NUTRIENT, CARBON, AND WATER DYNAMICS OF A TITI SHRUB SWAMP ECOSYSTEM IN APALACHICOLA, FLORIDA

By

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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By

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December 1989

Chairman: G. Ronnie Best
Major Department: Environmental Engineering Sciences

The main components and processes of a titi shrub swamp were quantified for incorporation into a simulation model to predict their long-term responses to wastewater discharge. The main components were vegetation, water, and soil; and the processes were carbon, nitrogen and phosphorus cycling, and water flow.

Quantification of model compartments indicated that 1) aboveground biomass is in the low to intermediate range of values cited for forested wetlands, 2) precipitation is the principal source of water and nutrients to this system, and 3) relative concentrations of nitrogen and phosphorus in precipitation, surface water and groundwater indicate that nutrients are conserved within the system. Therefore, small amounts of nutrients were cycled within this system, and low nutrient input limited the simulated productivity.

The simulated response to increased nutrients was an increase in annual biomass and litter and increased storage of nutrients in biomass, litter and soil, and the rates of these increases decreased with time.

Wastewater discharged to wetlands with a N:P ratio similar to that stored in vegetation would maximize the lifetime of the system for phosphorus assimilation. Therefore, nutrient loading criteria should be based on maximizing the longevity of the system, which can be estimated by determination of the phosphorus adsorption capacity of the soil.

Mineral soils dominated by titi had a low capacity for phosphorus adsorption while organic soils dominated by black gum had a higher capacity for phosphorus adsorption. The adsorption capacities of these soils were related to the content and availability of amorphous and poorly crystalline oxides of aluminum.

Sweetbay had low rates of transpiration per leaf area relative to other forested wetland species. An increase occurred from the individual to the community level due to high leaf area index in the bay swamp. This community transpires at a rate greater than open water evaporation when water is readily available as indicated by the pan ratio. There is variability among forested wetland communities and among seasons and these systems evapotranspire at low rates when water is scarce and at higher rates when water is readily available. Therefore, these systems are adapted for water conservation during dry periods.

CHAPTER 1
INTRODUCTION

A need has emerged to include wetlands in the overall strategy of managing our environment. Wetlands can be used to treat wastewater and we must determine how to manage these systems for this purpose to the benefit of nature and humanity. In order to properly manage and optimize the role of these complex ecosystems in the landscape, we must understand quantitatively how these systems function.

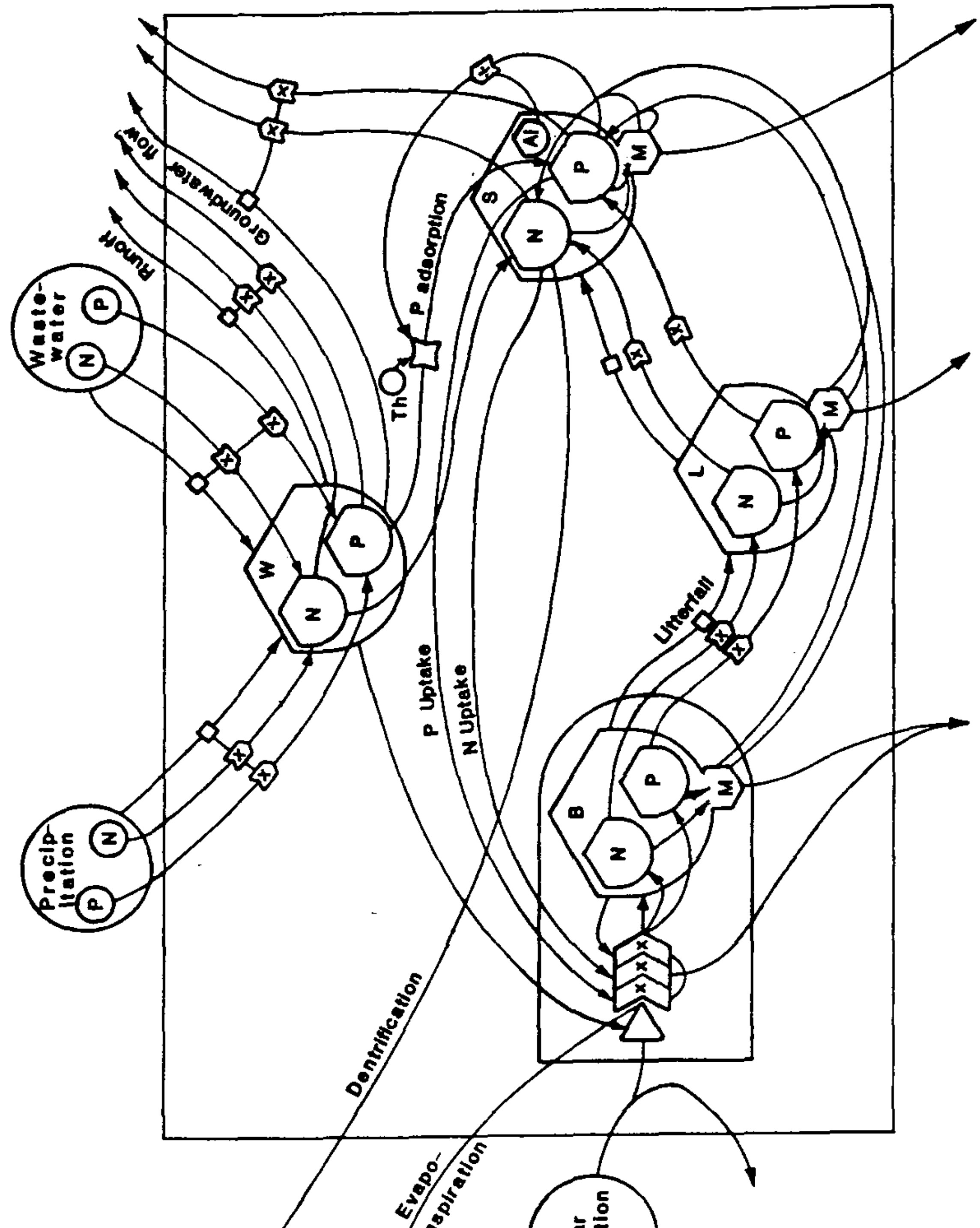
Due to the increasing amount of domestic wastewater generated every day, new alternatives for wastewater treatment merit consideration. The treatment of domestic wastewater in natural wetlands is one such alternative. Although many kinds of wetlands have been shown to treat wastewater, the effects of wastewater discharge to wetlands and their treatment capacity must be evaluated so that the appropriate loading can be selected that will maintain their type, nature, and function. Only then can the suitability of using a specific wetland for wastewater treatment be evaluated. The need has emerged for reliable design procedures for wetland treatment systems (Hammer 1984). A simple, tractable model must be developed to predict the long-term performance of wetland treatment systems. In order to develop such a model, the main components and processes of wetlands must be quantified.

Prior to 1985, the City of Apalachicola, Florida, discharged municipal wastewater to the Apalachicola River. The discharge violated state and federal water quality standards. Discharge of the municipal wastewater to a nearby titi shrub swamp was suggested as an appropriate and cost effective treatment alternative. This was in accordance with section 17-4.243(4) of the Florida Administrative Code, which provides an exemption from water quality standards to allow the experimental use of wetlands for low-energy water and wastewater recycling. The discharger must monitor the long-term ecological effects of wastewater discharge to the wetland and evaluate the wastewater recycling efficiency of the wetland. An exemption was granted to the City of Apalachicola, Florida, for the use of a titi shrub swamp for wastewater treatment. A research program began at the Center for Wetlands, University of Florida, to insure compliance with the above stated provisions of the exemption.

The objectives of this study were to characterize and quantify the main components and processes of the titi shrub swamp ecosystem in Apalachicola, Florida, necessary to predict their long-term responses to wastewater discharge. The main components were vegetation, water and soil; and the processes were carbon, nitrogen and phosphorus cycling, and water flow. This information was incorporated into a simulation model (Figure 1) to predict the long-term responses of these components and processes to wastewater discharge.

Phosphorus retention in soil has been shown to occur in wetlands used for wastewater treatment but the capacity for this retention has not been determined. Therefore, the potential for phosphorus adsorption in titi shrub swamp soils was a management issue evaluated in this study. In order to manage wetlands properly, we must quantify their processes. This includes their rate of evapotranspiration, over which

Figure 1. Conceptual systems diagram of the titi shrub swamp in Apalachicola, Florida. W= water, B= biomass, L= litter, S= soil, N= nitrogen, P= phosphorus, M = microbes.


Precipitation
P
N
Waste-water
N
P
Runoff
Groundwater flow
W
N
P
Th
P adsorption
S
N
P
Al
M
L
N
P
M
Litterfall
B
N
P
M
P Uptake
N Uptake
Dentrification
Evapo-transpiration
Solar Radiation

there is great debate. Therefore, the rate of forested wetland plant evapotranspiration was an additional management issue evaluated in this study.

Geology and Physiography

The City of Apalachicola is located at the western edge of the Big Bend region of the state (Figure 2). The titi shrub swamp study site is located 1 km west of the City of Apalachicola, Florida, and from 1 to 2 km north of St. Vincent Sound (Figure 3). The entire Big Bend region of Florida is underlain by a bedrock of limestone, which dates back no later than the early Miocene age (Clewell 1971). Limestone is encountered beneath the Apalachicola area approximately 40 m below the surface (Schmidt 1978). Above the limestone lies an assortment of various Miocene clastics and above them a veneer of Pleistocene sands. These materials were deposited during ancient sea level fluctuations. Usually there is a shell bed in a sand and clayey matrix, overlain by a gravel and coarse sand unit, by a clayey sand, and finally by a medium fine sand composed of sand, silt and clay, and organic debris. In addition to peat deposits there are beds of humate along the coast (up to 1 m thick). The humate is dark brown to black firmly cemented sand of late Pleistocene to Recent age and was probably formed in an ancient swamp when sea level was a few feet higher than the present.

The western portion of the Big Bend region lies in the Apalachicola Coastal Lowlands unit of the Gulf Coastal Lowlands Physiographic Province (Schmidt 1978). These coastal lowlands are low in elevation due to the reworking by coastal processes and are generally poorly drained. Much of the land area in this unit is covered by swamp. The

Figure 2. Location of the titi shrub swamp study site in Apalachicola, Florida.

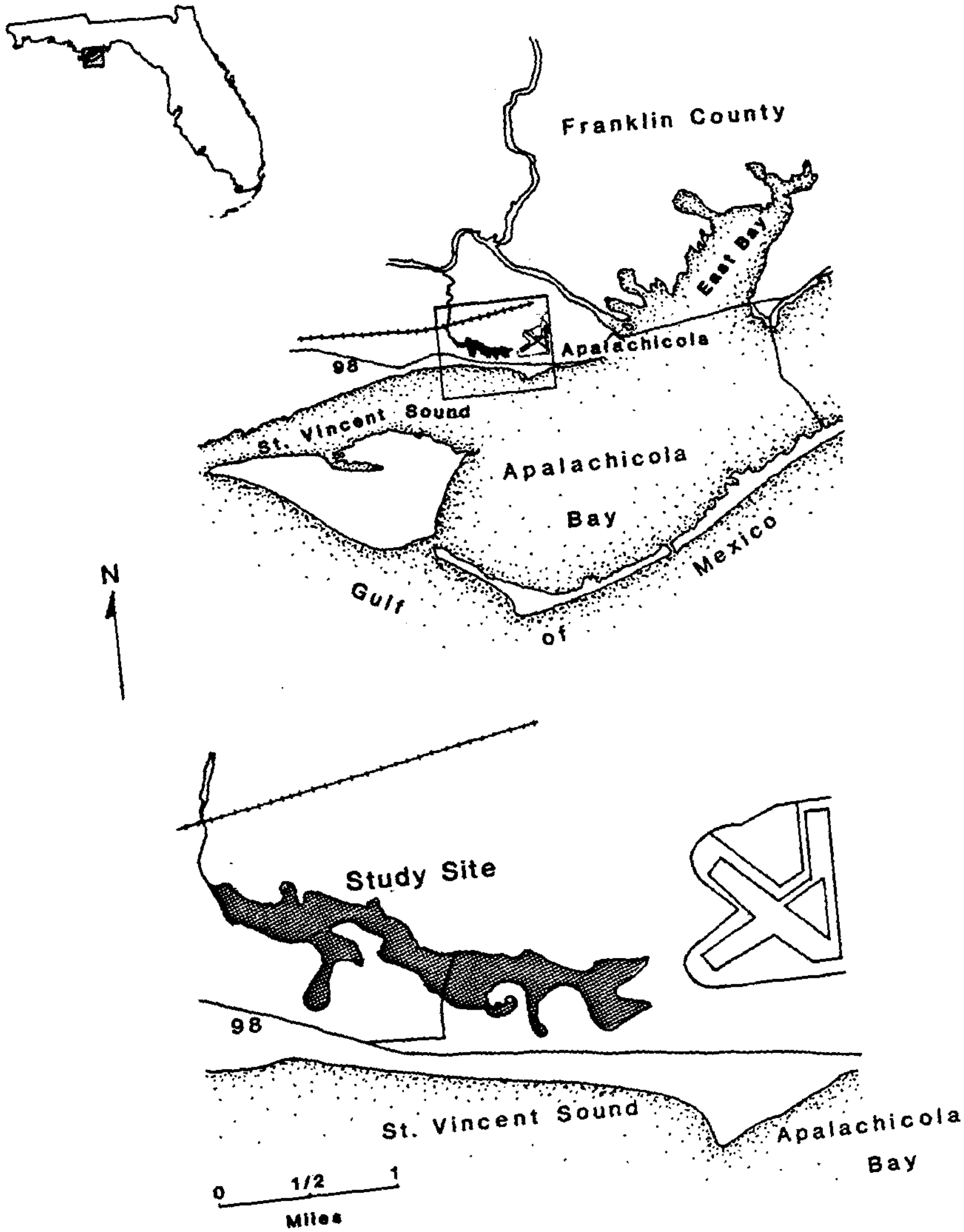
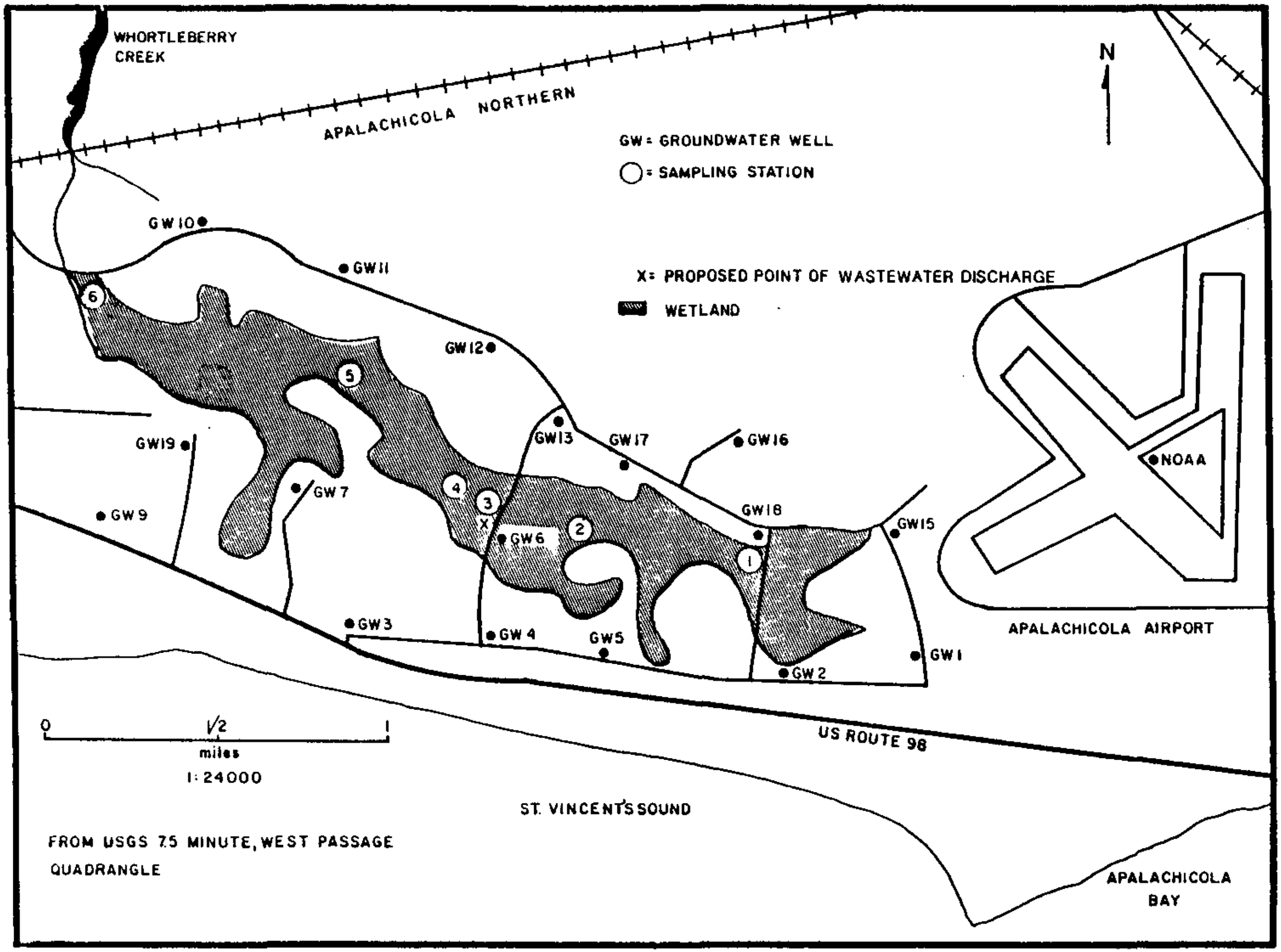

Franklin County
East Bay
Apalachicola
98
St. Vincent Sound
Apalachicola
Bay
Gulf
of
Mexico
N
Study Site
98
St. Vincent Sound
Apalachicola
Bay
0
1/2
1
Miles

Figure 3. The titi shrub swamp study site in Apalachicola, Florida, including surface water and groundwater sampling stations.


WHORTLEBERRY
CREEK
APALACHICOLA NORTHERN
N
GW = GROUNDWATER WELL
◯ = SAMPLING STATION
X = PROPOSED POINT OF WASTEWATER DISCHARGE
WETLAND
GW10
GW11
GW12
GW13
GW17
GW16
GW18
GW15
GW19
GW9
GW7
GW6
GW3
GW4
GW5
GW2
GW1
NOAA
APALACHICOLA AIRPORT
US ROUTE 98
0
1/2
1
miles
1:24000
ST. VINCENT'S SOUND
FROM USGS 7.5 MINUTE, WEST PASSAGE
QUADRANGLE
APALACHICOLA
BAY

impermeable clastics contain fine grained clay and silt (as indicated above), which retard water movement. The permeability is low and groundwater is perched near the surface. This is enhanced by low relief, making it difficult for surface water to run off.

The swamps occupy irregularly shaped shallow depressions that mostly do not join to form drainages (Clewell 1971). These depressions are likely the result of gentle undulations of a former Pleistocene sea-bottom. These swamps may have been accentuated by more recent localized slumping of the surface that would slowly form a depression having a higher water table than the surrounding lands. These geomorphic features are interlevee swamps, oriented parallel to the coast, indicating their formation through marine forces (Schmidt 1978).

These types of systems are referred to as bogs and bog-fed streams by Wharton et al. (1982). The depressions that feed the streams are areas of internal perched drainage underlain by clay aquicludes. Surface drainage occurs through slow moving streams originating from flat swamp areas. These streams have limited distribution and generally occupy the linear depressions or swales between adjacent sand ridges and reworked relict coastal lowland deposits.

Vegetation in Titi Shrub Swamps

The vegetation in titi swamps is often undifferentiated into strata (Clewell 1981). Broad-leaved evergreen or semi-deciduous shrubs and small trees are dominant, especially one of three species commonly called titi: *Cliftonia monophylla* (black titi or buckwheat tree), *Cyrilla racemiflora* (red titi or swamp titi) and *Cyrilla parviflora* (little-leaf titi). All three species occur in the same habitats, sometimes individually but often together. Black titi is usually more abundant than the two species of Cyrilla and tends to occupy slightly higher sites than red titi (Clewell 1981).

Infrequent but destructive crown fires occur in titi swamps. These fires serve a homeostatic function, rejuvenating and perpetuating the community. The vegetation is rarely greater than 25 m in height. The taller the vegetation, the lower the frequency of fire, or at least the longer since the last destructive fire occurred (Clewell 1981).

Titi swamps border pine flatwoods (which frequently burn) and only burn at their fringe, serving as a fire buffer for bay swamps (Clewell 1971). Groundwater seldom fluctuates far below the surface in titi swamps (Wharton et al. 1977). Occasionally titi swamps border pond cypress or black gum swamps, protecting these areas from fire as well (Clewell 1971). Irregular fires destroy the aerial portion of the vegetation in titi swamps, and coppicing after fire is very common, leading to multiple trunks (Clewell 1981). In discussing the distribution of the three species of titi, Clewell (1981) stated that they do not segregate according to subtle gradients in the habitat. Their distribution appears random, as if once a titi plant, regardless of species, by chance becomes established at a given location, it persists indefinitely, surviving fire by coppicing and regenerating the stand without intervening successional stages.

Titi swamps grade imperceptibly into bay swamps (Clewell 1981). Bay swamps occupy those portions of acid swamps that are wetter and less frequently burned than titi swamps (Clewell 1981). The dominants of titi swamps often make up the understory of bay swamps, and when a fire does consume a bay swamp, the understory species such as black titi appear to grow faster than do the overstory species such as sweetbay (Clewell 1971). As a result, the site becomes a titi swamp for perhaps 10 to 25 yrs, until the overstory of sweetbay trees forms (Clewell 1971). It was suggested by Clewell (1971) that titi swamps, therefore, seem to be successional to bay swamps. Monk and Brown (1965) also suggested that bay swamps are climax communities.

Pond cypress and black gum occupy the deepest swamps in the panhandle, and few species are present in any given stand (Clewell 1971). The understory species of pond cypress/black gum swamps, such as titi, usually dominate other communities of acid swamp systems (Clewell 1981). Also, fire is rare. These swamps have been widely drained, lowering the water table and allowing invasion of other acid swamp species. These swamps usually occupy peaty acid depressions in the deeper interior sites, and bay swamps occupy the shallower exterior sites. Intergradations sometimes occur, particularly between pond cypress swamps and bay swamps. Pond cypress/black gum swamps can also intergrade with bay swamps along the upper reaches of streams. Black gum swamps, which are also referred to as gum ponds, are usually bordered by pond cypress swamps, which occupy slightly higher elevations.

Clewell (1971) raised the possibility that black gum is successional to pond cypress or vice versa. Black gum consistently occupies the lowest and wettest sites and these areas are bordered by pond cypress at slightly higher elevations. Monk and Brown (1965) also found that black gum importance increased sharply and pond cypress importance decreased sharply with decreasing depth of maximum flooding.

In addition, with increasing levels of calcium, the importance of black gum increased sharply and that of pond cypress decreased sharply (Monk and Brown 1965). Initially pond cypress is favored in the lower sites, which are surrounded by bay swamps, which, when surrounded by titi swamps, burn infrequently (Clewell 1971). Peat formation is relatively rapid, and calcium released from peat decomposition promotes the establishment of black gum over pond cypress (Clewell 1971). Swamps that contain a large proportion of black gum and particularly pond cypress may represent transitional phases between a pond cypress/black gum system and an acid swamp system or, as suggested by Clewell (1981), may be included as a distinct and important part of the acid swamp system.

Biomass in Forested Wetlands

Forested wetlands may be grouped into three categories based on water movement and differences in nutrient inputs: still-water wetlands, slow-flowing water wetlands, and flowing water wetlands (Brown 1981). Still-water wetlands receive nutrients and water predominantly from precipitation. Slow-flowing wetlands receive water and nutrients from groundwater and surface water runoff. Flowing water wetlands receive water and nutrients from flooding streams.

The aboveground biomass of forested wetlands ranges from 3.6 kg/m^2 for a dwarf cypress forest to 45.2 kg/m^2 for a cypress tupelo alluvial river swamp (Brown 1981; Conner and Day 1982). Large biomass exists in both still-water and flowing water wetlands. Small biomass in the dwarf cypress forest appears to be due to nutrient limitations or other stressors rather than the pattern of water delivery. However, the major source of water is precipitation, and floodwaters tend to be stagnant and generally shallow (Brown and Lugo 1982). There is a relationship between productivity and hydrologic and nutrient sources. Wood production and litterfall are highest in flowing water wetlands, less in slow-flowing wetlands, and lowest in still-water wetlands (Brinson et al. 1981; Brown and Lugo 1982).

The leaf litterfall portion of total litterfall has been reported for only a few freshwater forested wetland sites. In the Dismal Swamp the average leaf litterfall for cypress and mixed hardwood species is 492 $g/m^2 \cdot yr$, with the peak in the autumn (Day 1983). Average litterfall for 2 yrs in Austin Cary cypress dome was 420 $g/m^2 \cdot yr$ (Deghi et al. 1980). The peak litterfall period was in November and December. Leaf litterfall for the floodplain forest of the Apalachicola River was 464 $g/m^2 \cdot yr$ (Elder and Cairns 1982). Seasonal variability in leaf litterfall was observed. Maximum leaf litterfall occurred in November and other high values occurred in autumn months. Maximum leaf litterfall may occur in the spring in association with the development of new leaves (Bray and Gorham 1964). This bimodal seasonal cycle for leaf litterfall (autumn and spring peak) was also found in a Mississippi coastal stream (Post and de la Cruz 1977).

Chemistry in Acidic Waters

Most natural waters are buffered principally by a carbon dioxide-bicarbonate system. By observing the equilibrium chemistry (dissociation relationships) of a system, the proportions of carbonic acid (plus dissolved carbon dioxide), bicarbonate, and carbonate at various pH values can be evaluated in order to determine what buffers the system. Because of the ubiquitous nature of carbonate rocks and the equilibrium reactions of carbon dioxide, bicarbonate and carbonate are present as bases in most natural waters (Stumm and Morgan 1981), but all waters with a pH less than 8.5 contain acidity (Sawyer and McCarty 1978). Uncombined carbon dioxide, organic acids (such as tannic or fulvic), and salts of strong acids are responsible for the acidity of natural waters (Wetzel 1975). In waters with a pH below 5, carbonic acid (plus dissolved carbon dioxide) dominates the carbonate equilibria (Wetzel 1975), but depression of pH below 4.5 is due to mineral acidity which is exhibited by waters containing acids stronger than carbonic acid (Stumm and Morgan 1981). At a pH of 3 to 4.5, carbonate and bicarbonate are not buffering the water; rather, organic acids are the buffer (Thurman 1985).

The proportions of carbonate in surface waters come from the weathering of rocks, and the solubility of carbon dioxide in water increases markedly in water that contains carbonate (Wetzel 1975). If surface waters are isolated from the carbonate rich Floridan Aquifer (Fernald and Patton 1984), then there is probably very little free carbon dioxide present in those surface waters. Conductivity is a useful indicator of whether the water entering a peatland is primarily from precipitation and shallow mineral soil inflow (and therefore not in contact with carbonate containing parent material) or groundwater (Verry 1975). Values less than 80 μmhos/cm indicate a perched water table. Values greater than 80 μmhos/cm indicate a groundwater table.

The carbonate equilibria for Austin Cary cypress dome (mean pH = 4.5) was examined by Dierberg (1980). Only trace amounts of bicarbonate existed in the water as there was no titratable alkalinity. Therefore, it is appropriate to measure phenolphthalein acidity rather than alkalinity in acidic waters. Phenolphthalein acidity is a measure of the free (or uncombined) carbon dioxide and the mineral acidity present in the surface water (Sawyer and McCarty 1978). Highly colored natural surface waters typically have low pH due to the acidic nature of humic substances that are present. The color is principally due to tannins, humic acid, humates, and the decomposition of lignins (Sawyer and McCarty 1978), but color in surface waters in Florida streams and canals may be of organic or mineral origin (Kaufman 1975b). The inorganic sources are metallic substances such as iron and manganese compounds (Christman et al. 1967).

Low pH values are found in natural waters rich in dissolved organic matter, especially in systems that contain large amounts of sphagnum (Wetzel 1975). In wetlands, dissolved organic matter usually exceeds dissolved inorganic matter, which is not the usual case in surface waters (Thurman 1985). The most likely major sources of hydrogen ions in these waters are the dissociation of H_2SO_4 derived from H_2S (Gorham 1956) and the active cation exchange in the cell walls of sphagnum where the release of hydrogen ions occurs (Clymo 1964). Hydrogen ions are also produced by organic decomposition (Clymo 1967).

Increases in acidity occur whenever the production of organic matter is greater than decomposition, as in peat systems (Stumm and Morgan 1981). This is because the assimilation of ammonium produces hydrogen ions. The chemical nature of the plant tissues forming the peat (humic acids) tends to make this peat material acid, and the most acid peats are those formed from swamp plants and sphagnum moss (Davis

1946). In addition, the poor buffering capacity of precipitation reaching a wetland can further lower the pH (Thurman 1985).

Information on nitrogen transformations in acidic, highly organic flooded soils is limited, and these processes may occur in unique ways (Haack 1984). Compounds found in naturally occurring humic-colored waters reduce dissolved oxygen levels and, therefore, these waters act as a sink for dissolved oxygen (Dierberg 1980). Low dissolved oxygen can lead to anaerobic conditions where net ammonification (the release of ammonium during microbial decomposition of organic matter) is often noted (Tusneem and Patrick 1971). In addition, low pH as well as the presence of organic compounds inhibit the nitrification of ammonium to nitrate (Dierberg 1980). Therefore, low dissolved oxygen, low pH and the presence of organic compounds contribute to the dominance of ammonium rather than nitrate plus nitrite in these waters. Through the inhibition of nitrification, ammonium becomes the dominant inorganic nitrogen species, and this leads to conservation of nitrogen in the system (Dierberg 1980).

Nitrate plus nitrite concentrations may also be low in these waters due to rapid plant uptake and denitrification, although denitrification is inhibited at low pH (Mitchell 1974; Brezonik 1977). Nitrate was added to jar and core microcosms composed of water and soil from the titi shrub swamp in Apalachicola, Florida (Haack 1984). Nitrate loss did occur in both the jar and core microcosms but sediment was necessary for the nitrate loss. No mechanism for nitrate loss was substantiated, although it may be due to denitrification, which occurs in wetlands. Chemical reduction of nitrate at low pH may occur through several pathways. Wetlands with low pH, high organic matter, and humic compounds have pathways of nitrate loss other than biological denitrification (Haack 1984). Under highly reduced conditions, nitrate reduction to ammonium and organic nitrogen is possible (Buresh and Patrick 1978). These processes would also account for the dominance of ammonium in these waters.

The shallow surface water in cypress domes and hence the close proximity of soil and water suggests that the phosphorus content of the surface water may be controlled by the interaction of phosphorus with the soil (Dierberg 1980). Soil/phosphorus reactions are complex. In general, the inorganic phosphorus is partitioned between the solution phase (small fraction of total system phosphorus) and the solid phase (a larger portion of total system phosphorus). The chemical species of solution phosphorus are a function of the reactions of protonation and soluble metallic complex ion formation (Bohn et al. 1979). At low pH, iron and aluminum ions on solid (soil) surfaces form bonds with solution species (Stumm and Morgan 1981). The resulting precipitate removes phosphorus from the water column. The oxygen content of the water and soil also affects the amount of phosphorus in solution as phosphorus becomes more soluble under reduced anaerobic conditions (Stumm and Morgan 1981). Therefore, soluble metallic ion complex formation (phosphate and hydrous oxides of iron and aluminum) plays a great role in controlling phosphorus levels in natural waters.

The limit for the phosphorus concentration in solution is set by the dissolution and precipitation of these sparingly soluble phosphorus compounds and the adsorption of phosphorus on the surface of soil particles. In general the overall solubility of these metal phosphate complexes is inversely related to pH while adsorption and precipitation of phosphorus are directly related to pH (Stumm and Morgan 1981). Therefore, the lower the pH the greater the solubility of the metal phosphate complexes and the greater the adsorption and precipitation of phosphorus in the soil. Removal of phosphates from solution can also be linked to pH because of the dependency of the reactions upon soil aluminum (Dubuc et al. 1986). At a low pH in cypress domes studied by Dierberg (1980) aluminum rather than iron controlled phosphorus solubility. In addition, at a pH less than 6, organic phosphorus precipitates as a complex with iron and aluminum (Dubuc et al. 1986).

Solubilization of the sparingly soluble compounds can also occur due to the production of organic acids. These organic acids exist in water as negatively charged colloids that hold metallic ions such as iron and aluminum (Kaufman 1975b). The sorption of phosphate by these organometallic complexes occurs but the dynamics of the transformations are still unclear. Phosphate can react with metal ions to form complexes in the presence of organic ligands such as fulvic and humic acids (Boto and Patrick 1978). Phosphate ions may be acting as ligands in organometallic compounds (Sinha 1971). In either case the retention is a function of pH.

Biological immobilization of phosphorus also occurs in wetlands (Chan et al. 1982). Wetland trees assimilate phosphorus (Brown et al. 1975; Nessel et al. 1982; Dierberg and Brezonik 1983b). In addition high cation exchange capacity exhibited by peat can lead to the absorption of phosphate anions (Moore and Bellamy 1974). Therefore, it appears that through biological and chemical processes in wetlands, low levels of phosphorus are maintained in surface waters.

Phosphorus Adsorption in Soils

Phosphorus retention by soils may be an advantage of using wetlands as an alternative for wastewater treatment. Therefore, emphasis has been placed on using adsorption isotherms in order to predict soil types that would be amenable to receiving wastewater (Sommers and Sutton 1980).

A phosphorus adsorption isotherm describes the relationship between the amount of phosphorus sorbed and that remaining in solution at constant temperature. Several equations developed for gas-solid systems have been used to interpret the sorption of phosphate on charged surfaces. The adsorption data are fit to isotherms described by the equations. The isotherms can be used to give a relative adsorption maximum, interpreted as a "quantity" factor, indicating the capacity of the soil to adsorb and thus retain phosphorus.

The Langmuir equation is based on the assumptions that adsorption is on a finite number of localized sites, the energy of adsorption is constant, and maximum adsorption corresponds to a complete monolayer. Thus the equation describes a finite limit to adsorption so that a maximum value may be obtained. The Langmuir equation is described as follows:

$$x/m = KCb/(1 + KC)$$

where K is a constant related to the adsorption energy, C is the equilibrium phosphorus concentration (μg/ml), and x/m and b are phosphorus adsorbed and maximum phosphorus adsorption per unit weight of soil (μg/g), respectively. In the linear form the equation becomes:

$$Cm/x = (C/b) + (1/Kb)$$

and a plot of Cm/x versus C should give a straight line of slope 1/b from which b, the adsorption maximum can be calculated.

Straight line isotherms have been obtained when results from a limited concentration range are plotted according to the Langmuir equation (Olsen and Watanabe 1957). Although the Langmuir equation in its linear form has been used frequently in phosphorus adsorption studies the adsorption curves may not be linear over a wide concentration range (Olsen and Watanabe 1957; Rennie and Mekecher 1959; Gurney 1970; Bache and Williams 1971; Fitter and Sutton 1975). There are many possible explanations for the nonlinearity, but where it does occur the Fruendlich and other equations may be used to fit the adsorption data.

The Fruendlich equation is based on the assumption that the surface consists of sites at which the adsorbate molecules interact laterally, resulting in a continuous distribution of bonding energies that decrease exponentially with increasing saturation of the surface. The Fruendlich equation can be described as follows:

$$x/m = aC^b$$

where x/m and C are as before and a and b are constants that vary among soils. In the linear form the equation becomes:

$$\log x/m = \log a + b \log C$$

and a plot of log x/m versus log C should give a straight line. The Fruendlich equation has been found to give a good fit over a wide range of soils and concentrations (Gurney 1970; Fitter and Sutton 1975; Barrow and Shaw 1975; Barrow 1978).

The Tempkin equation is derived from the Langmuir equation but, like the Fruendlich equation, is based on the assumption of a continuous distribution of bonding energies. In this case the energy of adsorption decreases linearly with increasing surface coverage. The Tempkin equation can be described as follows:

$$xb/m = (RT/B) \log AC$$

where x, b, and C are as before and A and B are constants. A plot of x/m versus log C should give a straight line.

The phosphorus adsorption maxima of soils can be calculated from the slope of the regression lines according to the Langmuir equation. The Fruendlich equation does not have this characteristic and therefore a quadratic regression analysis of the adsorption data developed by Yuan and Lucas (1982) can be used as an alternative to obtain the adsorption maxima. If Y is the phosphorus adsorbed and X the equilibrium phosphorus concentration, then the quadratic equation is as follows:

$$Y = a_0 + a_1X + a_2X^2$$

and the first derivative of this equation is equal to zero when Y reaches the maximum, or

$$dY/dX = a_1 + 2a_2X = 0.$$

Therefore the phosphorus concentration (C) at the adsorption maximum would be

$$C = X = -a_1/2a_2.$$

The adsorption maximum is obtained by substituting $-a_1/2a_2$ for X in the quadratic equation. If this equilibrium phosphorus concentration and the corresponding adsorption maximum derived from the quadratic equation are correct, then substitution of the C values in the other equations should give comparative adsorption maxima (Yuan and Lucas 1982).

There has been a good deal of research on the nature of phosphorus adsorption in soils, and there has been debate as to whether or not organic matter increases phosphorus adsorption. A number of researchers reported a decrease in phosphorus adsorption by soils in the presence of organic matter, the decomposition of which produces organic acids that form stable complexes with aluminum and iron and consequently block phosphorus retention (Singh and Jones 1976). Other workers reported that organic matter increases phosphorus retention by the soil, possibly as a result of microbial assimilation. Adsorption and leaching of phosphorus in acid organic soils and high organic matter sand was determined by Fox and Kamprath (1971). These soils in which the colloids were organic had relatively low phosphorus adsorption capacities relative to mineral soils. Phosphorus adsorption by organic matter was negligible because any adsorption that occurred was due to the cations associated with organic matter (Wild 1950). Organic soils with only a trace of inorganic minerals have little aluminum or iron to be released for bounding with added phosphorus. Thus, although the influence of organic matter on phosphorus adsorption has been debated, organic matter appears to affect phosphorus adsorption in an indirect manner (Berkheiser et al. 1980).

Soluble inorganic phosphorus is readily immobilized in soils by adsorption and precipitation reactions with aluminum and iron under acid conditions (Nur and Bates 1979; Nichols 1983). Low phosphorus adsorption has been observed in sandy soils with low clay content and is primarily correlated with low content of extractable iron and aluminum (Ballard and Fiskell 1974; Yuan and Lucas 1982). Layer silicate minerals have low phosphorus fixing potential but amorphous colloids and sesquioxides are effective at fixing phosphorus. The less crystalline the form of the sesquioxides, the greater their capacity to sorb phosphorus. Phosphate ions are thought to be chemically adsorbed onto the surfaces of hydrous oxides of iron and aluminum by ligand exchange, the displacement of water molecules and hydroxyl groups coordinated with the iron and aluminum atoms and the coordination of oxygen atoms in the phosphate ions with the iron and aluminum (Nichols 1983). In addition to this chemical adsorption, Ryden and Syers (1977) presented evidence for a more physical type of adsorption that becomes operational as the chemical adsorption sites approach saturation at higher equilibrium concentrations of phosphorus in solution (Nichols 1983).

The chemical and physical adsorption of phosphate onto the surface of soil minerals is a rapid process, but slower phosphate fixation does occur and has been attributed to the shift of physically adsorbed phosphorus to chemically adsorbed forms, the diffusion of phosphorus adsorbed on the surface of porous oxides of aluminum and iron to positions inside the soil matrix, and the precipitation of crystalline aluminum and iron phosphates (Nichols 1983). The exact mechanisms involved in phosphorus retention in the soil are unknown. There are continuum of reaction mechanisms and there is little concern for distinguishing between adsorption and precipitation reactions as both phenomena can be considered together as sorption (Berkheiser et al.

1980). Adsorption and precipitation of phosphorus by soils are not necessarily a permanent sink for added phosphorus; there are at least partially reversible. A reduction in the phosphorus concentration in the solution in contact with the soil may release some phosphorus into solution (Nichols 1983).

Effort has been directed towards identifying measurable soil parameters that can be related to the phosphorus adsorption capacity of a soil. The active (exchangeable + amorphous) forms of aluminum provide the best single index of phosphorus retention in Coastal Plain forest soils (Ballard and Fiskell 1974). The contribution of active forms of iron to phosphorus retention was at least the equal of aluminum on a per unit weight basis. Poorly crystalline and amorphous oxides and hydroxides of aluminum and iron were postulated to play a primary role in phosphorus retention in flooded soils (Khalid et al. 1977). An organic matter aluminum peat complex in acid soils strongly adsorbed orthophosphate ions (Bloom 1981). Phosphorus adsorption was highly correlated with organic matter content and exchangeable aluminum content in a study that evaluated the phosphorus retention capacity of retention-detention wetland soils (Sompongse 1982). She proposed, in light of Bloom's (1981) findings, retention through an organic aluminum complex in the soils with high aluminum content. In soils with high iron content, iron seemed to play an important role in phosphorus retention.

Tamm oxalate extractable aluminum and in some cases Tamm oxalate extractable iron have the best correlation with phosphorus sorption in mineral soils (Lopez-Hernandez and Burnham 1974; Ballard and Fiskell 1974). Similar results were found in some wetland organic soils

(Richardson 1985). The Tamm oxalate extraction dissolves the amorphous and poorly crystalline oxides of aluminum and iron that have been postulated to play a primary role in phosphorus retention in flooded soils.

Wastewater Discharge to Wetlands

Wetlands are often viewed as highly dynamic and adaptable ecosystems. Nutrient transformation processes may enable some wetlands to assimilate and store increased levels of nutrients and other contaminants from wastewater (USEPA 1983). Many wetlands have been shown to process wastewater efficiently (Whigham 1982), tolerating anoxic conditions associated with BOD removal and eutrophication, and to remove nutrients from wastewater effectively (Ewel et al. 1982). In nearly all instances, wetlands renovate or improve water quality to some extent, but pollutant removal efficiencies are extremely variable (Chan et al. 1982).

There is great promise for the use of some wetland ecosystems as an effective medium of wastewater organic carbon removal (Khalid et al. 1982). The components remaining in wastewater that will exert oxygen demand, measured as BOD, are very effectively removed in wetland systems by the microbial flora (Kadlec and Tilton 1979). Optimal BOD removal is correlated with high surface area available for microbial growth, and shallow vegetated wetlands maximize this removal capability (Chan et al. 1982). BOD removal in natural wetlands ranges from 70% to 96% (Tchobanoglous and Culp 1980).

Wetlands may also provide a high degree of removal of suspended solids that originate in wastewater (Kadlec and Tilton 1979). Long detention times and thick vegetation filter suspended solids. Removal ranges from 60% to 90% in wetlands (Tchobanoglous and Culp 1980).

Pathogens (bacteria and viruses) in wastewater are reduced by any processes that promote sedimentation or filtration and increase detention time (Chan et al. 1982; USEPA 1983). Thus, large, shallow, non-channelized wetlands encourage die-off of microbes (Chan et al. 1982). Kadlec (1981) reviewed studies that documented the introduction of significantly elevated levels of fecal coliforms into wetlands. The levels of fecal coliforms were reduced with passage of wastewater through these wetlands.

It has been amply demonstrated that some wetlands are capable of removing nitrogen and phosphorus compounds via a variety of mechanisms (Kadlec and Tilton 1979). Whereas nitrogen processing is largely biologically mediated, redistribution of phosphorus to internal sinks is a result of adsorption/precipitation reactions (Ewel et al. 1982). Adsorption and precipitation by soils are not necessarily permanent sinks for wastewater phosphorus, as these processes are at least partially reversible (Richardson and Nichols 1985). Therefore, some wetlands may eventually lose their ability to immobilize large quantities of phosphorus, but may retain their ability to immobilize or dissipate large quantities of nitrogen (Kadlec and Kadlec 1979). Wetland removal efficiencies for total nitrogen and total phosphorus are variable, ranging from 10% to 90% (Richardson 1985).

The capacity for nitrogen removal in wetlands is large (Chan et al. 1982); processes include volatilization, plant uptake, soil uptake, microbial uptake, sedimentation, nitrification, and denitrification.

The major mechanism for removing nitrogen from wastewater applied to wetlands seems to be denitrification (Sloey et al. 1978; Kadlec and Tilton 1979; Nichols 1983), but Richardson and Nichols (1985) suggest that the disappearance of nitrogen from acid organic soils may be due as much to the chemical breakdown of nitrite as to denitrification.

Because the phosphorus cycle has no gaseous phase, less phosphorus is removed from wastewater added to wetlands, although high, short-term removal efficiencies have been observed (Nichols 1983). The magnitude of phosphorus retention capacity varies considerably among wetland types (Richardson and Nichols 1985; Kelly and Harwell 1985). Successful phosphorus immobilization by wetland soils is related to contact time with organic matter (Kadlec and Tilton 1979), but the quantity of phosphorus adsorbed depends on the exchange equilibrium with the dissolved phase (Kadlec 1987). Plant uptake is generally less important than soil adsorption/precipitation reactions for retaining phosphorus in wetland ecosystems (Ewel et al. 1982), but the best possibilities for using wetland plants for nutrient removal appear to occur when the nutrients are stored in woody plants (Ewel and Odum 1978).

Flow through a wetland in northern Canada reduced orthophosphate by more than 95% (Hartland-Rowe and Wright 1975). A similar reduction of phosphorus occurred in a northern peatland receiving sewage (Richardson et al. 1976). Greater exports of phosphate from channelized as compared with natural Coastal Plain streams occurred as a result of a reduction in the soil's capacity to assimilate phosphate (Kuenzler et al. 1977). Most of the phosphorus added to surface water accumulated in the sediments in an alluvial swamp forest in the North Carolina Coastal Plain (Holmes 1977). The floodplain of a small Coastal Plain stream in

North Carolina was a sink for phosphorus (Yarbro 1979). In the Santee River Swamp, phosphorus was adsorbed or deposited as sediments as water coursed through the floodplain from the river (Kitchens et al. 1975). Phosphorus accumulated in the floodplain of a tupelo swamp in southern Illinois (Mitsch et al. 1979).

In Wildwood, Florida, secondarily treated wastewater has been released for over 20 yrs into a series of three wetlands. The wetland that directly receives the wastewater is dominated by *Typha latifolia* (cattail) and *Salix* sp. (willow). This marsh is covered by *Lemna* sp. (duckweed). The discharge from this wetland flows through a ditch to a mixed hardwood swamp dominated by *Fraxinus profunda* (ash), *Taxodium distichum* (bald cypress), and *Nyssa biflora* (black gum). The discharge from this wetland flows through another ditch to a much larger mixed hardwood swamp with similar species composition.

The first two wetlands receive higher nutrient loadings than the third wetland (Brown et al. 1975). After flowing through the wetlands, the concentration of nutrients in the water was reduced to values equal to or less than those found in a control swamp (Boyt et al. 1977). Reductions in terms of mass loading were calculated to be 87% for phosphorus. No visible stress or damage to the natural system was evident. Dilution rather than chemical or biological processes played the key role in reducing nutrient and organic loads. No buildup of nutrients in sediments was indicated. Tree borings showed significant increases in tree growth for a 19-yr period as compared to the previous 19-yr period. Therefore, trees did play an active role in removing nutrients (Brown et al. 1975). In addition, the number of fecal coliforms declined to background levels within 1 km of the point of wastewater discharge to the wetland (Boyt et al. 1977).

A cypress strand in Waldo, Florida, dominated by Taxodium ascendens (pond cypress), black gum, and Acer rubrum (red maple) has been receiving wastewater since 1934 from overflow of a community septic tank. This wetland reduced nutrient concentrations to background levels due to phosphorus retention in the sediments (Nessel 1978). Total phosphorus concentrations were reduced by 51% in surface waters leaving this cypress strand and 77% after passing through the soil profile into shallow groundwater (Nessel 1978). Infiltration was a major route for water leaving this system. This facilitates phosphorus removal and explains the long-term effectiveness of this wetland in terms of phosphorus assimilation (Richardson and Davis 1987). Pond cypress tree growth was stimulated and increased nutrient concentrations in wood and foliage were recorded (Nessel et al. 1982), but this represented only 1% of the estimated phosphorus inflow to the system (Nessel and Bayley 1984). Bacteria had low survival rates; 99% reduction was achieved in 32 days for the viruses tested (Butner and Bitton 1982).

Another cypress strand, Basin Swamp, in Jasper, Florida, has been receiving raw wastewater or primary or secondarily treated wastewater since 1914 (Tuschall et al. 1981). Total nitrogen and phosphorus concentrations in the surface water were effectively reduced by 69% and 36%, respectively, between the inflow and outflow of the swamp. A portion of the reduction was attributed to dilution by surface runoff into the swamp. Discharge of raw and primary wastewater in the swamp decreased growth rates in pond cypress; however, discharge of secondarily treated wastewater enhanced growth over controls (Lemlich and Ewel 1984). The rate of fecal coliform export depended on the detention time of the strand (Brezonik et al. 1981). Based on their findings at the Jasper site, Fritz and Helle (1981) indicated that the use of a flow-through wetland system for additional treatment of secondarily treated wastewater is a workable and economical alternative to conventional physical-chemical treatment methods.

Most of the wastewater from the Walt Disney World Complex has been discharged into a mixed hardwood swamp since 1977. The site is dominated by red maple, black gum, bald cypress, and *Pinus elliottii* (slash pine). This wetland was isolated by berms and the discharge, which ultimately reaches Reedy Creek, was artificially controlled. This was the largest full-scale forested wetland effluent discharge system that has been extensively monitored in the U.S. (Knight et al. 1987). The long-term average removal rate was 75% for BOD and 80% for suspended solids. Total nitrogen concentration was reduced 88% but no total phosphorus reduction was observed (Kohl and McKim 1981). A net release of phosphorus from this system occurred, probably because the retention capacity of the swamp had become saturated (McKim 1982). Removal efficiency depended on input concentration as lower removal efficiencies resulted from lower input concentrations over the range of values observed (Knight et al. 1987).

Pottsburg Creek Swamp, a mixed hardwood swamp in Jacksonville, Florida, has been receiving secondarily treated wastewater since 1967. This wetland is vegetated by a mixture of species including ash, red maple, black gum, pond cypress and *Liquidambar styraciflua* (sweetgum). Based on mass balance calculations, total nitrogen loadings were reduced by 87% and total phosphorus loadings by 62% (Winchester and Emenhiser

1983). There were no net concentrating or diluting effects and, therefore, nutrient reduction was due to infiltration within the swamp.

Cypress domes are a common type of swamp in Florida. These forested wetlands are dominated by pond cypress and often have large numbers of black gum. The term "dome" comes from the characteristic profile of these wetlands, because the trees are taller in the center and decrease in size toward the edges. A study of the use of cypress domes for the advanced treatment of domestic wastewater was conducted from 1975 to 1979.

Biochemical oxygen demand was not substantially reduced as the wastewater traveled from the center to the edge of the domes (Dierberg and Brezonik 1978). In contrast to this, the concentrations of nutrients were generally lower in the surface waters at the edges of domes receiving wastewater than at the center, but the overall reduction of nutrient concentrations in the surface waters was less than 33% (Dierberg and Brezonik 1983a). Infiltration of secondarily treated effluent through organic sediments lining the basins of the cypress domes reduced nitrogen and phosphorus concentrations to background levels (Dierberg and Brezonik 1983a).

Eighty seven percent of the total nitrogen entering the system was stored in peat, roots, and wood, or was released to the atmosphere by denitrification, and approximately 92% of the phosphorus entering the system was removed by plant uptake or sediment deposition (Dierberg and Brezonik 1983b). Based on leaching studies using laboratory columns, organic soils in the domes have a large phosphorus adsorption capability (Dierberg 1980) and this removal capability could continue for a long time (Dierberg and Brezonik 1983a). The cypress trees accounted for storage of 24% of the estimated nitrogen inflow but only 1% of the estimated phosphorus inflow to the system (Dierberg and Brezonik 1984).

After 5.5 yrs of wastewater disposal, the understory vegetation and existing trees showed no detrimental effects (Ewel et al. 1981). The most striking response of understory vegetation was the development and persistence of a thick layer of duckweed over the entire surface of the domes receiving wastewater (Ewel 1984). Initially, it was reported that tree growth rates were unaffected (Ewel et al. 1981), but further investigation indicated that cypress trees grew faster under the influence of sewage effluent and that the response was almost immediate (Brown and van Peer 1989). The number of fecal coliforms (Fox et al. 1984) and viruses (Scheuerman 1978) were reduced during infiltration of surface water to the shallow groundwater aquifer. Binding of viruses may not be permanent (Scheuerman 1978) and the dome substrate may not be a perfect filter (Wellings et al. 1975). In summary, the cypress domes studied and their associated sediments can reduce the levels of major wastewater constituents to levels comparable to those of conventional tertiary treatment processes (Dierberg and Brezonik 1983b) and can thus serve as a natural tertiary treatment system (Dierberg and Brezonik 1983a).

Results from these studies are difficult to generalize quantitatively. However, some qualitative conclusions about wetland transformation and assimilation of different forms of nitrogen and phosphorus can be reached (Richardson and Davis 1987). First, nitrogen removal from water was consistent and substantial over a range of loading rates. Removal efficiency was generally 75% or more on a mass loading basis. Soils provided a finite and reversible sink for ammonium and phosphorus, and retention capacity depended on a complex of factors. In contrast to nitrogen removal, efficiency of phosphorus removal varied greatly. Natural wetlands can process significant amounts of nitrogen, and can be managed to assimilate even more (Richardson and Davis 1987). Phosphorus retention is highly variable and highly dependent on the characteristics of the wetland ecosystem involved and the loading rates.

Wetlands differ in their ability to store and release nutrients. Some types of wetlands dominated by woody plants (swamps) may be capable of assimilating excess nutrients through microbial processes and long-term storage in the soil and in vegetation. Caution must be used when making generalizations about nutrient removal efficiencies from a diverse and sparse data set that includes a variety of wetland types and a wide range of years of application (Richardson and Nichols 1985). However, trends from the most complete studies show a general pattern of decreased nutrient removal efficiency with time and with higher loading rates (Richardson and Nichols 1985).

Evapotranspiration in Forested Wetlands

Evaporation is the conversion of water from the liquid state into vapor, and its diffusion into the atmosphere. Transpiration is the return of water to the atmosphere by plants. Evapotranspiration then is the evaporation from all moist surfaces to the atmosphere. Evapotranspiration includes several processes that are difficult to quantify separately; therefore, potential evapotranspiration is usually estimated. Potential evapotranspiration is defined as the evaporative flux that will not exceed the available energy from both radiant and convective sources (Saxon and McGuinness 1982). In determining potential evapotranspiration, atmospheric variables are considered separately from plant and soil effects. Often water is not freely available and actual evapotranspiration is less than potential evapotranspiration. Therefore, potential evapotranspiration is estimated first, based on meteorological factors, and the amount of that potential used by the actual evapotranspiration processes is then estimated.

A water budget for the Okefenokee Swamp was developed by Rykiel (1977). Evapotranspiration was estimated as a residual term. An independent estimate of potential evapotranspiration was made with the Thornthwaite method for comparison with the residual estimate. Potential evapotranspiration was found to underestimate evapotranspiration and therefore should be used as a minimum value with normal rainfall (Rykiel 1977).

Estimates of potential evapotranspiration were compared to field measurements (groundwater level fluctuation) of evapotranspiration in a cypress strand (Carter et al. 1973). Evapotranspiration measured in this manner was higher than estimated potential evapotranspiration except when the groundwater level was well below the land surface and water was unavailable to plants. Evapotranspiration values measured in the same manner in these cypress strands were reported by Burns (1978). When the groundwater level was high, field evapotranspiration approached pan evaporation. These studies suggest that estimates of potential evapotranspiration may underestimate evapotranspiration when water availability is high.

In order for evapotranspiration to occur, a source of energy and a vapor pressure gradient between the evaporating surface and the atmosphere must exist. Solar energy is the main source of energy and advection of energy from outside an area may increase evapotranspiration (oasis effect). Evapotranspiration is influenced by a number of factors including solar radiation, air temperature, vapor pressure gradient, wind and air turbulence. In addition to the meteorological factors the nature of the evapotranspiring surface and availability of water are important. For example, the height and roughness of vegetation influence air turbulence, and transpiration can at times exceed open water evaporation (Linacre 1976).

On the other hand, the sheltering effect and high albedo of vegetation as well as the resistance to water movement in dry periods could decrease the rate of water loss during dry periods (Linacre 1976). The presence of vegetation in a wooded swamp in southern Ontario reduced water loss in relation to that from and open water surface (Monro 1979). Swamp vegetation was efficient in converting net radiation into turbulent energy exchange, thus minimizing water loss. Wetlands may evapotranspire at a low rate when water is limiting and at a higher rate when water is readily available.

Evapotranspiration in three cypress swamps in Withlacoochee State Forest was measured by Ewel (1985) by determining changes in water levels. Daytime reductions in water level due to evapotranspiration and infiltration could be distinguished from nighttime reductions in water level, due to infiltration only. Evapotranspiration rates were calculated as the difference between the daytime and nighttime water level changes converted to a volume basis. Average annual evapotranspiration was estimated to be 31 in. during the 3 yrs for which data were available. Average annual precipitation for the 3-yr period was 59 in.

Therefore, evapotranspiration was 52% of precipitation at these sites. Evapotranspiration in slash pine flatwoods in north Florida was estimated over the same 3-yr period to be 41 in./yr, or 74% of precipitation. The estimated evapotranspiration rate was 77% of this rate. This comparison confirmed earlier reports of low evapotranspiration rates for certain cypress swamps.

A decrease in the rate of water loss would be a water conservation mechanism and any discussion of water conservation by wetland vegetation should include reference to xeromorphy. Plants of acid habitats are often structurally adapted to conserve water, as are plants from xeric habitats (Clewell 1981). Such plants in acid habitats are called physiological xerophytes (Clewell 1981). Xeromorphic characteristics in plants include thick cuticles, deeply sunken stomata, and highly reflective surfaces. These are the characteristics of evergreen sclerophyllous leaves such as those of titi and sweetbay. These characteristics have evolved in desert plants in response to drought but some xeromorphic species have a "bimodal" distribution, i.e., they are found in both wet and dry habitats but not in intermediate habitats (Larsen 1982). A species could undergo selection for characteristics that adapt it more effectively to both wet and dry habitats than for the habitats between these extremes. In the process of evolving characteristics permitting survival in wet areas, the plants could have acquired characteristics fitting them for survival in dry areas.

These characteristics may develop in response to low fertility and potential water deficiency, but water loss is the key factor (Brunig 1971). On the other hand, xeromorphy in plants may be an adaptation to low fertility and water conservation features may be fortuitous (Larsen

1982). If xeromorphy is an adaptation to dry conditions the reduction of transpiration losses could be a necessary adaptation for survival during dry periods. Low transpiration rates for cypress domes may likewise be an adaptation for survival when water becomes limiting during dry periods (Brown 1981).

Evapotranspiration can be determined by various direct measures such as the measurement of the increase in water vapor in air flowing through gas exchange chambers (Odum et al. 1970; Odum and Jordan 1970; Cowles 1975; Brown 1978; Burns 1978). The metabolism and transpiration of some plants in a tropical rain forest were measured by Odum et al. (1970), and the effect of air velocity on leaf metabolism was evaluated. Air velocity in low ranges limited metabolism of living forest components. In addition, transpiration increased asymptotically with airflow over leaf surfaces (Odum et al. 1970). Therefore, flow rates in chambers should not minimize metabolism or enhance transpiration. Air flow rates were adjusted by Brown (1978) so as not to limit metabolism or enhance transpiration, and to insure that the maximum difference in temperature between the ambient and exhaust air never exceeded 3°C.

Freshwater Wetland Models and their Use in Simulating Wastewater Addition

The number of models of freshwater wetlands in the literature is large (Costanza and Sklar 1985). These authors provided a systematic review of freshwater wetland models that use some kind of formal mathematical description, either explicit equations or system diagrams with implied equations. The representative but not exhaustive review listed 87 models in 59 different studies. There were 18 forested swamp models, 9 bottomland hardwood models, 14 emergent marsh models, 5 floating marsh models, 30 shallow lake models, 2 bog or fen models, 4 tundra models, and 5 combination models. More than 60% of the models were non-linear.

There are two major types of ecological models, which can be classified for convenience as analytic models and simulation models (Hall and Day 1977). Analytic models use mathematical procedures to find exact solutions to differential and other equations. These models are not generally used to study whole ecosystems because they cannot be used to solve many non-linear systems of equations that may provide a better description of an ecosystem. Simulation models, on the other hand, do not give an exact solution to an equation over time, and, therefore, one type of error associated with these models is related to the inexact nature of the solution technique used. Simulation models can solve many equations nearly simultaneously and can incorporate non-linearity (Hall and Day 1977).

A wide diversity of types of models describe and simulate wetland dynamics (Mitsch et al. 1982). The major types were classified for their purposes as: energy/nutrient ecosystem models, hydrology models, spatial ecosystem models, tree growth models, process models, causal models, and regional energy models.

In energy/nutrient ecosystem models, materials pass through or cycle among biotic and abiotic components and exchange with the surroundings. These models are generally non-spatial, aggregated models with feedbacks and interactions among components. Both energy flow and nutrient cycling can be combined into one model. In spatial ecosystem models the attributes of ecosystem models are combined with spatial transport models (hydrodynamic transport models) describing wetland hydrology and pollutant transport over short periods and large areas. Although the dynamics of wetlands have been represented by a variety of ecological models, often involving great detail and complexity, few spatially distributed models have emerged (Mitsch 1983). Hydrodynamic transport models describing stream flow and storm runoff have been developed for wetlands (Hopkinson and Day 1980), and a model has been developed for overland flow through vegetated areas (Hammer and Kadlec 1986). Some of the energy/nutrient and spatial ecosystem models described by Mitsch et al. (1982) were developed to simulate the effects of the addition of wastewater on wetland components. These are described in more detail below.

Simulation models were developed as part of a long range study in north central Michigan to investigate the feasibility of using peatlands for disposal of treated wastewater (Kadlec and Tilton 1979). More specifically, the models predicted long-term changes in biomass and nutrient concentrations in this marsh/bog peatland ecosystem.

Initially, Dixon (1974) developed a model emphasizing the biomass dynamics of the system. This was combined with models of water and nutrient components into a macromodel to predict the effects of the addition of wastewater on these wetland components (Parker 1974). The ecosystem was divided into blocks, which were further divided into units or compartments, each of which represented the behavior of a biotic or abiotic variable. Each unit or compartment was represented by a time varying differential equation. Therefore, a set of ordinary, first-order, non-linear differential, mass balance equations comprised the model (Dixon and Kadlec 1975). This was the first spatially distributed model of a wetland ecosystem used to predict the impacts of wastewater addition. A series of simulations was run varying nitrogen and water parameters to determine the effects on the biomass, water and nutrient components. The simulations were intended to indicate the relative effects of added water and nutrients on the wetland and not predict actual results. Dixon and Kadlec (1975) pointed out that actual predictions should await complete updating and validation of the model.

Hammer and Kadlec (1983) then developed a simplified model of wastewater/wetland interactions that accounted for the movement of surface water in response to gradient and vegetation flow resistance, and allowed material balances to be determined in a wetland ecosystem receiving wastewater (Hammer 1984). This model also contained partial differential equations (Hammer 1984). The resultant analytical solution to the differential-integral equation described the solute balance in the surface water sheet for this idealized system (Hammer 1984).

In this model, the simulated removal of dissolved nutrients from surface waters is a two-step process, consisting of delivery and consumption. Delivery is accomplished by convective mass transfer within surface waters or by downward flow due to water infiltration. Consumption occurs principally at the surface of soil and plants. In addition, two treatment regimes exist in the wetland. In the vicinity of wastewater discharge a saturated region exists. Here component removal rates are quite slow, comprised of uptake due to adsorption in the deep soil, incorporation of material into new soil and woody plants, and microbial release of gases to the atmosphere. Outside this saturated region, surface water concentrations of wastewater components drop exponentially with distance. In this zone of rapid removal, the transport of dissolved components through the water sheet limits the overall rate (Hammer 1984). The combined total area required for assimilation of pollutants over time determines the treatment capacity of the system.

To facilitate the use of the model over long periods of time, all transfers between units or compartments were taken as the annual net accumulation in each compartment and, therefore, the cycling of nutrients and other materials on a seasonal basis was not explicitly addressed (Hammer and Kadlec 1983). This spatially distributed hydrological model provides a convenient means by which the response of natural or constructed wetlands components can be predicted using site specific information (Hammer 1984).

Simulation models were developed for a cypress dome in Florida to investigate management issues (Mitsch 1975a, 1975b; Odum et al. 1977; Deghi 1977; Deghi and Ewel 1984). The models were developed in part to indicate long-term (100 yrs) dynamics of a cypress dome receiving wastewater.

The model described by Mitsch (1975a, 1975b) and Odum et al. (1977) was designed to deal with several management questions involving cypress domes, including the optimum rate of harvesting, possible effects of fire, and their wastewater treatment capability. The model included two autotrophic components, the cypress trees and the understory. The sediment component consisted of nitrogen, phosphorus, organic peat and water. The model was designed to run for 10 to 100 yrs; therefore, annual variations in solar radiation were ignored. Flows such as litterfall and gross primary production were determined from yearly averages. Primary productivity was modeled with a non-stratified approach (equal competition for sunlight between the two autotrophic compartments) and with a stratified approach (cypress canopy having a competitive advantage). Each plant compartment could utilize 5% of the flow that was available to it. Two pathways for decomposition were designed into the model, their operation dependent on water level. Several limiting nutrient schemes were utilized in the model.

The model described by Deghi (1977) and Deghi and Ewel (1984) examined the long-term behavior of phosphorus in the cypress dome subsequent to wastewater addition. Four autotrophic components were distinguished in the model: cypress trees, hardwood trees, understory vegetation, and duckweed. The model was designed to run for 50 yrs; therefore, annual and seasonal variations in forcing functions were ignored. The amount of sunlight reaching any of the three strata within the cypress dome was related to the biomass of vegetation above it.

Incorporating aspects of the models described above, a simple tractable ecosystem simulation model was developed to predict the long-term responses of the main components and processes of the titi shrub swamp in Apalachicola, Florida, to wastewater discharge. The main components were vegetation, water and soil, and the processes were carbon, nitrogen and phosphorus cycling, and water flow. These components and processes were quantified in order to determine their responses to wastewater discharge and to add basic information to the study of forested wetlands in Florida.

CHAPTER 2
METHODS

Vegetation Analysis

A map of the vegetation of the titi shrub swamp study site was made utilizing both high and low altitude aerial photographs. Quantitative information about the structure and composition of the vegetation at the titi shrub swamp study site was obtained with a variation of the quadrat sampling technique (Smith 1978). Belt transects were laid out in each of four wetland community types delineated on the map. A species area curve was used to determine the minimum number of multiple plots needed for a satisfactory sample (Smith 1978). The identification and diameter at breast height (dbh) of individuals in the tree size class (dbh greater than or equal to 10 cm) were recorded in each of four 10 m x 20 m quadrats within each transect. The identification and dbh of individuals in the shrub size class (dbh less than 10 cm and greater than or equal to 4 cm, and height greater than 1.3 m) were recorded in each of four 5 m x 10 m quadrats (one within each tree-size-class quadrat). The dbh values of the individuals were then converted to basal area. The density, dominance, and frequency values were determined for each species as follows (Cox 1976):

density = number of individuals/area sampled,

dominance = total basal area/area sampled,

frequency = number of plots in which species occurs/total number of plots sampled.

These values were then converted to a hectare basis. For a particular species, these values were then expressed in a relative form, which shows the percentage of that species among all species (Cox 1976):

relative density = (density for a species/total density for all species) x 100,

relative dominance = (dominance for a species/total dominance for all species) x 100,

relative frequency = (frequency for a species/total of frequency values for all species) x 100.

Relative values for density, dominance, and frequency were added together to give a single importance value for each species. Each importance value was converted to a percentage basis and expressed for both the stratum (size class) and the community.

A line intercept method (Smith 1978) was used along the 80-m permanent transects in each of the four communities to determine the percent ground cover of the vegetation less than 1.3 m in height. This includes herbaceous and woody vegetation. The total linear distance covered by each species (or bare hummock) along the transect was recorded. The percent cover was calculated as the total intercept length of each species (or bare hummock), divided by the total transect length, multiplied by 100.

Biomass and Nutrient Standing Stock Estimates

Biomass of the titi shrub swamp at the study site was estimated using regression equations describing biomass as a function of selected physical dimensions. For three species harvested at the study site, a computer program (CURFIT: Spain 1982) for fitting ten basic model equations to a set of x,y data was used to determine the appropriate linear regression equations. Statistics on the best fitting model equation are provided. Regression equations developed by Brown (1978) were used for species not harvested at the study site.

Ten different sized individuals of three species were felled: black titi, red titi, and *Magnolia virginiana* (sweetbay). The dbh, height, location (height), and diameter of all primary branches (any branches extending from the bole with a diameter less than the bole) of each individual were recorded. The diameters of the two primary branches at the end of the bole were also recorded.

The diameters at the base of each individual (BD) and at a location where butt swell no longer occurred (S1D) were recorded. The length of this first section (S1L), with butt swell, was recorded. Beginning at this point and moving towards the end of the bole, the individual was divided into additional sections. The section length (SL) was determined by selecting a section with approximately the same diameter at each end. The length of each section and the diameter of the individual at the top of each section (SD) were recorded. A disc at the top of each section was harvested and each disc length (DL) was recorded. The discs were dried to a constant mass in the laboratory and their dry weights (DW) were determined.

The following formula was used to estimate the dry weight (SW) of all but the first section.

$$SW = SL \times DW / DL.$$

The dry weight of the first section (S1W), with butt swell, was estimated with the following formula.

$$S1W = (S1L \times D1W / D1L) + \{[(S1L \times D1W / D1L) \times (BD - S1D)] / (S1D \times 2)\}.$$

The bole biomass was estimated by summing the estimated dry weights of all sections.

The primary branches of each individual were divided into three size classes (small, medium and large) based on diameter. One primary branch in each size class was randomly selected from each tree and harvested (i.e., three per tree). Each primary branch was separated into leaf and branch material. Two hundred leaves were subsampled from each primary branch that was harvested and their area was determined in the laboratory with a Hayashi Denko Company model AAM-5 leaf area meter. Leaf and branch material were dried to a constant mass in the laboratory and their dry weights were determined. The leaf area and the dry weight of the 200 subsampled leaves were used to calculate the leaf biomass to area ratio. A leaf biomass to area ratio was calculated for each species based on tree height for two vertical intervals (9 to 12 m and 3 to 9 m).

The dry weight of branch material was predicted using primary branch diameter as the independent variable. In the same manner, the dry weight of leaf material was predicted using primary branch diameter as the independent variable.

The estimated bole, branch, and leaf biomasses for each individual were summed to obtain the estimated aboveground biomass for each individual. The estimated aboveground biomass and the dbh of the ten individuals for each species were used to predict the aboveground biomass using dbh as the independent variable. The regression equation for each species was used for individuals of that species greater than 4 cm dbh sampled in vegetation analysis quadrats to estimate their aboveground biomass on an areal basis. The estimated leaf biomass and the dbh of the ten individuals for each species were used to predict the leaf biomass using dbh as the independent variable. The regression equation for each species was used for individuals of that species greater than 4 cm dbh sampled in vegetation analysis quadrats in the bay swamp community to obtain an estimate of their leaf biomass on an areal basis.

The estimated aboveground biomass and the dbh of the smallest individual for each of the three species were used to predict the aboveground biomass using dbh as the independent variable. The regression equation was fitted through the origin. This regression equation was used for all individuals less than 4 cm dbh sampled in vegetation analysis quadrats to obtain an estimate of their aboveground biomass on an areal basis. Regression equations developed by Brown (1978) were used for black gum, pond cypress and slash pine trees.

Herbaceous biomass and litter were estimated by collecting all the material in five 0.5 m^2 circular plots randomly sampled within each 200 m^2 vegetation analysis quadrat (20 per community type). The material was separated into live (herbaceous) and dead (litter) components. Leaf litterfall samples were collected monthly for 1 yr from three 0.1 m^2 baskets located at 10 m intervals in each community.

A subsample of each disc (bole), leaf and branch material of each harvested primary branch, each herbaceous plot and of each litter plot, and triplicate subsamples of the yearly composite of leaf litterfall from each community were ground in a Wiley Mill. A 0.1-g sample of the ground material was digested with a mixture of K_2SO_4, $CuSO_4$ and selenium in a ratio of 100:10:1, and 2 ml of H_2SO_4 (Nelson and Sommers 1972). The samples were heated on a block digester, cooled, and diluted to 50 ml with deionized distilled water, and then analyzed by automated colorimetric analysis for ammonium nitrogen and total phosphorus (USEPA 1980).

Bole, branch and leaf biomass were estimated as the product of the average percent of the total biomass of these components for the three species intensively studied and the aboveground tree biomass for each community type. The total nitrogen and total phosphorus in the bole, branch and leaf material were determined as the product of the estimated bole, branch and leaf biomass and the average concentration for these components. The total nitrogen and total phosphorus in the herbaceous component for each community type were determined as the product of the herbaceous biomass and the average concentration of this component in each community type. The total nitrogen and total phosphorus of the bole, branch and leaf material, and the herbaceous component of each community type were summed to obtain the total nitrogen and total phosphorus in the aboveground biomass of each community type.

The total nitrogen and total phosphorus in litter for each community type were determined as the product of the dry weight of litter and the average concentration of total nitrogen and total phosphorus in litter in each community type. The total nitrogen and total phosphorus in leaf litterfall for each community type were determined as the product of the dry weight of leaf litterfall and the average concentration of total nitrogen and total phosphorus in leaf litterfall in each community type.

Water Chemistry

A composite precipitation sample was taken quarterly for 1 yr. Each sample was preserved in the field with mercuric chloride and then stored on ice during transport to the laboratory in Gainesville. Part of the sample was frozen for future analysis of total phosphorus, and the rest of the sample was refrigerated at approximately 4°C for future analysis of Kjeldahl nitrogen and nitrate-nitrite nitrogen. Eight shallow groundwater wells were sampled three times during 1 yr. Each well was pumped out approximately 24 hrs prior to sampling. Each sample was analyzed in the field for pH and then stored on ice during transport to the laboratory in Gainesville. Part of the sample was frozen for future analysis of total phosphorus, and the rest of the sample was refrigerated at approximately 4°C for future analysis of Kjeldahl nitrogen, nitrate-nitrite nitrogen, conductivity, and chloride. All precipitation and groundwater samples were preserved according to APHA (1980) and were filtered with a Gelman 0.45 μm membrane filter prior to analysis.

Surface water samples were taken at seven stations in the study site (Figure 3). A dissolved oxygen sample was taken at mid depth, the water temperature was recorded, and pH was measured in the field at each station monthly for 1 yr. A sample was taken monthly and filtered in the field with a Gelman 0.45 μm membrane filter for analysis of orthophosphate, ammonium nitrogen, nitrate-nitrite nitrogen, and total organic carbon. An unfiltered sample was taken monthly for analysis of total phosphorus, Kjeldahl nitrogen, biochemical oxygen demand, conductivity and turbidity. An unfiltered sample was taken quarterly for analysis of acidity, chloride, and color. All samples were stored on ice during transport to the laboratory in Gainesville and preserved according to APHA (1980).

An Orion Model 399A Ionanalyzer with a glass electrode was used to measure pH. Dissolved oxygen was determined using the Winkler method (azide modification) for the first 6 mo and with a YSI model 54 oxygen meter for the subsequent 6-mo period. Color was measured in centrifuged samples at pH 7 with a Perkin Elmer Model 552 spectrophotometer. Turbidity was measured with a Hach Analytical Nephelometer using a Hach 10 NTU calibration standard. Conductivity was measured with a YSI Model 31 conductivity bridge. Total organic carbon (TOC) was analyzed with a Beckman Model 915 Total Organic Carbon Analyzer. Chemical oxygen demand (COD) was determined using a semi-micro method of dichromate oxidation with ferrous ammonium sulfate titration using ferroin indicator. Biochemical oxygen demand (BOD_5) was determined with full strength, non-seeded, aerated samples incubated in 125 ml BOD bottles at 20°C for 5 days. Initial and final dissolved oxygen was measured in these samples using the Winkler method (azide modification). Phenolphthalein acidity was determined electrometrically at room temperature according to APHA (1980).

Nitrate-nitrite nitrogen (cadmium reduction method), ammonium nitrogen (alkaline phenol method), Kjeldahl nitrogen (semi-micro persulfate digestion followed by ammonium analysis), orthophosphorus (molybdate method), total phosphorus (sulfuric acid digestion followed by orthophosphorus analysis), and chloride (ferric thiocyanate method), analyses were performed using automated colorimetric methods according to USEPA (1980) and APHA (1980).

Soils and Phosphorus Adsorption

Replicate soil cores were taken with acrylic tubing (4 cm i.d.) at four sampling stations (2, 4, 5 and 6, Figure 3) representing the four wetland community types. Each 20-cm-long core was divided into 5-cm increments. Each 5-cm increment was placed in an individual urine cup and then stored on ice during transport to the laboratory in Gainesville. Total organic carbon was determined by the Walkey-Black method and percent carbon was assumed to be 58% of organic matter (Allison 1965).

An Orion Model 399A Ionanalyzer with a glass electrode was used to measure pH in deionized water with a soil:liquid ratio of 1:1 (v:v) (Peech 1965). Total nitrogen including nitrate was determined by the semi-micro Kjeldahl method (Bremner 1965). Total phosphorus was determined by the ignition method and 0.1 N HCL extraction (Anderson 1976). This procedure converts all the phosphorus to the orthophosphate form which was determined colorimetrically with the ascorbic acid method (Murphy and Riley 1962).

Phosphorus adsorption was measured for soils sampled at two stations (4 and 5) at two depths (0-5 cm and 15-20 cm). Duplicate 1 g air-dried samples were shaken for 24 hrs at 22°C with 25 ml of a 0.01M $CaCl_2$ electrolyte solution. One ml of toluene was added to eliminate microbial activity. Varying concentrations of phosphorus were added as follows: 0, 2.5, 5, 7.5, 10, 15, 20, 30, 40, and 50 mg/l as $Ca(H_2PO_4)_2$. The average concentration of phosphorus in secondarily treated wastewater effluent is within this range. The samples were then centrifuged and the supernatant solutions were analyzed for phosphorus by the ascorbic acid method (Murphy and Riley 1962). The amount of phosphorus removed by the soil from the solution was considered adsorbed.

The adsorption data are plotted in four ways: the regular plot (x/m versus C), linear Langmuir plot (Cm/x versus C), linear Fruendlich plot (log x/m versus log C), and Tempkin plot (x/m versus log C), where x/m and C represent the amount of phosphorus adsorbed by unit mass of soil (μg/g) and equilibrium phosphorus concentration in the solution (μg/ml), respectively. Linear regression analysis was performed on the last three plot types to obtain regression lines and coefficients of determination (R).

The soils evaluated for phosphorus adsorption were also analyzed for extractable phosphorus, extractable iron and extractable aluminum by 0.1 N HCL extraction (Mestan 1986) and the Tamm oxalate method (Saunders 1965). Phosphorus was measured by the ascorbic acid method (Murphy and Riley 1962), and iron and aluminum were analyzed using flame atomic absorption spectrophotometry (Mestan 1986). The Tempkin equation had the highest correlation when both soil types were considered together.

Therefore, the adsorption maxima obtained by substitution of the equilibrium phosphorus concentration derived from the quadratic equation into the Tempkin equation was correlated with measured soil properties. The phosphorus sorption index was computed from a single-point uptake adsorption value (x/m) corresponding to an equilibrium phosphorus concentration of 10 μg/ml. This single-point value was computed from the individual quadratic equations for each soil. This index was chosen on the basis of simplicity, and the 10 μg/ml equilibrium phosphorus concentration is within the range of phosphorus concentrations found in secondarily treated wastewater. Linear regression analysis was performed to relate the adsorption maxima and the phosphorus sorption index with measured soil properties.

Hydrology

The general hydrologic equation for determining the water budget in a wetland is

$$\text{Inflow} = \text{Outflow} \pm \Delta S \text{ (change in storage).}$$

The specific components of a wetland water budget have been further described by Carter et al. (1979) as:

$$P + SWI + GWI = ET + SWO + GWO + \Delta S$$

where P is precipitation, SWI is surface water inflow (including overland runoff), GWI is groundwater inflow, ET is evapotranspiration, SWO is surface water outflow, GWO is groundwater outflow (discharge through aquifers, seepage), and ΔS is the change in storage.

Determination of individual water budget components may not be a simple matter (Carter et al. 1979). Several assumptions were made to simplify estimation of water budget components. The basin storage was assumed to be constant over the period of time for which the budget was calculated; therefore, the change in storage (ΔS) was assumed to be zero. There are no tributaries providing surface water inflow to the site. Therefore, SWI was eliminated from the equation. The water budget was estimated on a depth basis rather than on a volume basis; therefore, wetland area is not taken into account, and the linear nature of shrub swamps in the panhandle precludes any significant watershed interception of precipitation beyond that falling directly on the system (Wharton et al. 1982). Therefore, in this simplified water budget there is no overland runoff to the site, and overland runoff and groundwater flow are assumed to be outflow components. GWI is thus eliminated from the equation. The simplified water budget equation for this study site is $P = R + G + ET$, where R is runoff and G is groundwater flow. An annual water budget for the study site was calculated using data for the 5-yr period from 1982 through 1986 and for October 1985 through September 1986 when transpiration measurements were made, hereafter referred to as the water budget year. All water data are reported in English System Units (inches) as is common in the hydrology field.

Precipitation and Runoff

Daily precipitation records are kept at the Apalachicola weather station approximately 1 km east of the study site (NOAA 1982-1986). Runoff was calculated from daily precipitation using the SCS curve number method presented in section 4 of the National Engineering Handbook (SCS 1972). Chow (1973) described the method that uses the following equation:

$$Q = [(P - 0.2\ S)^2]/(P + 0.8\ S),$$

where Q is the runoff in inches, P is the storm precipitation in inches, and S is the potential infiltration in inches, which is determined as follows:

$$S = (1000\ /\ Cn) - 10$$

where Cn is the curve number previously determined by the SCS (1972) for hydrologic soil-cover complexes that are a combination of soil type and cover. The curve number can be determined for antecedent moisture condition (AMC) classes based on total antecedent precipitation. Konyha et al. (1982) described five modifications for determining potential infiltration in accordance with the SCS curve number method in order to predict runoff in flat high water table watersheds in Florida. Two of the methods (AMC II and AMC III) were used to estimate runoff from precipitation at the study site for 1982 through 1986. In addition these two methods were utilized to estimate runoff from precipitation at the study site during the water budget year.

<u>Groundwater</u>

Water levels in shallow groundwater wells were measured monthly for 1 yr to construct maps of the potentiometric surface of the study site for high and low water periods. Water depth at stations 2, 3 and 5 (Figure 3) within the wetland were concurrently measured.

Groundwater flow is composed of two components at the study site, infiltration through a semi-impermeable organic layer and surface sands, and deep seepage through clayey sands. The former is highly variable and no data were collected to estimate this flow. Therefore, an estimate was made of the maximum groundwater flow that could occur from the upper surface sands to the lower clayey sands using a simplification of Darcy's law:

$$v = K \, \Delta h / \Delta z$$

where v is the velocity of the water passing from the surface sand zone to the clayey sand zone, K is the hydraulic conductivity of the clayey sand zone, and $\Delta h/\Delta z$ is the hydraulic gradient between the two zones. Δh is the change in piezometric head between the two zones and Δz is the thickness of the clayey sand zone.

Evapotranspiration

Depressional watersheds are dominated by flat slopes and long-term seasonal precipitation and flooding (Bedient 1975). They are dominated by lateral rather than vertical soil water movement, and the lateral movement is difficult to measure due to poorly defined drainage paths. The titi shrub swamp is in a depressional watershed, and its analysis requires an emphasis on soil storages and evapotranspiration changes over long periods of time as well as some quantification of lateral water movement. The water balance technique of Thornthwaite and Mather (1957) for determining evapotranspiration is ideal for analyzing depressional watersheds (Bedient 1975).

Evapotranspiration was determined with an empirical formula relating climate variables that drive evapotranspiration (Thornthwaite and Mather 1957). The Thornthwaite method uses mean monthly air temperatures to determine an annual heat index. Mean monthly air temperatures for the Apalachicola weather station were reported by NOAA (1982-1986). Unadjusted monthly potential evapotranspiration is determined from the mean monthly air temperature based on the annual heat index. Adjusted monthly potential evapotranspiration is determined by multiplying the unadjusted values by the monthly duration of sunlight (12 hr basis) at the station's latitude.

When precipitation was greater than potential evapotranspiration, actual evapotranspiration was taken to be equal to potential evapotranspiration. In months when precipitation was less than potential evapotranspiration, water was lost from the soil. The actual water loss varies with the amount of moisture in the soil. This monthly soil water loss was determined as the difference between the maximum soil moisture storage and the monthly soil moisture retained for the accumulated monthly water loss. The maximum soil moisture was determined using the following formula:

$$\text{maximum soil moisture} = (1000 / Cn) - 10$$

where Cn is the curve number previously determined by the SCS (1972) for hydrologic soil-cover complexes that are a combination of soil type and cover. The monthly soil moisture retained for the accumulated monthly water loss was determined using soil moisture depletion curves (Bedient 1975). The monthly soil water loss was added to the monthly precipitation to obtain an estimate of monthly actual evapotranspiration for those months when potential evapotranspiration was greater than precipitation.

Pan evaporation can also be used to estimate potential evapotranspiration. Pan evaporation values from U.S. Weather Bureau Class A Land Pans are measured at selected NOAA weather stations. The closest NOAA weather station measuring pan evaporation is in Milton, Florida, 160 km northwest of the study site. Pan evaporation data for the Milton weather station were reported by NOAA (1982–1986).

Brown (1978) measured surface evaporation for soil and water surfaces as well as transpiration from plants in several wetlands in Florida. Her surface evaporation values were used in this study to estimate the portion of evapotranspired water loss due to surface evaporation.

Transpiration

Transpiration at the study site was determined using the gas exchange chamber method. In five studies where chambers were used to measure metabolism and transpiration, airflows were selected so as not to limit metabolism or enhance transpiration. The volume and the number of turnovers per minute of six chambers of wide ranging size used in these five studies are given in Table 1. The computer program CURFIT (Spain 1982) was used to fit the data on chamber volume and turnover time. The best fitting equation for these data was a power function ($y = Ax^n$) where y = number of turnovers per minute, and x = chamber volume. This equation was used to determine the number of turnovers per minute and thus the airflow in the chambers used in this study that would not limit metabolism or enhance transpiration.

Three chambers were used in this study. The dimension, volume, turnover time (calculated with the model equation), and the airflow that

Table 1. Chamber volume and number of turnovers per minute in four studies where metabolism and transpiration were measured.

Chamber Volume (m^3)	# of Turnovers (per minute)	Source
0.0002	73.0	Odum et al. 1970
0.0004	30.0	Brown 1978
0.052	8.0	Brown 1978
0.898	5.0	Burns 1978
8.0	1.35	Cowles 1975
4000.0	0.19	Odum and Jordan 1970

would not limit metabolism or enhance transpiration are given in Table 2. All three chambers' volumes were within the range of the chamber volumes used to develop the model equation. In the field, airflow in the chamber was set at the level calculated not to limit metabolism or enhance transpiration. The airflow was increased when the temperature inside the chamber increased above the temperature outside the chamber.

Flow-through cylindrical chambers were constructed with wooden hoops and polyethylene. Flow was provided by a variable speed fan mounted at one end. The other end was left open. A canopy branch was inserted into the chamber. Transpiration rates were determined by monitoring water vapor changes, with a dew point hygrometer, in the air passing through the chamber. Every attempt was made to maintain similar conditions inside and outside the chamber.

Transpiration of sweetbay and black titi was measured in a bay swamp from a 9-m tower. The chambers were suspended from the tower with an adjustable boom and pulley system. Measurements were recorded every 15 min from before transpiration began in the morning to after transpiration ended in the evening. This time period represented one run. The temperature inside the chamber and the ambient temperature outside the chamber were measured with mercury thermometers. An electric pump pulled either an intake or exhaust air sample from the chamber through the dew point hygrometer. The intake dew point temperature and the exhaust dew point temperature were measured with a EG and G Model 880 dew point hygrometer. The flow through the chamber was measured with a battery operated Weather Measure Model W141A hot wire anemometer and the solar input was measured with a Matrix Mark VI

Table 2. The dimension, volume, turnover time (calculated with model equations) and the airflow that would not limit metabolism and transpiration, for the three chambers used in this study.

Chamber	I	II	III
diameter (m)	0.58	0.58	0.58
radius (m)	0.29	0.29	0.29
length (m)	2.00	1.00	1.40
volume (m^3)	0.528	0.264	0.370
# turnovers (per min)*	3.97	5.01	4.47
minimum airflow (m/sec)	1.75	1.10	1.38

*calculated with model equation $y = Ax^n$

$A = 326.5$
$n = -.3344$

solar radiometer. At the end of each run the branch inside the chamber was harvested and the leaf biomass was determined. These measurements were the basis for the following calculations performed with a computer spread sheet program.

The ambient temperature and the intake and exhaust dew point temperatures were converted to saturation vapor pressure with the Clausius–Clapeyron relationship, as follows:

$$\text{saturation vapor pressure (mb)} = 6.841\ \text{EXP}(0.0608) \times \text{T}\ (^\circ\text{C}).$$

The saturation vapor pressure was converted to absolute humidity with a manipulated form of the gas law, as follows:

$$\text{absolute humidity (g/m}^3\text{)} = \text{saturation vapor pressure} \times \text{MW} \times (10^3\ \text{erg} \cdot \text{cm}^{-3} \cdot \text{mb}^{-1} \cdot 10^6\ \text{cm}^3 \cdot \text{m}^{-3})/\text{R} \times \text{TK}$$

where MW = molecular weight of water (18 g/mole)

R = gas constant (8.31×10^7 erg/°K · mole), and

TK = ambient temperature in °K.

Relative humidity saturation deficit were calculated as follows:

$$\text{relative humidity} = \text{ambient absolute humidity/intake absolute humidity at saturation} \times 100.$$

$$\text{saturation deficit} = (\text{ambient saturation vapor pressure})\ (1 - \text{relative humidity}).$$

The flow rate was calculated as the product of the cross-sectional area of the fan duct and the measured flow.

The rate water was released (the transpiration rate) was calculated as follows:

transpiration rate in g H_2O/hr = (flow rate)(exhaust absolute humidity at saturation - intake absolute humidity at saturation).

These hourly transpiration rates were integrated with a computer program using trapezoidal integration (Appendix A) to obtain the total daily transpiration rate. The leaf area was determined as the product of the leaf biomass measured at the end of the run and the leaf biomass to area ratio for the vertical interval where transpiration was measured (9 to 12 m). The transpiration rate per leaf area was calculated as the dividend of the transpiration rate and the leaf area. The total daily transpiration rate per leaf area was calculated as the dividend of the total daily transpiration rate and the leaf area. The transpiration rate per biomass was calculated as the dividend of the transpiration rate per leaf area and the leaf biomass to area for the vertical interval where transpiration was measured (9 to 12 m).

In order to extrapolate the transpiration measurements to the ecosystem level the total daily transpiration rate per ground area was determined as the product of total daily transpiration rate per leaf area and the leaf area index.

In order to calculate the leaf area index the vertical distribution of leaf biomass was determined with the plumb-bob method similar to the method used by Benedict (1975) and Brown (1978). A marked line was lowered through the vegetation from the tower where transpiration was measured, with a three part extension pole. The number of leaves hitting the line and their species and location along the line were recorded. This was performed at 16 compass points and at three pole extension distances for a total of 48 samples. The number of leaves of each species hitting the line at a given vertical interval (9 to 12 m or 3 to 9 m) in terms of the percent of 48 samples was multiplied by the leaf biomass to area ratio for a given vertical interval for that species. The percent of the total leaf biomass for each species at each given vertical interval was the vertical distribution of leaf biomass for that species. The leaf area index for each species was calculated as the ratio of the estimated leaf biomass per ground area for that species and the leaf biomass to area ratio for a given vertical interval for that species, multiplied by the vertical distribution of leaf biomass for that species. The estimated leaf biomass per ground area was determined with dimension analysis of ten trees of each species applied to trees sampled in community analysis quadrats.

Model Development and Simulation

An ecosystem model was developed to characterize and quantify the main components and processes of the titi shrub swamp wetland ecosystem in Apalachicola, Florida. This ecosystem model was developed using a diagrammatic language presented by Odum (1971, 1972). This energy-flow or material-flow symbolic language is based on a series of modules that represent both systems processes and mathematical functions connected by lines representing transfer pathways of energy, materials or information (Hall and Day 1977). The modular components can be used to construct compartmental models of ecosystems. The language is also a tool for developing computer programs to simulate a system of first order nonlinear differential equations (Costanza and Sklar 1985) and was used to develop a computer program to simulate the discharge of wastewater to the titi shrub swamp in order to predict the long-term effects of the addition of wastewater on wetland components.

The model was composed of forcing functions and storage compartments or state variables. The forcing functions were solar radiation, precipitation and wastewater. The storage compartments or state variables were surface water, biomass, litter and soil, and the water, carbon, nitrogen and phosphorus in these compartments. The initial condition of each state variable was specified and transfer coefficients were determined from the values of the storages and flows.

The simulation model was developed to indicate long-term (100 yrs) dynamics of the titi shrub swamp receiving wastewater. In order to facilitate the use of the model over long periods of time, all transfers between compartments or state variables were taken as the annual net accumulation in each compartment and, therefore, the cycling of nutrients and other materials on a seasonal basis was not addressed. Annual and seasonal variations in the forcing functions were also ignored. There was only one autotrophic component (biomass), and production was modeled as the interaction of an external limiting factor (a flow limited source, solar radiation) and internal limiting factors (nutrients). Therefore, production was limited by the rate of supply of the external factor and by the recycling of internal factors.

The computer program was written in BASIC. Integration interval of the differential equations was 0.1 yr.

CHAPTER 3
RESULTS

Vegetation Analysis

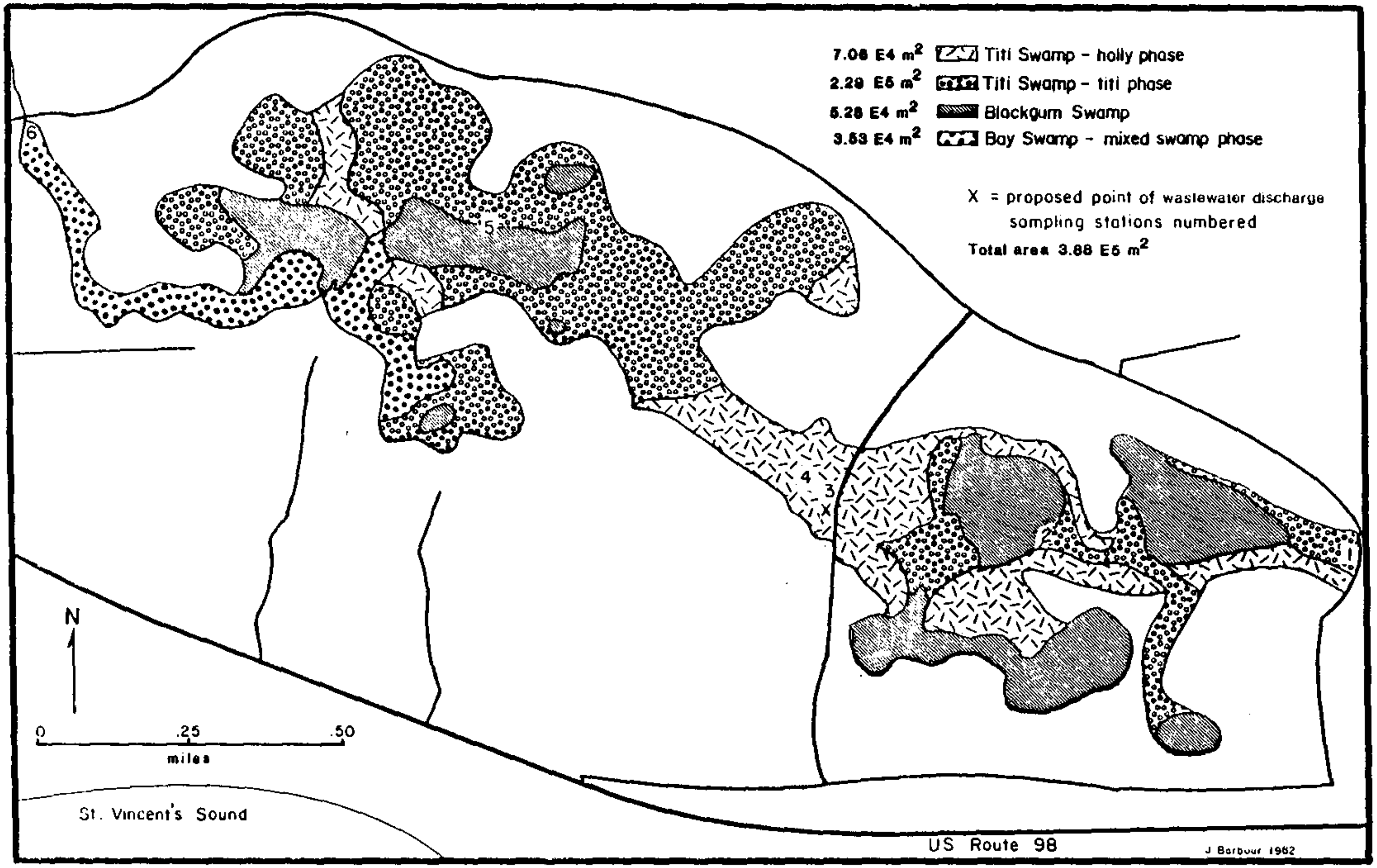
The titi shrub swamp study site (Figure 4) is bordered by flatwoods that were logged and then planted with slash pine. This silvicultural activity included an attempt to drain the wetland with a perimeter ditch.

Four wetland community types occur within the titi shrub swamp study site: titi swamp-titi phase, titi swamp-holly phase, bay swamp-mixed swamp phase, and black gum swamp.

Five phases of titi swamps were described by Clewell (1971). Two phases, titi and holly, occur at the study site. In the titi phase either red titi or black titi is dominant. Pines and the overstory are usually absent (Clewell 1971). In the titi phase at the study site, red titi is dominant, making up 28% of the community and black titi make up 16% of the community (Table 3). Together the titi species make up 45% of the community. Slash pine make up less than 3% and shrub-size-class individuals make up 83% of the community.

In the holly phase, *Ilex myrtifolia* (myrtle-leaf holly) is dominant and an overstory is absent (Clewell 1971). Also, in small swamps at the heads of minor drainages little-leaf cyrilla and myrtle-leaf holly tend to grow together (Clewell 1971). In the holly

Figure 4. Map of the vegetation of the titi shrub swamp study site in Apalachicola, Florida, including surface water sampling stations.



7.06 E4 m²
Titi Swamp - holly phase
2.29 E5 m²
Titi Swamp - titi phase
5.28 E4 m²
Blackgum Swamp
3.53 E4 m²
Bay Swamp - mixed swamp phase
X = proposed point of wastewater discharge
sampling stations numbered
Total area 3.88 E5 m²
6
5
4
3
X
N
0
.25
.50
miles
St. Vincent's Sound
US Route 98
J Barbour 1982

Table 3. Species characteristics of woody vegetation (>1.3 m high) in a titi phase of the titi swamp in Apalachicola, Florida.

Species	Relative Frequency % Stratum	Density: Actual Stems/ha	Density: Relative % Stratum	Dominance: Basal Area m^2/ha	Dominance: Relative % Stratum	Importance Value Basis of 100%: % Stratum	Importance Value Basis of 100%: Community
TREE SIZE CLASS							
Taxodium ascendens	20.0	12.5	3.3	5.30	51.16	24.82	6.95
Cyrilla racemiflora	20.0	250.0	66.7	2.91	28.09	38.26	4.54
Pinus elliottii	20.0	12.5	3.3	0.94	9.07	10.79	2.15
Magnolia virginiana	20.0	50.0	13.3	0.68	6.56	13.29	1.90
Nyssa biflora	20.0	50.0	13.3	0.53	5.12	12.81	1.75
Tree Total	100.0	375.0	100.0	10.36	100.0	100.0	17.28
SHRUB SIZE CLASS							
Cyrilla racemiflora	16.0	8150.0	22.7	10.94	54.89	31.20	23.98
Lyonia lucida	16.0	9000.0	25.1	1.07	5.37	15.49	13.90
Cliftonia monophylla	12.0	8400.0	23.4	4.62	23.18	19.53	11.15
Clethra alnifolia	16.0	2150.0	6.0	0.19	0.95	7.65	6.63
Ilex coriacea	4.0	3100.0	8.6	0.29	1.45	7.38	6.51
Leucothoe axillaris	4.0	1800.0	5.0	0.52	2.62	3.87	3.34
Nyssa biflora	12.0	2400.0	6.7	1.75	8.78	3.47	2.96
Rhododendron sp.	8.0	700.0	2.0	0.08	0.40	3.47	2.96
Magnolia virginiana	4.0	150.0	0.4	0.47	2.36	2.25	1.76
Shrub Total	100.0	35850.0	100.0	19.93	100.0	100.0	82.72
GRAND TOTAL		36225.0		30.29			100.0

phase at the study site, titi species together make up 35% of the community, but myrtle-leaf holly make up 20% of the community (Table 4). Black titi make up 18% of the community and little-leaf cyrilla make up 13% of the community. Three other species make up at least 10% of the community. There are no tree-size-class individuals.

In the mixed swamp phase of bay swamps dominance is shared between sweetbay and other species (Clewell 1971). The understory is usually undifferentiated from the overstory and is composed of woody species common in titi swamps. In the bay swamp at the study site, sweetbay make up 35% of the community and black titi make up 58% of the community (Table 5). Shrub-size-class individuals make up 64% of the community of which 63% are titi species.

In black gum swamps, black gum is dominant and pond cypress is usually present. The understory is absent or composed of saplings of overstory species (Clewell 1971). In the black gum swamp at the study site black gum make up 26% of the community and pond cypress make up 20% of the community (Table 6). Shrub-size-class individuals make up 62% of the community.

Tree-size-class individuals make up 16% of the vegetation at the study site, but shrub-size-class individuals are the major component, making up 84% (Table 7). Black titi has the highest importance value of any species at the study site (21%) and the titi species together make up 39% of the vegetation at the study site (Table 8).

The ground cover in titi swamps is continuous with the understory and herbaceous species are absent except where these swamps border flatwoods. Sphagnum sp. (sphagnum or peat moss) may also be present (Clewell 1971). In the titi phase at the study site, no herbaceous

Table 4. Species characteristics of woody vegetation (>1.3 m high) in a holly phase of the titi swamp in Apalachicola, Florida.

Species	Relative Frequency % Stratum	Density: Actual Stems/ha	Density: Relative % Stratum	Dominance: Basal Area m^2/ha	Dominance: Relative % Stratum	Importance Value Basis of 100%: % Stratum	Importance Value Basis of 100%: Community
SHRUB SIZE CLASS							
Ilex myrtifolia	7.69	4350.	21.43	33.56	14.87	19.66	19.66
Cliftonia monophylla	15.38	3000.	14.78	53.72	23.81	17.99	17.99
Cyrilla parviflora	7.69	2450.	12.07	42.73	18.94	12.90	12.90
Magnolia virginiana	15.38	3650.	17.98	10.72	4.75	12.70	12.70
Lyonia lucida	15.38	2350.	11.58	9.92	4.40	10.45	10.45
Myrica cerifera	15.38	800.	3.94	26.17	11.60	10.31	10.31
Hypericum reductum	3.86	2050.	10.10	22.77	10.09	8.02	8.02
Nyssa biflora	7.69	850.	4.18	6.85	3.04	4.97	4.97
Cyrilla racemiflora	7.69	450.	2.22	5.33	2.36	4.09	4.09
Persea borbonia	3.86	350.	1.72	13.86	6.14	3.91	3.91
Shrub Total	100.00	20300.00	100.00	225.63	110.00	100.00	100.00

Table 5. Species characteristics of woody vegetation (>1.3 m high) in a mixed swamp phase of the Bay Swamp in Apalachicola, Florida.

		Density		Dominance		Importance Value Basis of 100%	
Species	Relative Frequency % Stratum	Actual Stems/ha	Relative % Stratum	Basal Area m^2/ha	Relative % Stratum	% Stratum	Community
TREE SIZE CLASS							
Cliftonia monophylla	50.00	1025.	71.30	16.52	67.09	62.80	21.49
Magnolia virginiana	37.50	400.	27.79	7.31	29.69	31.66	11.59
Taxodium ascendens	12.50	12.5	0.91	0.79	3.21	5.54	2.39
Tree Total	100.00	1437.5	100.00	24.62	100.00	100.00	35.47
SHRUB SIZE CLASS							
Cliftonia monophylla	40.00	4900.	63.64	18.35	64.09	55.91	36.77
Magnolia virginiana	40.00	2650.	34.41	9.68	33.81	36.07	23.13
Cyrilla racemiflora	20.00	150.	1.95	0.60	2.10	8.02	4.63
Shrub Total	100.00	7700.0	100.00	28.63	100.00	100.00	64.53
GRAND TOTAL		9137.5		53.25			100.00

Table 6. Species characteristics of woody vegetation (>1.3 m high) in the blackgum swamp in Apalachicola, Florida.

Species	Relative Frequency	Density: Actual	Density: Relative	Dominance: Basal Area	Dominance: Relative	Importance Value Basis of 100%	
	% Stratum	Stems/ha	% Stratum	m^2/ha	% Stratum	% Stratum	Community
TREE SIZE CLASS							
Taxodium ascendens	30.77	487.5	31.50	14.30	47.34	36.54	15.97
Nyssa biflora	30.77	725.0	46.80	10.23	33.86	37.14	13.04
Cyrilla racemiflora	30.77	325.0	21.00	4.97	16.45	32.71	8.00
Pinus elliottii	7.69	12.5	0.80	0.71	2.35	3.61	1.44
Tree Total	100.00	1550.0	100.00	30.21	100.00	100.00	38.45
SHRUB SIZE CLASS							
Nyssa biflora	14.81	3350.0	19.50	3.940	38.210	24.70	12.54
Lyonia lucida	14.81	4250.0	24.80	0.418	4.050	14.56	11.25
Cyrilla racemiflora	14.81	2200.0	12.80	2.970	28.840	18.83	9.70
Clethra alnifolia	14.81	1800.0	10.50	0.454	4.400	9.90	6.93
Ilex coriacea	7.40	2250.0	13.10	0.233	2.260	7.59	5.87
Leucothoe axillaris	11.11	1850.0	10.80	0.162	1.570	7.83	5.93
Taxodium ascendens	7.40	850.0	5.00	1.618	15.690	9.36	4.51
Ilex myrtifolia	7.40	350.0	2.00	0.186	1.800	3.73	2.44
Cliftonia monophylla	3.70	150.0	0.90	0.321	3.110	2.57	1.36
Magnolia virginiana	3.70	100.0	0.60	0.005	0.048	1.46	1.02
Shrub Total	100.00	17150.0	100.00	10.310	100.000	100.00	61.55
GRAND TOTAL		18700.0		40.520			100.00

Table 7. Species characteristics of woody vegetation (>1.3 m high) in the titi shrub swamp in Apalachicola, Florida.

		Density		Dominance			
Species	Relative Frequency % Stratum	Actual Stems/ha	Relative % Stratum	Basal Area m^2/ha	Relative % Stratum	Importance Values Basis of 100% % Stratum	Community
TREE SIZE CLASS							
Taxodium ascendens	20.9	512.5	15.2	20.4	31.3	22.5	3.8
Cliftonia monophylla	18.6	1025.0	30.5	16.5	25.3	24.8	3.5
Nyssa biflora	17.5	775.0	23.0	10.8	16.5	19.0	2.8
Magnolia virginiana	18.7	450.0	13.4	7.8	12.3	14.8	2.5
Cyrilla racemiflora	17.5	575.0	17.1	7.8	12.1	15.6	2.4
Pinus elliottii	6.8	25.0	0.8	1.6	2.5	3.3	0.7
Tree Total	100.0	3362.5	100.0	65.3	100.0	100.0	15.7
SHRUB SIZE CLASS							
Cliftonia monophylla	13.7	16450.0	20.4	77.0	27.1	20.3	17.4
Lyonia lucida	13.7	15600.0	19.4	11.4	4.0	12.3	10.7
Cyrilla recemiflora	13.7	10950.0	13.5	19.8	7.0	11.4	9.7
Magnolia virginiana	11.3	6400.0	7.9	20.4	7.2	8.8	7.3
Nyssa biflora	10.2	6600.0	8.2	12.5	4.4	7.6	6.4
Ilex myrtifolia	4.6	4700.0	5.8	33.8	11.9	7.4	6.2
Cyrilla parviflora	2.2	2450.0	3.0	42.7	15.0	6.8	5.6
Myrica cerifera	4.6	800.0	1.0	26.2	9.2	4.9	4.0
Clethra alnifolia	9.1	3950.0	4.9	0.6	0.2	4.8	3.9
Ilex coriacea	5.7	5350.0	6.6	0.5	0.2	4.2	3.6
Hypericum reductum	1.1	2050.0	2.5	22.8	8.0	4.0	3.3
Leucothoe axillaris	4.6	3650.0	4.5	0.7	0.2	3.1	2.7
Persea borbonia	1.1	350.0	0.4	13.9	4.9	2.1	1.7
Taxodium ascendens	2.2	850.0	1.1	1.6	0.6	1.3	1.0
Rhododendron canascens	2.2	700.0	0.9	0.1	0.1	1.0	0.8
Shrub Total	100.0	80850.0	100.0	284.0	100.0	100.0	84.3
GRAND TOTAL		84212.5		349.2			100.0

Table 8. Importance values for woody vegetation species (>1.3 m high) in the titi shrub swamp in Apalachicola, Florida. All species combined regardless of size class.

Species	Importance Value
Cliftonia monophylla	20.9
Cyrilla racemiflora	12.1
Lyonia lucida	10.7
Magnolia virginiana	9.8
Nyssa biflora	9.1
Ilex myrtifolia	6.2
Cyrilla parvifolia	5.6
Taxodium ascendens	4.9
Myrica cerifera	4.0
Clethra alnifolia	3.9
Ilex coriacea	3.6
Hypericum reductum	3.3
Leucothoe axillaris	2.7
Persea borbonia	1.7
Rhododendron sp.	0.8
Pinus elliottii	0.7
TOTAL	100.0

species are present, sphagnum is abundant (63%) (Table 9), and shrub ground cover species are predominantly the same as those in the understory (Table 3). The holly phase is bordered by flatwoods (Figure 4) which accounts for the presence of herbaceous species such as *Hypericum reductum*, *Xyris* sp. (yellow-eyed grass), and *Lachnanthes tinctoria*. Sphagnum is abundant (56%) and shrub ground cover species are primarily the same as the vegetation greater than 1.3 m in height (Table 4).

The ground cover in bay swamps is also continuous with the understory or else sparse and patchy. Beds of peat moss are often conspicuous and sedges may be scattered (Clewell 1971). Sphagnum is abundant (46%) in the bay swamp, yellow-eyed grass, a sedge, is present, and the shrub ground cover species are primarily the same as those in the understory (Table 5). Ground cover in black gum swamps is absent (Clewell 1971). Sphagnum is very abundant in the black gum swamp (94%) and the shrub ground cover species are primarily the same as those in the understory (Table 6).

Aquatic macrophytes, including emergents, floating leaved plants, and submergents, are not a significant component of the titi shrub swamp. Shading prevents their growth but *Utricularia* sp. (bladderwort) does occur in the deep water areas. Although not a significant component, aquatic macrophytes do exist in open areas of flatwood depressions and along the margins of deeper swamps. Species found in these areas at the study site include *Hypericum reductum*, *Lachnanthes tinctoria*, yellow-eyed grass, *Rhynchospora* sp., *Scleria* sp., bladderwort, *Eriocaulon* sp., *Sarracenia* sp., and *Drosera* sp.

Table 9. Percent ground cover in the four community types in the titi shrub swamp in Apalachicola, Florida.

Titi swamp - titi phase		Titi swamp - holly phase	
Sphagnum sp.	63	*Sphagnum* sp.	56
Lyonia lucida	22	*Lyonia lucida*	20
Bare hummock	13	*Hypericum reductum*	15
Clethra alnifolia	2	*Xyris* sp.	12
Ilex corriacea	2	*Cliftonia monophylla*	8
Rhododendron sp.	2	*Cyrilla parvifolia*	6
Cyrilla racemiflora	1	*Myrica cerifera*	6
Pierus pillyreifolia	1	*Lachnanthes tinctoria*	3
Leucothoe axillaris	<1	*Ilex myrtifolia*	3
Cliftonia monophylla	<1	*Sabal palmetto*	3

Bay swamp - mixed swamp phase		Black gum swamp	
Bare hummock	46	*Sphagnum* sp.	94
Lyonia lucida	37	*Bare hummock*	7
Xyris sp.	11	*Ilex corriacea*	7
Sphagnum sp.	4	*Cyrilla racemiflora*	6
Cyrilla racemiflora	1	*Lyonia lucida*	3
Clethra alnifolia	1	*Rhododendron* sp.	<1
Cliftonia monophylla	<1		

Biomass and Nutrient Standing Stock Estimates

For the three species measured, the bole, branch and leaf biomass make up 69%, 28% and 3% of the total aboveground biomass, respectively (Table 10). The regression equations used to estimate branch and leaf biomass based on primary branch diameter, and aboveground biomass and leaf biomass based on the dbh of individuals in vegetation analysis quadrats are presented in Appendix B.

Aboveground estimates of the woody vegetation (greater than 1.3 m high) in the four community types are presented in Tables 11, 12, 13 and 14. Herbaceous biomass and litter estimates in the four community types are presented in Table 15. A summary of the aboveground biomass estimate of the four community types is presented in Table 16.

The holly phase of the titi swamp has the smallest aboveground biomass of the four community types. This is not surprising as no tree-size-class individuals are present. The herbaceous component makes up 24% of the biomass of this community, a large portion of which is sphagnum (Table 9). In the titi phase of the titi swamp, tree-size-class individuals make up 58% and shrub-size-class individuals make up 41% of the biomass. The herbaceous component makes up less than 1.5% of the biomass of this community. In the black gum swamp, tree-size-class individuals make up 76% and shrub-size-class individuals make up only 21% of the biomass of this community. The herbaceous component makes up 3% of the biomass of this community and is almost entirely composed of sphagnum (Table 9). Very little litter was recorded in the black gum swamp as compared to the other community types. The bay swamp has the largest aboveground biomass of the four community types. Trees make up 52% and shrubs make up 48% of the biomass of this community. The

Table 10. The dbh,estimated bole, branch, leaf and above ground biomass for ten individuals for black titi, red titi, and sweetbay sampled at the study site.

Species	dbh (cm)	height (m)	bole (kg)	branch (kg)	leaf (kg)	above ground biomass (kg)
Black titi	18.5	11.4	90.5	35.4	6.5	132.5
	16.8	15.0	74.3	18.8	2.9	96.1
	15.0	13.1	57.5	25.4	3.7	86.6
	12.5	11.4	31.9	15.6	2.1	49.7
	8.6	10.2	17.3	5.4	0.8	23.5
	6.9	8.6	10.8	7.7	1.0	19.4
	6.5	7.4	7.0	3.7	0.4	11.1
	4.5	5.6	3.0	0.6	0.1	3.8
	3.9	5.5	1.9	0.6	0.1	2.6
	3.6	4.8	1.8	0.5	0.1	2.4
Total			296.0	113.7	17.8	427.7
%			69.0	27.0	4.0	100.0
Red titi	22.0	8.6	40.2	52.9	3.4	96.5
	18.2	8.3	24.3	17.1	0.7	42.2
	14.9	8.7	31.5	17.9	1.0	50.4
	12.8	7.7	20.9	15.4	0.8	37.0
	10.4	7.9	16.1	12.1	0.4	28.7
	7.6	6.9	4.7	1.3	0.2	6.2
	5.2	6.1	3.1	0.9	94.1	4.1
	5.0	6.8	3.1	0.9	0.2	4.2
	4.0	5.5	1.9	0.2	0.1	2.3
	3.4	5.0	2.0	0.3	7.1	2.4
Total			147.8	119.0	7.0	274.0
%			54.0	44.0	2.0	100.0

Table 10. Continued.

Species	dbh (cm)	height	bole (kg)	branch (kg)	leaf (kg)	above ground biomass (kg)
Sweet bay	17.6	11.7	61.5	16.6	2.8	80.8
	13.9	12.7	49.0	3.8	1.1	54.0
	13.5	12.0	44.6	5.3	1.2	51.1
	10.5	10.8	23.2	3.5	0.7	27.4
	9.1	12.0	17.4	0.6	0.2	18.1
	7.4	8.3	9.1	0.7	0.3	10.1
	6.8	9.6	8.9	1.1	0.4	10.4
	6.2	9.4	7.2	0.7	0.3	8.2
	4.4	7.4	3.4	0.2	0.1	3.6
	4.1	6.2	2.9	0.4	0.1	3.4
Total			227.2	32.9	7.2	267.1
%			85.0	12.0	3.0	100.0
Average % for three species			69.0	28.0	3.0	

Table 11. Aboveground biomass estimate of woody vegetation (>1.3m high) in a titi phase of the titi swamp in Apalachicola, Florida.

Species	Size Class (cm dbh)	Regression # in Appendix B	Biomass (g/m^2)
Cyrilla racemiflora	≥10	8	669.2
Cyrilla racemiflora	10< ≥4	8	470.2
Cyrilla racemiflora	<4	10	473.0
			1612.4
Cliftonia monophylla	10< ≥4	7	661.7
Cliftonia monophylla	<4	10	645.1
			1306.8
Magnolia virginiana	≥10	9	209.4
Magnolia virginiana	10< ≥4	9	103.2
			312.6
Nyssa biflora	≥10	11	191.4
Nyssa biflora	10< ≥4	11	145.3
Nyssa biflora	<4	10	303.7
			640.4
Taxodium ascendens	≥10	13	2575.8
Pinus elliottii	≥10	12	1223.0
Leucothoe axillaris	<4	10	146.9
Clethra alnifolia	<4	10	54.2
Ilex coriacea	<4	10	86.4
Lyonia lucida	<4	10	295.7
Rhododendron sp.	<4	10	22.6
Total			8276.8

Table 12. Aboveground biomass estimate of woody vegetation (>1.3m high) in a holly phase of the titi swamp in Apalachicola, Florida.

Species	Size Class (cm dbh)	Regression # in Appendix B	Biomass (g/m^2)
Magnolia virginiana	<4	10	299.1
Cliftonia monophylla	<4	10	147.4
Cyrilla parviflora	<4	10	146.5
Cyrilla racemiflora	<4	10	17.6
Ilex myrtifolia	<4	10	113.2
Myrica cerifera	<4	10	72.0
Lyonia lucida	<4	10	38.8
Nyssa biflora	<4	10	22.0
Persea borbonia	<4	10	37.9
Hypericum reductum	<4	10	70.6
Total			965.1

Table 13. Aboveground biomass estimate of woody vegetation (>1.3m high) in a mixed swamp phase of the bay swamp in Apalachicola, Florida.

Species	Size Class (cm dbh)	Regression # in Appendix B	Biomass (g/m^2)
Magnolia virginiana	≥10	9	2245.2
Magnolia virginiana	10< ≥4	9	2435.0
Magnolia virginiana	<4	10	76.6
			4756.8
Cliftonia monophylla	≥10	7	7277.7
Cliftonia monophylla	10< ≥4	7	6669.0
			13946.7
Taxodium ascendens	≥10	13	301.2
Cyrilla racemiflora	10< ≥4	8	47.8
Cyrilla racemiflora	<4	10	9.9
			57.6
Total			19120.0

Table 14. Aboveground biomass estimate of woody vegetations (>1.3m high) in the black gum swamp in Apalachicola, Florida.

Species	Size Class (cm dbh)	Regression # in Appendix B	Biomass (g/m^2)
Nyssa biflora	≤10	11	4012.8
Nyssa biflora	10< ≥4	11	901.7
Nyssa biflora	<4	10	244.9
			5159.4
Pinus elliottii	≥10	12	791.4
Taxodium ascendens	≥10	13	4509.4
Taxodium ascendens	10< ≥4	13	475.3
Taxodium ascendens	<4	10	72.5
			5057.2
Cyrilla racemiflora	≥10	8	1171.2
Cyrilla racemiflora	10< ≥4	8	459.8
Cyrilla racemiflora	<4	10	156.1
			1787.1
Magnolia virginiana	10< ≥4	9	65.3
Magnolia virginiana	<4	10	10.4
			75.7
Cliftonia monophylla	10< ≥4	7	107.8
Cliftonia monophylla	<4	10	9.3
			117.1
Clethra alnifolia	<4	10	124.7
Ilex myrtifolia	<4	10	44.6
Ilex coriacea	<4	10	92.0
Lyonia lucida	<4	10	132.8
Leucothoe axillaris	<4	10	49.4
Total			13431.4

Table 15. Herbaceous biomass and litter estimates of the four community types in the titi shrub swamp in Apalachicola, Florida.

Community Type	Herbaceous Biomass (g/m^2)	Litter (g/m^2)
Titi swamp - titi phase	123.7	750.4
Titi swamp - holly phase	301.5	511.5
Bay swamp - mixed swamp phase	10.7	878.2
Black gum swamp	459.4	90.7
Average for titi shrub swamp (n=20)	224	558

Table 16. Aboveground biomass estimate of the four community types in the titi shrub swamp in Apalachicola, Florida.

	Biomass (g/m^2)					
	Tree Size Class	Shrub Size Class		Herbaceous	Total	Total
Community Type	$\geq$10 cm dbh	10 $\leq$4 cm dbh	<4 cm dbh			kg/m^2
Titi swamp - titi phase	4868.8	1380.4	2027.6	123.7	8400.5	8.4
Titi swamp - holly phase	0	0	965.1	301.5	1266.6	1.3
Bay swamp - mixed swamp phase	9824.1	9151.7	86.4	10.7	19072.9	19.1
Black gum swamp	10484.7	2009.9	936.8	459.4	13890.8	13.9

herbaceous component makes up less than 0.1% of the biomass of this community.

The leaf biomass to area ratios for black titi and sweetbay were greater for the 9 to 12 m vertical interval than for the 3 to 9 m vertical interval (Table 17). Red titi did not occur in the 9 to 12 m vertical interval. The estimated leaf biomass per ground area of the woody vegetation in the bay swamp community was 582 g/m^2 (Table 18).

The titi swamps had the lowest leaf litterfall (283 and 265 $g/m^2 \cdot yr$) and the bay swamp the highest leaf litterfall (584 $g/m^2 \cdot yr$) (Table 19). The value for the bay swamp community is similar to the estimated leaf biomass per ground area (582 g/m^2) (Table 18). The black gum swamp had an intermediate leaf litterfall value. The average leaf litterfall for the titi shrub swamp is 359.3 $g/m^2 \cdot yr$ (Table 19), but the variability of the samples is high as indicated by coefficients of variation. Forty five percent of the annual leaf litterfall occurred in autumn (September through December), with the peak occurring in November. The second highest value was in the month of May.

For the three species measured the concentrations of total nitrogen and total phosphorus were as follows: leaf > branch > bole (Table 20). Sweetbay had the greatest concentration of nitrogen and phosphorus of all three species sampled at the study site for all components (Table 20). The holly phase of the titi swamp had the greatest concentration of nitrogen and phosphorus for herbaceous, litter

Table 17. The leaf biomass to area ratio of black titi, red titi, and sweetbay at two vertical intervals (9 to 12 meters, and 3 to 9 meters) at the study site.

	Leaf biomass to area ratio (g biomass/m^2 leaf area)			
Species	9-12 meters	number of trees	3-9 meters	number of trees
Black titi	140.4	5	126.8	5
Red titi	-	0	142.5	10
Sweetbay	109.4	7	98.4	3

Table 18. Estimated leaf biomass per ground area (LBGA) of the woody vegetation (>1.3m high) in the bay swamp community.

Species	Size Class (cm dbh)	Regression # in Appendix B	Leaf Biomass (g/m^2)
Cliftonia monophylla	≥10	14	255.9
Cliftonia monophylla	10< ≥4	14	178.2
			434.2
Magnolia virginiana	≥10	16	86.9
Magnolia virginiana	10< ≥4	16	55.0
			141.9
Taxodium ascendens	≥10	17	4.1
Cyrilla racemiflora	10< ≥4	15	0.8
Cyrilla racemiflora	<4	15	0.7
Total			581.7

Table 19. Leaf litterfall (g/m^2) in the four communities in the titi shrub swamp in Apalachicola, Florida from May 1982 through April 1983. $\bar{x}$ = mean, s = standard deviation, c.v. = coefficient of variation.

Month	Titi swamp titi phase			Titi swamp holly phase			Bay swamp mixed swamp phase			Black gum swamp		
	$\bar{x}$	s	c.v.	$\bar{x}$	s	c.v.	$\bar{x}$	s	c.v.	$\bar{x}$	s	c.v.
1983 Jan	26.9	20.1	74.7	14.0	7.1	50.7	24.6	5.1	20.7	12.0	5.8	48.3
Feb	21.4	21.0	98.1	10.9	2.6	23.8	13.7	6.4	46.7	13.4	5.4	40.3
Mar	15.4	10.2	66.2	15.7	3.8	24.2	34.4	13.8	40.1	18.2	7.2	39.6
Apr	25.7	10.0	38.9	23.6	9.9	41.9	50.3	22.1	43.9	25.9	3.4	13.1
1982 May	50.6	15.1	29.8	30.9	7.4	23.9	111.7	49.8	44.6	12.5	4.5	36.0
Jun	16.9	7.2	42.6	10.2	3.5	34.3	44.3	28.3	63.9	6.3	5.7	90.5
Jul	8.7	1.7	19.5	8.4	5.4	64.3	19.9	13.2	66.3	8.0	1.5	18.8
Aug	12.8	4.0	31.2	12.2	5.2	42.6	59.1	20.1	34.0	18.0	3.1	17.2
Sep	17.5	3.2	18.3	28.1	12.4	44.1	60.1	13.9	23.1	28.2	15.1	53.5
Oct	19.9	2.2	11.1	32.2	4.3	13.3	50.7	32.7	64.5	48.9	29.4	60.1
Nov	49.8	13.5	27.1	45.6	10.8	23.7	76.2	20.8	27.3	78.8	39.4	50.0
Dec	17.7	2.7	15.2	33.6	6.8	20.2	38.8	15.9	41.0	29.5	20.4	69.2
Total	283.0	110.9	39.2	265.0	79.2	29.9	584.0	232.1	39.7	305.0	140.9	46.2

Table 20. Total nitrogen and total phosphorus concentrations (mg/g) of the bole, branch and leaf of black titi, red titi and sweetbay sampled at the study site. $\bar{x}$ = mean, s = standard deviation, c. v. = coefficient of variation.

	Black titi				Red titi				Sweetbay				3 species average			
	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n
Total Nitrogen																
Bole	1.79	0.39	21.8	9	2.91	1.46	50.2	11	3.42	5.04	14.7	10	2.71	1.14	42.1	30
Branch	7.85	3.62	46.1	30	9.09	5.25	57.8	28	12.64	10.06	19.6	27	9.86	6.99	70.9	85
Leaf	8.88	2.32	26.1	29	10.32	3.40	32.9	26	28.57	6.35	22.2	30	15.92	10.15	63.8	85
Total Phosphorus																
Bole	0.08	0.05	62.5	9	0.11	0.07	63.6	11	0.15	0.06	40.0	10	0.12	0.06	50.0	30
Branch	0.20	0.13	65.0	30	0.19	0.14	73.7	28	0.73	0.61	83.6	27	0.37	0.24	64.9	85
Leaf	0.30	0.11	36.7	29	0.30	0.12	40.0	26	1.56	0.42	26.9	30	0.72	0.64	88.9	85

and leaf litterfall (Table 21). Total nitrogen and total phosphorus standing stocks in the aboveground biomass at the study site were as follows: bay swamp > black gum swamp > titi swamp-titi phase > titi swamp-holly phase (Table 22). Total nitrogen and total phosphorus standing stocks in litter and leaf litterfall were greater in the bay swamp than in the other communities at the study site (Table 23).

Water Chemistry

Fernald and Patton (1984) presented a map of annual pH values for precipitation based on biweekly or more frequent sampling at 24 sites for 2 yrs (1978-79). The map indicates that the pH of rainfall at the study site averages 4.7.

Nutrients in precipitation vary seasonally (Hendry and Brezonik 1980) as is the case at this study site (Table 24), and depend largely on local factors such as agricultural activity, soil pH, and vegetative cover (Fernald and Patton 1984). Nutrient levels in precipitation at the study site were comparable to levels found at similar rural sites in Florida (Brezonik et al. 1983) as the average total nitrogen and total phosphorus of precipitation at the study site were 0.94 mg/l and 0.05 mg/l, respectively (Table 24).

Groundwater in the upper Floridan Aquifer approximately 120 ft below the study site (Schmidt 1978) is very hard in terms of both total and noncarbonate hardness (greater than 180 mg/l). The dominant ions are sodium and chloride. High concentrations of noncarbonate hardness, total dissolved solids, sodium, chloride and sulfate are indicative of the predominantly marine deposits in this coastal area (Fernald and Patton 1984). The chemistry of shallow groundwater in general reflects surface water values and does exhibit seasonal variation (Table 25).

Table 21. Total nitrogen and total phosphorus concentrations (mg/g) of the herbaceous component, litter component and leaf litterfall in the four communities in the titi shrub swamp in Apalachicola, Florida. $\bar{x}$ = mean, s = standard deviation, c.v. = coefficient of variation.

	Total Nitrogen												Total Phosphorus											
	herbaceous				litter				leaf litterfall				herbaceous				litter				leaf litterfall			
Community type	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n	$\bar{x}$	s	c.v.	n
Titi swamp - titi phase	7.78	3.47	44.5	14	6.10	1.77	29.0	19	5.74	1.09	19.0	3	0.34	0.20	58.8	14	0.17	0.08	47.1	19	0.22	0.08	36.4	3
Titi swamp - holly phase	9.99	3.89	38.9	14	11.32	3.43	30.3	19	9.10	0.31	3.4	3	0.46	0.23	50.0	14	0.29	0.12	41.4	19	0.36	0.08	22.2	3
Bay swamp - mixed swamp phase	9.20	4.88	53.0	15	8.58	2.63	30.6	18	7.80	0.40	5.1	3	0.36	0.14	38.9	15	0.23	0.09	39.1	18	0.25	0.01	4.0	3
Black gum swamp	7.23	3.28	45.4	17	6.67	2.01	30.1	17	7.02	0.22	3.1	3	0.23	0.11	47.8	17	0.21	0.09	42.9	17	0.18	0.04	22.2	3

Table 22. Total nitrogen and total phosphorus in the aboveground biomass biomass in the four communities in the titi shrub swamp in Apalachicola, Florida.

Community Type	bole biomass g/m^2	branch biomass g/m^2	leaf biomass g/m^2	total aboveground tree biomass g/m^2	herbaceous biomass g/m^2	total aboveground standing stock gN/m^2	gP/m^2
Titi swamp -	5744.1	2276.1	256.6	8276.8	123.7		
titi phase	15.6	22.4	4.1	gN/m^2	1.0	43.1	
	0.7	0.8	0.2	gP/m^2	<0.1		1.7
Titi swamp -	669.8	265.4	29.9	965.1	301.5		
holly phase	1.8	2.6	0.5	gN/m^2	3.0	7.9	
	0.1	0.1	<0.1	gP/m^2	0.1		0.3
Bay swamp -	13269.3	5258	592.7	19120.0	10.7		
mixed swamp phase	36.0	51.8	9.4	gN/m^2	0.1	97.3	
	1.6	1.9	0.4	gP/m^2	<0.1		3.9
Blackgum swamp	9321.4	3693.6	416.4	13431.4	459.4		
	25.3	36.4	6.6	gN/m^2	3.3	71.6	
	1.1	1.4	0.3	gP/m^2	0.1		2.9

Table 23. Total nitrogen and total phosphorus in litter and leaf litterfall in the four communities in the titi shrub swamp in Apalachicola, Florida.

	Litter		Leaf Litterfall	
	Total standing stock		Total standing stock	
Community type	gN/m^2	gP/m^2	gN/m^2	gP/m^2
Titi swamp - titi phase	4.58 (2.02-8.14)	0.13 (0.04-0.26)	1.63 (0.8-2.69)	0.06 (0.02-0.12)
Titi swamp - holly phase	5.79 (2.68-10.08)	0.15 (0.06-0.28)	2.41 (1.63-3.24)	0.10 (0.05-0.15)
Bay swamp - mixed swamp phase	7.54 (3.73-12.68)	0.20 (0.09-0.36)	4.61 (0.27-6.78)	0.15 (0.08-0.21)
Black gum swamp	0.60 (0.13-1.32)	0.02 (0.003-0.05)	2.14 (1.12-3.23)	0.05 (0.02-0.10)

Table 24. Chemical analysis of precipitation at the titi shrub swamp in Apalachicola, Florida.

Quarter	TKN (mg/l)	NO_3-N (mg/l)	TN (mg/l)	TP (mg/l)
1	-	0.13	-	0.06
2	0.96	0.13	1.09	0.09
3	0.36	0.14	0.50	0.02
4	1.12	0.11	1.24	0.01
Average	0.82 ± 0.33	0.13 ± 0.01	0.94 ± 0.32	0.05 ± 0.03

Table 25. Chemical analysis of shallow groundwater in the titi shrub swamp in Apalachicola, Florida.

Well #	4				6				7			
Quarter (1982)	Apr	Jul	Oct	$\bar{x}$	Apr	Jul	Oct	$\bar{x}$	Apr	Jul	Oct	$\bar{x}$
pH	4.5	4.5	4.2	4.4	4.4	4.1	4.0	4.2	4.2	4.1	3.9	4.1
Conductivity *	61.0	61.0	61.0	61.0	62.0	64.0	76.0	67.0	72.0	64.0	80.0	72.0
TKN	1.04	0.53	0.44	0.67	0.89	3.09	3.64	2.55	2.5	0.87	1.37	1.58
NO -N	<0.01	0.02	0.01	0.01	<0.01	0.00	0.02	0.01	<0.01	0.10	0.01	0.01
TP	0.06	0.01	0.01	0.02	0.06	0.02	0.38	0.16	0.08	0.02	0.01	0.04
TN	1.04	0.55	0.44	0.68	0.89	3.09	3.68	2.55	2.5	0.88	1.38	1.58
N:P	16.8	78.1	89.0	61.3	14.1	140.5	8.6	54.7	33.3	48.2	105.8	61.8
Cl	6.2	12.0	-	9.1	6.9	6.7	-	6.8	8.8	8.8	-	8.8

Well #	10				11				13			
Quarter (1982)	Apr	Jul	Oct	$\bar{x}$	Apr	Jul	Oct	$\bar{x}$	Apr	Jul	Oct	$\bar{x}$
pH	4.9	5.1	4.4	4.8	4.8	5.1	4.6	4.8	4.8	4.6	4.4	4.5
Conductivity *	28.0	34.0	41.0	34.0	37.0	40.0	35.0	38.0	52.0	50.0	50.0	51.0
TKN	2.48	0.76	0.03	1.09	2.99	0.42	0.03	1.15	0.79	1.46	0.74	0.10
NO -N	0.02	0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01
TP	0.082	0.01	0.01	0.03	<0.01	0.01	0.01	<0.01	0.04	0.02	0.01	0.02
TN	2.49	0.77	0.03	1.07	2.99	0.43	0.03	1.15	0.80	1.46	0.75	1.00
N:P	30.4	154.6	6.6	63.9	996.7	86.2	6.2	363.0	19.1	73.0	107.0	66.4
Cl	4.9	3.7	-	4.3	6.5	6.0	-	6.25	9.1	8.8	-	8.95

Well #	16				19				All
Quarter (1982)	Apr	Jul	Oct	$\bar{x}$	Apr	Jul	Oct	$\bar{x}$	x
pH	4.3	4.2	4.4	4.4	4.3	4.0	4.2	4.6	4.4
Conductivity *	84.0	68.0	45.0	65.0	58.0	50.0	50.0	53.0	55.0
TKN	1.04	1.23	2.34	1.54	0.89	0.96	1.22	1.02	1.32
NO -N	<0.01	0.012	0.081	0.03	<0.01	0.01	0.01	<0.01	0.01
TP	0.06	0.01	0.01	0.03	0.06	0.04	0.01	0.04	0.04
TN	1.04	1.24	2.42	1.57	0.89	0.96	1.22	1.03	1.33
N:P	16.8	248.8	186.5	150.7	14.1	26.1	111.4	50.5	109.0

The chemical characterization of surface water at this study site includes physical and chemical properties, nutrient concentrations, and demand levels (Table 26). There are no surface water quality data in the literature on wetlands dominated by titi. The surface water in this titi shrub swamp can be characterized as highly colored and acidic (mean color = 306 c.u., mean pH = 3.9 units). The buffering capacity, as assessed by phenolphthalein acidity, is minimal (mean acidity = 39.1 mg $CaCO_3$/l). The mean conductivity (66.2 μmhos/cm) is low, as are the mean levels of dissolved oxygen (2.8 mg/l), BOD_5 (2.8 mg/l), TOC (41.6 mg/l), and COD (90.8 mg/l). The mean surface water nutrient concentrations at the study site were 0.99 mg/l for total nitrogen and 0.01 mg/l for total phosphorus.

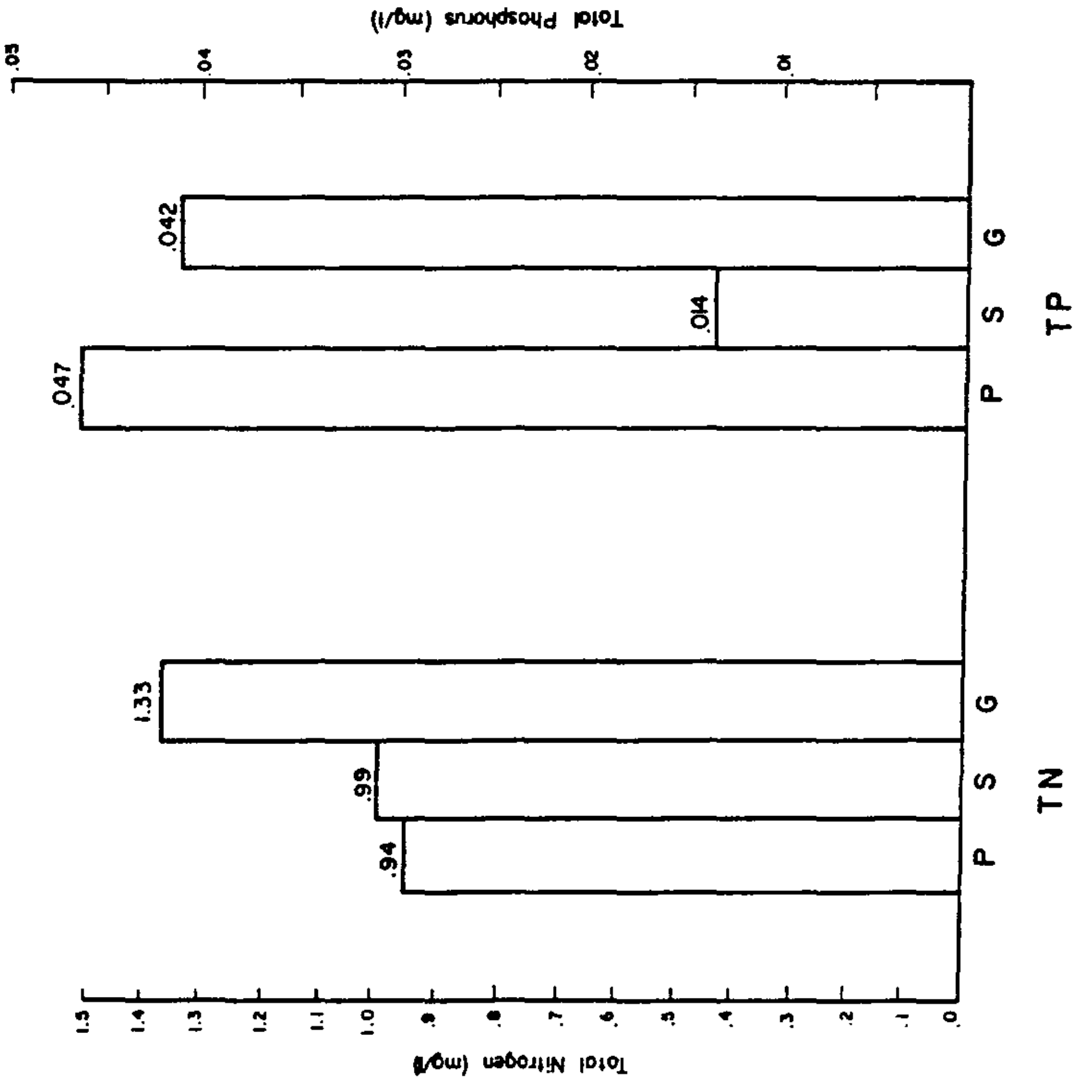
Ninety percent of the mean concentration of total nitrogen in the surface water is organic (0.89 mg/l). The mean concentration of organic nitrogen in the surface water is almost an order of magnitude greater than the mean concentration of inorganic nitrogen (0.09 mg/l). Ammonium in the surface water at the study site is the greatest inorganic nitrogen form. The mean ammonium concentration in the surface water (0.08 mg/l) is almost an order of magnitude greater than the mean concentration of nitrate plus nitrite (0.01 mg/l) in the surface water. The mean orthophosphate concentration in the surface water is very low (0.01 mg/l).

The mean total nitrogen and mean total phosphorus concentrations in precipitation relative to surface waters suggest that precipitation is the primary nutrient input to this system (Figure 5). This is consistent with the fact that there are no point sources of surface

Table 26. Monthly surface water parameters in the titi shrub swamp in Apalachicola, Florida.

	SITE																	
	1		2		3		4		5		6		7		All			
	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	min	max
Temperature (°C)	19.6	13	19.0	13	21.0	10	22.1	10	20.5	12	21.0	12	23.8	5	21.0	75	8.8	32.4
pH	4.1	14	3.9	14	3.6	13	3.6	12	4.0	15	4.0	14	4.0	6	3.9	88	3.0	4.7
Conductivity (umhos/cm)	51.2	16	63.0	16	87.5	14	85.7	14	52.5	16	62.7	15	60.7	6	66.2	97	29.0	128.0
Turbidity (JTU)	1.2	14	1.3	14	1.4	12	2.2	12	2.7	14	1.8	13	0.9	6	1.6	85	0.3	7.8
Color mg (Pt/l)	209	6	333	6	406	5	428	5	162	6	254	6	349	2	306	36	72	480
Acidity (mg $CaCO_3$/l)	27.4	8	41.4	8	48.2	9	47.1	5	33.6	7	28.3	8	47.9	3	39.1	48	21.0	68.9
Dissolved Oxygen (mg/l)	3.1	13	1.4	13	3.6	11	4.0	10	2.4	12	3.5	12	1.3	5	2.8	72	<0.1	7.1
Percent Saturation (%)	32.0	13	15.0	13	41.0	11	47.0	10	25.0	11	37.0	11	14.0	4	30.1	69	<0.1	91.0
BOD (mg/l O_2)	3.2	11	2.9	11	2.7	10	3.0	9	2.3	11	2.3	11	2.9	5	2.8	68	0.3	5.9
COD (mg/l O_2)	14.8	13	98.3	13	115.8	10	113.9	11	56.5	13	75.8	13	100.7	6	90.8	79	30.3	166.8
TOC (mg/l O_2)	35.5	5	48.1	5	51.8	4	45.8	4	25.1	5	33.2	5	51.9	1	41.6	34	8.9	83.1
NH_3-N (mg N/l)	0.01	14	0.01	14	0.01	12	0.02	12	0.02	14	0.01	13	0.01	6	0.01	85	<0.01	0.10
NO_3-N (mg N/l)	0.09	13	0.06	12	0.08	11	0.08	11	0.07	13	0.01	13	0.11	5	0.08	78	<0.01	0.42
TKN (mg N/l)	0.92	7	0.98	8	1.08	6	1.12	6	0.62	7	0.87	7	1.30	6	0.98	47	0.03	2.28
Org N (mg N/l)	0.80	6	1.05	6	0.10	5	1.00	5	0.51	5	0.67	6	1.21	5	0.89	39	0.39	2.19
TN (mg N/l)	0.94	6	0.10	7	1.08	5	1.11	5	0.64	6	0.83	6	1.33	5	0.99	40	0.04	2.28
TP (mg P/l)	0.01	11	<.01	10	0.01	9	0.01	9	0.01	11	0.01	11	0.03	6	0.01	67	<0.01	0.01
OP (mg P/l)	0.01	9	0.003	10	<0.01	8	<0.01	8	0.01	10	<0.01	10	0.01	6	0.01	61	<0.01	0.07
N:P	96.0	4	109.0	4	135.0	3	109.0	3	43.0	2	106.0	3	58.0	3	94.0	22	8.0	234.0
Cl (mg/l)	5.65	4	5.33	3	7.45	4	7.65	4	5.15	4	5.97	4	6.0	1	6.17	24	3.30	12.2

Figure 5. Mean total nitrogen (TN) and mean total phosphorus (TP) concentrations in precipitation (P), surface water (S) and groundwater (G) at the titi shrub swamp study site in Apalachicola, Florida. Sources of data are Tables 24, 25, and 26.


Total Phosphorus (mg/l)
.05
.04
.03
.02
.01
.042
.014
.047
P
S
G
TP
1.33
.99
.94
P
S
G
TN
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.
Total Nitrogen (mg/l)

water supplying the system. The mean total nitrogen and mean total phosphorus concentrations in shallow groundwater are slightly higher than in surface water.

Soils

There are two soil types at the study site (Table 27). The communities dominated by species of titi (titi swamps and bay swamp at the study site) occur on Typic Humaquepts of the Rutlege Series. These Inceptisols are nearly black or peaty, strongly acidic, very poorly drained sandy soils (SCS 1975). The black gum swamp occurs on Terric Medisaprists of the Pamlico Series. These Histosols are extremely acidic, very poorly drained organic soils (SCS 1975). Both soils occur where the water table is at or near the surface for long periods of the year and ponding is common.

Aquepts (the suborder of Inceptisols at the study site) and Saprists (the suborder of Histosols at the study site) have bulk densities greater than 0.2 g/cm^3 and 0.85 g/cm^3, respectively (SCS 1975). This is the case for these soils at the study site (Table 28). Histosols that are saturated with water contain at least 12 to 18% organic carbon depending on the clay content of the mineral fraction and kind of materials (SCS 1975). The soils at the study site dominated by black gum meet this criterion; they have from 24 to 50% organic carbon and are therefore organic soils (Table 28). The soils at the study site dominated by the species of titi all have less than 12% organic carbon and are therefore mineral soils. Bulk density increased with depth

Table 27. Classification of soils of the titi shrub swamp in Apalachicola, Florida.

Order	Suborder	Great Group	Subgroup	Family	Series	Community Type
Inceptisols	Aquepts	Humaquepts	Typic Humaquepts	Sandy, siliceous, thermic	Rutlege	Titi swamp, titi phase holly phase
						Bay swamp mixed phase
Histosols	Saprists	Medisaprists	Terric Medisaprists	Sandy, siliceous, dysic, thermic	Pamlico	Blackgum swamp

Table 28. Characteristics of soils of the titi shrub swamp in Apalachicola, Florida.

Community Type	Station	Depth cm	Bulk Density g/cm³	Organic Carbon %	Organic Carbon mg/g	Organic Matter %	pH	TN mg/g	TP mg/g
Titi swamp- titi phase	2	5	0.86	9.7	97.0	16.7	3.8	2.45	90.63
		10	1.00	7.8	77.0	13.4	3.8	2.06	59.00
		15	1.30	5.3	53.2	9.2	3.9	1.40	46.14
		20	1.43	3.5	35.3	6.1	4.0	0.42	45.13
Titi swamp - holly phase	4	5	0.90	7.0	69.7	12.0	4.1	3.08	64.19
		10	1.12	4.0	39.8	6.9	4.2	1.69	42.62
		15	1.17	3.7	36.6	6.3	4.2	1.20	38.75
		20	1.41	3.3	33.4	5.8	4.2	0.95	37.13
Bay swamp - mixed phase	6	5	1.02	4.6	45.5	7.8	4.5	1.16	38.37
		10	1.16	3.6	36.2	6.2	4.6	0.85	27.50
		15	1.53	2.7	27.3	4.7	4.8	0.50	16.87
		20	1.68	2.1	21.0	3.6	4.8	0.36	14.63
Black gum swamp	5	5	0.65	50.0	499.7	86.1	3.7	3.54	180.00
		10	0.99	36.8	368.4	63.5	3.9	2.46	182.25
		15	1.19	29.0	289.6	49.9	4.2	1.90	204.00
		20	1.24	24.0	240.5	41.5	4.2	1.53	224.87

while percent organic matter decreased with depth for all soils at the study site (Table 28). The pH also increased with depth (Table 28).

Total nitrogen in the soils was greatest at the surface where organic matter was greatest and decreased with depth as did organic matter (Table 28). Total phosphorus was highest in the surface layers of the mineral soils at the study site, but increased with depth in the organic soils. Overall, soils in the study site were low in nitrogen and phosphorus.

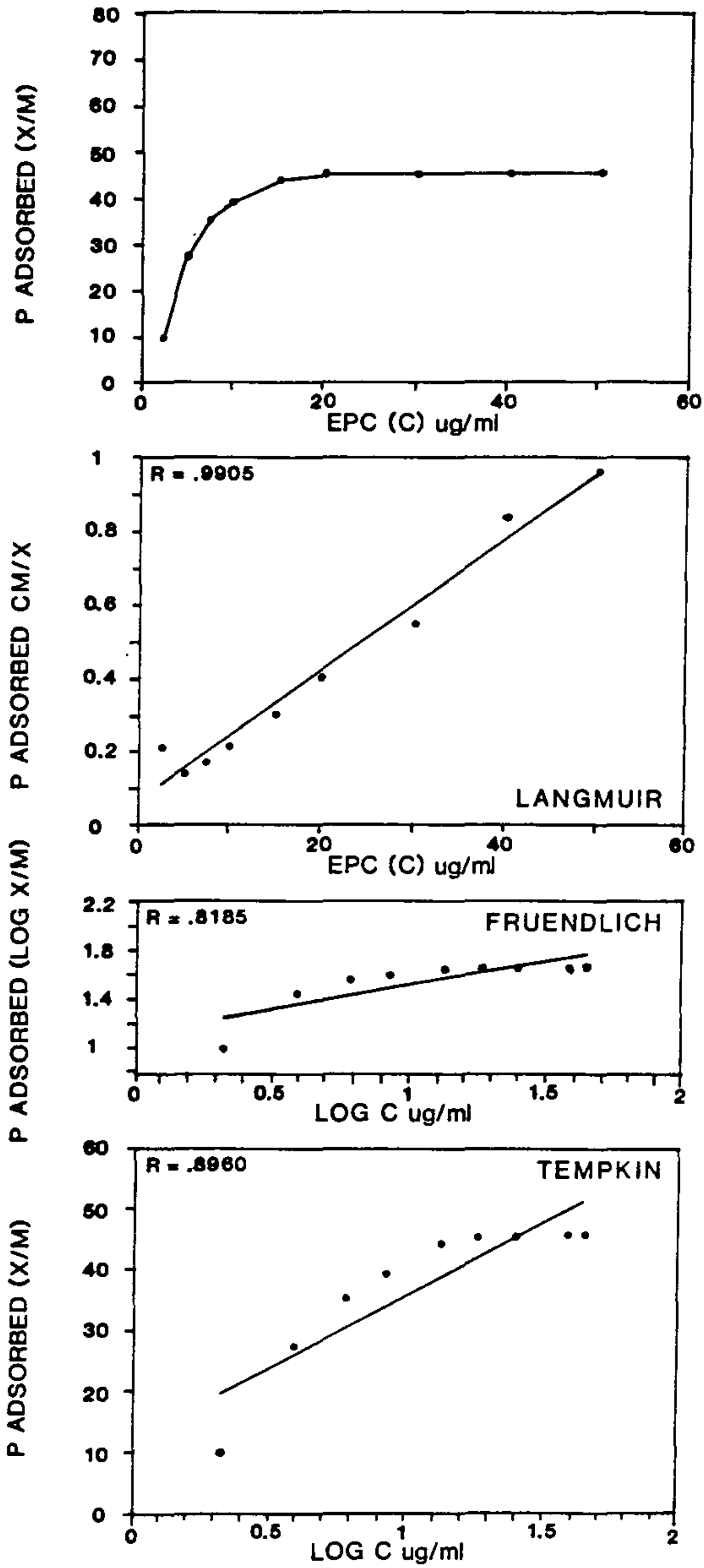
Phosphorus Adsorption

The amount of phosphorus adsorbed by the soil varied with soil type (Figures 6 through 9). The regular plots for the site four mineral soils are curved, which suggests a finite limit to adsorption, characteristic of the Langmuir equation. The regular plots for the organic soils are straight lines, which suggests a decrease in the energy of adsorption with increasing surface coverage, characteristic of the Fruendlich and Tempkin equations.

The fit of these equations can be evaluated by comparing the coefficients of determination of their regression lines (Table 29). The site four mineral soils show high correlation when plotted with the Langmuir equation and lower correlation when plotted with both the Fruendlich and Tempkin equations. The site five organic soils show the highest correlation when plotted with the Fruendlich equation, high correlation when plotted with the Tempkin equation, and no correlation when plotted with the Langmuir equation.

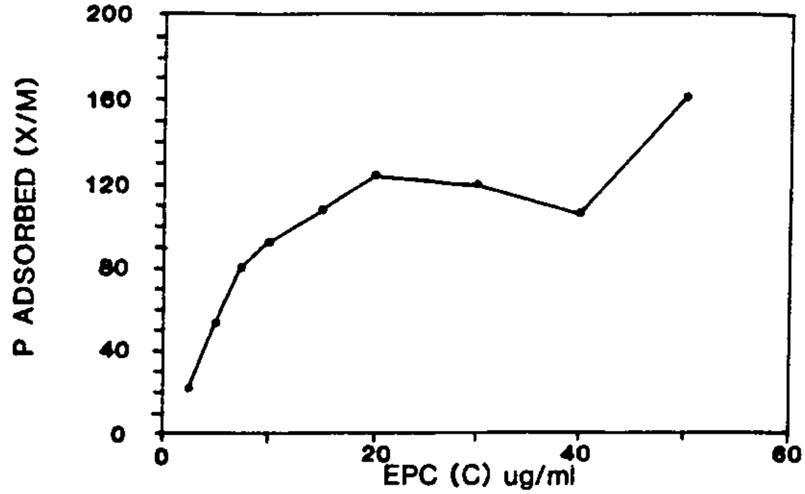
The adsorption maxima obtained directly from the slope of the linear Langmuir equation and the adsorption maxima calculated by

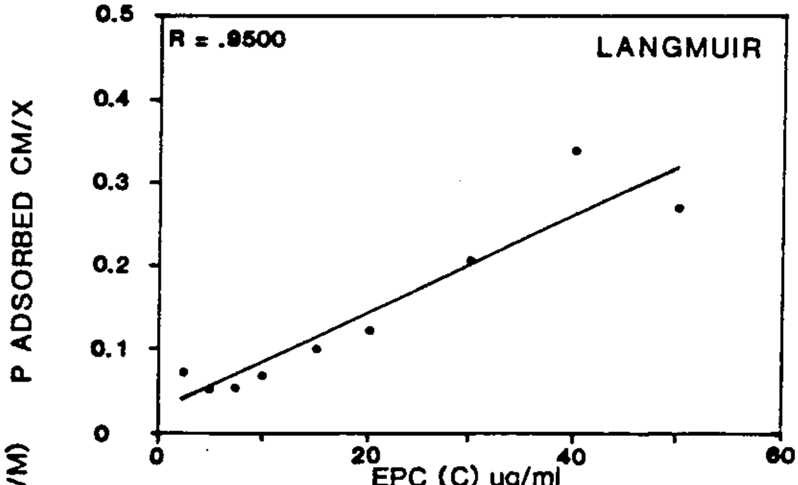
Figure 6. Phosphorus adsorption isotherms for the mineral soil (Rutlege Series) at a depth of 0-5 cm. Plots: regular, Langmuir, Fruendlich and Tempkin.

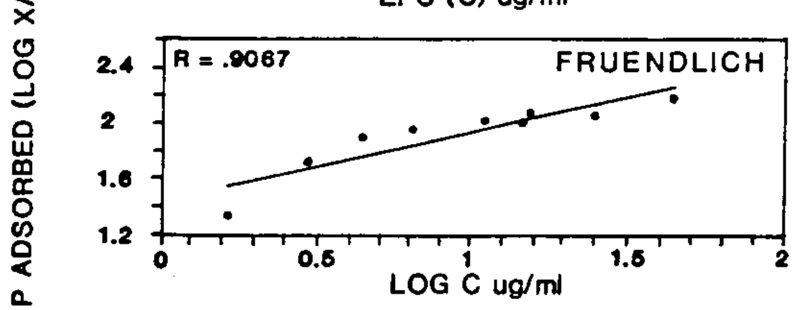


P ADSORBED (X/M)
EPC (C) ug/ml
P ADSORBED CM/X
R = .9905
LANGMUIR
EPC (C) ug/ml
P ADSORBED (LOG X/M)
R = .8185
FRUENDLICH
LOG C ug/ml
P ADSORBED (X/M)
R = .8960
TEMPKIN
LOG C ug/ml

Figure 7. Phosphorus adsorption isotherms for the mineral soil (Rutlege Series) at a depth of 15-20 cm. Plots: regular, Langmuir, Fruendlich and Tempkin.


P ADSORBED (X/M)
EPC (C) ug/ml
200
160
120
80
40
0
0
20
40
60


R = .9500
LANGMUIR
P ADSORBED CM/X
EPC (C) ug/ml
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60


R = .9067
FRUENDLICH
P ADSORBED (LOG X/M)
LOG C ug/ml
2.4
2
1.6
1.2
0
0.5
1
1.5
2

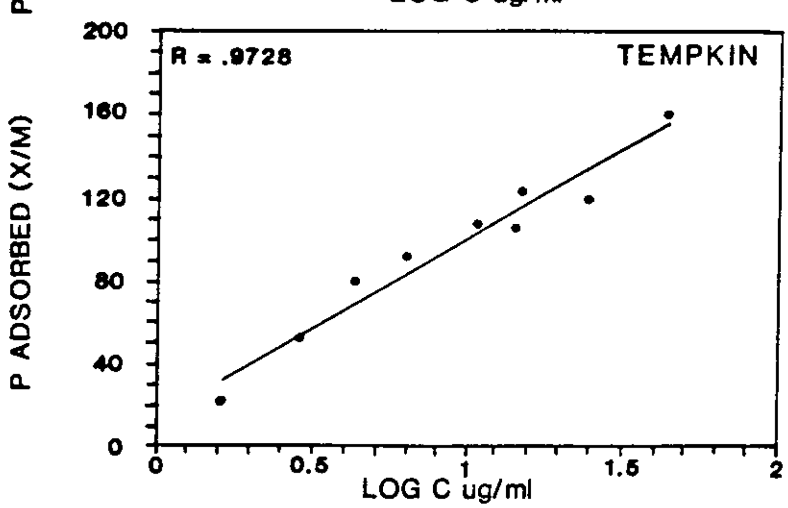

R = .9728
TEMPKIN
P ADSORBED (X/M)
LOG C ug/ml
200
160
120
80
40
0
0
0.5
1
1.5
2

Figure 8. Phosphorus adsorption isotherms for the organic soil (Pamlico Series) at a depth of 0-5 cm. Plots: regular, Langmuir, Fruendlich and Tempkin.

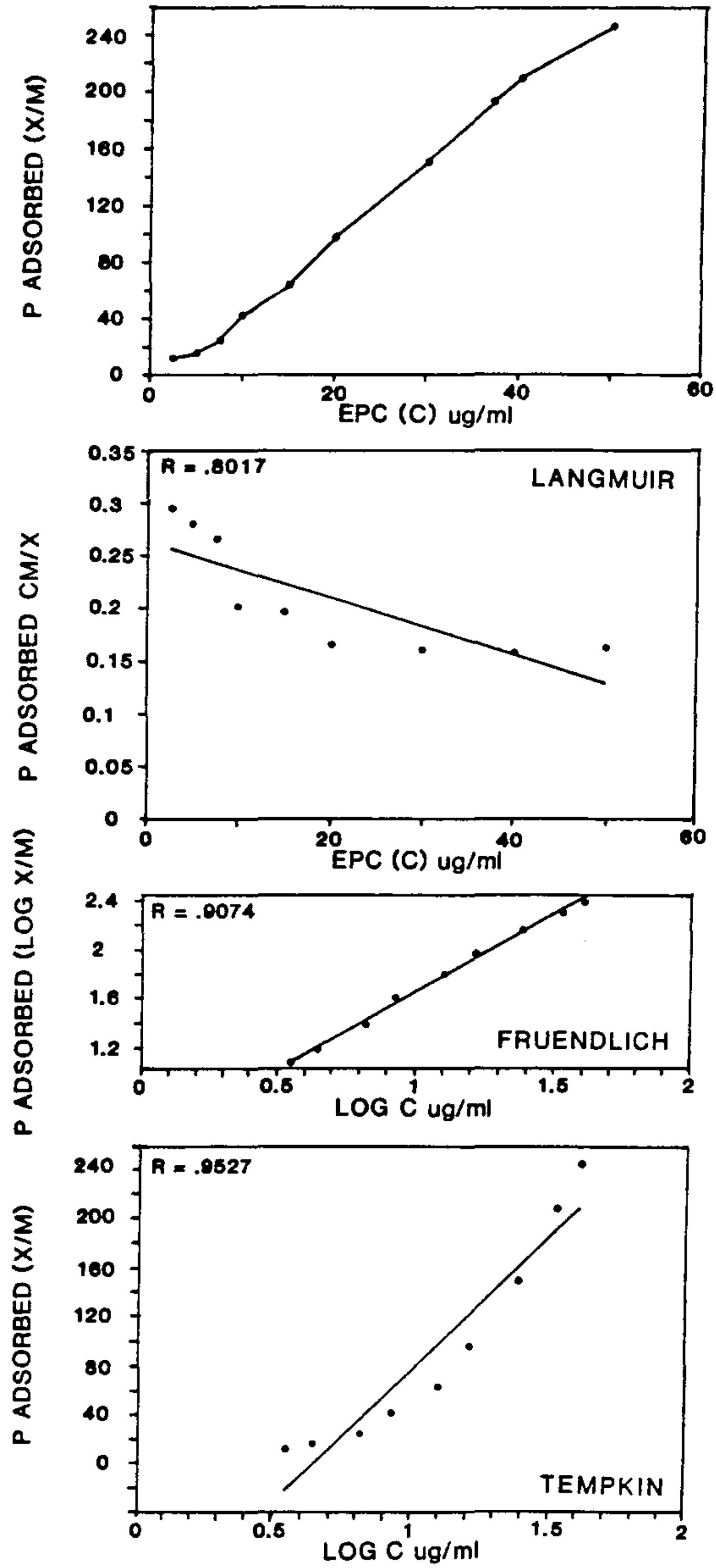
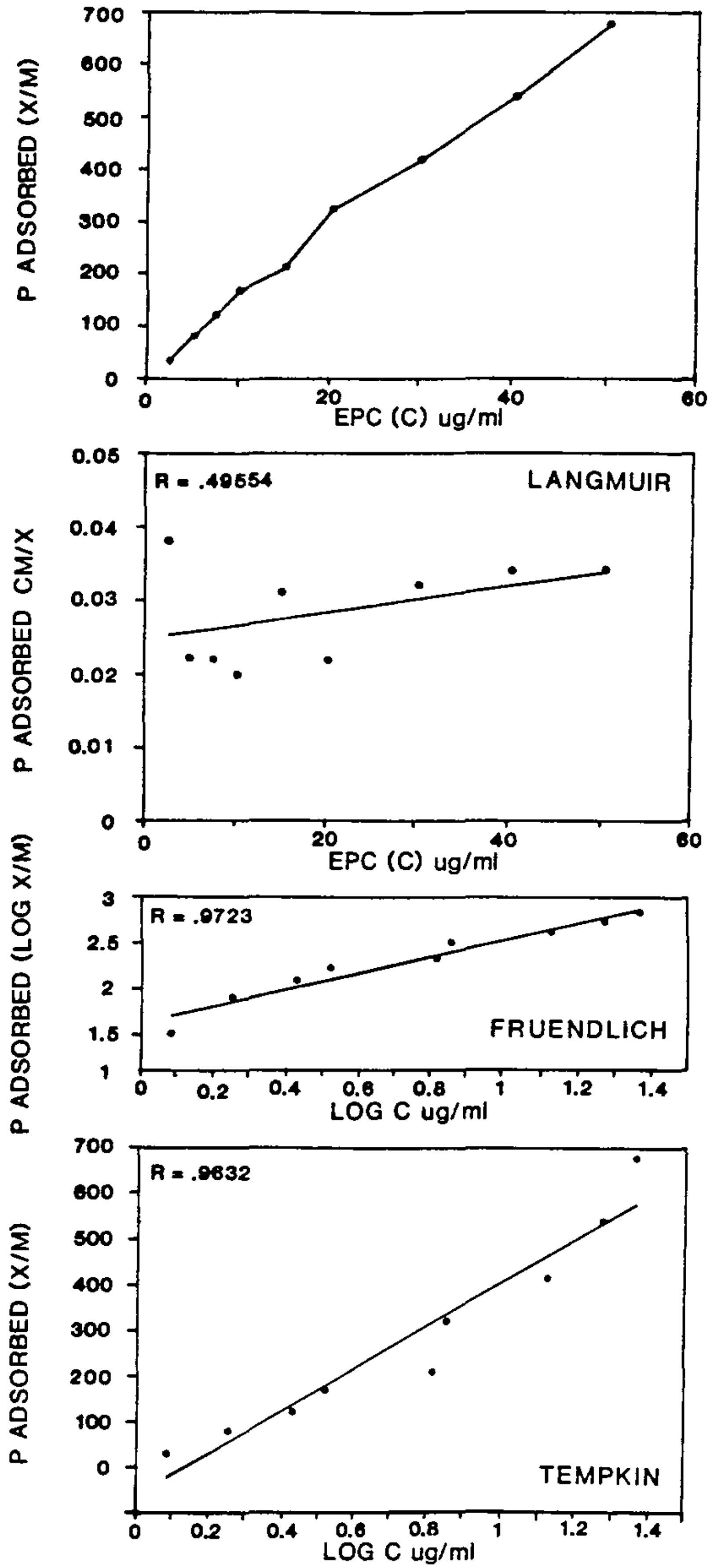

P ADSORBED (X/M)
240
200
160
120
80
40
0
0
20
40
60
EPC (C) ug/ml
P ADSORBED CM/X
R = .8017
LANGMUIR
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
EPC (C) ug/ml
P ADSORBED (LOG X/M)
R = .9074
FRUENDLICH
2.4
2
1.6
1.2
0
0.5
1
1.5
2
LOG C ug/ml
P ADSORBED (X/M)
R = .9527
TEMPKIN
240
200
160
120
80
40
0
0
0.5
1
1.5
2
LOG C ug/ml

Figure 9. Phosphorus adsorption isotherms for the organic soil (Pamlico Series) at a depth of 15–20 cm. Plots: regular, Langmuir, Fruendlich and Tempkin.



700
600
500
400
300
200
100
0
P ADSORBED (X/M)
0
20
40
60
EPC (C) ug/ml
0.05
0.04
0.03
0.02
0.01
0
R = .49554
LANGMUIR
P ADSORBED CM/X
EPC (C) ug/ml
3
2.5
2
1.5
1
R = .9723
FRUENDLICH
P ADSORBED (LOG X/M)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
LOG C ug/ml
R = .9632
TEMPKIN
P ADSORBED (X/M)
LOG C ug/ml

Table 29. Coefficients of determination (R) between the adsorption of added phosphorus by study site soils and the equilibrium phosphorus concentrations (EPC) in solution for the Langmuir Fruendlich, Tempkin, and quadratic equations.

Soil	depth (cm)	Langmuir	Fruendlich	Tempkin	Quadratic
4	0-5	.9905	.8185	.8960	.8845
	15-20	.9500	.9067	.9728	.8409
5	0-5	.8017	.9074	.9527	.9990
	15-20	.4955	.9723	.9032	.9895

substituting the equilibrium phosphorus concentration into the quadratic, Langmuir, Fruendlich, and Tempkin equations are similar (Table 30). The adsorption maxima for the site four mineral soils were less than 230 $\mu g/g$ soils. The adsorption maxima for the site five organic soils were from 294 to 2888 $\mu g/g$ soil. The adsorption maxima all increased with depth.

Tamm oxalate extractable phosphorus concentrations were higher than the 0.1 N HCl extractable phosphorus concentrations (Table 31) but less than total phosphorus concentrations. The Tamm oxalate extractable aluminum and iron concentrations were also higher than the 0.1 N HCl extractable aluminum and iron concentrations (Table 31). In addition, the dry weight of aluminum per gram of soil is much greater than the dry weight of phosphorus per gram of soil, and aluminum concentrations in the soil increase with depth (Table 31).

Linear regression of the adsorption maxima, phosphorus sorption index, and the measured soil properties indicate that the highest correlation obtained for both the adsorption maxima and the phosphorus sorption index was with Tamm oxalate extractable aluminum ($R = .9852$ and .9469 respectively) and 0.1 N HCl extractable aluminum ($R = .9838$ and .9389, respectively) (Table 31). There was also high correlation between the adsorption maxima and the phosphorus sorption index with Tamm oxalate extractable phosphorus ($R = .9825$ and .8454, respectively), but only the adsorption maxima had high correlation with total phosphorus ($R = .9266$) (Table 31). There was low correlation for both the adsorption maxima and the PSI with Tamm oxalate extractable iron ($R = .2851$ and .2004, respectively), 0.1 N HCl extractable iron ($R = .1715$

Table 30. Phosphorus adsorption maxima of study site soils calculated by substitution of the equilibrium phosphorus concentration (EPC) derived from quadratic equation into different equations.

			adsorption maxima $\mu g/g$				
Soil	Depth (cm)	EPC ($\mu g/ml$)*	Quadratic	Fruendlich	Tempkin	Langmuir	Langmuir +
4 (mineral)	0-5	29.3	84.6	49.5	47.1	45.2	51.0
	15-20	36.3	229.2	174.4	148.6	132.3	153.8
5 (organic)	0-5	238.8	1715.7	2887.2	380.1	437.2	294.1
	15-20	48.2	1726.1	1442.3	722.0	1093.9	2500.0

* EPC at adsorption maximum obtained from quadratic equation
+ Adsorption maximum obtained from slope of linear Langmuir equation

Table 31. Measured soil properties for the study site soils and the coefficient of determination (R) between these properties and 1) the adsorption maxima derived by substitution into the Tempkin equation, and 2) the phosphorus sorption index.

Community type	Site	Depth (cm)	% OM	TP	HCl ex P	Tamm ex P	HCl ex Al	Tamm ex Al	HCl ex Fe	Tamm ex Fe
							ug/g			
Titi swamp - holly phase	4	0-5	11.0	64.2	14.5	34.0	318.5	556.0	44.0	103.0
		15-20	5.8	37.1	2.0	28.0	685.0	925.0	26.0	66.5
Black gum swamp	5	0-5	86.1	180.0	33.5	85.0	516.5	2252.0	217.0	372.0
		15-20	41.5	224.9	36.0	143.0	4035.5	5700.0	46.5	138.0
Adsorption maxima substitution into Tempkin equation		R	.5197	.9266	.8130	.9825	.9838	.9852	.1715	.2851
Phosphorus sorption index 10 $\mu g/ml$ (quadratic equation)		R	.0553	.6774	.5192	.8454	.9389	.9469	.3146	.2004

and .3146, respectively), and percent organic matter (R = .5197 and .0553, respectively) (Table 31).

Hydrology

Precipitation and Runoff

The climate in the locality of the Apalachicola weather station is typical of that experienced on the northern Gulf of Mexico (NOAA 1982-1986). Temperatures are usually mild and subtropical in nature. Average annual precipitation is about 56 in., but actual monthly and yearly totals vary widely. Thunderstorms occur in all months, but about 75% occur during the summer months. Monthly precipitation data at the Apalachicola weather station for the 5-yr period from 1982 through 1986 and for the Water Budget Year are presented in Appendix C. The average annual precipitation for the 5-yr period from 1982 through 1986 was 66 in. (Table 32). This was almost 10 in. greater than the preceding 74 yr average of 56 in. for this weather station (Kennedy 1982) and was similar to precipitation for the water budget year (65 in.).

Soils at the study site are Group D type soils in the SCS (1972) hydrologic soil group classification system. Soils in this group are characterized by high runoff potential, very slow water transmission rates and a high permanent water table. The curve numbers (Cn) for these soils assuming average (AMC II) and wet (AMC III) watershed conditions were 77 and 89.5, respectively. Monthly estimated

Table 32. Average annual precipitation (P), estimated runoff (R), pan evaporation (PE), potential evapotranspiration (PET), actual evapotranspiration (AET) and water budget residual (RES) for the study site from 1982 through 1986 and for the water budget year (WBY).

Year		P (in)	R (in)	PE (in)	PET (in)	AET (in)	R+AET (in)	R+PET (in)	RES I (in)	RES II (in)
1982		71.96	23.60	56.91	40.83	38.67	62.27	64.43	9.69	7.53
1983		64.38	16.49	57.84	40.05	34.42	50.91	56.64	13.47	7.74
1984		56.50	16.82	62.14	39.84	32.90	49.72	56.66	6.78	-0.16
1985		68.57	20.92	54.91	41.27	39.05	59.97	62.19	8.60	6.38
1986		66.81	21.35	57.93	43.42	37.35	58.70	64.77	8.11	2.04
Average	(in)	65.64	19.84	57.95	41.08	36.48	56.31	60.94	9.33	4.72
	(m)	1.67	0.50	1.47	1.04	0.93	1.43	1.54	0.24	0.13
	(%)	100.0	30.2	88.3	62.6	55.6	85.8	92.8	14.2	7.2
WBY	(in)	64.71	21.16	58.00	43.20	37.14	58.30	64.36	6.41	0.36
	(%)	100.0	32.7	89.6	66.8	57.4	90.1	99.5	9.9	0.5

runoff at the study site for the 5-yr period from 1982 through 1986 and for the water budget year using methods assuming average (AMC II) and wet (AMC III) watershed conditions are presented in Appendix C. Assuming average (AMC II) watershed conditions underpredict large runoff events and assuming wet (AMC III) watershed conditions overpredicts small runoff events (Konyha et al. 1982). The estimate of runoff assuming wet (AMC III) watershed conditions was at least 45% greater than the estimate of runoff assuming average (AMC II) watershed conditions. The average of the two methods was therefore selected. The average annual estimated runoff for the 5-yr period from 1982 through 1986 was 20 in. (Table 32). This was 30% of the average annual precipitation at the study site for this period. Estimated runoff for the water budget year was similar (21 in.).

Groundwater

The potentiometric surfaces for high and low groundwater periods are presented in Figures 10 and 11, respectively. The difference between potentiometric contours of the wetland is 4 ft for both the high and low periods (16' to 12' and 14' to 10', respectively). During low water, flow was in the southwest direction, shifting towards the north-west during high water flow. The average water depth and fluctuation for all three stations within the wetland were 0.51 m and 0.93 m, respectively (Table 33).

The natural gamma log for a well located 2 km northeast of the study site indicates that there is a zone of surface sands extending to

Figure 10. Potentiometric surface of the surficial aquifer at the titi shrub swamp study site in Apalachicola, Florida; July 30, 1982 (high groundwater).

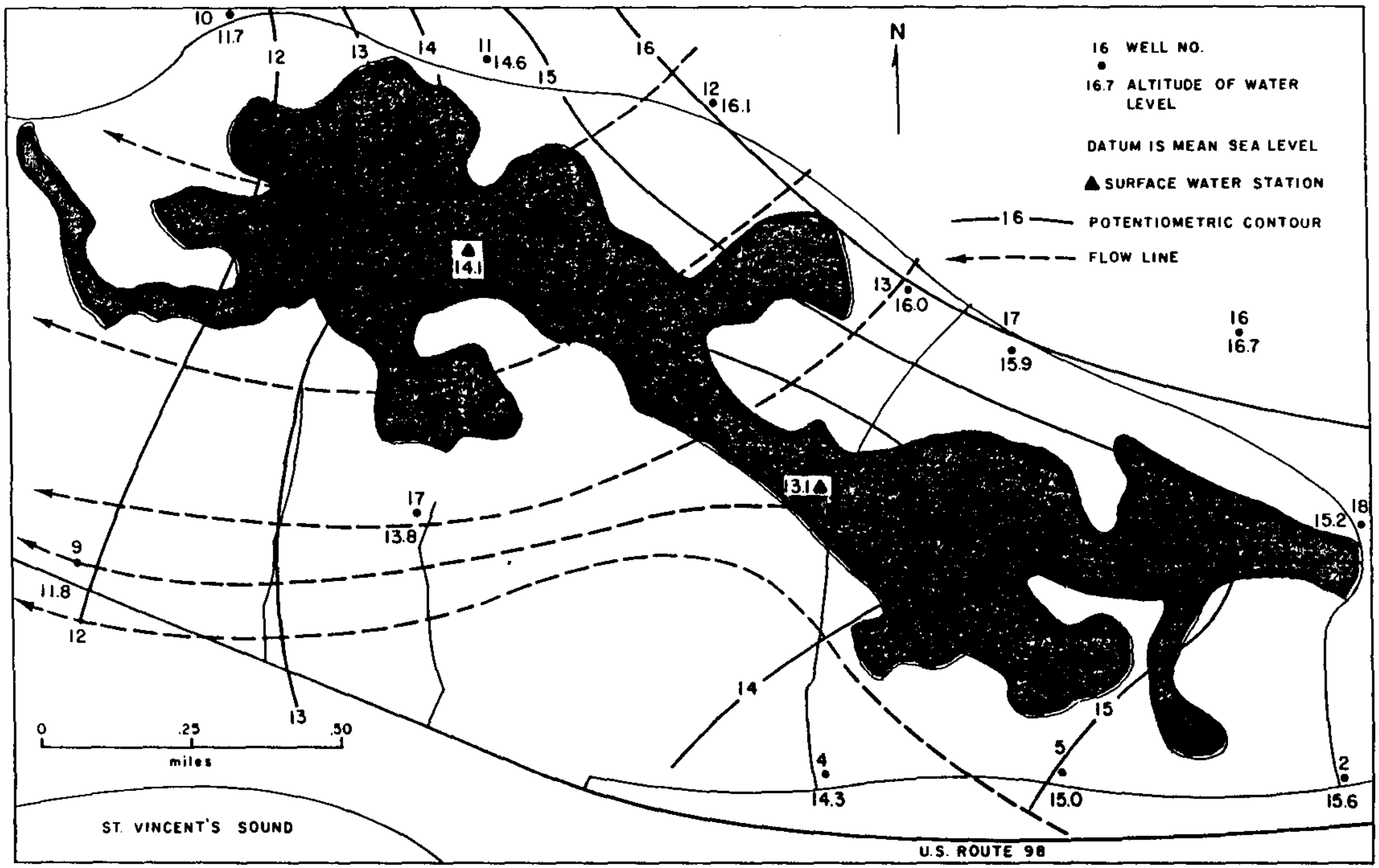

N
16 WELL NO.
16.7 ALTITUDE OF WATER LEVEL
DATUM IS MEAN SEA LEVEL
SURFACE WATER STATION
16 POTENTIOMETRIC CONTOUR
FLOW LINE
14.1
13.1
10
11.7
11
14.6
12
16.1
13
16.0
17
15.9
16
16.7
18
15.2
2
15.6
5
15.0
4
14.3
17
13.8
9
11.8
12
13
14
15
16
0
.25
.50
miles
ST. VINCENT'S SOUND
U.S. ROUTE 98

Figure 11. Potentiometric surface of the surficial aquifer at the titi shrub swamp study site in Apalachicola, Florida; May 30, 1982 (low groundwater).

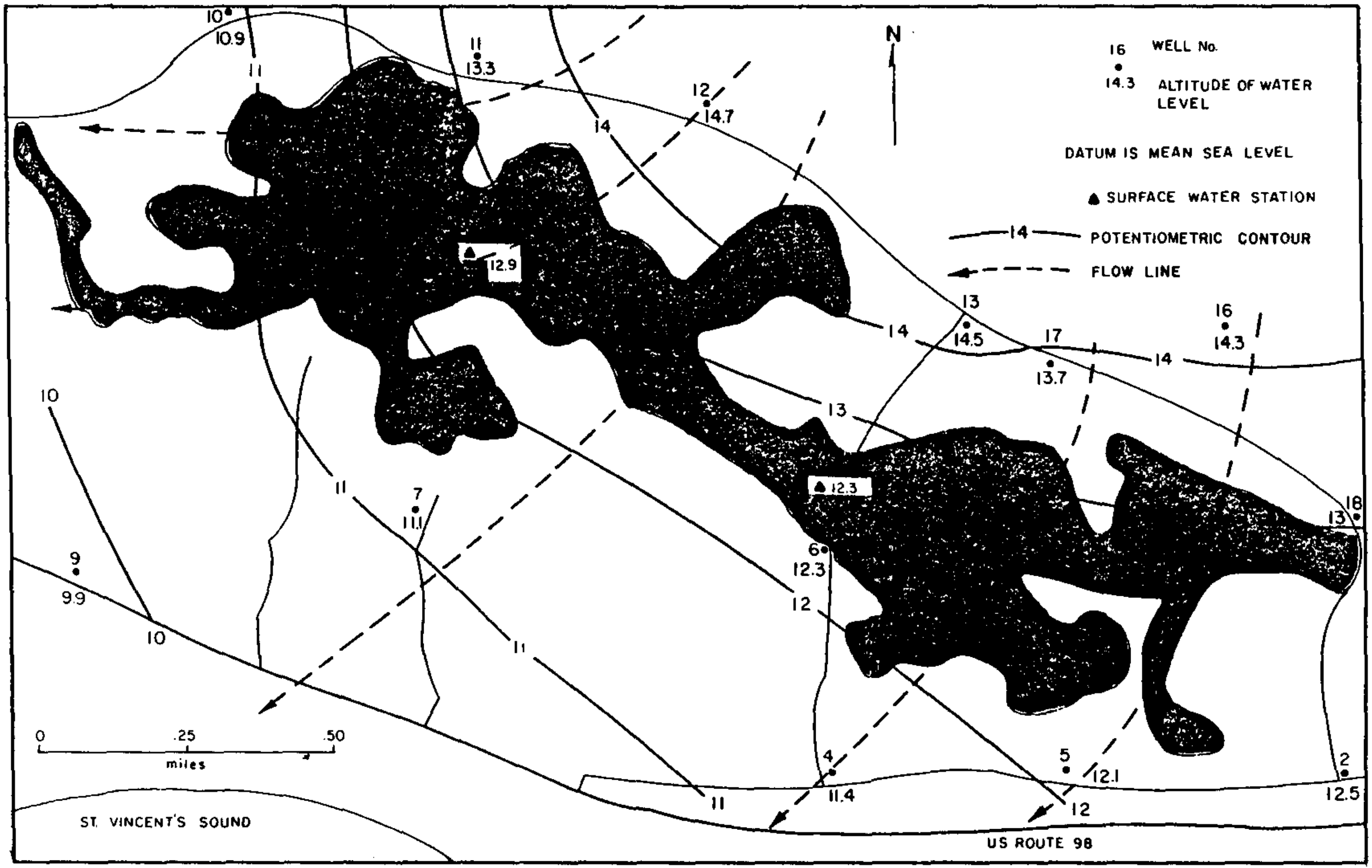

N
16 WELL No.
14.3 ALTITUDE OF WATER LEVEL
DATUM IS MEAN SEA LEVEL
SURFACE WATER STATION
14 POTENTIOMETRIC CONTOUR
FLOW LINE
0 .25 .50
miles
ST. VINCENT'S SOUND
US ROUTE 98
10 10.9
11 13.3
12 14.7
13 14.5
17 13.7
16 14.3
18
7 11.1
9 9.9
6 12.3
4 11.4
5 12.1
2 12.5
12.9
12.3

Table 33. Water depth (m) for three stations with the titi shrub swamp in Apalachicola, Florida.

	Depth (m)		
Date	Station 2	Station 3	Station 5
Mar 30, 1982	0.62	0.43	0.73
Apr 29, 1982	0.54	0.35	0.62
May 30, 1982	0.15	0.03	0.39
Jun 29, 1982	0.20	0.23	0.66
Jul 29, 1982	0.95	0.76	1.53
Aug 29, 1982	0.71	0.55	0.80
Sep 29, 1982	0.62	0.38	0.69
Oct 29, 1982	0.60	0.38	0.31
Nov 28, 1982	0.43	0.08	0.26
Dec 30, 1982	0.51	0.32	0.62
Jan 30, 1983	0.47	0.41	0.54
Feb 28, 1983	0.55	0.46	0.67
Average	0.53	0.36	0.65
Range	0.15-0.95	0.03-0.76	0.26-1.53
Fluctuation	0.80	0.73	1.27

Average water depth for all sites = 0.51 meters
Average fluctuation for all sites = 0.93 meters
Average high water for all sites = 1.08 meters

a depth of 42 ft overlying a zone of clayey sands extending to a depth of 178 ft (Figure 12).

Hydraulic conductivities for similar zonation (a semi-impermeable organic layer and surface sands underlain by clayey sands) beneath cypress domes in Alachua County ranged from 0.01 to 0.1 ft/wk for the semi-impermeable organic layer, from 1 to 10 ft/wk for the surface sands and from 0.001 to 0.01 ft/wk for the clayey sands (Cutright 1974). In estimating the upper limit of deep seepage through the clayey sand zone, the high end of the hydraulic conductivity range measured by Cutright (1974) for clayey sands was used ($K = 0.01$ ft/wk). The change in the piezometric head Δh between the two zones is 178 ft and the thickness of the clayey sand zone Δz is 136 ft (178-42). Therefore, the maximum velocity ($v = K \Delta h / \Delta z$) of the water passing from the surface sand zone to the clayey sand zone is 0.013 ft/wk; at most 0.676 ft or 8 in. pass through the clayey sand zone per year.

Evapotranspiration

Monthly values for the 5-yr period from 1982 through 1986 and the Water Budget Year for pan evaporation, mean temperature, heat index, unadjusted potential evapotranspiration, mean sunlight, adjusted potential evapotranspiration, accumulated water loss, soil moisture retained, soil water loss and actual evapotranspiration are presented in Appendix C.

The maximum soil moisture used to calculate the soil water loss and the actual evapotranspiration was 2.01 in. This was determined from an average curve number (Cn) of 83.25 (AMC II Cn=77, AMC III Cn=89.5) for the soils at the study site. The average curve number (Cn) was used because annual estimated runoff was determined based on the average of the two runoff estimate methods.

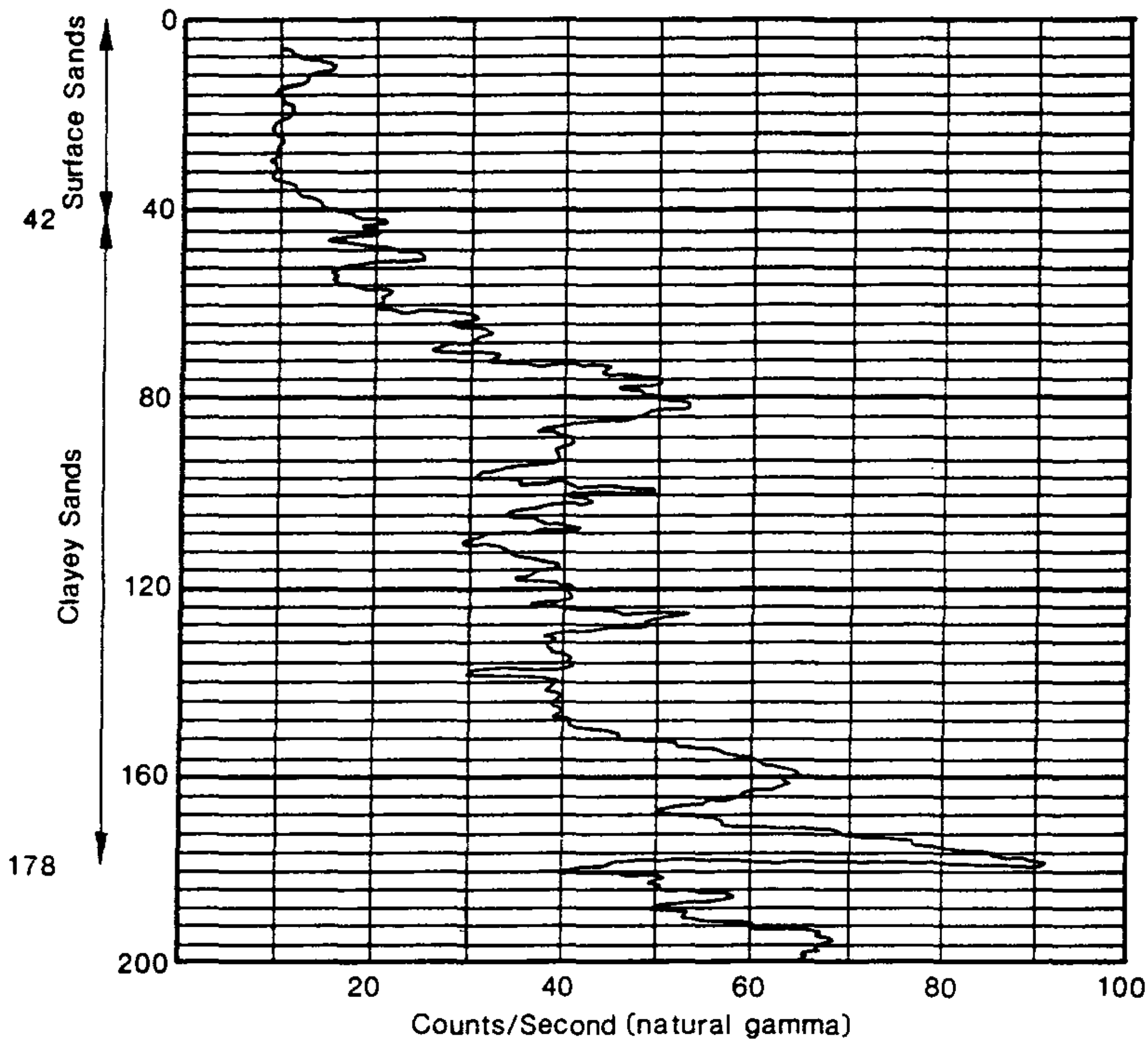


Figure 12. Natural gamma log of a well located 2.0 miles northeast of the titi shrub swamp study site in Apalachicola, Florida.

During months when precipitation was greater than potential evapotranspiration, actual evapotranspiration was taken to be equal to potential evapotranspiration. The difference between precipitation and potential evapotranspiration is the water surplus. A water surplus occurred from November through March except for December 1984, when very low precipitation (0.91 in.) was recorded (74 yr average for December for this weather station = 3.79 in.; Kennedy 1982). These are the coldest months, and transpiration is low. When precipitation was less than potential evapotranspiration, water was lost from the soil. The difference between the potential evapotranspiration and actual evapotranspiration is the water deficit. A water deficit always occurred in May during the 5-yr study period and in June for 4 of the 5 yrs that were analyzed. This water deficit coincides with the spring burst of productivity. Water deficits also occurred at various times from 1982 through 1986 in April, July, August, September and October.

For the 5-yr period from 1982 through 1986 the annual average potential evapotranspiration was 41 in., or 63% of precipitation, and the annual average actual evapotranspiration was 36 in., or 56% of precipitation (Table 32). The potential evapotranspiration and the actual evapotranspiration for the water budget year were similar (43 in. and 37 in.) to annual average values for the 5-yr period from 1982 through 1986.

Annual average pan evaporation for the Milton weather station for the 5-yr period from 1982 through 1986 was 58 in. Annual average potential evapotranspiration for the Apalachicola weather station for the 5-yr period from 1982 through 1986 was 41 in. Therefore, potential evapotranspiration was 0.71 of pan evaporation.

Water Budget

The water budget for the water budget year is similar to the water budget for the 5-yr period from 1982 through 1986. All values presented below are the average for the 5-yr period.

Precipitation was 66 in. Estimated runoff was 20 in., or 30% of precipitation reaching the study site. Estimated actual evapotranspiration was 36 in., or 56% of precipitation reaching the study site. Estimated potential evapotranspiration was 41 in., or 63% of precipitation reaching the study site. Runoff and estimated actual evapotranspiration together (56 in.) account for 86% of precipitation reaching the study site. The difference between these components and precipitation reaching the study site is water budget residual I (RES-I), which was 10 in., or 15% of precipitation reaching the study site. Runoff and estimated potential evapotranspiration together (61 in.) account for 93% of precipitation reaching the study site. The difference between these components and precipitation reaching the study site is water budget residual II (RES-II), which was 5 in., or 7% of precipitation reaching the study site. This value is the estimate of groundwater flow.

Transpiration

Transpiration was measured on 11 days. There was standing water present and it never rained when transpiration was measured. Chamber I was used on October 21, 1984, and November 2, 1984. Chamber II, a shorter chamber, was used on April 21, 1985, and was destroyed by a hurricane in August 1985. Chamber III was used for the remaining runs, between October 5, 1985, and September 14, 1986. Transpiration of black titi was measured on November 2, 1984. Transpiration of sweetbay was measured on the other 10 days.

A spread sheet for each run is presented in Appendix D. Transpiration never began before 8:45 AM and always ended by 6:15 PM. The shortest period of transpiration was 7 hrs on December 14, 1985, and the longest periods were 9 hrs on June 28, 1986, and August 20, 1986. In general, for all runs, as solar input, ambient temperature and saturation deficit increased, transpiration increased (Figures 13–23). Conversely, as solar input, ambient temperature and saturation deficit decreased, transpiration decreased. An inverse relationship existed between relative humidity and transpiration.

The vertical distribution of leaf biomass for black titi and sweetbay in the bay swamp community was largest in the vertical interval from 9 to 12 m (Table 34). Most of the leaf biomass was concentrated in the canopy where transpiration was measured.

Daily transpiration rates ranged from 412 to 1924 g H_2O/day (Table 35). There was a definite seasonality in the results; the lowest values occurred in December and March, and the highest values occurred in May and June. The average daily transpiration rate for the ten sweetbay runs was 1154 g H_2O/day. The daily transpiration rate for the black titi run was 1073 g H_2O/day. Daily transpiration rates per leaf area ranged from 651 to 3124 g H_2O/m^2 leaf area • day (Table 35). The average daily transpiration rate per leaf area for the ten sweetbay runs was 1593 g H_2O/m^2 leaf area • day. The daily transpiration rate per leaf area for the black titi run was 801 g H_2O/m^2 leaf area • day.

Daily transpiration rates per ground area ranged from 866 to 4155 g H_2O/m^2 ground area • day (Table 35). The average daily transpiration

Figure 13. Transpiration run October 21, 1984 (sweetbay).

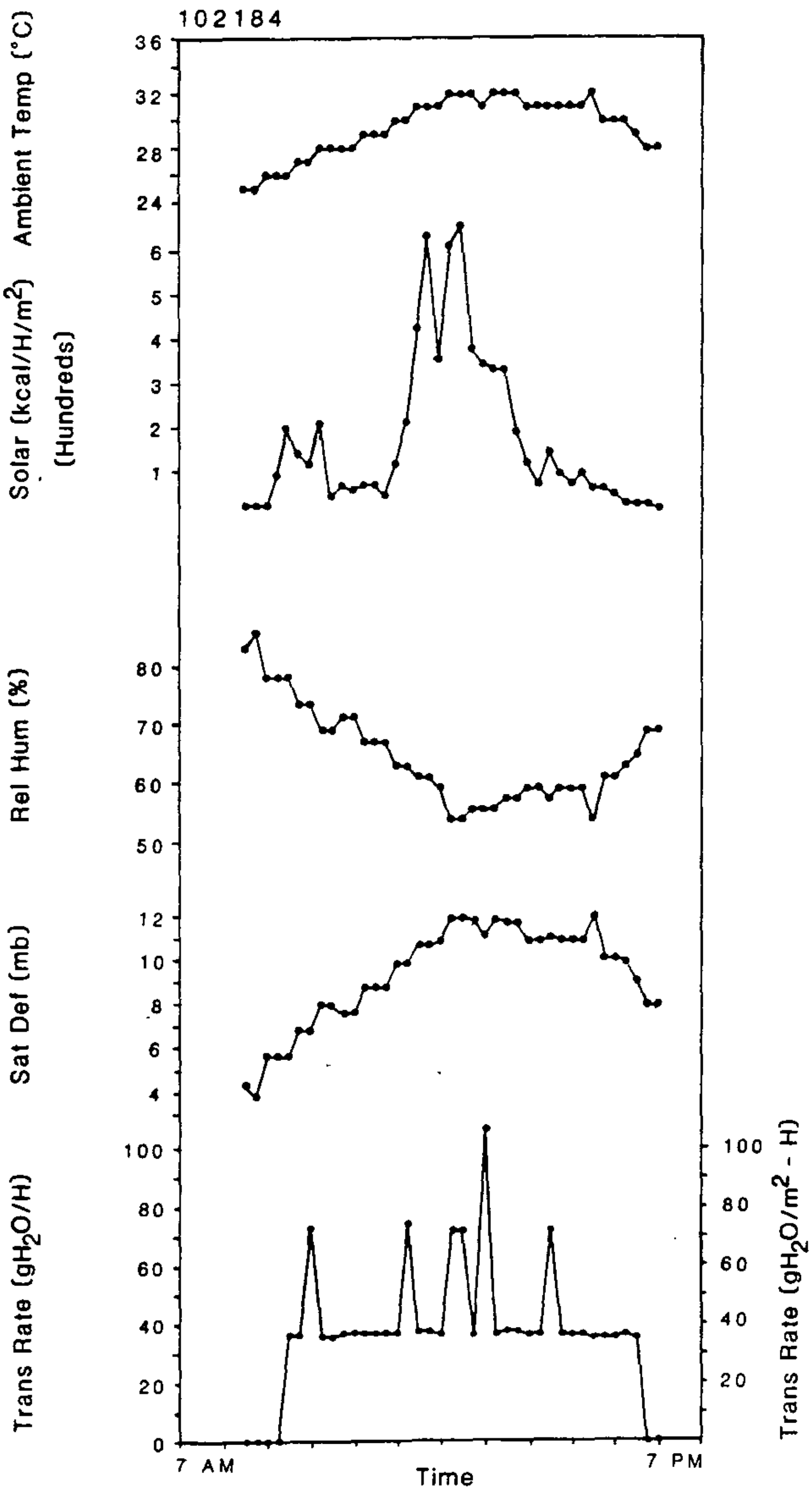
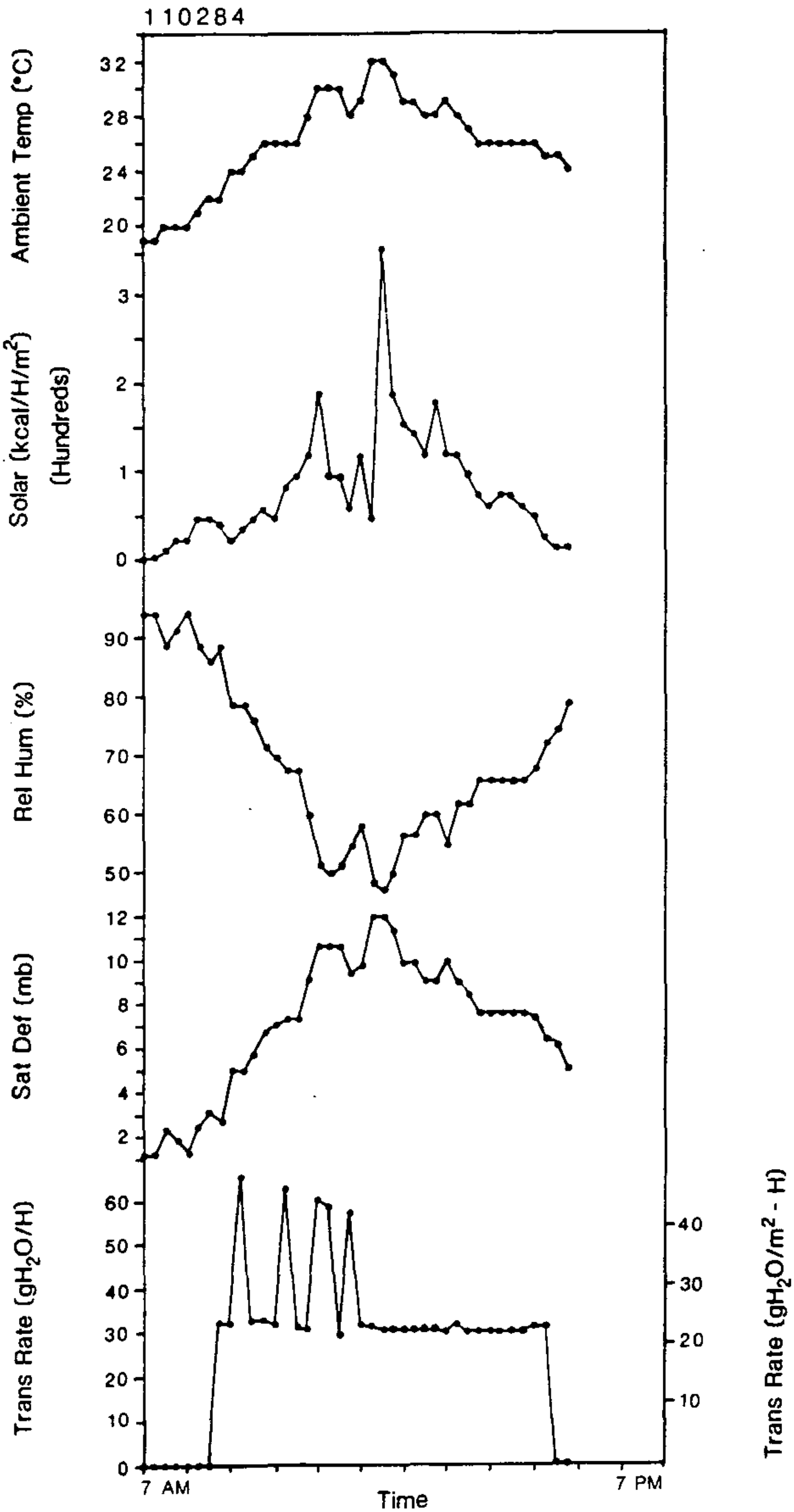

102184
Ambient Temp (°C)
36
32
28
24
Solar (kcal/H/m2)
(Hundreds)
6
5
4
3
2
1
Rel Hum (%)
80
70
60
50
Sat Def (mb)
12
10
8
6
4
Trans Rate (gH2O/H)
100
80
60
40
20
0
Trans Rate (gH2O/m2 - H)
100
80
60
40
20
7 AM
Time
7 PM

Figure 14. Transpiration run November 2, 1984 (black titi).



110284
Ambient Temp (°C)
32
28
24
20
Solar (kcal/H/m²) (Hundreds)
3
2
1
0
Rel Hum (%)
90
80
70
60
50
Sat Def (mb)
12
10
8
6
4
2
Trans Rate (gH₂O/H)
60
50
40
30
20
10
0
Trans Rate (gH₂O/m² - H)
40
30
20
10
7 AM
Time
7 PM

Figure 15. Transpiration run April 21, 1985 (sweetbay).

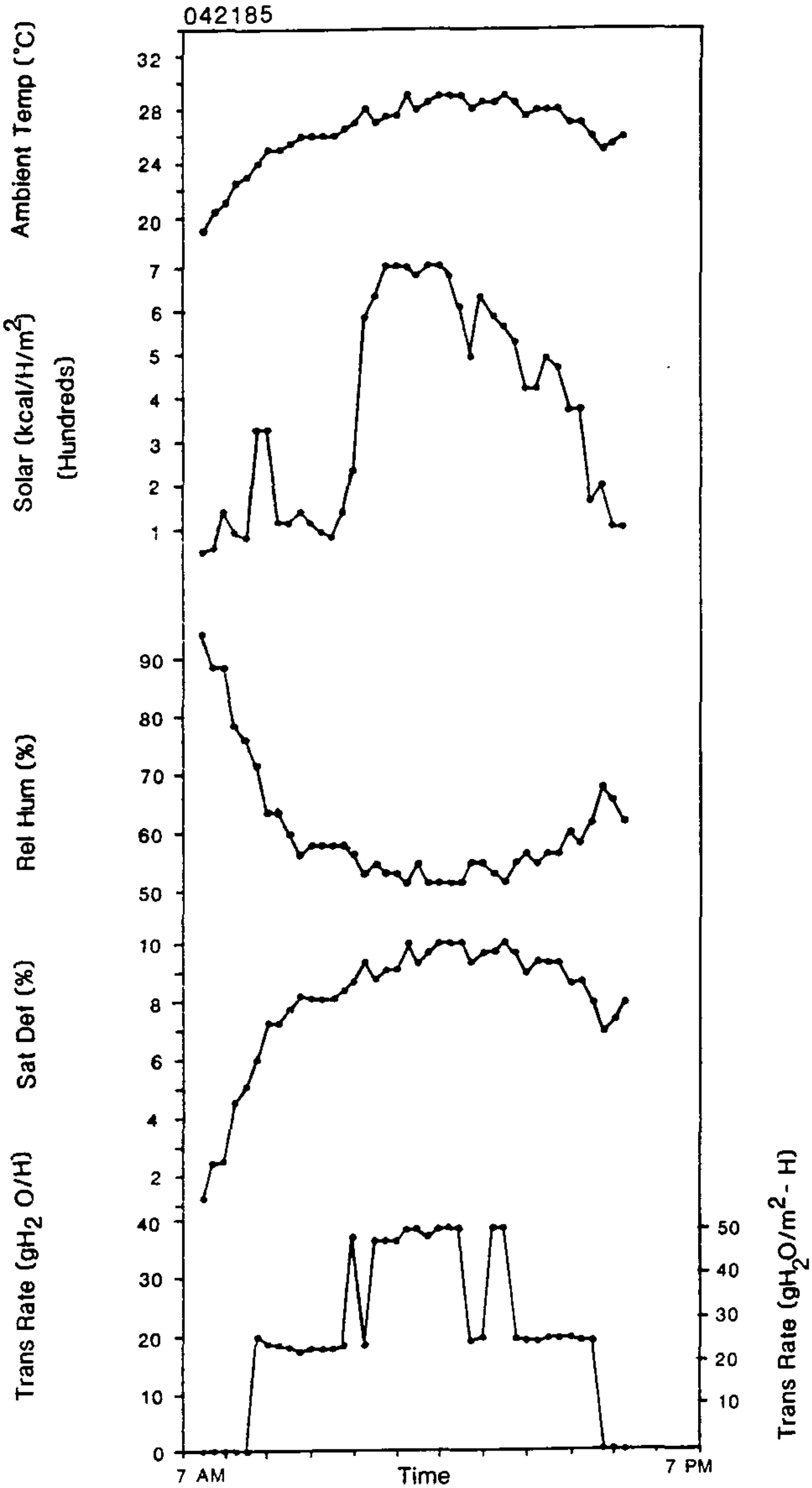

042185
Ambient Temp (°C)
32
28
24
20
Solar (kcal/H/m2)
(Hundreds)
7
6
5
4
3
2
1
Rel Hum (%)
90
80
70
60
50
Sat Def (%)
10
8
6
4
2
Trans Rate (gH2 O/H)
40
30
20
10
0
Trans Rate (gH2O/m2- H)
50
40
30
20
10
7 AM
Time
7 PM

Figure 16. Transpiration run October 5, 1985 (sweetbay).

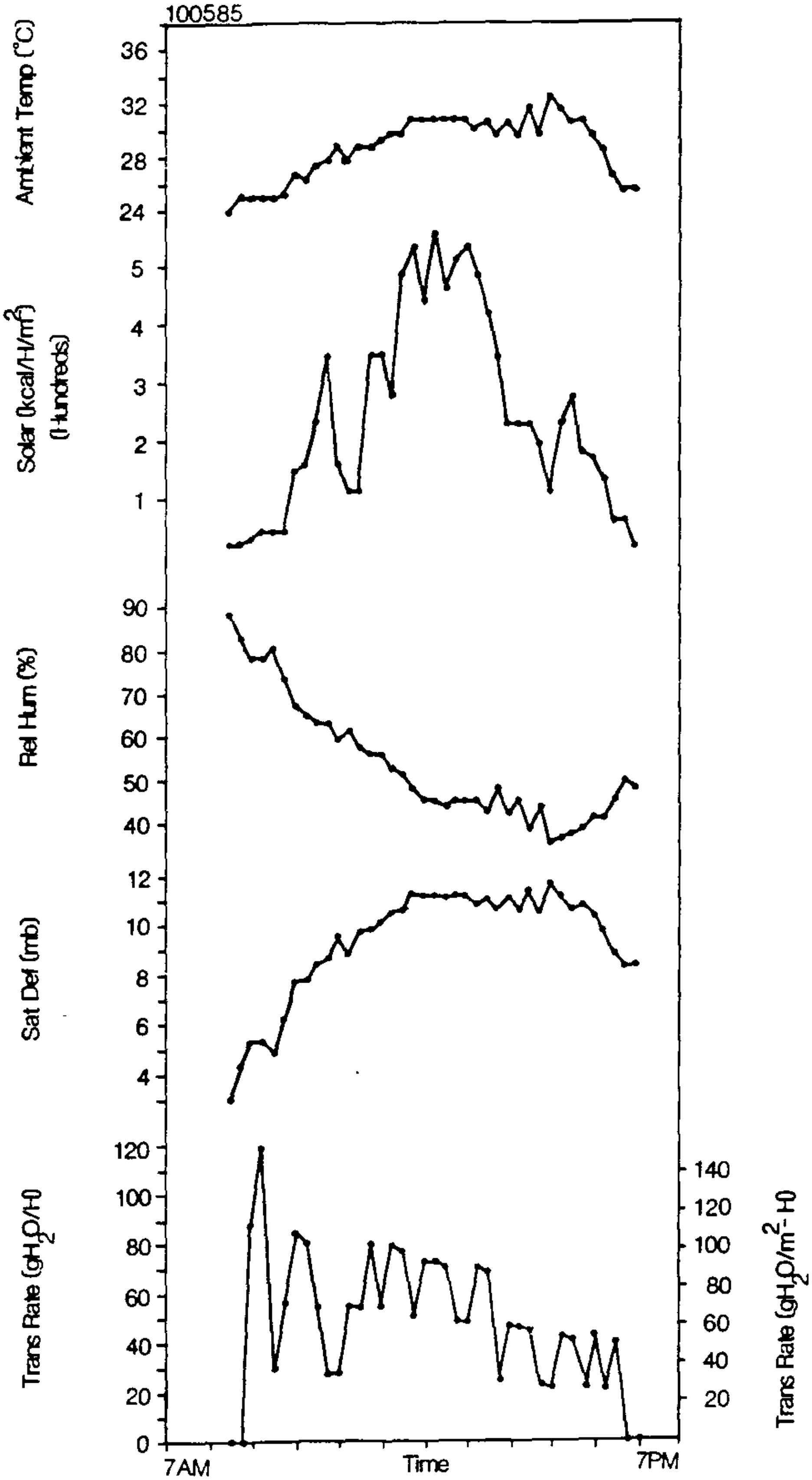
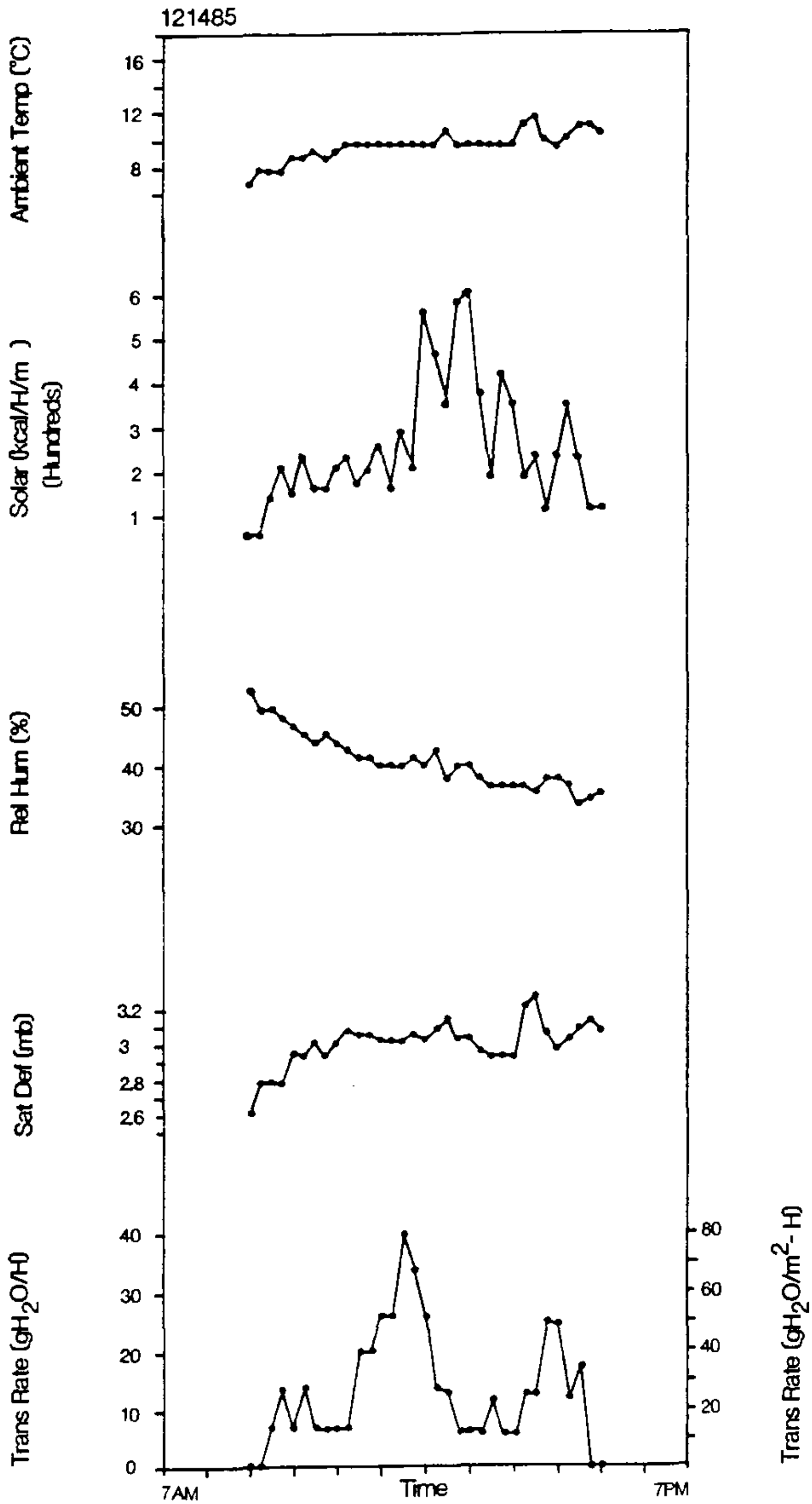
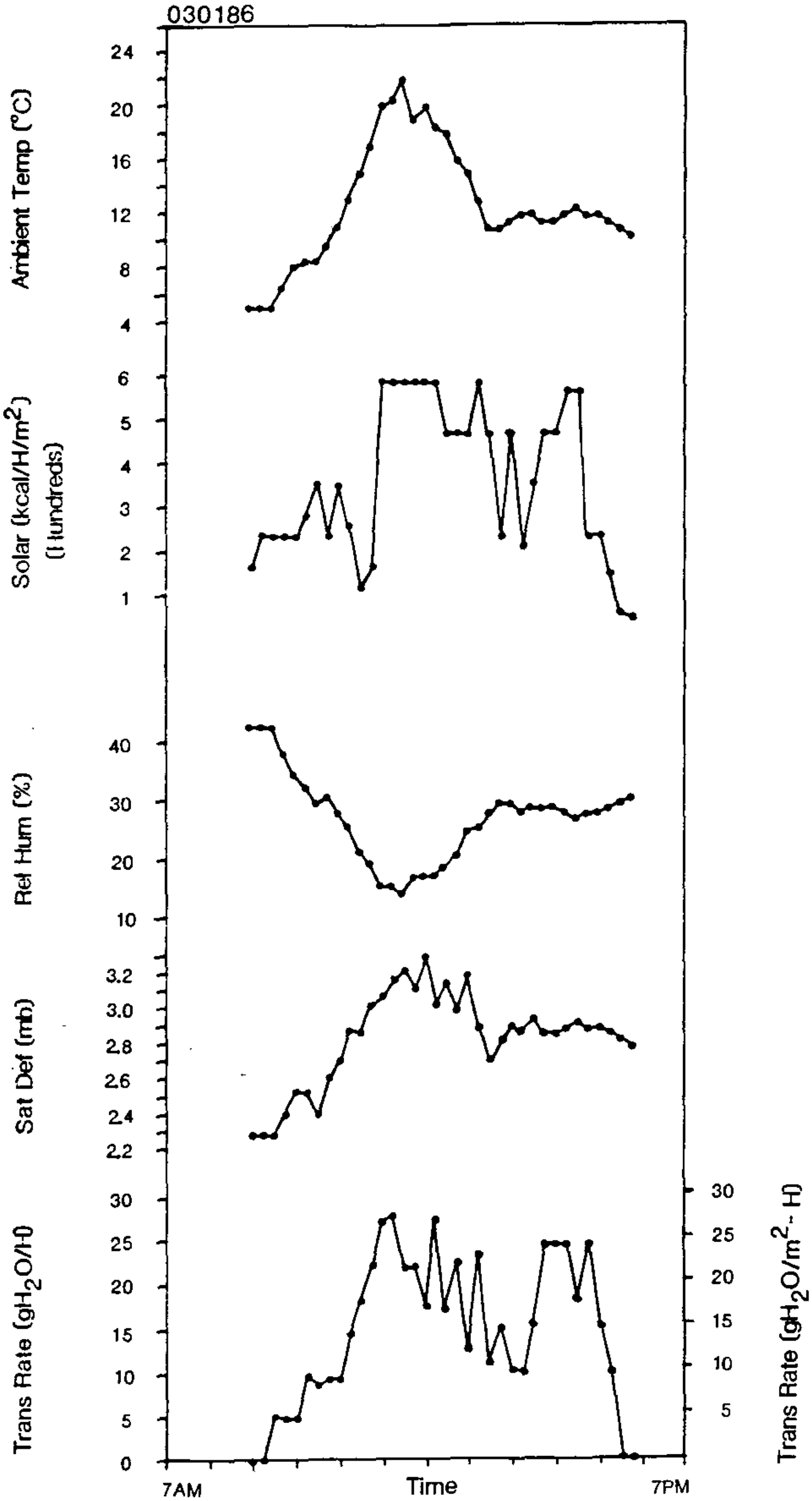

100585
Ambient Temp (°C)
36
32
28
24
Solar (kcal/H/m^2)
(Hundreds)
5
4
3
2
1
Rel Hum (%)
90
80
70
60
50
40
Sat Def (mb)
12
10
8
6
4
Trans Rate (gH$_2$O/H)
120
100
80
60
40
20
0
140
120
100
80
60
40
20
Trans Rate (gH$_2$O/m^2-H)
7AM
Time
7PM

Figure 17. Transpiration run December 14, 1985 (sweetbay).



121485
Ambient Temp (°C)
16
12
8
Solar (kcal/H/m)
(Hundreds)
6
5
4
3
2
1
Rel Hum (%)
50
40
30
Sat Def (mb)
3.2
3
2.8
2.6
Trans Rate (gH2O/H)
40
30
20
10
0
Trans Rate (gH2O/m2- H)
80
60
40
20
7AM
Time
7PM

Figure 18. Transpiration run March 3, 1986 (sweetbay).



030186
Ambient Temp (°C)
24
20
16
12
8
4
Solar (kcal/H/m²) (Hundreds)
6
5
4
3
2
1
Rel Hum (%)
40
30
20
10
Sat Def (mb)
3.2
3.0
2.8
2.6
2.4
2.2
Trans Rate (gH2O/H)
30
25
20
15
10
5
0
Trans Rate (gH2O/m2- H)
30
25
20
15
10
5
7AM
Time
7PM

Figure 19. Transpiration run April 19, 1986 (sweetbay).

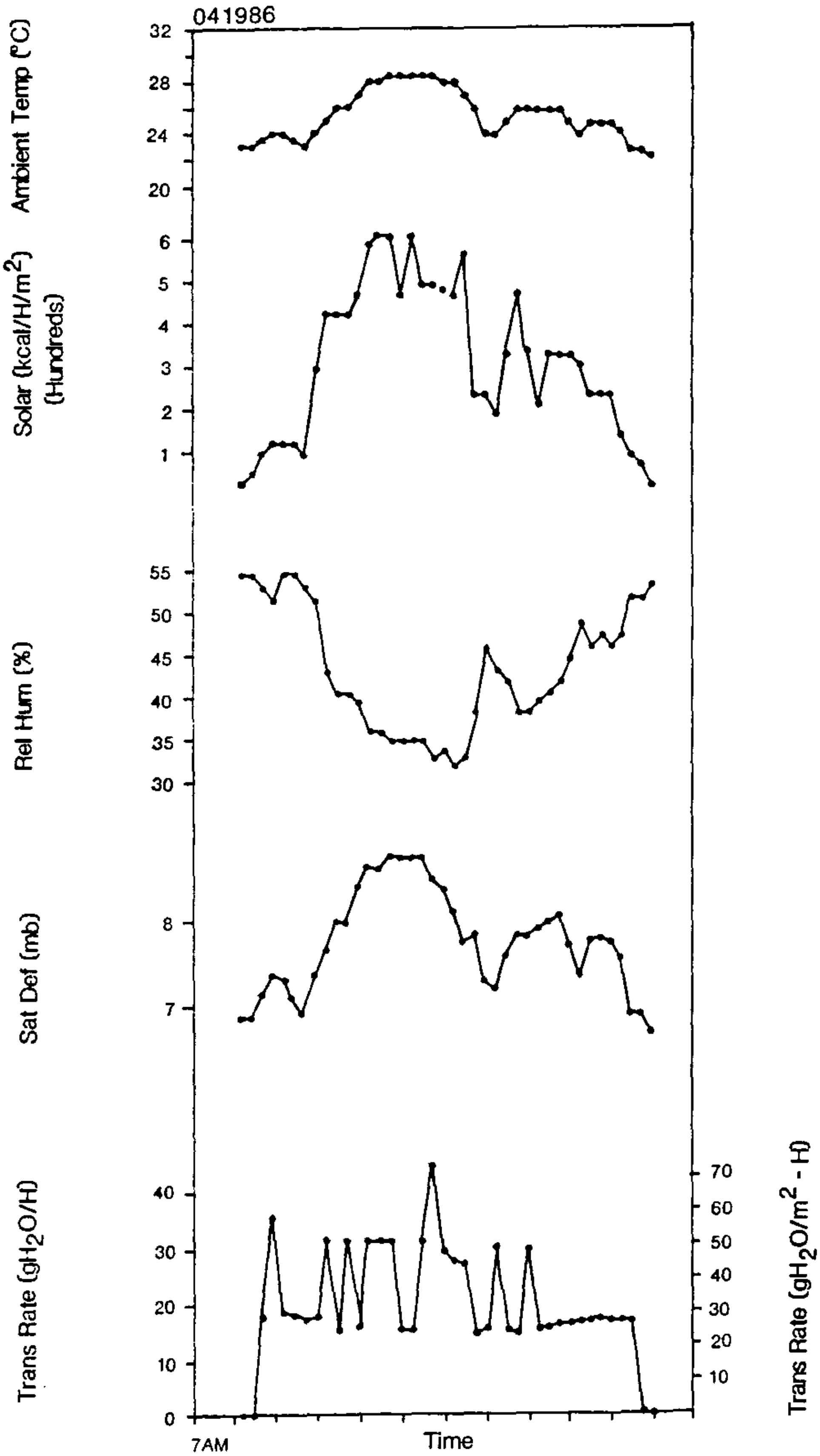
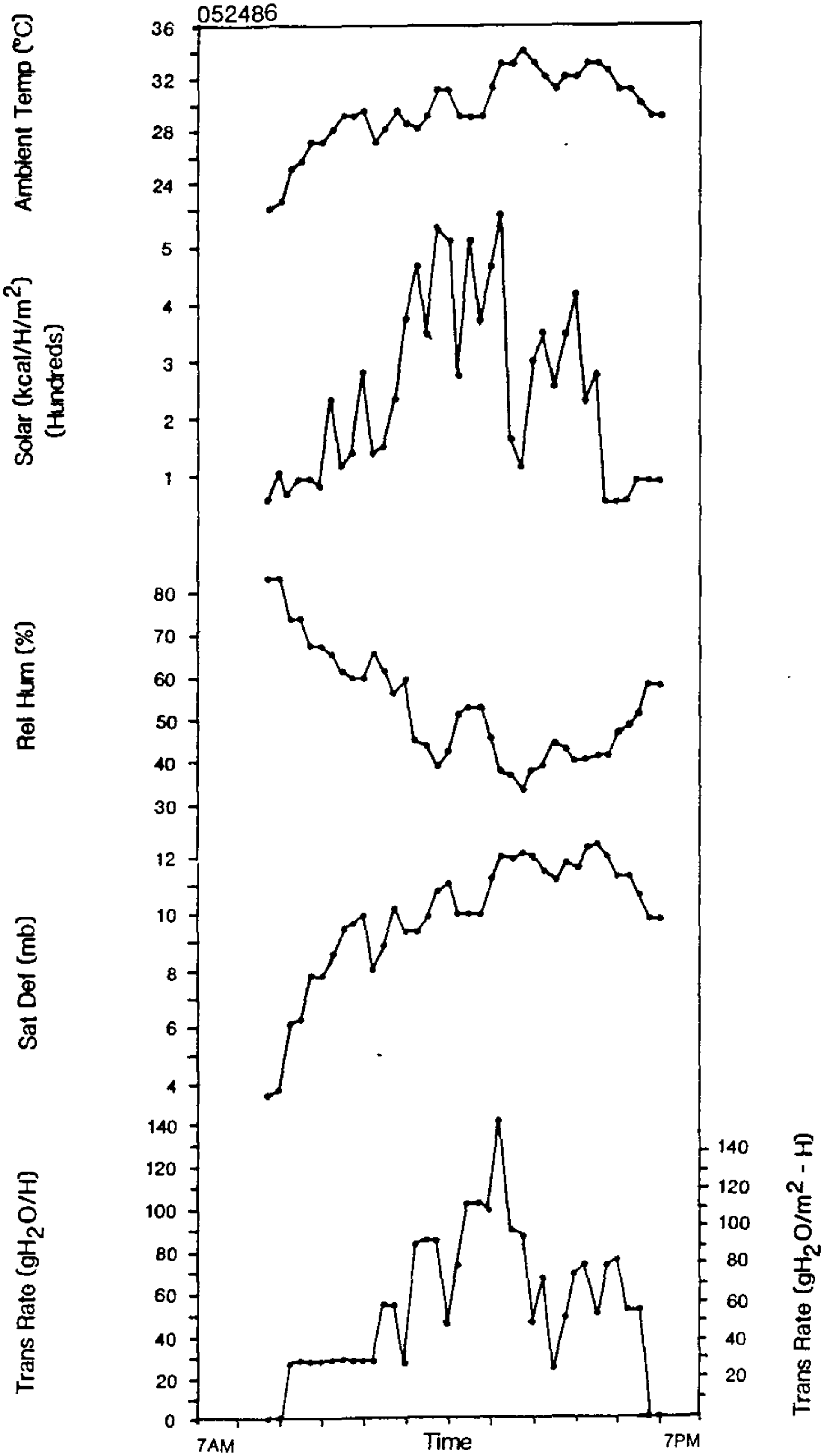
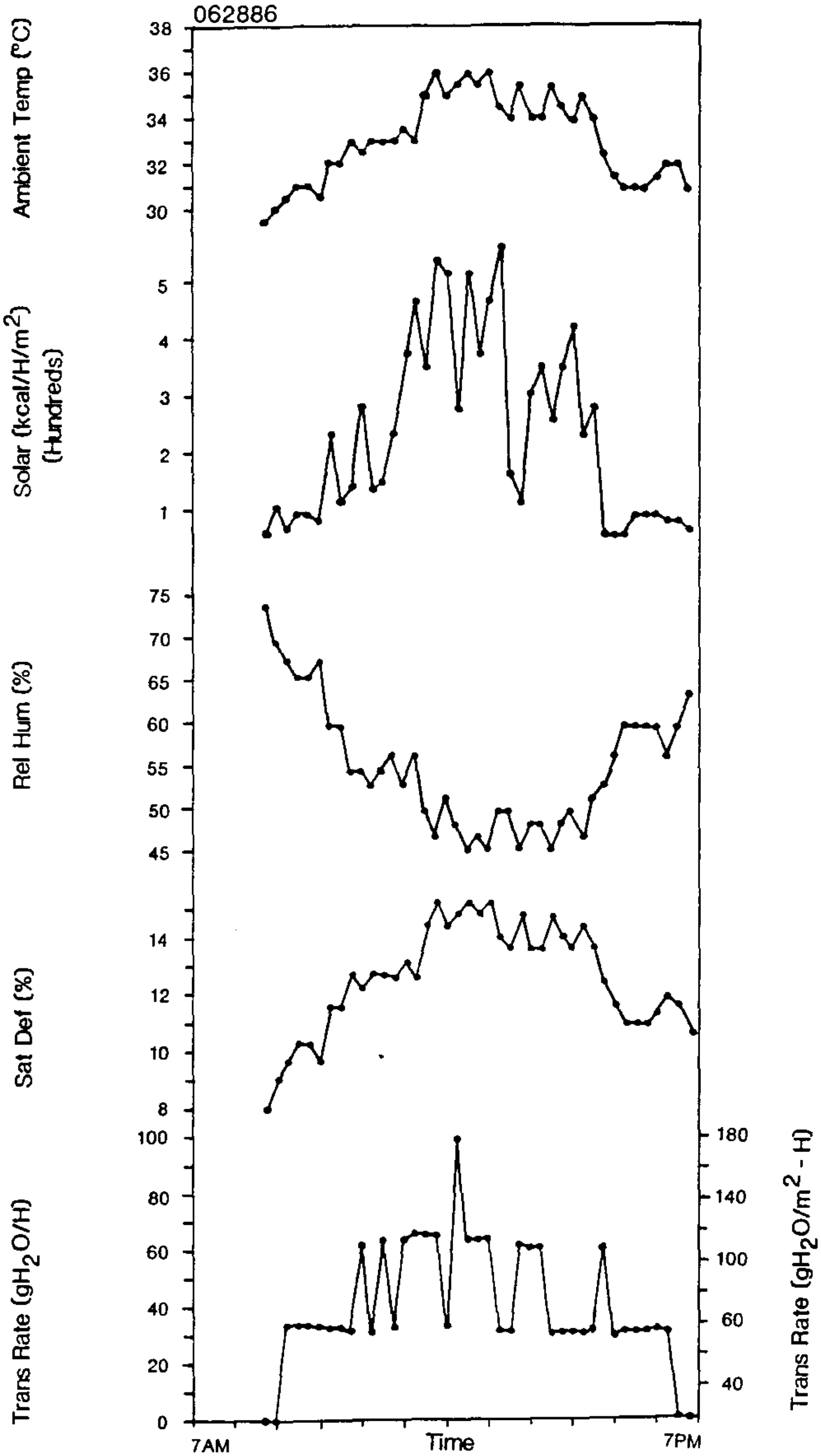

041986
Ambient Temp (°C)
32
28
24
20
Solar (kcal/H/m²) (Hundreds)
6
5
4
3
2
1
Rel Hum (%)
55
50
45
40
35
30
Sat Def (mb)
8
7
Trans Rate (gH₂O/H)
40
30
20
10
0
Trans Rate (gH₂O/m² - H)
70
60
50
40
30
20
10
7AM
Time

Figure 20. Transpiration run May 24, 1986 (sweetbay).



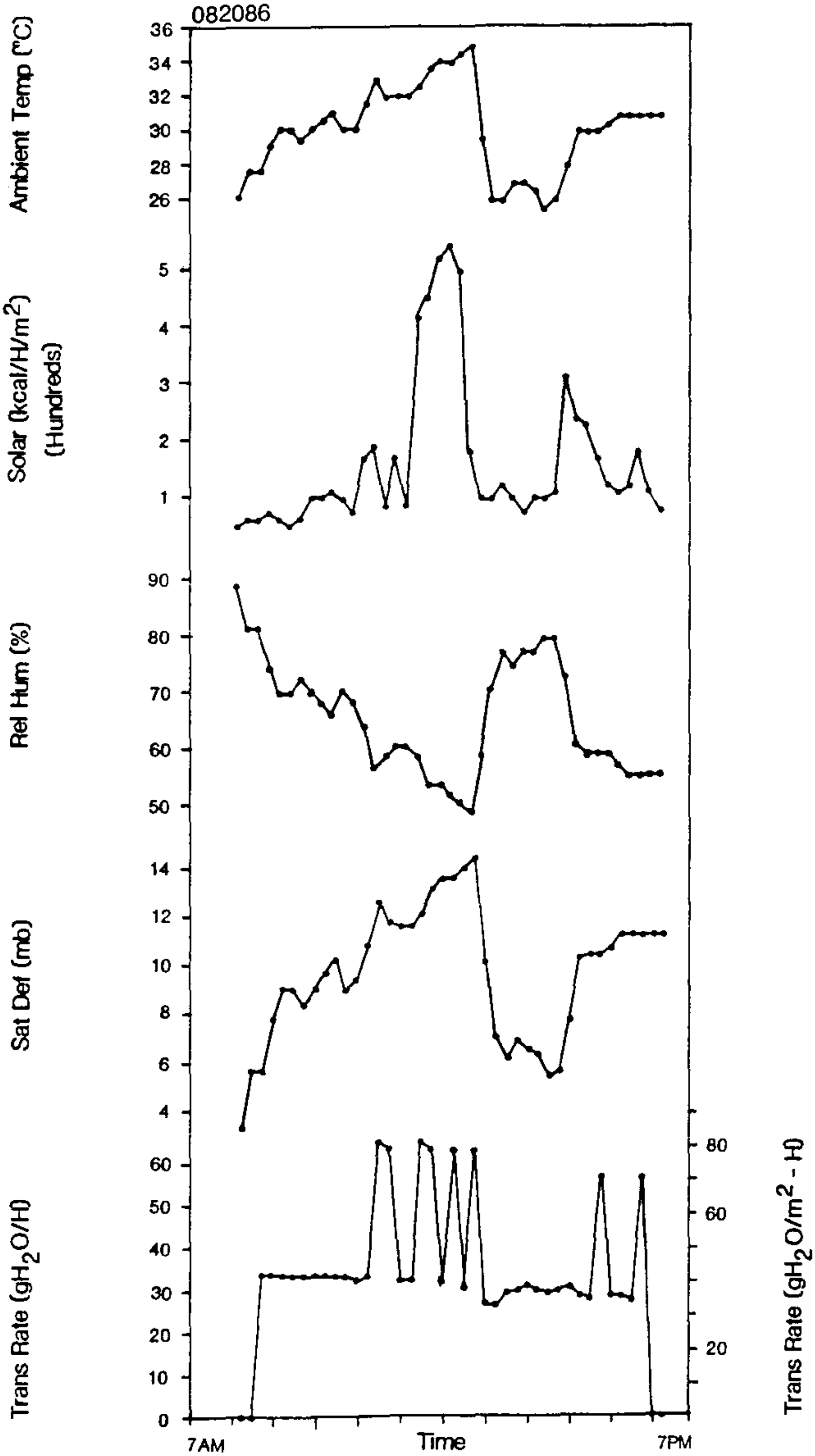
052486
Ambient Temp (°C)
36
32
28
24
Solar (kcal/H/m2)
(Hundreds)
5
4
3
2
1
Rel Hum (%)
80
70
60
50
40
30
Sat Def (mb)
12
10
8
6
4
Trans Rate (gH2O/H)
140
120
100
80
60
40
20
0
Trans Rate (gH2O/m2 - H)
7AM
Time
7PM

Figure 21. Transpiration run June 28, 1986 (sweetbay).



062886
Ambient Temp (°C)
38
36
34
32
30
Solar (kcal/H/m2) (Hundreds)
5
4
3
2
1
Rel Hum (%)
75
70
65
60
55
50
45
Sat Def (%)
14
12
10
8
Trans Rate (gH2O/H)
100
80
60
40
20
0
Trans Rate (gH2O/m2 - H)
180
140
100
60
40
7AM
Time
7PM

Figure 22. Transpiration run August 20, 1986 (sweetbay).



082086
Ambient Temp (°C)
36
34
32
30
28
26
Solar (kcal/H/m²) (Hundreds)
5
4
3
2
1
Rel Hum (%)
90
80
70
60
50
Sat Def (mb)
14
12
10
8
6
4
Trans Rate (gH₂O/H)
60
50
40
30
20
10
0
Trans Rate (gH₂O/m² - H)
80
60
20
7AM
Time
7PM

Figure 23. Transpiration run September 14, 1986 (sweetbay).

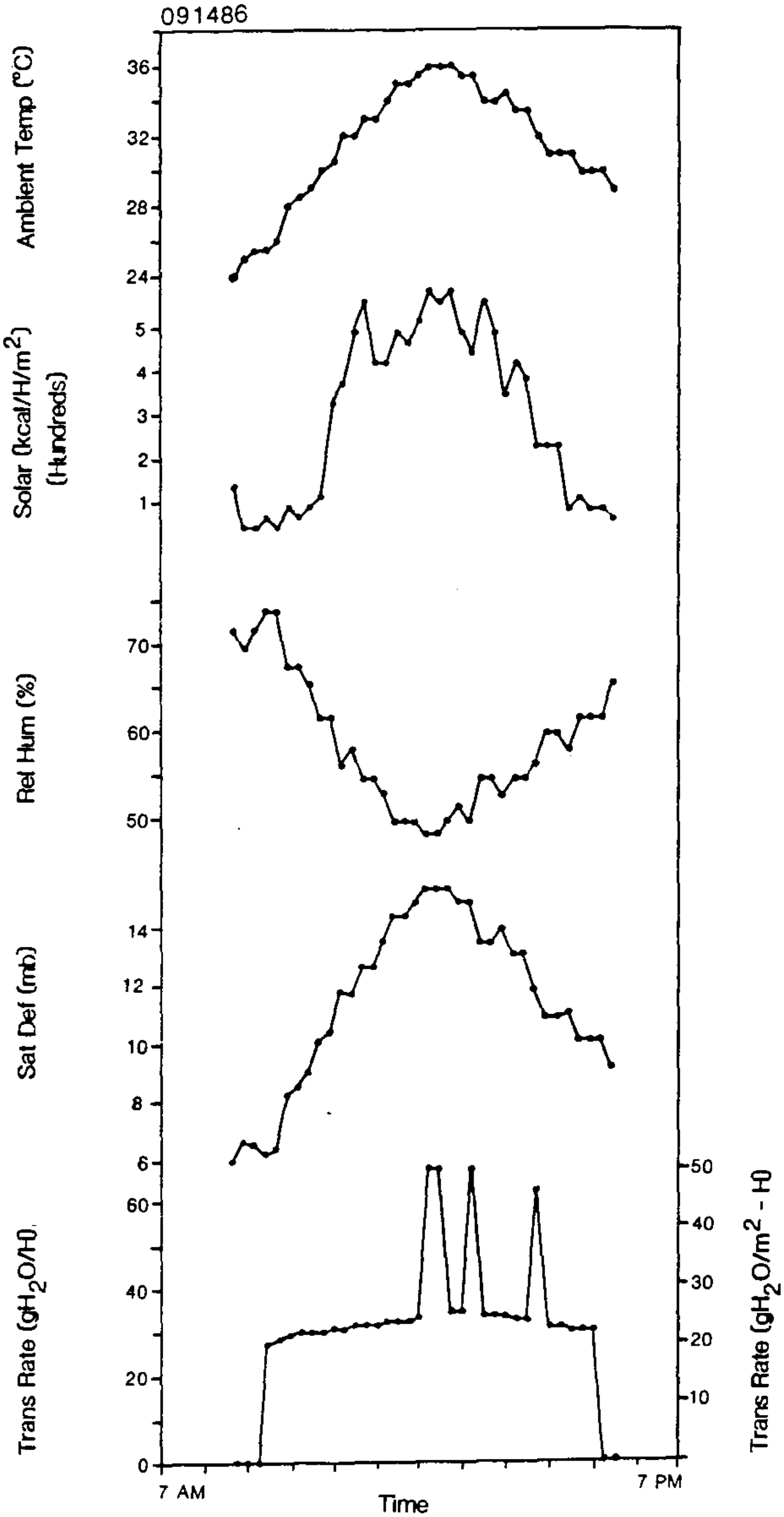

091486
Ambient Temp (°C)
36
32
28
24
Solar (kcal/H/m^2)
(Hundreds)
5
4
3
2
1
Rel Hum (%)
70
60
50
Sat Def (mb)
14
12
10
8
6
Trans Rate (gH$_2$O/H)
60
40
20
0
Trans Rate (gH$_2$O/m^2 - H)
50
40
30
20
10
7 AM
7 PM
Time

Table 34. The vertical distribution of leaf biomass (VDLB) and the leaf area index (LAI) for black titi and sweetbay in the bay swamp community.

Species	interval (m)	hits/ intervals	as % of 48	LBAR[1] g/m² leaf area	VDLB as % of total	LBGA[2] g/m² ground area	LAI[3] m² leaf area/ m² ground area
Sweetbay	9-12	23/48	0.48	109.4	74	141.90	0.96
	3-9	9/48	0.19	98.4	26	141.90	0.37
							1.33
Black titi	9-12	35/48	0.73	140.4	84	434.16	2.60
	3-9	7/48	0.15	126.8	16	434.16	0.55
							3.15
						TOTAL	4.48

[1] LBAR from Table 17
[2] LBGA from Table 18
[3] LAI = (LBGA/LBAR) x VDLB

Table 35. Daily transpiration rate (DTR), daily transpiration per leaf area (DTRLA) and daily transpiration rate per ground area (DTRGA) for eleven transpiration runs.

Date	Chamber	DTR gH_2O/day	LA m^2	DTRLA[1] gH_2O/m^2 leaf area -day	DTRGA[2] gH_2O/m^2 ground area -day	PE at Milton, FL (in)
Oct 21, 1984	I	1415	0.97	1459	1940	0.21
Nov 02, 1984	I*	1073	1.34	801	2523	0.14
Apr 21, 1985	II	730	0.73	1000	1330	0.22
Oct 05, 1985	III	1778	0.73	2436	3240	0.16
Dec 14, 1985	III	412	0.36	1144	1522	0.20
Mar 01, 1986	III	514	0.79	651	866	0.13
Apr 19, 1986	III	761	0.49	1553	2065	0.18
May 24, 1986	III	1924	0.83	2318	3083	0.25
Jun 28, 1986	III	1593	0.51	3124	4155	0.19
Aug 20, 1986	III	1348	0.87	1549	2060	0.22
Sep 14, 1986	III	1068	1.54	694	923	0.18

[1] DTRLA = DTR/LA
[2] DTRGA = DTRLA x LAI (Table 35)

DTR (mean of all sweetbay) = 1154 gH_2O/day
DTRLA (mean of all sweetbay) = 1593 gH_2O/m^2 leaf area-day
DTRGA (mean of all sweetbay) = 2118 gH_2O/m^2 ground area-day

*-*Cliftonia monophylla*-black titi
all other runs *Magnolia virginiana*-sweetbay

PE average of all runs = 0.19 in. = 4.8 mm rate per ground area for the ten sweetbay runs was 2118 g H_2O/m^2 ground area • day. The daily transpiration rate per ground area for the black titi run was 2523 g H_2O/m^2 ground area • day. Therefore, the daily transpiration rate per ground area for the bay swamp community was 4641 g H_2O/m^2 ground area • day.

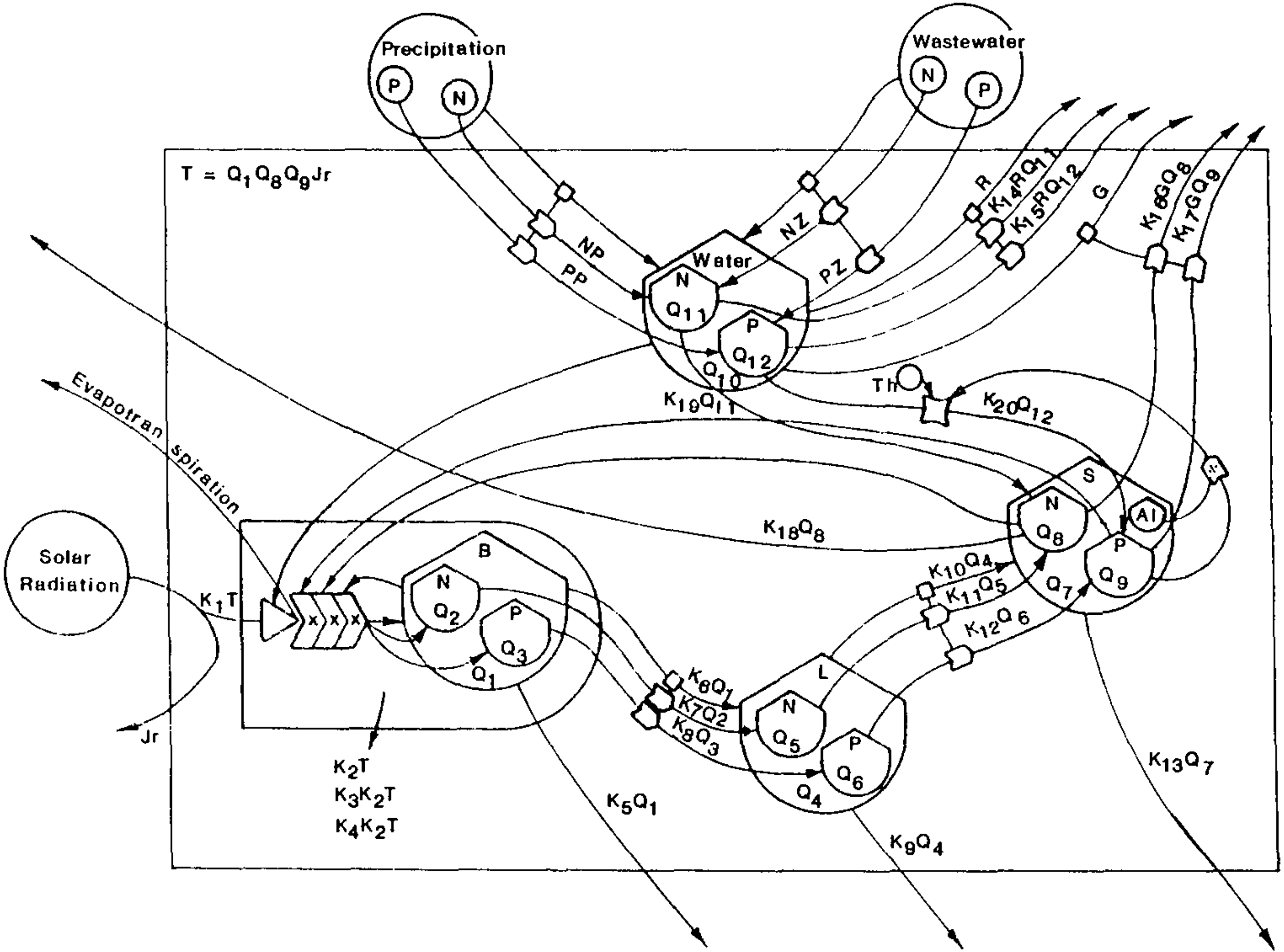
Daily transpiration rates per ground area for a species in each run can also be calculated as the product of the daily transpiration rate per leaf area and the leaf area index for that species in the vertical interval where transpiration was measured (9 to 12 m) (Table 34). This seems appropriate because, as Brown et al. (1984) indicated, transpiration rates decreased for leaves lower in the canopy in the wetlands investigated. When calculated in this manner, the average daily transpiration rate per ground area for the ten sweetbay runs was 1529 g H_2O/m^2 ground area • day, and the daily transpiration rate ground area for the black titi run was 2083 g H_2O/m^2 ground area • day. Therefore, if the measured rate of transpiration occurs only in the canopy, then the daily transpiration rate per ground area for the bay swamp community was 3612 g H_2O/m^2 ground area • day.

Soil surface and water surface water losses in Austin Cary cypress dome were 460 and 973 g H_2O/m^2 ground area • day, respectively (Brown 1981). The average of these two values (717 g H_2O/m^2 ground area • day) was used in this study as an estimate of forest floor evaporation in the bay swamp community.

Model Development and Simulation

The simulation model of the titi shrub swamp receiving wastewater is presented in Figure 24. The differential equations for the simula-

Figure 24. Systems diagram of the simulation model of the titi shrub swamp in Apalachicola, Florida. W= water, B= biomass, L= litter, S= soil, N= nitrogen, P= phosphorus.


Precipitation
P
N
Wastewater
N
P
$T = Q_1 Q_8 Q_9 Jr$
NP
PP
NZ
PZ
Water
N
Q_{11}
P
Q_{12}
Q_{10}
R
$K_{14}RQ_{11}$
$K_{15}RQ_{12}$
G
$K_{16}GQ_8$
$K_{17}GQ_9$
Th
$K_{19}Q_{11}$
$K_{20}Q_{12}$
Evapotranspiration
S
N
Q_8
Al
P
Q_9
Q_7
$K_{18}Q_8$
Solar Radiation
K_1T
Jr
B
N
Q_2
P
Q_3
Q_1
K_2T
K_3K_2T
K_4K_2T
K_5Q_1
K_6Q_1
K_7Q_2
K_8Q_3
L
N
Q_5
P
Q_6
Q_4
K_9Q_4
$K_{10}Q_4$
$K_{11}Q_5$
$K_{12}Q_6$
$K_{13}Q_7$

tion model are presented in Table 36. Initial conditions of the storages for the simulation model are presented in Table 37. Flow rates for the simulation model are presented in Table 38. The BASIC computer program to simulate the discharge of wastewater to the titi shrub swamp is presented in Appendix E. This includes transfer coefficients which were determined from storages and flows. Results of model development and simulation include material (water, carbon, nitrogen, phosphorus) and energy budgets for the titi shrub swamp. The calculations of storages and flows for the simulation model and for the material and energy budgets are presented in Appendix F.

Storages of carbon, nitrogen and phosphorus in biomass, leaf litterfall, litter and soil were determined for each community type on an areal basis and presented as a single value for the titi shrub swamp. The annual water budget (Table 32) was modified to include wastewater flow and an upper limit of deep seepage (groundwater flow). Runoff was then calculated as the balance of the budget. The amount of nitrogen in surface water was held constant, and the amount of phosphorus in surface water was held constant until maximum phosphorus adsorption in the soil was reached. The biomass component could use 5% of the solar radiation that was available to it (Odum 1971). The average efficiency of gross primary productivity in the cypress domes was 0.335% (Mitsch 1975b). A lower value of 0.3% was used for this system with lower biomass. Plant respiration in the cypress dome was 52% of gross primary productivity (Mitsch 1975b). Lower respiration occurred in nutrient-poor systems (Brown 1978). Therefore, a lower value of 40% of gross primary productivity was used for this nutrient-poor system. All of the nitrogen and phosphorus deposited in litter was assumed to remain in the

Table 36. Differential equations for each state variable used in the simulation model of the titi shrub swamp in Apalachicola, Florida, presented in Figure 24.

$$dQ_1/dt = k_2Q_1Q_8Q_9J_r - k_5Q_1 - k_6Q_1$$

$$dQ_2/dt = k_3k_2Q_1Q_8Q_9J_r - k_7Q_2$$

$$dQ_3/dt = k_4k_2Q_1Q_8Q_9J_r - k_8Q_3$$

$$dQ_4/dt = k_6Q_1 - k_9Q_4 - k_{10}Q_4$$

$$dQ_5/dt = k_7Q_2 - k_{11}Q_5$$

$$dQ_6/dt = k_8Q_3 - k_{12}Q_6$$

$$dQ_7/dt = k_{10}Q_4 - k_{13}Q_7$$

$$dQ_8/dt = k_{11}Q_5 + k_{19}Q_{11} - k_3k_2Q_1Q_8Q_9J_r - k_{18}Q_8 - k_{16}GQ_8$$

$$dQ_9/dt = k_{12}Q_6 + k_{20}Q_{12} - k_4k_2Q_1Q_8Q_9J_r - k_{17}GQ_9$$

$$dQ_{10}/dt = P + Z - ET - G - R$$

$$dQ_{11}/dt = NP + NZ - k_{14}RQ_{11} - k_{19}Q_{11}$$

$$dQ_{12}/dt = PP + PZ - k_{15}RQ_{12} - k_{20}Q_{12}$$

Table 37. Initial conditions for the storages for the simulation model of the titi shrub swamp in Apalachicola, Florida. Sources for the values are presented in Appendix F.

Storage	Description	Value	Note in Appendix F
Q_1	Aboveground biomass	4.4 E4 kcal/m^2	1
Q_2	N in biomass	45.4 g N/m^2	1
Q_3	P in biomass	1.9 g P/m^2	1
Q_4	Dry weight of litter	3.1 E3 kcal/m^2	2
Q_5	N in litter	4.53 g N/m^2	2
Q_6	P in litter	0.13 g P/m^2	2
Q_7	Carbon in soil	1.99 E5 kcal/m^2	3
Q_8	N in soil	338.7 g N/m^2	3
Q_9	P in soil	15.8 g P/m^2	3
Q_{10}	Surface water	1.08 m^3/m^2	4
Q_{11}	N in surface water	1.07 g N/m^2	5
Q_{12}	P in surface water	0.01 g P/m^2	6

Table 38. Flow rates for the simulation model of the titi shrub swamp in Apalachicola, Florida. Sources of the values are given in Appendix F.

Flow	Description	Value	Note in Appendix F
P	Precipitation	1.67 m/yr	7
NP	N in precipitation	1.57 g N/m^2 · yr	8
PP	P in precipitation	0.08 g P/m^2 · yr	9
R	Runoff	3.98 m/yr	7
$k_{14}RQ_{11}$	N in runoff	3.30 g N/m^2 · yr	10
$k_{15}RQ_{12}$	P in runoff	0.4 g P/m^2 · yr	11
G	Groundwater flow	0.21 m/yr	7
$k_{16}GQ_8$	N in groundwater	0.28 g N/m^2 ·yr	12
$k_{17}GQ_9$	P in groundwater	0.01 g P/m^2 · yr	13
$k_1Q_1Q_8Q_9J_r$	J	7.3 E4 kcal/m^2 · yr	14
$k_2Q_1Q_8Q_9J_r$	GPP	2.78 E3 kcal/m2 · yr	14
$k_3k_2Q_1Q_8Q_9J_r$	N uptake by vegetation	2.86 g N/m^2 · yr	15
$k_4k_2Q_1Q_8Q_9J_r$	P uptake by vegetation	0.12 g P/m^2 · yr	16
k_5Q_1	Plant respiration	1.11 E3 kcal/m^2 · yr	17
k_6Q_1	Leaf litterfall	1.55 E3 kcal/m^2 · yr	18
k_7Q_2	N deposited by litterfall	2.11 g N/m^2 · yr	18
k_8Q_3	P deposited by litterfall	0.08 g P/m^2 · yr	18
k_9Q_4	Litter respiration	7.75 E2 kcal/m^2 · yr	19
$k_{10}Q_4$	Litter remaining in soil	7.75 E2 kcal/m^2 · yr	19
$k_{13}Q_7$	Soil respiration	3.88 E2 kcal/m^2 · yr	20

Table 38. continued.

Flow	Description	Value	Note in Appendix F
$k_{11}Q_5$	Litter N remaining in soil	2.11 g N/m^2	21
$k_{12}Q_6$	Litter P remaining in soil	0.08 g P/m^2	21
Z	Wastewater flow	3.56 m/yr	7
NZ	N in wastewater flow	16.0 g $N/m^2 \cdot yr$	22
PZ	P in wastewater flow	7.0 g $P/m^2 \cdot yr$	23
$k_{18}Q_8$	Denitrification	2.01 g $N/m^2 \cdot yr$	24
$k_{19}Q_{11}$	Movement of N in surface water to soil	14.3 g $N/m^2 \cdot yr$	25
$k_{20}Q_{12}$	Phosphorus adsorption	6.68 g $P/m^2 \cdot yr$ up to a maximum of 96.6 g/m^2 in Q_9	26

soil, and the movement of nitrogen from surface water in to the soil was assumed to be at steady state. The maximum amount of phosphorus adsorbed in the soil was a function of the adsorption maxima of the two soil types (on an areal basis) and the percent of TAMM extractable aluminum in the soil. A switch prevented phosphorus adsorption in the soil when maximum adsorption was reached.

Annual budgets were developed for water, carbon, nitrogen, and phosphorus in the titi shrub swamp prior to wastewater discharge and after 100 yrs of wastewater discharge. The relative amounts of carbon, nitrogen, and phosphorus within the compartments prior to wastewater discharge were as follows: soil > biomass > litter (Figure 25). The total amounts of nitrogen and phosphorus entering and leaving the system were low.

The relative amounts of carbon and phosphorus within the compartments after 100 yrs of wastewater discharge were as follows: soil > biomass > litter (Figure 26). The relative amounts of nitrogen within the compartments were as follows: biomass > soil > litter (Figure 26). The biomass and litter compartments increased 19-fold, and the soil carbon compartment increased fivefold. The biomass and litter phosphorus compartments increased 26-fold, and the soil phosphorus compartment increased sixfold. The biomass and litter nitrogen compartments increased 24-fold, and the soil nitrogen compartment increased twofold. After 100 yrs of wastewater discharge 58%, 36% and 6% of the stored nitrogen was in biomass, soil and litter, respectively. After 100 yrs of wastewater discharge 33%, 65% and 2% of the stored phosphorus was in biomass, soil and litter, respectively. Although

Figure 25. Material and energy budgets for the titi shrub swamp in Apalachicola, Florida. Calculation of storages and flows presented in Appendix F. Storage of water m^3/m^2, flow of water m/yr, storage of carbon E4 $kcal/m^2$, flow of carbon E4 $kcal/m^2$-yr, storage of nitrogen and phosphorus g/m^2, flow of nitrogen and phosphorus g/m^2-yr.

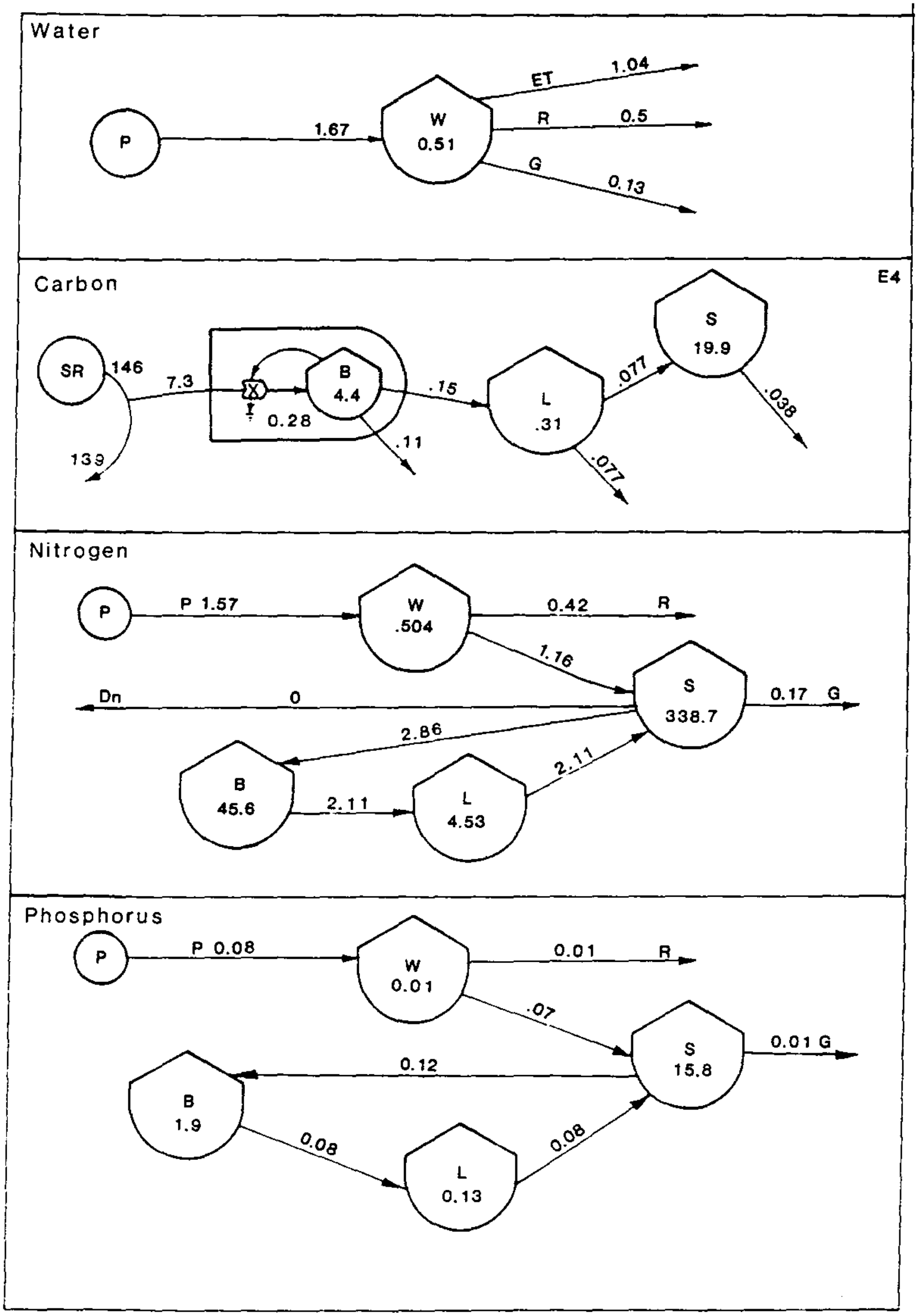
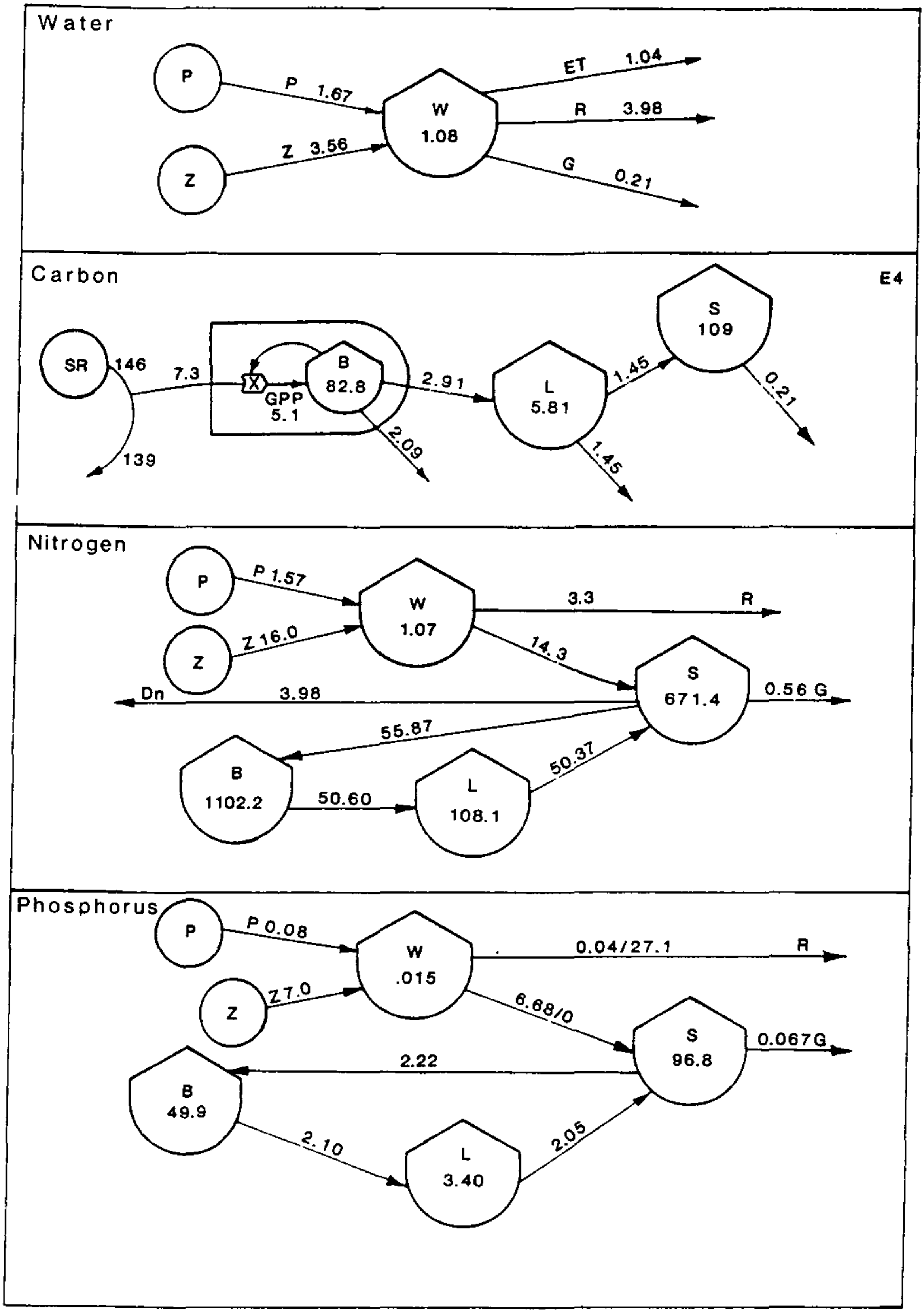

Water
P
1.67
W
0.51
ET
1.04
R
0.5
G
0.13
Carbon
E4
SR
146
7.3
139
X
B
4.4
0.28
.11
.15
L
.31
.077
S
19.9
.038
.077
Nitrogen
P
P 1.57
W
.504
0.42
R
1.16
S
338.7
0.17
G
Dn
0
2.86
B
45.6
2.11
L
4.53
2.11
Phosphorus
P
P 0.08
W
0.01
0.01
R
.07
S
15.8
0.01 G
0.12
B
1.9
0.08
L
0.13
0.08

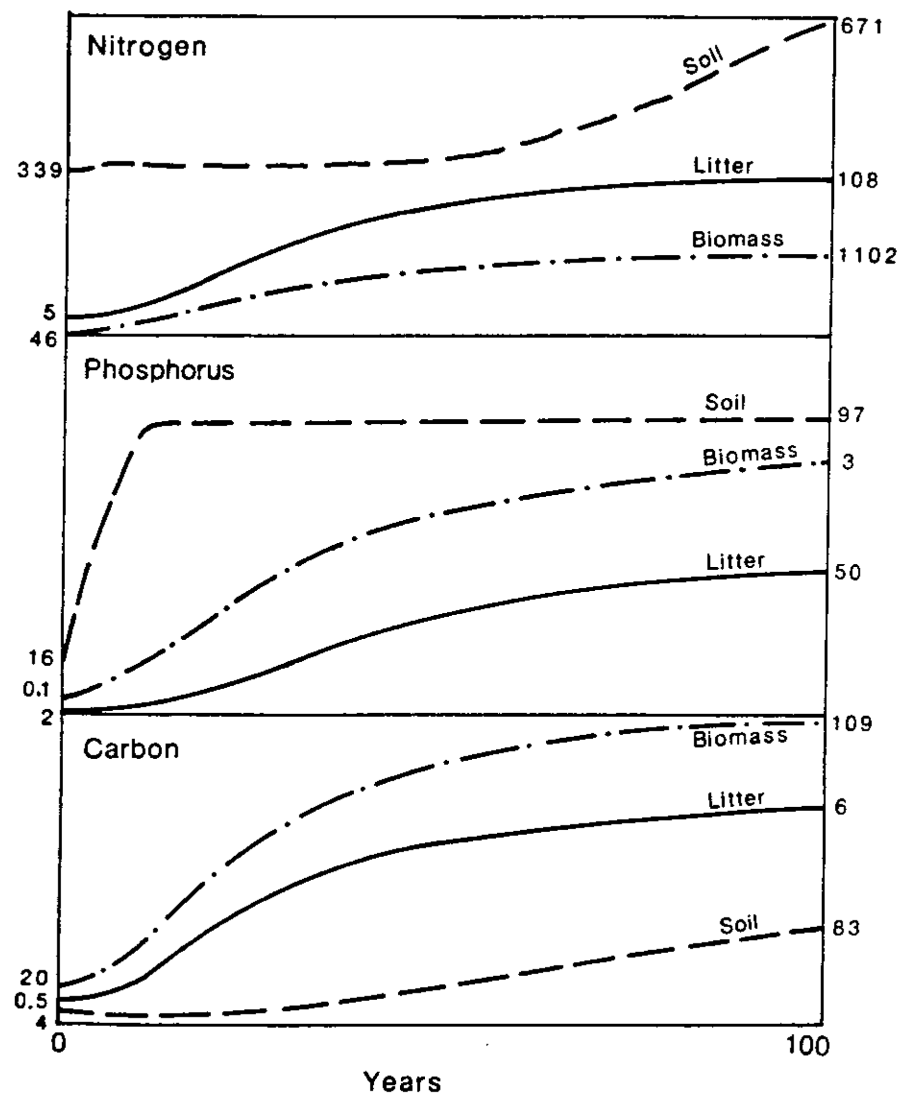
Figure 26. Material and energy budgets for the titi shrub swamp in Apalachicola, Florida, after 100 years of wastewater discharge. Calculation of storages and flows presented in Appendix F. Storage of water m^3/m^2, flow of water m/yr, storage of carbon E4 $kcal/m^2$, flow of carbon E4 $kcal/m^2$-yr, storage of nitrogen and phosphorus g/m^2, flow of nitrogen and phosphorus g/m^2-yr. Z = wastewater.


Water
P
Z
P 1.67
Z 3.56
W
1.08
ET 1.04
R 3.98
G 0.21
Carbon
E4
SR
146
7.3
139
X
GPP
5.1
B
82.8
2.91
2.09
L
5.81
1.45
1.45
S
109
0.21
Nitrogen
P
P 1.57
W
1.07
3.3
R
Z
Z 16.0
14.3
S
671.4
0.56 G
Dn
3.98
55.87
B
1102.2
50.60
L
108.1
50.37
Phosphorus
P
P 0.08
W
.015
0.04/27.1
R
Z
Z 7.0
6.68/0
S
96.8
0.067G
2.22
B
49.9
2.10
L
3.40
2.05

nitrogen was primarily stored in biomass, phosphorus was primarily stored in soil. At a phosphorus loading of 2 mg/l, the model predicted that phosphorus adsorption in the soil will end after 11.7 yrs of wastewater discharge to the titi shrub swamp.

The plots of biomass, litter and soil carbon over time and the nitrogen and phosphorus in biomass and litter over time are limiting factor hyperbolas (Figure 27). The dynamics of nitrogen and phosphorus storage in the soil did not follow this pattern. Phosphorus was rapidly adsorbed in the soil until maximum adsorption was reached. Then the amount of phosphorus in the soil remained constant. Very little nitrogen was stored in the soil until a limit to production was reached. Then the amount of nitrogen entering the system was greater than required to maintain that level of production and storage of nitrogen in the soil increased.

Figure 27. Results of the simulation model of the titi shrub swamp in Apalachicola, Florida, after 100 years of wastewater discharge. Values are g N/m^2, g P/m^2 and E4 $kcal/m^2$ for nitrogen, phosphorus, and carbon, respectively.


Nitrogen
Soil
Litter
Biomass
339
5
46
671
108
1102
Phosphorus
Soil
Biomass
Litter
16
0.1
2
97
3
50
Carbon
Biomass
Litter
Soil
20
0.5
4
109
6
83
0
100
Years

CHAPTER 4
DISCUSSION

Vegetation Analysis

In general, the communities at this study site are what Clewell (1981) described as acid swamp systems. This includes a holly phase of a titi swamp, a titi phase of a titi swamp, a mixed swamp phase of a bay swamp bordered by pond cypress and titi, and a black gum swamp bordered by pond cypress and titi. Although black titi makes up 58% of the community in the bay swamp, sweetbay is the dominant overstory species. Therefore, as Clewell (1971) suggested, titi swamps seem to be successional to bay swamps. Although black gum has the largest importance value in the black gum swamp at the study site (26%), pond cypress makes up a significant portion of the community (20%). Therefore, the black gum swamp may be transitional in a scenario in which there is initial dominance of pond cypress in the lowest sites followed by the establishment and eventual dominance of black gum through time. This is consistent with the high percent cover of sphagnum (94%) found at this site. The black gum swamp is a distinct and important component of the titi shrub swamp.

Shrub class individuals make up 84% of the vegetation at the study site and titi species make up 38%. Thus, this site can be described as a titi shrub swamp even though the central and deepest portions of the site are dominated by tree-size-class individuals that are not titi species.

Biomass and Nutrient Standing Stock Estimates

The aboveground biomass estimate of the holly phase of the titi swamp (1.3 kg/m^2) is much less than values reported by Brown (1981) and Conner and Day (1982) but this community experienced a recent fire and is therefore in an early successional stage of development. The aboveground biomass estimates of the titi phase of the titi swamp (8.4 kg/m^2) and the black gum swamp (13.9 kg/m^2) are in the low range of values cited by Brown (1981) and Conner and Day (1982), while the mixed swamp phase of the bay swamp (19.1 kg/m^2) is in the intermediate range.

The titi phase of the titi swamp and the black gum swamp communities can be characterized as still-water wetlands and the aboveground biomass estimates for these communities are low. Fire is an important component limiting biomass accumulation in the titi swamps but it rarely reaches the black gum swamp (Clewell 1971). Large trees survive and the biomass is greater in the black gum swamp than in the titi swamp. In general, the bay swamp community may be characterized as a slow-flowing wetland as it is located along the upper reaches of a stream. Bay swamps in general appear to be maintained by seepage from higher terrain, and may receive some nutrient input from these higher areas that may be unavailable to more isolated systems (Wharton et al. 1977). Sweetbay had the greatest concentration of nutrients in vegetation sampled at the study site (Table 20) and the bay swamp had the greatest standing stocks of nutrients in aboveground biomass of all the communities at the study site (Table 22). The high level of nutrients in the bay swamp relative to the other communities may explain why this community has the greatest aboveground biomass at the study site. In addition, the greatest leaf litterfall at the study site is in the bay swamp community, (Table 19), and the estimated leaf biomass of the woody vegetation in the bay swamp community was similar to the value reported by Brown (1978) for a floodplain forest with high biomass (Table 18).

Even though there is some rapid water flow during certain times of the year, which may contribute to greater productivity and the subsequent accumulation of biomass in the bay swamp community relative to the other communities at the study site, the biomass is in the intermediate range of values cited above for forested wetlands because of low overall nutrient input to the system. Nutrient input is primarily from precipitation at the study site (Figure 5), as is the case for the dwarf cypress community cited above. Low nutrient input accounts for the overall low biomass in this wetland.

The leaf biomass to area ratios for the three species measured at the study site at all vertical intervals (98.4 to 142.5) are lower than leaf biomass to area ratios reported by Brown (1978) for cypress in the dwarf cypress forest and in Austin Cary cypress dome at all vertical intervals (150 to 403), but they are similar to the value of 135 reported by Brown (1978) for fetterbush (an evergreen species) in Austin Cary cypress dome. The estimated leaf biomass per ground area of the woody vegetation in the bay swamp community (582 g/m^2) is greater than the value reported by Brown (1978) for Austin Cary cypress dome (465 g/m^2), and less than the value reported by Brown (1978) for a floodplain forest (663 g/m^2).

As is the case in the titi shrub swamp, cypress trees in the Okefenokee Swamp (Schlesinger 1978) and species analyzed in cypress domes (Post and Straub 1974) had concentrations of nitrogen and phosphorus as follows: leaf > branch > bole. Total nitrogen concentrations of branch (12.64 mg/g) and leaf (28.59 mg/g) material of sweetbay were similar to values for branch (11.30 mg/g) and leaf (21.0 mg/g) material of this species in a cypress dome (Post and Straub (1974). Total nitrogen (10.32 mg/g) and total phosphorus (0.29 mg/g) concentrations in the leaves of red titi were similar to values for current growth of this species in the Okefenokee Swamp (TN = 12.3 mg/g, TP = 0.48 mg/g) (Schlesinger 1978).

The average (three species) total phosphorus concentrations of the bole (0.11 mg/g), branch (0.38 mg/g) and leaf (0.72 mg/g) material were similar to values for bole (0.06 mg/g), branch (0.40 mg/g) and leaf (0.63 mg/g) material of black gum (a hardwood species) in Austin Cary dome (Deghi 1977). The average (three species) total phosphorus concentration of the leaf (0.72 mg/g) material is intermediate between values for cypress leaf (0.52 mg/g) material in a dwarf cypress community (Brown 1978) and for cypress leaf (0.84 mg/g) material in Austin Cary cypress dome (Straub and Post 1977). Although the average (three species) total phosphorus concentration of the bole (0.11 mg/g) material is greater than the values for cypress bole (0.034 mg/g) material in Austin Cary cypress dome (Straub and Post 1977) and for cypress bole (0.042 mg/g) material in a dwarf cypress community (Brown 1978), this value is similar to values for cypress bole (0.09 mg/g) material in the Okefenokee Swamp (Schlesinger 1978). The average total phosphorus concentration for leaf litterfall (0.25 mg/g) at the study site was similar to values for litterfall at Austin Cary dome (0.36 mg/g) (Deghi 1977).

The standing stocks of total phosphorus in aboveground biomass in Florida cypress swamps as summarized by Brown (1981) and in titi shrub swamp communities are presented in Table 39. The standing stocks of total nitrogen in aboveground biomass in titi shrub swamp communities are also presented. The standing stock of total phosphorus in aboveground biomass of different systems was positively related to the phosphorus input to those systems (Brown 1981). Total phosphorus inputs increased in the following order: dwarf cypress forest, Austin Cary cypress dome, floodplain forest. There was a corresponding increase in the standing stocks of total phosphorus in the aboveground biomass in these systems. A similar relationship may exist at the study site as the standing stocks of total phosphorus and total nitrogen in the aboveground biomass increased along a gradient within the system (Figure 4) from the titi swamps to the black gum swamp and ultimately to the bay swamp.

The annual average leaf litterfall at this titi shrub swamp was 359 $g/m^2 \cdot yr$ and is less than the other swamp systems cited above. This is probably due to low overall nutrient input to this system relative to the other swamp systems cited above. The highest leaf litterfall at the study site occurred in November, but the second highest value occurred in May (Table 19). Therefore there is a bimodal seasonal cycle at the study site which may be due to the replacement of leaves in the spring.

Table 39. Standing stock of total phosphorus in aboveground biomass in Florida cypress forests (Brown 1981), and in titi shrub swamp communities in Apalachicola, Florida. The standing stock of total nitrogen in aboveground biomass in titi shrub swamp communities are also presented.

	TP		*TP	*TN
	g/m^2		g/m^2	g/m^2
Dwarf cypress	0.26	Titi swamp	1.0	25.5
Austin Cary dome	2.45	Black gum swamp	2.9	71.6
Floodplain forest	4.78	Bay swamp	3.9	97.3

* source: Table 22

Water Chemistry

In general, the chemical composition of surface water varies with time to a much greater extent than does that of deep groundwater (Fetter 1980). This is because the source of surface water is from overland runoff and baseflow, the chemistry of which varies with meteorological and seasonal conditions. Variations in the chemical composition of shallow groundwater may be similar to surface water (Fetter 1980), as is the case at the study site because in wetlands where the water level seldom fluctuates below the ground surface, groundwater and surface water are closely related (Lichtler and Walker 1974).

A mean conductivity of 66.2 μmhos/cm at the study site indicates this system has a perched water table and is not in contact with carbonate containing parent material. Therefore there is very little free carbon dioxide present in these surface waters. This is substantiated by a low mean acidity (39.1 mg $CaCO_3$/l), which is similar to values reported by Verry (1975) for five perched peatlands in Minnesota (mean acidity = 48.2 mg $CaCO_3$/l). These peatlands are isolated from groundwater and derive most of their water from ion-poor rainfall (Verry 1975). Low mean conductivity also indicates that the surface water is low in dissolved solids and therefore low in the amount of inorganic and organic material in solution (Fernald and Patton 1984). While low dissolved oxygen indicates a high degree of biological decomposition, low demand levels coupled with low inorganic constituent levels suggest that decomposition is low and outweighed by productivity in this system. The presence of sphagnum and the high level of production relative to decomposition at the study site as indicated by low demand levels coupled with low dissolved oxygen levels contribute to the acidic nature of this system.

The mean surface water nutrient concentrations at the study site (TN = 0.99 mg/l and TP = 0.01 mg/l) were similar to but lower than the mean surface water nutrient concentrations of an unimpacted cypress dome (Austin Cary) in north central Florida (TN = 1.6 mg/l and TP = 0.18 mg/l, Dierberg 1980) and the dwarf cypress forest in the Big Cypress Swamp (TN = 1.98 mg/l and TP = 0.04 mg/l, Flohrschutz 1978). The mean surface water pH of Austin Cary cypress dome (4.5) was slightly higher than the mean surface water pH at the study site (3.9) but the mean conductivity values of the surface waters were similar (60 and 66.2 μmhos/cm, respectively). The mean surface water pH of the dwarf cypress forest (8.9) was much higher than the mean surface water pH at the study site. The surface water at the study site is also similar to surface water in pocosin wetlands of more northern climates. Pocosins resemble bogs of more northern climates, which have nutrient-poor, acid conditions (Mitsch and Gosselink 1986). The surface water leaving pocosins is low in dissolved solids, low or acidic in pH, and highly colored by organic compounds (Daniel 1981).

Organic nitrogen is the dominant nitrogen species at practically all surface water stations throughout Florida (Slack and Goolsby 1976), as is the case at the study site. The mean concentration of organic nitrogen in the surface water is almost an order of magnitude greater than the mean concentration of inorganic nitrogen (0.09 mg/l) in the surface water. Similar results were found at Austin Cary cypress dome (Dierberg 1980). Abundance of ammonium along with low dissolved oxygen levels indicates the reduced nature of this system.

A map of the generalized distribution and concentration of orthophosphate in Florida streams indicates that in the region including the study site the maximum orthophosphate concentration is less than 0.2 mg/l (Kaufman 1975a). Results from the study site are consistent with this finding (mean orthophosphate $<$ 0.01 mg/l). A map of the generalized distribution of dissolved phosphorus (total phosphorus) in Florida waters indicates that in the region including the study site the maximum dissolved phosphorus concentration is approximately 0.05 mg/l (Odum 1953). Results from the study site are consistent with this finding as the mean total phosphorus concentration in the surface water is 0.01 mg/l. The low mean total phosphorus concentration and the high mean nitrogen to phosphorus ratio (94:1) is indicative of phosphorus-limited, unenriched natural waters.

An evaluation of the relative concentration of nutrients in precipitation, surface water and groundwater provides insight into their flux through the system. The mean total nitrogen and mean total phosphorus levels in precipitation relative to surface waters suggest that precipitation is the primary nutrient input to this system. Similar results were found in Austin Cary cypress dome (Dierberg 1980). Nitrate plus nitrite nitrogen and total phosphorus levels were lower in the surface water of Austin Cary cypress dome than in precipitation (as is the case at the study site). Precipitation is a major contributor of nitrogen to Thoreau's Bog in Massachusetts (Hemond 1983). The fact that surface water had lower total phosphorus than precipitation (and the phosphorus cycle had no gaseous phase) suggested to Dierberg (1980) that the system acted as a biological and/or chemical sink for phosphorus. This is the case at the study site as the mean total nitrogen and mean total phosphorus concentrations in shallow groundwater are slightly higher than in surface water. Surface water at the study site has a lower mean total phosphorus concentration than in precipitation. Thus, phosphorus is important in biological and chemical processes within the system, and the system is acting as a sink for phosphorus. The dominance of ammoniacal nitrogen and the low level of phosphorus dissolved in surface waters indicate that nutrients are conserved within this system.

The chemical composition of surface waters is influenced by many factors, including chemical composition of precipitation and the reaction of water with soils, bed materials, decomposing organic matter and surficial rocks (Kaufman 1972). Florida streams can be delineated in terms of the dominant cations and anions (Kaufman 1972). Water containing no predominant cation (calcium, magnesium, sodium) or inorganic anion (bicarbonate, chloride, sulfate) is considered to be a mixed type. The major anions in acidic wetlands are organic acids (Thurman 1985). Surface waters in the area where the study site is located are of the mixed type (Kaufman 1972). Water of this type is associated with noncarbonate terranes and reflects the chemical characteristics of precipitation, soils, and decomposed organic matter in natural swampland areas (Kaufman 1972). This is consistent with findings from other systems such as bogs or pocosins. In these systems the wetland is isolated from deep groundwater so that nutrient concentrations of the surface water and its acidity reflect primarily input from precipitation and decomposition (Moore and Bellamy 1974; Richardson 1981).

Soils in Titi Shrub Swamps

Precise descriptions of the soils are generally lacking for acid swamps of the Coastal Plain (Coultas et al. 1979). Soils in low elevation titi swamps in the Apalachicola National Forest were in the Humaquepts great group, soils in high elevations in the Apalachicola National Forest were in the Haplaquod great group (Coultas 1977). The general morphological characteristics of these soils were described by Coultas (1977). They had sandy and loamy sandy texture throughout the solum (surface layer in which topsoil forms) because they were developed in sands of marine origin of the Pleistocene Series. Sphagnum occurred above most of the soils in these swamps and a thin organic layer occurred at the surface of most of the soils in these swamps. In the lowest areas the organic horizon was thicker and textures were finer with sandy clay loams common. Structural development was essentially absent in these soils except for the presence of a weak granular structure in the Al horizon. Mineral soils were found under cypress but not black gum in cypress and gum swamps in the Apalachicola National Forest, and organic soils rarely occurred under titi (Coultas 1978). This is the case at the study site, as soils at the study site dominated by black gum had from 24% to 50% organic carbon. Organic soils in black gum swamps in the Apalachicola National Forest had from 44% to 53% organic carbon (Coultas 1978). Soils at the study site dominated by the species of titi all had less than 12% organic carbon. The Humaquept mineral soils dominated by species of titi in the Apalachicola National Forest had from 10% to 13% organic carbon.

Organic materials are deposited on the soil surface, and poor drainage and slower decomposition result in higher than normal organic matter content, particularly at the surface. Bulk density (weight per given volume) is low for organic materials. It increased with depth and percent organic matter decreased with depth for all soils at the study site. These soils tend to be more acid at the soil surface (Coultas 1978; Coultas et al. 1979). Titi and bay forest peats had similar pH values (Davis 1946) as those at the study site. Soils of titi swamps and gum ponds were very low in extractable bases (Ca, Mg, K, Na) and relatively high in terms of their cation exchange capacity (CEC), which was highest in organic horizons and decreased with depth (titi swamps 93.7 - 114.7 meq/100 g, blackgum swamps 73.8 - 165.7 meq/100 g) (Coultas 1977, 1978).

Over 90% of total nitrogen in soil is in the organic fraction (Kadlec and Tilton 1979). A similar relationship exists in the soils at the study site as total nitrogen is greatest at the surface where organic matter is greatest and decreases with depth as does organic matter. Organic nitrogen complexes with lignin, polyphenols and basic acids at a pH below 6 (Overcash and Pal 1979). Total phosphorus in the soils of the titi swamps in the Apalachicola National Forest investigated was highest in the surface layers (Coultas 1977). This is the case for the mineral soils at the study site, which are dominated by species of titi.

Soils of the titi swamps in the Apalachicola National Forest were extremely low in plant nutrients as was the case for the study site soils (Coultas 1977). Total nitrogen concentrations ranged from 0.2 to 12.5 mg/g for a Humaquept dominated by species of titi in the Apalachicola National Forest. The total nitrogen concentrations of the Humaquepts at the study site are in the low end of this range (0.36 to

3.08 mg/g). Total nitrogen concentrations were in a range from 1.1 to 20.5 mg/g for a Medisaprist dominated by black gum (Coultas 1978). The total nitrogen concentrations of the Medisaprists at the study site are in the low end of this range (1.53 to 3.54 mg/g). Total phosphorus concentrations were in a range from 26 to 232 μg/g for a Humaquept mineral soil dominated by species of titi in the Apalachicola National Forest (Coultas 1977). Total phosphorus concentrations were in a range from 1 to 230 μg/g for 30 Florida sandy soils including a Humaquept (Yuan and Lucas 1982). The total phosphorus concentrations of the soils at the study site were within this range (14 to 225 μg/g).

Phosphorus Adsorption

The adsorption maxima are useful in describing the soil phosphorus retention capacity although at higher phosphorus concentrations these values may be exceeded by the actual adsorption (Yuan and Lucas 1982). This parameter is indicative of the phosphorus retention potential but may overestimate the actual field adsorption maximum because channelized water movement will reduce contact with a large portion of the soil matrix (Richardson 1985).

The adsorption maxima for the site four mineral soils are generally low (less than 230 μg/g soil) suggesting a limited capacity for phosphorus adsorption. The site five organic soils have higher adsorption maxima (294-2888 μg/g soil) suggesting a greater capacity for phosphorus adsorption. Yuan and Lucas (1982) reported adsorption maxima calculated in the same manner from 82 to 1148 μg/g for 30 Florida sandy mineral soils including a Humaquept. Krottje et al. (1982) reported adsorption maxima in a range from 62 to 775 μg/g for four Florida soils with less than 19% organic matter. They also reported an adsorption maximum of 2000 $\mu g/g$ for a Florida soil with 67.2% organic matter. The adsorption maxima of these five soils were calculated as the slope of the Langmuir equation. Phosphorus adsorption was highly correlated with organic matter and exchangeable aluminum content (Krottje et al. 1982).

The 0.1 N HCl extractable phosphorus may be considered surface active phosphorus or the labile soil phosphorus (Bache and Williams 1971). The Tamm oxalate extract is a stronger reagent, disturbing more than just the surface active (labile) phosphorus. Therefore Tamm oxalate extractable phosphorus concentrations were higher than the 0.1 N HCl extractable phosphorus concentrations but less than the total phosphorus concentrations which include more tightly bound forms of phosphorus.

The adsorption maxima and a phosphorus sorption index were correlated with measured soil properties in order to indicate which soil factors are best related to phosphorus adsorption in the soil. The relatively low phosphorus adsorption capacity of the site four mineral soils and the much higher phosphorus adsorption capacity of the site five organic soils are related to the content and availability of aluminum in these soils rather than the amount of organic matter present. The dry weight of aluminum per gram of soil is much greater than the dry weight of phosphorus per gram of soil, and aluminum concentrations in the soil as well as the phosphorus adsorption maxima increased with depth. The high correlation of extractable aluminum with both the adsorption maxima and the phosphorus sorption index as well as the increase in the adsorption maxima and aluminum concentrations with depth indicate the importance of aluminum in phosphorus adsorption in the study site soils. The high correlation of the adsorption maxima and the phosphorus sorption index with Tamm oxalate extractable aluminum indicates that phosphorus adsorption is related to the amorphous and poorly crystalline oxides of aluminum.

Pre-treatment to remove phosphorus from wastewater entering flow-through wetlands in particular will be necessary unless site-specific information is available to indicate a capacity for its retention in the system. The phosphorus adsorption maxima for soils at this titi shrub swamp indicate quantitatively the potential for phosphorus retention in the soil. The site five organic soils have a high capacity for phosphorus adsorption. The capacity for phosphorus adsorption is much lower in the site four mineral soils. The finding by Fox and Kamprath (1970) that soils that have low capacity to adsorb phosphorus require very high concentrations of phosphorus in solution to compensate for a lack of total available phosphorus suggests that, although a soil may have a low phosphorus adsorption capacity, it may indirectly contribute to a net uptake of phosphorus in the system through plant immobilization. Therefore, whether through adsorption or immobilization this study site appears to have potential for phosphorus treatment of added wastewater.

Hydrology

Hydrology is the primary determinant of wetland ecosystems and the most important factor influencing wetland biogeochemistry (Gosselink and Turner 1978). Despite the recognized importance of the hydrologic regime to the structure and function of wetlands, it is often the component of wetland ecosystem research which is least thoroughly investigated (LaBaugh 1986). In order to assess impacts to a wetland properly, a water budget must be prepared. Only when the water budget is combined with measurements of nutrient concentrations can an interpretation of wetland treatment system performance be made (Hammer and Kadlec 1983). A water budget for the wetland study site was determined for use in the simulation model of the titi shrub swamp receiving wastewater.

Runoff

Estimates of runoff using 5-day antecedent precipitation to determine antecedent moisture class (AMC) are not recommended for use in Florida (Konyha et al. 1982). The method predicts erratically, sometimes predicting with reasonable accuracy and sometimes underpredicting runoff by more than 3 in. The method that assumes average (AMC II) watershed conditions also underpredicts large runoff events. When wet (AMC III) watershed conditions are assumed the predictions are acceptable for large runoff events, but most small runoff events are overpredicted. It may have been best to assume average (AMC II) watershed conditions for small runoff events and wet (AMC III) watershed conditions for large runoff events, but this would have required selecting a cutoff point for runoff events in terms of precipitation, for which there is no basis.

Evapotranspiration

Methods to estimate actual evapotranspiration incorporate factors that reflect different levels of water availability. In the Thornthwaite method, if monthly precipitation is less than potential evapotranspiration then water is lost from the soil, and actual evapotranspiration is less than potential evapotranspiration. The Thornthwaite method does not correct for changes in relative humidity, cloud cover and other solar radiation effects, wind or cover type. Therefore, results from this method can only be interpreted as average values, particularly for estimates of actual evapotranspiration when water availability is high. Prediction formulae are general equations that do not compensate for variation in transpiration among species (Scheffe 1978).

Average potential evapotranspiration and actual evapotranspiration were calculated by Dohrenwend (1977) using the Holdridge method for 21 weather stations in Florida for a 5-yr period. The precipitation, potential evapotranspiration, potential evapotranspiration to precipitation ratio, actual evapotranspiration and the actual evapotranspiration to potential evapotranspiration ratio reported by Dohrenwend (1977) for weather stations in Milton and Tallahassee, Florida, are presented in Table 40. These are the closest stations to the Apalachicola weather station for which data are reported. The average annual precipitation at the Apalachicola weather station, for the 5-yr period analyzed, was greater than the average annual precipitation reported by Dohrenwend (1977) for the other two stations. Therefore, the potential evapotranspiration and the actual evapotranspiration values were also greater. Although these values were greater at the Apalachicola weather station, both the potential evapotranspiration to precipitation and actual evapotranspiration to potential evapotranspiration ratios for the Apalachicola weather station were similar to the ratios reported by Dohrenwend (1977) for the other two stations. Therefore, the estimate of these parameters in this study are consistent with what may be considered average values for this region of the state.

Table 40. Precipitation (P), potential evapotranspiration (PET), PET/P ratio, actual evapotranspiration (AET) and AET/PET ratio for Milton and Tallahasse, Florida reported by Dohrenwerd (1977) and for Apalachicola calculated in this study.

	P (in)	PET (in)	PET/P ratio	AET	AET/PET (%)
Milton	59.09	39.21	0.66	32.56	83
Tallahassee	56.85	39.68	0.68	32.95	83
Apalachicola (1982-1986)	65.64	41.08	0.63	36.48	89
Apalachicola (WBY)	64.71	43.20	0.67	37.14	86

Water Budget

Infiltration in this wetland is low due to the semi-impermeable organic humate layer. Water is held above this layer and leaves the wetland predominantly through runoff and evapotranspiration, which account for 86 to 93% of precipitation reaching the study site depending on whether actual or potential evapotranspiration is used in the calculation. The annual upper limit of deep seepage groundwater outflow from the study site was calculated to be 8 in. This was less than water budget residual I (RES I = 10 in.). The difference could be due to either an increase in storage within the study site or an underestimate of evapotranspiration. Some increase in storage within the study site might be expected because the annual average precipitation for the 5-yr period analyzed was almost 10 in. greater than the 74 yr average for the Apalachicola weather station. The water budget residual II (RES II = 5 in.) was less than the upper limit of deep seepage groundwater outflow. Therefore, if evapotranspiration is greater than estimated actual evapotranspiration in the simplified water budget and approaches the estimated potential evapotranspiration value, then the water budget residual can be accounted for through deep seepage groundwater flow. A value for deep seepage groundwater flow less than the estimated upper limit is consistent with low infiltration in the system.

Transpiration and Total Water Loss

The daily transpiration rate per leaf area for black titi in the bay swamp was similar to values for hardwood species in the floodplain forest (Table 41). The average daily transpiration rate per leaf area for sweetbay in the bay swamp was lower than values for cypress in the

Table 41. Leaf area index (LAI), daily transpiration rate per leaf area (DTRLA) daily transpiration rate per ground area (DTRGA), forest floor water loss (FFWL) and total water loss (TWL) for the dwarf cypress forest, Austin Cary cypress dome and floodplain forest reported by Brown (1981) and for the bay swamp community at the study site.

Community		Dwarf cypress forest	Austin Cary Cypress Dome	Bay swamp	Floodplain forest
LAI		0.5	3.4	4.6	8.5
<u>Transpiration</u>	<u>Vegetation</u>				
DTRLA	cypress	1840	2125	-	544
gH_2O/m^2	hardwood	-	527	-	868
leaf area/day	black titi	-	-	801	-
	sweetbay	-	-	1593	-
DTRGA	cypress	932	1679	-	2106
gH_2O/m^2	hardwood	-	1394	-	3099
ground area/day	black titi	-	-	2083	-
	sweetbay	-	-	1529	-
TOTAL		932	3073	3612	5205
<u>Evaporation</u>					
FFWL gH_2O/m^2 ground area/day		333	717	717	363
Total Water Loss (TWL)					
gH_2O/m^2 ground area/day		1265	3790	4329	5568
mm/d		1.27	3.79	4.33	5.57
Pan Ratio (PR) = TWL/pan evaporation		0.19	0.66	0.90	0.95

dwarf cypress forest and in Austin Cary cypress dome. This indicates relatively low levels of transpiration per leaf area for these species.

Daily transpiration rates per ground area for the bay swamp were greater than values for the dwarf cypress forest and Austin Cary cypress dome. The increase from the species level to the community level is reflected in greater leaf area index values in the bay swamp as compared to the dwarf cypress forest and Austin Cary cypress dome. Total water loss for the bay swamp is greater than for the dwarf cypress forest and Austin Cary cypress dome but less than for the floodplain forest. The estimated leaf biomass of the woody vegetation in the bay swamp community where transpiration was measured (Table 18) was similar to the value reported by Brown (1978) for the floodplain forest. Therefore, this community may be structurally similar to a floodplain forest and may transpire at a high rate when water is readily available.

When transpiration data are collected under different conditions of humidity, wind and sunlight (as was the case in this study), the pan ratio is a useful index to compare evapotranspiration between sites (Brown 1981). The pan ratio is the ratio of total water loss to pan evaporation. The average pan evaporation for the 11 days when transpiration was measured was 0.19 in. (4.8 mm). Open water evaporation is typically 0.7 to 0.8 of pan evaporation (Veihmeyer 1973). The pan ratios of the dwarf cypress forest and Austin Cary cypress dome were lower than the pan ratio of open water, suggesting that these swamps may conserve water. The pan ratio of the bay swamp and the floodplain forest were higher than the pan ratio of open water.

Potential evapotranspiration was 71% of pan evaporation suggesting that, on average, evapotranspiration was similar to open water evaporation. But in communities where the pan ratio exceeds the pan ratio of open water, total water loss may be greater than the average calculated for all the communities within the system. Considering that estimates of potential evapotranspiration may underestimate evapotranspiration for certain systems when water availability is high, and that transpiration may exceed open water evaporation, as are indicated above, it is not surprising that the total water loss from certain wetland communities is greater than the average calculated for all the communities within the system. The relative aboveground biomass (Table 16) and estimated leaf biomass (Table 22) for the titi and black gum swamps at the study site were lower than for the bay swamp. Therefore less total water loss is expected from these communities but this can only be substantiated with field measurements.

The range of daily evapotranspiration rates in three cypress swamps studied by Ewel (1985) was from 0.2 mm/day (in January) to 5.9 mm/day (in September). These daily maximum evapotranspiration rates were greater than the evapotranspiration rates for the floodplain forest measured by Brown (1978) and for the bay swamp community at the study site, expressed in Table 41 as total water loss. Evapotranspiration in cypress domes was measured by Heimburg (1976) by determining the change in water levels. Evapotranspiration varied seasonally in the cypress domes and in this study. Therefore, there is variability in evapotranspiration rates among forested wetland communities and among seasons, and it appears that forested wetlands evapotranspire at low rates when water is scarce and at higher rates when water is readily available.

When wetlands go dry, plants that limit water loss may have an adaptive advantage in these systems. When water is scarce, wetland vegetation may have the ability to ameliorate water loss and even survive drought periods through morphological and physiological adaptations. A species may require an increase in reflectance, as occurs in xeromorphic leaves, in order to maintain reasonable leaf temperatures as suggested by Odum (1984). A strategy of conserving water during dry seasons is achieved by increasing reflectance and reducing transpiration (Odum 1984). It also appears that during wet seasons a high rate of evapotranspiration can occur, and therefore these species have bimodal adaptation in that they are well adapted to both wet and dry conditions. Therefore, although certain forested wetland communities evapotranspire at a high rate when water is readily available, these systems are adapted for water conservation during dry periods.

Model Development and Simulation

Intrasystem cycling of nutrients in wetlands depends on the availability of the nutrients and the degree to which processes such as primary productivity and decomposition are controlled by the wetland environment (Mitsch and Gosselink 1986). Forested wetlands can be arranged according to the volume of water flowing to the wetland and the accompanying nutrients (Brown 1981; Odum 1984). Many isolated wetlands such as the wetlands at the study site have a low nutrient input and therefore low biomass. Quantification of initial model compartment conditions indicated that a small amount of nutrients were cycled within the system. Low nutrient input limited the simulated productivity in this systems as indicated in the annual budgets determined during model development (Figure 25). Wetlands in which precipitation is the primary nutrient input depend on intrasystem cycling for nutrients (Mitsch and Gosselink 1986). Therefore, if primary productivity and decomposition in the wetland are limited by hydrologic and nutrient conditions, then intrasystem cycling of nutrients is high and nutrients may be conserved, as was indicated above for this study site.

The simulated response of the wetland to the increase in nutrients was an increase in annual biomass and litter and increased storage of nutrients in biomass, litter and soil, and the rates of these increases decreased with time. This is consistent with the results from other models used to simulate the addition of wastewater to wetlands (Dixon and Kadlec 1975; Mitsch 1975b; Deghi and Ewel 1984; Hammer 1984) and with the results from research in which a quantitative determination was made of the storage in wetland compartments (Nessel 1978; Kadlec and Tilton 1979; Dierberg and Brezonik 1983b). Natural wetlands retained and stored much of their nutrient inputs even when loading increased 200-fold over natural inputs (Dierberg and Brezonik 1983b). As with initial models developed to predict the addition of wastewater to peatlands in Michigan, the simulations were intended to indicate relative effects of added water and nutrients on the wetland and should await complete model validation before being interpreted as actual results.

Without the simulated addition of wastewater the titi shrub swamp was a phosphorus limited system. The vegetation stored nitrogen and phosphorus at a N:P ratio (weight based) of 25:1 (Figure 25).

Wastewater was added to the system at a N:P ratio (weight based) of 2.26:1 (Figure 26). Therefore, there was a simulated overabundance of phosphorus added to the system relative to nitrogen. Production and storage in biomass increased as long as phosphorus was available to drive the process. When phosphorus adsorption in the soil ended (11.7 yrs), the amount of nitrogen entering the system was greater than that required to maintain the same level of production, and storage of nitrogen in the soil increased. A greater rate of denitrification than was used in the model could account for an overall lower level of nitrogen storage in the soil. Also, when phosphorus adsorption in the soil ended, phosphorus discharge in runoff greatly increased and the wetland would no longer assimilate enough phosphorus to protect downstream receiving water quality. Wastewater discharged to wetlands with a N:P ratio similar to that stored in vegetation would maximize the lifetime of the system for phosphorus assimilation, and nitrogen assimilation could be accounted for through storage and denitrification. Therefore, nutrient loading criteria should be based on maximizing the longevity of the system, which can be estimated by determining the phosphorus adsorption capacity of the soil.

In this simulation model, production was a function of the interaction of an external limiting factor (solar radiation) and internal limiting factors (nutrients). Therefore, production was strongly affected at low concentrations but becomes less affected as one factor becomes relatively more limiting. In certain situations, the limiting factor may not become relatively more limiting. Gilliland (1973) found that the effect of a great excess of one limiting factor (phosphorus in a Florida estuary) lowered the storage of another factor (nitrogen) so low that production was inhibited. Therefore, the N:P ratio changed to the extent that nitrogen and not phosphorus was limiting. Mitsch (1976b) considered this while evaluating the effects of multiplicative interactions and suggested that if nutrients become enriched beyond the internal limitations, then it may be best to model production as if only solar radiation were limiting. This may be a more realistic approach for modeling systems with excessive nutrient inputs.

An energy/nutrient ecosystem model was developed to characterize and quantify the main components and processes of a titi shrub swamp necessary to predict their long-term responses to wastewater discharge. This model can be used to simulate carbon, nitrogen and phosphorus cycling, and water flow in a forested wetland. Quantification of model compartments has added basic information to the study of forested wetlands in Florida. Many of the model compartments can be more accurately estimated for these systems and the capacity for phosphorus adsorption in soils can be incorporated into the model with minimal laboratory analysis. The model can be improved upon for evaluating the long-term responses of the main components and processes of wetlands to wastewater discharge by incorporating more appropriate dynamics for the interaction of limiting factors of a system receiving excessive nutrients.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Wetlands can be used to treat wastewater if managed properly. In order to manage these systems properly, we must understand quantitatively how they function. An energy/nutrient system model was used to simulate carbon, nitrogen and phosphorus cycling, and water flow of a titi shrub swamp and to predict the long-term responses of the main components and processes to wastewater discharge.

Quantification of model compartments indicated that:

1) the aboveground biomass in the titi shrub swamp is in the low to intermediate range of values cited for forested wetlands.
2) precipitation is the principal source of water and nutrients to this system, and
3) the relative concentrations of nitrogen and phosphorus in precipitation, surface water and groundwater and the dominance of ammoniacal nitrogen and low level of phosphorus dissolved in surface water indicate that nutrients are conserved within the system.

Therefore, small amounts of nutrients were cycled within this system and low nutrient input limited the simulated productivity.

The simulated response of the wetland to the increase in nutrients was an increase in annual biomass and litter and increased storage of nutrients in biomass, litter and soil, and the rates of these increases decreased with time. Wastewater discharged to wetlands with a N:P ratio similar to that stored in vegetation would maximize the lifetime of the system for phosphorus assimilation. Therefore, nutrient loading criteria should be based on maximizing the longevity of the system, which can be estimated by determination of the phosphorus adsorption capacity of the soil.

The phosphorus adsorption capacity of soils at the study site were quantitatively determined. The mineral soils dominated by titi had a low capacity for phosphorus adsorption while the organic soils dominated by black gum had a higher capacity for phosphorus adsorption. The adsorption capacities of these soils were related to the content and availability of amorphous and poorly crystalline oxides of aluminum.

Transpiration studies indicated that sweetbay had low rates of transpiration per leaf area relative to other forested wetland species. An increase occurred from the individual to the community level due to the high leaf area index in the bay swamp. This community transpires at a rate greater than open water evaporation when water is readily available as indicated by the pan ratio. There is variability among forested wetland communities and among seasons and it appears as though these systems evapotranspire at low rates when water is scarce and at higher rates when water is readily available. Therefore, these systems are adapted for water conservation during dry periods.

Quantification of model compartments has added basic information to the study of forested wetlands in Florida. The energy/nutrient ecosystem model can be improved upon for evaluating the long-term responses of the main components and processes of wetlands to wastewater discharge by incorporating more appropriate dynamics for the interaction of limiting factors of a system receiving excess nutrients.

APPENDIX A

COMPUTER PROGRAM TO INTEGRATE HOURLY TRANSPIRATION RATES TO OBTAIN A DAILY TRANSPIRATION RATE (DTR). A SAMPLE OUTPUT IS INCLUDED

```
10 CLS      'CLEAR SCREEN
20 DIM CLOK(49),TR(49)
25 INPUT "FILE: ",FILE$
26 LPRINT FILE$:LPRINT:LPRINT
30 OPEN "I",#1,"B:"+FILE$+".PRN" 'OPEN DATA FILE
40 REM ***  LOOP TO READ IN DATA ***
50 FOR L =   1 TO  49
60 LINE INPUT #1, CF$          :REM° READ DATA FILE ONE LINE AT A T
70 CLOK(L) =  VAL(MID$(CF$,9,4))  ' ASSIGNS VALUE TO VARIABLES
80 TR(L) =  VAL(MID$(CF$,15,7))
100 PRINT CLOK(L), TR(L)
101 LPRINT CLOK(L), TR(L)
110 NEXT L
120 REM **** COUNT # OF PANALS *****
130 P  =  0
140 FOR L  =  1 TO  49
150 IF TR(L) >·  0 THEN  P  =  P +1
160 NEXT L
170 PANALS  =  P-1
180 PRINT:PRINT:PRINT "PANALS: ";PANALS
181 LPRINT:LPRINT:LPRINT "PANALS: ";PANALS
185 REM **** FINDS START AND LAST OF DATA *****
190 FOR L  =  1 TO  49
200 IF TR(L) >   0 THEN 210 ELSE 220
210 START  =  L: LAST·  =  L +   PANALS:GOTO 230
220 NEXT L
230 PRINT "START: ";START, "LAST: ";LAST
231 LPRINT "START: ";START, "LAST: ";LAST
235 REM *** SUMS START AND LAST VALUES FOR TR FUNCTION ******
240 ESTR  =  TR(START) +  TR(LAST)
260 PRINT "END SUM: ";ESTR
261 LPRINT "END SUM: ";ESTR
270 PSTR  =  0
275 REM *** SUMS VALUES FOR TR EX FUNCTION ******
280 FOR X  =  START  +  1 TO  LAST-1
290 PSTR  =  PSTR  +  TR(X)
310 NEXT X
320 PRINT "PANAL SUM: ";PSTR
321 LPRINT "PANAL SUM: ";PSTR
325 REM *** INTEGRATES FUNCTIONS *****
330 ITR  = (ESTR  +  2 * PSTR)* .5
360 PRINT "TRANSPIRATION RATE = ";ITR; "gH2O/DAY"
361 LPRINT "TRANSPIRATION RATE = ";ITR; "gH2O/DAY"
```

091486Z

700	0
715	0
730	0
745	0
800	0
815	0
830	0
845	0
900	0
915	0
930	27.39
945	28.19
1000	28.86
1015	29.7
1030	29.65
1045	29.56
1100	30.42
1115	30.27
1130	31.2
1145	31.1
1200	31.1
1215	31.96
1230	31.85
1245	31.85
100	32.78
115	66.47
130	66.47
145	33.74
200	33.8
215	66.58
230	32.94
245	32.94
300	32.89
315	32.01
330	32.01
345	61.47
400	30.37
415	30.37
430	29.46
445	29.56
500	29.56
515	0
530	0
545	0
600	0
615	0
630	0
645	0
700	0

PANALS: 30
START: 11 LAST: 41
END SUM: 56.95
PANAL SUM: 1039.57
TRANSPIRATION RATE = 1068.045 gH2O/DAY

APPENDIX B

REGRESSION EQUATIONS USED TO ESTIMATE THE BIOMASS OF THE TITI SHRUB SWAMP IN APALACHICOLA, FLORIDA. pdb = PRIMARY BRANCH DIAMETER, dbh = DIAMETER AT BREAST HEIGHT

Appendix B. Regression equations used to estimate the biomass of the titi shrub swamp in Apalachicola, Florida. pbd = primary branch diameter, dbh = diameter breast height.

Regression x	Regression y	#	Species	Equation	Type	A	B	n	Source	r^2
pbd	dry wgt. branch material	1	Black titi	$y=A/(1+Bx^{n})$	sigmoid	10,000	823.5302	-3.7954	This study	0.95
		2	Red titi	$y=A/(1+Bx^{n})$	sigmoid	100,000	4054.564	-3.0351	This study	0.95
		3	Sweetbay	$y+Axe^{n}$	maxima function	5.4282	0	.9778	This study	0.81
pbd	dry wgt. leaf material	4	Black titi	$y=Ax^{n}+B$	mod. power function	5.4585	1	2.7948	This study	0.84
		5	Red titi	$y+Axe^{n}$	maxima function	8.4603	0	12.323	This study	0.83
		6	Sweetbay	$y=Ax^{n}+B$	mod. power function	4.0013	1	2.9197	This study	0.75
dbh	estimated above ground biomass (dbh > 4.0 cm)	7	Black titi	$y=A/(1+Bx^{n})$	sigmoid	1,000,000	10454.9841	-2.5348	This study	0.99
		8	Red titi	$y=Ax^{n}$	power function	143.1487	-	2.0946	This study	0.96
		9	Sweetbay	$y=A/(1+Be^{n})$	exponetial sigmoid	100,000	110.966	-0.3516	This study	1.00
dbh	estimated above ground biomass (dbh < 4.0 cm)	10	all	$y=Ax^{n}$	power function	256.626	-	1.8031	This study	1.00
dbh	estimated above ground biomass (dbh > 4.0 cm)	11	Blackgum	$\log_{10}y=A+B\log_{10}x$	double logarithmic	-.970	2.390	-	Brown 1978	0.99
		12	Slash pine	$\log_{10}y=A+B\log_{10}x$	double logarithmic	-1.585	3.066	-	Duever 1977 (cited in Brown 1978)	0.89
		13	Pond cypress	$\log_{10}y=A+B\log_{10}x$	double logarithmic	-0.900	2.258	-	Mitsch 1975 (cited in Brown 1978)	0.89
dbh	estimated leaf biomass	14	Black titi	$y+Axe^{n}$	max. function	20.5116	0	-.1559	This study	0.83
		15	Red titi	$y=Ax/B+x$	hyperbolic	451.9083	-24.477	-	This study	0.70
		16	Sweet bay	$y+Ae^{n}$	exponetial growth	47.8256	-	0.2323	This study	0.90
		17	Pond cypress	$\log_{10}y=A+B\log_{10}x$	double logarithmic	1.237	1.566	-	Mitsch 1975 (cited in Brown 1978)	0.83

APPENDIX C

ANNUAL WATER BUDGETS FOR 1982-1986 AND FOR THE WATER BUDGET YEAR (WBY) FOR THE TITI SHRUB SWAMP STUDY SITE. A KEY TO TERMS IS INCLUDED

1982		R												
Month	P	AMC II	AMC III	PE	MMAT	I	UPET	MMS	PET	P-PET	AWL	ST	SWL	AET
JAN	2.64	0.07	0.38	2.37	52.6	3.50	0.02	27.3	0.546	2.094	0	2.01	-	0.546
FEB	6.21	1.33	2.75	3.21	59.1	5.31	0.05	26.1	1.305	4.905	0	2.01	-	1.305
MAR	8.02	2.76	4.71	4.27	61.7	6.10	0.06	30.9	1.854	6.166	0	2.01	-	1.854
APR	3.34	0.57	1.51	5.74	66.8	7.75	0.08	32.1	2.568	0.772	0	2.01	-	2.568
MAY	1.48	0.01	0.19	7.11	73.4	10.08	0.13	36.1	4.693	-3.213	-3.213	0.43	1.58	3.060
JUN	5.56	1.03	2.39	7.79	80.6	12.85	0.18	34.8	6.264	-0.704	-0.704	1.38	0.63	6.190
JUL	10.84	1.89	4.43	5.84	80.4	12.77	0.18	35.7	6.426	4.414	0	2.01	-	6.426
AUG	4.54	0.06	0.66	5.85	81.2	13.09	0.18	33.9	6.102	-1.562	-1.502	0.90	1.11	5.650
SEP	15.37	6.03	9.30	5.20	76.8	11.35	0.15	30.9	4.635	10.735	0	2.01	-	4.635
OCT	6.88	1.56	3.41	4.30	70.2	8.92	0.11	29.4	3.234	3.646	0	2.01	-	3.234
NOV	2.18	0.07	0.51	2.87	63.9	6.79	0.07	26.7	1.869	0.311	0	2.01	-	1.869
DEC	4.90	0.23	1.35	2.36	59.9	5.55	0.05	26.7	1.335	3.565	0	2.01	-	1.335
TOTAL	71.96	15.61	31.59	56.91		104.06			40.831					38.672

1983

Month	P	R AMC II	AMC III	PE	MMAT	i	UPET	MMS	PET	P-PET	AWL	ST	SWL	AET
JAN	4.30	0.22	1.09	2.01	50.9	3.08	.03	27.3	0.819	3.481	0	2.01	-	0.819
FEB	5.49	0.57	1.89	3.19	54.2	3.92	.04	26.1	1.044	4.446	0	2.01	-	1.644
MAR	4.97	0.05	0.81	4.22	57.0	4.69	.05	30.9	1.545	3.425	0	2.01	-	1.545
APR	12.14	3.93	7.11	6.34	62.7	6.41	.07	32.1	2.247	9.893	0	2.01	-	2.247
MAY	0.25	0.00	0.00	7.02	72.8	9.85	.13	36.1	4.693	-4.443	-4.843	0.31	1.70	1.950
JUN	8.03	0.97	3.01	6.28	78.2	11.85	.17	34.8	5.916	2.114	0	2.01	-	5.916
JUL	2.24	0.00	0.15	7.68	81.7	13.29	.19	36.7	6.783	-4.543	-4.543	0.31	1.70	3.940
AUG	5.37	0.45	1.59	6.27	81.8	13.33	.19	33.9	6.441	-1.071	-1.071	1.18	0.83	6.200
SEP	6.89	0.68	2.35	6.13	76.5	11.24	.15	30.9	4.635	2.255	0	2.01	-	4.635
OCT	2.05	0.03	0.36	4.36	71.4	9.34	.12	29.4	3.528	-1.478	-1.478	0.94	1.07	3.120
NOV	6.69	1.44	3.17	3.04	59.4	5.40	.06	26.7	1.602	5.088	0	2.01	-	1.602
DEC	5.96	0.83	2.28	2.30	52.0	3.35	.03	26.7	0.801	5.159	0	2.01	-	0.801
TOTAL	64.38	9.17	24.81	57.84		95.75			40.054					34.419

1984

		R												
Month	P	AMC II	AMC III	PE	MMAT	i	UPET	MMS	PET	P-PET	AWL	ST	SWL	AET
JAN	4.73	0.40	1.45	2.48	50.1	2.89	.02	27.3	0.546	4.184	0	2.01	-	0.546
FEB	3.93	0.54	1.45	3.38	53.4	3.71	.03	26.1	0.783	3.147	0	2.01	-	0.783
MAR	6.08	0.80	2.49	5.10	57.8	4.92	.05	30.9	1.545	4.535	0	2.01	-	1.545
APR	9.18	4.15	6.18	5.86	69.9	7.12	.08	32.1	2.568	6.612	0	2.01	-	2.568
MAY	0.32	0.00	0.00	7.29	72.8	9.85	.13	36.1	4.693	-4.373	-4.371	0.35	1.66	1.980
JUN	3.37	0.05	0.51	7.56	77.3	11.54	.16	34.8	5.568	-2.198	-2.198	0.59	1.42	4.790
JUL	18.07	3.67	8.26	6.70	78.5	12.01	.17	36.7	6.069	12.001	0	2.01	-	6.069
AUG	4.72	0.67	1.69	6.06	80.6	12.85	.18	33.9	6.102	-1.382	-1.382	1.02	0.99	5.710
SEP	1.25	0.07	0.35	6.14	76.9	11.39	.16	30.9	4.944	-3.694	-3.694	0.39	1.62	2.870
OCT	1.78	0.10	0.44	5.51	72.8	9.85	.13	29.4	3.822	-2.042	-2.042	0.75	1.26	3.040
NOV	2.16	0.00	0.27	3.14	58.9	5.25	.05	26.7	1.335	0.825	0	2.01	-	1.335
DEC	0.91	0.00	0.10	2.92	62.8	6.44	.07	26.7	1.869	-0.959	-0.959	1.26	0.75	1.660
TOTAL	56.50	10.45	23.19	62.14		97.82			39.844					32.896

1985														
		R												
Month	P	AMC II	AMC III	PE	MMAT	i	UPET	MHS	PET	P-PET	AWL	ST	SWL	AET
JAN	5.58	1.29	2.56	2.59	48.1	2.41	.01	27.3	0.273	5.307	0	2.01	-	0.273
FEB	1.78	0.06	0.35	3.26	55.1	4.16	.03	26.1	0.783	0.997	0	2.01	-	0.783
MAR	2.55	0.15	0.73	4.62	64.0	6.82	.07	30.9	2.163	0.387	0	2.01	-	2.163
APR	0.86	0.00	0.00	6.02	66.2	7.55	.08	32.1	2.568	-1.708	-1.708	0.83	1.18	2.040
MAY	2.72	0.23	0.90	6.78	74.5	10.48	.13	36.1	4.693	-1.973	-1.973	0.71	1.30	4.020
JUN	3.91	0.09	0.61	7.27	79.9	12.57	.18	34.8	6.264	-2.354	-2.354	0.67	1.34	5.250
JUL	7.66	0.82	2.58	5.16	80.4	12.77	.18	35.7	6.426	1.234	0	2.01	-	6.426
AUG	16.18	4.47	8.26	5.78	80.4	12.77	.18	33.9	6.102	10.078	0	2.01	-	6.102
SEP	5.38	0.85	2.04	5.33	77.5	11.62	.16	30.9	4.944	0.436	0	2.01	-	4.944
OCT	11.23	3.21	6.10	3.33	75.4	10.82	.14	29.4	4.116	7.114	0	2.01	-	4.116
NOV	6.48	2.05	3.60	2.49	68.5	8.33	.09	26.7	2.403	4.077	0	2.01	-	2.403
DEC	4.24	0.10	0.78	2.28	52.5	3.48	.02	26.7	0.534	3.706	0	2.01	-	0.534
TOTAL	68.57	13.32	28.51	54.91		103.78			41.269					39.054

1986

		R												
Month	P	AMC II	AMC III	PE	MMAT	i	UPET	MMS	PET	P-PET	AWL	ST	SWL	AET
JAN	3.82	0.26	1.11	2.93	52.2	3.40	0.02	27.3	0.546	3.274	0	2.01	-	0.546
FEB	5.41	0.22	1.13	3.62	59.2	5.34	0.04	26.1	1.044	4.366	0	2.01	-	1.044
MAR	2.23	0.23	0.70	4.88	60.3	5.67	0,05	30.9	1.545	0.685	0	2.01	-	1.545
APR	0.26	0.00	0.00	6.60	66.5	7.32	0.08	32.1	2.568	-12.308	-2.308	0.67	1.34	1.660
MAY	4.36	2.09	3.20	7.07	73.8	10.22	0.13	36.1	4.693	-0.373	-0.373	1.73	0.28	4.640
JUN	2.01	0.02	0.21	6.44	81.5	13.21	0.19	34.8	6.612	-4.602	-4.602	0.31	1.70	3.710
JUL	3.34	0.10	0.59	8.01	83.1	13.85	0.20	35.7	7.140	-3.800	-3.8	0.35	1.66	5.000
AUG	12.04	2.95	5.76	5.54	81.4	13.70	0.19	33.9	6.441	5.599	0	2.01	-	6.441
SEP	9.29	3.79	4.83	4.81	80.5	12.81	0.18	30.9	5.562	3.728	0	2.01	-	5.562
OCT	9.19	2.29	4.41	4.04	72.2	9.64	0.12	29.4	3.528	9.662	0	2.01	-	3.528
NOV	5.18	0.70	1.74	2.37	68.8	8.44	0.10	26.7	2.670	2.510	0	2.01	-	2.670
DEC	9.68	2.51	3.87	1.62	58.2	5.04	0.04	26.7	1.068	8.612	0	2.01	-	1.066
TOTAL	66.81	15.16	27.55	57.93		108.64			43.417					37.354

WBY		R												
Month	P	AMC II	AMC III	PE	MMAT	i	UPET	MHS	PET	P-PET	AWL	ST	SWL	AET
OCT 1985	11.23	3.21	6.10	3.33	75.4	10.82	0.14	29.4	4.116	7.114	0	2.01	-	4.116
NOV	6.48	2.05	3.60	2.49	68.5	8.33	0.09	26.7	2.403	4.077	0	2.01	-	2.403
DEC	4.24	0.10	0.78	2.28	52.5	3.48	0.02	26.7	0.534	3.706	0	2.01	-	0.534
JAN 1986	3.82	0.26	1.11	2.93	52.2	3.40	0.02	27.3	0.546	3.274	0	2.01	-	0.546
FEB	5.41	0.22	1.13	3.62	59.2	5.34	0.04	26.1	1.044	4.366	0	2.01	-	1.044
MAR	2.23	0.23	0.70	4.88	60.3	5.67	0.05	30.9	1.545	0.685	0	2.01	-	1.545
APR	0.26	0.00	0.00	6.60	66.5	7.32	0.08	32.1	2.568	-2.308	-2.308	0.67	1.34	1.500
MAY	4.36	2.09	3.20	7.07	73.8	10.22	0.13	36.1	4.693	-0.373	-0.373	1.73	0.28	4.640
JUN	2.01	0.02	0.21	6.44	81.5	13.21	0.19	34.8	6.612	-4.602	-4.602	0.31	1.70	3.710
JUL	3.34	0.10	0.59	8.01	83.1	13.88	0.20	35.7	7.140	-3.800	-3.800	0.35	1.66	5.000
AUG	12.04	2.95	5.76	5.54	81.4	13.70	0.19	33.9	6.441	5.599	0	2.01	-	6.441
SEP	9.29	3.79	4.83	4.81	80.5	12.81	0.18	30.9	5.562	3.728	0	2.01	-	5.562
TOTAL	64.71	15.02	27.31	58.00		108.15			43.204					37.141

APPENDIX D

SPREAD SHEETS FOR TRANSPIRATION RUNS. A KEY TO TERMS IS INCLUDED

TRANSPIRATION PROGRAM

		UNITS	PARAMETER
*	TIC	°C	Temperature Inside the Chamber
*	TAM	°C	Ambient Temperature Outside the Chamber
*	DTIN	°C	Dew Point Temperature Intake
*	DTEX	°C	Dew Point Temperature Exhaust
	ESTAM	mb	Ambient Saturation Vapor Pressure
	ESDTIN	mb	Intake Saturation Vapor Pressure
	ESDTEX	mb	Exhaust Saturation Vapor Pressure
	AHTAM	g/m^3	Ambient Absolute Humidity
	AHIN	g/m^3	Absolute Humidity at Saturation Intake
	AHEX	g/m^3	Absolute Humidity at Saturation Exhaust
	RH	%	Relative Humidity
	SD	mb	Saturation Deficit
*	SE	$Btu/hr/ft^2$	Solar Input (english units)
	S	$kcal/hr/m^2$	Solar Input (metric units)
*	FL	m/sec	Measured Flow
	FR	m^3/hr	Flow Rate
	TR	gH_2O/hr	Transpiration Rate
	DTR	gH_2O/day	Daily Transpiration Rate
*	LB	g	Leaf Biomass
	LA	m^2	Leaf Area
	TRLA	gH_2O/m^2-hr	Transpiration Rate per Leaf Area
	DTRLA	gH_2O/m^2-day	Daily Transpiration Rate per Leaf Area
	LBAR	g/m^2 leaf area	Leaf Biomass Area to Ratio
	TRB	gH_2O/g-hr	Transpiration Rate per Biomass
	LBGA	g/m^2-ground area	Leaf Biomass to Ground Area
	LAI	m^2/m^2	Leaf Area Index
	DTRGA	gH_2O/m^2-day	Daily Transpiration Rate per Ground Area

* Measured in the field

9043195

		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730	19	18	18	21.72	20.44	20.44	16.14	15.19	15.19	1.2	41.04	0.00	109.4	79.91	0.73	0.00	94.10	1.21	20	46.80	0.00
4		745	20.5	18.5	18.5	23.79	21.07	21.07	17.59	15.58	15.58	1.2	41.04	0.00	109.4	79.91	0.73	0.00	88.55	2.41	25	58.50	0.00
5		800	21	19	19	24.53	21.72	21.72	18.10	16.03	16.03	1.2	41.04	0.00	109.4	79.91	0.73	0.00	90.55	2.49	60	140.40	0.00
6		815	22.5	18.5	18.5	26.87	21.07	21.07	19.73	15.47	15.47	1.2	41.04	0.00	109.4	79.91	0.73	0.00	78.41	4.55	40	93.60	0.00
7		830	23	18.5	18.5	27.70	21.07	21.07	20.31	15.44	15.44	1.2	41.04	0.00	109.4	79.91	0.73	0.00	76.06	5.34	35	81.90	0.00
8		845	24	18.5	19	29.43	21.07	21.72	21.51	15.39	15.87	1.2	41.04	19.50	109.4	79.91	0.73	26.70	71.58	5.99	140	327.60	0.24
9		900	25	17.5	18	31.28	19.82	20.44	22.78	14.44	14.60	1.2	41.04	18.29	109.4	79.91	0.73	25.04	63.38	7.36	140	327.60	0.23
10		915	25	17.5	18	31.28	19.82	20.44	22.78	14.44	14.58	1.2	41.04	18.29	109.4	79.91	0.73	25.04	63.38	7.36	50	117.00	0.23
11		930	25.5	17	17.5	32.24	19.23	19.82	23.44	13.98	14.41	1.2	41.04	17.71	109.4	79.91	0.73	24.25	59.64	7.76	50	117.00	0.22
12		945	26	16.5	17	33.24	18.66	19.23	24.12	13.54	13.96	1.2	41.04	17.15	109.4	79.91	0.73	23.48	56.12	8.19	60	140.40	0.21
13		1000	26	17	17.5	33.24	19.23	19.82	24.12	13.96	14.39	1.2	41.04	17.68	109.4	79.91	0.73	24.21	57.86	8.10	50	117.00	0.22
14		1015	26	17	17.5	33.24	19.23	19.82	24.12	13.96	14.39	1.2	41.04	17.68	109.4	79.91	0.73	24.21	57.86	8.10	40	93.60	0.22
15		1030	26	17	17.5	33.24	19.23	19.82	24.12	13.96	14.39	1.2	41.04	17.68	109.4	79.91	0.73	24.21	57.86	8.10	35	81.90	0.22
16		1045	26.5	17.5	18	34.27	19.82	20.44	24.83	14.36	14.81	1.2	41.04	18.20	109.4	79.91	0.73	24.91	57.86	8.35	60	140.40	0.23
17		1100	27	17.5	18.5	35.32	19.82	21.07	25.55	14.34	15.24	1.2	41.04	36.99	109.4	79.91	0.73	50.51	56.12	8.73	100	234.00	0.45
18		1115	28	17.5	18	37.54	19.82	20.44	27.06	14.29	14.73	1.2	41.04	18.11	109.4	79.91	0.73	24.73	52.81	9.35	250	585.00	0.23
19		1130	27	17	18	35.32	19.23	20.44	25.55	13.91	14.73	1.2	41.04	35.79	109.4	79.91	0.73	48.99	54.44	8.76	270	631.80	0.45
20		1145	27.5	17	18	36.41	19.23	20.44	26.30	13.99	14.76	1.2	41.04	35.73	109.4	79.91	0.73	48.91	52.81	9.07	300	702.00	0.45
21	PM	1200	27.5	17	18	36.41	19.23	20.44	26.30	13.99	14.76	1.2	41.04	35.73	109.4	79.91	0.73	48.91	52.81	9.07	300	702.00	0.45
22		1215	29	18	19	39.89	20.44	21.72	28.66	14.68	15.61	1.2	41.04	37.78	109.4	79.91	0.73	51.72	51.23	9.97	300	702.00	0.47
23		1230	28	18	19	37.54	20.44	21.72	27.06	14.73	15.66	1.2	41.04	37.90	109.4	79.91	0.73	51.89	54.44	9.31	290	678.60	0.47
24		1245	28.5	17.5	18.5	38.70	19.82	21.07	27.85	14.27	15.16	1.2	41.04	36.71	109.4	79.91	0.73	50.25	51.23	9.67	300	702.00	0.46
25		100	29	18	19	39.89	20.44	21.72	28.66	14.68	15.61	1.2	41.04	37.78	109.4	79.91	0.73	51.72	51.23	9.97	300	702.00	0.47
26		115	29	18	19	39.89	20.44	21.72	28.66	14.68	15.61	1.2	41.04	37.78	109.4	79.91	0.73	51.72	51.23	9.97	290	678.60	0.47
27		130	29	18	19	39.89	20.44	21.72	28.66	14.68	15.61	1.2	41.04	37.78	109.4	79.91	0.73	51.72	51.23	9.97	260	608.40	0.47
28		145	28	18	18.5	37.54	20.44	21.07	27.06	14.73	15.19	1.2	41.04	18.66	109.4	79.91	0.73	25.55	54.44	9.31	210	491.40	0.23
29		200	28.5	18.5	19	38.70	21.07	21.72	27.85	15.16	15.63	1.2	41.04	19.21	109.4	79.91	0.73	26.30	54.44	9.60	270	631.80	0.24
30		215	28.5	18	19	38.70	20.44	21.72	27.85	14.71	15.63	1.2	41.04	37.84	109.4	79.91	0.73	51.81	52.81	9.64	250	585.00	0.47
31		230	29	18	19	39.89	20.44	21.72	28.66	14.68	15.61	1.2	41.04	37.78	109.4	79.91	0.73	51.72	51.23	9.97	240	561.60	0.47
32		245	28.5	18.5	19	38.70	21.07	21.72	27.85	15.16	15.63	1.2	41.04	19.21	109.4	79.91	0.73	26.30	54.44	9.60	225	526.50	0.24
33		300	27.5	18	18.5	36.41	20.44	21.07	26.30	14.76	15.21	1.2	41.04	18.70	109.4	79.91	0.73	25.59	56.12	8.97	180	421.20	0.23
34		315	28	18	18.5	37.54	20.44	21.07	27.06	14.73	15.19	1.2	41.04	18.66	109.4	79.91	0.73	25.55	54.44	9.31	180	421.20	0.23
35		330	28	18.5	19	37.54	21.07	21.72	27.06	15.19	15.66	1.2	41.04	19.24	109.4	79.91	0.73	26.34	56.12	9.24	210	491.40	0.24
36		345	28	18.5	19	37.54	21.07	21.72	27.06	15.19	15.66	1.2	41.04	19.24	109.4	79.91	0.73	26.34	56.12	9.24	200	468.00	0.24
37		400	27	18.5	19	35.32	21.07	21.72	25.55	15.24	15.71	1.2	41.04	19.30	109.4	79.91	0.73	26.43	59.64	8.50	160	374.40	0.24
38		415	27	18	18.5	35.32	20.44	21.07	25.55	14.78	15.24	1.2	41.04	18.73	109.4	79.91	0.73	25.64	57.86	8.61	160	374.40	0.23
39		430	26	18	18.5	33.24	20.44	21.07	24.12	14.83	15.29	1.2	41.04	18.79	109.4	79.91	0.73	25.72	61.48	7.97	70	163.80	0.24
40		445	25	18.5	18.5	31.28	21.07	21.07	22.78	15.34	15.34	1.2	41.04	0.00	109.4	79.91	0.73	0.00	67.35	6.88	65	198.90	0.00
41		500	25.5	18.5	18.5	32.24	21.07	21.07	23.44	15.32	15.32	1.2	41.04	0.00	109.4	79.91	0.73	0.00	65.34	7.30	45	105.30	0.00
42		515	26	18	18	33.24	20.44	20.44	24.12	14.83	14.83	1.2	41.04	0.00	109.4	79.91	0.73	0.00	61.48	7.87	45	105.30	0.00
43		530																					
44		545																					
45		600																					
46		615																					
47		630																					
48		645																					
49		700																					

9110294

		TIME	TAM	BTIN	BTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	9	3	TRB
1	AM	700	19	18	18	21.72	20.44	20.44	16.14	15.19	15.19	1.8	61.56	0.00	140.4	188.67	1.34	0.00	94.10	1.21	0	0.00	0.00
2		715	19	18	18	21.72	20.44	20.44	16.14	15.19	15.19	1.8	61.56	0.00	140.4	188.67	1.34	0.00	94.10	1.21	2	4.68	0.00
3		730	20	18	18	23.08	20.44	20.44	17.09	15.14	15.14	1.8	61.56	0.00	140.4	188.67	1.34	0.00	88.55	2.34	5	11.70	0.00
4		745	20	18.5	18.5	23.08	21.07	21.07	17.09	15.60	15.60	1.8	61.56	0.00	140.4	188.67	1.34	0.00	91.38	1.84	10	23.40	0.00
5		800	20	19	19	23.08	21.72	21.72	17.09	16.08	16.08	1.8	61.56	0.00	140.4	188.67	1.34	0.00	94.10	1.29	10	23.40	0.00
6		815	21	19	19	24.53	21.72	21.72	18.10	16.03	16.03	1.8	61.56	0.00	140.4	188.67	1.34	0.00	88.55	2.49	20	46.80	0.00
7		830	22	19.5	19.5	26.06	22.39	22.39	19.17	16.47	16.47	1.8	61.56	0.00	140.4	188.67	1.34	0.00	85.90	3.16	20	46.80	0.00
8		845	22	20	20.5	26.06	23.08	23.79	19.17	16.58	17.50	1.8	61.56	32.26	140.4	188.67	1.34	24.01	88.55	2.64	18	42.12	0.17
9		900	24	20	20.5	29.43	23.08	23.79	21.51	16.36	17.38	1.8	61.56	32.04	140.4	188.67	1.34	23.84	78.41	4.98	10	23.40	0.17
10		915	24	20	21	29.43	23.08	24.53	21.51	16.36	17.92	1.8	61.56	65.07	140.4	188.67	1.34	48.42	78.41	4.98	15	35.10	0.34
11		930	25	20.5	21	31.28	23.79	24.53	22.78	17.32	17.56	1.8	61.56	32.32	140.4	188.67	1.34	24.50	76.06	5.69	20	46.80	0.17
12		945	26	20.5	21	33.24	23.79	24.53	24.12	17.27	17.80	1.8	61.56	32.81	140.4	188.67	1.34	24.42	71.58	6.76	25	58.50	0.17
13		1000	26	20	20.5	33.24	23.08	23.79	24.12	16.75	17.27	1.8	61.56	31.83	140.4	188.67	1.34	23.68	69.43	7.05	20	46.80	0.17
14		1015	26	19.5	20.5	33.24	22.39	23.79	24.12	16.25	17.27	1.8	61.56	62.70	140.4	188.67	1.34	46.66	67.35	7.31	35	81.90	0.33
15		1030	26	19.5	20	33.24	22.39	23.08	24.12	16.25	16.75	1.8	61.56	30.37	140.4	188.67	1.34	22.98	67.35	7.31	40	93.60	0.16
16		1045	28	19.5	20	37.54	22.39	23.08	27.06	16.14	16.64	1.8	61.56	30.67	140.4	188.67	1.34	22.82	59.64	9.04	50	117.00	0.16
17		1100	30	19	20	42.39	21.72	23.08	30.36	15.55	16.53	1.8	61.56	60.02	140.4	188.67	1.34	44.67	51.23	10.59	80	187.20	0.32
18		1115	30	18.5	19.5	42.39	21.07	22.39	30.36	15.09	16.03	1.8	61.56	58.22	140.4	188.67	1.34	43.33	43.70	10.60	40	93.60	0.31
19		1130	30	19	19.5	42.39	21.72	22.39	30.36	15.55	16.03	1.8	61.56	29.55	140.4	188.67	1.34	21.99	51.23	10.59	40	93.60	0.16
20		1145	28	18	19	37.54	20.44	21.72	27.06	14.73	15.66	1.8	61.56	56.55	140.4	188.67	1.34	42.31	54.44	9.31	25	58.50	0.30
21	PM	1200	29	20	20.5	39.89	23.08	23.79	28.66	16.58	17.10	1.8	61.56	31.51	140.4	188.67	1.34	23.45	57.86	9.73	50	117.00	0.17
22		1215	32	20	20.5	47.87	23.08	23.79	34.06	16.42	16.93	1.8	61.56	31.20	140.4	188.67	1.34	23.22	48.21	11.95	20	46.80	0.17
23		1230	32	19.5	20	47.87	22.39	23.08	34.06	15.93	16.42	1.8	61.56	30.27	140.4	188.67	1.34	22.52	46.77	11.32	150	351.00	0.16
24		1245	31	19.5	20	45.05	22.39	23.08	32.16	15.38	16.47	1.8	61.56	30.37	140.4	188.67	1.34	22.60	49.70	11.26	80	187.20	0.16
25		100	29	19.5	20	39.89	22.39	23.08	28.66	16.09	16.58	1.8	61.56	30.57	140.4	188.67	1.34	22.75	56.12	9.32	65	152.10	0.16
26		115	29	19.5	20	39.89	22.39	23.08	28.66	16.09	16.58	1.8	61.56	30.57	140.4	188.67	1.34	22.75	56.12	9.62	60	140.40	0.16
27		130	28	19.5	20	37.54	22.39	23.08	27.06	16.14	16.64	1.8	61.56	30.67	140.4	188.67	1.34	22.82	59.64	9.04	50	117.00	0.16
28		145	28	19.5	20	37.54	22.39	23.08	27.06	16.14	16.64	1.8	61.56	30.67	140.4	188.67	1.34	22.82	59.64	9.04	75	175.50	0.16
29		200	29	19	19.5	39.89	21.72	22.39	28.66	15.61	16.09	1.8	61.56	29.65	140.4	188.67	1.34	22.07	54.44	9.89	50	117.00	0.16
30		215	28	20	20.5	37.54	23.08	23.79	27.06	16.64	17.15	1.8	61.56	31.62	140.4	188.67	1.34	23.53	61.48	8.89	50	117.00	0.17
31		230	27	19	19.5	35.32	21.72	22.39	25.55	15.71	16.19	1.8	61.56	29.85	140.4	188.67	1.34	22.21	61.48	8.36	40	93.60	0.16
32		245	26	19	19.5	33.24	21.72	22.39	24.12	15.76	16.25	1.8	61.56	29.95	140.4	188.67	1.34	22.29	65.34	7.53	30	70.20	0.16
33		300	26	19	19.5	33.24	21.72	22.39	24.12	15.76	16.25	1.8	61.56	29.95	140.4	188.67	1.34	22.29	65.34	7.53	25	58.50	0.16
34		315	26	19	19.5	33.24	21.72	22.39	24.12	15.76	16.25	1.8	61.56	29.95	140.4	188.67	1.34	22.29	65.34	7.53	30	70.20	0.16
35		330	26	19	19.5	33.24	21.72	22.39	24.12	15.76	16.25	1.8	61.56	29.95	140.4	188.67	1.34	22.29	65.34	7.53	30	70.20	0.16
36		345	26	19	19.5	33.24	21.72	22.39	24.12	15.76	16.25	1.8	61.56	29.95	140.4	188.67	1.34	22.29	65.34	7.53	25	58.50	0.16
37		400	26	19.5	20	33.24	22.39	23.08	24.12	16.25	16.75	1.8	61.56	30.87	140.4	188.67	1.34	22.98	67.35	7.31	20	46.80	0.16
38		415	25	19.5	20	31.28	22.39	23.08	22.78	16.30	16.81	1.8	61.56	30.38	140.4	188.67	1.34	23.05	71.58	6.36	10	23.40	0.16
39		430	25	20	20	31.28	23.08	23.08	22.78	16.81	16.81	1.8	61.56	0.00	140.4	188.67	1.34	0.00	73.79	6.05	5	11.70	0.00
40		445	24	20	20	29.43	23.08	23.08	21.51	16.86	16.86	1.8	61.56	0.00	140.4	188.67	1.34	0.00	78.41	4.98	5	11.70	0.00
41		500																					
42		515																					
43		530																					
44		545																					
45		600																					
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	BTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	T20
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830	25	22	22	31.28	26.06	26.06	22.78	18.98	18.98	1.8	61.56	0.00	109.4	106.24	0.97	0.00	83.33	4.35	10	23.40	0.00
8		845	25	22.5	22.5	31.28	26.87	26.87	22.78	19.56	19.56	1.8	61.56	0.00	109.4	106.24	0.97	0.00	85.90	3.79	10	23.40	0.00
9		900	26	22	22	33.24	26.06	26.06	24.12	18.92	18.92	1.8	61.56	0.00	109.4	106.24	0.97	0.00	78.41	5.63	10	23.40	0.00
10		915	26	22	22	33.24	26.06	26.06	24.12	18.92	18.92	1.8	61.56	0.00	109.4	106.24	0.97	0.00	78.41	5.63	40	93.60	0.00
11		930	26	22	22.5	33.24	26.06	26.87	24.12	18.92	19.50	1.8	61.56	35.94	109.4	106.24	0.97	37.01	78.41	5.63	85	198.90	0.34
12		945	27	22	22.5	35.32	26.06	26.87	25.55	18.65	19.43	1.8	61.56	35.82	109.4	106.24	0.97	36.89	73.79	6.83	60	140.40	0.34
13		1000	27	22	23	35.32	26.06	27.70	25.55	18.95	20.03	1.8	61.56	72.75	109.4	106.24	0.97	74.92	73.79	6.83	50	117.00	0.68
14		1015	28	22	22.5	37.54	26.06	26.87	27.06	18.79	19.37	1.8	61.56	35.70	109.4	106.24	0.97	36.77	69.43	7.97	90	210.60	0.34
15		1030	28	22	22.5	37.54	26.06	26.87	27.06	18.79	19.37	1.8	61.56	35.70	109.4	106.24	0.97	36.77	69.43	7.97	20	46.80	0.34
16		1045	28	22.5	23	37.54	26.87	27.70	27.06	19.37	19.97	1.8	61.56	36.81	109.4	106.24	0.97	37.90	71.58	7.64	30	70.20	0.35
17		1100	28	22.5	23	37.54	26.87	27.70	27.06	19.37	19.97	1.8	61.56	36.31	109.4	106.24	0.97	37.90	71.58	7.64	25	58.50	0.35
18		1115	29	22.5	23	39.89	26.87	27.70	28.56	19.31	19.90	1.8	61.56	36.68	109.4	106.24	0.97	37.78	67.35	8.77	30	70.20	0.35
19		1130	29	22.5	23	39.89	26.87	27.70	28.56	19.31	19.90	1.8	61.56	36.68	109.4	106.24	0.97	37.78	67.35	8.77	30	70.20	0.35
20		1145	29	22.5	23	39.89	26.87	27.70	28.66	19.31	19.90	1.8	61.56	36.68	109.4	106.24	0.97	37.78	67.35	8.77	20	46.80	0.35
21	PM	1200	30	22.5	23	42.39	26.87	27.70	30.36	19.24	19.84	1.8	61.56	36.56	109.4	106.24	0.97	37.65	63.38	9.84	50	117.00	0.34
22		1215	30	22.5	23.5	42.39	26.87	28.55	30.36	19.24	20.45	1.8	61.56	74.25	109.4	106.24	0.97	76.46	63.38	9.84	90	210.60	0.70
23		1230	31	23	23.5	45.05	27.70	28.55	32.16	19.77	20.38	1.8	61.56	37.57	109.4	106.24	0.97	38.68	61.48	10.67	180	421.20	0.35
24		1245	31	23	23.5	45.05	27.70	28.55	32.16	19.77	20.38	1.8	61.56	37.57	109.4	106.24	0.97	38.68	61.48	10.67	270	631.80	0.35
25		100	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	150	351.00	0.34
26		115	32	22	23	47.87	26.06	27.70	34.06	18.54	19.71	1.8	61.56	71.56	109.4	106.24	0.97	73.69	54.44	11.87	260	608.40	0.67
27		130	32	22	23	47.87	26.06	27.70	34.06	18.54	19.71	1.8	61.56	71.56	109.4	106.24	0.97	73.69	54.44	11.87	280	655.20	0.67
28		145	32	22.5	23	47.87	26.87	27.70	34.06	19.12	19.71	1.8	61.56	36.32	109.4	106.24	0.97	37.40	56.12	11.73	160	374.40	0.34
29		200	31	21.5	23	45.05	25.29	27.70	32.16	18.05	19.77	1.8	61.56	106.09	109.4	106.24	0.97	109.24	56.12	11.09	145	339.30	1.00
30		215	32	22.5	23	47.87	26.87	27.70	34.06	19.12	19.71	1.8	61.56	36.32	109.4	106.24	0.97	37.40	56.12	11.73	140	327.60	0.34
31		230	32	23	23.5	47.87	27.70	28.55	34.06	19.71	20.31	1.8	61.56	37.44	109.4	106.24	0.97	38.56	57.86	11.67	140	327.60	0.35
32		245	32	23	23.5	47.87	27.70	28.55	34.06	19.71	20.31	1.8	61.56	37.44	109.4	106.24	0.97	38.56	57.86	11.67	80	187.20	0.35
33		300	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	50	117.00	0.34
34		315	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	30	70.20	0.34
35		330	31	22	23	45.05	26.06	27.70	32.16	18.60	19.77	1.8	61.56	71.79	109.4	106.24	0.97	73.93	57.96	10.38	60	140.40	0.68
36		345	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	40	93.60	0.34
37		400	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	30	70.20	0.34
38		415	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.8	61.56	36.44	109.4	106.24	0.97	37.53	59.64	10.84	40	93.60	0.34
39		430	32	22	22.5	47.87	26.06	26.87	34.06	18.54	19.12	1.8	61.56	35.24	109.4	106.24	0.77	36.29	54.44	11.87	25	58.50	0.33
40		445	30	22	22.5	42.39	26.06	26.87	30.36	18.67	19.24	1.8	61.56	35.47	109.4	106.24	0.97	36.52	61.48	10.04	25	58.50	0.33
41		500	30	22	22.5	42.39	26.06	26.87	30.36	18.67	19.24	1.8	61.56	35.47	109.4	106.24	0.97	36.52	61.48	10.04	20	46.80	0.33
42		515	30	22.5	23	42.39	26.87	27.70	30.36	19.24	19.84	1.8	61.56	36.56	109.4	106.24	0.97	37.65	63.38	9.84	10	23.40	0.34
43		530	29	22	22.5	39.89	26.06	26.87	28.66	18.73	19.31	1.8	61.56	35.59	109.4	106.24	0.97	36.64	65.34	9.03	10	23.40	0.33
44		545	28	22	22	37.54	26.06	26.06	27.06	18.79	18.79	1.8	61.56	0.00	109.4	106.24	0.97	0.00	69.43	7.97	10	23.40	0.00
45		600	28	22	22	37.54	26.06	26.06	27.06	18.79	18.79	1.8	61.56	0.00	109.4	106.24	0.77	0.00	69.43	7.97	5	11.70	0.00
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAN	ESDTIN	ESDTEX	RHTAN	RHIN	RHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830	24	22	22	29.43	26.06	26.06	21.51	19.04	19.04	1.5	51.3	0.00	109.4	80.3	0.73	0.00	88.55	2.98	10	23.40	0.00
8		845	25	22	22	31.38	26.06	26.06	22.78	18.98	18.98	1.5	51.3	0.00	109.4	80.3	0.73	0.00	83.33	4.35	10	23.40	0.00
9		900	25	21	22.5	31.28	24.53	26.87	22.78	17.86	19.56	1.5	51.3	87.49	109.4	80.3	0.73	119.19	78.41	5.29	15	35.10	1.09
10		915	25	21	23	31.28	24.53	27.70	22.78	17.86	20.17	1.5	51.3	116.47	109.4	80.3	0.73	161.40	78.41	5.29	20	46.80	1.48
11		930	25	21.5	22	31.28	25.28	26.06	22.78	18.41	18.98	1.5	51.3	29.15	109.4	80.3	0.73	39.72	80.83	4.85	20	46.80	0.36
12		945	25.5	20.5	21.5	32.24	23.79	25.28	23.44	17.30	18.38	1.5	51.3	55.62	109.4	80.3	0.73	75.78	73.79	6.24	20	46.80	0.69
13		1000	27	20.5	22	35.32	23.79	26.06	25.55	17.21	18.85	1.5	51.3	84.30	109.4	80.3	0.73	114.85	67.35	7.77	65	152.10	1.05
14		1015	26.5	19.5	21	34.27	22.39	24.53	24.83	16.22	17.77	1.5	51.3	79.46	109.4	80.3	0.73	108.26	65.34	7.76	70	163.80	0.99
15		1030	27.5	20	21	36.41	23.08	24.53	26.30	16.67	17.71	1.5	51.3	53.60	109.4	80.3	0.73	73.02	63.38	8.45	100	234.00	0.67
16		1045	28	20.5	21	37.54	23.79	24.53	27.06	17.15	17.68	1.5	51.3	27.16	109.4	80.3	0.73	37.00	63.36	8.71	150	351.00	0.34
17		1100	29	20.5	21	39.83	23.79	24.53	28.66	17.10	17.62	1.5	51.3	27.07	109.4	80.3	0.73	36.88	59.64	9.60	70	163.80	0.34
18		1115	28	20	21	37.54	23.08	24.53	27.06	16.64	17.68	1.5	51.3	53.51	109.4	80.3	0.73	72.90	61.48	8.89	50	117.00	0.67
19		1130	29	20	21	39.83	23.08	24.53	28.66	16.58	17.62	1.5	51.3	53.33	109.4	80.3	0.73	72.66	57.86	9.73	50	117.00	0.66
20		1145	29	19.5	21	39.83	22.39	24.53	28.66	16.09	17.62	1.5	51.3	78.80	109.4	80.3	0.73	107.36	56.12	9.82	150	351.00	0.98
21	PM	1200	29.5	20	21	41.12	23.08	24.53	29.50	16.56	17.59	1.5	51.3	53.24	109.4	80.3	0.73	72.54	56.12	10.13	150	351.00	0.66
22		1215	30	19.5	21	42.39	22.39	24.53	30.36	16.03	17.56	1.5	51.3	78.54	109.4	80.3	0.73	107.01	52.81	10.56	120	280.80	0.56
23		1230	30	19	20.5	42.39	21.72	23.79	30.36	15.55	17.04	1.5	51.3	76.19	109.4	80.3	0.73	103.80	51.23	10.59	210	491.40	0.95
24		1245	31	19	20	45.05	21.72	23.08	32.16	15.50	16.47	1.5	51.3	49.85	109.4	80.3	0.73	67.92	48.21	11.25	230	538.20	0.62
25		100	31	18	19.5	45.05	20.44	22.39	32.16	14.59	15.98	1.5	51.3	71.46	109.4	80.3	0.73	97.36	45.37	11.17	190	444.60	0.93
26		115	31	18	19.5	45.05	20.44	22.39	32.16	14.59	15.98	1.5	51.3	71.46	109.4	80.3	0.73	97.36	45.37	11.17	240	561.60	0.83
27		130	31	17.5	19	45.05	19.82	21.72	32.16	14.15	15.50	1.5	51.3	69.32	109.4	80.3	0.73	94.44	44.01	11.10	200	468.00	0.66
28		145	31	18	19	45.05	20.44	21.72	32.16	14.59	15.50	1.5	51.3	46.91	109.4	80.3	0.73	63.91	45.37	11.17	220	514.80	0.58
29		200	31	18	19	45.05	20.44	21.72	32.16	14.59	15.50	1.5	51.3	46.91	109.4	80.3	0.73	63.91	45.37	11.17	230	538.20	0.58
30		215	30.5	17.5	19	43.70	19.82	21.72	31.24	14.17	15.53	1.5	51.3	69.43	109.4	80.3	0.73	94.60	45.37	10.83	210	491.40	0.86
31		230	31	17	18.5	45.05	19.23	21.07	32.16	13.73	15.04	1.5	51.3	67.24	109.4	80.3	0.73	91.61	42.69	11.02	180	421.20	0.84
32		245	30	18	18.5	42.39	20.44	21.07	30.36	14.64	15.09	1.5	51.3	23.18	109.4	80.3	0.73	31.57	48.21	10.58	150	351.00	0.29
33		300	31	17	18	45.05	19.23	20.44	32.16	13.73	14.59	1.5	51.3	44.15	109.4	80.3	0.73	60.14	42.69	11.02	100	234.00	0.55
34		315	30	17	18	42.39	19.23	20.44	30.36	13.77	14.64	1.5	51.3	44.29	109.4	80.3	0.73	60.34	45.37	10.51	100	234.00	0.55
35		330	32	16.5	17.5	47.87	18.66	19.82	34.06	13.27	14.10	1.5	51.3	42.68	109.4	80.3	0.73	58.15	38.97	11.39	100	234.00	0.53
36		345	30	16.5	17	42.39	18.66	19.23	30.36	13.36	13.77	1.5	51.3	21.16	109.4	80.3	0.73	28.82	44.01	10.45	85	198.90	0.26
37		400	33	16	16.5	50.87	18.10	18.66	36.08	12.83	13.23	1.5	51.3	20.32	109.4	80.3	0.73	27.69	35.57	11.66	50	117.00	0.25
38		415	32	15.5	16.5	47.87	17.55	18.66	34.06	12.49	13.27	1.5	51.3	40.17	109.4	80.3	0.73	54.72	36.67	11.12	100	234.00	0.50
39		430	31	15	16	45.05	17.03	18.10	32.16	12.16	12.92	1.5	51.3	39.09	109.4	80.3	0.73	53.26	37.80	10.59	120	280.80	0.49
40		445	31	15.5	16	45.05	17.55	18.10	32.16	12.53	12.92	1.5	51.3	19.84	109.4	80.3	0.73	27.03	38.97	10.71	80	187.20	0.25
41		500	30	15.5	16.5	42.39	17.55	18.66	30.36	12.57	13.36	1.5	51.3	40.43	109.4	80.3	0.73	55.08	41.41	10.29	75	175.50	0.50
42		515	29	14.5	15	39.83	16.52	17.03	28.66	11.87	12.24	1.5	51.3	18.80	109.4	80.3	0.73	25.61	41.41	9.68	60	140.40	0.23
43		530	27	14	15	35.32	16.02	17.03	25.55	11.59	12.32	1.5	51.3	37.28	109.4	80.3	0.73	50.78	45.37	8.75	30	70.20	0.46
44		545	26	14.5	14.5	33.24	16.52	16.52	24.12	11.99	11.99	1.5	51.3	0.00	109.4	80.3	0.73	0.00	49.70	8.31	30	70.20	0.00
45		600	26	14	14	33.24	16.02	16.02	24.12	11.63	11.63	1.5	51.3	0.00	109.4	80.3	0.73	0.00	49.21	8.30	10	23.40	0.00
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	AH	SD	S	9	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830																					
8		845																					
9		900	7	-3.5	-3.5	10.47	5.53	5.53	8.11	4.39	4.39	1.5	51.3	0.00	109.4	39.24	0.36	0.00	52.81	2.61	25	58.50	0.00
10		915	8	-3.5	-3.5	11.13	5.53	5.53	8.59	4.27	4.27	1.5	51.3	0.00	109.4	39.24	0.36	0.00	49.70	2.78	25	58.50	0.00
11		930	8	-3.5	-3	11.13	5.53	5.70	8.59	4.27	4.40	1.5	51.3	6.76	109.4	39.24	0.36	18.85	49.70	2.78	60	140.40	0.17
12		945	8	-4	-3	11.13	5.36	5.70	8.59	4.14	4.40	1.5	51.3	13.32	109.4	39.24	0.36	37.14	48.21	2.78	90	210.60	0.34
13		1000	9	-3.5	-3	11.82	5.53	5.70	9.10	4.26	4.39	1.5	51.3	6.74	109.4	39.24	0.36	18.78	46.77	2.94	65	152.10	0.17
14		1015	9	-4	-3	11.82	5.36	5.70	9.10	4.13	4.39	1.5	51.3	13.27	109.4	39.24	0.36	37.01	45.37	2.93	100	234.00	0.34
15		1030	9.5	-4	-3.5	12.19	5.36	5.53	9.36	4.12	4.25	1.5	51.3	6.52	109.4	39.24	0.36	18.19	44.01	3.00	70	163.80	0.17
16		1045	9	-4	-3.5	11.82	5.36	5.53	9.10	4.13	4.26	1.5	51.3	6.54	109.4	39.24	0.36	18.22	45.37	2.93	70	163.80	0.17
17		1100	9.5	-4	-3.5	12.19	5.36	5.53	9.36	4.12	4.25	1.5	51.3	6.52	109.4	39.24	0.36	18.19	44.01	3.00	90	210.60	0.17
18		1115	10	-4	-3.5	12.57	5.36	5.53	9.63	4.11	4.24	1.5	51.3	6.51	109.4	39.24	0.36	18.16	42.69	3.07	100	234.00	0.17
19		1130	10	-4.5	-3	12.57	5.20	5.70	9.63	3.99	4.37	1.5	51.3	13.55	109.4	39.24	0.36	54.49	41.41	3.05	75	175.50	0.50
20		1145	10	-4.5	-3	12.57	5.20	5.70	9.63	3.99	4.37	1.5	51.3	13.55	109.4	39.24	0.36	54.49	41.41	3.05	85	196.90	0.50
21	PM	1200	10	-5	-3	12.57	5.05	5.70	9.63	3.87	4.37	1.5	51.3	25.67	109.4	39.24	0.36	71.58	40.17	3.02	110	257.40	0.65
22		1215	10	-5	-3	12.57	5.05	5.70	9.63	3.87	4.37	1.5	51.3	25.67	109.4	39.24	0.36	71.58	40.17	3.02	70	163.80	0.65
23		1230	10	-5	-2	12.57	5.05	6.06	9.63	3.57	4.64	1.5	51.3	39.73	109.4	39.24	0.36	110.77	40.17	3.02	125	292.50	1.01
24		1245	10	-4.5	-2	12.57	5.20	6.06	9.63	3.99	4.64	1.5	51.3	33.60	109.4	39.24	0.36	93.68	41.41	3.05	90	210.60	0.86
25		100	10	-5	-3	12.57	5.05	5.70	9.63	3.87	4.37	1.5	51.3	25.67	109.4	39.24	0.36	71.58	40.17	3.02	240	561.60	0.65
26		115	10	-4	-3	12.57	5.36	5.70	9.63	4.11	4.37	1.5	51.3	13.23	109.4	39.24	0.36	36.88	42.69	3.07	200	468.00	0.34
27		130	11	-5	-4	13.35	5.05	5.36	10.20	3.86	4.10	1.5	51.3	12.40	109.4	39.24	0.36	34.58	37.80	3.14	150	351.00	0.32
28		145	10	-5	-4.5	12.57	5.05	5.20	9.63	3.87	3.99	1.5	51.3	6.13	109.4	39.24	0.36	17.09	40.17	3.02	250	585.00	0.16
29		200	10	-5	-4.5	12.57	5.05	5.20	9.63	3.87	3.99	1.5	51.3	6.13	109.4	39.24	0.36	17.09	40.17	3.02	260	608.40	0.16
30		215	10	-6	-5.5	12.57	4.75	4.90	9.63	3.64	3.75	1.5	51.3	5.77	109.4	39.24	0.36	16.08	37.80	2.95	160	374.40	0.15
31		230	10	-6.5	-5.5	12.57	4.61	4.90	9.63	3.53	3.75	1.5	51.3	11.36	109.4	39.24	0.36	31.68	36.67	2.92	80	187.20	0.29
32		245	10	-6.5	-6	12.57	4.61	4.75	9.63	3.53	3.64	1.5	51.3	5.59	109.4	39.24	0.36	15.60	36.67	2.92	180	421.20	0.14
33		300	10	-6.5	-6	12.57	4.61	4.75	9.63	3.53	3.64	1.5	51.3	5.59	109.4	39.24	0.36	15.60	36.67	2.92	150	351.00	0.14
34		315	11.5	-5	-4	13.77	5.05	5.36	10.50	3.85	4.09	1.5	51.3	12.38	109.4	39.24	0.36	34.52	36.67	3.20	80	187.20	0.32
35		330	12	-5	-4	14.19	5.05	5.36	10.80	3.84	4.08	1.5	51.3	12.36	109.4	39.24	0.36	34.46	35.57	3.25	100	234.00	0.31
36		345	10.5	-5.5	-3.5	12.95	4.90	5.53	9.91	3.75	4.23	1.5	51.3	24.66	109.4	39.24	0.36	69.31	37.80	3.05	50	117.00	0.63
37		400	10	-6	-4	12.57	4.75	5.36	9.63	3.64	4.11	1.5	51.3	24.16	109.4	39.24	0.36	67.36	37.80	2.95	100	234.00	0.62
38		415	10.5	-6	-5	12.95	4.75	5.05	9.91	3.64	3.86	1.5	51.3	11.69	109.4	39.24	0.36	32.60	36.67	3.01	150	351.00	0.30
39		430	11.5	-6.5	-5	13.77	4.61	5.05	10.50	3.51	3.85	1.5	51.3	17.22	109.4	39.24	0.36	48.00	33.47	3.07	100	234.00	0.44
40		445	11.5	-6	-6	13.77	4.75	4.75	10.50	3.62	3.62	1.5	51.3	0.00	109.4	39.24	0.36	0.00	34.51	3.11	50	117.00	0.00
41		500	11	-6	-6	13.35	4.75	4.75	10.20	3.63	3.63	1.5	51.3	0.00	109.4	39.24	0.36	0.00	35.57	3.06	50	117.00	0.00
42		515																					
43		530																					
44		545																					
45		600																					
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESOTIN	ESOTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TALA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830																					
8		845																					
9		900	5	-9	-9	9.27	3.96	3.96	7.24	3.09	3.09	1.5	51.3	0.00	109.4	86.86	0.79	0.00	42.69	2.27	70	163.80	0.00
10		915	5	-9	-9	9.27	3.96	3.96	7.24	3.09	3.09	1.5	51.3	0.00	109.4	86.86	0.79	0.00	42.69	2.27	100	234.00	0.00
11		930	5	-9	-8.5	9.27	3.96	4.08	7.24	3.09	3.18	1.5	51.3	4.89	109.4	86.86	0.79	6.16	42.69	2.27	100	234.00	0.06
12		945	6.5	-9.5	-9	10.16	3.84	3.96	7.89	2.98	3.07	1.5	51.3	4.72	109.4	86.86	0.79	5.95	37.80	2.39	100	234.00	0.05
13		1000	8	-9.5	-9	11.13	3.84	3.96	8.59	2.96	3.06	1.5	51.3	4.69	109.4	86.86	0.79	5.91	34.51	2.51	100	234.00	0.05
14		1015	8.5	-10	-9	11.47	3.72	3.96	8.84	2.87	3.05	1.5	51.3	9.23	109.4	86.86	0.79	11.63	32.47	2.52	120	280.80	0.11
15		1030	8.5	-11.5	-10.5	11.47	3.40	3.61	8.84	2.62	2.79	1.5	51.3	8.43	109.4	86.86	0.79	10.62	29.64	2.39	150	351.00	0.10
16		1045	9.5	-10	-9	13.19	3.72	3.96	9.36	2.86	3.04	1.5	51.3	9.20	109.4	86.86	0.79	11.59	30.56	2.59	100	234.00	0.11
17		1100	11	-10	-9	13.35	3.72	3.96	10.20	2.85	3.02	1.5	51.3	9.15	109.4	86.86	0.79	11.53	27.89	2.69	150	351.00	0.11
18		1115	13	-9.5	-8	15.08	3.84	4.21	11.44	2.91	3.19	1.5	51.3	14.27	109.4	86.86	0.79	17.97	25.46	2.86	110	257.40	0.16
19		1130	15	-10.5	-6.5	17.03	3.61	4.08	12.83	2.72	3.07	1.5	51.3	18.06	109.4	86.86	0.79	22.74	21.22	2.85	50	117.00	0.21
20		1145	17	-10	-8	19.23	3.72	4.21	14.39	2.79	3.15	1.8	61.56	22.18	109.4	86.86	0.79	27.94	19.37	3.00	70	163.80	0.26
21	PM	1200	20	-10.5	-8	23.08	3.61	4.21	17.09	2.68	3.12	1.8	61.56	27.04	109.4	86.86	0.79	34.06	15.65	3.05	250	585.00	0.31
22		1215	20.5	-10	-7.5	23.79	3.72	4.34	17.59	2.75	3.21	1.8	61.56	27.83	109.4	86.86	0.79	35.05	15.65	3.14	250	585.00	0.32
23		1230	22	-10	-8	26.06	3.72	4.21	19.17	2.74	3.09	1.8	61.56	21.81	109.4	86.86	0.79	27.47	14.29	3.19	250	585.00	0.25
24		1245	19	-10	-6	21.72	3.72	4.21	16.14	2.77	3.13	1.8	61.56	22.03	109.4	86.86	0.79	27.75	17.15	3.09	250	585.00	0.25
25		100	20	-9	-7.5	23.08	3.96	4.34	17.09	2.93	3.21	1.8	61.56	17.23	109.4	86.86	0.79	21.70	17.15	3.39	250	585.00	0.20
26		115	16.5	-10.5	-8	21.07	3.61	4.21	15.68	2.69	3.13	1.8	61.56	27.18	109.4	86.86	0.79	34.23	17.15	2.99	250	585.00	0.31
27		130	18	-9.5	-8	20.44	3.84	4.21	15.24	2.86	3.14	1.8	61.56	16.83	109.4	86.86	0.79	21.20	18.79	3.12	200	468.00	0.19
28		145	16	-10	-6	16.10	3.72	4.21	13.59	2.80	3.16	1.8	61.56	22.26	109.4	86.86	0.79	28.04	20.58	2.96	200	468.00	0.26
29		200	15	-8	-7	17.03	4.21	4.47	12.83	3.17	3.37	1.8	61.56	12.23	109.4	86.86	0.79	15.40	24.70	3.17	200	468.00	0.14
30		215	13	-9.5	-7.5	15.08	3.84	4.34	11.44	2.91	3.29	1.8	61.56	23.19	109.4	86.86	0.79	29.21	25.46	2.86	250	585.00	0.27
31		230	11	-10	-9	13.35	3.72	3.96	10.20	2.85	3.02	1.8	61.56	10.98	109.4	86.86	0.79	13.83	27.89	2.69	200	468.00	0.13
32		245	11	-9	-7.5	13.35	3.96	4.34	10.20	3.02	3.31	1.5	51.3	14.81	109.4	86.86	0.79	16.66	29.64	2.78	100	234.00	0.17
33		300	11.5	-8.5	-7.5	13.77	4.08	4.34	10.50	3.11	3.31	1.5	51.3	10.01	109.4	86.86	0.79	12.60	29.64	2.87	200	468.00	0.12
34		315	12	-9	-8	14.19	3.96	4.21	10.80	3.01	3.20	1.5	51.3	9.69	109.4	86.86	0.79	12.21	27.89	2.85	90	210.60	0.11
35		330	12	-8.5	-7	14.19	4.08	4.47	10.80	3.11	3.40	1.5	51.3	15.22	109.4	86.86	0.79	19.17	26.75	2.91	150	351.00	0.18
36		345	11.5	-9	-7	13.77	3.96	4.47	10.50	3.02	3.41	1.8	61.56	24.03	109.4	86.86	0.79	30.27	26.75	2.82	200	468.00	0.28
37		400	11.5	-9	-7	13.77	3.96	4.47	10.50	3.02	3.41	1.8	61.56	24.03	109.4	86.86	0.79	30.27	26.75	2.82	200	468.00	0.28
38		415	12	-9	-7	14.19	3.96	4.47	10.80	3.01	3.40	1.8	61.56	23.99	109.4	86.86	0.79	30.21	27.89	2.85	240	561.60	0.28
39		430	12.5	-9	-7.5	14.63	3.96	4.34	11.12	3.01	3.30	1.8	61.56	17.68	109.4	86.86	0.79	22.27	27.06	2.99	240	561.60	0.20
40		445	12	-9	-7	14.19	3.96	4.47	10.80	3.01	3.40	1.8	61.56	23.99	109.4	86.86	0.79	30.21	27.89	2.85	100	234.00	0.28
41		500	12	-9	-7.5	14.19	3.96	4.34	10.80	3.01	3.30	1.5	51.3	14.76	109.4	86.86	0.79	18.59	27.89	2.85	100	234.00	0.17
42		515	11.5	-9	-8	13.77	3.96	4.21	10.50	3.02	3.21	1.5	51.3	9.71	109.4	86.86	0.79	12.23	26.75	2.82	65	152.10	0.11
43		530	11	-9	-9	13.35	3.96	3.96	10.20	3.02	3.02	1.5	51.3	0.00	109.4	86.86	0.79	0.00	29.64	2.78	25	58.50	0.00
44		545	10.5	-9	-9	12.95	3.96	3.96	9.91	3.03	3.03	1.5	51.3	0.00	109.4	86.86	0.79	0.00	30.56	2.75	20	46.80	0.00
45		600																					
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815	23	13	13	27.70	15.08	15.08	20.31	11.05	11.05	1.5	51.3	0.00	109.4	53.46	0.49	0.00	54.44	6.87	10	23.40	0.00
7		830	23	13	13	27.70	15.08	15.08	20.31	11.05	11.05	1.5	51.3	0.00	109.4	53.46	0.49	0.00	54.44	6.87	20	46.80	0.00
8		845	23.5	13	13.5	28.55	15.08	15.54	20.90	11.04	11.38	1.5	51.3	17.48	109.4	53.46	0.49	35.76	52.81	7.12	40	93.60	0.33
9		900	24	13	14	29.43	15.08	16.02	21.51	11.02	11.71	1.5	51.3	35.43	109.4	53.46	0.49	72.51	51.23	7.35	50	117.00	0.66
10		915	24	14	14.5	29.43	16.02	16.52	21.51	11.71	12.07	1.5	51.3	18.54	109.4	53.46	0.49	37.94	54.44	7.30	50	117.00	0.35
11		930	23.5	13.5	14	28.55	15.54	16.02	20.90	11.38	11.73	1.5	51.3	18.01	109.4	53.46	0.49	36.87	54.44	7.08	50	117.00	0.34
12		945	23	12.5	13	27.70	14.63	15.08	20.31	10.72	11.05	1.5	51.3	16.98	109.4	53.46	0.49	34.75	52.81	6.90	40	93.60	0.32
13		1000	24	13	13.5	29.43	15.08	15.54	21.51	11.02	11.36	1.5	51.3	17.45	109.4	53.46	0.49	35.70	51.23	7.35	125	292.50	0.33
14		1015	25	11	12	31.28	13.35	14.19	22.78	9.72	10.33	1.5	51.3	31.27	109.4	53.46	0.49	63.99	42.69	7.65	180	421.20	0.58
15		1030	26	11	11.5	33.24	13.35	13.77	24.12	9.69	9.99	1.5	51.3	15.35	109.4	53.46	0.49	31.40	40.17	7.99	180	421.20	0.29
16		1045	26	11	12	33.24	13.35	14.19	24.12	9.69	10.30	1.5	51.3	31.16	109.4	53.46	0.49	63.77	40.17	7.99	180	421.20	0.58
17		1100	27	11.5	12	35.32	13.77	14.19	25.55	9.56	10.26	1.5	51.3	15.77	109.4	53.46	0.49	32.26	38.97	8.40	200	468.00	0.29
18		1115	28	11	12	37.54	13.35	14.19	27.06	9.53	10.23	1.5	51.3	30.96	109.4	53.46	0.49	63.35	35.57	8.60	250	585.00	0.58
19		1130	28	11	12	37.54	13.35	14.19	27.06	9.63	10.23	1.5	51.3	30.96	109.4	53.46	0.49	63.35	35.57	8.60	260	608.40	0.58
20		1145	28.5	11	12	38.70	13.35	14.19	27.85	9.61	10.21	1.5	51.3	30.91	109.4	53.46	0.49	63.25	34.51	8.75	360	608.40	0.58
21	PM	1200	28.5	11	11.5	38.70	13.35	13.77	27.85	9.61	9.91	1.5	51.3	15.22	109.4	53.46	0.49	31.14	34.51	6.75	200	466.00	0.38
22		1215	28.5	11	11.5	38.70	13.35	13.77	27.85	9.61	9.91	1.5	51.3	15.22	109.4	53.46	0.49	31.14	34.51	8.75	260	608.40	0.38
23		1230	28.5	11	12	38.70	13.35	14.19	27.85	9.61	10.21	1.5	51.3	30.91	109.4	53.46	0.49	63.25	34.51	8.75	210	491.40	0.58
24		1245	28.5	10	11.5	38.70	12.57	13.77	27.85	9.04	9.91	1.5	51.3	44.30	109.4	53.46	0.49	90.66	32.47	8.49	210	491.40	0.83
25		100	28	10	11	37.54	12.57	13.35	27.06	9.06	9.63	1.5	51.3	29.13	109.4	53.46	0.49	59.61	33.47	8.36	205	479.70	0.54
26		115	28	9	10	37.54	11.82	12.57	27.06	8.52	9.06	1.5	51.3	27.41	109.4	53.46	0.49	56.10	31.50	8.10	200	468.00	0.51
27		130	27	8.5	9.5	35.32	11.47	12.19	25.55	8.30	8.82	1.5	51.3	26.68	109.4	53.46	0.49	54.60	33.47	7.75	240	561.60	0.50
28		145	26	10	10.5	33.24	12.57	12.95	24.12	9.12	9.40	1.5	51.3	14.44	109.4	53.46	0.49	29.55	37.80	7.82	100	234.00	0.27
29		200	24	11	11.5	29.43	13.35	13.77	21.51	9.76	10.06	1.5	51.3	15.45	109.4	53.46	0.49	31.61	45.37	7.30	100	234.00	0.29
30		215	24	10	11	29.43	12.57	13.35	21.51	9.18	9.76	1.5	51.3	29.52	109.4	53.46	0.49	60.42	42.69	7.20	80	187.20	0.55
31		230	25	10.5	11	31.28	12.95	13.35	22.78	9.43	9.72	1.5	51.3	14.94	109.4	53.46	0.49	30.56	41.41	7.59	140	327.60	0.28
32		245	26	10	10.5	33.24	12.57	12.95	24.12	9.12	9.40	1.5	51.3	14.44	109.4	53.46	0.49	29.55	37.80	7.82	200	468.00	0.27
33		300	26	10	11	33.24	12.57	13.35	24.12	9.12	9.69	1.5	51.3	29.33	109.4	53.46	0.49	60.01	37.80	7.82	145	339.30	0.55
34		315	26	10.5	11	33.24	12.95	13.35	24.12	9.40	9.69	1.5	51.3	14.89	109.4	53.46	0.49	30.46	38.97	7.91	90	210.60	0.28
35		330	26	11	11.5	33.24	13.35	13.77	24.12	9.69	9.99	1.5	51.3	15.35	109.4	53.46	0.49	31.40	40.17	7.99	140	327.60	0.29
36		345	26	11.5	12	33.24	13.77	14.19	24.12	9.99	10.30	1.5	51.3	15.82	109.4	53.46	0.49	32.37	41.41	8.06	140	327.60	0.30
37		400	25	11.5	12	31.28	13.77	14.19	22.78	10.02	10.33	1.5	51.3	15.87	109.4	53.46	0.49	32.48	44.01	7.71	140	327.60	0.30
38		415	24	12	12.5	29.43	14.19	14.63	21.51	10.37	10.69	1.5	51.3	16.42	109.4	53.46	0.49	33.60	48.21	7.35	130	304.20	0.31
39		430	25	12	12.5	31.28	14.19	14.63	22.78	10.33	10.65	1.5	51.3	16.36	109.4	53.46	0.49	33.48	45.37	7.75	100	234.00	0.31
40		445	25	12.5	13	31.28	14.63	15.08	22.78	10.65	10.98	1.5	51.3	16.87	109.4	53.46	0.49	34.52	46.77	7.79	100	234.00	0.32
41		500	25	12	12.5	31.28	14.19	14.63	22.78	10.33	10.65	1.5	51.3	16.36	109.4	53.46	0.49	33.48	45.37	7.75	100	234.00	0.31
42		515	24.5	12	12.5	30.34	14.19	14.63	22.13	10.35	10.67	1.5	51.3	16.39	109.4	53.46	0.49	33.54	46.77	7.55	60	140.40	0.31
43		530	23	12	12.5	27.70	14.19	14.63	20.31	10.40	10.72	1.5	51.3	16.47	109.4	53.46	0.49	33.71	51.23	6.92	40	93.60	0.31
44		545	23	12	12	27.70	14.19	14.19	20.31	10.40	10.40	1.5	51.3	0.00	109.4	53.46	0.49	0.00	51.23	6.92	30	70.20	0.00
45		600	22.5	12	12	26.87	14.19	14.19	19.73	10.42	10.42	1.5	51.3	0.00	109.4	53.46	0.49	0.00	52.81	6.70	10	23.40	0.00
46		615																					
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830																					
8		845	22	19	19	26.06	21.72	21.72	19.17	15.98	15.98	1.5	51.3	0.00	109.4	91.02	0.83	0.00	83.33	3.62	25	58.50	0.00
9		900	22.5	19.5	19.5	26.87	22.39	22.39	19.73	16.44	16.44	1.5	51.3	0.00	109.4	91.02	0.83	0.00	83.33	3.73	45	105.30	0.00
10		915	25	20	20.5	31.28	23.08	23.79	22.78	16.81	17.32	1.5	51.3	26.61	109.4	91.02	0.83	31.99	73.79	6.05	30	70.20	0.29
11		930	25.5	20.5	21	32.24	23.79	24.53	23.44	17.30	17.83	1.5	51.3	27.39	109.4	91.02	0.83	32.92	73.79	6.24	40	93.60	0.30
12		945	27	20.5	21	35.32	23.79	24.53	25.55	17.21	17.74	1.5	51.3	27.25	109.4	91.02	0.83	32.75	67.35	7.77	40	93.60	0.30
13		1000	277	20.5	21	35.32	23.79	24.53	25.55	17.21	17.74	1.5	51.3	27.25	109.4	91.02	0.83	32.75	67.35	7.77	35	81.90	0.30
14		1015	28	21	21.5	37.54	24.53	25.28	27.06	17.68	18.23	1.5	51.3	28.00	109.4	91.02	0.83	33.65	65.34	8.50	100	234.00	0.31
15		1030	29	21	21.5	39.89	24.53	25.28	28.66	17.62	18.17	1.5	51.3	27.91	109.4	91.02	0.83	33.54	61.48	9.45	50	117.00	0.31
16		1045	29	20.5	21	39.89	23.79	24.53	28.66	17.10	17.62	1.5	51.3	27.07	109.4	91.02	0.83	32.54	59.64	9.60	60	140.40	0.30
17		1100	29.5	21	21.5	41.12	24.53	25.28	29.50	17.59	18.14	1.5	51.3	27.66	109.4	91.02	0.83	33.49	59.64	9.90	120	280.80	0.31
18		1115	27	20	20.5	35.32	23.08	23.79	25.55	16.69	17.21	1.5	51.3	26.43	109.4	91.02	0.83	31.77	65.34	8.00	60	140.40	0.29
19		1130	28	20	21	37.54	23.08	24.53	27.06	16.64	17.68	1.5	51.3	53.51	109.4	91.02	0.83	64.31	61.48	8.89	65	152.10	0.59
20		1145	29.5	20	21	41.12	23.08	24.53	29.50	16.56	17.59	1.5	51.3	53.24	109.4	91.02	0.83	63.99	56.12	10.13	100	234.00	0.56
21	PM	1200	28.5	20	20.5	38.70	23.08	23.79	27.85	16.61	17.12	1.5	51.3	26.30	109.4	91.02	0.83	31.61	59.64	9.31	160	374.40	0.29
22		1215	28	15	17	37.54	17.03	19.23	27.06	12.28	15.06	1.5	51.3	81.44	109.4	91.02	0.83	97.89	45.37	9.30	200	468.00	0.89
23		1230	29	15.5	17.5	39.89	17.55	19.82	28.66	12.61	14.24	1.5	51.3	83.67	109.4	91.02	0.83	100.57	44.01	9.83	150	351.00	0.92
24		1245	31	15.5	17.5	45.05	17.55	19.82	32.16	12.53	14.15	1.5	51.3	85.12	109.4	91.02	0.83	99.91	39.97	10.71	230	538.20	0.91
25		100	31	17	18	45.05	19.23	20.44	32.16	13.73	14.59	1.5	51.3	44.15	109.4	91.02	0.83	53.06	42.69	11.02	220	514.80	0.49
26		115	29	18	19.5	39.89	20.44	22.39	28.66	14.68	16.09	1.5	51.3	71.93	109.4	91.02	0.83	86.46	51.23	9.97	120	280.80	0.79
27		130	29	18.5	20.5	39.89	21.07	23.79	28.66	15.14	17.10	1.5	51.3	100.41	109.4	91.02	0.83	120.69	52.81	9.94	220	514.80	1.10
28		145	29	18.5	20.5	39.89	21.07	23.79	28.66	15.14	17.10	1.5	51.3	100.41	109.4	91.02	0.83	120.69	52.81	9.94	160	374.40	1.10
29		200	31	18	20	45.05	20.44	23.08	32.16	14.59	16.47	1.5	51.3	96.77	109.4	91.02	0.83	116.31	45.37	11.17	200	468.00	1.06
30		215	33	17	20	50.87	19.23	23.08	36.08	13.64	16.37	1.5	51.3	139.99	109.4	91.02	0.83	169.26	37.80	11.36	240	561.60	1.54
31		230	33	16.5	18.5	50.87	18.66	21.07	36.08	13.23	14.94	1.5	51.3	87.75	109.4	91.02	0.83	105.47	36.67	11.81	70	163.80	0.96
32		245	34	16	18	54.06	18.10	20.44	38.21	12.79	14.45	1.5	51.3	84.85	109.4	91.02	0.83	101.98	33.47	12.04	50	117.00	0.93
33		300	33	17	18	50.87	19.23	20.44	36.08	13.64	14.49	1.5	51.3	43.66	109.4	91.02	0.83	52.71	37.80	11.96	130	304.20	0.48
34		315	32	16.5	18	47.87	18.66	20.44	34.06	13.37	14.54	1.5	51.3	65.02	109.4	91.02	0.83	78.15	39.97	11.39	150	351.00	0.71
35		330	31	17.5	18	45.05	19.82	20.44	32.16	14.15	14.59	1.5	51.3	22.41	109.4	91.02	0.83	26.93	44.01	11.10	110	257.40	0.25
36		345	32	18	19	47.87	20.44	21.72	34.06	14.54	15.45	1.5	51.3	46.76	109.4	91.02	0.83	56.20	42.69	11.71	150	351.00	0.51
37		400	32	17	18.5	47.87	19.23	21.07	34.06	13.68	14.99	1.5	51.3	67.02	109.4	91.02	0.83	80.56	40.17	11.51	180	421.20	0.74
38		415	33	18	19.5	50.87	20.44	22.39	36.08	14.49	15.88	1.5	51.3	70.99	109.4	91.02	0.83	85.33	40.17	12.23	100	234.00	0.79
39		430	33	18.5	19.5	50.87	21.07	22.39	36.08	14.94	15.88	1.5	51.3	48.04	109.4	91.02	0.83	57.75	41.41	12.34	120	280.80	0.53
40		445	32.5	18	19.5	49.35	20.44	22.39	35.05	14.52	15.90	1.5	51.3	71.11	109.4	91.02	0.83	85.47	41.41	11.97	25	58.50	0.78
41		500	31	18.5	20	45.05	21.07	23.08	32.16	15.04	16.47	1.5	51.3	73.67	109.4	91.02	0.83	88.54	46.77	11.21	25	58.50	0.81
42		515	31	19	20	45.05	21.72	23.08	32.16	15.50	16.47	1.5	51.3	49.85	109.4	91.02	0.83	59.92	48.21	11.25	25	58.50	0.55
43		530	30	19	20	42.39	21.72	23.08	30.36	15.55	16.53	1.5	51.3	50.02	109.4	91.02	0.83	60.12	51.23	10.59	40	93.60	0.55
44		545	29	20	20	39.89	23.08	23.08	28.66	16.58	16.58	1.5	51.3	0.00	109.4	91.02	0.83	0.00	57.86	9.73	40	93.60	0.00
45		600	29	20	20	39.89	23.08	23.08	28.66	16.58	16.58	1.5	51.3	0.00	109.4	91.02	0.83	0.00	57.86	9.73	40	93.60	0.00
46		615																					
47		630																					
48		645																					
49		700																					

SO53986

		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830																					
8		845	29.5	24.5	24.5	41.12	30.34	30.34	29.50	21.77	21.77	1.5	51.3	0.00	109.4	55.96	0.51	0.00	73.79	7.95	25	58.50	0.00
9		900	30	24	24	42.39	29.43	29.43	30.36	21.08	21.08	1.5	51.3	0.00	109.4	55.96	0.51	0.00	69.43	9.00	45	105.30	0.00
10		915	30.5	24	24.5	43.70	29.43	30.34	31.24	21.04	21.69	1.5	51.3	33.32	109.4	55.96	0.51	65.15	67.35	9.61	30	70.20	0.60
11		930	31	24	24.5	45.05	29.43	30.34	32.16	21.01	21.66	1.5	51.3	33.27	109.4	55.96	0.51	65.04	65.34	10.20	40	93.60	0.59
12		945	31	24	24.5	45.05	29.43	30.34	32.16	21.01	21.66	1.5	51.3	33.27	109.4	55.96	0.51	65.04	65.34	10.20	40	93.60	0.59
13		1000	30.5	24	24.5	43.70	29.43	30.34	31.24	21.04	21.69	1.5	51.3	33.32	109.4	55.96	0.51	65.15	67.35	9.61	35	81.90	0.60
14		1015	32	23.5	24	47.87	28.55	29.43	34.06	20.31	20.94	1.5	51.3	32.17	109.4	55.96	0.51	62.89	59.64	11.52	100	234.00	0.57
15		1030	32	23.5	24	47.87	28.55	29.43	34.06	20.31	20.94	1.5	51.3	32.17	109.4	55.96	0.51	62.89	59.64	11.52	50	117.00	0.57
16		1045	33	23	23.5	50.87	27.70	28.55	36.08	19.64	20.25	1.5	51.3	31.10	109.4	55.96	0.51	60.80	54.44	12.62	60	140.40	0.56
17		1100	32.5	22.5	23.5	49.35	26.87	28.55	35.05	19.08	20.28	1.5	51.3	61.37	109.4	55.96	0.51	119.98	54.44	12.24	120	280.80	1.10
18		1115	33	22.5	23	50.87	26.87	27.70	36.08	19.05	19.64	1.5	51.3	30.17	109.4	55.96	0.51	58.98	52.81	12.68	60	140.40	0.54
19		1130	33	23	24	50.87	27.70	29.43	36.08	19.64	20.87	1.5	51.3	63.16	109.4	55.96	0.51	123.48	54.44	12.62	65	152.10	1.13
20		1145	33	23.5	24	50.87	28.55	29.43	36.08	20.25	20.87	1.5	51.3	32.06	109.4	55.96	0.51	62.68	56.12	12.53	100	234.00	0.57
21	PM	1200	33.5	23	24	52.44	27.70	29.43	37.13	19.61	20.84	1.5	51.3	63.06	109.4	55.96	0.51	123.28	52.81	13.07	160	374.40	1.13
22		1215	33	23.5	24.5	50.87	28.55	30.34	36.08	20.25	21.52	1.5	51.3	65.11	109.4	55.96	0.51	127.29	56.12	12.53	200	468.00	1.16
23		1230	35	23.5	24.5	57.45	28.55	30.34	40.48	20.12	21.38	1.5	51.3	64.69	109.4	55.96	0.51	126.47	49.70	14.36	150	351.00	1.16
24		1245	36	23.5	24.5	61.05	28.55	30.34	42.88	20.05	21.31	1.5	51.3	64.48	109.4	55.96	0.51	126.06	46.77	15.20	230	538.20	1.15
25		100	35	24	24.5	57.45	29.43	30.34	40.48	20.74	21.38	1.5	51.3	32.84	109.4	55.96	0.51	64.19	51.23	14.35	220	514.80	0.59
26		115	35.5	23.5	25	59.22	28.55	31.28	41.66	20.08	22.00	1.5	51.3	98.38	109.4	55.96	0.51	192.33	48.21	14.73	120	280.80	1.76
27		130	36	23	24	61.05	27.70	29.43	42.88	19.45	20.67	1.5	51.3	62.55	109.4	55.96	0.51	122.28	45.37	15.13	220	514.80	1.12
28		145	35.5	23	24	59.22	27.70	29.43	41.66	19.48	20.70	1.5	51.3	62.65	109.4	55.96	0.51	122.48	46.77	14.74	160	374.40	1.12
29		200	36	23	24	61.05	27.70	29.43	42.88	19.45	20.67	1.5	51.3	62.55	109.4	55.96	0.51	122.28	45.37	15.13	200	468.00	1.12
30		215	34.5	23	23.5	55.73	27.70	28.55	39.33	19.55	20.15	1.5	51.3	30.95	109.4	55.96	0.51	60.51	49.70	13.93	240	561.60	0.55
31		230	34	22.5	23	54.06	26.87	27.70	38.21	18.99	19.58	1.5	51.3	30.07	109.4	55.96	0.51	58.79	49.70	13.52	70	163.80	0.54
32		245	35.5	22.5	23.5	59.22	26.87	28.55	41.66	18.90	20.08	1.5	51.3	60.78	109.4	55.96	0.51	118.81	45.37	14.68	50	117.00	1.09
33		300	34	22	23	54.06	26.06	27.70	38.21	18.42	19.58	1.5	51.3	59.24	109.4	55.96	0.51	115.82	48.21	13.50	130	304.20	1.06
34		315	34	22	23	54.06	26.06	27.70	38.21	18.42	19.58	1.5	51.3	59.24	109.4	55.96	0.51	115.82	48.21	13.50	150	351.00	1.06
35		330	35.5	22.5	23	59.22	26.87	27.70	41.66	18.30	19.48	1.5	51.3	29.93	109.4	55.96	0.51	58.50	45.37	14.68	110	257.40	0.53
36		345	34.5	22.5	23	55.73	26.87	27.70	39.33	18.96	19.55	1.5	51.3	30.02	109.4	55.96	0.51	58.69	48.21	13.91	150	351.00	0.54
37		400	34	22.5	23	54.06	26.87	27.70	38.21	18.99	19.58	1.5	51.3	30.07	109.4	55.96	0.51	58.79	49.70	13.52	180	421.20	0.54
38		415	35	22.5	23	57.45	26.87	27.70	40.48	18.33	19.51	1.5	51.3	29.97	109.4	55.96	0.51	58.60	46.77	14.30	100	234.00	0.54
39		430	34	23	23.5	54.06	27.70	28.55	38.21	19.58	20.18	1.5	51.3	31.00	109.4	55.96	0.51	60.60	51.23	13.51	120	280.80	0.55
40		445	32.5	22	23	49.35	26.06	27.70	35.05	18.51	19.67	1.5	51.3	59.53	109.4	55.96	0.51	116.39	52.81	12.30	25	58.50	1.06
41		500	31.5	22	22.5	46.44	26.06	26.87	33.09	18.57	19.15	1.5	51.3	29.41	109.4	55.96	0.51	57.50	56.12	11.44	25	56.50	0.53
42		515	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.5	51.3	30.37	109.4	55.96	0.51	59.37	59.64	10.84	25	58.50	0.54
43		530	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.5	51.3	30.37	109.4	55.96	0.51	59.37	59.64	10.84	40	93.60	0.54
44		545	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.5	51.3	30.37	109.4	55.96	0.51	59.37	59.64	10.84	40	93.60	0.54
45		600	31.5	23	23.5	46.44	27.70	28.55	33.09	19.74	20.35	1.5	51.3	31.25	109.4	55.96	0.51	61.10	59.64	11.18	40	93.60	0.56
46		615	32	22.5	23	47.87	26.87	27.70	34.06	19.12	19.71	1.5	51.3	30.27	109.4	55.96	0.51	59.18	56.12	11.79	35	81.90	0.54
47		630	32	23.5	23.5	47.87	28.55	28.55	34.06	20.31	20.31	1.5	51.3	0.00	109.4	55.96	0.51	0.00	59.64	11.52	35	81.90	0.00
48		645	31	23.5	23.5	45.05	28.55	28.55	32.16	20.39	20.39	1.5	51.3	0.00	109.4	55.96	0.51	0.00	63.38	10.46	30	70.20	0.00
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESDTIN	ESDTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRA	RH	SD	S	S	TRG
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815	26	24	24	33.24	29.43	29.43	24.12	21.36	21.36	1.5	51.3	0.00	109.4	95.17	0.87	0.00	86.55	3.37	20	46.80	0.00
7		830	27.5	24	24	36.41	29.43	29.43	26.30	21.25	21.25	1.5	51.3	0.00	109.4	95.17	0.87	0.00	80.83	5.64	25	56.50	0.00
8		845	27.5	24	24.5	36.41	29.43	30.34	26.30	21.25	21.91	1.5	51.3	33.66	109.4	95.17	0.87	38.69	80.83	5.64	25	58.50	0.35
9		900	29	24	24.5	39.89	29.43	30.34	28.66	21.15	21.80	1.5	51.3	33.49	109.4	95.17	0.87	38.50	73.79	7.72	30	70.20	0.35
10		915	30	24	24.5	42.39	29.43	30.34	30.36	21.08	21.73	1.5	51.3	33.33	109.4	95.17	0.87	38.37	69.43	9.00	25	56.50	0.35
11		930	30	24	24.5	42.39	29.43	30.34	30.36	21.08	21.73	1.5	51.3	33.38	109.4	95.17	0.87	38.37	69.43	9.00	20	46.80	0.35
12		945	29.5	24	24.5	41.12	29.43	30.34	29.50	21.11	21.77	1.5	51.3	33.43	109.4	95.17	0.87	38.43	71.58	8.37	25	56.50	0.35
13		1000	30	24	24.5	42.39	29.43	30.34	30.36	21.08	21.73	1.5	51.3	33.38	109.4	95.17	0.87	38.37	69.43	9.00	40	93.60	0.35
14		1015	30.5	24	24.5	43.70	29.43	30.34	31.24	21.04	21.69	1.5	51.3	33.32	109.4	95.17	0.87	38.31	67.35	9.61	40	93.60	0.35
15		1030	31	24	24.5	45.05	29.43	30.34	32.16	21.01	21.66	1.5	51.3	33.27	109.4	95.17	0.87	38.24	65.34	10.20	45	105.30	0.35
16		1045	30	24	24.5	42.39	29.43	30.34	30.36	21.08	21.73	1.5	51.3	33.39	109.4	95.17	0.87	38.37	69.43	9.00	40	93.60	0.35
17		1100	30	23.5	24	42.39	28.55	29.43	30.36	20.45	21.08	1.5	51.3	32.38	109.4	95.17	0.87	37.22	67.35	9.32	30	70.20	0.34
18		1115	31.5	24	24.5	46.44	29.43	30.34	33.09	20.98	21.62	1.5	51.3	33.21	109.4	95.17	0.87	38.18	63.38	10.78	70	163.80	0.35
19		1130	33	23.5	24.5	50.87	28.55	30.34	36.08	20.25	21.52	1.5	51.3	65.11	109.4	95.17	0.87	74.85	56.12	12.53	80	187.20	0.66
20		1145	32	23	24	47.87	27.70	29.43	34.06	19.71	20.94	1.5	51.3	63.37	109.4	95.17	0.87	72.85	57.86	11.67	35	81.90	0.67
21	PM	1200	32	23.5	24	47.87	28.55	29.43	34.06	20.31	20.94	1.5	51.3	32.17	109.4	95.17	0.87	36.98	59.64	11.52	70	163.80	0.34
22		1215	32	23.5	24	47.87	28.55	29.43	34.06	20.31	20.94	1.5	51.3	32.17	109.4	95.17	0.87	36.98	59.64	11.52	35	81.90	0.34
23		1230	32.5	23.5	24.5	49.35	28.55	30.34	35.05	20.38	21.55	1.5	51.3	65.32	109.4	95.17	0.87	74.97	57.86	12.03	175	409.50	0.69
24		1245	33.5	23	24	52.44	27.70	29.43	37.13	19.61	20.84	1.5	51.3	63.06	109.4	95.17	0.87	72.49	52.81	13.07	190	444.60	0.66
25		100	34	23.5	24	54.06	28.55	29.43	38.21	20.18	20.80	1.5	51.3	31.96	109.4	95.17	0.87	36.74	52.81	13.47	220	514.80	0.34
26		115	34	23	24	54.06	27.70	29.43	38.21	19.58	20.80	1.5	51.3	62.96	109.4	95.17	0.87	72.37	51.23	13.51	230	538.20	0.66
27		130	34.5	23	23.5	55.73	27.70	28.55	39.33	19.55	20.15	1.5	51.3	30.95	109.4	95.17	0.87	35.56	49.70	13.93	210	491.40	0.33
28		145	35	23	24	57.45	27.70	29.43	40.48	19.51	20.74	1.5	51.3	62.75	109.4	95.17	0.87	72.14	43.21	14.34	75	175.50	0.65
29		200	29.5	20.5	21	41.12	23.79	24.53	29.50	17.07	17.59	1.5	51.3	27.03	109.4	95.17	0.87	31.07	57.86	10.03	40	93.60	0.28
30		215	26	20	20.5	33.24	23.08	23.79	24.12	16.75	17.27	1.5	51.3	26.52	109.4	95.17	0.87	30.49	69.43	7.05	40	93.60	0.28
31		230	26	21.5	22	33.24	25.28	26.06	24.12	16.35	16.92	1.5	51.3	29.06	109.4	95.17	0.87	33.40	76.06	6.05	50	117.00	0.31
32		245	27	22	22.5	35.32	26.06	26.87	25.55	18.85	19.43	1.5	51.3	29.85	109.4	95.17	0.87	34.32	73.79	6.63	40	93.60	0.31
33		300	27	22.5	23	35.32	26.87	27.70	25.55	19.43	20.03	1.5	51.3	30.77	109.4	95.17	0.87	35.38	76.06	6.43	30	70.20	0.32
34		315	26.5	22	22.5	34.27	26.06	26.87	24.83	18.85	19.47	1.5	51.3	29.90	109.4	95.17	0.87	34.37	76.06	6.24	40	93.60	0.31
35		330	25.5	21.5	22	32.24	25.28	26.06	23.44	16.38	16.95	1.5	51.3	29.10	109.4	95.17	0.87	33.46	76.41	5.46	40	93.60	0.31
36		345	26	22	22.5	33.24	26.06	26.87	24.12	18.92	19.50	1.5	51.3	29.95	109.4	95.17	0.87	34.43	73.41	5.63	45	105.30	0.31
37		400	28	22.5	23	37.54	26.87	27.70	27.06	19.37	19.37	1.5	51.3	30.67	109.4	95.17	0.87	35.26	71.58	7.64	130	304.20	0.32
38		415	30	21.5	22	42.39	25.26	26.06	30.36	18.11	15.67	1.5	51.3	28.67	109.4	95.17	0.87	32.96	59.64	10.20	100	234.00	0.30
39		430	30	21	21.5	42.39	24.53	25.26	30.36	17.56	16.11	1.5	51.3	27.81	109.4	95.17	0.87	31.97	57.86	10.34	95	222.30	0.29
40		445	30	21	22	42.39	24.53	26.06	30.36	17.56	15.67	1.5	51.3	56.49	109.4	95.17	0.87	64.93	57.86	10.34	70	163.80	0.59
41		500	30.5	21.5	22	43.70	25.28	26.06	31.24	16.08	18.64	1.5	51.3	28.62	109.4	95.17	0.87	32.90	57.86	10.66	50	117.00	0.30
42		515	31	21.5	22	45.05	25.28	26.06	32.16	16.05	18.60	1.5	51.3	28.58	109.4	95.17	0.87	32.85	56.12	11.09	45	105.30	0.30
43		530	31	21	21.5	45.05	24.53	25.28	32.16	17.51	18.05	1.5	51.3	27.72	109.4	95.17	0.87	31.87	54.44	11.17	50	117.00	0.29
44		545	31	21	22	45.05	24.53	26.06	32.16	17.51	18.60	1.5	51.3	56.30	109.4	95.17	0.87	64.72	54.44	11.17	75	175.50	0.59
45		600	31	21	21	45.05	24.53	24.53	32.16	17.51	17.51	1.5	51.3	0.00	109.4	95.17	0.87	0.00	54.44	11.17	45	105.30	0.00
46		615	31	21	21	45.05	24.53	24.53	32.16	17.51	17.51	1.5	51.3	0.00	109.4	95.17	0.87	0.00	54.44	11.17	30	70.20	0.00
47		630																					
48		645																					
49		700																					

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		TIME	TAM	DTIN	DTEX	ESTAM	ESOTIN	ESOTEX	AHTAM	AHIN	AHEX	FL	FR	TR	LBAR	LB	LA	TRLA	RH	SD	S	S	TRB
1	AM	700																					
2		715																					
3		730																					
4		745																					
5		800																					
6		815																					
7		830																					
8		845	24	19.5	18.5	29.43	21.07	21.07	21.51	15.39	15.39	1.5	51.3	0.00	109.4	167.96	1.54	0.00	71.58	5.99	60	140.40	0.00
9		900	25	19	19	31.28	21.72	21.72	22.78	15.81	15.81	1.5	51.3	0.00	109.4	167.96	1.54	0.00	69.43	6.64	20	46.80	0.00
10		915	25.5	20	20	32.24	23.08	23.08	23.44	16.79	16.78	1.5	51.3	0.00	109.4	167.96	1.54	0.00	71.58	6.56	20	46.80	0.00
11		930	25.5	20.5	21	32.24	23.79	24.53	23.44	17.30	17.83	1.5	51.3	27.39	109.4	167.96	1.54	17.84	73.79	6.24	30	70.20	0.16
12		945	26	21	21.5	33.24	24.53	25.28	24.12	17.80	18.35	1.5	51.3	28.19	109.4	167.96	1.54	18.36	73.79	6.43	20	46.80	0.17
13		1000	28	21.5	22	37.54	25.28	26.06	27.06	18.23	18.79	1.5	51.3	28.96	109.4	167.96	1.54	18.80	67.35	8.25	40	93.60	0.17
14		1015	28.5	22	22.5	38.70	26.06	26.87	27.85	18.75	19.34	1.5	51.3	29.70	109.4	167.96	1.54	19.35	67.35	8.51	30	70.20	0.19
15		1030	29	22	22.5	39.99	26.06	25.87	28.66	18.73	19.31	1.5	51.3	29.65	109.4	167.96	1.54	19.32	65.34	9.03	40	93.60	0.18
16		1045	30	22	22.5	42.39	26.06	26.87	30.36	18.67	19.24	1.5	51.3	29.56	109.4	167.96	1.54	19.35	61.48	10.04	50	117.00	0.19
17		1100	30.5	22.5	23	43.70	26.87	27.70	31.24	19.21	19.60	1.5	51.3	30.42	109.4	167.96	1.54	19.81	61.48	10.35	140	327.60	0.18
18		1115	32	22.5	23	47.87	26.87	27.70	34.06	19.12	19.71	1.5	51.3	30.27	109.4	167.96	1.54	19.72	56.12	11.79	160	374.40	0.19
19		1130	32	23	23.5	47.87	27.70	28.55	34.06	19.71	20.31	1.5	51.3	31.20	109.4	167.96	1.54	20.32	57.86	11.67	210	491.40	0.19
20		1145	33	23	23.5	50.97	27.70	28.55	36.08	19.64	20.25	1.5	51.3	31.10	109.4	167.96	1.54	20.26	54.44	12.62	240	561.60	0.19
21	PM	1200	33	23	23.5	50.87	27.70	28.55	36.08	19.64	20.25	1.5	51.3	31.10	109.4	167.96	1.54	20.26	54.44	12.62	180	421.20	0.19
22		1215	34	23.5	24	54.06	28.55	29.43	38.21	20.18	20.90	1.5	51.3	31.36	109.4	167.96	1.54	20.82	52.81	13.47	180	421.20	0.19
23		1230	35	23.5	24	57.45	28.55	29.43	40.48	20.12	20.74	1.5	51.3	31.85	109.4	167.96	1.54	20.75	49.70	14.36	210	491.40	0.19
24		1245	35	23.5	24	57.45	28.55	29.43	40.48	20.12	20.74	1.5	51.3	31.85	109.4	167.96	1.54	20.75	49.70	14.55	200	468.00	0.19
25		100	35.5	24	24.5	59.22	29.43	30.34	41.66	20.70	21.34	1.5	51.3	32.78	109.4	167.96	1.54	21.35	49.70	14.81	220	514.80	0.20
26		115	36	24	25	61.05	29.43	31.28	42.88	20.67	21.97	1.5	51.3	66.47	109.4	167.96	1.54	43.30	48.21	15.24	250	585.00	0.40
27		130	36	24	25	61.05	29.43	31.28	42.88	20.67	21.97	1.5	51.3	66.47	109.4	167.96	1.54	43.30	48.21	15.24	240	561.60	0.40
28		145	36	24.5	25	61.05	30.34	31.28	42.39	21.31	21.97	1.5	51.3	33.74	109.4	167.96	1.54	21.98	49.70	15.26	250	585.00	0.20
29		200	35.5	24.5	25	59.22	30.34	31.28	41.66	21.34	22.00	1.5	51.3	33.80	109.4	167.96	1.54	22.01	51.23	14.80	210	491.40	0.20
30		215	35.5	24	25	59.22	29.43	31.28	41.66	20.70	22.00	1.5	51.3	66.58	109.4	167.96	1.54	43.37	49.70	14.91	190	444.60	0.40
31		230	34	24	24.5	54.06	29.43	30.34	38.21	20.80	21.45	1.5	51.3	32.94	109.4	167.96	1.54	21.46	54.44	13.41	240	561.60	0.20
32		245	34	24	24.5	54.06	29.43	30.34	38.21	20.80	21.45	1.5	51.3	32.94	109.4	167.96	1.54	21.46	54.44	13.41	210	491.40	0.20
33		300	34.5	24	24.5	55.73	29.43	30.34	39.33	20.77	21.41	1.5	51.3	32.89	109.4	167.96	1.54	21.42	52.81	13.89	150	351.00	0.20
34		315	33.5	23.5	24	52.44	28.55	29.43	37.13	20.21	20.84	1.5	51.3	32.01	109.4	167.96	1.54	20.85	54.44	13.01	180	421.20	0.19
35		330	33.5	23.5	24	52.44	28.55	29.43	37.13	20.21	20.84	1.5	51.3	32.01	109.4	167.96	1.54	20.85	54.44	13.01	165	386.10	0.19
36		345	32	22.5	23.5	47.87	26.87	28.55	34.06	19.12	20.31	1.5	51.3	61.47	109.4	167.96	1.54	40.04	56.12	11.79	100	234.00	0.37
37		400	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.5	51.3	30.37	109.4	167.96	1.54	19.78	59.64	10.84	100	234.00	0.18
38		415	31	22.5	23	45.05	26.87	27.70	32.16	19.18	19.77	1.5	51.3	30.37	109.4	167.96	1.54	19.78	59.64	10.84	100	234.00	0.19
39		430	31	22	22.5	45.05	26.06	26.87	32.16	18.60	19.18	1.5	51.3	29.46	109.4	167.96	1.54	19.19	57.66	10.98	40	93.60	0.18
40		445	30	22	22.5	42.39	26.06	25.87	30.36	18.67	19.24	1.5	51.3	29.56	109.4	167.96	1.54	19.25	61.48	10.04	50	117.00	0.18
41		500	30	22	22.5	42.39	26.06	26.87	30.36	18.67	19.24	1.5	51.3	29.56	109.4	167.96	1.54	19.25	61.48	10.04	40	93.60	0.18
42		515	30	22	22	42.39	26.06	26.06	30.36	18.67	18.67	1.5	51.3	0.00	109.4	167.96	1.54	0.00	61.48	10.04	40	93.60	0.00
43		530	29	22	22	39.89	26.06	26.06	28.66	18.73	18.73	1.5	51.3	0.00	109.4	167.96	1.54	0.00	65.34	9.03	30	70.20	0.00
44		545																					
45		600																					
46		615																					
47		630																					
48		645																					
49		700																					

APPENDIX E

BASIC COMPUTER PROGRAM TO SIMULATE THE DISCHARGE OF WASTEWATER TO THE TITI SHRUB SWAMP

```
10  REM  SIM MODEL TITIWWTR
20  HGR : HCOLOR= 7
25  HPLOT 0,0 TO 0,159 TO 100,159
       TO 100,0 TO 0,0
30  HPLOT 0,50 TO 100,50
32  HPLOT 0,110 TO 100,110
50  REM  SCALING FACTORS
55 DT = .1
60 T0 = 1
100 AS = .00005
110 BS = .01
120 CS = .8
130 DS = .0005
140 ES = .25
150 FS = 4
160 GS = .000015
170 HS = .07
180 IS = .5
190 JS = 5
200 KS = 10
210 LS = 1
300 KA = 2.23E - 10
305 KB = 8.49E - 12
310 KC = 1.03E - 3
315 KD = 4.32E - 5
320 KE = 2.52E - 2
325 KF = 3.52E - 2
330 KG = 4.65E - 2
335 KH = 4.21E - 2
340 KI = 2.5E - 1
345 KJ = 2.5E - 1
350 KK = 4.66E - 1
355 KL = 6.15E - 1
360 KM = 1.95E - 3
365 KN = 7.75E - 1
370 KO = 10.05
375 KP = 3.94E - 3
380 KQ = 3.32E - 3
390 KR = 5.93E - 3
450 KX = 13.36
460 KY = .668
500 QA = 4.4E4
510 QB = 45.4
520 QC = 1.9
530 QD = 3.1E3
540 QE = 4.53
550 QF = 0.13
560 QG = 1.99E5
570 QH = 338.7
580 QI = 15.8
590 QJ = 1.08
600 QK = 1.07
610 QL = 0.01
620 P = 1.67
```

```
630 R = 3.98
640 ET = 1.04
650 G = 0.21
660 Z = 3.56
670 NP = 1.57
675 NZ = 16.0
680 PP = 0.08
685 PZ = 7.0
693 TH = 805
694 AL = .12
695 JO = 1.46E6
700  REM  PLOTTING
708  REM  BIOMASS+CONTENTS-NPC
709  HCOLOR= 5
710  HPLOT T0 * T,50 - BS * QB
711  HPLOT T0 * T,110 - CS * QC
712  HPLOT T0 * T,160 - AS * QA
713  REM  LITTER+CONTENTS-NPC
714  HCOLOR= 3
715  HPLOT T0 * T,50 - ES * QE
716  HPLOT T0 * T,110 - FS * QF
717  HPLOT T0 * T,160 - DS * QD
718  REM  SOIL+CONTENTS-NPC
719  HCOLOR= 2
720  HPLOT T0 * T,50 - HS * QH
721  HPLOT T0 * T,110 - IS * QI
722  HPLOT T0 * T,160 - GS * QG
790  IF QI / AL > TH THEN X = 0
795  IF QI / AL < TH THEN X = 1
799 JR = JO / (1 + KA * QA * QH *
     QI)
800 DA = KB * QA * QH * QI * JR -
     KE * QA - KF * QA
810 DB = KC * KB * QA * QH * QI *
     JR - KG * QB
820 DC = KD * KB * QA * QH * QI *
     JR - KH * QC
830 DD = KF * QA - KI * QD - KJ *
     QD
840 DE = KG * QB - KK * QE
850 DF = KH * QC - KL * QF
860 DG = KJ * QD - KM * QG
870 DH = KK * QE + KX * QK - KC *
     KB * QA * QH * QI * JR - KR *
     QH - KP * G * QH
875  IF DH < 0 THEN DH = 0
880 DI = KL * QF - KD * KB * QA *
     QH * QI * JR + KY * QL * X -
     KQ * G * QI
881  IF DI < 0 THEN DI = 0
890 DJ = P + Z - ET - R - G
900 DK = NP + NZ - KN * R * QK -
     KX * QK
910 DL = PP + PZ - KO * R * QL -
     KY * QL * X
915  IF DL < 0 THEN DL = 0
1000 QA = QA + DA * DT
1010 QB = QB + DB * DT
```

```
1020 QC = QC + DC * DT
1030 QD = QD + DD * DT
1040 QE = QE + DE * DT
1050 QF = QF + DF * DT
1060 QG = QG + DG * DT
1070 QH = QH + DH * DT
1080 QI = QI + DI * DT
1090 QJ = QJ + DJ * DT
1100 QK = QK + DK * DT
1110 QL = QL + DL * DT
1120 T = T + DT
2000  IF T0 * T < 100 GOTO 700
2100  PRINT QA
2110  PRINT QB
2120  PRINT QC
2130  PRINT QD
2140  PRINT QE
2150  PRINT QF
2160  PRINT QG
2170  PRINT QH
2180  PRINT QI
2190  PRINT QJ
2200  PRINT QK
2210  PRINT QL
2220  PRINT KN * R * QK
2230  PRINT KO * R * QL
```

APPENDIX F

CALCULATION OF STORAGES AND FLOWS FOR THE SIMULATION MODEL OF THE TITI SHRUB SWAMP IN APALACHICOLA, FLORIDA, PRESENTED IN FIGURE 24

Appendix F. Calculations of the storages and flows for the simulation model of the titi shrub swamp in Apalachicola, Florida, presented in Figure 24.

1. <u>Aboveground Biomass, N in Biomass, P in Biomass</u>

Source:	Figure 4	Table 16		Table 22		Table 22	
	% of Area	g bio-mass/m^2	Study site g bio-mass/m^2	g N/m^2	Study site g N/m^2	g P/m^2	Study site g P/m^2
Titi swamp-titi phase	59.1	8400.5	4964.7	43.1	25.5	1.7	1.0
Titi swamp-holly phase	18.2	1266.6	230.5	7.9	1.4	0.3	0.1
Bay swamp	9.1	19072.9	1735.6	97.3	8.8	3.9	0.4
Black gum swamp	13.6	13890.7	1889.1	71.6	9.7	2.9	0.4
Total	100.0		8819.9		45.4		1.9

$$(8819.9\ g/m^2) \times (5\ kcal/g) = 4.4 \times 10^4\ kcal/m^2.$$

2. <u>Litter, N in Litter, P in Litter</u>

Source:	Figure 4	Table 15		Table 23		Table 24	
	% of Area	g dry wt litter/m^2	Study site g dry wt litter/m^2	g N/m^2	Study site g N/m^2	g P/m^2	Study site g P/m^2
Titi swamp-titi phase	59.1	750.4	443.5	4.58	2.71	0.13	0.08

Titi swamp-holly phase	18.2	511.5	93.1	5.79	1.05	0.15	0.03
Bay swamp	9.1	878.2	79.9	7.54	0.69	0.20	0.02
Black gum swamp	13.6	90.7	12.3	0.60	0.08	0.02	<0.01
Total	100.0		628.8		4.53		0.13

$$(628.8\ g/m^2) \times (5\ kcal/g) = 3.1 \times 10^3\ kcal/m^2.$$

3. Carbon in Soil, N in Soil, P in Soil

Titi Swamp - Titi Phase

Source:	Table 28	Table 28		Table 28		Table 28	
Soil Depth (cm)	Bulk Density g/cm^3	Carbon Content mg/g	g C/m^2*	N Content mg/g	g N/m^2*	P Content $\mu g/g$	g P/m^2+
0-5	0.86	97.0	4171	2.45	105.4	90.63	3.9
5-10	1.00	77.7	3885	2.06	103.0	59.00	3.0
10-15	1.30	53.2	3458	1.40	91.0	46.14	3.0
15-20	1.43	35.3	2524	0.42	30.0	45.13	3.2
Total			14038		329.4		13.1

* $(g\ soil/cm^3)(mg/g\ soil)(1 \times 10^6\ cm^3/m^3)(.05\ m)(1\ g/1 \times 10^3\ mg)$

\+ $(g\ soil/cm^3)(\mu g/g\ soil)(1 \times 10^6\ cm^3/m^3)(.05\ m)$
$(1\ g/1 \times 10^3\ mg)(1\ mg/1 \times 10^3\ \mu g)$

Titi Swamp - Holly Phase

Source:	Table 29	Table 28		Table 28		Table 28	
Soil Depth (cm)	Bulk Density g/cm^3	Carbon Content mg/g	g C/m^2*	N Content mg/g	g N/m^2*	P Content μg/g	g P/m^{2+}
0-5	0.90	69.7	3156	3.08	138.6	64.19	2.9
5-10	1.12	39.8	2229	1.69	94.6	42.62	2.4
10-15	1.17	36.6	2141	1.20	70.2	38.75	2.3
15-20	1.41	33.4	2355	0.95	67.0	37.13	2.6
Total			9881		370.4		10.2

* Same calculation as above.
\+ Same calculation as above.

Bay Swamp

Source:	Table 28	Table 28		Table 28		Table 28	
Soil Depth (cm)	Bulk Density g/cm^3	Carbon Content mg/g	g C/m^2*	N Content mg/g	g N/m^2*	P Content μg/g	g P/m^{2+}
0-5	1.02	45.5	2320	1.16	59.2	38.37	2.0
5-10	1.16	36.2	2100	0.85	49.3	27.50	1.6
10-15	1.53	27.3	2088	0.50	38.2	16.87	1.3
15-20	1.68	21.0	1764	0.36	30.2	14.63	1.2
Total			8272		176.9		6.1

* Same calculation as above.
\+ Same calculation as above.

Black gum Swamp

Source:	Table 28	Table 28		Table 28		Table 28	
Soil Depth (cm)	Bulk Density g/cm^3	Carbon Content mg/g	g C/m^2*	N Content mg/g	g N/m^2*	P Content $\mu g/g$	g P/m^{2+}
0–5	0.65	499.7	16240	3.54	115.0	180.00	5.8
5–10	0.99	368.4	18236	2.46	121.8	182.25	9.0
10–15	1.19	289.6	17231	1.90	113.0	204.00	12.1
15–20	1.24	240.5	14911	1.53	94.9	224.87	13.9
Total			66618		444.7		40.8

* Same calculation as above.
$^+$ Same calculation as above.

Total - Titi Shrub Swamp

Source:	Figure 4	Above		Above		Above	
	% of Area	g dry wt C/m^2	Study site g dry wt C/m^2	g N/m^2	Study site g N/m^2	g P/m^2	Study site g P/m^2
Titi Swamp - titi phase	59.1	14038	8296	329.4	194.7	13.1	7.7
Titi Swamp - holly phase	18.2	9881	1798	370.4	67.4	10.2	1.9
Bay swamp	9.1	8272	753	176.9	16.1	6.1	0.6
Black gum swamp	13.6	66618	9060	444.7	60.5	40.8	5.6
Total	100.0		19907		338.7		15.8

$$(19907 \text{ g C/m}^2) \times (10 \text{ kcal/g C}) = 1.99 \times 10^5 \text{ kcal/m}^2.$$

		Source
4. Surface Water		
Average high water for all sites: 1.08 m = 1.08 m^3/m^2		Table 33
5. N in Surface Water		
Without wastewater:		
Average TN	0.99 mg N/l (0.99 g N/m^3)	Table 26
Average depth	0.51 meters	Table 33
	0.50 g N/m^2	
With wastewater:		
Average TN	0.99 mg N/l (0.99 g N/m^3)	Table 26
Average depth	1.08 meters	Table 33
	1.07 g N/m^2	
6. P in Surface Water		
Without wastewater:		
Average TP	0.01 mg P/l (0.01 g P/m^3)	Table 26
Average depth	0.51 meters	Table 33
	0.01 g P/m^2	
With wastewater:		
Average TP	0.01 mg P/l (0.01 g P/m^3)	Table 26
Average depth	1.08 meters	Table 33
	0.01 g P/m^2	
7. Annual Water Budget		
Without wastewater:	$P = R + G + ET$	Table 32
	P = 1.67 m	
	R = 0.50 m	
	G = 0.13 m	
	ET = 1.04 m	
With wastewater:	$P + Z = R + G + ET$	Table 32
	P = 1.67 m	
	Z = 3.56 m [1 MGD = 1.38 x 10^6 m^3/3.88 x 10^5 m^2]	MOR's Apalachicola WWTP (9/85-7/86)
	ET = 1.04 m	Table 32
	G = 0.21 m (upper limit of deep seepage)	

$$
\begin{aligned}
R &= IN - OUT \\
&= (P + Z) - (ET + G) \\
&= (1.67\ m + 3.56\ m) - (1.04\ m + 0.21\ m) \\
&= 3.98\ m.
\end{aligned}
$$

8. N in Precipitation

Precipitation	1.67 m/yr	Table 32
AVG TN in prec.	0.94 mg N/l (0.94 g N/m^3)	Table 24
	1.57 g N/m^2 · yr	

9. P in Precipitation

Precipitation	1.67 m/yr	Table 32
AVG TP in prec.	0.05 mg P/l (0.05 g P/m^3)	Table 24
	0.08 g P/m^2 · yr	

10. N in Runoff

Without wastewater:

Runoff	0.50 m/yr	Table 32
AVG TN Sta. 6	0.83 mg N/l (0.83 g N/m^3)	Table 26
(most downstream station)	0.42 g N/m^2 · yr	

With wastewater:

Runoff	3.98 m/yr	Note 7, Appx F
AVG TN Sta. 6	0.83 mg N/l (0.83 g N/m^3)	Table 26
	3.30 g N/m^2 · yr	

11. P in Runoff

Without wastewater:

Runoff	0.50 m/yr	Table 32
AVG TP Sta. 6	0.01 mg P/l (0.01 g P/m^3)	Table 26
(most downstream station)	0.01 g P/m^2 · yr	

With wastewater:

Runoff	3.98 m/yr	Note 7, Appx F
AVG TP Sta. 6	0.01 mg P/l (0.01 g P/m^3)	Table 26
	0.04 g P/m^2 · yr	

12. N in Groundwater Flow

Without wastewater:

Groundwater flow	0.13 m/yr	Table 32
AVG TN in ground-water wells	1.33 mg N/l (1.33 g N/m^3)	Table 25
	0.17 g N/m^2 · yr	

With wastewater:

Groundwater flow	0.21 m/yr	Note 7, Appx F
AVG TN in groundwater wells	$\underline{1.33 \text{ mg N/l } (1.33 \text{ g N/m}^3)}$	Table 25
	$0.28 \text{ g N/m}^2 \cdot \text{yr}$	

13. P in Groundwater Flow

Without wastewater:

Groundwater flow	0.13 m/yr	Table 32
AVG TP in groundwater wells	$\underline{0.04 \text{ mg P/l } (0.04 \text{ g P/m}^3)}$	Table 25
	$0.01 \text{ g P/m}^2 \cdot \text{yr}$	

With wastewater:

Groundwater flow	0.21 m/yr	Note 7, Appx F
AVG TP in groundwater wells	$\underline{0.04 \text{ mg P/l } (0.04 \text{ g P/m}^3)}$	Table 25
	$0.01 \text{ g P/m}^2 \cdot \text{yr}$	

14. Solar Radiation and GPP

AVG Solar Rad., J0	$= 1.46 \times 10^6 \text{ kcal/m}^2 \cdot \text{yr}$	Mitsch 1975b
Solar rad converted as GPP, J	= 5% of J0	Odum 1971
	$= 7.3 \times 10^4 \text{ kcal/m}^2 \cdot \text{yr}$	
JR = J0 − J	$= 1.39 \times 10^6 \text{ kcal/m}^2 \cdot \text{yr}$	
AVG efficiency of GPP	= .3% x (8/12) of J0	*
	$\underline{= 2.78 \times 10^3 \text{ kcal/m}^2 \cdot \text{yr}}$	

*Mitsch (1975b) presents a value of .335% x (8/12) of J0 for cypress domes. A lower value was assumed for this low biomass (productivity) system.

15. N Uptake by Vegetation

N in biomass	$45.4 \text{ g N/m}^2 \div$	Note 1, Appx F
Aboveground biomass	$\underline{8819.9 \text{ g/m}^2}$	Note 1, Appx F
	5.15×10^{-3} g N/g biomass x	
GPP	$2.78 \times 10^3 \text{ kcal/m}^2 \cdot \text{yr} \div$	Note 14, Appx F
	$\underline{5 \text{ kcal/g}}$	
	$2.86 \text{ g N/m}^2 \cdot \text{yr}$	

16. P Uptake by Vegetation

P in Biomass	$1.9\ g\ P/m^2$ ÷	Note 1, Appx F
Aboveground Biomass	$8819.9\ g/m^2$	Note 1, Appx F
	2.15×10^{-4} g P/g biomass x	
GPP	$2.78 \times 10^3\ kcal/m^2 \cdot yr$ ÷	Note 14, Appx F
	5 kcal/g	
	$0.12\ g\ N/m^2 \cdot yr$	

17. Plant Respiration

GPP	$2.78 \times 10^3\ kcal/m^2 \cdot yr$	Note 14, Appx F
	40% of GPP	*
	$1.11 \times 10^3\ kcal/m^2 \cdot yr$	

*Mitsch (1975b) presents a value of 52% of GPP for cypress domes. Brown (1978) indicated low respiration in nutrient poor systems. A lower value was assumed for this nutrient poor system.

18. Leaf Litterfall, N in Leaf Litterfall, P in Leaf Litterfall

Source:	Figure 4	Table 19		Table 21		Table 21	
	% of Area	g dry wt. Leaf Litter-fall/m^2	Study Site g dry wt. Leaf Litter-fall/m^2	N Content mg/g	Study site $g\ N/m^2$	P Content $\mu g/g$	Study site $g\ P/m^2$
Titi swamp-titi phase	59.1	283.3	167.4	5.74	0.96	0.22	0.04
Titi swamp-holly phase	18.2	205.4	48.3	9.10	0.44	0.36	0.02
Bay Swamp	9.1	583.8	53.1	7.90	0.42	0.25	0.01
Black gum swamp	13.6	304.7	41.4	7.02	0.29	0.18	0.01
Total	100.0		310.2		2.11		0.08

$$(310.2\ g/m^2) \times (5\ kcal/g) = 1.55 \times 10^3\ kcal/m^2 \cdot yr$$

19. Litter Respiration and Litter Remaining in Soil

Leaf litterfall	1.55×10^3 kcal/m^2 · yr	Note 18, Appx F
Approx 50% of leaf litterfall remains in soil	0.50	Deghi 1977
	7.75×10^2 kcal/m^2 · yr	

20. Soil Respiration

Litter remaining in soil	7.75×10^2 kcal/m^2 · yr	Note 19, Appx F
Assume 50% of litter remains in soil	0.5	
	3.88×10^2 kcal/m^2 · yr	

21. Litter N Remaining in Soil, Litter P Remaining in Soil

Assume 100% of leaf litterfall N and P remain in soil

N deposited by leaf litterfall = 2.11 g N/m^2	Note 18 Appx F
P deposited by leaf litterfall = 0.08 g P/m^2	Note 18 Appx F

22. N in Wastewater Flow

Wastewater flow	3.56 m/yr	Note 7, Appx F
N in wastewater	4.5 mg N/1 (4.5 g N/m^3)	MORs from Apalachicola WWTP 9/85–7/86
	16.0 g N/m^2 · yr	

23. P in Wastewater Flow

Wastewater flow	3.50 m/yr	Note 7, Appx F
P in wastewater	2.0 mg/1 (2.0 g P/m^3)	MORs from Apalachicola WWTP 2/86
	7.0 g P/m^2 · yr	

24. Denitrification

Denitrification in a cypress dome receiving wastewater	2.01 g $N/m^2 \cdot yr$	Dierberg 1980

25. Movement of N out of Surface Water

Assume steady state in surface water nitrogen

$$NP + NZ - k_{14}RQ_{11} = 1.57 + 16.0 - 3.30 = 14.3 \text{ g } N/m^2 \cdot yr$$

26. P Adsorption in Soil

at steady state $PP + PZ - k_{15}RQ_{12} = 0.08 + 7.0 - 0.04 = 7.04 \text{ g } P/m^2 \cdot yr$

Source:	Figure 4		Table 28		Table 27		
	Area m^2	Volume cm^3*	Bulk Density g/cm^3+	Grams of Soil	Soil Type	Adsorption Maxima $\mu g/g$#	kg P adsorbed at Adsorption Maxima
Titi Swamp-titi phase	2.29×10^5	4.58×10^{10}	1.15	5.27×10^{10}	M	102.4	5393.4
Titi Swamp-holly phase	7.06×10^4	1.41×10^{10}	1.15	1.62×10^{10}	M	102.4	1662.8
Bay swamp	3.53×10^4	7.06×10^9	1.35	9.53×10^9	M	102.4	976.0
Blackgum swamp	5.28×10^4	1.06×10^{10}	1.02	1.08×10^{10}	O	2164.8	23317.5
Total							31349.7

* Area multiplied by 0.2 m depth.

\+ Average of 4 depth intervals.

\# Adsorption maxima. For mineral soil slope of Langmuir equation used 4(0-5) = 51.0 (Table 30), 4(15-20) = 153.8 (Table 30), average = 102.4. For organic soil EPC derived from quadratic equation substituted into Fruendich equation 5(0-5) = 2887.2 (Table 30), 5(15-20) = 1442.3 (Table 30), average = 2164.8.

31349.7 kg P/3.88 x 10^5 m^2 = 80.8 g P/m^2

Threshold = maximum adsorbed + initial storage = 80.8 g P/m^2 + 15.8 g P/m^2 (Note 3, Appendix F) = 96.6 g P/m^2.

27. <u>Percent Aluminum</u>

Source:	Table 27		Table 31	Figure 4	
	Soil Type	Depth (cm)	Tamm ex Al µg/g	% of Area	Study Site µg/g
Titi Swamp-holly phase	Mineral	0-5	556.0		
(used for all mineral soils)		15-20	925.0		
AVG			740.5	86.4	639.8
Black gum Swamp	Organic	0-5 15-20	2252.0 5700.0		
AVG			3976.0	13.6	540.7
Total					1180.5*

*1180.5 = 0.12%.

LITERATURE CITED

Allison, L. E. 1965. Organic carbon. Pages 1367-1378 in C. A. Black (ed.), Methods of soil analysis. American Society of Agronomy, Madison, Wisconsin.

American Public Health Association. 1980. Standard methods for the examination of water and wastewater, 15th ed. APHA, New York.

Anderson, J. M. 1976. An ignition method for determination of total phosphorus in lake sediments. Water Research 10:329-331.

Bache, B. W. and E. G. Williams. 1971. A phosphate sorption index for soils. Journal of Soil Science 22:289-301.

Ballard, R. and J. G. A. Fiskell. 1974. Phosphorus retention in Coastal Plain forest soils, I: relationship to soil properties. Soil Science Society of America Proceedings 38:250-255.

Barrow, N. J. 1978. The description of phosphate adsorption curves. Journal of Soil Science 29:447-462.

Barrow, N. J. and T. C. Shaw. 1975. The slow reaction between soil and anions, 2: effect of time and temperature on the decrease in phosphate concentration in the soil solution. Soil Science 119:167-177.

Bedient, P. B. 1975. Hydrologic-land use interactions in a Florida river basin. Ph.D. dissertation. University of Florida, Gainesville.

Benedict, F. F. 1975. Herbivory rates and leaf properties in four forests in Puerto Rico and Florida. Master's thesis. University of Florida, Gainesville.

Berkheiser, V. E., J. J. Street, P. S. C. Rao and T. L. Yuan. 1980. Partitioning of inorganic orthophosphate in soil-water systems. Critical Reviews in Environmental Control, CRC Press Inc., New York.

Bloom, P. R. 1981. Phosphorus adsorption by an aluminum-peat complex. Soil Science Society of America Journal 45:267-262.

Bohn, H., B. McNeal, and G. O'Connor. 1979. Soil Chemistry. A Wiley-Interscience Publication, John Wiley and Sons, New York.

Boto, K. G. and W. H. Patrick, Jr. 1978. Role of wetlands in the removal of suspended sediments. In P. E. Greeson, J. R. Clark and J. E. Clark (eds.), Wetland function and values: the state of our understanding. American Water Resources Association Tech. Pub. No. TPS 79-2, Minneapolis, Minnesota.

Boyt, F. L., S. E. Bayley, and J. Zoltek, Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. Journal of the Water Pollution Control Federation 48:789-799.

Bray, J. R. and E. Gorham. 1964. Litter production in forests of the world. Page 101-157 in J. B. Cragg (ed.), Advances in ecological research, Vol. 2. Academic Press, New York.

Bremner, J. M. 1965. Total nitrogen. Pages 1149-1176 in C. A. Black (ed.), Methods of soils analysis, Part II. American Society of Agronomy, Inc., Madison, Wisconsin.

Brezonik, P. L. 1977. Denitrification in natural waters. Progress in Water Technology 8:272-392.

Brezonik, P. L., J. R. Butner, W. F. DeBusk, and J. R. Tuschall, Jr. 1981. In W. R. Fritz and S. C. Helle (eds.), Tertiary treatment of wastewater using flow-through wetland systems. Boyle Engineering Corporation, Orlando, Florida.

Brezonik, P. L., C. D. Hendry, E. S. Edgerton, R. L. Schulze, and T. L. Crisman. 1983. Acidity, nutrients, and minerals in precipitation over Florida: deposition patterns, mechanisms, and ecological effects. EPA, Office of Research and Development, Corvallis Environmental Research Laboratory, EPA-600/3-83-004, Corvallis, Oregon.

Brinson, M. M., A. E. Lugo, and J. Brown. 1981. Primary and secondary productivity in wetlands. Annual Review of Ecology and Systematics 12:123-161.

Brown, J. L. 1978. A comparison of cypress ecosystems in the landscape of Florida. Ph.D. dissertation. University of Florida, Gainesville.

Brown, M. T., S. L. Brown, R. Costanza, E. DeBellevue, K. C. Ewel, R. Gutierrez, D. Layland, W. J. Mitsch, and M. Sell. 1975. Natural systems and carrying capacity of the Green Swamp. Final report to Florida Department of Administration, Division of State Planning, Tallahassee, Florida. Contract No. M74-30317. Center for Wetlands, University of Florida, Gainesville.

Brown, S. 1981. A comparison of the structure, primary productivity, and transpiration of cypress ecosystems in Florida. Ecological Monographs 51:403-427.

Brown S. and A. E. Lugo. 1982. A comparison of structural and functional characteristics of salt water and freshwater forested wetlands. Pages 103-130 in B. Gopal, R. E. Turner, R. G. Wetzel, and D. F. Whigham (eds.), Wetlands: ecology and management. National Institute of Ecology and International Scientific Publications, Jaipur, India.

Brown, S., S. W. Cowles, III and H. T. Odum. 1984. Metabolism and transpiration of cypress domes in north-central Florida. Pages 145-163 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University Press of Florida, Gainesville.

Brown, S., and R. van Peer. 1989. Response of pond cypress growth rates to sewage effluent application. Wetlands Ecology and Management 1(1):13-20.

Brunig, E. F. 1971. On the ecological significance of drought in the equatorial wet evergreen (rain) forests of Sarawak (Borneo). Pages 66-88 in J. R. Flenley (ed.), The water relations of Malaysian forests. Transactions of the First Aberdeen-Hull Symposium on Malaysian Ecology, Hull, England. Institute for Southeast Asian Biology, University of Aberdeen, Aberdeen, Scotland.

Buresh, R. J. and W. H. Patrick, Jr. 1978. Nitrate reduction to ammonium in anaerobic soil. Soil Science Society of America Journal 42:913-918.

Burns, L. A. 1978. Productivity, biomass and waste relations in a Florida cypress forest. Ph.D. dissertation. University of University of North Carolina, Chapel Hill.

Butner, J., and G. Bitton. 1982. Comparative survival of enteric microorganisms in freshwater wetlands. Abstract presented at ASM Annual Meeting, Atlanta, Georgia.

Carter, M. R., L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells, and T. W. Schmidt. 1973. Ecosystems analysis of the Big Cypress Swamp and estuaries. USEPA Region IV, Surveillance and Analysis Division, Atlanta. EPA-904/9-740002.

Carter, V., M. S. Bedinger, R. P. Novitzki, and W. D. Wilen. 1979. Water resources and wetlands. Pages 344-376 in P. E. Greeson, J. R. Clark, and J. E. Clark (eds.), Wetland functions and values: the state of our understanding. American Water Resources Association, Minneapolis, Minnesota.

Chan, E., T. A. Bursztynsky, N. Hantzche and Y. J. Litwin. 1982. The use of wetlands for water pollution control. USEPA, Cincinnati, Ohio. 600/2-82-036.

Chow, U. T. 1973. Handbook of applied hydrology: a compendium of water-resources technology. McGraw-Hill Book Company, New York.

Christman, R. F., W. L. Lamar, R. F. Packham, J. Shapiro, J. E. Singley, C. Steelink, J. F. J. Thomas, J. Ungar, and G. Simon. 1967. Research committee on color problems: report for 1966. Journal of the American Water Works Association 1023-1035.

Clewell, A. F. 1971. The vegetation of the Apalachicola National Forest: an ecological perspective. USDA Forest Service 38-2249.

Clewell, A. F. 1981. Natural setting and vegetation of the Florida panhandle: an account of the environments and plant communities of the Northern Florida West of the Suwannee River (Volume I and II). US Army Corps of Engineers, Mobile, Alabama DACW01-77-0104.

Clymo, R. S. 1964. The origin of auditing in Sphagnum bogs. The Bryologist 67:427-431.

Clymo, R. S. 1967. Control of cation concentrations, and in particular of pH, in Sphagnum dominated communities. Pages 273-284 in H. L. Golterman and R. S. Clymo (eds.), Chemical environment in the aquatic habitat. N. V. Woord-Hollandsche vitgevers Maatschappij, Amsterdam.

Conner, W. H. and J. W. Day, Jr. 1982. The ecology of forested wetlands in the Southeastern United States. Pages 69-87 in B. Gobal, R. E. Turner, R. G. Wetzel, and D. F. Whigham (eds.), Wetlands: ecology and management. National Institute of Ecology and International Scientific Publications, Jaipur, India.

Costanza, R. and F. H. Sklar. 1985. Articulation, accuracy and effectiveness of mathematical models: a review of freshwater wetland applications. Ecological Modeling 27:45-68.

Coultas, C. L. 1977. Soils of the Apalachicola National Forest wetlands, Part 1: titi swamps and savannahs. Soil and Crop Science Society of Florida Proceedings 36:72-77.

Coultas, C. L. 1978. Soils of the Apalachicola National Forest wetlands, Part 2: cypress and gum swamps. Soil and Crop Science Society of Florida Proceedings 37:154-159.

Coultas, C. L., A. F. Clewell, and E. M. Taylor, Jr. 1979. An aberrant toposequence of soils through a titi swamp. Soil Science Society of America Journal 43:377-383.

Cowles, S. W., III. 1975. Metabolism measurements in a cypress dome. Master's thesis. University of Florida, Gainesville.

Cox, G. W. 1976. Laboratory manual of general ecology. W. C. Brown, Co., Des Moines, Iowa.

Cutright, B. L. 1974. Hydrology of a cypress swamp, north-central Alachua County, Florida. Master's thesis. University of Florida, Gainesville.

Daniel, C. C., III. 1981. Hydrology, geology and soils of pocosins: a comparison of natural and altered systems Pages 69-108 in C. J. Richardson (ed.), Pocosin wetlands. Hutchinson Ross Publishing Co., Stroudsburg, Pennsylvania.

Davis, J. H., Jr. 1946. The peat deposits of Florida: their occurrence, development, and uses. Geological Bulletin No. 30. Florida Geological Survey.

Day, F. P., Jr. 1983. Biomass and litter accumulation in the Great Dismal Swamp. Pages 386-392 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville, Florida.

Deghi, G. S. 1977. Effect of sewage effluent application on phosphorus cycling in cypress domes. Master's thesis. University of Florida, Gainesville.

Deghi, G. S. and K. C. Ewel. 1984. Simulated effect of wastewater application on phosphorus distribution in cypress domes. Pages 102-111 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Deghi, G. S., K. C. Ewel and W. J. Mitsch. 1980. Effects of sewage effluent application or litterfall and litter decomposition in cypress swamps. Journal of Applied Ecology 17:397-408.

Dierberg, F. E. 1980. The effects of secondary sewage effluent on the water quality, nutrient cycles and mass balances, and accumulation of soil organic matter in cypress domes. Ph.D. dissertation. University of Florida, Gainesville.

Dierberg, F. E. and P. L. Brezonik. 1978. The effect of secondary sewage effluent on the surface water and groundwater quality of cypress domes. Pages 178-270 in H. T. Odum and K. C. Ewel (eds.), Cypress wetlands for water management, recycling and conservation. Fourth Annual Report to the National Science Foundation and The Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Dierberg, F. E. and P. L. Brezonik. 1983a. Tertiary treatment of municipal wastewater by cypress domes. Water Resources 17(9): 1027-1040.

Dierberg, F. E. and P. L. Brezonik. 1983b. Nitrogen and phosphorus mass balances in natural and sewage-enriched cypress domes. Journal of Applied Ecology 20:323-337.

Dierberg, F. E. and P. L. Brezonik. 1984. Nitrogen and phosphorus mass balances in a cypress dome receiving wastewater. Pages 112-118 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Dixon, K. R. 1974. A model for predicting the effects of sewage effluent on wetland ecosystems. Ph.D. dissertation. University of Michigan, Ann Arbor.

Dixon, K. R. and J. A. Kadlec. 1975. A model for predicting the effects of sewage effluent on wetland ecosystems. Publication No. 3, University of Michigan Wetlands Ecosystem Research Group, Ann Arbor.

Dohrenwend, R. E. 1977. Evapotranspiration patterns in Florida. Florida Scientist 40(2):184-192.

Dubuc, Y., P. Janneteau, R. LaBonte, C. Roy, and F. Briere. 1986. Domestic wastewater treatment by peatlands in a northern climate: a water quality study. Water Resources Bulletin 22(2):297-303.

Elder, J. F. and D. J. Cairns. 1982. Production and decomposition of forest litterfall on the Apalachicola River floodplain, Florida. USGS Water-Supply Paper 2196-B.

Ewel, K. C. 1984. Effects of fire and wastewater on understory vegetation in cypress domes. Pages 119-126 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Ewel, K. C. 1985. Effects of harvesting cypress swamps on water quality and quantity. Publication number 87, Florida Water Resources Research Center, University of Florida, Gainesville.

Ewel, K. C. and H. T. Odum. 1978. Cypress domes: nature's tertiary treatment filter. Pages 35-60 in H. T. Odum and K. C. Ewel (eds.), Cypress wetlands for water management, recycling and conservation. Fourth Annual Report to National Science Foundation and The Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Ewel, K. C., M. A. Harwell, J. R. Kelly, H. D. Grover and B. L. Benford. 1982. Evaluation of the use of natural ecosystems for wastewater treatment. ERC Report No. 15, Ecosystems Research center, Cornell University, Ithaca, New York.

Ewel, K. C., P. A. Straub and H. T. Odum. 1981. Project summary: biological adaptations by cypress swamps to treated sewage. Center for Wetlands, University of Florida, Gainesville.

Fernald, E. A. and D. J. Patton (eds.). 1984. Water resources atlas of Florida. Institute of Science and Public Affairs, Florida State University, Tallahassee.

Fetter, C. W., Jr. 1980. Applied hydrogeology. Charles E. Merrill Publishing Co., Columbus, Ohio.

Fitter, A. H. and C. D. Sutton. 1975. The use of the Fruendlich isotherm for soil phosphate sorption data. Journal of Soil Science 26:241-246.

Flohrschutz, E. W. 1978. Dwarf cypress in the Big Cypress Swamp of southwestern Florida. Master's thesis. University of Florida, Gainesville.

Fox, R. L. and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphorus requirements of soils. Soil Science Society of America Proceedings 34:902-907.

Fox, R. L. and E. J. Kamprath. 1971. Adsorption and leaching of P in acid organic soils and high organic matter sand. Soil Science Society of America Proceedings 35:154-156.

Fox, J. L., D. E. Price, and J. Allinson. 1984. Distribution of fecal coliform bacteria in and around experimental cypress domes. Pages 225-226 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Fritz, W. R. and S. C. Helle (eds.). 1981. Tertiary treatment of wastewater using flow through wetland systems. Boyle Engineering Corporation, Orlando, Florida.

Gilliland, M. W. 1973. Man's impact on the phosphorus cycle in Florida. Ph.D. dissertation. University of Florida, Gainesville, Florida.

Gorham, E. 1956. On the chemical composition of some water from the Moor House Nature Reserve. Journal of Ecology 44:375-382.

Gosselink, J. G. and R. E. Turner. 1978. The role of hydrology in freshwater wetlands ecosystems. Pages 63-78 in R. E. Good, D. F. Whigham and R. L. Simpson (eds.), Freshwater wetlands: ecological processes and management potential. Academic Press, New York.

Gurney, D. 1970. A new adsorption isotherm for phosphate in soil. Journal of Soil Science 21:72-77.

Haack, S. K. 1984. Aquatic macroinvertebrate community structure in a forested wetland: interrelationships with environmental parameters. Master's thesis. University of Florida, Gainesville, Florida.

Hall, C. A. S. and J. W. Day, Jr. 1977. Ecosystem modeling in theory and practice. John Wiley and Sons, New York.

Hammer, D. E. 1984. An engineering model of wetland/wastewater interactions. Ph.D. dissertation. University of Michigan, Ann Arbor.

Hammer, D. E. and R. H. Kadlec. 1983. Design principles for wetland treatment systems. USEPA Report No. PB 83-188-722.

Hammer, D. E. and R. H. Kadlec. 1986. A model for wetland surface water dynamics. Water Resources Research 22(13):1951-1958.

Hartland-Rowe, R. and P. B. Wright. 1975. Effects of sewage effluent on a swampland stream. International Association of Theoretical and Applied Limnology Verhandlugen 19:1575-1583.

Heimburg, K. F. 1976. Hydrology of some northcentral Florida cypress domes. Master's thesis. University of Florida, Gainesville.

Hemond, H. F. 1983. The nitrogen budget of Thoreau's Bog. Ecology 64:99-109.

Hendry, C. D. and P. L. Brezonik. 1980. Chemistry of precipitation at Gainesville, Florida. Environmental Science and Technology 14(7):843-849.

Holmes, R. N. 1977. Phosphorus cycling in an alluvial swamp forest in the North Carolina Coastal Plain. East Carolina University, Greenville, North Carolina.

Hopkinson, C. S., Jr. and J. W. Day, Jr. 1980. Modeling hydrology and eutrophication in a Louisiana swamp forest ecosystem. Environmental Management 4:325-335.

Irwin, G. A. and R. T. Kirkland. 1980. Chemical and physical characteristics of precipitation at selected sites in Florida. U.S. Geological Survey Water-Resources Investigations 80-81, Tallahassee, Florida.

Kadlec, J. A. 1987. Nutrient dynamics in wetlands. Pages 393-420 in K. R. Reddy and W. H. Smith (eds.), Aquatic plants for water treatment and resource recovery. Magnolia Publishing Inc., Orlando, Florida.

Kadlec, R. H. 1981. How natural wetlands treat wastewater. Pages 241-254 in B. Richardson (ed.), Selected proceedings of the Midwest conference on wetlands values and management. Minnesota Water Planning Board, St. Paul.

Kadlec, R. H. and J. A. Kadlec. 1979. Wetlands and water quality. Pages 436-456 in P. E. Greeson, J. R. Clark and J. E. Clark (eds.), Wetland functions and values: the state of our understanding. American Water Resources Association, Minneapolis, Minnesota.

Kadlec, R. H. and D. L. Tilton. 1979. The use of freshwater wetlands as a tertiary wastewater treatment alternative. Critical Reviews in Environmental Control 9:185-212.

Kaufman, M. I. 1972. The chemical type of water in Florida streams. Florida Bureau of Geology Map Series No. 51, Tallahassee, Florida.

Kaufman, M. I. 1975a. Generalized distribution and concentration of orthophosphate in Florida streams. Florida Bureau of Geology Maps Series No. 33, Tallahassee, Florida.

Kaufman, M. I. 1975b. Color of water in Florida streams and canals. Florida Bureau of Geology Map Series No. 35, Tallahassee, Florida.

Kelly, J. R. and M. A. Harwell. 1985. Comparisons of the processing of elements by ecosystems, I: nutrients. Pages 137-157 in P. J. Godfrey, E. R. Kaynor, S. Pelczarski, and J. Benforado (eds.), Ecological considerations in wetlands treatment of municipal wastewater. Van Nostrand Reinhold Co., New York.

Kennedy, L. R. 1982. Rainfall summary for the Northwest Florida Water Management District. Water Resources Special Report 82-3.

Khalid, R. A., R. P. Gambrell and W. H. Patrick, Jr. 1982. An overview of the utilization of wetlands for wastewater organic carbon removal. Pages 405-424 in P. M. McCaffrey, T. Beemer, and S. E. Gatewood (eds.), Progress in wetlands utilization and management. Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, Tallahassee, Florida.

Khalid, R. A., W. H. Patrick and R. D. DeLaune. 1977. Phosphorus sorption characteristics of flooded soils. Soil Science Society of America Journal 41:305-310.

Kitchens, W. M., J. M. Dean, L. H. Stevenson and J. C. Cooper. 1975. The Santee Swamp as a nutrient sink. Pages 349-366 in F. G. Howell, J. B. Gentry, and M. H. Smith (eds.), Mineral cycling in southeastern ecosystems. U.S. ERDA, Technical Information Center, Springfield, Virginia.

Knight, R. L., T. W. KcKim, and H. R. Kohl. 1987. Performance of a natural wetland treatment system for wastewater management. Journal of the Water Pollution Control Federation 59(8):746-754.

Kohl, H. R. and T. W. McKim. 1981. Nitrogen and phosphorus reduction from land application systems at the Walt Disney World Complex. Reedy Creek Utilities Report, Orlando, Florida.

Konyha, K. D., K. L. Campbell, and L. B. Baldwin. 1982. Runoff estimation from flat, high-water-table watersheds. Final Report from the Agriculture Engineering Department under contract to the Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, University of Florida, Gainesville.

Krottje, P. A., D. A. Graetz, and D. Sompongse. 1982. Nitrogen and phosphorus removal potential of wetland soils. Pages 111-124 in P. M. McCaffrey, T. Beemer, and S. E. Gatewood (eds.), Progress in wetlands utilization and management. Coordinating Council on the Restoration of the Kissimmee River Valley and Taylor Creek-Nubbin Slough Basin, Tallahassee, Florida.

Kuenzler, E. J., P. J. Mulholland, L. A. Ruley and R. P. Sniffen. 1977. Water quality in North Carolina Coastal Plain streams and effects of channelization. North Carolina Water Resources Research Institute Report No. 127, Raleigh.

LaBaugh, J. W. 1986. Wetland ecosystem studies from a hydrologic perspective. Water Resources Bulletin 22(1):1-4.

Larsen, J. A. 1982. Ecology of the northern lowland bogs and conifer forests. Academic Press, New York.

Lemlich, S. K., and K. C. Ewel. 1984. Effects of wastewater disposal on growth rates of cypress trees. Journal of Environmental Quality 13:602-604.

Lichtler, W. F., and P. N. Walker. 1974. Hydrology of the Dismal Swamp, Virginia-North Carolina. U.S. Geological Survey, Water Resources Division.

Linacre, E. T. 1976. Swamps. Pages 329-347 in J. C. Monteith (ed.), vegetation and the atmosphere, vol. 2: case studies. Academic Press, London.

Lopez-Hernandez, D., and C. P. Burnham. 1974. The covariance of phosphate sorption with other soil properties in some British and tropical soils. Journal of Soil Science 25(2):207-216.

McKim, T. W. 1982. Advanced wastewater treatment at the Walt Disney World Resort complex. Reedy Creek Utilities Report, Orlando, Florida.

Mestan, R. J. 1986. The nature of phosphorus uptake and release by organic soils under laboratory conditions. Ph.D dissertation. University of Florida, Gainesville.

Mitchell, R. 1974. Introduction to environmental microbiology. Prentice-Hall, Englewood Cliffs, New Jersey.

Mitsch, W. J. 1975a. Simulation of possible effects of sewage application, fire and harvesting on a cypress dome. Pages 276-304 in H. T. Odum and K. C. Ewel (eds.), Cypress wetlands for water management, recycling and conservation. Second Annual Report to the National Science Foundation and The Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Mitsch, W. J. 1975b. Systems analysis of nutrient disposal in cypress wetlands and lake ecosystems in Florida. Ph.D dissertation. University of Florida, Gainesville.

Mitsch, W. J. 1983. Ecological models for management of freshwater wetlands. Pages 283-310 in S. E. Jorgensen and W. J. Mitsch (eds.), Application of ecological modeling in environmental management, part B: developments in environmental modeling, 4B. Elsevier Publishing Co., Amsterdam.

Mitsch, W. J., J. W. Day, Jr., J. R. Taylor, and C. H. Madden. 1982. Models of North America freshwater wetlands. International Journal of Ecology and Environmental Science 8:109-140.

Mitsch, W. J., C. L. Dorge, and J. R. Wiemhoff. 1979. Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in Southern Illinois. Ecology 60:1116-1124.

Mitsch, W. J. and J. G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., New York.

Monk, C. D. and T. W. Brown. 1965. Ecological consideration of cypress heads in northcentral Florida. American Midland Naturalist 74:126-140.

Moore, P. D. and D. J. Bellamy. 1974. Peatlands. Springer-Verlag, New York.

Munro, D. S. 1979. Daytime energy exchange and evaporation from a wooded swamp. Water Resources Research 15(5):1259-1265.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 7:31-36.

National Oceanic and Atmospheric Administration. 1982-1986. Local climatological data, Apalachicola and Milton, Florida. National Oceanic and Atmospheric Administration. National Climatic Data Center, Asheville, North Carolina.

Nelson, D. W. and L. E. Sommers. 1972. A simplified digestion procedure for estimation of total nitrogen in soil and sediments. Journal of Environmental Quality 1:423-425.

Nessel, J. K. 1978. Distribution and dynamics of organic matter and phosphorus in a sewage enriched cypress swamp. Master's thesis. University of Florida, Gainesville.

Nessel, J. K. and S. E. Bayley. 1984. Distribution and dynamics of organic matter and phosphorus in a sewage-enriched cypress swamp. Pages 262-278 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Nessel, J. K., K. C. Ewel, and M. S. Burnett. 1982. Wastewater enrichment increases mature pond cypress growth rates. Forest Service 28:400-403.

Nichols, D. S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. Journal of the Water Pollution Control Federation 55:(5)495-505.

Nur, R. and M. Bates. 1979. The effects of pH on the aluminum, iron and calcium phosphate fractions of lake sediments. Water Research 13:813-815.

Odum, H. T. 1953. Dissolved phosphorus in Florida waters. Florida Geological Survey Report of Investigation No. 9, Tallahassee, Florida.

Odum, H. T. 1971. Environment, power, and society. Wiley Interscience, New York.

Odum, H. T. 1972. An energy circuit language for ecological and social systems: its physical basis. Pages 140-211 in B. C. Patten (ed.), Systems analysis and simulation in ecology. Academic Press, New York.

Odum, H. T. 1984. Summary: cypress swamps and their regional role. Pages 416-443 in K. C. Ewel and H. T. Odum (eds.), Cypress swamps. University of Florida Press, Gainesville.

Odum, H. T., K. C. Ewel, W. J. Mitsch, and J. W. Ordway. 1977. Recycling treated sewage through cypress wetlands in Florida. Pages 35-57 in F. M. D'Itri (ed.), Wastewater renovation and reuse. Marcel Dekker Press, New York.

Odum, H. T. and C. F. Jordan. 1970. Metabolism and evapotranspiration of some rain forest plants and soil. Chapter I-9 in H. T. Odum (ed.), A tropical rain forest. A study of irradiation and ecology at El Verde, Puerto Rico. Office of Information Services, U.S. Atomic Energy Commission, Washington, D.C.

Odum, H. T., A. Lugo, G. Cintron, and C. F. Jordon. 1970. Metabolism and evapotranspiration of some rain forest plants and soil. Chapter I-8 in H. T. Odum (ed.), A tropical rain forest. A study of irradiation and ecology at El Verde, Puerto Rico. Office of Information Services, U.S. Atomic Energy Commission, Washington, D.C.

Olsen, S. R. and F. S. Wantanabe. 1957. A method to determine a phosphorus adsorption maximum of soils as measured by the Langmuir isotherm. Soil Science Society of America Proceedings 21:144-149.

Overcash, M. R. and D. Pal. 1979. Design of land treatment systems for industrial wastes, theory and practices. University of Michigan Press, Ann Arbor, Michigan.

Parker, P. E. 1974. A dynamic ecosystem simulator. Ph.D. dissertation. University of Michigan, Ann Arbor.

Peech, M. 1965. Hydrogen-ion activity. Pages 914-926 in C. A. Black (ed.), Methods of soils analysis, Part II. American Society of Agronomy Inc., Madison, Wisconsin.

Post, D. M. and P. A. Straub. 1974. Rates of growth and nutrient concentrations of trees in cypress domes. Pages 420-444 in H. T. Odum and K. C. Ewel (eds.), Cypress wetlands for water management, recycling and conservation. First Annual Report to the National Science Foundation and The Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Post, H. A. and A. A. de la Cruz. 1977. Litterfall, litter composition, and flux of particular organic matter in a coastal plan stream. Hydrobiologia 55(3):201-208.

Rennie, D. A. and C. W. McKercher. 1959. Adsorption of phosphorus by four Saskatchewan soils. Canadian Journal of Soil Science 39:64-75.

Richardson, C. J. (ed.). 1981. Pocosin wetlands. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania.

Richardson, C. J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. Science 228:1424-1427.

Richardson, C. J. and J. A. Davis. 1987. Natural and artificial wetland ecosystems: ecological opportunities and limitations. Pages 819-854 in K. R. Reddy and W. H. Smith (eds.), Aquatic plants for water treatment and resource recovery. Magnolia Publishing Inc., Orlando, Florida.

Richardson, C. J. and D. S. Nichols. 1985. Ecological analysis of wastewater management criteria in wetland ecosystems. Pages 351-391 in P. J. Godfrey, E. R. Kaynor, S. Pelczarski, and J. Benforado (eds.), Ecological considerations in wetlands treatment of municipal wastewaters. Van Nostrand Reinhold Co., New York.

Richardson, C. J., W. A. Wentz, J. P. Chamie, J. A. Kadlec, and D. L. Tilton. 1976. Plant growth, nutrient accumulation and decomposition in a central Michigan peatland used for effluent treatment. Pages 77-117 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson (eds.), Freshwater wetlands and sewage effluent disposal. The University of Michigan, Ann Arbor.

Ryden, J. C. and J. K. Syers. 1977. Origin of the labile phosphate pool in soils. Soil Science 123:353-361.

Rykiel, E. J., Jr. 1977. The Okefenokee Swamp watershed: water balance and nutrient budgets. Ph.D. dissertation. University of Georgia, Athens.

Saunders, W. M. 1965. Phosphate retention by New Zealand soils and its relationship to free sesquioxides, organic matter, and other soil properties. New Zealand Journal of Agricultural Research 8:30-57.

Sawyer, C. N. and P. L. McCarty. 1978. Chemistry for environmental engineering, Third edition. McGraw-Hill Book Company, New York.

Saxton, K. E. and J. L. McGuinness. 1982. Evapotranspiration. In C. T. Haan, H. P. Johnson and D. L. Brakensiek (eds.), Hydrologic modeling of small watersheds. An ASAE monograph, number 5 in a series. American Society of Agriculture Engineers, St. Joseph, Michigan.

Scheffe, R. D. 1978. Estimation and prediction of summer evapotranspiration from a northern wetland. Master's thesis. University of Michigan, Ann Arbor.

Scheuerman, P. R. 1978. The effect of soluble humic substances on the retention capacity of soils toward virus. Master's thesis, University of Florida, Gainesville.

Schlesinger, W. H. 1978. Community structure, dynamics and nutrient cycling in the Okefenokee cypress swamp forest. Ecological Monographs 48:43-65.

Schmidt, W. 1978. Environmental geology series, Apalachicola sheet. Bureau of Geology, Florida Department of Natural Resources, Division of Resource Management, Tallahassee, Florida.

Singh, B. B. and J. P. Jones. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Science Society of America Journal 40:389-394.

Sinha, M. K. 1971. Organic-metallic phosphates, I: interaction of phosphorus compounds with humic substances. Plant and Soil 35:471-478.

Slack, L. J. and D. A. Goolsby. 1976. Nitrogen loads and concentrations in Florida streams. Florida Bureau of Geology Map Series No. 75, Tallahassee, Florida.

Sloey, W. E., F. L. Spangler, and C. W. Fetter, Jr. 1978. Management of freshwater wetlands for nutrient assimilation. Pages 321-340 in R. E. Good, D. F. Whigham, and R. L. Simpson (eds.), Freshwater wetlands: ecological processes and management potential. Academic Press, New York.

Smith, R. L. 1978. Ecology and field biology, second edition. Harper and Row Publishers, New York.

Soil Conservation Service. 1972. National engineering handbook, section 4, hydrology. U.S. Department of Agriculture, Washington, D.C.

Soil Conservation Service. 1975. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service. U.S. Department of Agriculture, Handbook No. 436, Washington, D.C.

Sommers, L. E. and A. L. Sutton. 1980. Use of waste materials as sources of phosphorus. Pages 514-544 in F. E. Khasawneh, E. C. Sample, and E. J. Kamprath (eds.), The role of phosphorus in agriculture. ASA, CSSA, SSSA, Madison, Wisconsin.

Sompongse, D. 1982. The role of wetland soils in nitrogen and phosphorus removal from agricultural drainage waters. Ph.D dissertation. University of Florida, Gainesville.

Spain, J. D. 1982. User's guide: basic utility programs and sample exercises. Addison Wesley Publishing Inc., Advanced Book Program/World Science Division, Reading, Massachusetts.

Straub, P. A. and D. M. Post. 1977. Rates of growth and nutrient concentrations of trees in cypress domes. Pages 271-318 in H. T. Odum and K. C. Ewel (eds.), Cypress wetlands for water management, recycling and conservation. Fourth Annual Report to the National Science Foundation and The Rockefeller Foundation. Center for Wetlands, University of Florida, Gainesville.

Stumm, W., and J. J. Morgan. 1981. Aquatic chemistry: an introduction emphasizing chemical equilibria in natural waters, second edition. A Wiley-Interscience Publication, John Wiley and Sons, New York.

Tchobanoglous, G. and G. L. Culp. 1980. Wetland systems for wastewater treatment: engineering assessment. Pages 13-42 in S. C. Reed and R. K. Bastian (eds.), Aquaculture systems for wastewater treatment: an engineering assessment. USEPA, Washington, D.C.

Thornthwaite, C. W. and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and water balance. Drexel Institute of Technology. Laboratory of Climatological Publications in Climatology 10(3):185-311.

Thurman, E. M. 1985. Organic geochemistry of natural waters. Martinus Nijhoff/Dr. W. Junk Publishers, Dordrecht.

Tuschall, J. R., P. L. Brezonik, and K. C. Ewel. 1981. Tertiary treatment of wastewater using flow-through wetland systems. Pages 558-565 in F. M. Saunders (ed.), National conference on environmental engineering. American Society of Civil Engineers, New York.

Tusneem, M. E. and W. H. Patrick, Jr. 1971. Nitrogen transformation in waterlogged soils. Bull No. 657, Louisiana State University, Department of Agronomy, Baton Rouge.

United States Environmental Protection Agency. 1980. Methods for chemical analysis of water and wastes. USEPA, Cincinnati, Ohio.

United States Environmental Protection Agency. 1983. Phase I report: freshwater wetlands for wastewater management. Environmental Impact Statement. Region IV, Atlanta. 904/9-83-107.

Veihmeyer, F. J. 1973. Evapotranspiration. Pages 11-1 through 4-38 in V. T. Chow (ed.), Handbook of applied hydrology. McGraw-Hill Book Company, New York.

Verry, E. S. 1975. Streamflow chemistry and nutrient yields from upland-peatland watersheds in Minnesota. Ecology 56(5):1149-1157.

Wellings, F. M., A. L. Lewis, C. W. Mountain, and L. V. Pierce. 1975. Demonstration of virus in groundwater after effluent discharge into soil. Applied Microbiology 29:751-757.

Wetzel, R. G. 1975. Limnology. W. B. Sanders Company, Philadelphia.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton, T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the Southeast: a community profile. U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS-81/37, Washington, D.C.

Wharton, C. H., H. T. Odum, K. C. Ewel, M. J. Duever, A. E. Lugo, R. Boyt, J. Bartholomew, E. DeBellevue, S. L. Brown, M. T. Brown, and L. C. Duever. 1977. Forested wetlands: their management and use. Division of State Planning, Tallahassee, and Center for Wetlands, University of Florida, Gainesville.

Whigham, D. F. 1982. Using freshwater wetlands for wastewater management in North America. Pages 508-514 in B. Gopal, R. E. Turner, R. G. Wetzel, and D. F. Whigham (eds.), Wetlands: ecology and management. Natural Institute of Ecology and International Scientific Publications, Jaipur, India.

Wild, A. 1950. The retention of phosphate by soil: a review. Journal of Soil Science 1:221-238.

Winchester, B. H. and T. C. Emenhiser. 1983. Dry season wastewater assimilation by a North Florida hardwood swamp. Wetlands 3:90-107.

Yarbro, L. A. 1979. Phosphorus cycling in the Creeping Swamp floodplain and exports from the Creeping Swamp watershed. Ph.D. dissertation. University of North Carolina, Chapel Hill.

Yuan, T. L. and D. E. Lucas. 1982. Retention of phosphorus by sandy soils as evaluated by adsorption isotherms. Soil and Crop Science Society of Florida 41:195-201.

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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 dissertation for the degree of Doctor of Philosophy.

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