	-27	-24	-21	-25	.	43	-26								
Mg^{2+}	.	.	.	.	.	-38	-31	-37	.	.	.	**92**							
Cl^-	.	.	.	.	-21	.	.	.	-22	38	.	45	36						
SO_4^{2-}	**-60**	**-59**	**-59**	.	54	.	.	.	**-69**	**74**	-59	23	.	.					
COLOR	.	.	.	-22	-48	44	.	40	.	.	.	.	.	.	.				
COND	-48	-48	-49	.	-48	.	.	.	-47	**77**	-39	**65**	48	50	58	.			
TFe	43	46	46	.	29	**62**	57	**63**	27	.	.	-33	-38	-22	-25	43	-37		
THg	25	25	25	.	23	30	27	29	.	.	.	.	.	.	.	.	.	31	
TMn	.	.	.	.	25	.	.	.	.	.	23	.	.	.	.	.	.	36	.

. = Correlation not significant
* = Bold values ≥ (r = 0.60)

Appendix B (con't)

Correlation coefficients x 100[*]
Interstitial pore water 0-60 cm (Field C)

	SRP	TP	TDP	NO$_x$	NH$_4^+$	TKN	TDKN	TN	SiO$_2$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	Cl$^-$	SO$_4^{2-}$	COL	COND	TFe	THg
TP	100																		
TDP	100	99																	
NO$_x$	49	47	49																
NH$_4^+$	40	39	41	.															
TKN	26	25	26	25	.														
TDKN	28	28	29	33	.	73													
TN	51	49	51	95	.	54	52												
SiO$_2$	73	72	73	52	34	28	27	54											
Na$^+$	.	.	.	.	.	.	.	.	43										
K$^+$	74	71	73	36	.	.	.	35	51	.									
Ca^{2+}	60	53	61	53	.	.	.	49	42	.	48								
Mg^{2+}	50	44	51	33	.	.	.	31	30	.	38	72							
Cl$^-$	77	74	77	54	27	.	25	54	71	32	76	76	64						
SO$_4^{2-}$	23	24	23	36	.	27	34	39	.	.	27	71	55	38					
COLOR	.	.	.	.	.	39	30	.	.	.	.	.	.	.	.				
COND	65	57	65	32	.	.	.	29	51	28	89	68	41	95	29	.			
TFe	.	.	.	.	28	40	49	.	.	.	.	.	.	.	.	32	.		
THg	.	.	.	.	.	38	31	.	.	.	.	.	.	.	.	.	.	.	
TMn	.	.	.	.	.	38	44	.	.	.	.	.	.	.	0.38	0.42	.	0.36	.

. = Correlation not significant
* = Bold values ≥ (r = 0.60)

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