PERSPECTIVES ON INTERFACING PAPER MILL WASTEWATERS AND WETLANDS

By

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Abstract of Thesis Presented to the Graduate School
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PERSPECTIVES ON INTERFACING PAPER MILL WASTEWATERS AND WETLANDS

By

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Major Department: Environmental Engineering Sciences

Wetland responses to paper mill wastewaters were studied in an artificial wetland near Pensacola, FL, in peaty microcosms and in a former floodplain discharge site in Palatka, FL. After one year, planted seedlings of bald cypress (*Taxodium distichum*), pond cypress (*Taxodium ascendens*), pop ash (*Fraxinus caroliniana*), and blackgum (*Nyssa sylvatica*) in six plots within the pilot effluent treatment marsh and one irrigated reference plot outside the wetland exhibited high survival and growth. Pond cypress exhibited the highest growth over the entire study in the pilot wetland followed by blackgum, bald cypress and pop ash. Pop ash and blackgum were the species most retarded in growth by increased depth of inundation.

Metabolism was evaluated from data on diurnal temperature, dissolved oxygen, redox potential and pH measured over a 24-hour period at four stations in the pilot wetland. Temperature and dissolved oxygen were highly stratified. Gross primary production in the pilot wetland was moderate to high with the highest rate calculated at 7.6 $g/m^2/day$. The production/respiration increased along the length of the cell with deep zones. pH and redox (Eh) data from the pilot wetland plotted on an Eh-pH diagram were in the range found in natural ecosystems.

Forested wetland peat-effluent interface microcosms proved to be an effective medium for the reduction of biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia nitrogen (NH_4-N), total kehldahl nitrogen (TKN), nitrite - nitrate nitrogen (NO_2-NO_3) and total phosphorus (TP). The microcosms lowered effluent pH and increased color.

Data on species composition, diversity and growth rate of bald cypress were collected from the Rice Creek floodplain where effluent from the Georgia Pacific mill in Palatka had been discharged. Growth and diversity were similar to those in an unaffected site upstream.

An emergy evaluation of tertiary treatment alternatives indicated that a wetland interface might require less purchased inputs, thus benefiting industry, the environment and society. The several kinds of data presented may justify a large scale pilot test of reconditioning paper mill wastewaters in a peaty forested wetland.

INTRODUCTION

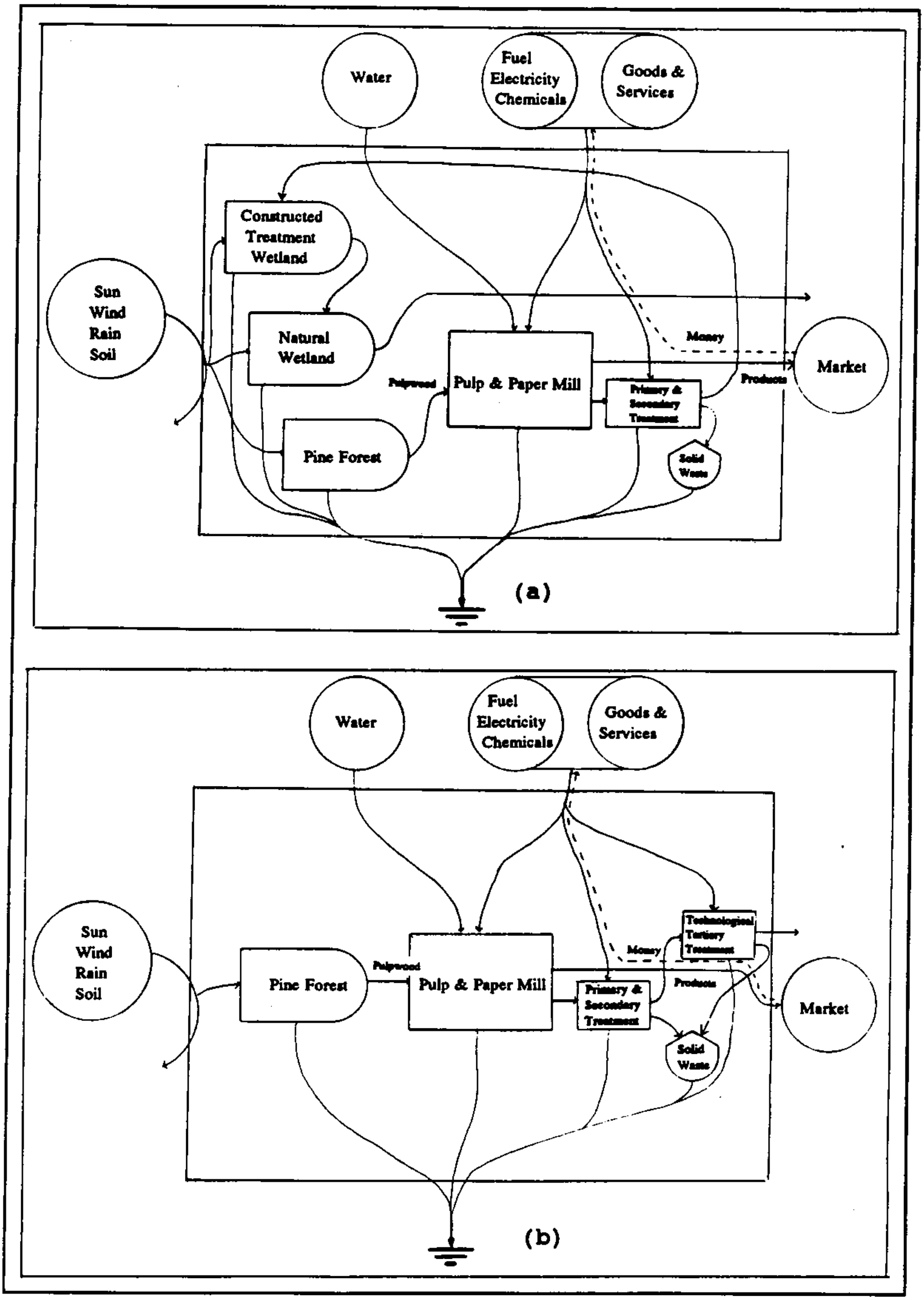
Integrating wetlands into municipal and industrial effluent waste treatment processes has stimulated considerable research and implementation over the past decade. Wastewater-wetland systems have been proven effective in reducing biochemical oxygen demand (BOD), nutrient concentrations, total suspended solids (TSS), heavy metals, pathogens, and some organic pollutants. (Knight, 1990; EPA, 1988; Gillette, 1989; Ewel and Odum, 1986; Thut, 1990). Wetland ecosystems self-organize to adapt to environmental inputs such as treated sewage and industrial wastes. Biological, chemical, and physical processes are involved in purification and attenuation of pollutants.

The paper industry uses large volumes of water, producing and discharging effluent often high in lignaceous organic compounds. A fascinating possibility for the paper industry is interfacing wetland systems with effluent discharge, thus recycling water through natural environmental processes, metabolizing and sequestering pollutants of concern to the public, helping to maintain local water tables and providing the ancillary benefits of ecosystem and habitat conservation. Such a symbiosis between industry and the environment, if it can be shown to benefit the receiving ecosystem as it adapts, would benefit the paper industry, the environment, and society. Using exploratory measurements, this study assembles evidence that may justify more extensive pilot testing.

Included are: 1) Measurements of aquatic metabolism and tree seedling survival and growth in a pilot wetland treatment system constructed by Champion Paper Corp. near Pensacola, FL; 2) measurements of water quality in peat microcosms receiving paper mill wastewaters at the Pensacola site and; 3) measurements of indices of mature wetland ecosystems that formerly received paper mill wastewaters at Rice Creek near Palatka, FL.

Two aggregated systems representing hypothetical paper mills and the supporting environment and economy were diagramed (Figure 1). (See Odum, H.T. (1983) for energy circuit systems diagramming methods). Large scale policy implications of wetland interfacing as opposed to technologically advanced wastewater treatment in the pulp and paper industry are considered using emergy evaluation in the discussion of this report.

Figure 1. Aggregated Systems Diagrams of Paper Mills with Supporting Environment and Economy. a) Wetland interface for secondary effluent discharge; b) Advanced tertiary effluent treatment.


Water
Fuel
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Goods &
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Sun
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Feasibility Questions

Many concepts are involved in using wetlands as an interface between paper mill effluent discharges and public waters. Some substances may be simply absorbed by plants, peat microorganisms and chemical reactions. Self-organizing ecosystems that have a high diversity of microbial species often develop processes needed to utilize waste substances.

Consensus is developing that lignaceous substances from natural wood decomposition or paper mill waste are good at binding many kinds of toxic substances and are useful for purification either as peat filters or as blackwaters (Fuhr, 1987; Larrson and Lemkemeir, 1989). Even though water treatment for human consumption requires clarification, blackwaters are natural all over the world and may contribute to the health of ecosystems and humans before water treatment. Many of the healthiest waters in Florida start as highly colored drainages from elevated swamps such as Okefenokee, Santa Fe, Green and Big Cypress swamps. One concept of interfacing wetlands with paper mill wastewaters is to pass them through enough natural wetland area so that the lignaceous materials from the effluent are exchanged or diluted by the color from the swamp. The color is not changed much but the waters become normal for wetland outflow.

In order to learn more about wetland potential as an interface, changes in chemical characteristics were studied and the properties of adapting ecosystems were examined.

Although costly, conventional effluent treatment technology and modern process configurations such as chlorine dioxide substitution and oxygen delignification have been largely effective in reducing biochemical oxygen demand (BOD), total suspended solids (TSS), toxic resin acids, and much of adsorbable organic halide (AOX) in pulp and paper mill effluent. However, problems with persistent effluent characteristics, including color, chemical oxygen demand (COD), foaming propensity, nutrients, and AOX exist in many mills. The cost of engineered tertiary treatment facilities is often prohibitive. Alternatives being considered include return of the secondarily treated effluent in a dispersed manner to the environment via a carefully managed constructed or natural wetland system. Running on natural environmental energies, a wetland wastewater treatment system in which a viable and appropriate ecosystem can develop can be an interface between effluent discharge and public waters.

Environmental Fate of Kraft Effluent

Numerous studies have been conducted worldwide on the impact of pulp and paper mill effluent on aquatic organisms in receiving waters. (Gellman, 1988; Gove, 1982; Hutchins,

1979) However, the environmental storage, cycling and degradation mechanisms for many of the compounds are not well understood.

The kraft pulping process involves the digestion of wood chips in a highly alkaline sodium sulfide solution under heat and pressure. The resulting black liquor is a mixture of solubilized lignin and wood extractives which have been separated from the wood fiber used in paper production. The liquor is successively screened and washed, with 95% recovery and recycling of process chemicals. Dilute wash waters are discharged to the effluent treatment system, where they typically receive primary and secondary treatment. At this point in the pulping process, the pollutants of concern in waste water are BOD, TSS, nutrients, color, foam, and resin acids. With the exception of color, these pollutants can usually be reduced to levels acceptable for permitting and discharge into Class III receiving waters using primary and conventional biological treatment. The pulp bleaching process is responsible for the formation of the most problematic group of chemicals found in paper mill effluent, chlorinated phenolics and other halogenated lignin byproducts. These chemicals tend to be resistant to biological degradation and some are toxic and/or genotoxic to aquatic organisms and may bio-accumulate (Earl and Reeve, 1990; Hutchins, 1979).

To produce white paper, pulp must go through a series of bleaching and extraction steps. The bleaching is accomplished using either aqueous chlorine, chlorine dioxide or a combination of the two. Caustic sodium hydroxide is used in extraction. Many western European mills have switched to ozone bleaching, thus eliminating the environmental problems associated with chlorinated organic compounds. The cost, however, is three times as much as chlorine, and some fiber strength is sacrificed (Swann, 1990).

Of the many constituents of AOX (a parameter which includes all chlorinated organics), a wide range of molecular weight compounds are represented. Those of low molecular weight contribute most to AOX related effluent toxicity. These toxic compounds, including chloroform, chlorophenols, chlorinated guiacols and catechols are generally reduced to sub-chronic toxicity levels for aquatic indicator organisms by mills that use modern process control and secondary effluent treatment systems such as aerated stabilization basins (ASB) and oxidation ponds or activated sludge plants. Total AOX can range from 3-6 kg/ton of paper produced, depending on the level of chlorine dioxide substitution used in the bleaching process (Presley, 1990). The EPA and several states are in the process of issuing NPDES permits reflecting new effluent standards on AOX and dioxin. The suggested limit on dioxin in streams is 0.013

ppq., well below the detectable limit (Pulp and paper, 1991). The suggested regulatory limit for AOX in mill effluent is 1.5 kg/ton (Presley, 1990).

The recalcitrant nature of high molecular weight kraft lignins responsible for the color and COD in paper mill effluent is due to the molecular structure of lignin itself. Lignin is a complex aromatic polymer which contains many non-hydrolyzable linkages protecting the polysaccharides from enzymatic degradation (Kirk and Chang, 1981). The role of certain basidiomycetes, specifically white rot fungi, in the catabolism of lignin related compounds has been shown. The white rot fungi *Phanerochaete chrysosporium* and *Coriolus versicolor* were able to degrade lignin as measured by $^{14}CO_2$ generation from a ^{14}C labeled lignin compound culture (Crawford, 1981; Kirk et al., 1980). Depolymerization involves a powerful extracellular enzyme system present in the fungi (Bumpus, et al., 1985). The process requires aerobic conditions and the presence of an additional carbohydrate food source. The by-products formed can then undergo further ring cleavage and degradation through the enzyme systems of various bacteria and other microorganisms (Cain, 1980).

A study conducted on kraft mill effluent in an aerated lagoon reported a reduction of total organic halide (TOX) of 1/3 to 1/2. The dehalogenation and degradation of chlorinated organics under anaerobic conditions in the benthal layer of the lagoon was determined to be important in overall TOX reduction. Biosorption of the persistent chlorinated organic molecules onto settling biomass played a crucial role in the further degradation of TOX components in the benthal layer (Amy, et al., 1988).

Microbial synthesis and complexation of lignin related aromatic compounds is known to occur in the process of soil humification (Martin, 1980). Larrson and Lemkeimeier (1989) compared the mineralization of chlorinated phenols and biphenols in humic lake systems vs. clear lake systems. Substantially higher rates of degradation occurred in the humic environments, where microbial populations were adapted to degrading and complexing similar natural aromatic humic compounds.

Previous Studies

Apparently only one large scale wetland effluent treatment systems exist for the pulp and paper industry in Columbus, MS. Information on it's operation had not been reported in time for inclusion in this report.

Two pilot scale studies have been reported on tertiary treatment of pulp mill effluents by artificial wetlands (Allender, 1984 and Thut, 1990). Two larger and more significant studies were initiated by Pope and Talbot, Inc. Halsey, OR and Champion International Corp. in Cantonment, FL.

Allender's study, conducted under static hydroponic greenhouse conditions, showed a reduction of lignosulfonate, color, TSS, BOD, and foaming propensity of secondary treated effluents in small planted reactors. The experiment was conducted over a ten-week period using four plant species indigenous to the mill location in Victoria, Australia. Plants were planted in four liter plastic tubs filled with bleach plant and paper machine effluent. Various concentrations of the indicator pollutant lignosulfonate were tested as well as the effect of nutrient addition and biocide treatment. Three of the four plant species were collected from the mill's final effluent ponds, giant rush (*Juncus ingens*), pale rush (*Juncus pallidus),* common reed (*Phragmites australis)* and cumbungi bulrush *(Typha orientalis)*. *Juncus* and *Typha* showed the greatest pollutant removal efficiency under high loading conditions. Allender concluded that all species tested were able to tolerate large and repeated changes in effluent quality and that the enzyme mediated processes involved in phenolic compound degradation occurred primarily in bacteria associated with the rhizosphere of a living root system.

Rudolf N. Thut, Scientific Advisor to The Weyerhaeuser Co., conducted several small scale pilot studies on bleached kraft mill effluent in 2.6 m^2 marsh reactors, and initiated a three year larger scale investigation (0.4 ha.) treating thermomechanical pulp mill effluent (Thut, 1990a,b). Using wetland plants in a gravel substrate, Thut attempted to maximize both plant uptake and anaerobic breakdown. The plant species used in the studies included giant cordgrass *(Spartina cynosuroides)*, cattail *(Typha latifolia)*, reed *(Phragmites australis)*, bulrush *(Scirpus californicus)*, torpedo grass *(Panicum repens)*, and sawgrass *(Cladium jamaicense)*.

After one year no difference in the treatment efficacy between species was shown. Removal efficiencies were: TSS-54%, BOD-29%, ammonia-64%, total organic nitrogen-33%, total phosphorus-18%. Removal of fatty and resin acids, an important constituent of effluent toxicity, was between 20-25%. The optimum retention time based on these parameters was 15 hours. No significant removal of color or total organic chlorine (TOCL) was reported, although a reduction in chlorinated phenolics of 50% was noted.

Thut concluded that artificial wetland treatment would have no appreciable positive effect on color and adsorbable organic halide (AOX) in wastewaters. Evidence exists, however, that biosorption and biodegradation under a combination of aerobic and anaerobic conditions can reduce AOX and dioxin concentrations (Amy, et al., 1988; Presley, 1990).

Pope and Talbot, Inc. in Halsey, OR initiated a large scale artificial wetland tertiary treatment project scheduled to run for five years (NCASI, 1991; Pope & Talbot, 1990). With the cooperation of Oregon State University, 40,000 cattails and bulrushes were planted and the area was inundated with 18 inches of secondary treated Kraft mill effluent. Proposed retention times were 24-48 hours. The effluent was circulated by gravity and pumping. No results were available, but the preliminary goals were a BOD and TSS reduction from 15 ppm to 8 ppm, reduction of color, and reduction of the dioxin concentration in the effluent. However, the discharge from the mill contained less than the detectable level (10 ppq) of dioxin.

Champion International and CH2M-Hill studied a effluent-wetland interface at a kraft pulp and paper mill in Cantonment, FL. A pilot wetland and nitrification plant was constructed to the east of aerated stabilization basin (ASB2), one of the four lagoons in Champion's secondary effluent treatment system. Rigorous quarterly water quality, vegetation and fauna sampling and analysis was conducted over a one year period (CH2M Hill, 1992). The wetland consisted of six cells 100 meters long with three pairs of cells of the following widths: 40 meters, 20 meters, and 10 meters. The paired cells were identical except for two additional deep zones in one cell of each pair. The purpose of the deep zones was to assess the effects of increased water storage, increased hydraulic retention time, and increased atmospheric reaeration. Ten herbaceous plant species in six identical planting zones within each wetland cell were planted. Species included were softrush *(Juncus effusus)*, maidencane (*Panicum hemitomon*), sawgrass (*Cladium jamaicense*), canna (*Canna flacida*), fireflag (*Thalia geniculata*), duck potato (*Sagittaria lancifolia*), pickerelweed (*Pontedaria cordata*), cordgrass (*Spartina bakerii*), bulrush (*Scirpus californicus*), and cattail (*Typha latifolia*).

The goal of the pilot study was to obtain design criteria for full scale implementation and to assess the critical effluent parameter removal or reduction potential of such a system under different design and loading rates. The variables tested were hydraulic loading rate (HLR): 2 - 30 cm/day, theoretical hydraulic retention time (HRT): 0.3 - 35 days, mass loading rates for the various effluent parameters, depth of inundation: 0 - 60 cm, nitrification pretreatment and the presence of deep zones.

The pollutant removal efficiency ranged as follows: five day biochemical oxygen demand (BOD_5): 36 - 77%, total suspended solids (TSS): 72 - 90%, NH_3: 8 - 96%, total nitrogen (TN): 37 - 79%, and total phosphorus (TP): 26 -78%. Removal efficiency for these parameters was found to be inversely correlated to HLR, while the removal of total dissolved solids (TDS) and color was only weakly correlated with HLR. Significant reductions in alkalinity, soluble total organic carbon ($_{S}TOC$), TDS, color and conductivity were achieved only in the two cells which received the lowest HLR's. TDS and color mass removal rates were most dependent on HRT. The color mass removal at a HRT of 20 days was between 30 and 50%. Nitrification pre-treatment resulted in significantly reduced outflow concentrations of NH_3 and TN, and increased DO. Adsorbable organic halide (AOX) was reduced by an average of 50% during the first quarter of operation.

Bioassays of the fathead minnow (*Pimephales promelas*) and the cladoceran (*Ceriodaphnia dubia*) were conducted to determine toxicity characteristics of the wetland influent and effluent. No acute toxicity was associated with the inflow from ASB 2 and the chronic toxicity was reduced to near zero in most cases by wetland treatment. Cells with deep zones reduced chronic toxicity more efficiently than those without.

Sediment and plant and fish tissue samples from the pilot marsh were analyzed for metals, dioxin, and extractable organic halide (EOX). No harmful accumulation levels were reported in the biota samples and it was assumed that near steady state concentrations existed.

Of the plant species tested, bulrush and cattail were the most successful, but all of the ten planted species except for canna, maidencane and arrowroot grew well under effluent inundation. 29 invading plant species were identified. The wetland developed a rich diversity of macroinvertebrates and was utilized by many bird species as well as other wildlife.

Some interface studies have considered the use of paper mill effluent for spray or flood irrigation of forest plantations. Irrigation of an intensely cultured plantation of *Salix* and *Populus* with paper mill effluent led to *Populus* growth rates of 1.8-2.1 m/year and *Salix* growth rate of 90 cm/year (Hansen, et al., 1980). In this experiment the rate of irrigation was approximately 28 cm per week of secondary treated groundwood and kraft process effluent. After two years, samples were taken from water percolating through the sandy soil and quality was better than the tertiary treated effluent normally discharged by the mill. However, one potential concern noted was the transmission of most Na, Cl, and SO_4 to the groundwater table.

Once a broader information base is established on tertiary treatment of pulp and paper mill effluent with natural systems through pilot studies it is possible that this ecological engineering approach to wastewater treatment may be accepted by the industry as a cost effective component of an overall strategy for compliance with environmental regulations.

Study Sites and Their Operation

Two study sites were involved in this research project. (1) A pilot tertiary effluent treatment marsh operated by

CH2M-Hill for the Champion paper mill located in Cantonment, FL. (Figure 2,3) (see previous section for review of recent studies there. (2) The Rice Creek forested swamp floodplain in Palata, FL, where effluent from the Georgia Pacific mill was discharged in the past (Figures 4,5).

Champion Artificial Wetland

In 1991, in order to improve wastewater quality for discharge into receiving waters, an artificial wetland was constructed near Pensacola by Champion International and CH2M-Hill (environmental consultants). The Class III water quality criteria which are of concern are ammonia, dissolved oxygen, transparency, conductivity, zinc, and iron. Available in process and end of pipe alternatives were considered for effluent quality improvement. NCASI, three environmental consulting companies, and Champion's own environmental staff were involved in evaluating options. A report was prepared on several engineered capital intensive treatment systems including ultrafiltration, carbon adsorption, ammonium ion exchange, alum coagulation, and lime treatment (Sirrene Environmental, 1990).

In the 1991 - 1992 study in Pensacola, CH2M-Hill was testing a pilot nitrification plant in series with a pilot constructed wetland.

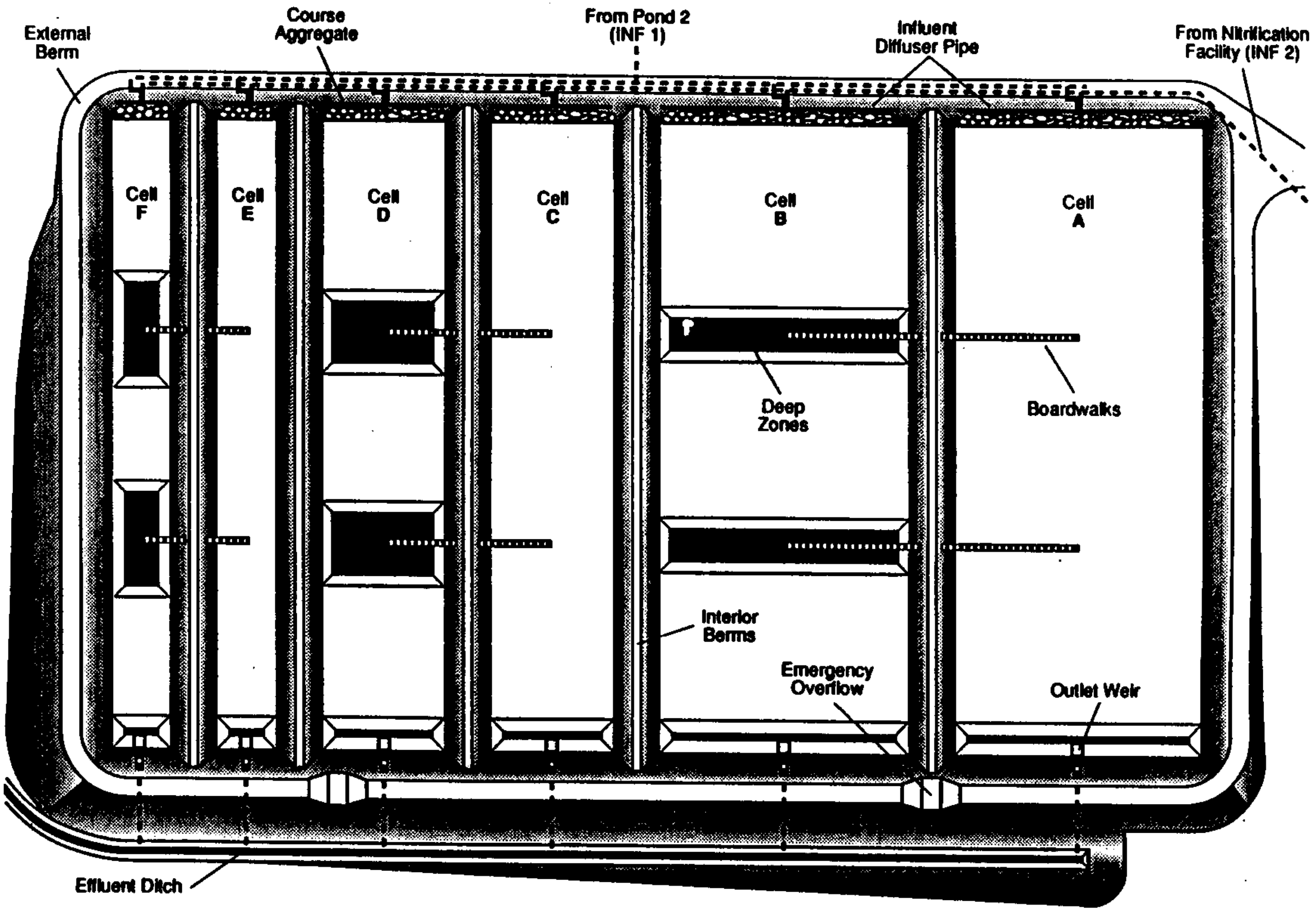


Figure 2. Pilot Wetland Plan View. Champion Corp. Cantonment, FL. (CH2M-Hill, 1990).

Figure 3. Pilot Wetland. June 6, 1991 (start up). Champion Corp., Cantonment, FL.

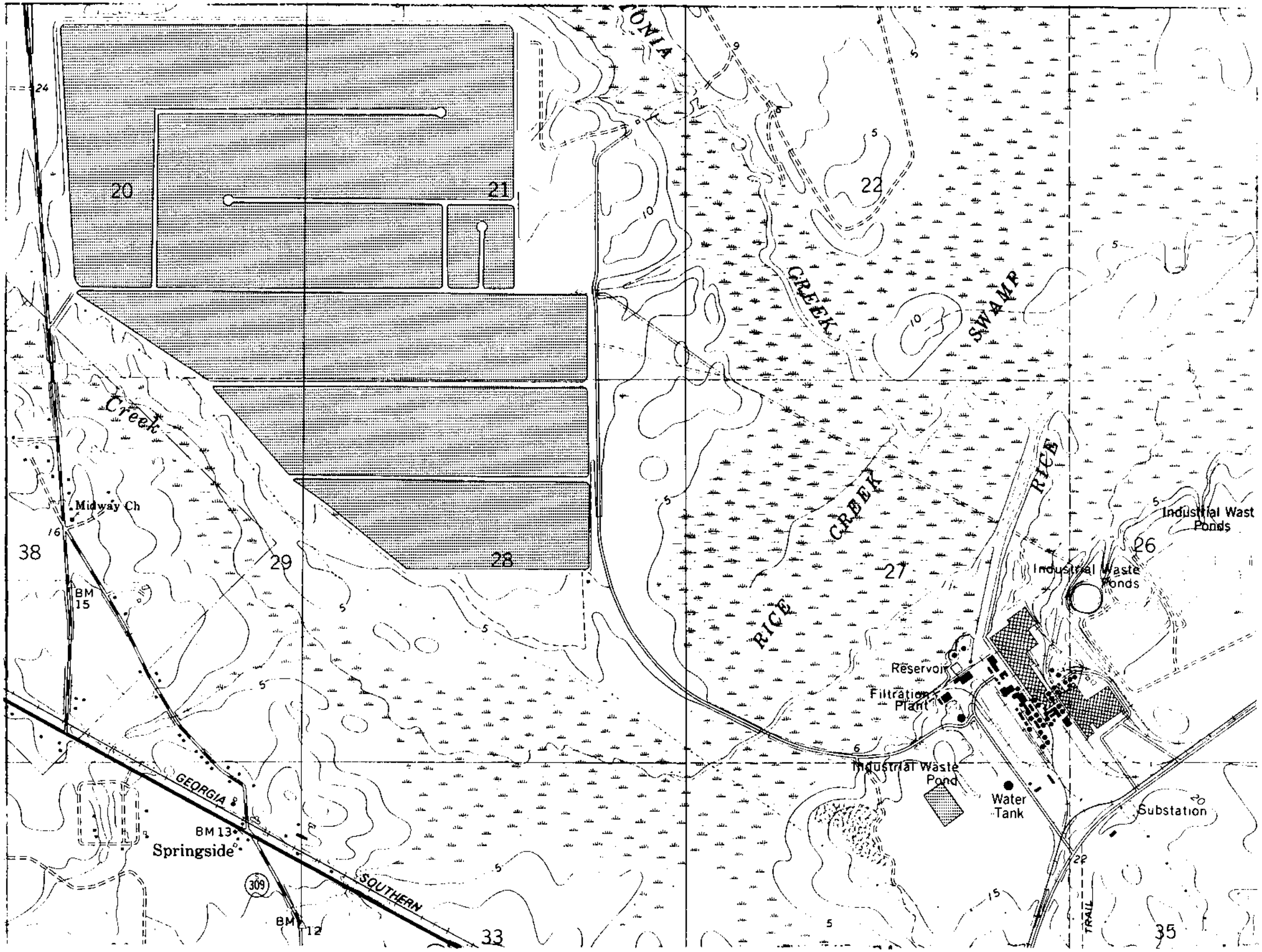


Figure 4. Rice Creek Site Map. Palatka, FL.

Figure 5. Rice Creek Swamp. July, 1992. Palatka, FL.

Although the pollutant removal efficiency and positive ecological impacts of wetland tertiary treatment systems for municipal effluent have been well documented (EPA, 1988), little was known specifically about the feasibility of wetland treatment for secondary effluent of pulp and paper mills. CH2M-Hill analyzed seven different natural land treatment alternatives including zero discharge rapid infiltration land application, and both natural and created wetland treatment with subsequent discharge to surface waters.

The climate in the panhandle of Florida is temperate, with warm humid summers and mild winters. The average temperature is 20 degrees C and average annual rainfall is 1.57 m, with a peak occurrence between June and September.

The Champion effluent was from a bleached kraft process. Integration of oxygen delignification and chlorine dioxide substitution in pulp processing increased the recovery of process chemicals and reduced the organic load in effluent. Effluent treatment consisted of a primary settling pond followed by consecutive aerated stabilization basins (ASB). With the exception of polyamine treatment used in primary settling, this system is the most commonly used effluent treatment process among paper mills in the Southeast.

The pilot marsh was constructed in a high clay soil with extremely low permeability. Approximately 15 cm of topsoil were added to the wetland cells. Mill effluent from ASB 2 was pumped into a pilot marsh on the site for one year under various loading rates and cell configurations. The herbaceous community was allowed to self organize after the initial planting of 10 species. Figure 6 is a profile of pilot wetland Cell C and Cell D including plant community zones.

Rice Creek Floodplain Site

The Rice Creek drainage area near the current Georgia Pacific secondary effluent discharge in Palatka, FL was chosen to study the impact of historical effluent inundation on vegetative community development. The mill has been in operation since 1947 and in the past it discharged effluent from it's 900 acres of secondary oxidation ponds to forested wetlands along Rice Creek. The mill presently discharges directly to Rice Creek through a channel from oxidation pond 4. The channel was constructed to improve dissolved oxygen levels in receiving waters. In addition, the mill currently injects liquid oxygen into Rice Creek at three locations beyond the discharge. Rice Creek drains into the St. Johns River shortly beyond the mills location.

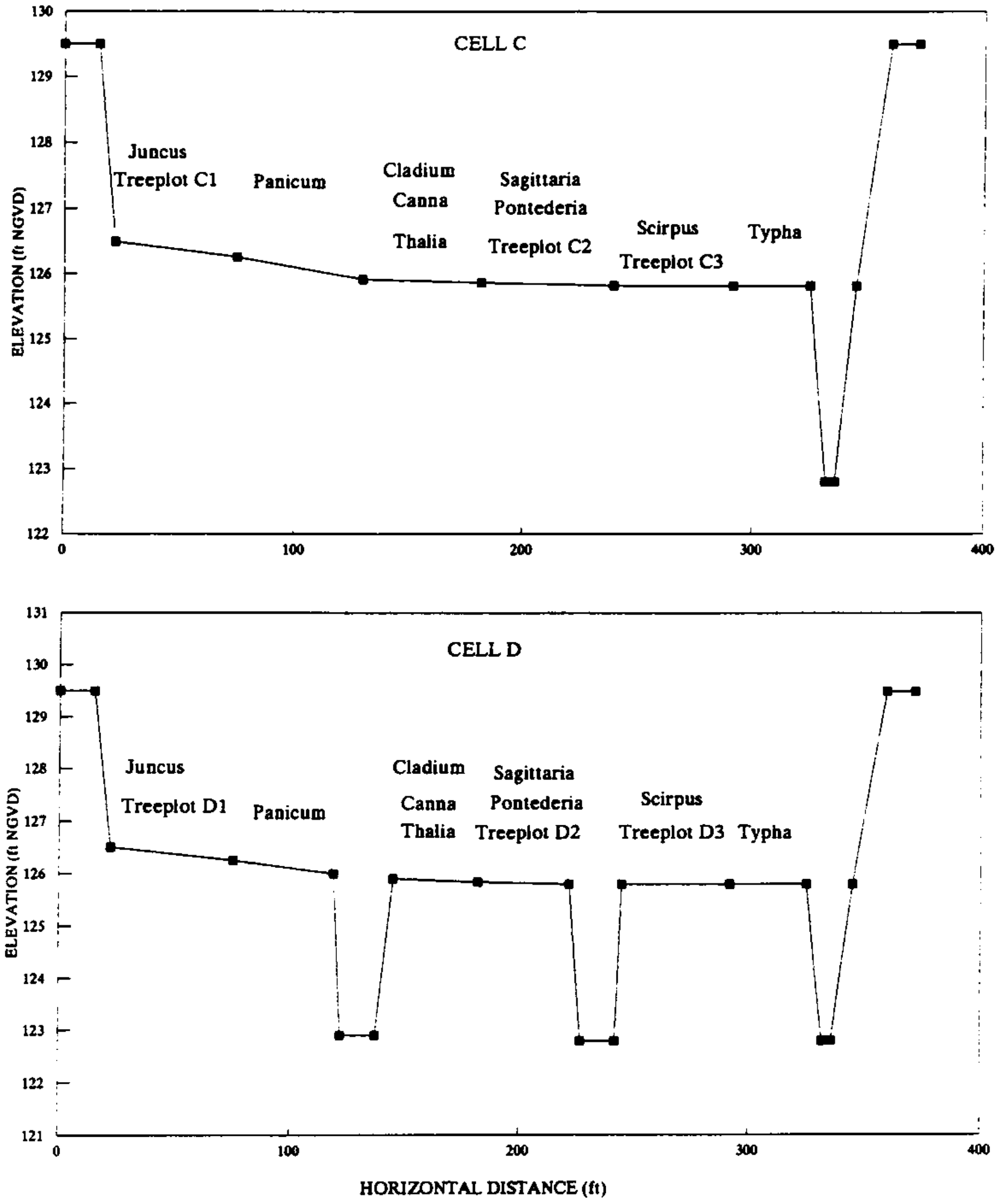


Figure 6. Pilot Wetland Vegetation Profile. Cell C and Cell D.

Two soil types are described in this area of the Rice Creek floodplain by the U.S. Geological Survey Soil Survey for Putnam County: Riviera fine sand - frequently flooded and Terra ceia muck - frequently flooded. Peat accumulation depths were up to 1.5 m. The study site was located far enough upstream to be beyond the area of tidal influence from the St. Johns River. Average depth of inundation in the floodplain measured in July, 1992 was 0.2-0.5 m, with a maximum depth determined by lichen lines of approximately 1.0 m.

Study Plan

This study was designed to integrate information from both study sites, making observations and theorizing on the prospects for natural and or constructed wetland effluent interfaces for the paper industry. The objectives of the research conducted can be summarized as follows: 1) To determine the survival and growth rate of selected wetland tree specie seedlings in the Champion pilot marsh and relate this to possible system successional development. 2) To measure diurnal aquatic productivity and water chemistry within the pilot marsh under different cell configurations and make inferences about system metabolism and nutrient cycles. 3) To determine the water chemistry dynamics of the effluent - organic peat sediment interface of a mature forested wetland through both surface flow and infiltration using microcosm reactors. 4) To collect and present data on the structure, growth rate and diversity of the plant community in a forested wetland impacted by historical effluent inundation. 5) To present an industrial - environmental systems analysis comparing wetland interface discharge of paper mill effluent with technological tertiary treatment alternatives using the emergy method.

METHODS AND MATERIALS

Tests of Tree Seedling Survival and Growth in Pilot Marsh

560 tree seedlings, donated for use in this study by Pete Wallace of Wallace and Garren Environmental Consultants were delivered to the Champion constructed wetland site on June 4, 1990. 152 individuals of the following 4 species were included: bald cypress (*Taxodium distichum*), pond cypress (*Taxodium ascendens*), pop ash (*Fraxinus caroliniana*), and blackgum (*Nyssa sylvatica* var. *biflora*).

Six tree plots were planted in the wetland, three in cell C and 3 in cell D. The plots were located in each of the three slope zones on a gradient from wetland inflow to outflow within both cells and in the following three plant communities: *Juncus* zone, *Sagittaria* / *Pontedaria* zone, and *Scirpus* zone. Seedlings were planted on five foot centers to correlate with the two and one half foot centers used for the herbaceous species, expedite future monitoring and allow sufficient spacing for the one year monitoring program. A reference plot was planted outside the wetland, approximately 60 meters west of the northwest corner of the wetland. The plot receives sun all day and consists of the same high clay content soil type as the wetland. A sprinkler system was purchased to maintain soil moisture in the reference plot. Each of the seven tree plots was planted with 20 individuals of the four species located at random within the plots. A total of 80 individuals were planted in each plot.

Equipment used for tree planting and monitoring included three dibbles, 12 lengths of 1/2 in. PVC pipe and flagging tape, one 100 m and one 20 m tape measure, meter sticks, 100 m of hose and a sprinkler.

At the time of initiation for this study, the constructed wetland had already been planted with ten herbaceous wetland plant species at the end of April, and each cell was divided into six plant communities (see study sites). Mill effluent from the number 2 ASB was being pumped into the wetland at a low rate, approximately 40 gallons per minute (GPM) in cells A & B, and 20 GPM in the remaining cells. These flows were maintained until the end of June to allow the plants to become established. Average depth of inundation under this loading was 0-8 cm in the influent zone, 15-23 cm in the middle zone, and 23-30 cm in the effluent zone. Implementation of prescribed flow rates for the pilot study began on June 27, 1991.

Initial tree heights were recorded on June 6, 1991 to the nearest centimeter and entered into a Lotus spreadsheet designed to calculate average growth by species by plot, average height per species by plot, and mortality. The tree plots were monitored for growth and mortality three times in the 1991 growing season and twice in the 1992 growing season. The exact monitoring dates were: June 6, 1991, July 15, 1991, September 18, 1991, March 3, 1992, and April 20, 1992.

Aquatic Productivity with Diurnal Chemical Measurements

Beginning at 8:00 AM on July 16 a crew measured diurnal dissolved oxygen (DO), temperature, pH, and redox potential for approximately 25 hours at 43 points within the pilot marsh and at a reference location within the stormwater retention wetlands adjacent to aeration pond 4. The equipment used was supplied by CH2M-Hill and included a portable DO meter (YSI Model 57 #106, Probe Model 5739) and a portable pH meter (Orion Model SA235). The D.O. meter was calibrated with a Winkler Titration before use by CH2M-Hill's laboratory in Gainesville. The instrument was air calibrated before and after measurements were made at each sampling station. The pH meter was also calibrated at each station using two buffer solutions, pH 7 and 10.

Weather conditions on Tuesday, July 16 were characteristic for summer and ideal for determining aquatic productivity. Most of the day was sunny with the high reaching 34 degrees C. Some afternoon cloudiness set in around 3:00 PM but the site received no rain. Wind conditions were calm, reducing the significance of atmospheric diffusion of DO, which was not accounted for in calculations. Overnight lows reached 22 degrees C. Sunrise was at 5:58 AM and sunset was at 7:52 PM.

Diurnal measurements of DO, temperature, redox and pH were made from the two boardwalks in Cell C and Cell D and the reference station, with four replications at each station. In addition, depth profile readings of D.O. and temperature were made in the deep zones of cell D and the reference location at 7 cm, 15 cm, 30 cm, and 60 cm depths. Four replications were also made at each depth. Redox and pH readings were averaged over a depth of 7-15 cm at each of the five stations.

Readings were taken at two hour intervals for 24 hours with the exception of two three hour intervals during the middle of the night. The data was adjusted according to field calibration and entered into a Lotus spreadsheet for plotting diurnal curves. Graphed curves of concentration or value of a parameter over time and rate of change of DO per square meter are presented. One rate of change curve for D.O. was derived from the depth profile curves at stations D1 and D2 (deep zones) using planimetry (Vollenweider, 1969).

The rate curves and the depth of the aquatic production profile at each station was used to calculate gross aquatic photosynthetic production and respiration. The area under the rate of change of D.O. curve (ppm/day) multiplied by depth yielded gross primary production ($g/m^2/day$) (Odum, 1956). Night respiration was calculated in a similar manner and subtracted from gross production to obtain a value for net primary production. See Figure 7 for aquatic production calculation methods. Diurnal pH and redox potential data from the pilot wetland and reference station (ten cm depth) were plotted in an Eh-pH diagram (Bass Becking, et al., 1960). Although there has been controversy concerning the use of empirical redox (Eh) data in drawing definite conclusions about chemical and biological characteristics of ecosystems, the data collected in this study fall within the area grouping on the Eh-pH diagram where reliable results can be expected using the platinum electrode in measurement (Faust and Aly, 1981).

Chemical Changes in Peaty Microcosms

To study the effluent - peat interface microcosm reactors were used. Two troughs were constructed (Figure 8) and six three meter infiltration columns (Figure 9) were already at the site, having been used in a CH2M-Hill soils study.

The troughs were constructed using 2 in. by 10 in. #2 SYP lumber and 5/8 in. BC plywood. One experimental and one control were implemented. Inside dimensions were 3.0 m by 0.6 m, resulting in a surface area of 1.8 m^2.

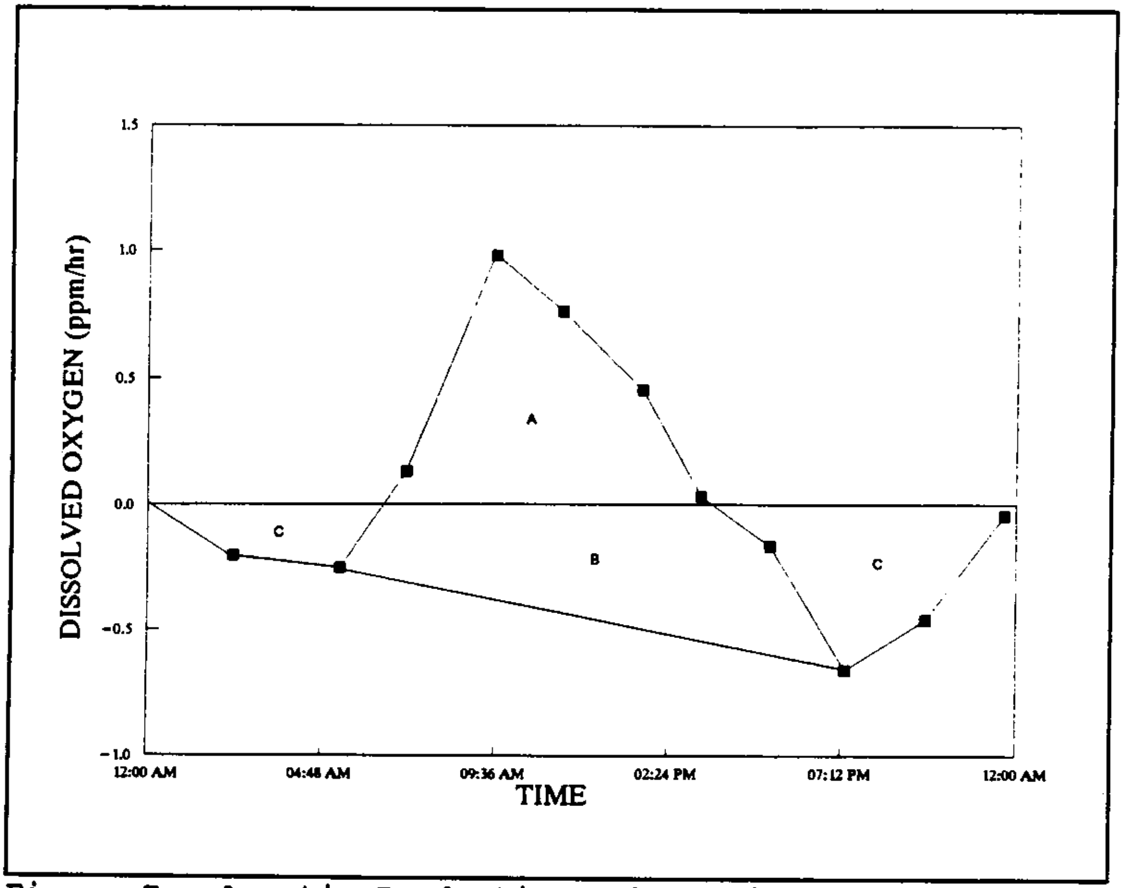


Figure 7. Aquatic Production Calculation Methods.
A + B * Depth = Gross Primary Production.
B * Depth = Day Respiration.
C * Depth = Night Respiration.

Figure 8. Experimental Trough Microcosm.

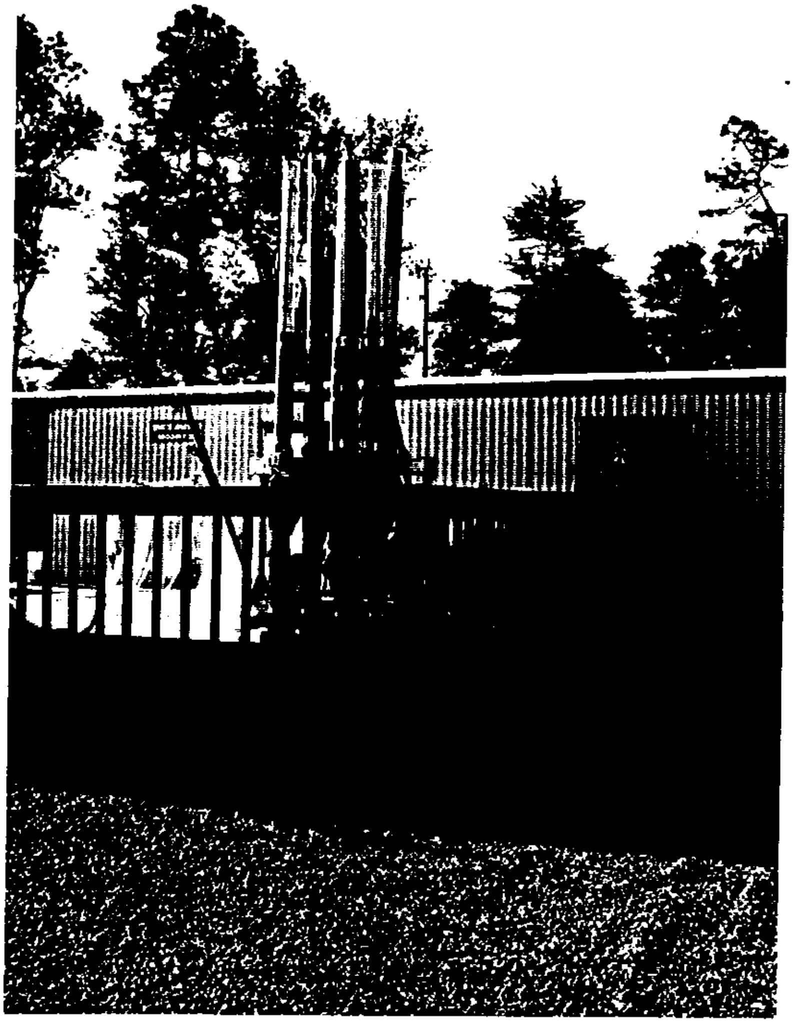


Figure 9. Infiltration Column Microcosm.

Design parameters were chosen to correlate with available drip irrigation fittings and flow rate alternatives and transport feasibility. A v-notch weir was cut to an equal depth at one end of each trough and fitted with a plastic overflow structure. The wood was treated with a water sealant and then the troughs were lined with double 6 mm poly liner.

Approximately 1.2 m^3 of peat were collected from a mixed swamp located on the Rainwater tract, the proposed site for full scale implementation of constructed wetlands to natural wetlands discharge. Keys were obtained from Champion to gain access to tram roads on the site. The chosen collection area is characterized by the following plant species: *Nyssa sylvatica* var. *biflora*, *Taxodium distichum*, *Taxodium ascendens*, *Smilax spp.*, and *Sphagnum spp.* Peat depth was measured at 2 m and consisted of both woody and fibrous peat. The color was dark black, indicating a high C/N ratio. Later lab analysis revealed a peat bulk density of 0.1 g/cm^3. The peat was collected manually with a spade in 5 gallon buckets and transported back to the site in 35 gallon plastic garbage cans. During collection an effort was made to obtain a representative profile of more and less decomposed material. Troughs were filled with peat to an approximate depth of 15 cm.

Drip irrigation hardware by Raindrip was used for hydraulic loading of both troughs. Components included:

3/4 in. hose to pipe thread adapters with screen filter, pipe thread pressure regulators, pipe thread to 1/4 in. tubing adapters, 1/4 in. plastic tubing, and 1/2 gallon per hour (GPH) drip heads. The effluent trough was located at the influent end of cell E directly below and parallel to the wetland influent pressure pipe, which pumps from ASB #2 of the mill's secondary effluent treatment system. This trough was loaded directly from the influent pressure pipe. One in. PVC pipe was glued into a ball valve drainage port on the pipe and routed through a 90 degree joint to a 3/4 in. faucet thread ball valve which connects to the drip irrigation setup. At a constant flow of 0.5 GPH the hydraulic loading rate (HLR) for the experimental trough was 2.5 cm./day and the theoretical residence time was 2 days.

The same loading hardware was used for the control trough only it adapted to a standard 3/4 in. hose and was loaded with tap water from the mill's own well. The control trough was located next to the pilot nitrification plant. Flow rate was the same as in the effluent trough, 1/2 GPH, equating to a HLR of 2.5 cm/day and a theoretical residence time of 2 days.

Clear PVC columns were used to asses the water quality impacts of infiltration through organic peat. Fortunately, a column setup was on the site, and soil infiltration studies related to a land application alternative being explored by CH2M-Hill had been completed. Use of the columns was granted by the CH2M-Hill scientists involved in the project. The apparatus consisted of eight clear PVC columns three meters in length and 10 cm inside diameter mounted on a wheeled frame with steel U braces and wing nuts. At the base of each column was a pressure plate with an internal plastic filter and a 3/4 in. hose thread outflow with a ball valve. A length of hose directed each column outflow to a separate enclosed bucket for collection. The columns were in two pieces connected by rubber sealed pipe clamps to allow for disassembly and handling. Before setting up this experiment, the apparatus was completely disassembled and cleaned.

Six columns were used in this experiment, three experimental and three control. The columns were prepared as follows: 5 cm of pool filter sand was added to prevent clogging of the drainage filter; peat was loaded in each column to a depth of 2 m; grey plastic was wrapped around each column to prevent excessive heating by the sun and algae growth. Columns 1-3 were loaded with 500 ml. of ASB2 effluent every Monday, Wednesday, and Friday and columns 4-6 received the same loading with tap water. Loading rates equated to a HLR of 2.7 cm/day. The loading was conducted manually by the full time operator of the CH2M-Hill lab at the site.

Baseline water quality monitoring was conducted one week after loading initiation and subsequent monitoring followed at one month intervals. Sample analysis for BOD, TSS, TP and color was supported by Champion's on site analytical laboratory. Analysis of TKN and NO_2-NO_3 was supported by NCASI, through PPB Environmental Laboratory in Gainesville. NH_3 and pH were measured by the author on site using Champion's mobile laboratory on the pilot wetland treatment site. Temperature measurements were made using a NBS certified thermometer at each sample location. pH measurements were made with an Orion Model 250A specific ion meter. The instrument was calibrated to the appropriate pH range and the slope recorded. Ammonia was measured using an Orion Model 720A ammonia selective electrode meter. The instrument was calibrated at 10, 1, and 0.1 mg/l and the slope recorded. NaOH was added to each 40 ml sample to bring the pH to 11 before analysis. Meter readings were accurate to 0.1 mg/l and readings below 0.1 mg/l are reported as <0.1 mg/l. Table 1 lists the parameters analyzed, collection, preservation, analytical method, and support labs.

Stand Characteristics, Growth Rate, Species Diversity in The Historically Effluent Inundated Rice Creek Floodplain Forested Wetland

In June, 1992 plant community data were collected from two sites along the Rice Creek Floodplain.

Table I. Peat Microcosm Water Chemistry Methods.

	Collection	Preservation	Analytical Method	Support Lab
BOD-5	(2) 500 ml Plastic	Cool to 4°C	Standard Method 5210	Champion
TSS	(2) 500 ml Plastic	Cool to 4°C	Standard Method 2540 D	Champion
Color	(2) 500 ml Plastic	Cool to 4°C	NCASI Tech. Bull. 253	Champion
TP	(2) 500 ml Plastic	Cool to 4°C	SM 4500-PB	Champion
NH_4-N	(1) 125 ml Plastic		Standard Method 4500-NH_3 F	Peter Keller on site
pH	(1) 125 ml Plastic		Standard Method 4500-H	Peter Keller on site
TKN	(1) 125 ml Plastic	H_2SO_4 to pH <=2; Cool to 4°C	EPA-600/4-79-020	NCASI/PPB
NO_2/NO_3	(1) 125 ml Plastic	H_2SO_4 to pH <=2; Cool to 4°C	EPA-600/4-79-020	NCASI/PPB

Three Plots measuring 20 by 10 m were laid out at random in both the experimental and reference sites. The experimental plots were located in an area of the floodplain where mill effluent had been discharged prior to 1985, directly south from the southeast corner of oxidation pond 4 and approximately 200 m upstream of the mill's present channelized discharge (see Study Sites). The reference plots were located upstream from any historic effluent discharge in the Rice Creek floodplain beyond the zone of tidal influence from the Saint Johns River. The area was between Bardin Road and the southwest facing side of oxidation pond 2.

All tree and shrub species in each plot above 1 cm diameter breast height (dBH) were identified and measured to the nearest centimeter. Tree cores were taken from 10 bald cypress individuals selected from the 3 plots in each site. Two cores were taken from each individual at 90 degree angles.

The forest data was entered into Lotus spreadsheets and summary graphs of stand characteristics produced. The diversity of tree and shrub species in each site was calculated using the Shannon - Weaver Diversity Index logarithmic base 2. Tree cores were mounted and prepared according to methods described in Ewel and Parendes (1984). Annual rings were measured using a dissecting microscope and a caliper calibrated to 0.1 mm. The growth rates were averaged in four year increments for the past 40 years and converted to basal area growth increments using a formula described in Bray and Struik (1963).

Emergy Evaluation of Effluent Treatment Alternatives

An emergy evaluation was conducted to compare two tertiary treatment alternatives for pulp and paper mills. First, a energy circuit diagram was drawn (Figure 1) depicting the major inputs to the kraft pulp and paper process using technological tertiary treatment (granular media filtration, carbon adsorption and ammonium ion exchange) and using a wetland interface. The inputs to each process were listed in energy or mass units per oven dry ton of pulp (ODTP).

Energy or mass units were converted to emergy, a measure of "energy memory" or value defined as the sum of all available energy previously used to make a product or a service expressed in energy of one kind, solar equivalent joules (sej). The ratio of emergy to energy is termed transformity and has the units of solar emjoules per joule (sej/J). By this method all process inputs were put on a common basis for comparison (sej/ODTP). Transformities were calculated by summing all the environmental, fuel and service inputs to a product. Some transformities were taken from previous emergy evaluations (Odum, 1992a,b; Odum and Arding, 1991; Pritchard, 1992).

RESULTS

Tests of Tree Seedling Survival and Growth in Pilot Marsh

On April 11, 1991 flow of mill effluent to the Champion pilot wetland commenced. The flow levels were minimal and designed to allow the herbaceous plant community to establish before initiation of operational flow rates on June 27, 1991. Tree seedling plots were planted in Cell C and Cell D of the wetland on June 5 and 6, 1991. See Figure 6 under Study Sites for a profile diagram of both cells including vegetation zones and tree plots.

Morality and growth of the four species, bald cypress (*Taxodium distichum*), pond cypress (*Taxodium ascendens*), pop ash (*Fraxinus caroliniana*), and blackgum (*Nyssa sylvatica* var. *biflora*) are presented in Figures 10-15. The results from three monitoring periods are included. Monitoring period one was from planting, June 6, 1991 to September 18, 1991, representing initial survival and first season growth. Monitoring period two was from planting to April 21, 1992, the final monitoring event. Monitoring period three was from September 18, 1991 to April 21, 1992, representing winter mortality and second season initial growth.

Growth data between species, plots and cells for all monitoring periods were compared using Student's t Test statistics with a significance level of 0.05. Statistical results are presented in Appendix A.

Monitoring Period 1

Monitoring period 1 included three weeks of startup conditions, with the remainder of the period falling in the first operational phase of the experimental wetland, which was from June 27, 1991 to February 8, 1992. (CH2M Hill, 1992) The target flow rate for Cells C and D during this phase was 120 m^3/day. The actual average hydraulic loading rate (HLR) for the period was 4.81 cm/day. The depth of inundation, as controlled by the staging of outlet weirs was held constant in both cells during the first operational phase. The actual depths did vary as a result of precipitation and evapotranspiration. Average depth of inundation for individual tree plots was recorded during growth monitoring events. For operational phase one they were as follows: Plot C1, 0 - 4 cm; Plot D1, 0 - 4 cm; Plot C2, 8 - 12 cm; Plot D2, 12 - 16 cm; Plot C3, 12 - 16 cm; Plot D3, 12 - 16 cm.

Pond cypress had the highest growth averaged over all four wetland plots during monitoring period 1, 25.2 cm, followed by blackgum, 13.4 cm, bald cypress, 10.3 cm and pop ash, 6.1 cm (Figure 10(c)). When comparing Plot 1 growth to the Reference Plot, only pop ash showed significantly less growth in the wetland for Cell C and D, and blackgum grew more in Cell D Plot 1 than in the Reference Plot. (Figure 10(a,b)) All species grew significantly more in the Reference Plot relative to Plots 2 and 3 in the wetland, but only pop ash showed substantial growth reduction under inundation. It's average growth was 6.1 cm in the wetland and 29.0 cm in the Reference Plot (Figure 10(d)). This was indicative of the low relative flood tolerance of the species.

All four species grew significantly more in Plot 1 than Plot 2 or 3 when the data from both cells was combined. This showed an inverse correlation between depth of inundation and growth during this period (Figure 10(a,b)). There was no significant difference between growth rate in Plot 2 and Plot 3 for both cells (Figure 10(d)). Competition by herbaceous species was not a major factor during monitoring period 1, as the communities were just becoming established. No distinct difference in growth between the cell totals was noted although bald cypress grew significantly more in Cell C, 12.3 cm vs. 8.4 cm, and blackgum grew significantly more in Cell D, 15.2 cm vs. 11.5 cm (Figure 10(c)).

Pond cypress had the highest seedling mortality within the wetland during monitoring period 1 (Figure 11(c)).

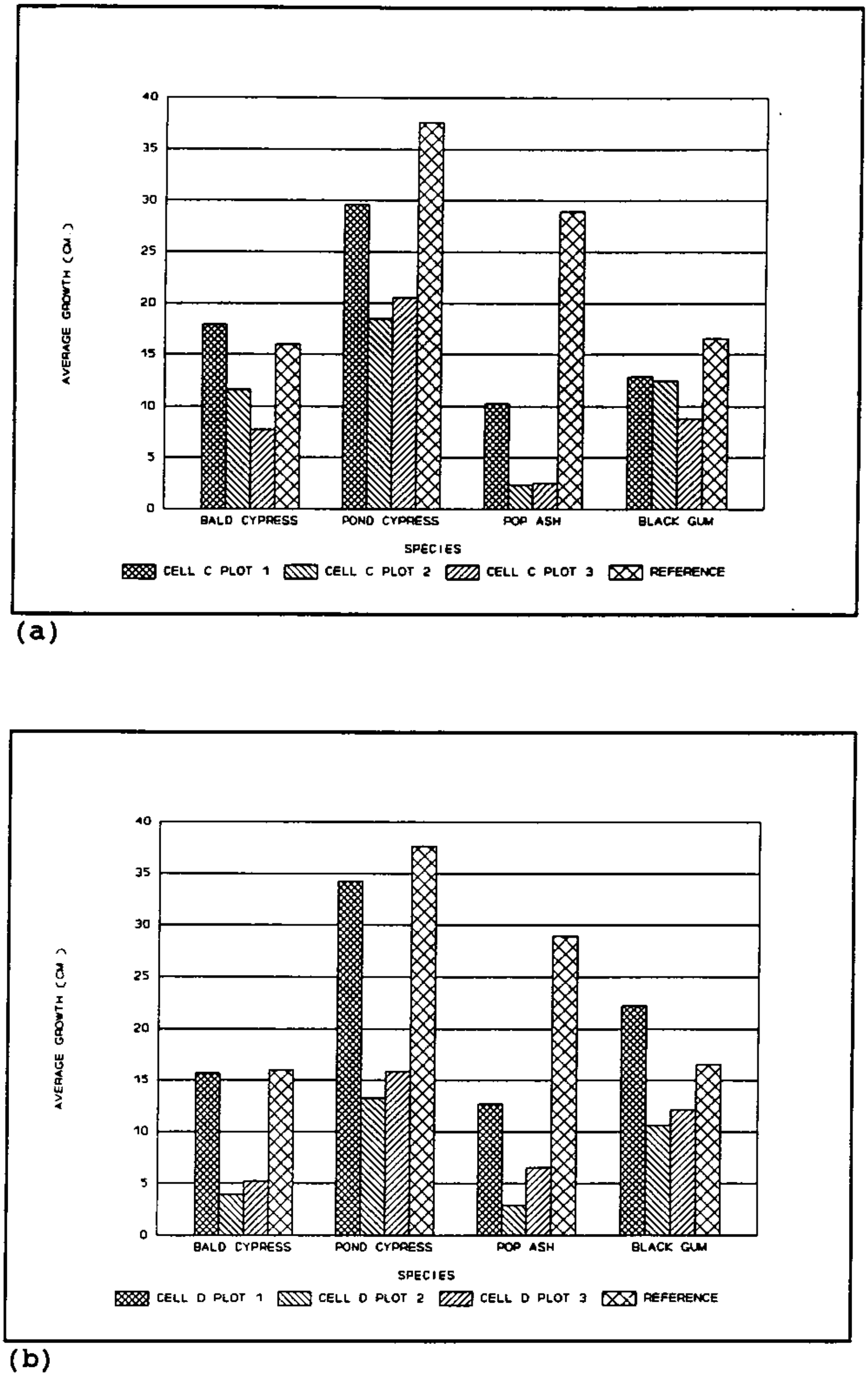
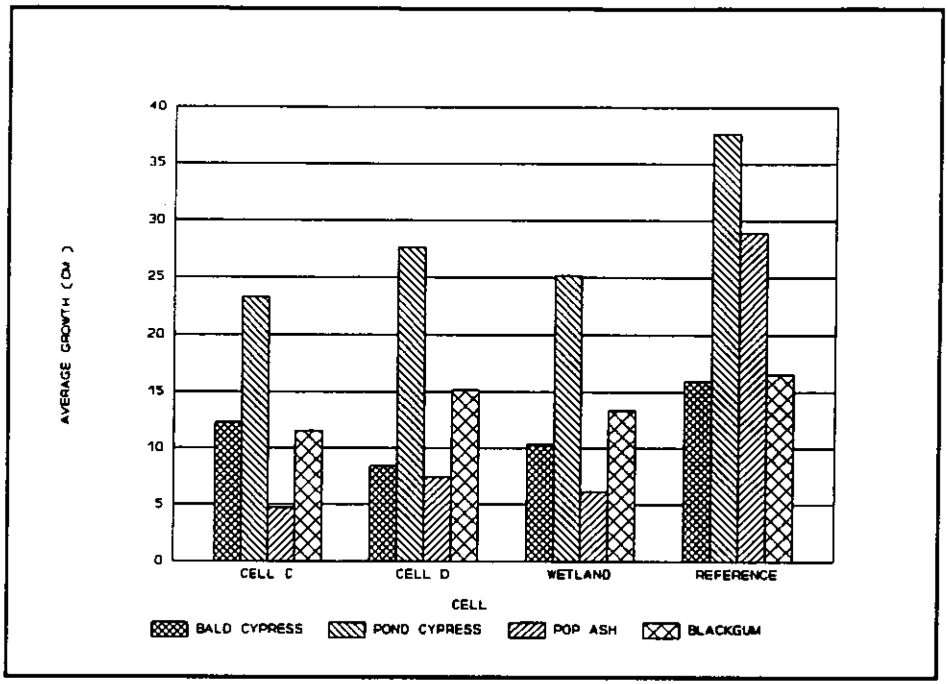


Figure 10. Average Seedling Growth 6/6/91 - 9/18/91. a) Cell C and reference; b) Cell D & reference; c) Total by cell; d) Total by plot.



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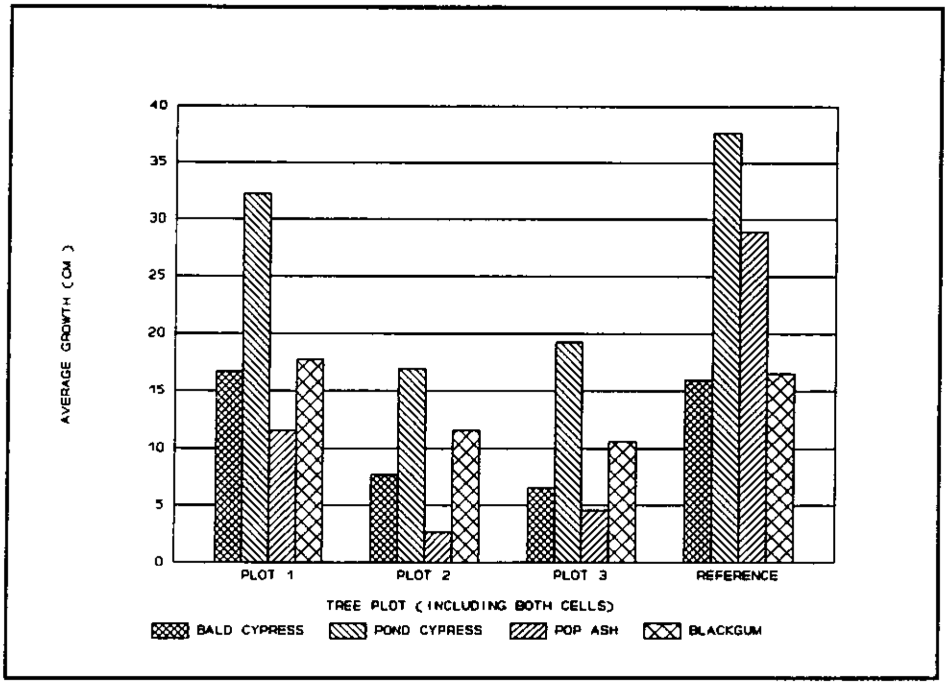

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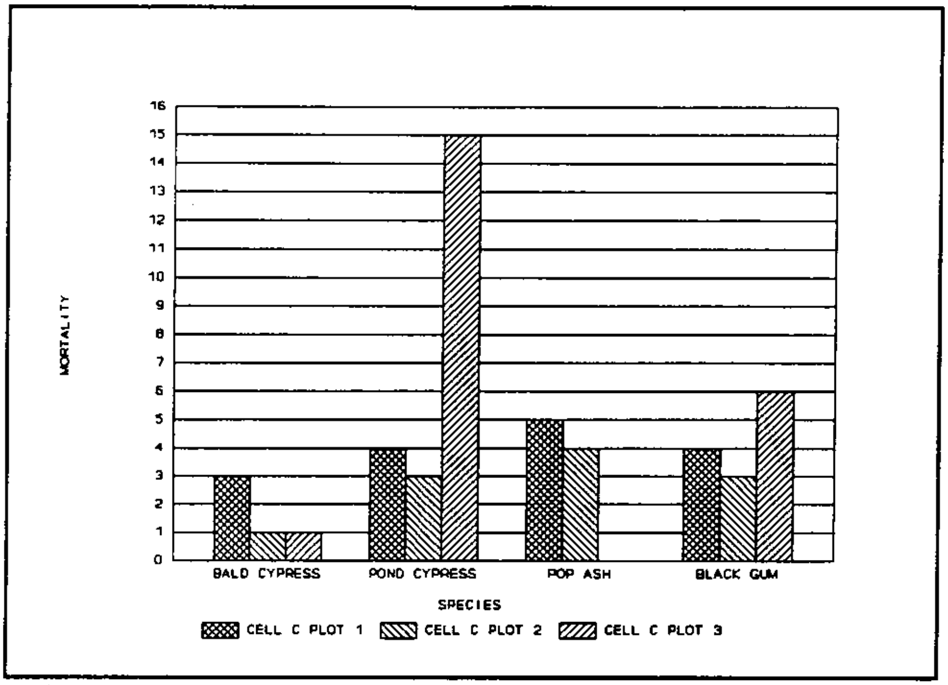
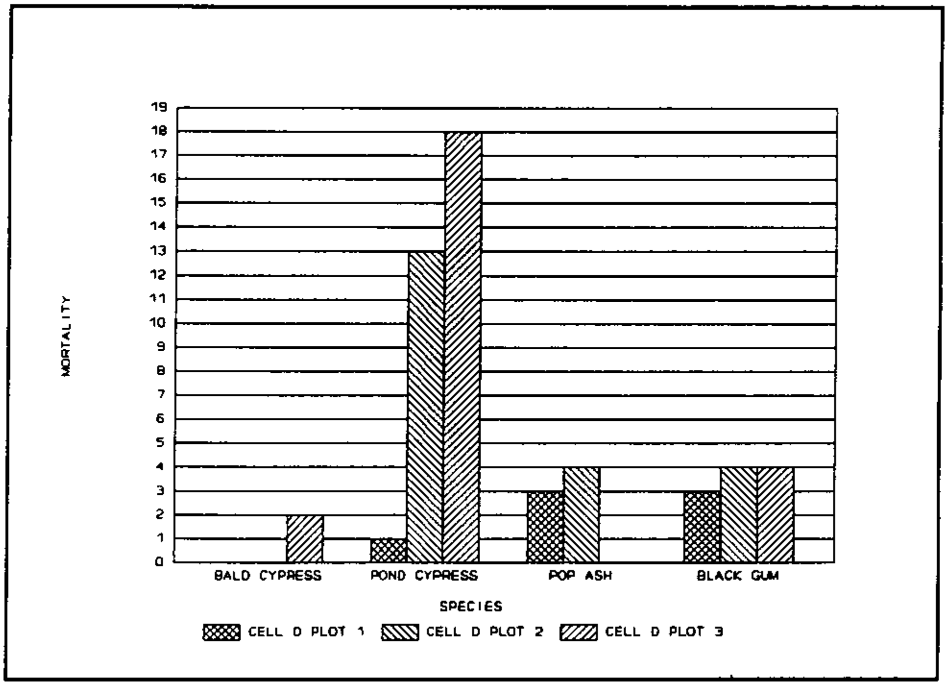
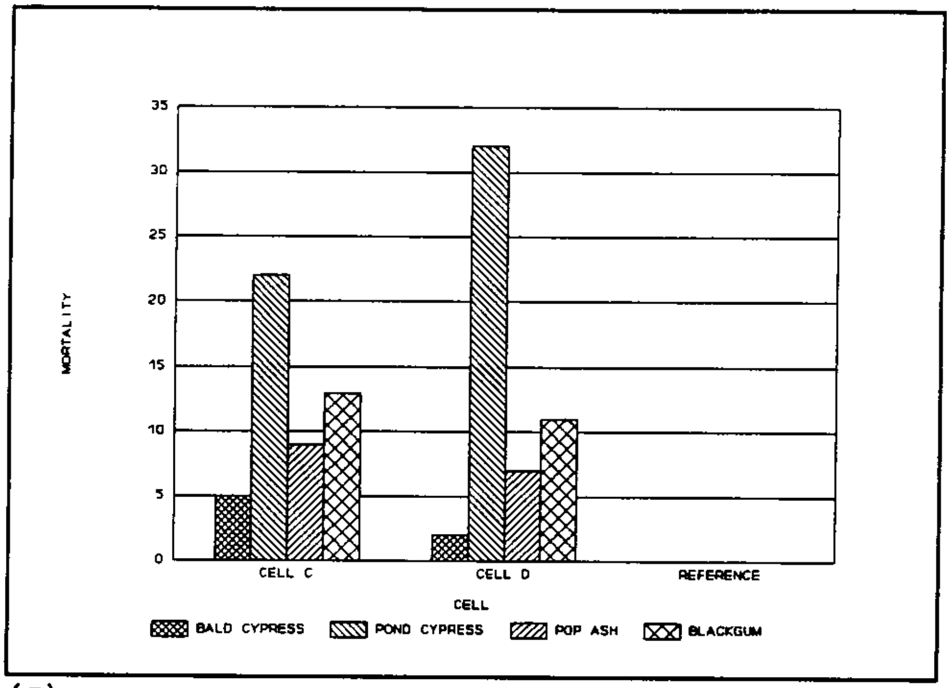


(a)



(b)

Figure 11. Seedling Mortality 6/6/91 - 9/18/91. a) Cell C; b) Cell D; c) Total by cell; d) Total by plot.



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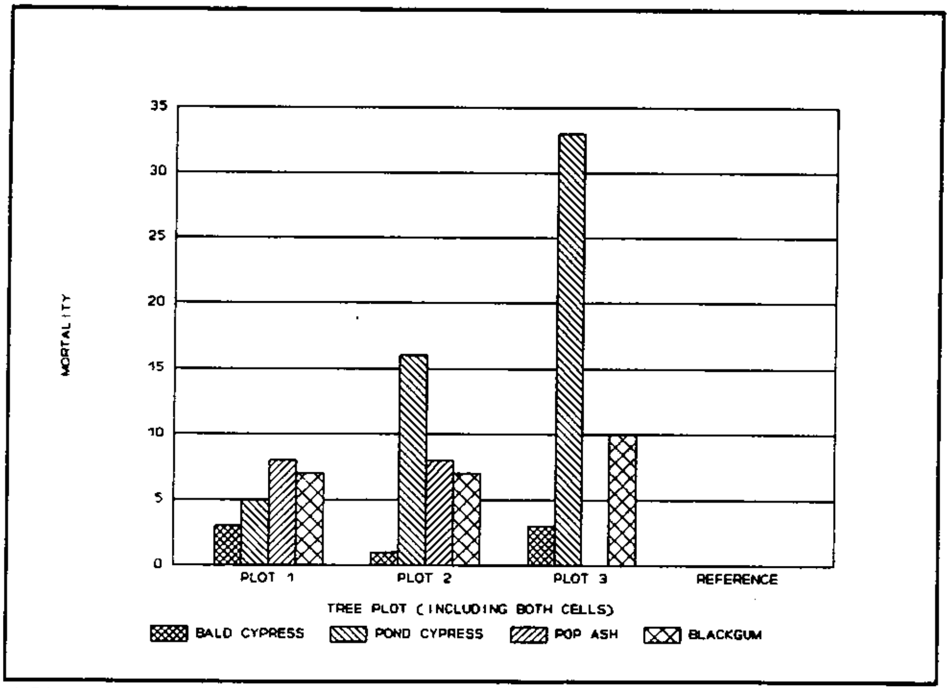


(d)

Figure 11. (continued).

There was no mortality for all species in the Reference Plot. Mortality during this period was correlated with depth of inundation and initial seedling height. The correlation of seedling mortality with depth gradient by plot is shown in Figure 11(d). The initial height of pond cypress at planting was the lowest, 38.3 cm, followed by blackgum, 47.2 cm, pop ash, 49.5 cm and bald cypress, 54.9 cm.

Monitoring Period 2

The second monitoring period recorded seedling growth and mortality trends over the entire duration of the study, from planting through April 21, 1992. The period included the first and second operational phase of the wetland. Conditions under the second operational phase were decreased flow rates, 60 m^3/day for Cells C and D, and increased depths due to the raising of outlet weirs in all cells by approximately 21 cm. The second wetland operational phase commenced on February 9, 1992. On February 24, 1992 Cell D influent was replaced by effluent from the pilot nitrification plant which CH2M Hill was testing. The increased weir elevations corresponded to the following depths of inundation for tree plots: Plot C1, 14 - 18 cm; Plot D1, 14 - 18 cm; Plot C2, 26 - 30 cm; Plot D2, 28 - 32 cm.

Plot 3 in both cells was not monitored in the second growing season due to the prolific growth of bulrush. Storm conditions had caused the bulrush to lay down, making location of tree seedlings in these plots impossible. Probable survival of seedlings in Plots C3 and D3 was near zero.

Pond cypress exhibited the highest growth over the entire study in the wetland and reference plots (Figure 12(a,b)). In all wetland plots the relative growth of the four species for the period was as follows: Pond cypress, 38.8 cm; blackgum, 27.1 cm; bald cypress, 20.3 cm; and pop ash, 18.1 cm (Figure 12(c)). In the Reference Plot, pond cypress and pop ash grew the most, 40.8 cm and 35.6 cm respectively, followed by blackgum and bald cypress at 20.8 cm and 19.2 cm. Growth in the wetland relative to the Reference Plot was greater than for monitoring period 1. Only pop ash grew significantly more in the Reference Plot than in the wetland, and blackgum showed significantly greater growth in the wetland (Figure 12(c)).

Again there was a strong correlation between plot number and growth rate in both cells. All species except pond cypress grew significantly more in Plot 1 than Plot 2 (Figure 12(d)). Pop ash and blackgum were the species most retarded in growth by the increased depth of inundation in Plot 2, both having grown 16 cm more in Plot 1 (Figure 12(d)).

Differences in seedling growth between cells were minimal and only blackgum showed significantly higher growth in Cell D than Cell C (Figure 12(c)). The difference can probably be attributed to patchy invasion of dense cattail and eel grass (*Eleocharis* spp.) in Plot 1 and pennywort (*Hydrocotyle* spp.) in Plot 2.

Competitive interaction with herbaceous species during the early second season was most prominent in Plot 1, where softrush and cordgrass were growing well and considerable invasion by cattail had occurred. Plot 2 in both cells was essentially devoid of herbaceous vegetation with the exception of duckweed (*Lemna* spp.) and some pennywort. This was due to the later growing cycle of *Sagittaria* and *Pontedaria* which were planted in this zone and the increased depth created for wetland operational phase 2, hindering invading emergent species.

Seedling mortality within the wetland during monitoring period 2 was highest for pop ash and pond cypress, followed by backgum and bald cypress (Figure 13(a,b)). Total mortality of pop ash occurred in Cell D Plot 2. The high mortality of pond cypress was attributed to it's low initial height, as some individuals in Plot 2 were nearly completely submerged under the depth regime of operational phase 2.

Mortality was correlated to plot number when the data from both cells was combined (Figure 13(d)). Differences in mortality between cells were also noted.

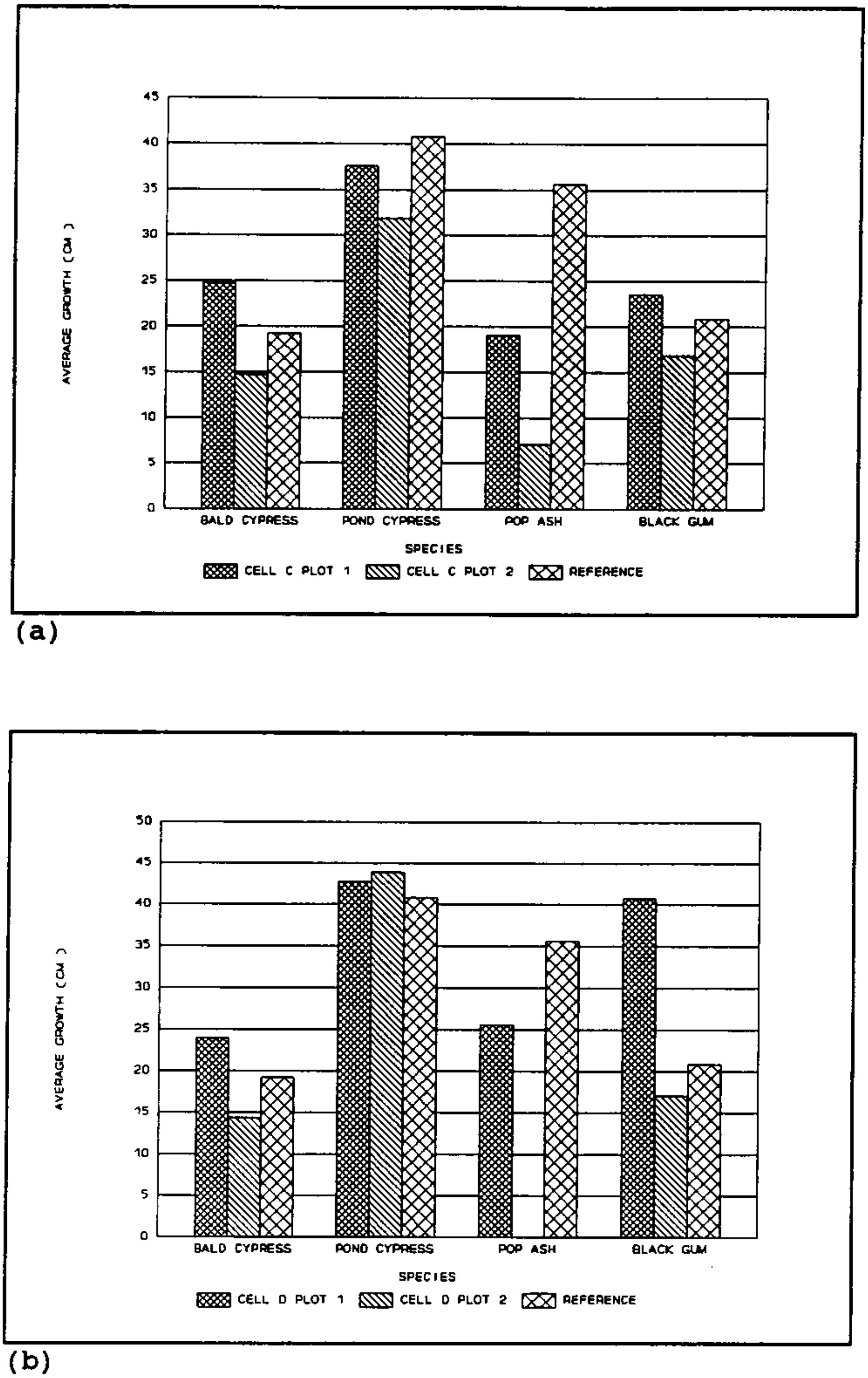
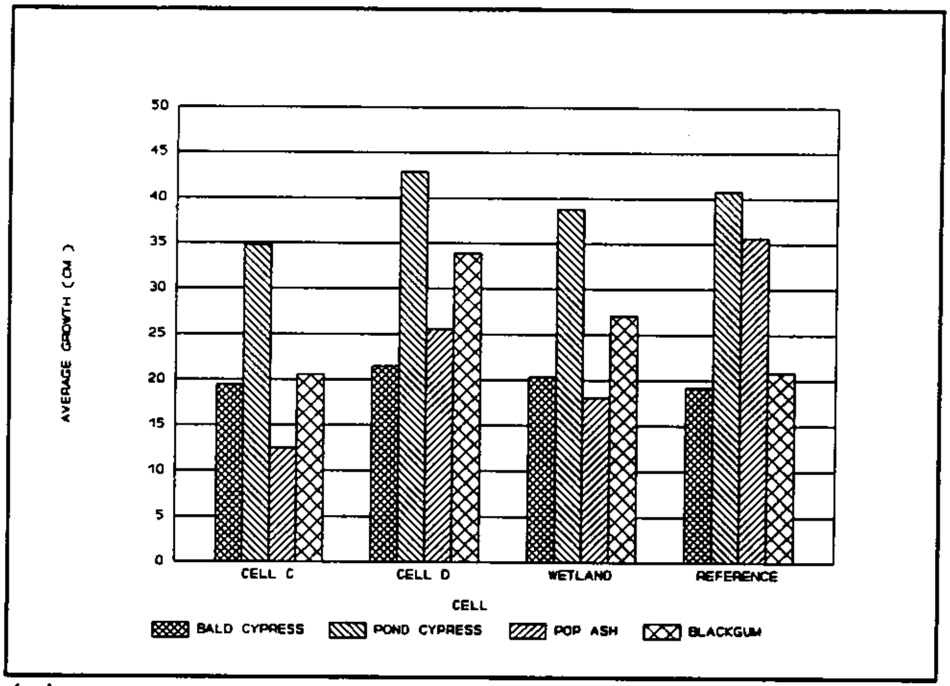


Figure 12. Average Seedling Growth 6/6/91 - 4/21/92. a) Cell C and reference; b) Cell D & reference; c) Total by cell; d) Total by plot.



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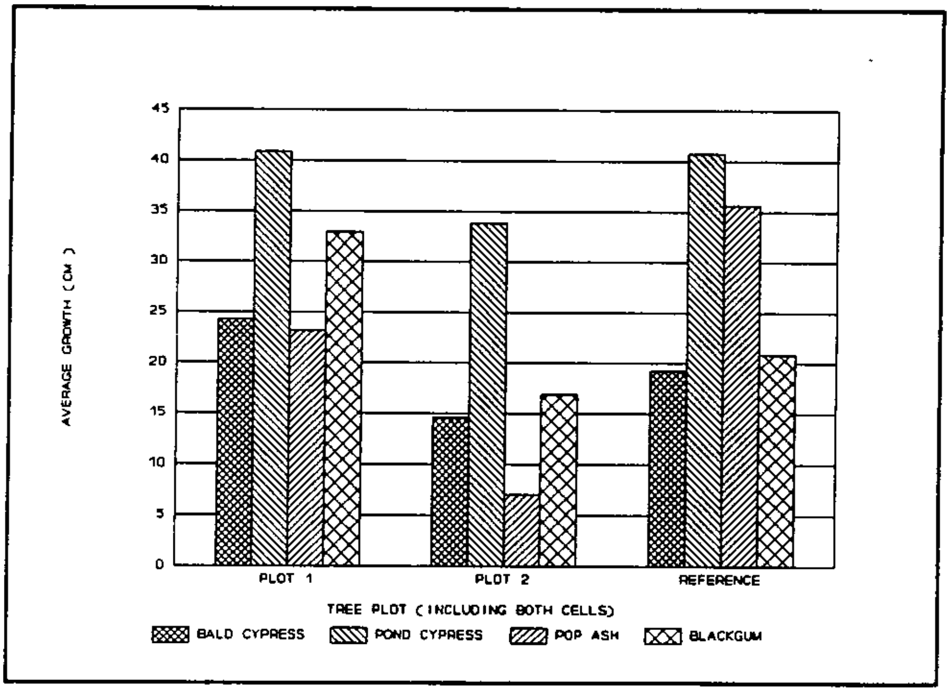

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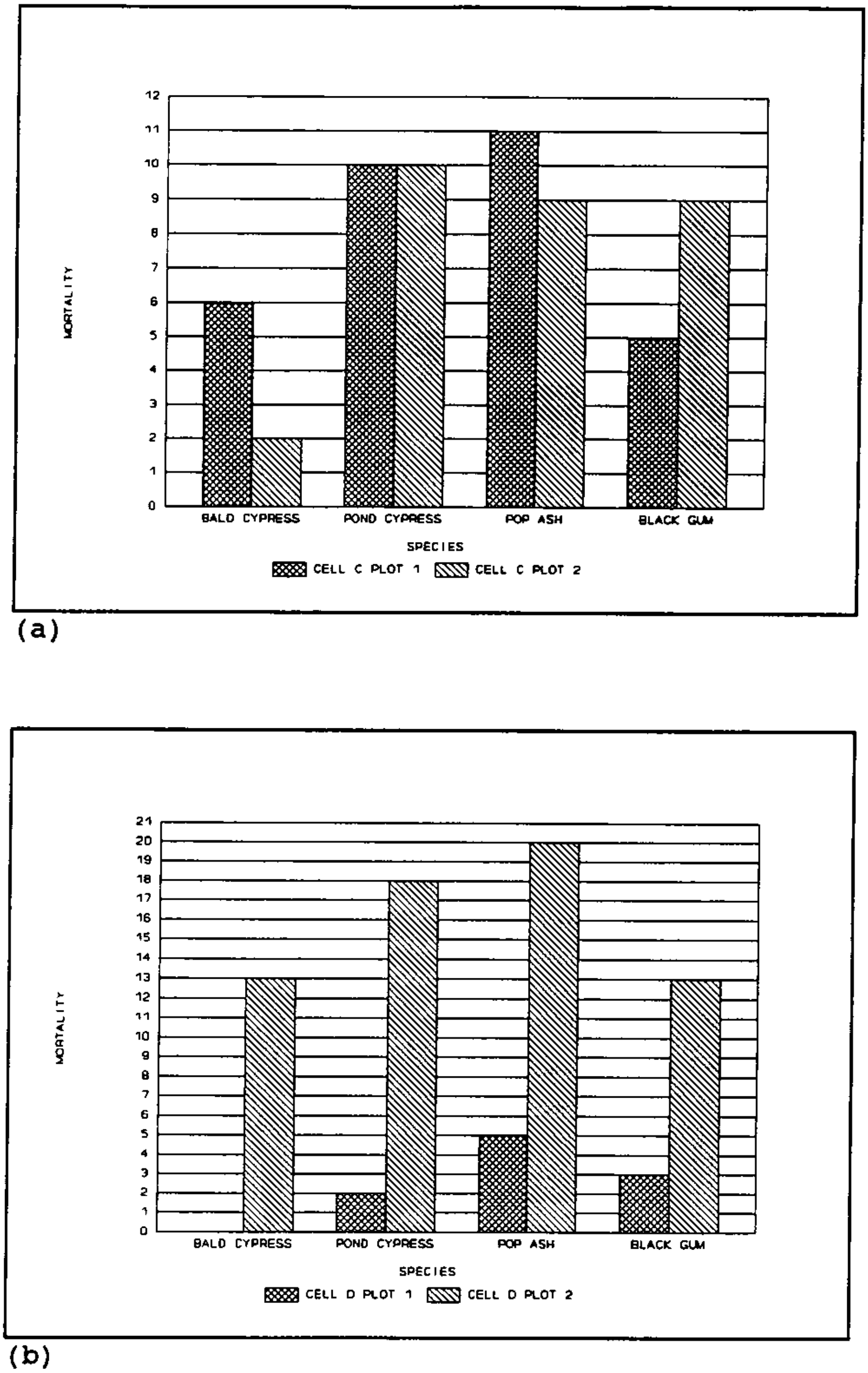
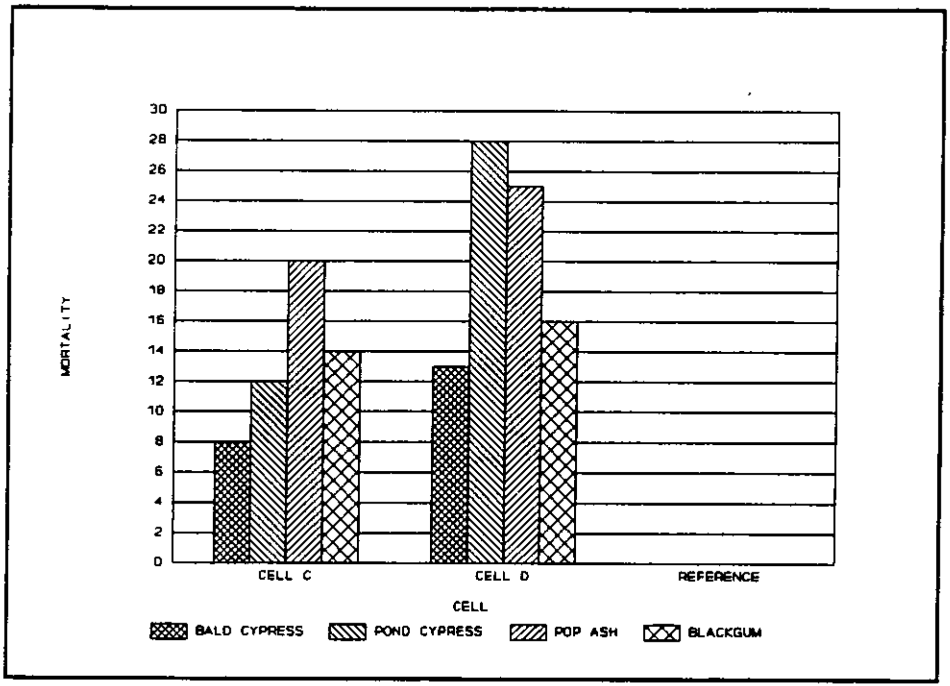


Figure 13. Seedling Mortality 6/6/91 - 4/21/92. a) Cell C; b) Cell D; c) Total by cell; d) Total by plot.



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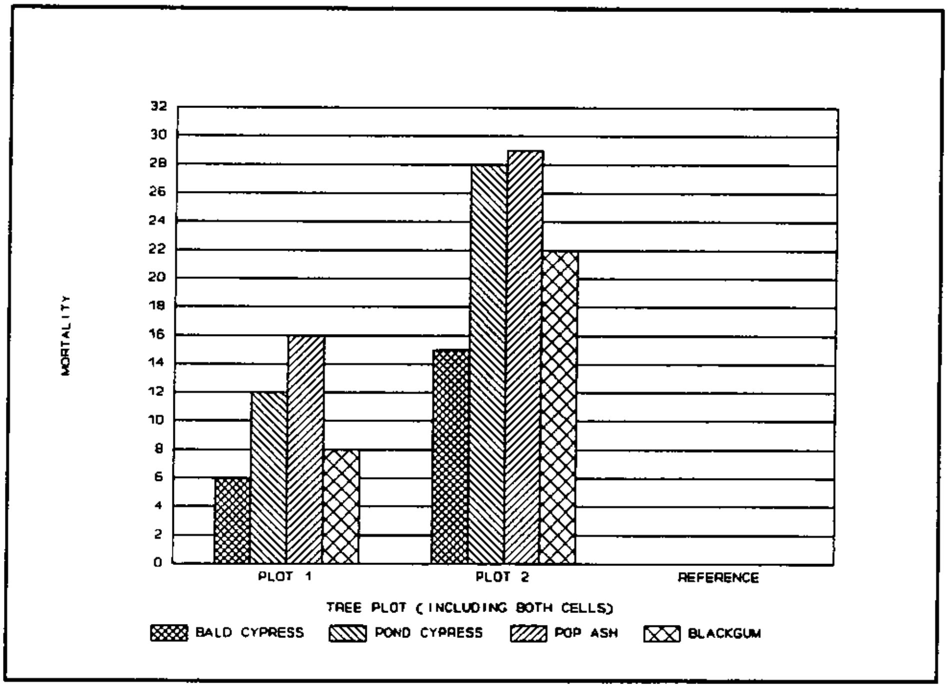


(d)

Figure 13. (continued).

Overall mortality was higher in Cell D than Cell C (Figure 13(c)). Cell C Plot 1 showed higher mortality than Cell D Plot 1 for all species. This can be attributed to the greater density and extent of invading herbaceous species, especially cattail, found in Cell C Plot 1 during the second growing season. Cell D Plot 2 had significantly higher mortality for all species than Cell C Plot 2. This may have been due to the slightly deeper inundation in Cell D Plot 2.

Monitoring Period 3

Monitoring period 3 examined the growth and mortality of the tree seedlings from September 18, 1991 through the end of the study, April 21, 1992. This data reflects the impact of the first winter and the initiation of wetland operational phase 2 as well as the early second growing season trends.

Blackgum showed the highest growth in the wetland during this period, 10.9 cm, followed by pond cypress, 8.4 cm, pop ash, 7.9 cm and bald cypress, 6.5 cm (Figure 14(c)). All species showed significantly higher growth in the wetland than in the reference plot, while only pond cypress grew significantly more in wetland Plot 2 than in the Reference Plot (Figure 14(d)). In the Reference Plot, pop ash showed the greatest growth, 6.7 cm, followed by blackgum, 4.9 cm, bald cypress, 5.4 cm and pond cypress, 5.4 cm.

Pop ash and blackgum initiated growth earlier than the cypress species during the second growing season. Pop ash already had fully developed leaves on April 21, 1992, while cypress was still in the budding stage. This explains the apparently high growth rate of these hardwood species in monitoring period 3 as compared to the overall relationship.

Differences in growth between Plots 1 and 2 were less pronounced in monitoring period 3 due to the removal of unadapted individuals from the dada base through mortality and the increased competitive stress in Plot 1 from both planted and invading species. Only blackgum showed significantly higher growth in wetland Plot 1 compared with Plot 2 (Figure 14(d)).

No conclusive difference in growth between cells was noted in monitoring period 3 although blackgum, pond cypress and bald cypress showed marginally higher growth in Cell D (Figure 14(c)).

Seedling mortality during this period was considerable, reflecting the increased stage height initiated in February and the first winter. All species showed higher mortality in Plot 2 than Plot 1 (Figure 15(d)). Including all wetland plots, pop ash had the highest mortality, followed by pond cypress, bald cypress and blackgum. Bald cypress, pop ash and blackgum all showed higher mortality in Cell D than Cell C, possibly due to the slightly higher depth of inundation in Cell D (Figure 15(c)). Cell C Plot 1 produced higher mortality for all species than Cell D Plot 1, while Cell D Plot 2 produced higher mortality than Cell C Plot 2 for all species but pond cypress (Figure 15(a,b).

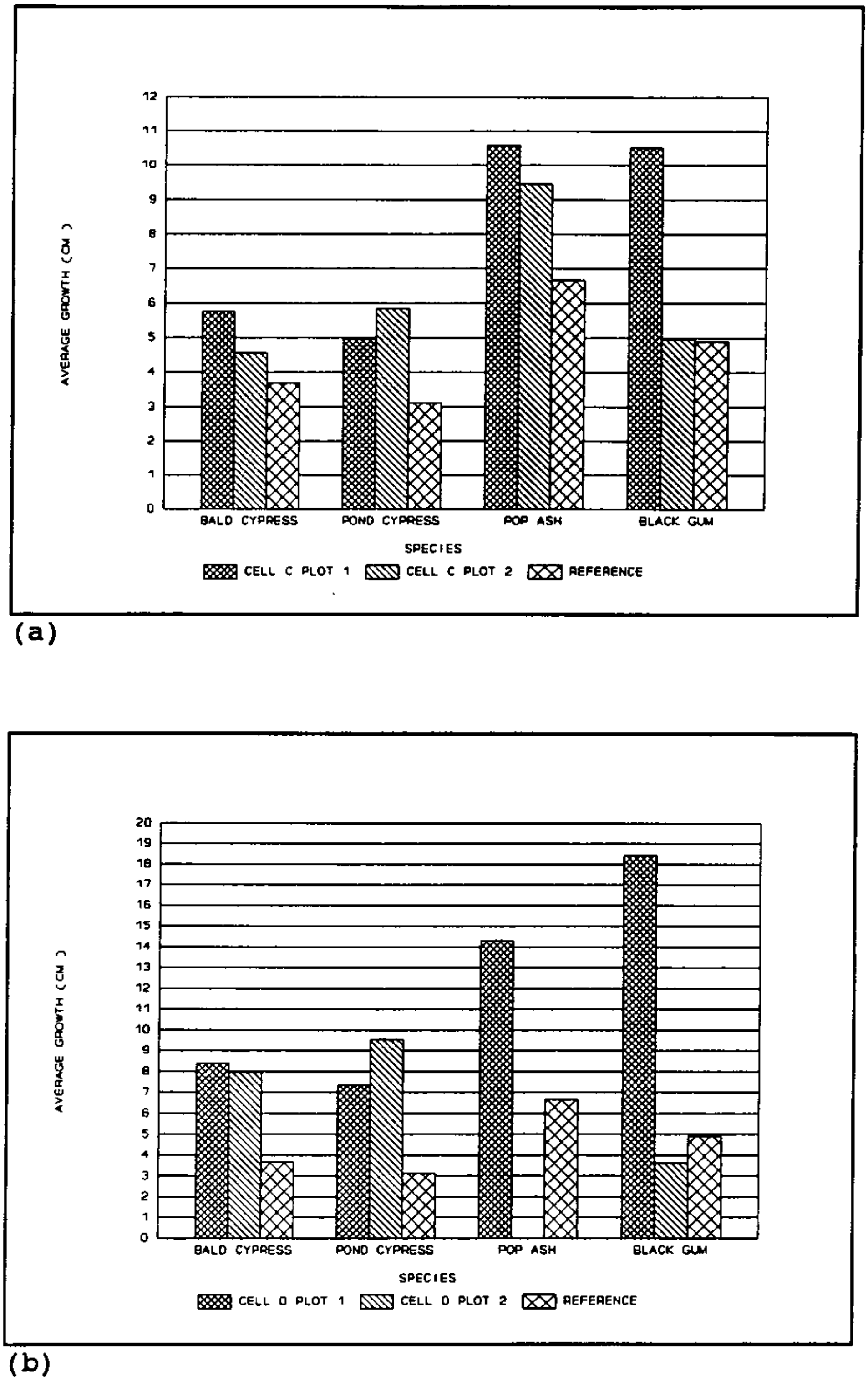
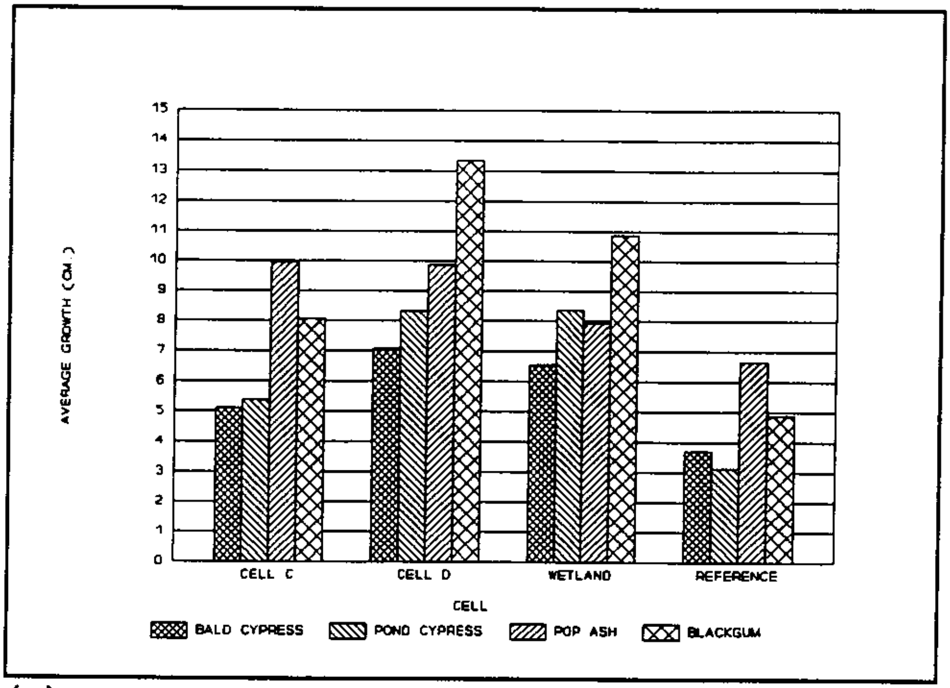
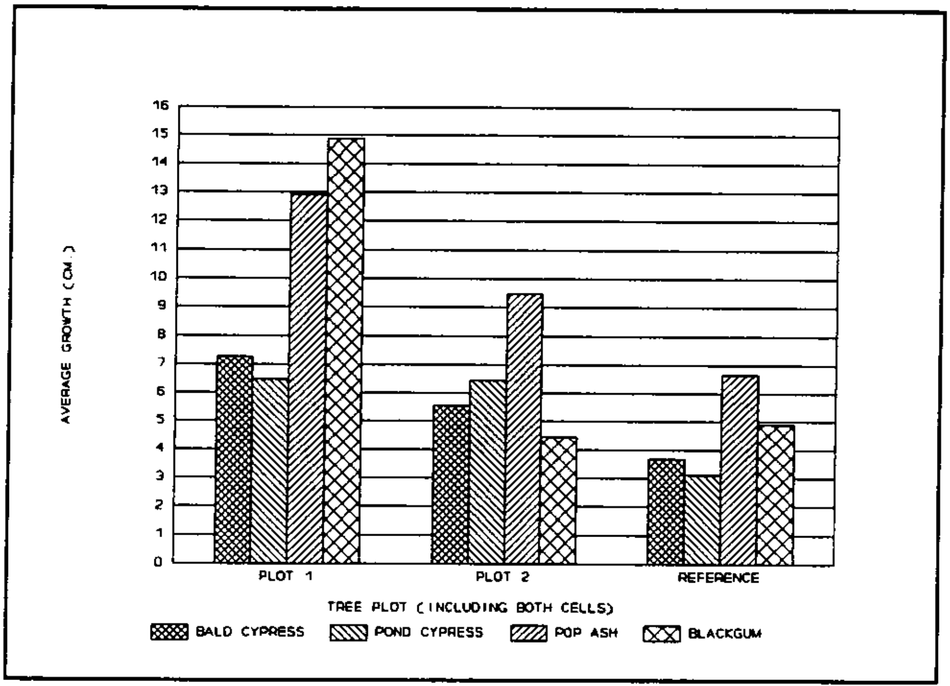


Figure 14. Average Seedling Growth 9/18/91 - 4/21/92.
a) Cell C and reference; b) Cell D & reference;
c) Total by cell; d) Total by plot.

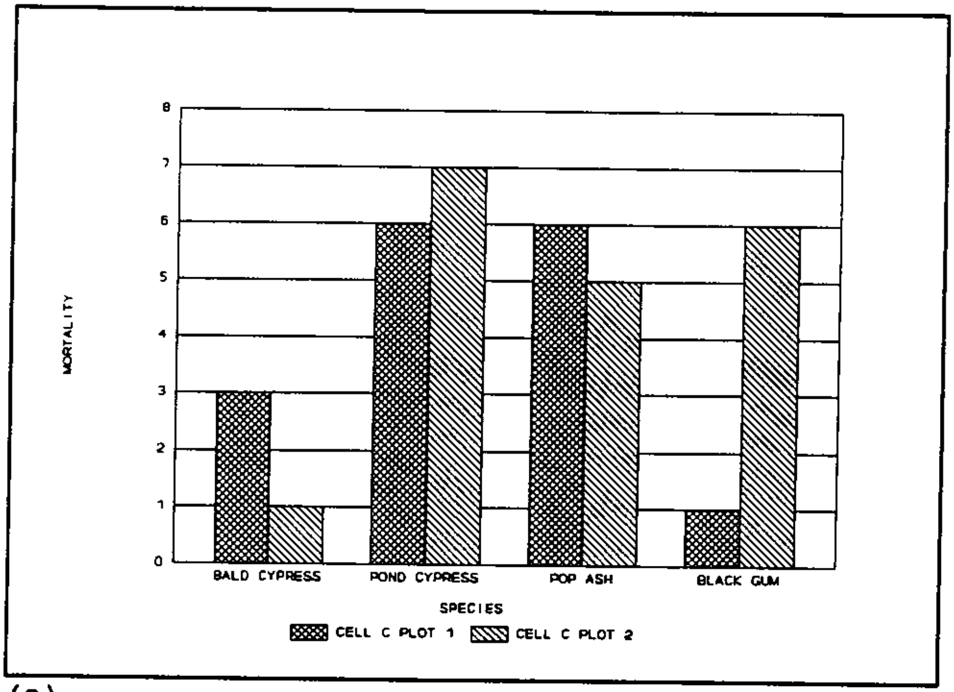


(c)

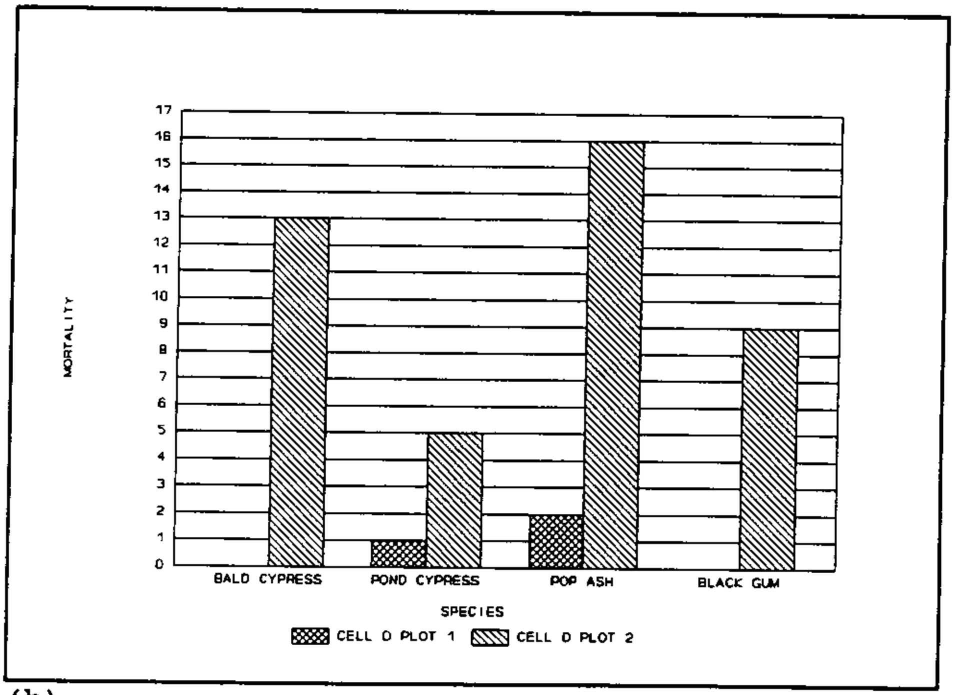


(d)

Figure 14. (continued).

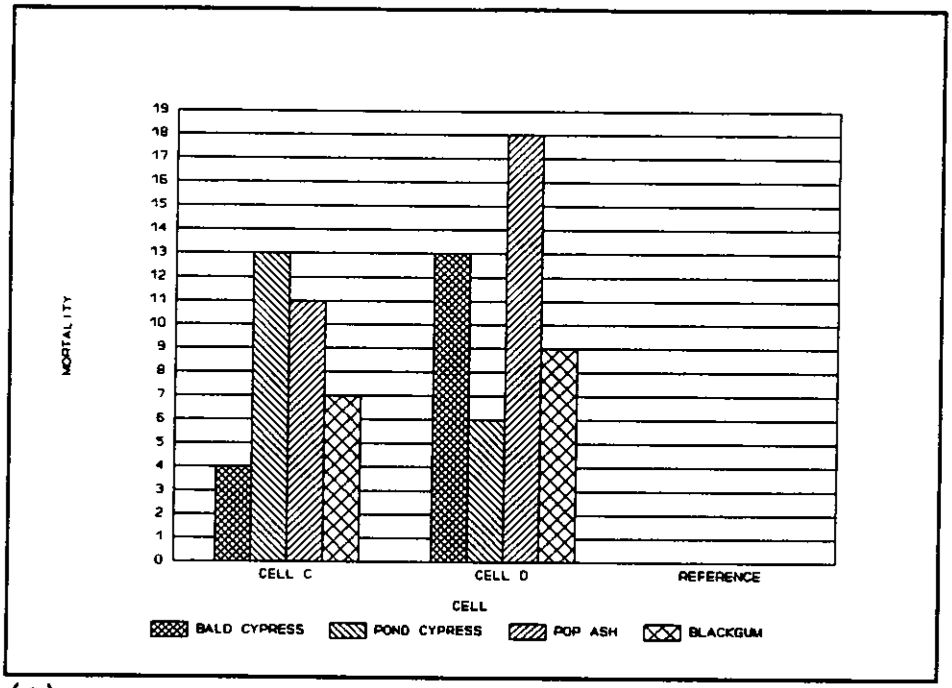


(a)

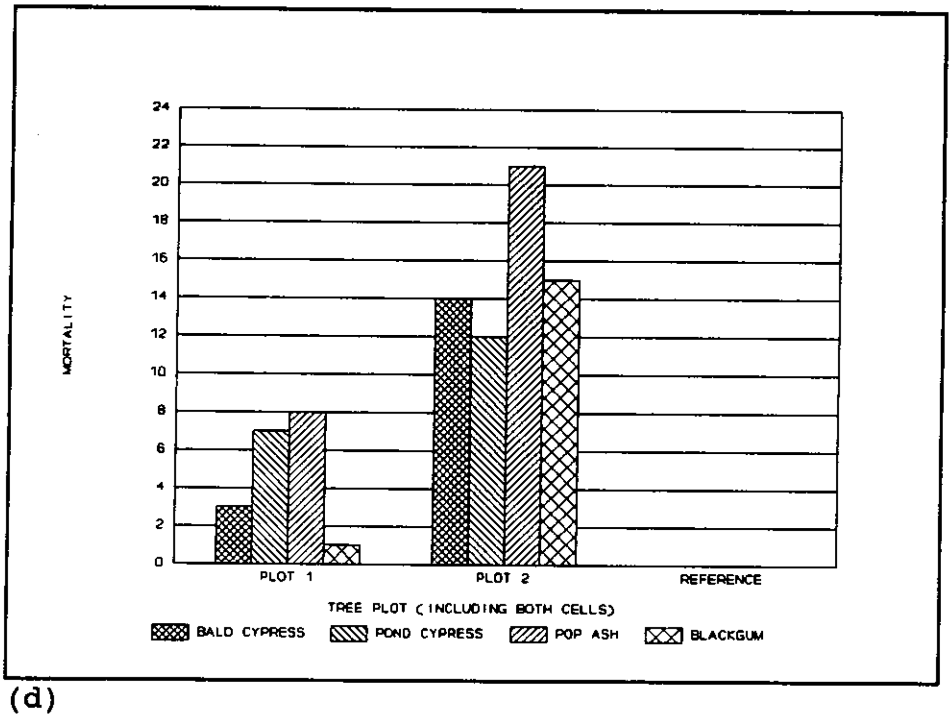


(b)

Figure 15. Seedling Mortality 9/18/91 - 4/21/92. a) Cell C; b) Cell D; c) Total by cell; d) Total by plot.



(c)



(d)

Figure 15. (continued).

Aquatic Productivity with Diurnal Chemical Measurements

Temperature

Diurnal temperature data collected on July 16-17, 1992 at the four stations in the pilot wetland and the reference station including depth profiles for deep zones are presented in Figures 16-20. Temperature fluctuations in the pilot wetland were dramatic when compared to the reference station due to the high color of the effluent and the resultant solar heating both in exposed areas of the wetland (plant cover in most areas < 40%) and in the preceding primary and secondary treatment ponds. The diurnal temperature of the upper depth stratum at all wetland stations was similar. The temperature depth profile at station D1 and D2 was highly stratified.

Dissolved Oxygen (DO) and Aquatic Production

Diurnal DO data collected on July 16-17, 1991 from the pilot wetland and reference stations including depth profiles for deep zones is presented in Figures 21-25. The diurnal rate of change of DO at each station, from which aquatic production was calculated is presented in Figures 26-30.

Diurnal DO concentrations were approximately twice as high in the lower deep zone of Cell D (Station D2) than station D1.

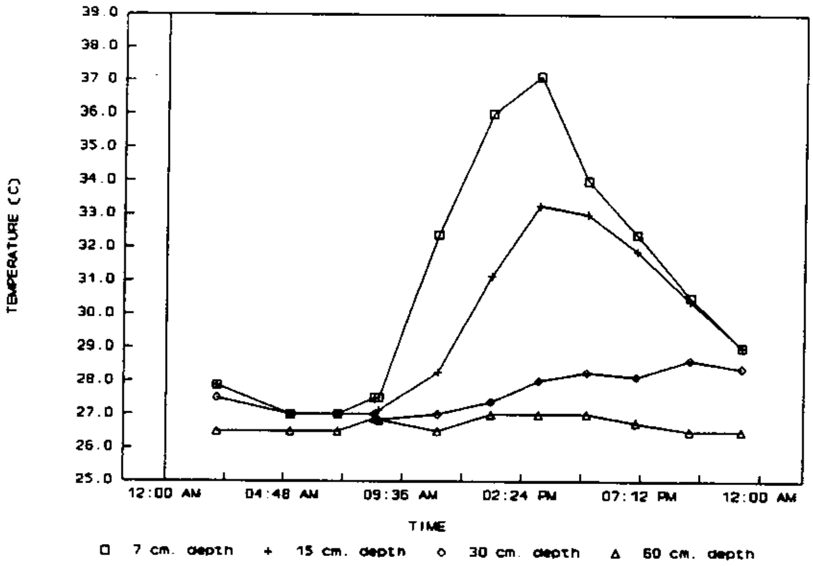


Figure 16. Station D1. Diurnal Temperature Profile. July 16-17, 1991.

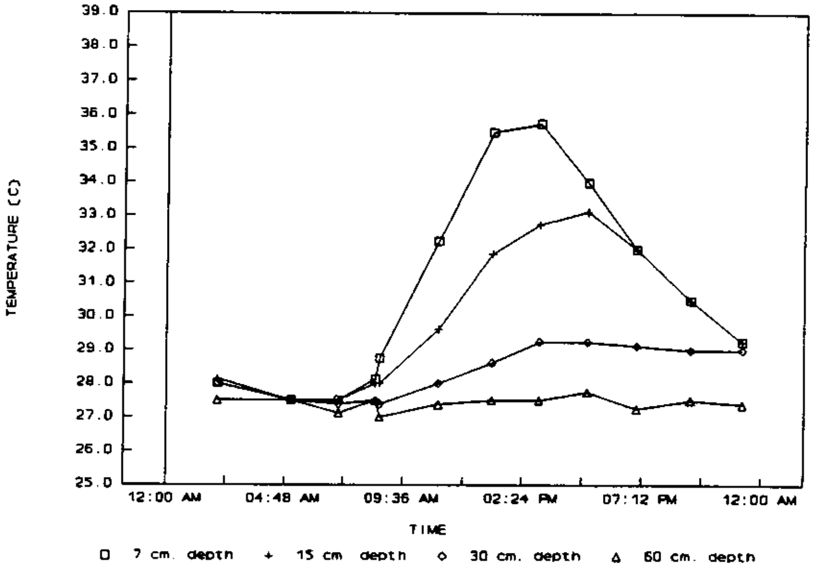


Figure 17. Station D2. Diurnal Temperature Profile. July 16-17, 1991.

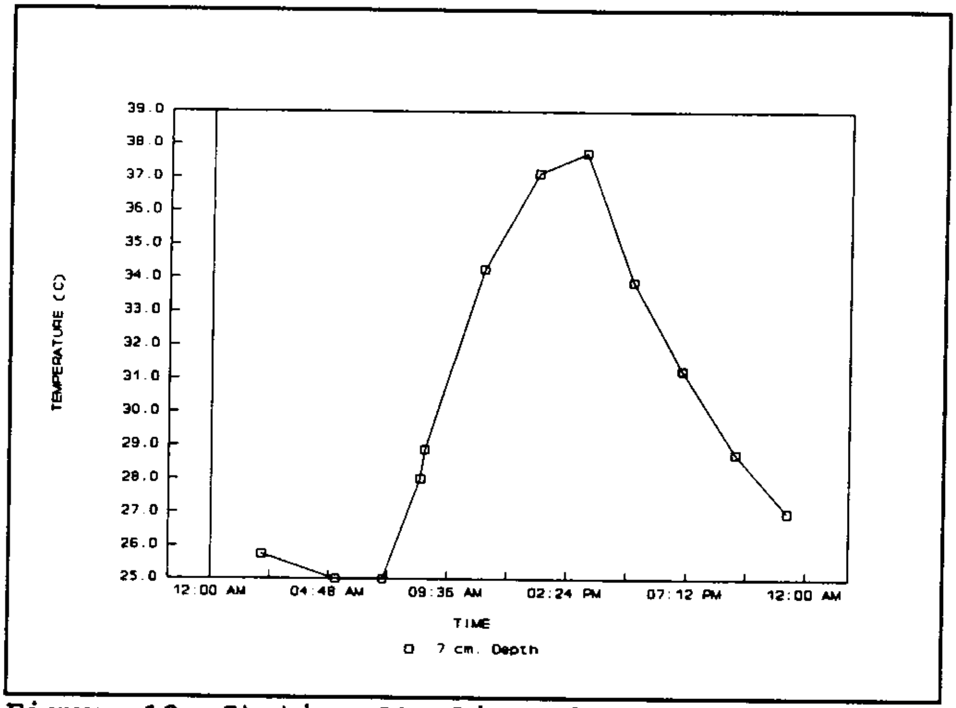


Figure 18. Station C1. Diurnal Temperature Profile. July 16-17, 1991.

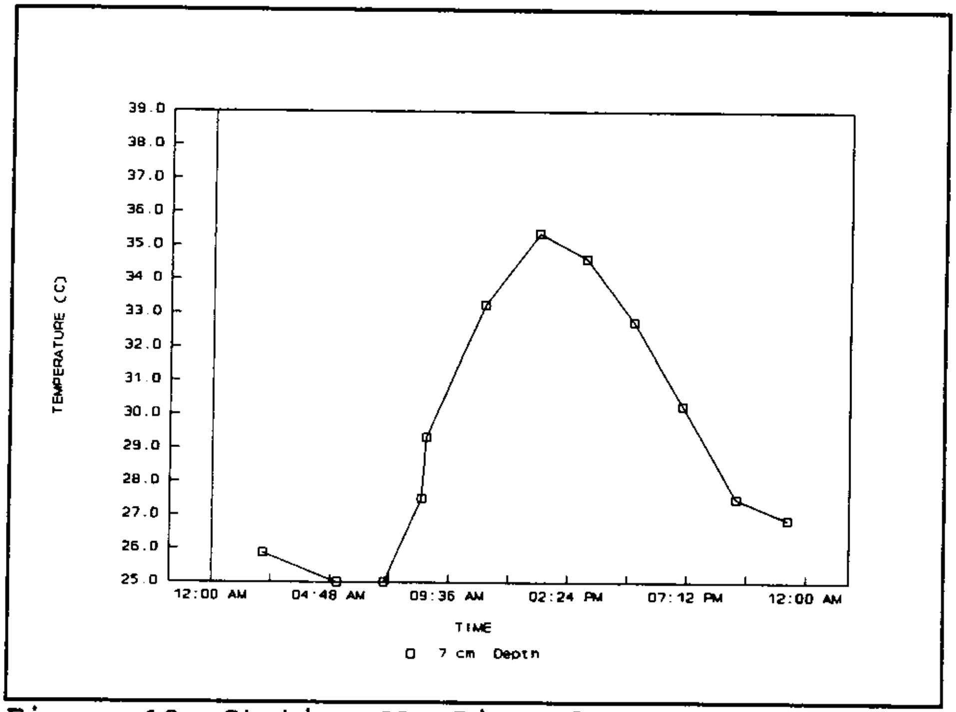


Figure 19. Station C2. Diurnal Temperature Profile. July 16-17, 1991.

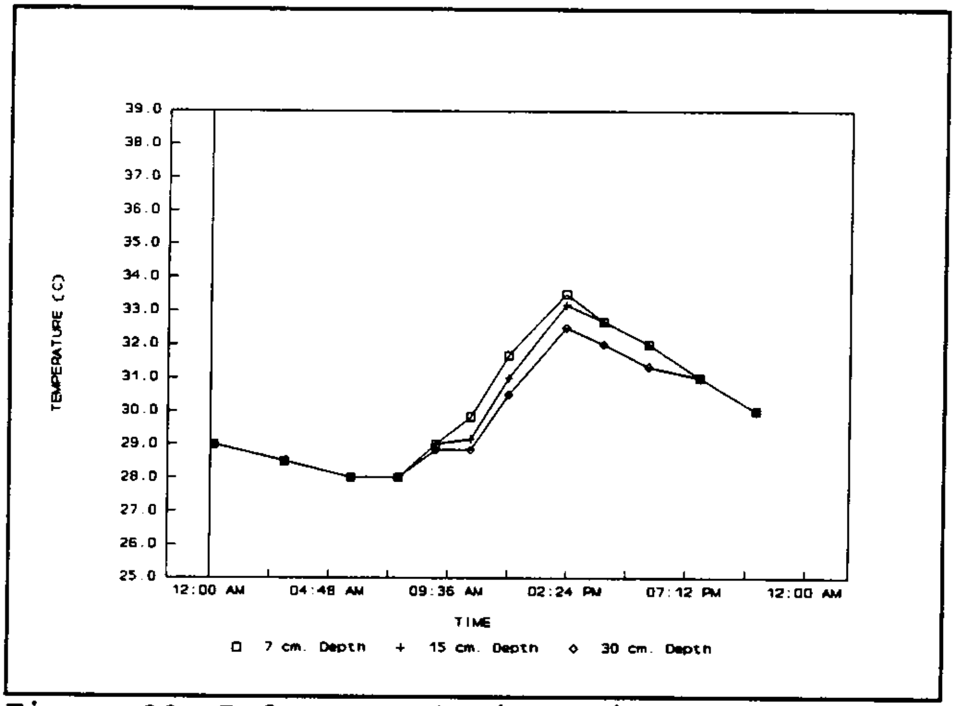


Figure 20. Reference Station. Diurnal Temperature Profile. July 16-17, 1991.

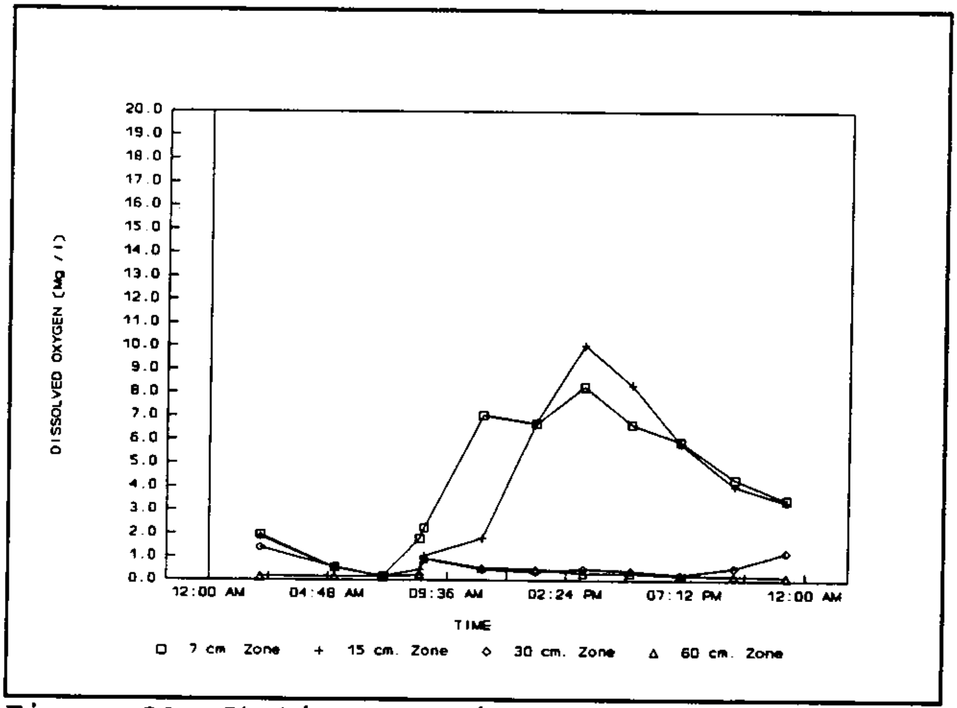


Figure 21. Station D1. Diurnal Dissolved Oxygen Profile. July 16-17, 1991.

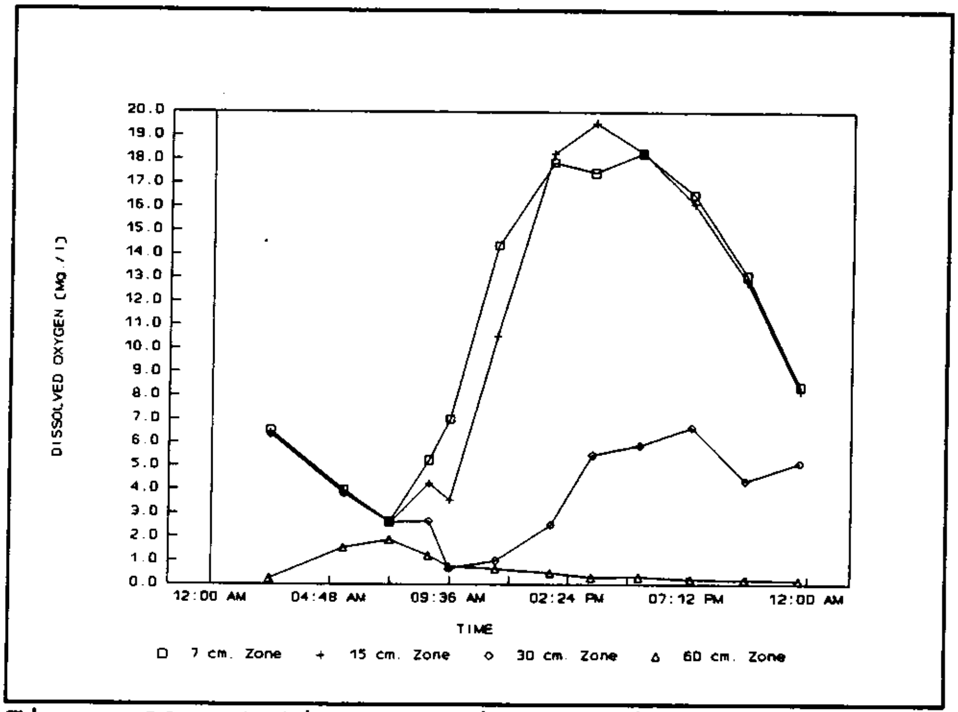


Figure 22. Station D2. Diurnal Dissolved Oxygen Profile. July 16-17, 1991.

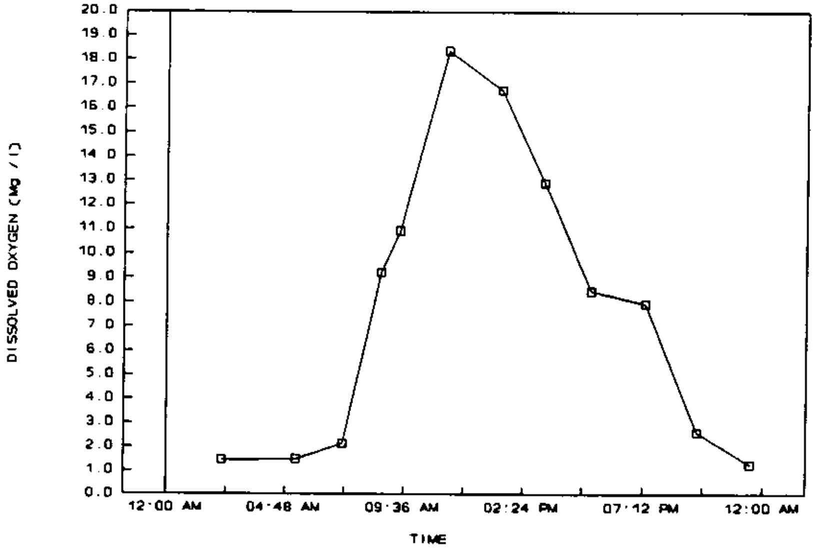


Figure 23. Station C1. Diurnal Dissolved Oxygen Profile. July 16-17, 1991.

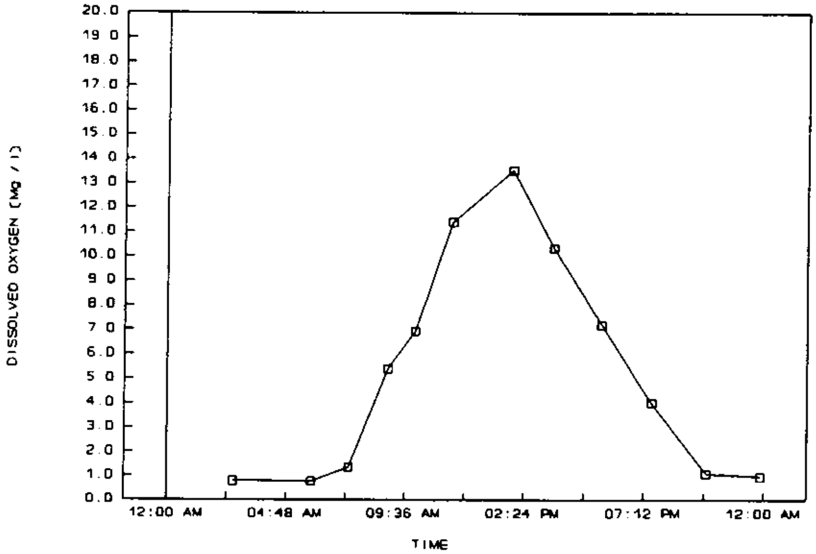


Figure 24. Station C2. Diurnal Dissolved Oxygen Profile. July 16-17, 1991.

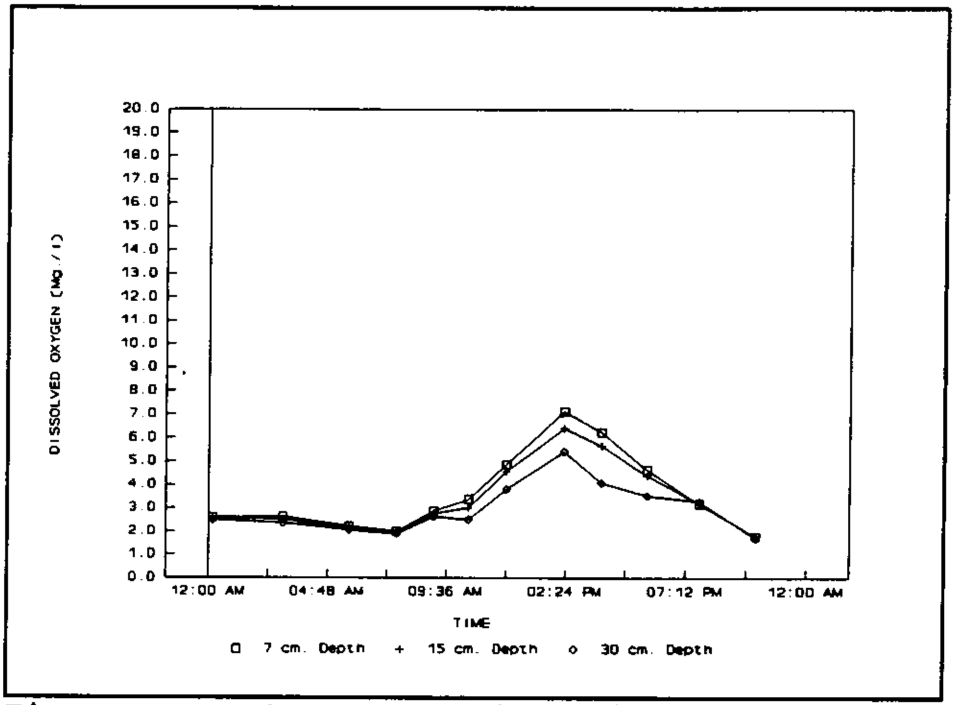


Figure 25. Reference Station. Diurnal Dissolved Oxygen Profile. July 16-17, 1991.

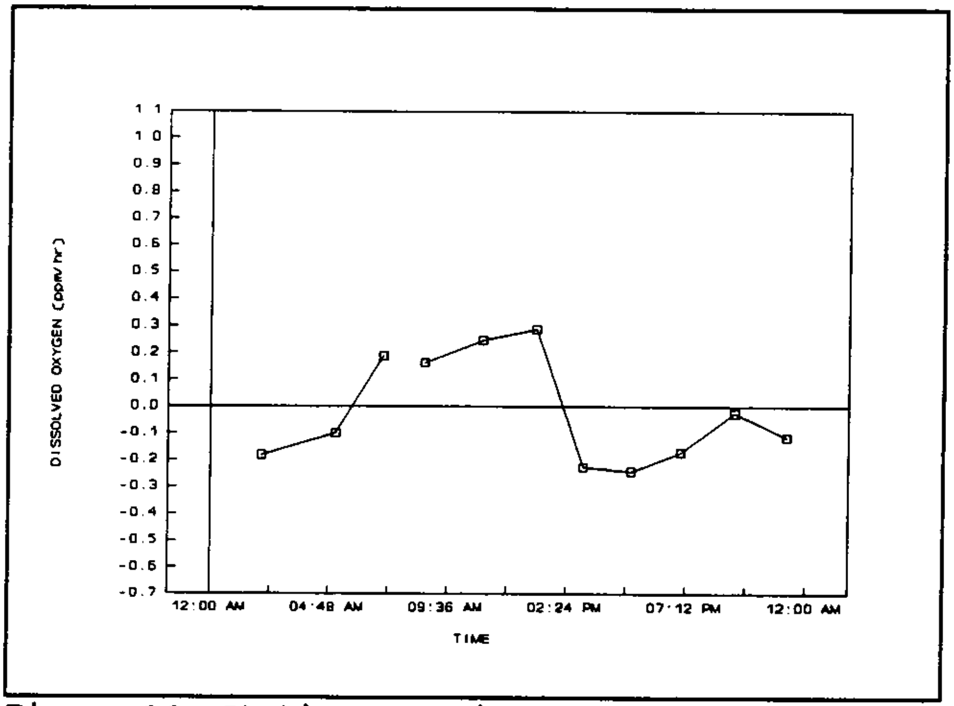


Figure 26. Station D1. Diurnal Rate of Change - Dissolved Oxygen/m^2. July 16-17, 1991.

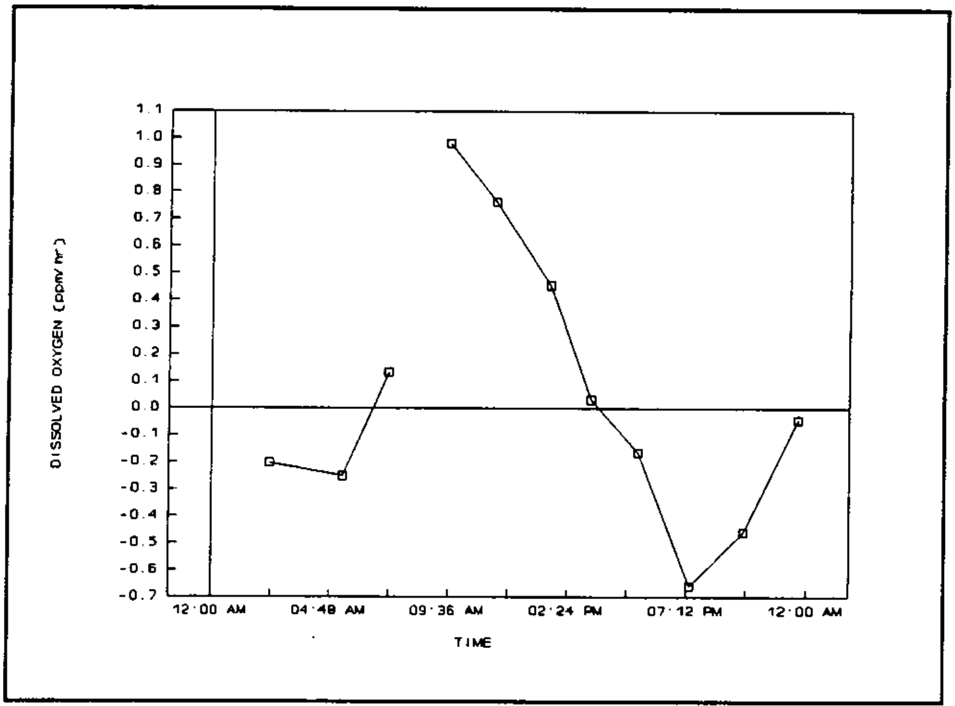


Figure 27. Station D2. Diurnal Rate of Change - Dissolved Oxygen/m^2. July 16-17, 1991.

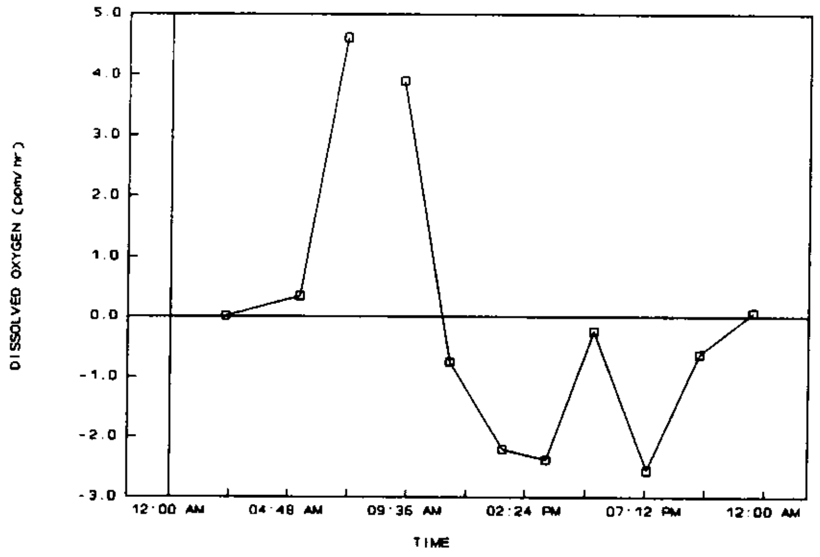


Figure 28. Station C1. Diurnal Rate of Change - Dissolved Oxygen/m^2. July 16-17, 1991.

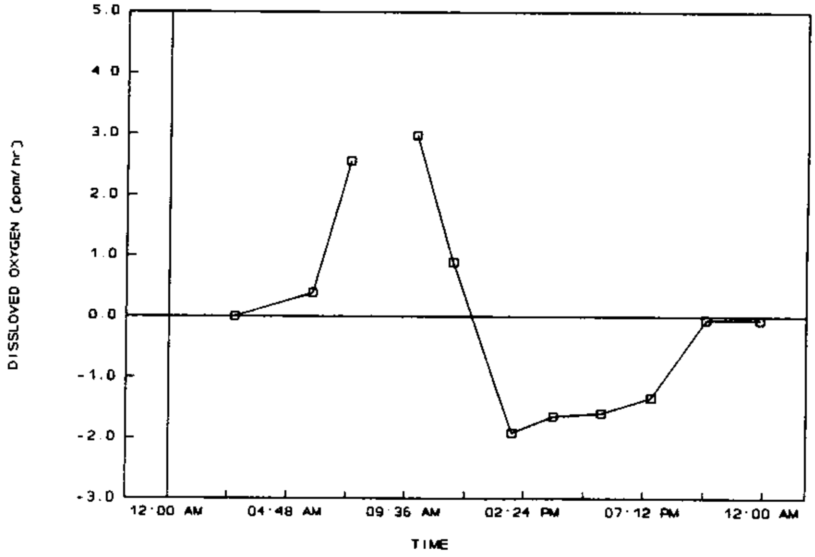


Figure 29. Station C2. Diurnal Rate of Change - Dissolved oxygen/m^2. July 16-17, 1991.

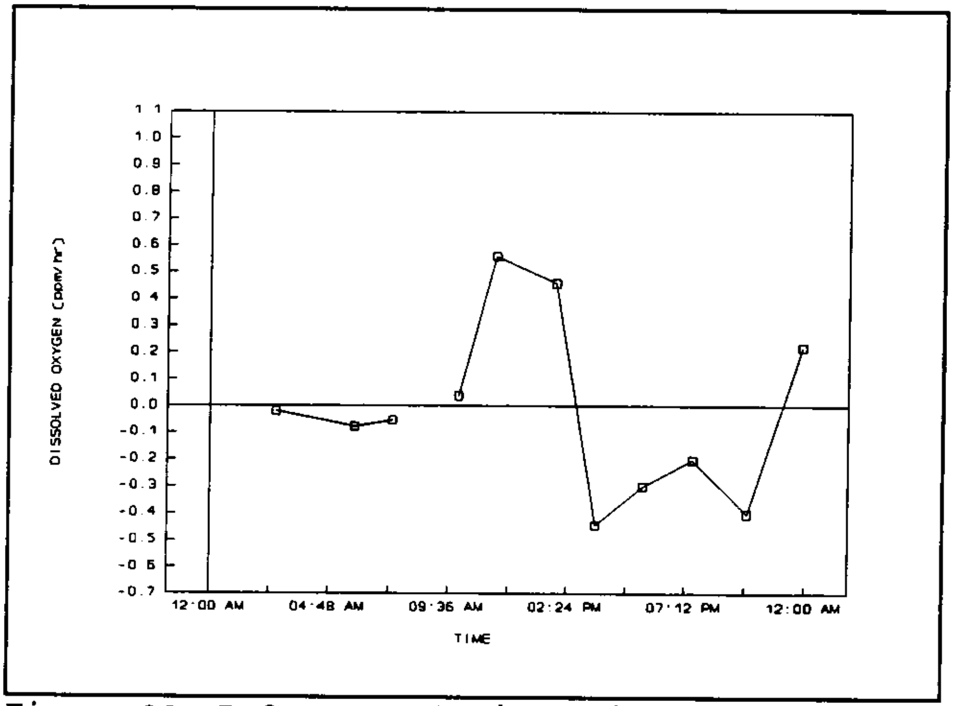


Figure 30. Reference Station. Diurnal Rate of Change - Dissolved Oxygen/m^2. July 16-17, 1991.

Table II. Aquatic Production in Pilot Wetland (g/m^2/day).
July 16 - 17, 1991.

	D1	D2	C1	C2	REFERENCE
Depth (m)	1.20	1.25	0.08	0.13	1.00
Gross Primary Production:	2.5	7.6	1.5	2.4	4.3
Net Primary Production:	0.6	4.7	0.3	0.7	1.8
Day Respiration:	1.1	4.3	0.3	0.7	2.3
Night Respiration:	1.9	2.9	1.3	1.7	2.4
Net Primary Production-Night Respiration Ratio (P_{net}/R_{night}):	0.3	1.6	0.2	0.4	0.7

Note: Station D1 = first deep zone in Cell D; Station D2 = Second deep zone in Cell D; Station C1 = influent end boardwalk in Cell C; Station C2 = effluent end boardwalk in Cell C.

In the upper strata of both of these deep zones and at station C1 and C2 DO fluctuated from a lower pre-dawn concentration (near 0 ppm) to much higher daytime levels in comparison to the reference station. The depth profile of DO in the wetland deep zones was highly stratified. Elevated diurnal DO levels extended deeper at station D2 compared to station D1.

Gross and net primary production in the pilot wetland and reference station are presented in Table III.

PH and Redox Potential

Figures 30 and 31 are plots of the diurnal pH and redox potential (Eh) data collected from the surface waters (10 cm depth) of the pilot wetland and reference station on July 16-17, 1991. In the data from all stations the impact of aquatic primary production was evidenced by an increase in pH and corresponding increase in Eh during daylight hours. Oxidative respiratory processes release energy and available nutrients contributing to the rapid increase in photosynthesis at dawn. Photosynthesis produces reduced conditions, incorporating dissolved CO_2 into biomass, increasing the pH and oxidizing the surrounding environment.

The effluent aquatic system was more alkaline and reduced compared to the reference station. The diurnal curves indicate that photosynthesis reached a peak earlier in the reference system than in the pilot wetland, possibly due to nutrient limitation.

Figure 32 is the diurnal pH and redox (Eh) data from the pilot wetland and the reference station plotted on a Eh-pH diagram. The groupings represent the diurnal pulsing within a discrete electrochemical range (moderate to high pH and medium Eh in the pilot wetland) that were used to interpret redox reactions, chemical equilibria and some microbiotic ecosystem components (see Discussion).

Chemical Changes in Peaty Microcosms

The results of three water chemistry monitoring events for the peat trough and column microcosms are summarized in Table II. The peat interface proved an effective medium for the chemical, physical and biological processes involved in the reduction of biochemical oxygen demand (BOD), total suspended solids (TSS), ammonia nitrogen (NH_4-N), total kehldahl nitrogen (TKN), nitrite - nitrate nitrogen (NO_2-NO_3) and total phosphorus (TP). Results were more consistent in the surface flow trough reactors than in the infiltration columns.

pH

In the first 2 monitoring events the pH of ASB 2 effluent was reduced by the experimental troughs.

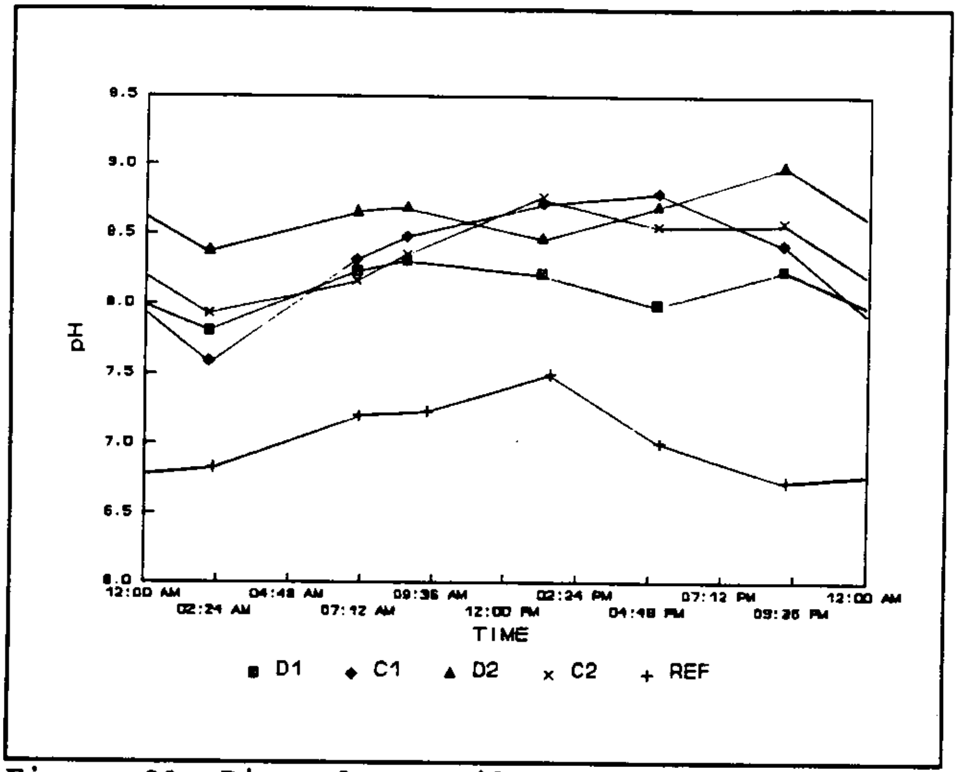


Figure 31. Diurnal pH. Pilot Wetland and Reference Station. July 16-17, 1991.

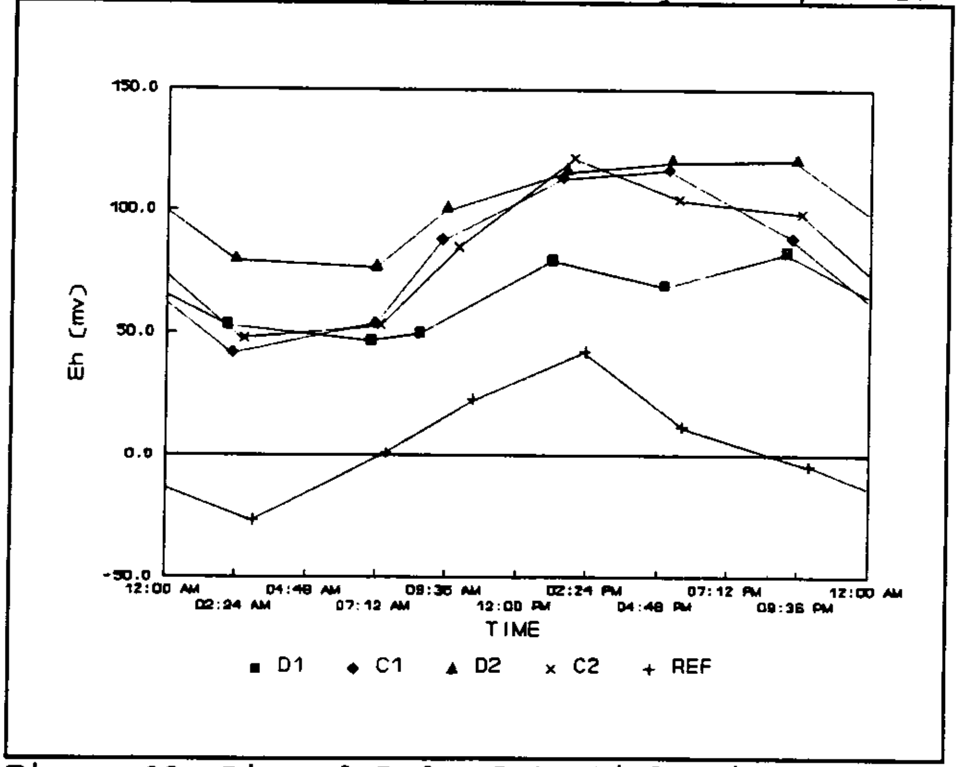


Figure 32. Diurnal Redox Potential. Pilot Wetland and Reference Station. July 16-17, 1991.

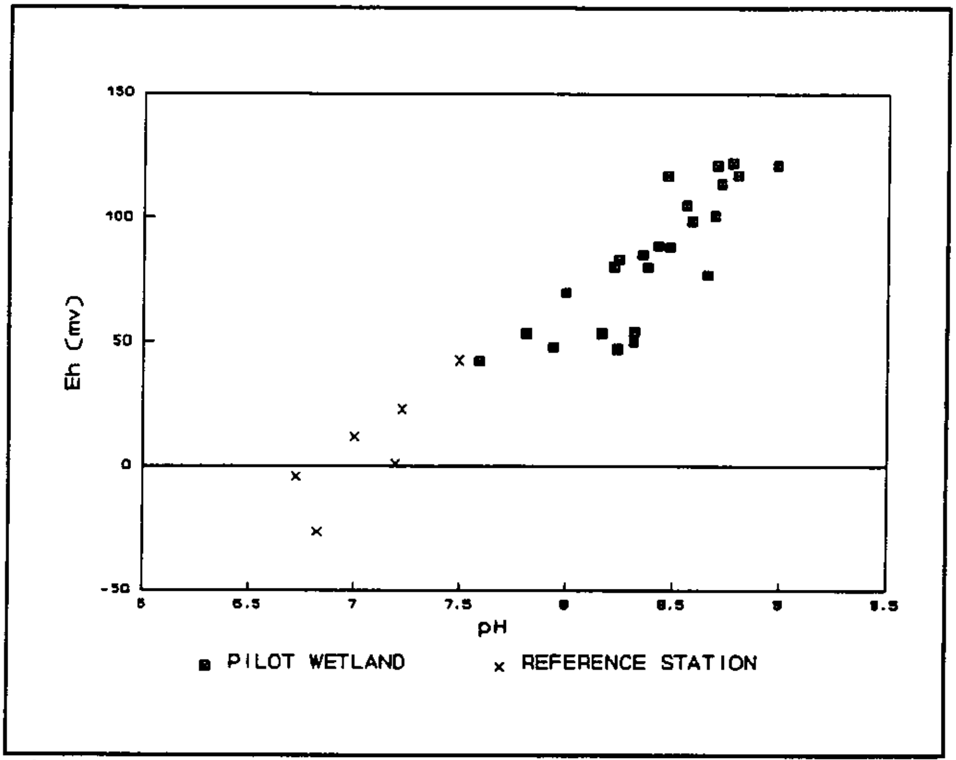


Figure 33. Eh-pH Diagram of Data Collected in Pilot Wetland and Reference Station. July 16-17, 1991.

At the final monitoring period the experimental trough effluent experienced an increase in pH from 7.9 to 8.5 due to high photosynthetic production by the dense algal community. The average experimental influent pH was 7.8 over the monitoring period. The control trough showed the same trend with a lower influent pH and less photosynthetic production translating to a lower relative pH difference.

The experimental infiltration columns produced a more substantial decrease in effluent pH. The influent pH of 7.8 was reduced to an average of 4.6 over the three monitoring periods. The pH in the control columns was reduced from an average of 5.2 to 5.0.

Biochemical Oxygen Demand (BOD)

BOD-5 concentrations were reduced by an average of 38% in the experimental trough. Influent concentrations ranged from 16 mg/l to 27 mg/l. The control trough produced an increase in BOD from 0 to 3 mg/l during the initial monitoring period but subsequent monitorings showed only a slight increase in BOD-5.

Total Suspended Solids (TSS)

Experimental influent TSS was highly variable over the monitoring period, ranging from 12 mg/l to 154 mg/l.

Table III. Peat Microcosm Water Chemistry Results. a) Samples Collected January 31, 1992; b) Samples Collected March 4, 1992; c) Samples Collected April 21, 1992.

Station	Location	Temp.	pH	BOD-5	TSS	Color	NH4-N	TKN	NO2-NO3	TP
Part (a)										
		(C)	(S.U.)	(mg/l)	(mg/l)	(Pt-Co)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
E	Experimental Trough									
	Influent (ASB 2)	20.0	7.8	22.0	12.0	343	1.77	9.72	0.048	0.420
E3	Experimental Trough									
	Effluent	18.0	6.9	11.0	10.0	509	0.72	3.48	<0.005	0.230
T	Control Trough									
	Influent (Tap)	17.5	5.3	0.0	0.0	39	< 0.10	<0.10	0.018	0.130
T3	Control Trough									
	Effluent	16.5	5.2	3.0	5.0	90	< 0.10	1.28	<0.005	0.115
C1	Column 1 Effluent	19.0	4.6		1.0	198	< 0.10	1.40	<0.005	0.120
C2	Column 2 Effluent	18.0	4.7		10.0	100	< 0.10	1.08	<0.005	0.170
C3	Column 3 Effluent	18.0	5.2		7.0	89	< 0.10	1.63	<0.005	0.142
C4	Column 4 Effluent	19.0	5.1		8.0	109	< 0.10	1.88	<0.005	0.115
C5	Column 5 Effluent	17.0	4.8		6.0	80	< 0.10	1.43	<0.005	0.050
C6	Column 6 Effluent	18.0	4.7		7.0	91	< 0.10	1.46	<0.005	0.110

Table III. (continued).

Station	Location	Temp.	pH	BOD-5	TSS	Color	NH4-N	TKN	NO2-NO3	TP
Part (b)		(C)	(S.U.)	(mg/l)	(mg/l)	(Pt-Co)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
E	Experimental Trough									
	Influent (ASB 2)	22.0	7.5	27.0	164.0	284	5.66	18.00	0.079	1.160
E3	Experimental Trough									
	Effluent	16.0	7.1	20.0	60.0	774	<0.10	5.41	<0.005	0.496
T	Control Trough									
	Influent (Tap)	17.0	5.1	0.0	0.0	15	< 0.10	0.19	0.079	0.070
T3	Control Trough									
	Effluent	17.0	5.0	<0.3	36.0	533	< 0.10	2.98	0.019	0.225
C1	Column 1 Effluent	22.5	3.2		22.0	36	6.58	12.00	0.019	0.040
C2	Column 2 Effluent	22.5	3.9		10.0	7	8.82	12.20	<0.005	0.130
C3	Column 3 Effluent	23.0	4.0		9.0	12	1.00	3.60	<0.005	1.750
C4	Column 4 Effluent	23.0	4.3		2.0	22	0.70	2.01	0.019	0.170
C5	Column 5 Effluent	23.0	6.0		15.0	349	< 0.10	1.56	<0.005	0.115
C6	Column 6 Effluent	23.0	5.5		4.0	137	0.20	2.01	<0.005	0.140

Table III. (continued).

Part (c)

Station	Location	Temp.	pH	BOD-5	TSS	Color	NH4-N	TKN	NO2-NO3	TP
		(C)	(S.U.)	(mg/l)	(mg/l)	(Pt-Co)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
E	Experimental Trough Influent (ASB 2)	24.0	7.9	16	25	298	6.03	7.49	0.019	0.89
E3	Experimental Trough Effluent	24.5	8.5	10	19	497	< 0.10	3.50	< 0.005	0.23
T	Control Trough Influent (Tap)	24.0	5.1	0	0	12	< 0.10	< 0.10	0.091	0.00
T3	Control Trough Effluent	17.0	5.5	<1	4	210	1.24	1.24	< 0.005	0.08
C1	Column 1 Effluent	25.0	4.3		1	222	9.45	9.56	< 0.005	0.12
C2	Column 2 Effluent	22.5	4.4		1	229	11.10	9.77	0.118	0.14
C3	Column 3 Effluent	23.0	4.4		25	380	12.10	12.80	6.390	0.14
C4	Column 4 Effluent	23.0	4.6		2	100	< 0.10	0.86	< 0.005	0.08
C5	Column 5 Effluent	23.0	4.8		1	47	< 0.10	1.43	< 0.005	0.09
C6	Column 6 Effluent	23.0	4.8		2	45	< 0.10	1.08	< 0.005	0.10

The experimental trough yielded a 68% reduction in TSS under the highest mass loading of 154 mg/l. Under lower loading the reduction was only 21%. TSS was increased in the control trough from 0 mg/l to and average of 15 mg/l over the three monitoring events.

The infiltration columns produced greater and more variable changes in TSS. The experimental columns decreased influent TSS by an average of 68% with a maximum reduction of 91%. The control columns caused an increase in TSS, most notably in the initial monitoring period. Control influent TSS was 0 mg/l and the average discharge was 5 mg/l.

Color

In all monitoring periods the experimental and control troughs produced an increase in color. The average experimental influent color was 312 (Pt-Co units). The average color increase was 92% over the study period. The control trough increased the average influent color of 22 units by an average of 215%.

The results of the experimental column microcosms showed an average color reduction of 55%. Individual results, however, had considerable variability. The control columns increased the tap water color from it's average value of 22 units by an average of 597%.

Total Ammonia Nitrogen

Total ammonia nitrogen was most consistently reduced by the surface flow troughs. Average experimental inflow concentration over the study period was 4.15 mg/l and the average outflow concentration was 0.31 mg/l. Nitrification and assimilation of ammonia increased in the experimental trough from the initial startup monitoring through the remainder of the study. Removal efficiency for the last two monthly monitoring periods was greater than 98%. Control trough outflow concentrations remained unchanged from the influent ammonia concentration of <0.10 mg/l for the first two monitoring periods but showed an increase to 1.24 mg/l in the final monitoring event.

The experimental columns, organized under mostly anaerobic conditions, went from a 94% reduction of ammonia in the startup period to no change in the second monitoring period to a 116% increase in the final monitoring event. The control troughs showed no significant change in the inflow ammonia concentration of <0.10 mg/l except at the second monitoring event, where it was increased by 0.23 mg/l.

Total Kjeldahl Nitrogen (TKN)

TKN (NH3-N + Organic N) was reduced by an average of 62% in the experimental trough during the study period. The average influent TKN concentration was 11.74 mg/l and the average experimental trough effluent concentration was 4.12 mg/l. TKN was increased by the control troughs from an average influent concentration of <0.13 mg/l to an average outflow concentration of 1.83 mg/l.

The experimental column outflow concentration of TKN increased over the study period from 1.37 mg/l at the initial monitoring event to 9.27 mg/l and 10.71 mg/l in the subsequent monthly monitoring events. The corresponding inflow concentrations were 9.72 mg/l, 18.00 mg/l and 7.49 mg/l respectively. The control columns increased TKN from an average inflow concentration of <0.13 mg/l to an average of 1.52 mg/l over the study period.

Organic Nitrogen

Organic nitrogen (TKN - NH3-N) experimental influent concentrations varied considerably over the study period. At the monitoring events the experimental inflow concentrations were 7.95 mg/l, 12.34 mg/l and 2.46 mg/l. The experimental trough effluent concentrations were 2.24

mg/l, 5.31 mg/l and 3.4 mg/l respectively. The trend indicated increased assimilation of inorganic nitrogen to organic forms as the system organized. The control trough increased the average influent organic nitrogen concentration of <0.03 mg/l to 1.32 mg/l.

The experimental columns reduced the influent concentration of organic nitrogen by an average of 81% over the study period. The control columns increased the inflow concentration, which averaged <0.03 mg/l by and average of 1.29 mg/l.

Nitrate and Nitrite Nitrogen

The average experimental influent concentration of NO_2 + NO_3 was 0.049 mg/l. In all monitoring periods the experimental trough reduced NO_2 + NO_3 to <0.005 mg/l. The results of the control trough were essentially the same, reducing the average inflow concentration of .061 mg/l to an average outflow concentration of <0.010 mg/l.

The experimental column results for NO_2 + NO_3 were consistent for the first two monitoring periods, reducing the influent concentration to <0.005 mg/l. The final monitoring, however, showed high variability with two columns increasing the NO_2 + NO_3 concentration in the discharge.

Total Phosphorus

The average experimental inflow concentration of TP was 0.82 mg/l over the study period. This concentration was consistently reduced in the experimental trough by an average of 59%. The control trough initially reduced the influent concentration of TP, 0.130 mg/l to 0.115 mg/l but increased the concentration by an average of 0.117 mg/l in subsequent monitoring periods .

The experimental columns were slightly more effective in reducing influent concentrations of TP than the trough. Concentrations were reduced by an average of 65%. The control columns yielded similar results to the control trough, initially decreasing the TP concentration slightly and then increasing the concentration by an average of 0.081 mg/l in the subsequent two monitoring periods.

Stand Characteristics and Cypress Growth Rate in The Effluent Impacted Rice Creek Floodplain Swamp

Stand Characteristics

The raw forest stand data collected in the Rice Creek experimental site (Table IV) and reference site (Table V), including basal area coverage, frequency and species diversity were summarized.

Table IV. Rice Creek Experimental Site Forest Stand Data.

Plot 1	Basal Area (cm ^2)		Frequency
Acer rubrum	744.56	Acer	16
Cephelanthus occidentalis	6.28	Cephelanthus	2
Cornus spp.	47.12	Cornus	8
Fraxinus caroliniana	1894.38	Fraxinus	34
Itea virginica	0.79	Itea	1
Nyssa sylvatica	1807.99	Nyssa	4
Quercus laurifolia	25.13	Quercus	2
Sambucus spp.	1.58	Sambucus	2
Taxodium distichum	176.71	Taxodium	1
Ulmus americana	358.14	Ulmus	15
Shannon Diversity			2.48
Plot 2			
Acer rubrum	27.49	Acer	4
Cephelanthus occidentalis	41.63	Cephelanthus	15
Fraxinus caroliniana	1551.95	Fraxinus	38
Myrica cerifera	105.24	Myrica	10
Nyssa sylvatica	95.03	Nyssa	1
Sambucus spp.	7.07	Sambucus	1
Taxodium distichum	3216.21	Taxodium	6
Ulmus americana	223.05	Ulmus	7
Shannon Diversity			2.28
Plot 3			
Acer rubrum	71.47	Acer	5
Baccharis spp.	9.42	Baccharis	3
Cephelanthus occidentalis	57.33	Cephelanthus	21
Fraxinus caroliniana	2473.22	Fraxinus	70
Ilex cassine	8.64	Ilex	5
Myrica cerifera	37.70	Myrica	5
Nyssa sylvatica	3276.68	Nyssa	5
Quercus laurifolia	7.07	Quercus	1
Sambucus spp.	9.42	Sambucus	6
Taxodium distichum	2976.66	Taxodium	8
Ulmus americana	357.36	Ulmus	5
Shannon Diversity			2.43

Average	Basal Area/Hectare (m ^2)		#/Hectare
Taxodium	10.53	Fraxinus	2315.12
Fraxinus	10.13	Ceph.	607.21
Nyssa	7.93	Ulmus	497.86
Acer	1.74	Acer	456.63
Ulmus	1.64	Myrica	265.50
Myrica	0.26	Taxodium	241.76
Ceph.	0.17	Nyssa	161.35
Cornus	0.10	Cornus	156.34
Quercus	0.06	Sambucus	134.85
Sambucus	0.03	Ilex	62.92
Baccharis	0.01	Quercus	51.67
Ilex	0.01	Baccharis	37.75
Itea	0.00	Itea	19.54
Total	32.62		5008.50
		SHANNON DIVERSITY:	2.40

Size Class Frequency

dBH Class	Plot 1	Plot 2	Plot 3	Ave. #/Hectare
1-5	38	54	92	3066.67
5-10	28	14	19	1016.67
10-15	14	6	4	400.00
15-20	2	5	9	266.67
20-25	2	1	2	83.33
25-30	0	1	2	50.00
30-35	0	0	3	50.00
35-40	0	0	0	0.00
40-45	1	0	1	33.33
45-50	0	1	0	16.67

Table V. Rice Creek Reference Site Forest Stand Data.

Plot 1	Basal Area (cm ^2)		Frequency
Acer rubrum	178.27	Acer	3
Cephelanthus occidentalis	179.06	Cephelanthus	20
Fraxinus caroliniana	5510.74	Fraxinus	38
Gleditsia aquatica	927.49	Gleditsia	2
Liquidambar styraciflua	581.15	Liquidambar	4
Myrica cerifera	1.57	Myrica	2
Nyssa sylvatica	296.07	Nyssa	2
Ostrya virginiana	56.54	Ostrya	2
Quercus laurifolia	755.50	Quercus	2
Taxodium distichum	1982.99	Taxodium	2
Ulmus americana	423.30	Ulmus	7
Shannon Diversity			2.46
Plot 2			
Acer rubrum	1931.29	Acer	14
Cephelanthus occidentalis	113.88	Cephelanthus	18
Fraxinus caroliniana	633.82	Fraxinus	15
Nyssa sylvatica	1834.69	Nyssa	15
Ostrya virginiana	281.96	Ostrya	5
Salix caroliniana	50.27	Salix	1
Taxodium distichum	63.62	Taxodium	1
Shannon Diversity			2.38
Plot 3			
Acer rubrum	2704.13	Acer	9
Cephelanthus occidentalis	121.74	Cephelanthus	7
Fraxinus caroliniana	3356.79	Fraxinus	36
Gleditsia aquatica	10.21	Gleditsia	2
Liquidambar styraciflua	1167.89	Liquidambar	8
Myrica cerifera	38.48	Myrica	1
Nyssa sylvatica	462.60	Nyssa	8
Ostrya virginiana	99.75	Ostrya	6
Quercus laurifolia	176.71	Quercus	1
Salix caroliniana	254.47	Salix	1
Taxodium distichum	50.27	Taxodium	1
Ulmus americana	452.39	Ulmus	1
Shannon Diversity			2.64

Average	Basal Area/Hectare (m ^2)		#/Hectare
Fraxinus	13.89	Fraxinus	1448.48
Acer	9.80	Cephelanthus	761.00
Nyssa	6.22	Acer	454.64
Taxodium	2.75	Nyssa	441.96
Liquidambar	2.53	Ostrya	221.45
Ulmus	1.23	Liquidambar	190.30
Quercus	1.22	Ulmus	124.38
Gleditsia	1.18	Taxodium	65.84
Ostrya	1.01	Gleditsia	63.05
Cephelanthus	0.73	Quercus	47.00
Salix	0.53	Myrica	47.00
Myrica	0.06	Salix	34.89
Total	41.18		3900.00
		SHANNON DIVERSITY:	2.49

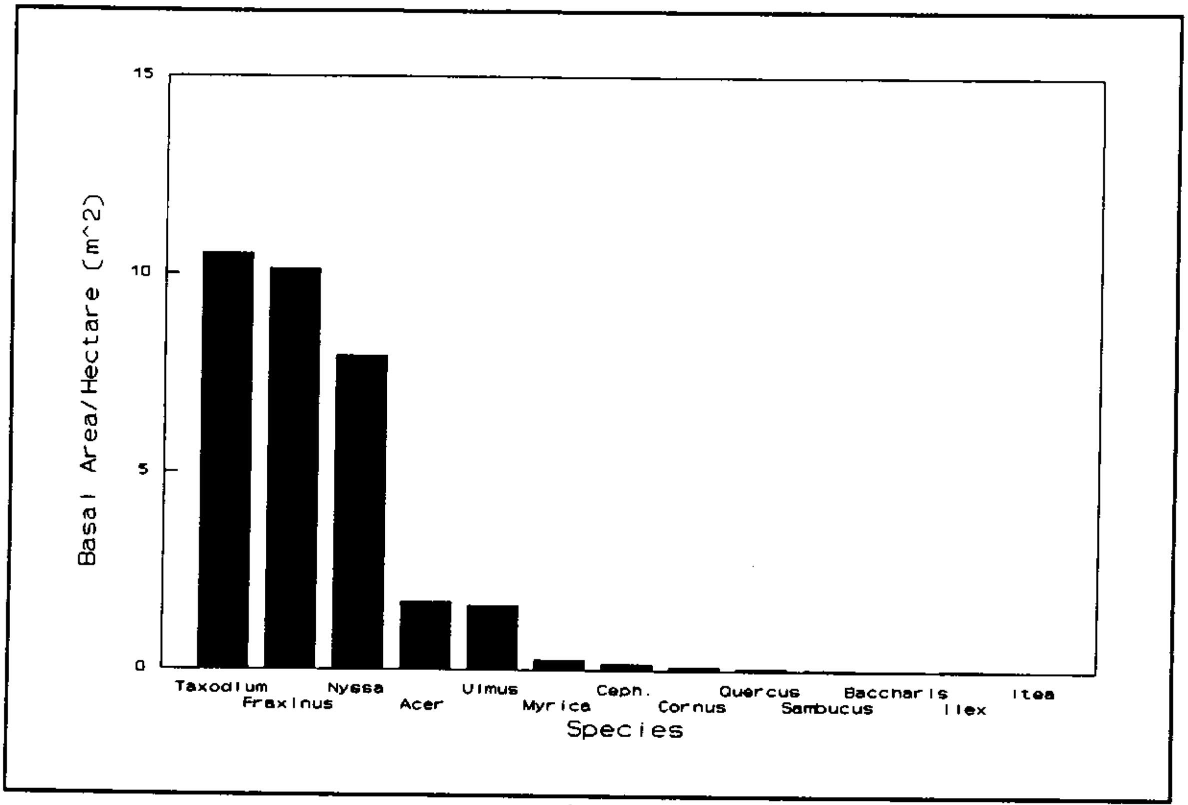
Size Class Frequency

dBH Class	Plot 1	Plot 2	Plot 3	Average/Hectare
1-5	43	43	34	2000.00
5-10	17	10	20	783.33
10-15	11	7	10	466.67
15-20	3	3	7	216.67
20-25	3	4	7	233.33
25-30	3	2	3	133.33
30-35	2	0	0	33.33
35-40	1	0	0	16.67
40-45	0	0	0	0.00
45-50	1	0	0	16.67

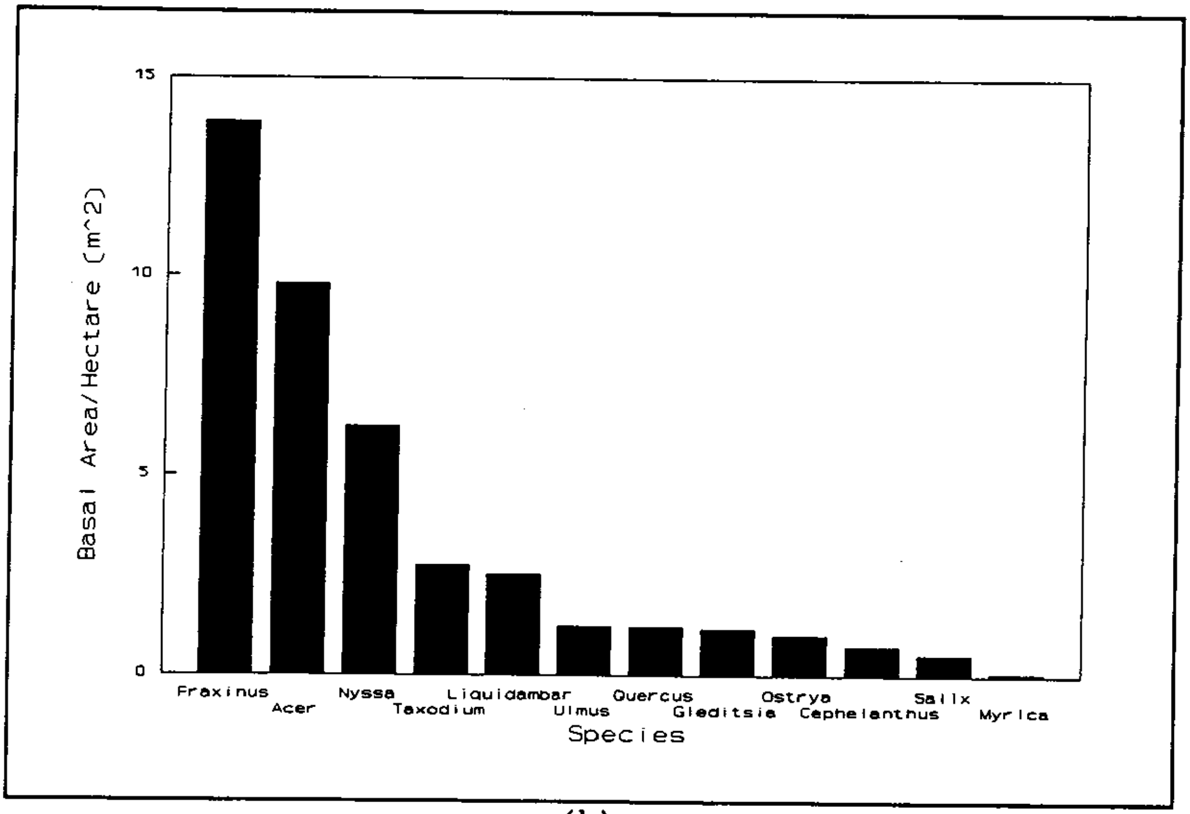
Relative coverage. The basal area coverage (m^2/hectare) of tree and shrub species in the experimental and reference site is presented in Figure 34. The total average basal area per hectare was somewhat higher in the reference site, 41.2 m^2/ha, compared to 32.6 m^2/ha in the experimental site. The species of greatest dominance in both sites were pop ash (*Fraxinus caroliniana*), bald cypress (*Taxodium distichum*), blackgum (*Nyssa sylvatica*) and red maple (*Acer rubrum*). Bald cypress was significantly more dominant in the experimental site (32% relative coverage) than in the reference site (7% relative coverage).

Relative Frequency. The frequency of tree and shrub species (#/hectare) in the experimental and reference site is presented in Figure 35. In both sites ash showed the highest relative frequency followed by buttonbush (*Cephelanthus occidentalis*). The frequency of ash was higher in the experimental site (46% relative frequency) than the reference (37% relative frequency) but was attributed mainly to individuals of sapling size. Bald cypress and elm (*Ulmus americana*) had a higher frequency in the experimental site while ironwood (*Ostrya virginiana*) and locust (*Gleditsia aquatica*) were found only in the reference site.

Figure 34. Relative Coverage (basal area) of Tree and Shrub Species in Rice Creek Floodplain Swamp. a) Experimental Site; b) Reference Site.

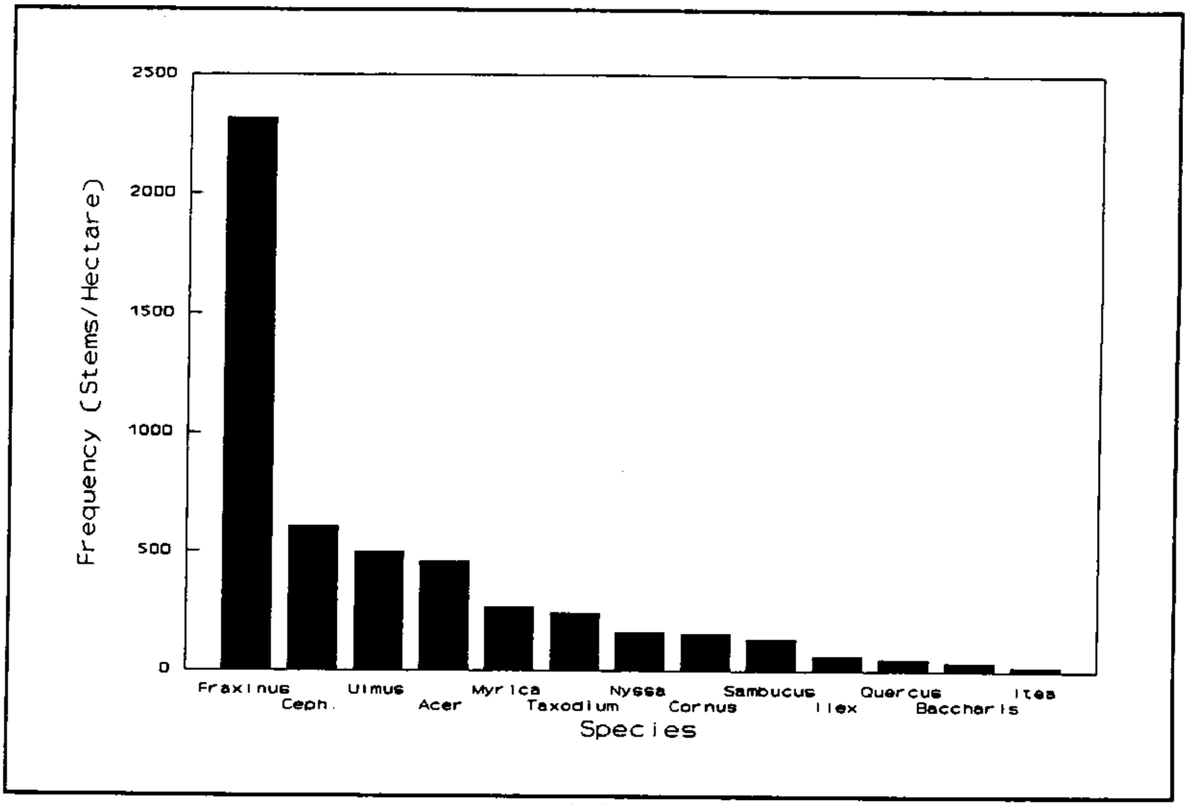

15
10
5
0
Basal Area/Hectare (m^2)
Taxodium
Fraxinus
Nyssa
Acer
Ulmus
Myrica
Ceph.
Cornus
Quercus
Sambucus
Baccharis
Ilex
Itea
Species

(a)

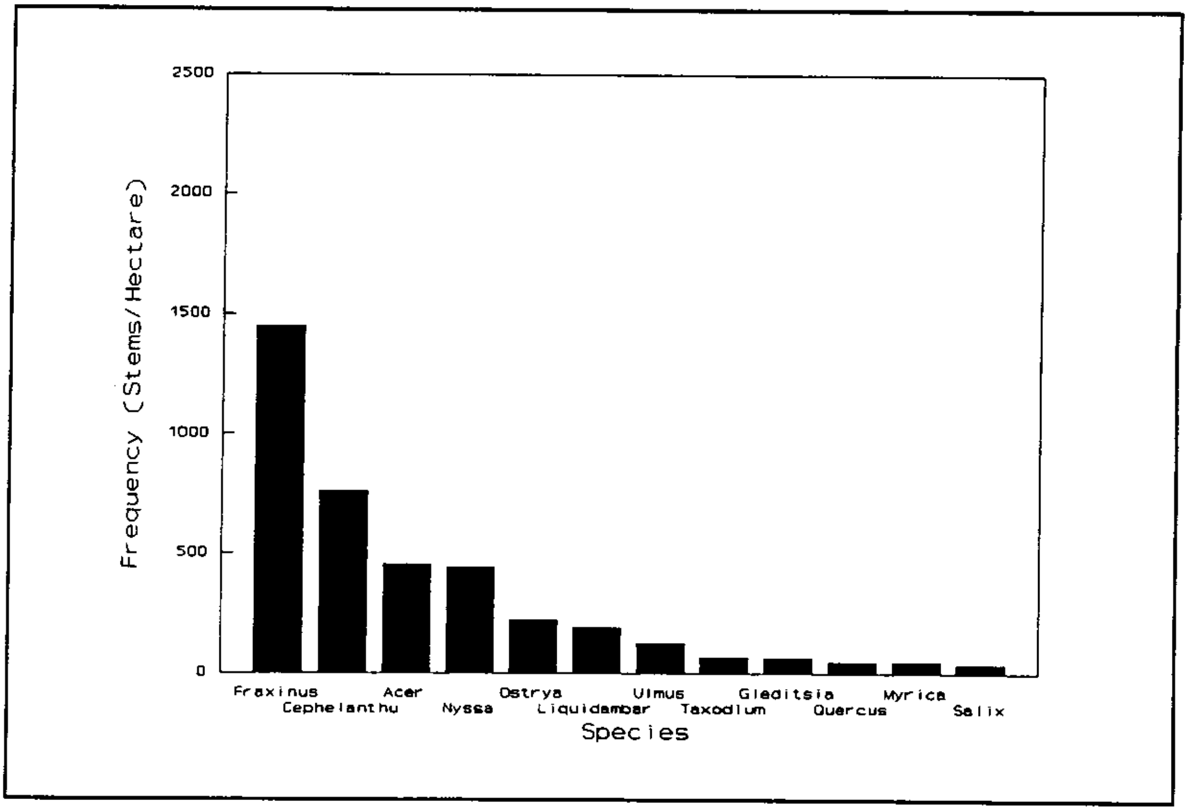

15
10
5
0
Basal Area/Hectare (m^2)
Fraxinus
Acer
Nyssa
Taxodium
Liquidambar
Ulmus
Quercus
Gleditsia
Ostrya
Cephelanthus
Salix
Myrica
Species

(b)

Figure 35. Relative Frequency of Tree and Shrub Species in Rice Creek Floodplain Swamp.
a) Experimental Site; b) Reference Site.


2500
2000
1500
1000
500
0
Frequency (Stems/Hectare)
Fraxinus
Ceph.
Ulmus
Acer
Myrica
Taxodium
Nyssa
Cornus
Sambucus
Ilex
Quercus
Baccharis
Itea
Species

(a)


2500
2000
1500
1000
500
0
Frequency (Stems/Hectare)
Fraxinus
Cephelanthu
Acer
Nyssa
Ostrya
Liquidambar
Ulmus
Taxodium
Gleditsia
Quercus
Myrica
Salix
Species

(b)

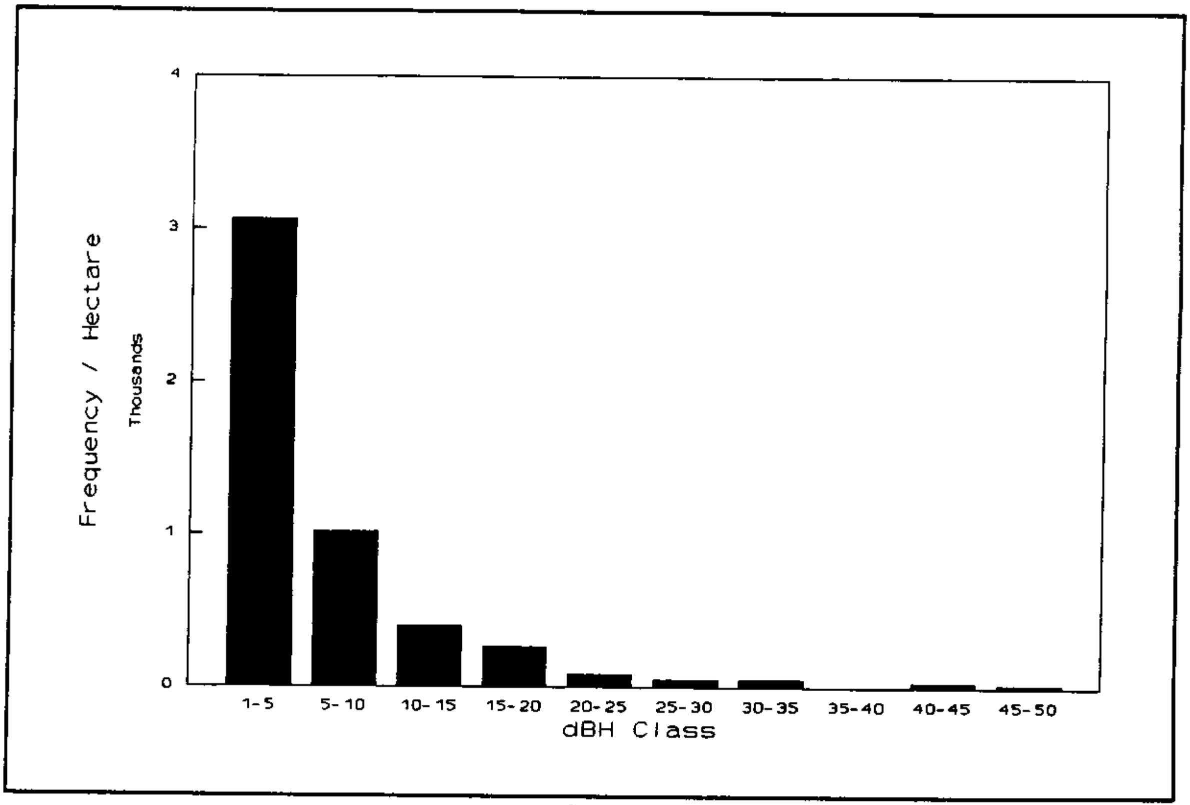
Size class frequency. The basal area size class frequency per hectare of tree and shrub species in the experimental and reference site is presented in Figure 36. The relative frequency of individuals in the 1-5 cm and 5-10 cm dBH class was significantly higher in the experimental site. This may be attributed to a lowering of the water level in 1985 when effluent was re-routed and no longer discharged to this area to the floodplain.

Species diversity. The Shannon-Weaver diversities (log base 2) of tree and shrub species were similar in the experimental site (2.40) and the reference site (2.49). Student's t Test statistics (0.05 significance level) revealed no significant difference in the two mean diversities.

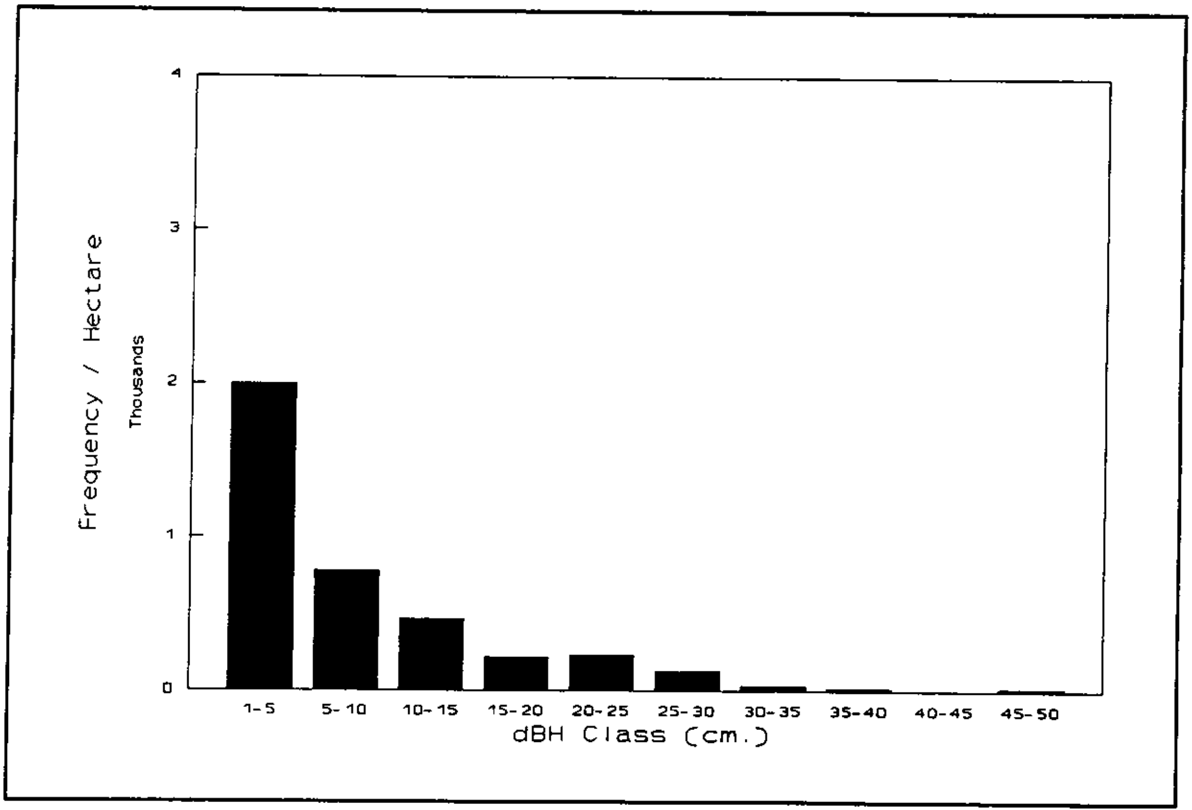
Cypress Growth Rate

The annual basal area growth rate in cm^2 of cypress averaged in four year increments for the 40 years period from 1953-1992 is presented in Figure 37 and 38 for the experimental and reference site respectively. In both the experimental and reference site average cypress growth was greatest during the time period 1973-1988. This may be attributed to canopy release and weather conditions.

Figure 36. Size Class Frequency per Hectare of Trees and Shrubs in Rice Creek Floodplain Swamp.
a) Experimental Site; b) Reference Site.


Frequency / Hectare
Thousands
4
3
2
1
0
1-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
dBH Class

(a)


Frequency / Hectare
Thousands
4
3
2
1
0
1-5
5-10
10-15
15-20
20-25
25-30
30-35
35-40
40-45
45-50
dBH Class (cm.)

(b)

The period of effluent discharge to the experimental site was from 1973-1985 (Simmons, Marvin. G.P. Palatka 1992, personal communication). This represents the period of any potential impacts on growth due to effluent inundation. Student's t Test statistics (0.05 significance level) were applied to the growth data from both sites. Although there was no significant difference in the growth trends of cypress in both sites over most of the 40 year period, average growth was significantly higher in the experimental site during the time period 1977-1980 when effluent was being discharged to this area of the floodplain.

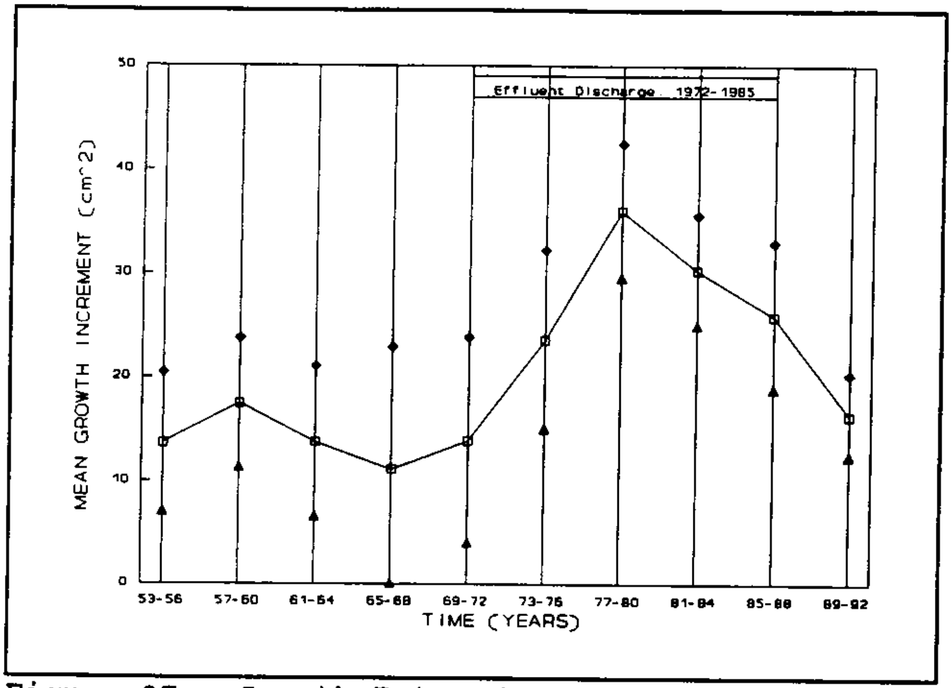


Figure 37. Growth Rates (Mean +- SE) of 10 Cypress Trees in Rice Creek Experimental Site.

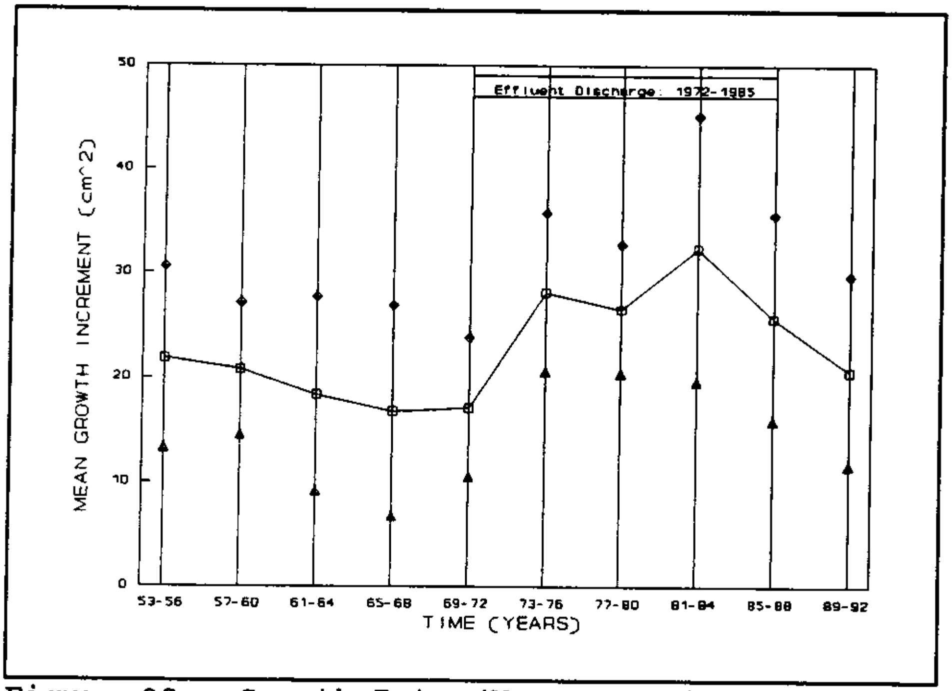


Figure 38. Growth Rate (Mean +- SE) of 10 Cypress Trees in Rice Creek Reference Site.

DISCUSSION

Successional Potential of Pilot Marsh To Forested System

According to classical ecosystem succession theory, communities develop through time, self organizing to autogenically altered biotic and abiotic parameters in a direction towards a mature climax system (Odum, E.P., 1971). Gleason, 1917 advocated an individualistic continuum concept of community succession, where sets of species exist according to allogenic environmental conditions.

More mature ecosystems are sometimes considered of higher value as measured by gross production, species diversity and long term organic matter and information storage. Anthropogenic impacts on ecosystems, such as wastewater discharge, can alter successional patterns, often causing an arrested early successional state to persist. The question to be answered about the Champion pilot wetland was whether succession to a swamp dominated by wetland trees was feasible. After the ecosystem was primed by planting propagules, herbaceous and tree species were monitored to determine what succession was taking place.

The tree seedling study showed that a forested wetland was feasible. There was no phytotoxicity or growth inhibition associated with moderate effluent inundation. The most significant factors in seedling survival and growth were depth of inundation and competition with herbaceous communities. Tree species performance in the pilot wetland mirrored the relationships found in a relative flood tolerance study conducted by Harms, et al. (1980). Pond cypress (*Taxodium ascendens*) and bald cypress (*Taxodium distichum*) showed the greatest flood tolerance followed by black gum (*Nyssa sylvatica*) and pop ash (*Fraxinus caroliniana*), which had the least successful growth and survival in the pilot marsh.

The stress associated with inundation is caused primarily by the anaerobic soil conditions, but can also relate to water quality parameters such as dissolved oxygen, suspended solids, and compounds which are reduced to phytotoxic forms in the sediments such as sulfide (Ewel and Odum, 1986). Growth limiting and potentially toxic substances are also produced by anaerobic respiration in the roots and by microbes in the sediments (Kowzlowski, 1984).

Tree species differ in their morphological and physiological response to flooding as well as in the timing of adaptation. Hook and Brown (1973) established a strong correlation between flood tolerance and specialized root adaptations. Five floodplain tree species were tested under greenhouse conditions. Those species which were able to undergo morphological and physiological root adaptations showed greater flood tolerance. Among the adaptations identified by Hook and Brown were the ability to regenerate secondary roots, often succulent and less branched, the development of adventitious water roots, the ability to respire anaerobically, tolerate high concentrations of carbon dioxide, and oxidize the rhizosphere.

In the Champion pilot wetland, tree seedling survival and growth was excellent except under almost complete submersion or where dense herbaceous communities strangled individual seedlings. Growth of the two cypress species and blackgum was comparable or higher in the wetland than in an irrigated drained site of the same soil type outside the wetland. The author concluded that initial mortality and growth retardation in the wetland was due to the normal stress of inundation. Once individuals adapted they thrived in the nutrient enriched effluent. High aquatic algal production during daylight hours increasing dissolved oxygen levels in the water profile and sediment interface likely also contributed to seedling success.

Although tissue analysis was not conducted on tree seedlings, it was assumed from the positive results of analysis of herbaceous plant tissue for chlorinated organic compounds (measured as extractable organic halogen (EOX)) that some uptake did occur. Enough time had transpired to achieve near steady state concentrations (CH2M-Hill, 1992). Assuming similar uptake, these low concentrations (<2 - 25 mg/kg EOX measured in *Juncus*) did not significantly impact the health of tree seedlings. The low water solubility of dioxin and it's affinity to adsorb on sediments limits plant uptake. Dioxin was not detected in plant, fish or benthos samples from the pilot wetland (CH2M-Hill, 1992).

Implications of Aquatic Production, Eh-pH Parameters and Ecosystem Structure on Pollutant Dynamics

In the first year of operation, the pilot treatment wetland supported high gross primary production, up to 7.6 g/m^2/day in the lower deep zone of cell D. Although highly stratified, gross and net primary production was highest in deep zones and increased dramatically from the influent end deep zone of Cell D to the effluent end deep zone. The net production/night respiration (P/R ratio) increased from 0.3 to 1.6 from station D1 to station D2. This indicated longitudinal succession of the phytoplanktonic and algal community and possibly the impact of a reduced organic load in the effluent. The longitudinal succession follows patterns observed in sewage outfalls in streams where heterotrophic (P>R) aquatic communities give rise to autotrophic (P>R) communities down stream (Odum, 1956). This pattern was not observed in cell C which did not have deep zones and had a significantly shorter hydraulic retention time.

Different Eh-pH parameters of aquatic systems are due primarily to photosynthesis, respiration and redox changes in the sulfur iron system. Microorganisms including bacteria, fungi and algae are important in the mediation or catalysis of redox reactions (Faust and Aly, 1981). The Eh-pH characteristics of the pilot wetland were compared to similar data from numerous aquatic and benthal systems presented by Baas Becking et al. (1960). The pilot wetland data falls within the lower right hand quadrant (moderate to high pH and medium to low redox potential) of the Eh-pH envelope including over 4000 aquatic environments. The relatively high pH is due to alkaline mill process waters and photosynthetic production in the mill's secondary treatment lagoons and the wetland itself. Often liquid carbon dioxide is added to the primary effluent to lower the pH. The redox potential of the pilot wetland surface water was higher than the reference wetland, indicating higher average dissolved oxygen levels in the productive stratum. In comparison to redox potential distributions for aquatic systems described by Bass Becking, et al. (1960) the pilot wetland Eh was medium to low. Reduced conditions may be attributed to the effluent organic load.

Given the Eh-pH conditions measured in the surface water of the pilot wetland and the effluent water chemistry the following conclusions were drawn. In the narrow upper strata of the water column where high dissolved oxygen levels are produced and when eddy diffusion to lower strata and active plant oxygen transport to sediments occur, aerobic respiration and other chemical oxidation processes occur including microbially catalyzed nitrification of ammonia nitrogen. The resulting highly mobile oxidized nitrogen (NO_2 + NO_3) is either quickly assimilated by plants and microbes or readily undergoes denitrification reduction under the anaerobic conditions which prevail in the wetland. Loss of nitrogen to the system is limited by dissolved oxygen levels, temperature and the relative thermodynamic stability of ammonia, present in the wetland mainly in unionized form, over a large Eh range (Faust and Aly, 1981).

After nitrogen, manganese, iron and sulfur compounds serve next as electron acceptors in the absence of oxygen. If sulfate is present in high concentrations in effluent or sediments, sulfides formed under reduced conditions may cause toxic effects on plants and microbes. The presence of iron in sediments can mediate this by forming insoluble ferrous sulfide (Mitsch and Gosselink, 1986). Concentrations of sulfate in the kraft effluent in this study were not of concern at approximately 15 ppm.

Organic carbon compounds may also serve as electron acceptors in microbial anaerobic respiration. This fermentation process results in low molecular weight acids and alcohols and carbon dioxide which are available for further microbial degradation (Mitsch and Gosselink, 1986).

Under extreme reducing conditions (-250 to -350 mv) which may occur in wastewater treatment wetland sediments, methanogenesis, the reduction of carbon dioxide or a methyl group to methane, could also occur.

The sequence of biologically mediated chemical reactions from surface waters to sediments in eutrophic wetland systems is analogous to the temporal succession in an anaerobic batch digester; aerobic heterotrophs, denitrifiers, fermentors, sulfate reducers, and methane bacteria. In a wetland, however, these biological and chemical processes may occur concurrently.

As a marsh wetland develops, the macrophyte coverage eventually reduces aquatic production unless areas of open water are present. The presence of dissolved oxygen is necessary and can become limiting for the metabolism of many pollutants of concern including nitrification of ammonia. Nitrification is generally the limiting step in ammonia removal from wetlands as denitrification occurs readily in the anaerobic benthic zone (Knight, 1990). CH2M-Hill (1992) reported slightly lower ammonia reduction in the second season of operation for the pilot wetland and attributed this to increased macrophyte cover and thus lower dissolved oxygen levels. Alternating open areas supporting high rates of photosynthesis and shallow and deep marsh areas were design components in the full scale wetland treatment system conceptual design (CH2M-Hill, 1992).

As the degradation, complexation and assimilation processes of kraft effluent pollutants occur slowly in nature, hydraulic retention time is an important design consideration for any full scale constructed wetland. The pilot wetland cells with deep zones and thus longer hydraulic retention times were more effective in reducing the effluent chronic toxicity to water fleas and fathead minnows (possibly caused by ammonia and trace low molecular weight chlorinated organics) than those without (CH2M-Hill, 1992).

The Potential Role of Forested Wetland Peat Substrate in Pollutant Conversion and Retention

In the global carbon-oxygen cycle, lignin is a rate limiting factor, sometimes taking several thousand years to recycle once the polyaromatic compounds are complexed in soil humic matter (Crawford, 1981). Under anaerobic conditions caused by flooding in wetlands the rate of lignocellulose degradation is further reduced, leading to the accumulation of peat.

Kraft lignins, which contribute the major portion of persistent pollutants in kraft mill effluent such as chemical oxygen demand (COD), color, and chlorinated organics, are similarly resistant to degradation, causing difficulty in designing effective and economically feasible secondary or tertiary effluent treatment systems.

Unlike engineered biological treatment systems which culture discrete associations of microbes, wetlands with physical, chemical and structural diversity develop a synergistic heterotrophic microbial food chain capable of slowly degrading or converting recalcitrant lignaceous materials, such as those found in kraft mill effluent, to forms which are available for natural metabolic cycles or biologically inactive in peat humic compounds. The peat serves as a chemical and biological medium for natural wastewater treatment.

The physical and chemical characteristics of peat as well as biological processes it supports are important in understanding its potential role in a paper mill effluent treatment wetland. In general, the level of organic matter decomposition and bulk density increases with increasing depth in the sediment profile. The average bulk density of peat is low, 0.1 g/cm^3 for the peat used in microcosms in this study. The hydraulic conductivity of peat is very low, especially in more advanced stages of decomposition and exchange with groundwater is usually insignificant. In certain cases however, as in perched wetlands in Florida, some groundwater recharge may occur (Ewel and Odum, 1986).

Humic and fulvic compounds in blackwater and peat, often in the form of negatively charged colloids, have an affinity to form complexes with metal ions. Also, due to their large void fraction and functional groups which undergo hydrogen bonding, peat substrates can adsorb other organic compounds including trace toxic materials (Strumm and Morgan, 1981).

The acidification of peat interstitial water is caused by the high cation exchange capacity of peat and by active cation exchange by plant species, most importantly Sphagnum spp. (Baas Becking, et al., 1960). Under lower pH conditions the microbiotic community associated with the peat shifts towards more fungal relative to bacterial species in the food chain (Mitsch and Gosselink, 1986).

Species of white rot fungi, which posses some of the strongest oxidative enzyme systems in nature, have been shown to be an important first step in the degradation and conversion of kraft lignins. Hall, et al., (1980) studied this process in submerged culture fermentations of the white rot fungus *Coriolis versicolor*. Some of the kraft lignins were metabolized to carbon dioxide while most were extensively transformed to higher molecular weight compounds with a higher oxygen content.

The peat microcosm study showed that forested wetland peat can serve as a medium for degradation, conversion, and long term storage of nutrients, suspended solids, oxygen demanding organics, and potentially toxic and persistent chlorolignins. Although color was not reduced, the complexation of effluent color constituents (mainly kraft lignins) into humic and fulvic compounds natural to blackwater systems may have occurred. Evidence exists that peat serves as a significant sink for chlorinated organics and may in fact participate to a degree in their formation (Asplund, et al., 1989). One can conclude that interfacing pulp and paper mill effluent with an appropriate wetland ecosystem man can utilize this natural pollutant conversion and long term storage system in a mutually beneficial manner.

Impacts of Kraft Mill Effluent on a Natural Forested Floodplain Swamp

The Rice Creek forest data did not show negative impacts on tree growth during the period of secondary treated effluent discharge. As noted in other studies of municipal effluent in natural wetlands, the growth rate of plant species may be stimulated by enriched nutrient conditions (Best, 1984; Ewel and Odum, 1984). Although more rigorous sampling would be necessary to prove cypress growth stimulation by effluent discharge in the Rice Creek experimental site, the data collected in this study did indicate that growth was stimulated during the period of effluent discharge to the experimental floodplain site and that growth followed the normal pattern over time for a floodplain system. The growth rate of bald cypress in both sites was high (reaching approximately 25 cm^2 per year) compared to data presented on several hundred bald cypress in floodplains throughout north and central Florida by Odum, et al. (1983). The average growth rate reported by Odum et al. (1983) reached a plateau at approximately 13 cm^2 per year.

Some differences in the stand composition of the experimental site were found compared to the upstream reference site were noted, but the diversity was similar and comparable to diversities reported for forested wetland systems in the Southeast (Monk, 1966, 1968). Species differences may be attributed to relative geographic location in the floodplain. The experimental site was in a broader, less channelized area of the floodplain with deeper peat deposits. The relatively high percentage of small size class individuals in the experimental site (1-10 cm dBH) indicates that increased regeneration occurred after effluent discharge to the site ceased. Perhaps the difference was due to a change in hydroperiod and an overall lowering of water depth in the absence of the effluent input.

Important design consideration in any natural or coupled constructed - natural wetland treatment system are loading rates and dispersion mechanisms which can maintain the hydroperiod within the limits of toleration of the natural plant community. Changes in hydroperiod and nutrient conditions may cause a shift in relative species composition at the effluent discharge point, but under reasonable loading rates and with a relatively high quality of secondary treated effluent the conditions can be within the range found in Florida wetlands naturally.this would be a localized and tolerable impact.

Certainly more research is warranted concerning the fate of chlorinated organics in natural wetland ecosystems, but evidence presented in this paper suggests that low molecular weight potentially toxic adsorbable organic halide (AOX) constituents are rapidly degraded and that higher molecular weight kraft lignins enter the natural sedimentation, humification and peat storage cycle, becoming biologically inactive.

Emergy Evaluation of Effluent Treatment Alternatives

The major inputs to two effluent treatment alternatives shown in Figure 1 were compared using the emergy method. Treatment alternative B (Figure 1(b)) is tertiary treatment using granular media filtration, carbon adsorption and ammonium ion exchange, and treatment alternative A (Figure 1(a)) is tertiary treatment using a wetland interface. A wetland such as that in the Rice Creek Floodplain was assumed with a hydraulic loading rate of 2 cm/day so that the effluent would be within the wetland long enough for the processes discussed in this thesis to operate. The results of the emergy evaluation per oven dry ton of pulp (ODTP) are presented in Table VI.

In emergy evaluation the inputs to the process, including contributions from nature and high quality feedbacks from society such as fuels and human service, are evaluated on a common basis, solar emjoules (sej). This allows the inclusion of work done by nature which is largely ignored by cost analysis, as money is paid only for the human services. The solar transformity (sej/J) of the final products, paper and effluent, was calculated for the kraft pulp and paper process using conventional primary and secondary treatment and using both tertiary treatment alternatives (Table VII).

The relatively high transformity of final effluent (5.66E+6 sej/J) indicates a high potential value to the economy or to the environment if the system can adapt to use the materials as by-products. The principle here is that high transformity substances are most valuable interacting with a larger quantity, lower transformity component adapted to utilize this value, such as a wetland (Odum and Arding, 1991). Using effluent to reinforcement environmental processes benefits the industry, environment and society. The industry would benefit from a less costly treatment process using a larger percentage of natural energies and making more high quality feedbacks from society such as fuels, chemicals and human services available for other uses. In addition, society and the environment benefit from the values associated with wetland conservation.

Table VI. Emergy Evaluation of Tertiary Treatment Alternatives. All Data per Oven Dry Ton of Pulp (ODTP).

Note	Item		Units /ODTP	Emergy/Unit (sej/unit)	Solar Emergy (E14 sej/ODTP)
Kraft Pulp and Paper Mill					
1	Water	J	4.45E+08	4.10E+04	0.18
2	Pine Pulpwood	J	6.84E+10	6.72E+03	4.60
3	NaOH (Pulping)	g	9.07E+03	7.45E+09	0.68
4	NaOH (Bleaching)	g	2.72E+04	7.45E+09	2.03
5	Na2SO4	g	3.63E+04	1.20E+09	0.44
6	Cl2	g	5.67E+04	8.42E+09	4.77
7	Fossil Fuel (Coal)	J	1.05E+10	4.00E+04	4.20
8	Services (Capital Costs)	$	400	1.60E+12	6.40
9	Services (Labor)				0.75
10	Services (Production Costs)	$	150	1.60E+12	2.40
	Sum (Emergy/ODTP)				26.44
Tertiary Treatment (Granular media filtration, carbon adsorption, ammonium ion exchange).					
11	NaOH	g	1.25E+05	7.45E+09	9.31
12	H2SO4	g	4.15E+04	4.56E+08	0.19
13	NaCl	g	1.06E+03	1.22E+09	0.01
14	Carbon	g	1.62E+04	1.42E+09	0.23
15	Electricity	J	2.70E+08	2.00E+05	0.54
16	Oil	J	9.22E+09	5.40E+04	4.98
17	Services (Capital Costs)	$	48.00	1.60E+12	0.77
18	Services (Operation /Maintenance Costs)	$	10.00	1.60E+12	0.16
	Sum (Emergy/ODTP)				42.63
Wetland Tertiary Treatment					
19	Treatment Wetland	hectare-yr	0.12	6.40E+15	7.68
20	Services (Capital Costs)	$	13.23	1.60E+12	0.21
21	Services (Operation /Maintenance Costs)	$	1.17	1.60E+12	0.02
	Sum (Emergy/ODTP)				34.35

Table VI. (continued).

NOTES

1 Water –(23500 gal./ODTP)(1 m^3/264.17205 gal.)
(1E+6 g/m^3)(5 J/g) = 4.45E+8 J (Personal Conversation (P.C.)
Dr Robert Fisher & Dr. Arun Someshwar, NCASI Gainesville, Fl.,
1992) Transformity = 4.10E+4 (Odum, 1992b)

2 Pine Pulpwood – (5 tons)(9.072E+5 g/ton)(3.6 kcal/g)
(4186 J/kcal) = 6.84E+10 J (Champion, 1991; Britt, 1970)
Transformity = 6.72E+3 sej/J (Odum, 1992a)

3 NaOH – Pulping – (20 lbs)(453.5923 g/lb) = 9.07E+3 g
(P.C. NCASI, 1992) Transformity = 7.45E+9 sej/g (Pritchard, 1992)

4 NaOH – Bleaching – (80 lbs)(453.5923 g/lb) = 3.63E+4 g
(P.C. NCASI, 1992)

5 Na2SO4 – (80 lbs)(453.5923) = 3.63E+4 g (P.C. NCASI, 1992)
Transformity = 1.20E+9 sej/g = 1.00E+9 sej/g raw material
(Odum, 1992b) + fuel in mining and transportation
0.50E+8 sej/g + services in capital and labor 1.50E+8 sej/g
(Majmundar, 1985)

6 Cl2 – (125 lbs)(453.5923 g/lb) = 5.67E+4 g (P.C. NCASI, 1992)
Transformity = 8.42E+9 sej/g calculated from joint production
process caustic + chlorine (1 ton chlorine/1.13 ton caustic)
(Pritchard, 1992; Hardie, 1975)

7 Fossil Fuel (Coal) – (10E+6 btu)(1054.35 J/btu) = 1.05E+10 J
(P.C. NCASI, 1992) Transformity = 5.40E+4 sej/J (Odum, 1992b)

8 Capital Cost (interest and depreciation) – ($600/ODTP total annual
cost) – ($150 O/M cost) – ($50 labor cost) = $400
(P.C. NCASI, 1992) U.S. 1991 emergy/money ratio = 1.60E12 sej/$

9 Services (Labor) – Emergy * Work Hours = Emergy Delivery Rate.
(800 emp. school +)(2.58E+14 sej/day)/(1400 tons/day)
= 4.30E+13 sej/ODTP
(200 emp. college +)(7.67E+14 sej/day)/(1400 tons/day)
= 1.10E+14 sej/ODTP
4.30E+13 + 1.10E+14 = 1.53E+14 sej/ODTP
(Champion, 1991; Odum, 1992b)

10 Services (embodied in production costs) – ($600 total production
cost per ODT paper)(.25 – percentage of total cost in capital costs
and costs other than labor, energy and raw material) = $150
U.S. emergy/money ratio = 1.60E+12 sej/$
(P.C. NCASI, 1992; OECD, 1985)

11 NaOH – (70080 ton/yr)/(365 day/yr)/(1400 ton/day)(2000 lb/ton)
(453.59 g/lb) = 1.25E+5 g (Sirrine, 1989)

12 H2SO4 – (23360 ton/yr)/(365 day/yr)/(1400 ton/day)(2000 lb/ton)
(453.59 g/lb) = 4.15E+4 g (Sirrine, 1989)
Transformity = 4.56E+8 sej/g – calculated for 100% H2SO4 from
Pritchard (1992)

13 NaCl – (2.35 lb/ODTP)(453.59 g/lb) = 1.06E+3 g (Sirrine, 1989)
Transformity = 1.22E+9 sej/g = 1.00E+9 sej/g raw material
(Odum, 1992b) + fuel in mining and transportation 0.50E+8 sej/g
+ services in capital costs 1.50E+8 sej/g (estimated)

14 Carbon – (18.3E+6 lb/yr)/(365 day/yr)/(1400 ton/day)(453.59 g/lb)
= 1.62E+4 g (Sirrine, 1989)
Transformity = 1.42E+9 sej/g = coal transformity converted to mass
basis (Odum, 1992b)

Table VI. (continued).

15 Electricity - (5884 HP)(42.44 btu/min/HP)(1440 min/day)/
(1400 ton/day)(1054.35 J/btu)+(2.7E+5 kwh/yr)(3.6E+6 J/kwh)
= 2.70E+8 J (Sirrine, 1989)
Transformity = 2.00E+5 sej/J (Odum, 1992b)

16 Fuel Oil - (31.4E+6 gal/yr)(1.5E+8 J/gal)/(365 d/yr)(1400 ton/day)
= 9.22E+9 J (Sirrine, 1989)
Transformity = 5.40E+4 sej/J (Odum, 1992b)

17 Capital Cost (interest and depreciation) - $1.87E+7 (granular media
filtration & carbon adsorption) + $5.89E+6 (ammonium ion exchange)
= ($2.46E+7/yr)/((365 day/yr)/(1400 ton/day) = $48 (Sirrine, 1989)
U.S. 1991 emergy/money ratio = 1.60E+12 sej/$

18 Operation/Maintenance Costs - ($4.24E+7/yr)
+ ($8.67E+6/yr)/(365 day/yr)/(1400 ton/day) = $10 (Sirrine, 1989)
U.S. 1991 emergy/money ratio = 1.60E+12 sej/J

19 Treatment Wetland - (50 ac/mgd)(0.0235 mgd/ODTP) = (1.175 ac)
(estimated retention time 0.25 yr)/(2.47 ac/hectare) =
0.24 hectare-yr (CH2M-Hill, 1990a)
Loading (50 ac/mgd) based on 80% reduction of ammonia-N
= 2.00 cm/day (CH2M-Hill, 1990a)
Emergy use/hectare = 6.40E+15 sej/hectare-yr calculated for
floodplain wetland using transpiration (Ewel and Odum, 1984)

20 Capital Costs - ($58.8E+6)(0.115)/(365 day/yr)/(1400 ton/day)
= $13.23 (CH2M-Hill, 1990a)
U.S. 1991 emergy/monmey ratio = 1.60E+12 sej/$

21 Operation/Maintenance Costs - ($0.6E+6)/(365 day/yr)/(1400 ton/day)
= $1.17 (CH2M-Hill, 1990)
U.S. 1991 emergy/monmey ratio = 1.60E+12 sej/$

Table VII. Emergy Indices of Tertiary Treatment Alternatives and Transformities of Final Products.

Note		Net Emergy Yield Ratio	Emergy Investment Ratio	Solar Transformity of Final Products (sej/J)
	Kraft Pulp & Paper Process with Primary & Secondary Effluent Treatment	1.22	4.53	
1	Paper			1.42E+05
2	Final Effluent			5.66E+06
	With Technological Tertiary Treatment (granular media filtration, carbon adsorption, ammonium ion exchange)	1.13	8.07	
3	Paper			2.29E+05
	With Wetland Tertiary Treatment	1.57	1.76	
4	Paper			1.85E+05

FOOTNOTES

1 Transformity of Paper: (1 ton)(2000 lbs/ton)(453.59 g/lb)
(2.052E+4 J/g) = 1.86E+10 J (Doherty, et.al., 1992)
Transformity = 26.44E+14 sej/1.86E+10 J = 1.42E+5 sej/J

2 Transformity of Final Effluent:
Final Effluent Solids - (3250 lbs black liquor
solids/ton pulp)(6000 BTU)(1.055E+3 J/BTU) = 2.06E+10 J/ton
/(2000 lbs/ton)/(453.59 g/lb) = 2.27E+4 J/g (P.C. NCASI, 1992)
Effluent Solids = (1559 mg/l TDS + TSS)(1E-3 g/mg)/(0.2642 gal/l)
= 0.412 g/gal(2350 gal/ODTP) = 9.68E+2 g (CH2M-Hill, 1990)
(2.27E+4 J/g)(9.68E+2 g) = 2.20E+7 J
Water -(23500 gal./ODTP)(1 m^3/264.17205 gal.)
(1E+6 g/m^3)(5 J/g) = 4.45E+8 J (Personal Conversation (P.C.)
Dr Robert Fisher & Dr. Arun Someshwar, NCASI Gainesville, Fl., 1992)
Transformity of Effluent = 26.44E+14 sej/(2.20E+7 J + 4.45E+8 J)
= 5.66E+6 sej/J

3 Transformity of Paper: (1 ton)(2000 lbs/ton)(453.59 g/lb)
(2.052E+4 J/g) = 1.86E+10 J (Doherty, et.al., 1992)
Transformity = 42.63E+14 sej/1.86E+10 J = 2.29E+5 sej/J

4 Transformity of Paper: (1 ton)(2000 lbs/ton)(453.59 g/lb)
(2.052E+4 J/g) = 1.86E+10 J (Doherty, et.al., 1992)
Transformity = 34.35E+14 sej/1.86E+10 J = 1.85E+5 sej/J

Wetland values include water storage and groundwater table maintenance, primary and secondary production, habitat diversity, and aesthetic and educational human uses (Knight, 1992).

The net emergy yield ratio and emergy investment ratio were used in interpreting the emergy evaluation (Table VII). The net emergy yield ratio is the emergy yield divided by the emergy used for processing. Fuels, water, wood and other raw materials have a high net emergy yield ratio (2-10) and are capable of contributing more to the economy than they require from it for processing. However, at the end of processes generating high quality products such as paper, net emergy yield ratios are close to one. Paper is a high emergy product with a high transformity. It is too valuable to use as a fuel. Paper contributes to the economy about what is taken from the economy in it's manufacture.

The net emergy yield ratio of pulp and paper production using technological tertiary treatment was considerably lower than that for the system using wetland treatment (1.13 vs. 1.57). Although the transformity of final product was higher in alternative B, the lower net emergy yield ratio indicates a lower efficiency when high quality resources from society are scarce.

The emergy investment ratio measures the purchased inputs relative to the free ones from using environmental resources. In the U.S., where the intensity of economic development is high, systems using the environment such as forestry operations typically have seven times more emergy brought in with purchased inputs as supplied free from the environment. Any process that has a lower emergy investment ratio than 7 uses the environment more, has lower costs and tends to compete economically with alternative investments. The low value of 1.76 for the wetland tertiary treatment alternative suggests it would be economic.

The emergy investment ratio of alternative B was 8.07 as opposed to 1.76 for alternative A. Alternative B relies heavily on intensive technological processes while alternative A uses a larger percentage of free natural emergy.

Recommendations

The black wastewaters discharged from kraft pulp and paper mills have a solar transformity of 5.66E+6 sej/J, a value higher than fresh water. Potentially, these waters can make a contribution to an environmental system capable of developing a good ecosystem. The various pieces of evidence assembled in this thesis suggest that wastewaters passing through wetlands including some long stretches of peaty forested wetlands can be reconditioned and become similar to normal blackwater characteristic of Florida's streams. It should be possible to reorganize water processing and recycling between pinelands that develop wood, the 10-20% of wetlands and small streams among the pinelands and the paper mills so as to maintain a fairly normal landscape of wetlands and wildlife while closing the loop of water use and reuse. Such a symbiotic interfacing of industrial process wastes with environmental systems will be increasing value to society as fossil fuels and other high quality resources become scarce and as landfill space becomes limiting.

The groundwork has been laid for a large scale pilot test of wetlands for general reconditioning of pulp and paper wastewaters. The test should include large areas of peaty forested wetland and have the objective of converting the wastewater to normal swamp blackwater.

APPENDIX
SEEDLING GROWTH STUDY STATISTICS

SEEDLING GROWTH STATS 6/6/91 - 9/18/91

CELL C

	BC	PC	PA	BG
MEAN	4.85	9.16	1.87	4.53
VAR	12.44	33.00	9.42	6.95
SS	684.02	1188.03	471.00	319.75
n	56	37	51	47
DF	55	36	50	46

CELL D

	BC	PC	PA	BG
MEAN	3.30	10.89	2.92	5.97
VAR	18.35	62.08	10.00	12.00
SS	1046.12	1676.10	520.19	576.20
n	58	28	53	49
DF	57	27	52	48

PLOT 1

	BC	PC	PA	BG
MEAN	6.58	12.68	4.55	6.97
VAR	16.44	39.76	18.47	10.73
SS	608.32	1312.18	572.71	343.24
n	38	34	32	33
DF	37	33	31	32

PLOT 2

	BC	PC	PA	BG
MEAN	3.03	6.67	1.05	4.56
VAR	10.00	40.33	2.63	8.91
SS	379.98	927.51	81.55	284.97
n	39	24	32	33
DF	38	23	31	32

PLOT 3

	BC	PC	PA	BG
MEAN	2.57	7.57	1.79	4.17
VAR	12.14	19.46	3.57	5.61
SS	436.94	116.76	139.37	162.56
n	37	7	40	30
DF	36	6	39	29

CELL C PLOT 1

	BC	PC	PA	BG
MEAN	7.03	11.67	4.03	5.06
VAR	7.18	25.22	19.25	4.34
SS	122.06	353.11	269.48	65.10
n	18	15	15	16
DF	17	14	14	15

CELL C PLOT 2

	BC	PC	PA	BG
MEAN	4.58	7.26	0.94	4.91
VAR	10.64	36.97	4.06	9.36
SS	191.49	591.58	60.88	149.76
n	19	17	16	17
DF	18	16	15	16

CELL C PLOT 3

	BC	PC	PA	BG
MEAN	3.05	8.10	1.00	8.76
VAR	11.42	10.64	1.38	10.09
SS	205.53	42.56	26.13	161.47
n	19	5	20	17
DF	18	4	19	16

CELL D PLOT 1

	BC	PC	PA	BG
MEAN	6.18	13.47	5.00	4.19
VAR	24.43	49.80	17.35	8.15
SS	464.21	896.43	277.65	122.29
n	20	19	17	16
DF	19	18	16	15

CELL D PLOT 2

	BC	PC	PA	BG
MEAN	1.55	5.21	1.16	4.78
VAR	4.92	45.49	1.18	5.00
SS	93.53	272.94	17.68	74.99
n	20	7	16	16
DF	19	6	15	15

CELL D PLOT 3

	BC	PC	PA	BG
MEAN	2.06	6.25	2.58	4.78
VAR	12.39	39.06	4.53	5.00
SS	210.56	39.06	86.11	74.99
n	18	2	20	16
DF	17	1	19	15

REFERENCE

	BC	PC	PA	BG
MEAN	6.30	14.83	11.40	6.50
VAR	5.01	7.76	22.22	4.15
SS	95.19	147.38	422.09	78.85
n	20	20	20	20
DF	19	19	19	19

GROWTH COMPARISON - STUDENTS t TEST

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CELL C PLOT 1 / CELL C PLOT 2

SP2       8.95855  31.4898  11.3918  6.93082
          0.98447  1.98788  1.21303  0.91699

             BC       PC       PA       BG
      t      2.49     2.21     2.55     0.16
Crit. t      2.03     2.04     2.04     2.04

CELL C PLOT 1 / CELL C PLOT 3

SP2       9.35958  21.9817  8.95786  4.81985
          1.00627  2.42111  1.02229  0.80344

             BC       PC       PA       BG
      t      3.95     1.47     2.97     1.99
Crit. t      2.03     2.10     2.03     2.05

CELL C PLOT 2 / CELL C PLOT 3

SP2       11.0283  31.7072  2.55893  7.57297
          1.09230  3.12920  0.54278  1.01390

             BC       PC       PA       BG
      t      1.40     0.27     0.12     1.43
Crit. t      2.03     2.09     2.03     2.04

CELL D PLOT 1 / CELL D PLOT 2

SP2       14.6771  48.7239  9.52670  9.15329
          1.21149  3.08625  1.07508  1.05380

             BC       PC       PA       BG
      t      3.82     2.68     3.58     4.34
Crit. t      2.02     2.06     2.04     2.04

CELL D PLOT 1 / CELL D PLOT 3

SP2       18.7434  49.2367  10.3929  7.62749
          1.40658  5.21629  1.06348  0.96197

             BC       PC       PA       BG
      t      2.93     1.38     2.28     4.14
Crit. t      2.03     2.09     2.03     2.04

CELL D PLOT 2 / CELL D PLOT 3

SP2       8.44683  44.5716  3.05253  6.57568
          0.94425  5.35286  0.58601  0.90662

             BC       PC       PA       BG
      t      0.54     0.19     2.42     0.65
Crit. t      2.03     2.36     2.03     2.04
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CELL C PLOT 1 / CELL D PLOT 1

SP2     16.2850  39.0483  18.2377  7.30854
        1.31109  2.15833  1.51283  0.94164

           BC       PC       PA       BG
      t    0.65     0.84     0.64     3.93
Crit. t    2.03     2.04     2.04     2.04

CELL C PLOT 2 / CELL D PLOT 2

SP2     7.70325  39.2965  2.61865  8.77557
        0.88915  2.81519  0.57212  1.03183

           BC       PC       PA       BG
      t    3.41     0.73     0.38     0.70
Crit. t    2.03     2.07     2.04     2.04

CELL C PLOT 3 / CELL D PLOT 3

SP2     11.8882  16.3245  2.95343  5.17299
        1.13408  3.38040  0.54345  0.83235

           BC       PC       PA       BG
      t    0.88     0.55     2.90     1.58
Crit. t    2.03     2.57     2.05     2.05

CELL C PLOT 1 / REFERENCE

SP2     6.03462  15.1664  20.9566  4.23375
        0.79811  1.33019  1.56363  0.69014

           BC       PC       PA       BG
      t    0.91     2.37     4.71     2.08
Crit. t    2.03     2.03     2.03     2.03

CELL C PLOT 2 / REFERENCE

SP2     7.74819  21.1132  14.2048  6.53165
        0.89174  1.51579  1.26413  0.84308

           BC       PC       PA       BG
      t    1.93     4.99     8.28     1.88
Crit. t    2.03     2.03     2.03     2.03

CELL C PLOT 3 / REFERENCE

SP2     8.12754  8.25828   11.795  4.64713
        0.91331  1.43686  1.08604  0.75119

           BC       PC       PA       BG
      t    3.56     4.68     9.58     4.04
Crit. t    2.03     2.06     2.02     2.04
```

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CELL D PLOT 1 / REFERENCE

SP2       14.7209  28.2112  19.9923  6.86620
          1.21329  1.70157  1.47500  0.86440

             BC        PC        PA        BG
      t      0.10      0.79      4.34      2.62
Crit. t      2.02      2.03      2.03      2.03

CELL D PLOT 2 / REFERENCE

SP2       4.96625  16.8127  12.9342  5.91573
          0.70471  1.80068  1.20627  0.81579

             BC        PC        PA        BG
      t      6.74      5.34      8.49      2.83
Crit. t      2.02      2.06      2.03      2.03

CELL D PLOT 3 / REFERENCE

SP2       8.49301  9.32215  13.3734  4.52456
          0.94682  2.26432  1.15643  0.71345

             BC        PC        PA        BG
      t      4.48      3.79      7.63      2.41
Crit. t      2.03      2.09      2.02      2.03

CELL C / CELL D

SP2       15.4476  45.4623  9.71760  9.53139
          0.73633  1.68889  0.61146  0.63032

             BC        PC        PA        BG
      t      2.10      1.02      1.72      2.28
Crit. t      1.98      2.00      1.98      1.99

PLOT 1 / PLOT 2

SP2       13.1772  39.9943  10.5524  9.81588
          0.82743  1.68604  0.81211  0.77129

             BC        PC        PA        BG
      t      4.29      3.56      4.31      3.12
Crit. t      1.99      2.00      2.00      2.00

PLOT 1 / PLOT 3

SP2       14.3187  36.6393  10.1725  8.29187
          0.87395  2.51233  0.75644  0.72640

             BC        PC        PA        BG
      t      4.59      2.03      3.65      3.86
Crit. t      1.99      2.02      1.99      2.00
```

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PLOT 2 / PLOT 3

SP2       11.0394  36.0090  3.15598  7.33663
          0.76251  2.57769  0.42133  0.68328

             BC        PC        PA        BG
      t      0.60      0.35      1.76      0.58
Crit. t      1.99      2.04      1.99      2.00

PLOT 1 / REFERENCE

SP2       12.5627  28.0684  19.8958  8.27634
          0.97914  1.49297  1.27143  0.81523

             BC        PC        PA        BG
      t      0.28      1.44      5.39      0.58
Crit. t      2.01      2.01      2.01      2.01

PLOT 2 / REFERENCE

SP2       8.33622  25.5925  10.0726  7.13379
          0.79407  1.53166  0.90465  0.75687

             BC        PC        PA        BG
      t      4.12      5.33     11.44      2.56
Crit. t      2.00      2.01      2.01      2.01

PLOT 3 / REFERENCE

SP2       9.67515  10.5654  9.68026  5.02939
          0.86327  1.42745  0.85206  0.64739

             BC        PC        PA        BG
      t      4.32      5.08     11.28      3.60
Crit. t      2.01      2.06      2.00      2.01
```

SEEDLING GROWTH STATS 6/6/91 - 4/21/92

CELL C

	BC	PC	PA	BG
MEAN	7.64	13.68	4.90	8.10
VAR	13.93	21.88	38.57	13.20
SS	431.69	415.76	732.74	316.80
n	32	20	20	25
DF	31	19	19	24

CELL D

	BC	PC	PA	BG
MEAN	8.44	16.88	10.07	13.31
VAR	35.43	56.32	47.76	42.43
SS	921.23	1070.12	668.67	975.97
n	27	20	15	24
DF	26	19	14	23

PLOT 1

	BC	PC	PA	BG
MEAN	9.56	16.11	9.10	12.97
VAR	24.84	45.38	54.19	32.24
SS	844.55	1225.30	1246.30	967.23
n	35	28	24	31
DF	34	27	23	30

PLOT 2

	BC	PC	PA	BG
MEAN	5.75	13.33	2.77	6.67
VAR	14.00	27.60	10.33	12.75
SS	322.00	303.57	103.35	216.75
n	24	12	11	18
DF	23	11	10	17

CELL C PLOT 1

	BC	PC	PA	BG
MEAN	9.73	14.80	7.50	9.25
VAR	10.66	13.31	60.78	12.21
SS	149.24	119.79	486.24	158.73
n	15	10	9	14
DF	14	9	8	13

CELL C PLOT 2

	BC	PC	PA	BG
MEAN	5.79	12.55	2.77	6.64
VAR	9.53	27.92	10.33	10.64
SS	152.48	251.28	103.30	106.40
n	17	10	11	11
DF	16	9	10	10

CELL D PLOT 1

	BC	PC	PA	BG
MEAN	9.42	16.83	10.07	16.03
VAR	35.43	61.72	47.76	27.98
SS	673.17	1049.24	668.64	447.68
n	20	18	15	17
DF	19	17	14	16

CELL D PLOT 2

	BC	PC	PA	BG
MEAN	5.64	17.25		6.71
VAR	24.84	7.56		16.06
SS	149.04	7.56		96.36
n	7	2		7
DF	6	1		6

REFERENCE

	BC	PC	PA	BG
MEAN	7.57	16.05	14.02	8.20
VAR	8.08	8.65	27.76	6.32
SS	153.52	164.35	527.44	120.08
n	20	20	20	20
DF	19	19	19	19

GROWTH COMPARISON - STUDENTS t TEST

CELL C PLOT 1 / CELL C PLOT 2

SP2	10.0573	20.615	32.7522	11.5273
	1.12343	2.03051	2.57227	1.36796

	BC	PC	PA	BG
t	3.51	1.11	1.84	1.91
Crit. t	2.04	2.10	2.10	2.06

CELL D PLOT 1 / CELL D PLOT 2

SP2	32.8884	58.7111		24.7290
	2.51848	5.71115		2.23324

	BC	PC	PA	BG
t	10.28	5.92		7.76
Crit. t	2.06	2.10		2.07

CELL C PLOT 1 / CELL D PLOT 1

SP2	24.9215	44.9626	52.4945	20.9106
	1.70514	2.64465	3.05489	1.65035

	BC	PC	PA	BG
t	0.18	0.77	0.84	4.11
Crit. t	2.03	2.06	2.07	2.04

```
CELL C PLOT 2 / CELL D PLOT 2

SP2       13.7054  25.884            12.6725
          1.66256  3.94086           1.72116

            BC       PC       PA       BG
     t      0.09     1.19              0.04
Crit. t     2.07     2.23              2.12

CELL C PLOT 1 / REFERENCE

SP2       9.17454  10.1478  37.5437  8.71281
          1.03458  1.23376  2.45941  1.02858

            BC       PC       PA       BG
     t      2.09     1.01     2.65     1.02
Crit. t     2.03     2.05     2.05     2.04

CELL C PLOT 2 / REFERENCE

SP2       8.74285  14.8439  21.7496  7.80965
          0.97541  1.49217  1.75063  1.04902

            BC       PC       PA       BG
     t      1.82     2.35     6.43     1.49
Crit. t     2.03     2.05     2.04     2.04

CELL D PLOT 1 / REFERENCE

SP2        21.755  33.7108  36.2448  16.2217
          1.47495  1.88636  2.05634  1.32864

            BC       PC       PA       BG
     t      1.25     0.41     1.92     5.89
Crit. t     2.02     2.03     2.03     2.03

CELL D PLOT 2 / REFERENCE

SP2       12.1024   8.5955            8.6576
          1.52775  2.17428           1.29216

            BC       PC       PA       BG
     t      1.26     0.55              1.15
Crit. t     2.06     2.10              2.06

CELL C / CELL D

SP2       23.7355  39.1018  42.4668  27.5058
          1.27311  1.97741  2.22586  1.49876

            BC       PC       PA       BG
     t      0.63     1.62     2.32     3.48
Crit. t     2.00     2.03     2.04     2.01
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PLOT 1 / PLOT 2

SP2     20.4657  40.2333  40.8984  25.1909
        1.19894  2.18853  2.32855  1.48731

          BC       PC       PA       BG
     t    3.18     1.27     2.72     4.24
Crit. t   2.00     2.03     2.04     2.01

PLOT 1 / REFERENCE

SP2     18.8314  30.2097  42.2319  22.1899
        1.21639  1.60916  1.96755  1.35103

          BC       PC       PA       BG
     t    1.63     0.04     2.50     3.53
Crit. t   2.01     2.01     2.02     2.01

PLOT 2 / REFERENCE

SP2     11.3219  15.5973  21.7512  9.35638
        1.01874  1.44209  1.75070  0.99379

          BC       PC       PA       BG
     t    1.79     1.88     6.42     1.54
Crit. t   2.02     2.04     2.04     2.03
```

SEEDLING GROWTH STATS   9/18/91 - 4/21/92

CELL C

	BC	PC	PA	BG
MEAN	2.02	2.13	3.93	3.18
VAR	2.18	4.20	24.71	5.98
SS	67.56	79.74	469.43	143.46
n	32	20	20	25
DF	31	19	19	24

CELL D

	BC	PC	PA	BG
MEAN	3.26	2.98	5.63	5.56
VAR	9.34	5.31	19.12	16.38
SS	242.84	100.93	267.62	376.77
n	27	20	15	24
DF	26	19	14	23

PLOT 1

	BC	PC	PA	BG
MEAN	2.86	2.55	5.08	5.85
VAR	5.58	4.68	20.31	12.83
SS	189.71	126.49	467.03	384.77
n	35	28	24	31
DF	34	27	23	30

PLOT 2

	BC	PC	PA	BG
MEAN	2.19	2.54	3.73	1.75
VAR	5.95	5.52	27.70	1.26
SS	136.95	60.71	276.98	21.37
n	24	12	11	18
DF	23	11	10	17

CELL C PLOT 1

	BC	PC	PA	BG
MEAN	2.27	1.95	4.17	4.14
VAR	1.46	4.87	20.94	7.94
SS	20.47	43.85	167.56	103.27
n	15	10	9	14
DF	14	9	8	13

CELL C PLOT 2

	BC	PC	PA	BG
MEAN	1.79	2.30	3.73	1.95
VAR	2.71	3.46	27.70	0.79
SS	43.32	31.14	276.98	7.93
n	17	10	11	11
DF	16	9	10	10

CELL D PLOT 1

	BC	PC	PA	BG
MEAN	3.30	2.89	5.63	7.26
VAR	8.21	4.27	19.12	12.44
SS	155.99	72.51	267.62	199.11
n	20	18	15	17
DF	19	17	14	16

CELL D PLOT 2

	BC	PC	PA	BG
MEAN	3.14	3.75		1.43
VAR	12.55	14.06		1.82
SS	75.31	14.06		10.90
n	7	2		7
DF	6	1		6

REFERENCE

	BC	PC	PA	BG
MEAN	1.45	1.23	2.63	1.93
VAR	0.65	0.99	2.02	1.23
SS	12.30	18.75	38.42	23.41
n	20	20	20	20
DF	19	19	19	19

GROWTH COMPARISON - STUDENTS t TEST

CELL C PLOT 1 / CELL C PLOT 2

SP2	2.12643	4.16625	24.6966	4.83496
	0.51657	0.91282	2.23365	0.88594

	BC	PC	PA	BG
t	0.91	0.38	0.20	2.47
Crit. t	2.04	2.10	2.10	2.06

CELL D PLOT 1 / CELL D PLOT 2

SP2	9.25184	4.80971		9.54600
	1.33577	1.63464		1.38753

	BC	PC	PA	BG
t	4.12	0.49		8.40
Crit. t	2.06	2.10		2.07

CELL C PLOT 1 / CELL D PLOT 1

SP2	5.34730	4.47557	19.7806	10.4270
	0.78984	0.83438	1.87524	1.16539

	BC	PC	PA	BG
t	1.31	1.13	0.78	2.68
Crit. t	2.03	2.06	2.07	2.04

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CELL C PLOT 2 / CELL D PLOT 2

SP2        5.39217 4.52025           1.17699
           1.04283 1.64686           0.52453

              BC       PC      PA       BG
       t      1.29     0.88             1.00
Crit.  t      2.07     2.23             2.12

CELL C PLOT 1 / REFERENCE

SP2        0.99313 2.23582 7.62856 3.95862
           0.34039 0.57911 1.10862 0.69331

              BC       PC      PA       BG
       t      2.40     1.25    1.39     3.20
Crit.  t      2.03     2.05    2.05     2.04

CELL C PLOT 2 / REFERENCE

SP2        1.58926 1.78180 10.8758 1.08067
           0.41587 0.51698 1.23794 0.39022

              BC       PC      PA       BG
       t      0.83     2.08    0.89     0.08
Crit.  t      2.03     2.05    2.04     2.04

CELL D PLOT 1 / REFERENCE

SP2         21.755 33.7108 36.2448 16.2217
           1.47495 1.88636 2.05634 1.32864

              BC       PC      PA       BG
       t      1.25     0.41    1.92     5.89
Crit.  t      2.02     2.03    2.03     2.03

CELL D PLOT 2 / REFERENCE

SP2        12.1024  8.5955           8.6576
           1.52775 2.17428           1.29216

              BC       PC      PA       BG
       t      1.26     0.55             1.15
Crit.  t      2.06     2.10             2.06

CELL C / CELL D

SP2        23.7355 39.1018 42.4668 27.5058
           1.27311 1.97741 2.22586 1.49876

              BC       PC      PA       BG
       t      0.63     1.62    2.32     3.48
Crit.  t      2.00     2.03    2.04     2.01
```

```
PLOT 1 / PLOT 2

SP2        20.4657 40.2333 40.8984 25.1909
           1.19894 2.18853 2.32855 1.48731

              BC       PC      PA       BG
       t      3.18     1.27    2.72     4.24
Crit.  t      2.00     2.03    2.04     2.01

PLOT 1 / REFERENCE

SP2        18.8314 30.2097 42.2319 22.1899
           1.21639 1.60916 1.96755 1.35103

              BC       PC      PA       BG
       t      1.63     0.04    2.50     3.53
Crit.  t      2.01     2.01    2.02     2.01

PLOT 2 / REFERENCE

SP2        11.3219 15.5973 21.7512 9.35638
           1.01874 1.44209 1.75070 0.99379

              BC       PC      PA       BG
       t      1.79     1.88    6.42     1.54
Crit.  t      2.02     2.04    2.04     2.03
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Peter Keller was born on July 9, 1963, in Van Nuys, CA. He attended Weston High School in Weston, CT. Following high school graduation Peter enrolled at Oregon State University and graduated with a Bachelor of Science degree in forest management in 1986. He then spent four years as a commodity lumber trader in Boston, MA before enrolling in the University of Florida masters program in environmental engineering sciences.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

H T Odum

H.T. Odum, Chairman
Graduate Research Professor
of Environmental Engineering
Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Scientist of Environmental
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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