A MIXED HARDWOOD SWAMP AS AN ALTERNATIVE TO TERTIARY WASTEWATER TREATMENT

By

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Chairman: Suzanne E. Bayley
Major Department: Environmental Engineering

A mixed hardwood swamp near Wildwood, Florida, which has recieved domestic sewage effluent for 20 years was examined to determine the effectiveness of the swamp to reprocess wastewater. After flowing through the experimental swamp, the nutrient concentration of the water was less than the concentration of nutrients in the control swamp and Lake Panasoffkee, the final receiving body. The total phosphorus level after flowing through the experimental swamp was 0.131 mg/l and in the control swamp was 0.274 mg/l. The nitrate nitrogen concentration in the experimental swamp was 0.0942 mg/l, and in the control swamp the level was 0.07 mg/l. The total phosphorous concentration was reduced by 98.0%, and the total nitrogen concentration was reduced by 89.7%. These reduction rates are similar to those obtained in an advanced wastewater treatment facility.

Water samples throughout the experimental and control swamp were examined for pathogenic bacteria. After flowing through approximately one mile of swamp, the water from the sewage effluent produced a fecal

coliform to fecal streptococci ratio well below 4.4; this indicates that the fecal contamination was not of human origin.

Growth rates for trees in the swamp receiving the sewage directly were higher (5.5 cm/20 yrs., cypress) than the growth rates in the control areas (3.87 cm/20 yrs., cypress). In addition the understory standing crop, biomass in the experimental swamp was approximately 6 times the understory biomass in the control area. The data indicate that the excess nutrients from the sewage are taken up in the experimental swamp.

The use of the swamp near Wildwood as an alternative to an advanced treatment facility represented a large monetary savings for the city. The total cost of a 0.5 mgd advanced treatment facility for the 25 year life expectancy of the plant would have been $1,984,975, or $79,399/year. This small swamp of 506 acres is therefore worth at least $79,399/year to man.

Suzanne E. Bayley
Chairman

INTRODUCTION

The City of Wildwood, Florida has been releasing secondarily treated sewage effluent into a mixed hardwood swamp for 20 years. By using the swamp as a receiving body for the sewage effluent, the city made use of a natural system to do work for them without a high expenditure of fossil fuels. During the past 25 years we have been able to subsidize urban areas with low cost fossil fuel technology which helped reduce many problems such as waste disposal and water supply. However, since fossil fuel is now more expensive it has become necessary to look for less energy intensive systems to aid urban areas. Situations such as the one at Wildwood may provide some important answers on how best to utilize resources and conserve fossil fuel. The purpose of this thesis is to explore the use of a wetlands system to process wastewater.

Recent studies conducted by Parizek and Myers (1968); Sopper and Kardos (1973) and Cluff *et al.* (1971) have indicated that spray irrigation of sewage effluent is one effective method of water recharge involving a natural system. In addition, Sagmuller and Sopper (1967) have presented data showing that spray irrigation of municipal waste caused increased growth of white spruce. This process, however, does involve some cost in elaborate transport and distribution equipment. In Florida such distribution costs can be eliminated by using a wetlands system. There are two reasons why wetlands systems are well suited for receiving large volumes of nutrient laden water: 1) the wetlands system disperses water over a large area; 2) the vegetation itself is adapted to filter nutrients from the water. Swamp systems have been reported by Carter *et al.* (1973) to have a very high productivity of 990-1170 $g/m^2 \cdot yr$. High productivity derives from the swamp's acting as a filter to trap nutrients from the water and store them in plant biomass. The high productivity and filtering function of swamps are characteristics comparable to a salt marsh (Odum, 1969). Studies done in a North Carolina salt marsh by Marshall (1970) have shown the effectiveness of nutrient uptake by marsh vegetation receiving municipal wastes. The *Spartina* biomass in the experimental marsh increased significantly in the area receiving municipal sewage. Kitchens *et al.* (1974) and Wharton (1970) report that riverfloodplain swamps functioned effectively as a nutrient sink for both urban and agricultural waste.

For a swamp to serve as a viable alternative to tertiary waste-water treatment it must remove nutrients, especially nitrogen and phosphorus from the waste. There are many mechanisms by which natural systems can remove nutrients. Ellis (1973), Stumm and Loeckie (1970), and Hayes and Phillips (1958) reported the ability of the soil to act as a chemical filter emphasizing the high rate of phosphorus absorption in soils which are high in iron and aluminum content. Nitrogen in water is not so easily removed by purely chemical processes, however denitrification has been shown to be an important natural sink for nitrogen (Godfrey, 1973; Brezonik and Lee, 1968). The dominant form of nitrogen in domestic sewage is ammonia which is readily transformed to nitrite and nitrate by the bacteria *Nitrosomonas* and *Nitrobacter* respectively. The nitrate is then readily denitrified into nitrogen gas by bacteria such as *Pseudomonas*, *Achromobactor*, and *Micrococcus* (Keeney, 1973).

The other major concern in the use of land sewage disposal is the possible public health problems created by pathogens or heavy metals in the waste. The presence of some heavy metals such as lead and mercury are known to cause disease and death in man. Other metals for example copper may cause a disturbance or death of the vegetation or other aquatic organisms. For these reasons, wastes which are high in heavy metals may be unsuitable for land disposal. However, these metals are more abundant in industrial wastes rather than the strictly domestic wastes released by Wildwood. The soil itself has been shown to be an effective physical filter for pathogens (Miller, 1973). McGauhey *et al.* (1966) estimated that in a moderately permeable soil the bacteria are retained in the top 5 cm and therefore do not reach the groundwater. Virus can present a problem particularly if the groundwater is near the surface. Wellings *et al.* (1974) has found viruses to survive after 1.5 m of percolation through sand. But Duboise *et al.* (1974) reported better virus absorption to soil when the sewage was applied intermittently. Others (Drewry and Eliassen, 1968) have found that the majority of the viruses are removed after filtering through 1.3 m of soil, using soil columns in the laboratory. A more complete review of the absorptive properties of virus was done by Bitton (1975).

Description of the Study Area

The city of Wildwood has a population of 2,500 and has been releasing about 0.15 mgd of treated effluent into the wetlands area for 20 yr. The secondary effluent meanders through 590.9 ha (1,460 acres) of swamp before reaching moderately eutrophic Lake Panasoffkee. The present sewage treatment facilities include a trickling filter plant with a capacity of 0.25 mgd. However, the plant does not operate properly and the effluent receives little more than primary treatment. Presently under construction is a new activated sludge plant with a 0.5 mgd capacity that will maintain a higher quality of secondary treatment.

The Florida Department of Environmental Regulation became concerned that pollutants from the sewage effluent might reach Lake Panasoffkee causing the accelerated eutrophication of the lake. If this were the case then Wildwood would be required to construct and operate a tertiary treatment facility. This study is an analysis of the swamp disposal of secondary effluent to determine whether or not this method is a reasonable alternative to tertiary treatment.

METHODS

Vegetation

At the sewage treatment plant the secondary effluent empites into a ditch which carries it into a ponded area, called marsh A, that is covered by *Lemna* sp. (duckweed). Marsh A also contains *Typha latifolia* (cattail), *Salix* sp. (willow) and *Azolla* sp. The flow continues into the area marked swamp B on the map. This swamp is a narrow band of the largest swamp which has been isolated by the construction of the Florida Sunshine Parkway. The surrounding land is fairly high and probably would not be flooded most of the time if it were not for the steady input of sewage. The swamp is composed of *Fraxinus profunda* (ash), *Taxodium distichum* (cypress), and *Nyssa sylvatica* (blackgum). The understory includes *Serona repens* (saw palmetto), *Polygonum punctatum* (smartweed), *Cephalanthus occidentalis* (button bush), and *Rhus radicans* (poison ivy). The flow passes through this swamp into a ditch which runs through an improved pasture and finally empties into swamp C. It is composed of mainly *F. profunda* with *T. distichum, N. sylvatica, Acer rubrum* (maple), *Magnolia virginiana* (sweet bay), and *Liquidambar styraciflua* (sweet gum). The ground in swamp C is lower than swamp B and more moist, with an understory including *Itea virginica* (Virginia sweetspire), *Cornus foemina* (stiff dogwood), *Panicum sphagnicola* (grass), *Smilax walteri* (greenbriar), *R. radicans, Sabal minor* (palmetto), and *Saururus cernuus* (lizard's tail).

The control swamp D was originally part of the experimental swamp C but was cut off by the Florida Sunshine Parkway. Swamps B, C, and D are mixed hardwood swamps as defined by Penfound (1952) and Monk (1966). Swamp D is composed of the same tree species and understory as is found in swamp C. However, in the northern portion of swamp D, which is directly adjacent to an improved pasture the trees are smaller and there are many clumps of several species of grass.

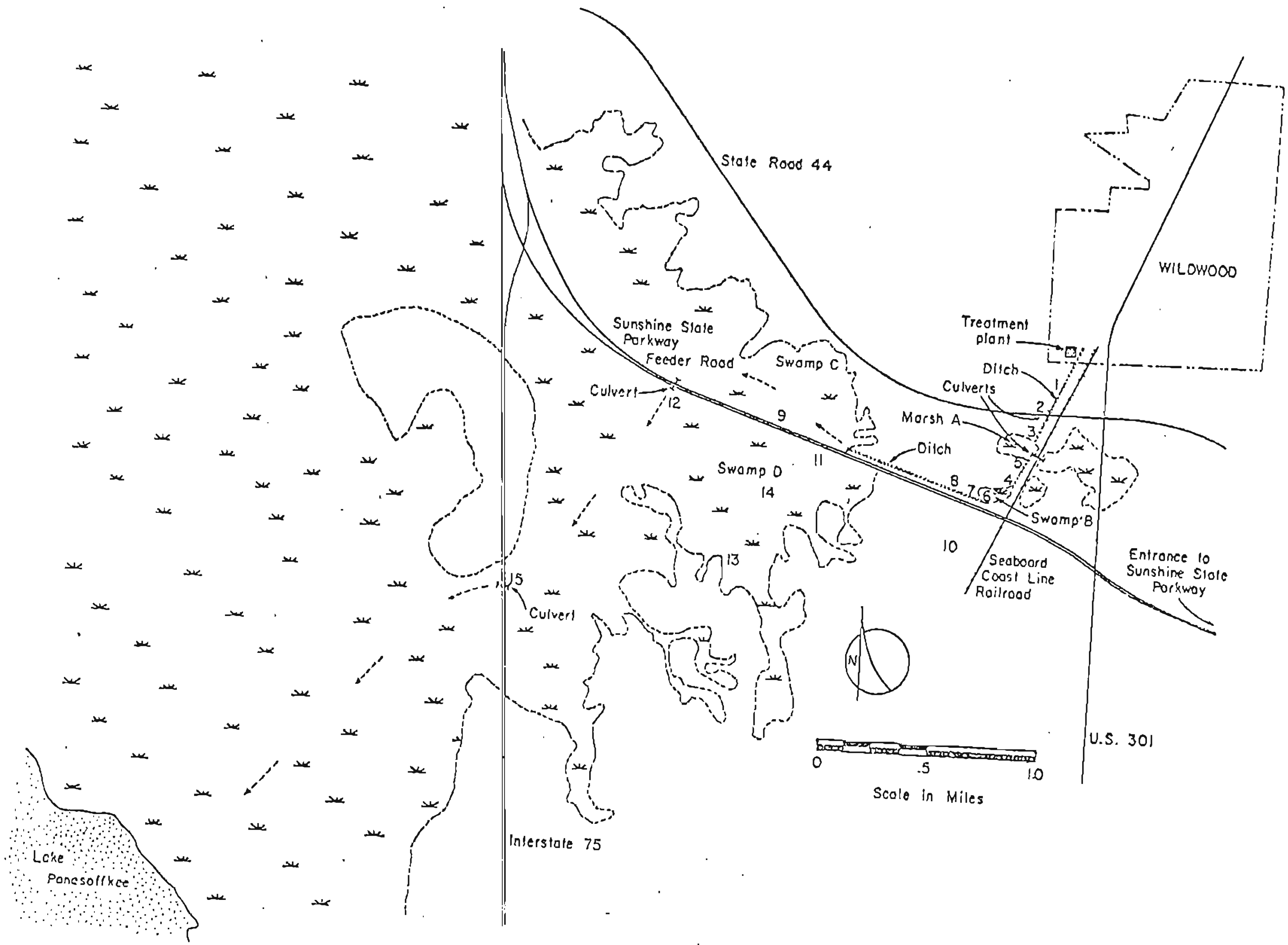
Sampling Locations

A map of the area is shown in Figure 1 with arrows indicating the general flow of water. Sampling stations are numbered consecutively with number 1 located at the sewage plant and number 16 at the lake. Marsh A and swamp B receive the sewage directly and include stations 1 through 6. Urban runoff from the city enters marsh A at station 5. The flow then continues through swamp C on the north side of the Florida Sunshine Parkway past stations 7, 8, 9, and 12. A culvert allows the overflow of water during periods of high rainfall to flow through the northern corner of swamp D, under Interstate 75 at station 15, and then to Lake Panasoffkee. The control area is located in the southeastern portion of swamp D and is comprised of stations 10, 11, 13, and 14.

Water Chemistry

Water samples were collected on a monthly basis at 17 stations and stored on ice until taken to the lab for analysis. The samples were then analyzed to determine the concentrations of PO_4^{-}-P, Total P, NO_3^{-}-N, NO_2^{-}-N, NH_3-N, Kjeldahl N, inorganic and organic carbon. After the phosphate test, the samples were poisoned with mercuric chloride. The

Figure 1. Map of the area showing sampling locations, flows, and Lake Panasoffkee.


State Road 44
WILDOWOOD
Treatment plant
Ditch
Culverts
Sunshine State Parkway Feeder Road
Swamp C
Culvert
12
9
Marsh A
1
2
3
5
4
Ditch
11
8
7
6
Swamp D
14
Swamp B
10
13
Seaboard Coast Line Railroad
Entrance to Sunshine State Parkway
15
Culvert
N
0
.5
1.0
Scale in Miles
U.S. 301
Interstate 75
Lake Panasoffkee

tests were performed as described in *Standard Methods for the Examination of Water and Wastewater*, 13th Edition, (1973). Total organic carbon was measured with a Beckman Analyzer. At approximately 3-month intervals, temperature and dissolved oxygen were measured using a dissolved oxygen meter. The water samples were also analyzed for the levels of magnesium, calcium, sodium, potassium, iron, zonc, copper, lead, and cadmium, following the procedures described in *Standard Methods* (1973).

Bacteria

Fecal coliforms were determined for the month of July 1974, by the MPN technique. During the March and August 1975 samplings, fecal coliforms and fecal streptococci were measured using the Millipore filter techniques as described in *Standard Methods* (1973). The samples were diluted and filtered in the field using a Millipore field kit, then returned to the laboratory for incubation. After incubation the colonies were counted and the ratio of fecal coliforms to fecal streptococci was computed.

Hydrologic Calculations

In order to construct a nutrient budget for the swamp, hydrologic calculations concerning rainfall and runoff were needed to estimate the inflow and outflow rate of water for the swamp. Rain data were collected at the sewage treatment plant by the operator. Runoff was estimated from these data. Since the watershed was only approximately 648 ha (1660 acres), monthly rainfall data were used to compute runoff according to a method described by Chow (1964). The equations are given below:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$Cn = \frac{1000}{S + 10}$$

$$S = \frac{1000}{Cn} - 10$$

where Q = runoff, inches; P = rainfall, inches; S = potential infiltration, inches; Cn = curve number. The potentiometric map, soil map, and aerial photographs were used to determine a weighted average curve number based on soil type and vegetation. The estimated land cover was 34.8% urban land (Astatula-Tavares soil association) which has a curve number of 60.2. The remaining 65.2% was improved pasture (Myakka-Wabasso soil association) with a curve number of 39 (Chow, 1964). The resulting average curve number was 46.3.

The flow from the sewage plant was measured by a flow meter. The average flow was approximately 0.15 mgd which is below the design capacity of the plant. Some water was probably lost in the ditch by evapotranspiration and did not enter the swamp. In other areas of the swamp it was impossible to determine flow; therefore only the depth of the water was measured.

The rate of ground water infiltration was determined using the relationship (Parizek, 1973):

$$V = Ki$$

where V = velocity of infiltration; K = permeability, meters/year; i = potentiometric gradient. The value of K was reported by Smith (1975) to be 0.369 m/yr for clay. The value for i was computed by determining the potentiometric head produced in the Wildwood area due to the varying depth in meters to the Floridan aquifer (Klein, 1971). This value was then divided by the distance, in meters, over which the change in depth occurred.

Sediment Analyses

Sediment cores were taken twice to a depth of 7.6 cm (3 in) and analyzed for nitrogen and phosphorus according to the procedure outlined in *Standard Methods* (1973). Both the wet and dry weight of the soil were determined. Deeper sediment cores were also taken so that a soil profile could be constructed.

A soil auger was used to determine the different soil layers beside the sewage ditch as station 3. At stations 6 and 9 in the experimental swamps, soil samples were taken by use of a pipe sampler. The soil core was then removed from the pipe and the depth to the clay layer was recorded. A series of shorter sediment cores was used to determine the depth of the organic soil and the depth of the sand layer.

Growth Rates of Trees

Tree growth data for both cypress and ash were collected in all the swamps with a tree corer to measure the thickness of the growth rings, and a clinometer to determine height. The diameter at breast height (dbh) was also measured. The use of a single core to measure rings may have introduced a source of error because of the presence of discontinuous growth rings which result in an underestimation of the age of the tree. Discontinuous growth rings are more common in older trees, especially ash (Panshin and Zeeuw, 1970). They are found when the cambium layer in one section of the trunk is dormant and does not produce a growth ring. If the core is taken through such an inactive section, the age of the tree is underestimated. For the purposes of this study, it was assumed that the error produced was random. The cypress cores were split and examined carefully under a dissecting scope to reduce the possible error produced by the "false rings" sometimes found in cypress. These "false rings" occur when some cells are very dense and small and give the appearance of a growth ring. In contrast to the normal growth ring, however, the false ring does not exhibit the gradual progression of size from the large cells put down in the spring to the small cells put down in the winter.

Productivity of Ash

The ash trees comprised roughly 70% of the trees in swamps B, C, and D with no single species dominating the remaining 30%. Since ash was dominant only the net productivity for ash was determined. To calculate the net productivity of the ash trees in all swamps, the parabolic volume of the trees at the present time was compared to the parabolic volume of the trees 20 years ago. An estimation of the parabolic volume, V, was made based on height and dbh according to the relationship $V = r^2 h$. The dbh in 1955 (20 years ago) was calculated by subtracting the thickness of the past 20 growth rings from the dbh measured in 1975. Determination of the height of the trees in 1955 was a more complex problem. The height vs. dbh was plotted (Figure 2) and a regression equation calculated. The equation and constants used to estimate the height of the trees in 1955 are shown in Table 1. The correlation coefficient, r, was 0.844 which represents a good correlation for a sample size of 44.

Table 1. The regression relationship used to estimate the height of an ash tree given only the dbh.

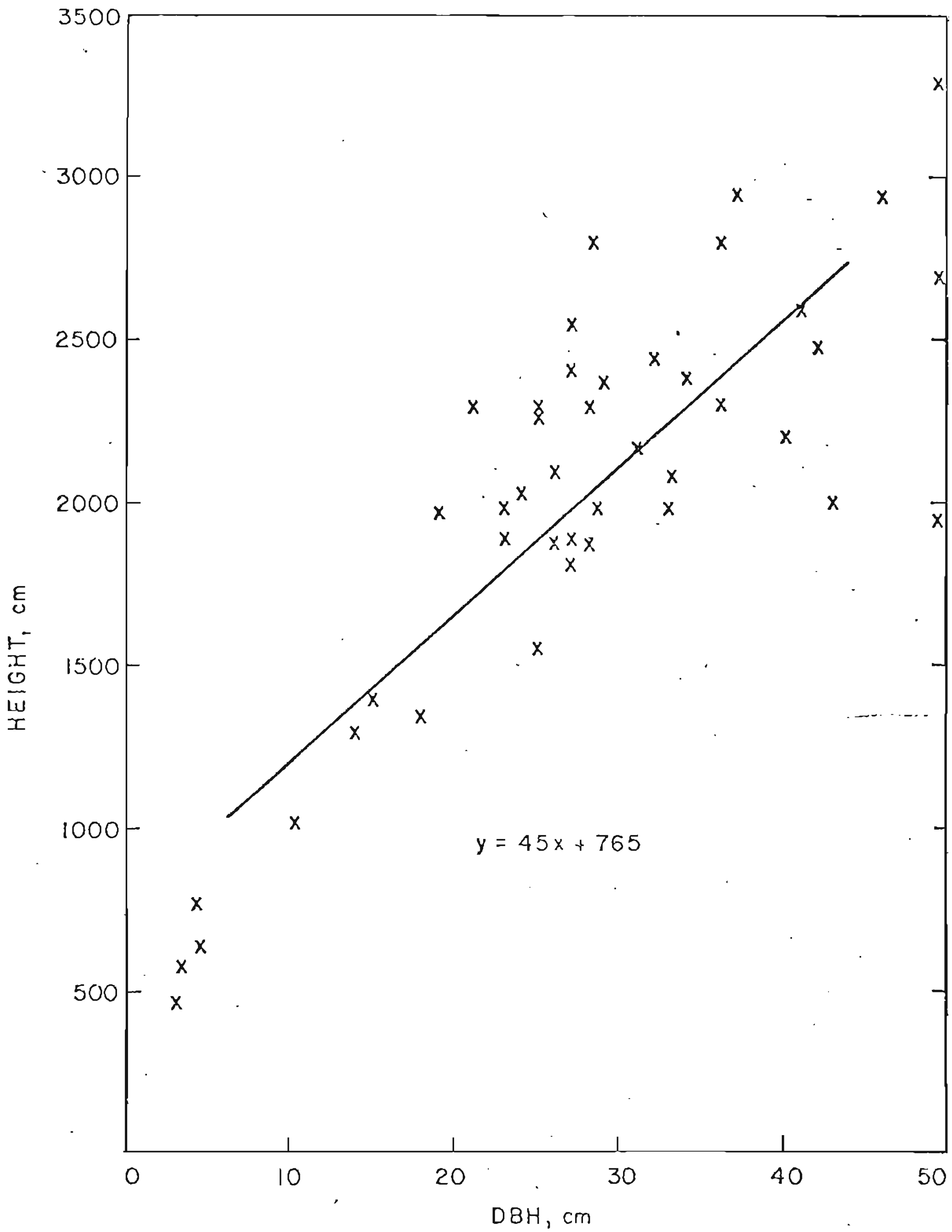
$$y = ax + b$$

$$y = \text{height, cm}$$

$$\text{dbh} = \text{diameter at breast height, cm}$$

	Number of Trees	Regression	Constants	Correlation Coefficient
	n	a	b	r
Ash	44	45.073	765.096	0.844

Figure 2. The relationship between height and dbh for *Fraxinus profunda*.



3500
3000
2500
2000
1500
1000
500
HEIGHT, cm
y = 45x + 765
0
10
20
30
40
50
DBH, cm

The net wood productivity of the trees was determined by the method of Rochow (1974).

$$Pn = \frac{(Vn - Vp) \times (sp.\ gr)}{20 \text{ years}}$$

Pn = net wood productivity in g/yr-tree

Vn = parabolic volume per tree in 1975

Vp = parabolic volume per tree in 1955

sp. gr. = specific gravity of *F. profunda*, 0.52

The specific gravity of the wood cores was determined by weighing them and then measuring the volume of water which they displaced. The value determined in this study agreed well with the specific gravity of 0.53 for *F. profunda* as reported by Newlin and Wilson (1917).

To construct a nutrient budget for the swamp, the rate of phosphorus uptake by the ash was estimated from the productivity calculations. The leaves, small twigs, and trunk cores from trees in both the experimental and control swamps were analyzed to determine the phosphorus content for each gram of biomass. The samples were oven-dried, ground into a homogeneous mixture, treated with acid to extract the phosphorus, and analyzed following the procedure for orthophosphate described in *Standard Methods*. Since the average productivity had already been calculated, the phosphorus content expressed as g-P/g-biomass was converted into the net phosphorus uptake each year.

Understory Sampling

Limited manpower prevented the measurement of understory productivity. However, the standing crop was determined in swamps B, C, and D. The understory included all plants from the ground to 6 feet above the ground, excluding epiphytes on trees. To obtain a sample, small markers were thrown along a crossection of the swamp. The markers were used as a center point for a 0.25 m^2 wooden frame which was laid down. All green plants within the frame were harvested, taken to the laboratory and oven dried at 103 C. Both wet and dry weights were determined.

RESULTS

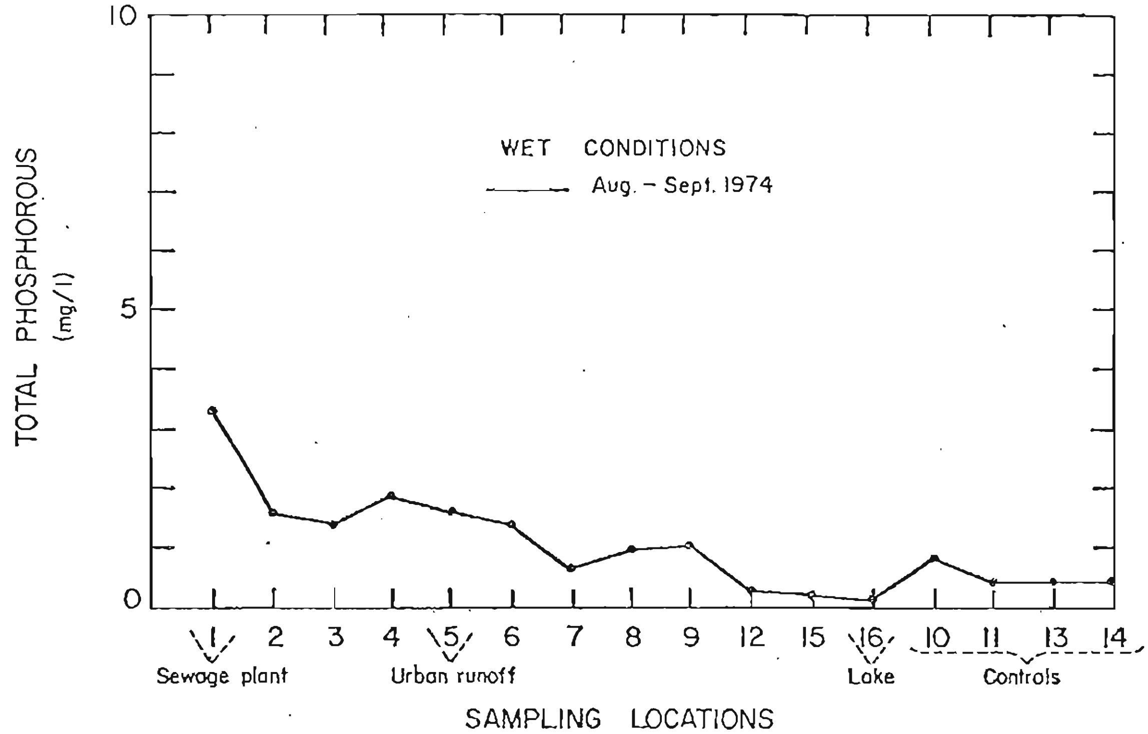
Changes in Nutrient Concentrations

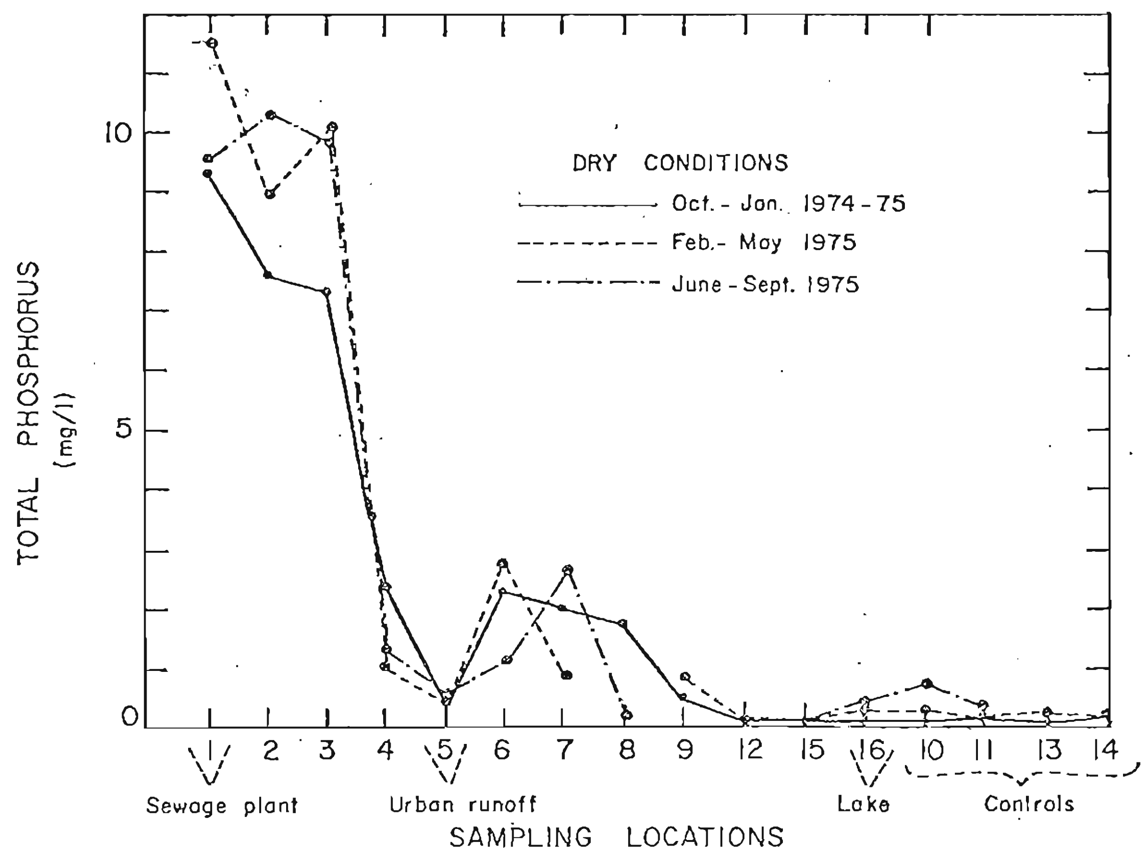
After flowing through the experimental swamp the concentration of nutrients was reduced to values equal to or less than those found in the control swamp or Lake Panasoffkee, as shown in Figures 3, 4, 5, 6, and 7. Low concentrations of nutrients were often recorded at station 5 since it is the point at which urban runoff from the city enters the swamp. Apparently the urban runoff diluted the treated sewage and thereby lowered the nutrient concentrations. The only exception to this was for the concentration of ammonia nitrogen which increased at station 5 during the wet conditions of 1974. This was probably due to the rapid flow of water which may have disturbed the sediments and released some ammonia from previous decomposition.

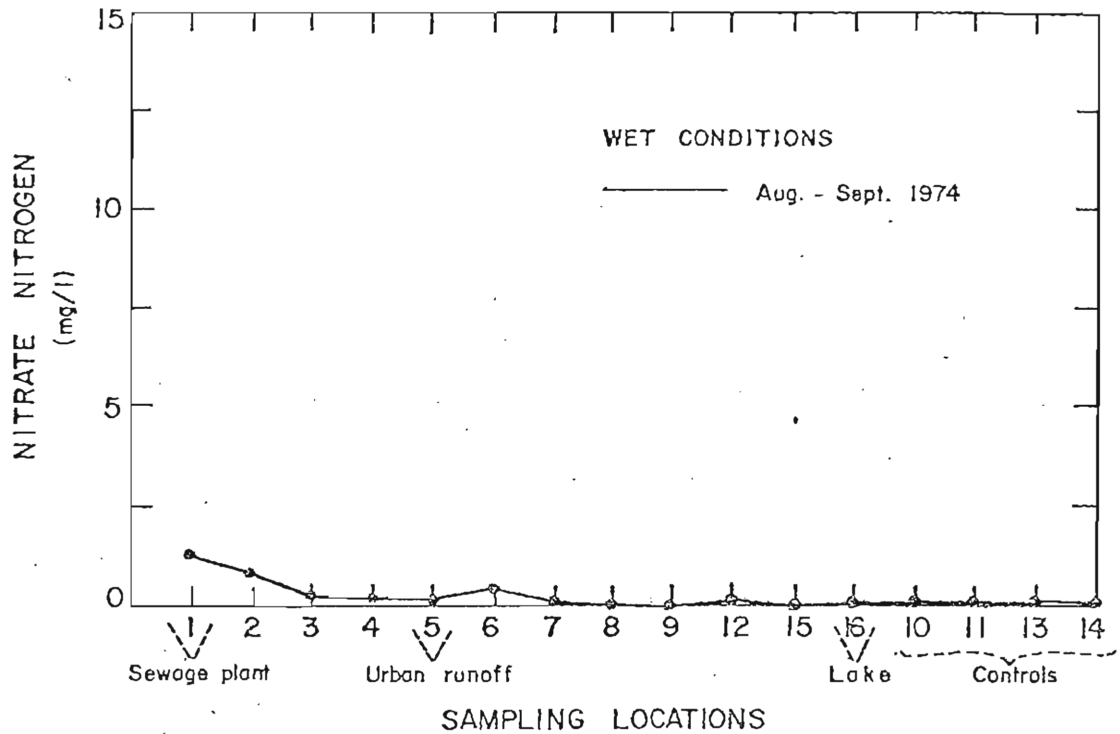
The concentration of nutrients in the water at station 2, approximately 487 m (1600 ft) from the sewage plant, was on the average 6.4 mg/l of total phosphorus and 15.3 mg/l of total nitrogen. At station 12 which is located at the culvert on the Florida Parkway connecting swamp C and swamp D, and is 3.7 km (2.3 mi) from the sewage plant, the average concentrations for one year were 0.124 mg/l of total phosphorus and 1.61 mg/l of total nitrogen.

The concentration of total phosphorus declined from station 1 to station 12 as shown in Figure 3. The average yearly concentration of total phosphorus at station 12 was 0.124 mg/l while the average for all the control stations was 0.274 mg/l. The consistent, rapid decline of

Figure 3. The concentration of total phosphorus during wet and dry conditions at the various sampling stations.


WET CONDITIONS
Aug. – Sept. 1974
TOTAL PHOSPHOROUS (mg/l)
10
5
0
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS


DRY CONDITIONS
Oct. - Jan. 1974-75
Feb.- May 1975
June - Sept. 1975
TOTAL PHOSPHORUS (mg/l)
10
5
0
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS


15
10
5
0
NITRATE NITROGEN
(mg/l)
WET CONDITIONS
Aug. - Sept. 1974
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

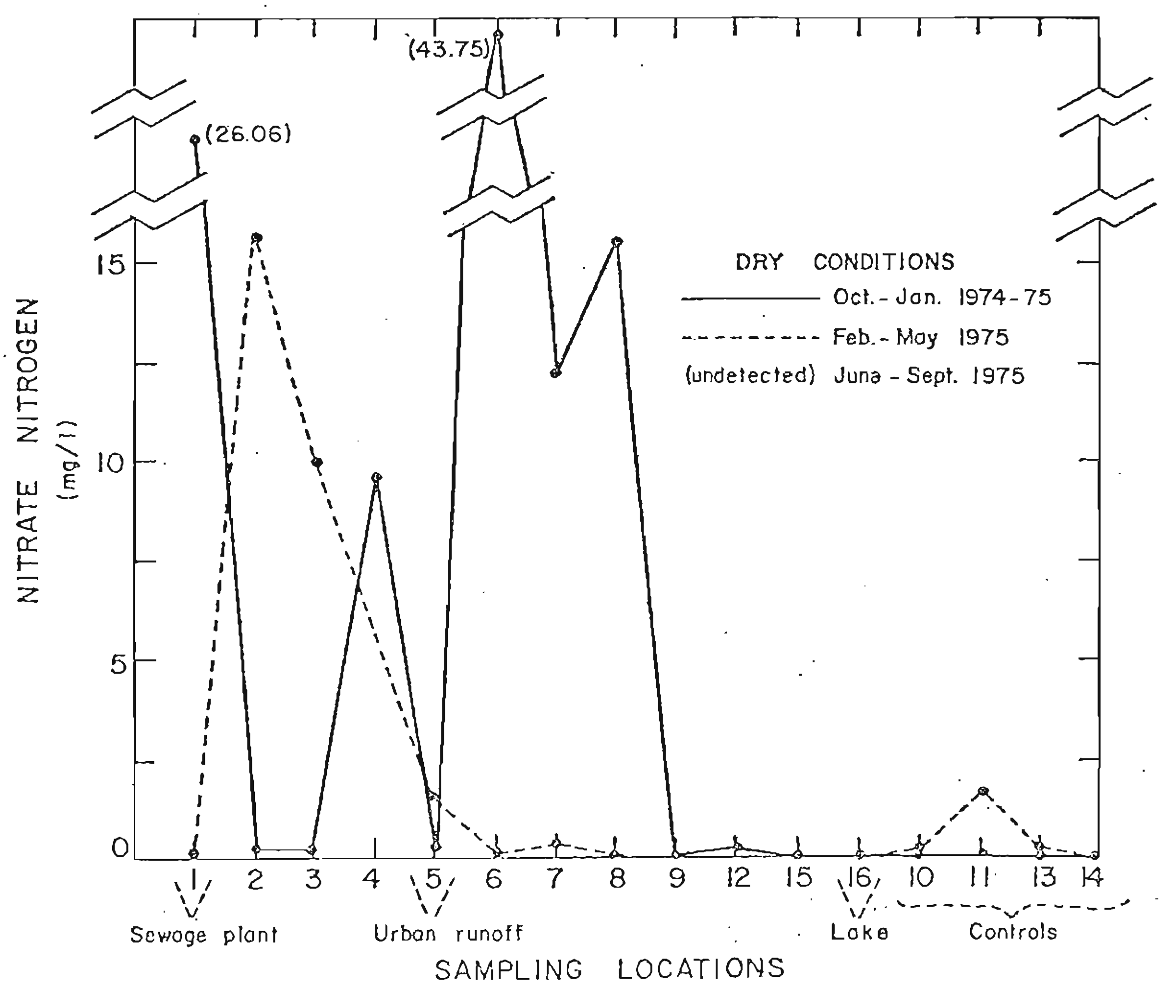
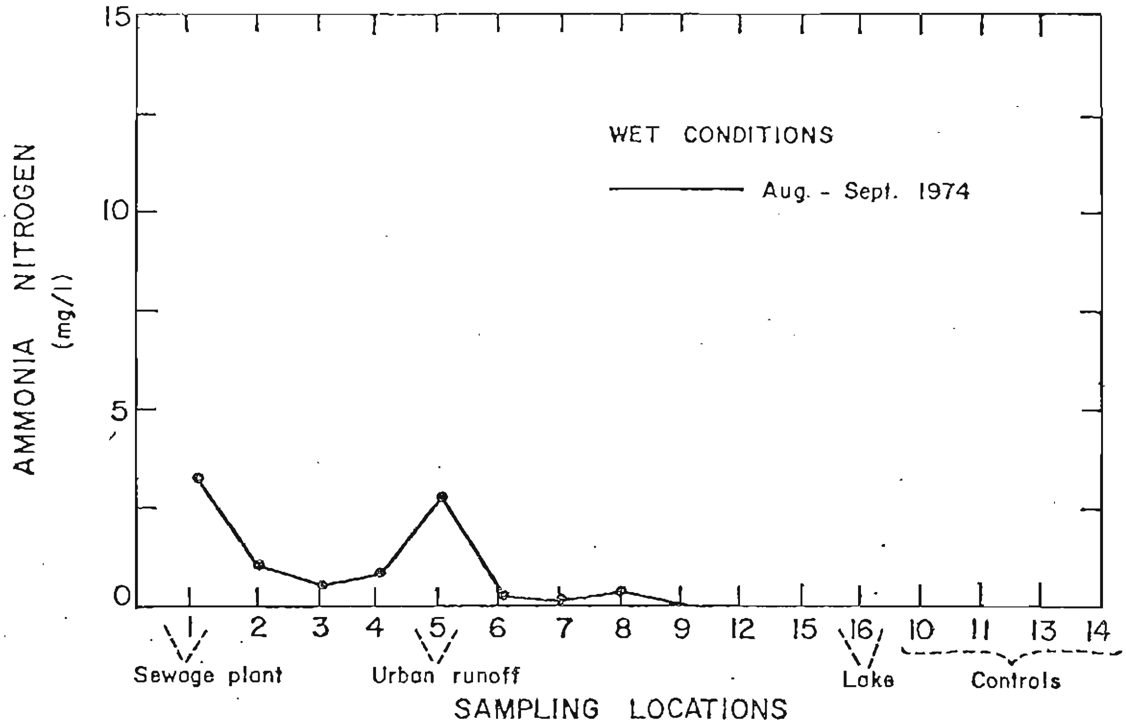
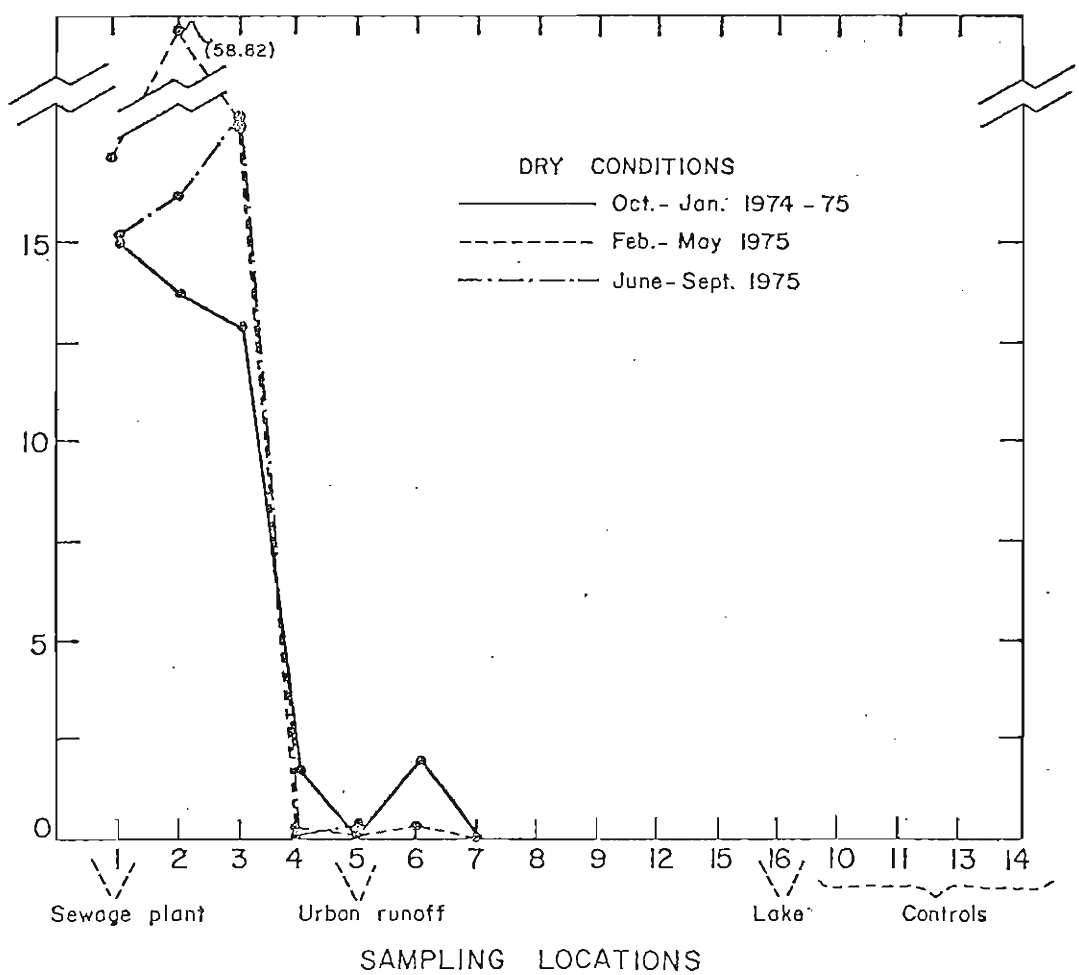

(43.75)
(26.06)
15
10
5
0
NITRATE NITROGEN
(mg/l)
DRY CONDITIONS
Oct. - Jan. 1974-75
Feb. - May 1975
(undetected) June - Sept. 1975
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

Figure 5. The concentration of ammonia nitrogen present in water samples.

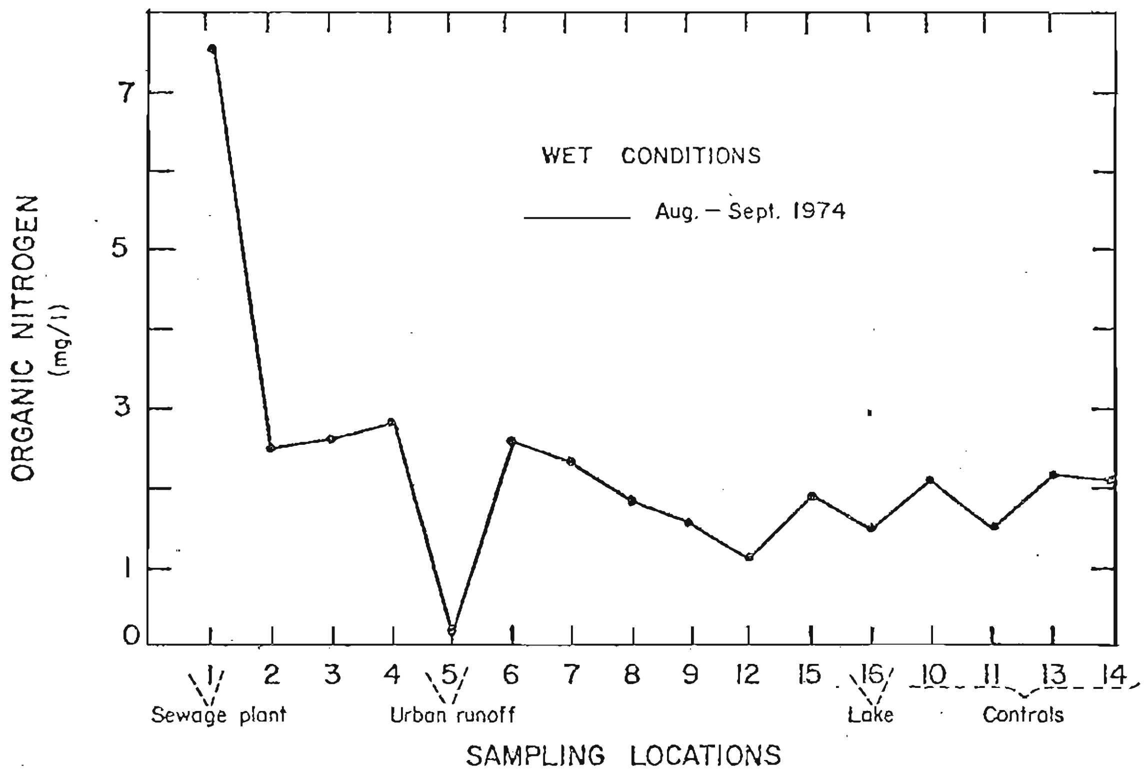


WET CONDITIONS
Aug. - Sept. 1974
AMMONIA NITROGEN (mg/l)
15
10
5
0
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS



(58.82)
DRY CONDITIONS
Oct.- Jan. 1974 - 75
Feb.- May 1975
June- Sept. 1975
AMMONIA NITROGEN (mg/l)
15
10
5
0
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

Figure 6. The concentration of organic nitrogen during wet and dry conditions at the various sampling locations. The discontinuous lines indicate that no water was present at some of the sampling stations.


ORGANIC NITROGEN (mg/l)
WET CONDITIONS
Aug. – Sept. 1974
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

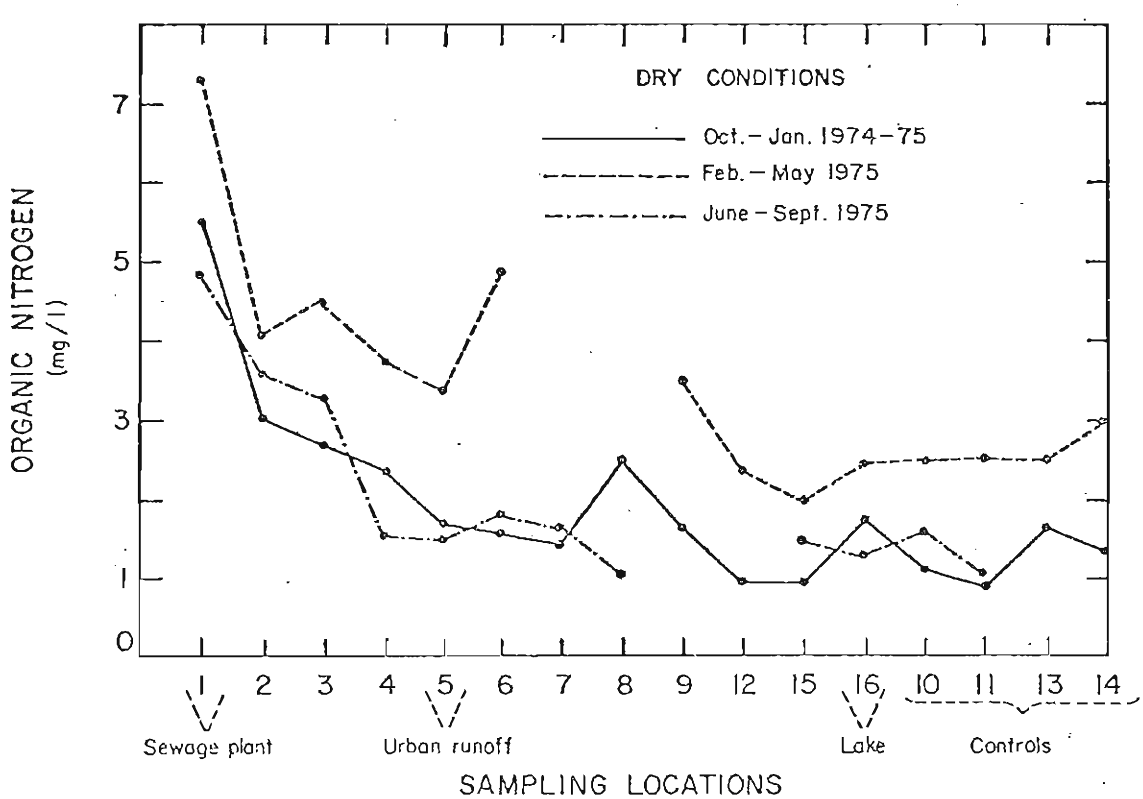
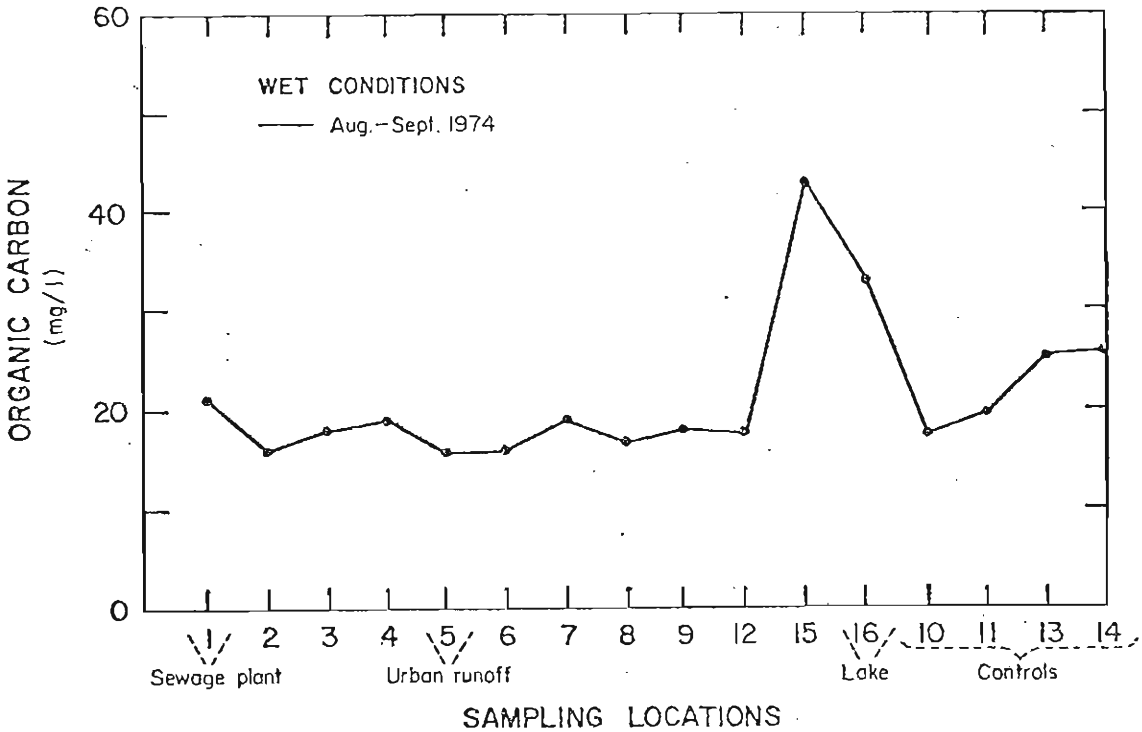
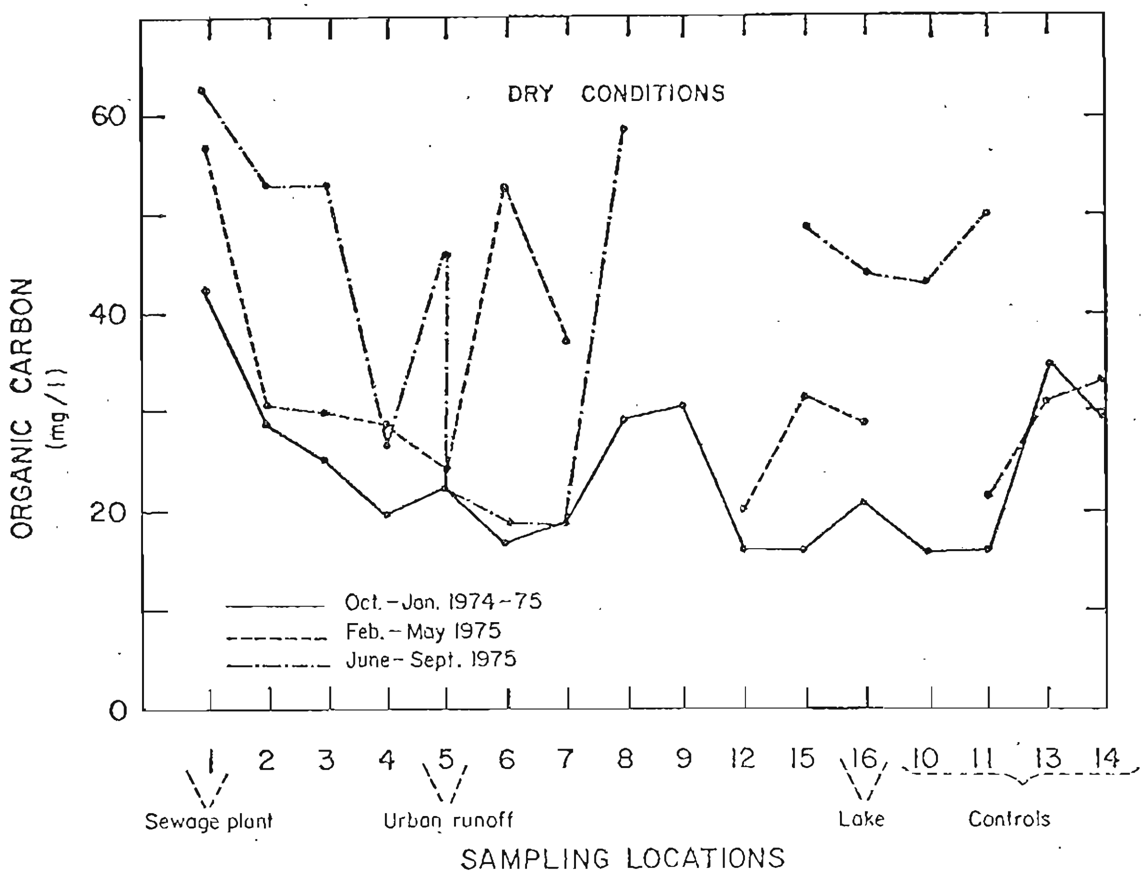

ORGANIC NITROGEN (mg/l)
DRY CONDITIONS
Oct. – Jan. 1974–75
Feb. – May 1975
June – Sept. 1975
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

Figure 7. The concentration of organic carbon during wet and dry conditions at the various sampling locations.


WET CONDITIONS
Aug.-Sept. 1974
ORGANIC CARBON (mg/l)
60
40
20
0
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS


DRY CONDITIONS
ORGANIC CARBON (mg/l)
60
40
20
0
Oct.-Jan. 1974-75
Feb.-May 1975
June-Sept. 1975
1 2 3 4 5 6 7 8 9 12 15 16 10 11 13 14
Sewage plant
Urban runoff
Lake
Controls
SAMPLING LOCATIONS

total phosphorus from about 11.0 mg/l to below 1 mg/l by station 9 showed that excess phosphorus was quickly taken out of the water. The concentrations of orthophosphate phosphorus showed the same type of response as the total phosphorus and the values are included in Appendix A.

The concentration of nitrate nitrogen was variable during this study (Figure 4). During August and September of 1974 the concentration of nitrate remained below 1.5 mg/l at all stations. However, from October 1974 until January 1975 there were very high peaks of nitrate nitrogen at stations 4, 6, 7, and 8. The increase in nitrate was probably due in part to the microbial conversion of NH_3 to NO_3^-. This was supported by the data in Figure 5 in which the concentration of NH_3-N decreased steadily during the same sampling period. In addition during dry conditions better aeration favored the conversion of NH_4 to NO_3^-. During February through May of 1975, the nitrate nitrogen level was high at station 2 but declined to almost zero at station 6 and remained low except for a small increase at one of the control stations. Nitrate nitrogen was not detectable at any of the experimental or control stations in August and September of 1974 nor from June until September of 1975. During these months the nitrate was probably rapidly utilized by various plants and phytoplankton. Additional explanations were that nitrification was reduced during this time or denitrification was increased, however, no data were collected to confirm these explanations.

The pattern of change in concentration of ammonia nitrogen did not show a seasonal variation (Figure 5). The concentration was high near the sewage plant but was almost completely absent beyond station 6 and in the control area.

In general the concentration of organic nitrogen exhibited an 85% reduction during the wet conditions and a 75% reduction during dry conditions. Organic nitrogen (Figure 6) ranged from about 1.0 mg/l to 7.5 mg/l and showed less variation than other parameters. Background levels of organic nitrogen were always attained by station 12, about 3.7 km (2.3 mi) from the sewage treatment plant.

The organic carbon concentration in the water (Figure 7) was much higher, ranging from approximately 57.0 mg/l to 16 mg/l. There was no significant difference between organic carbon levels in the control and experimental swamp at the 95% level of confidence. Only station 1 showed a significantly higher organic carbon concentration.

The effect of dilution from rain and runoff was noted in comparing the concentration of nutrients in both wet and dry conditions. During August and September 1974, the swamp was very wet and the concentrations were more uniform throughout the experimental and control areas. The drier conditions from October 1974 until September 1975 resulted in a higher concentration of nutrients to the experimental swamp, but the level of nutrients continued to decline with distance from the sewage plant often to levels below those observed in the control swamp. In the dry conditions the nutrients showed a rapid decline by station 6, at which point the decline became more gradual. Apparently, under wet conditions the nutrients are diluted and carried farther into swamp C, while under dry conditions the nutrients from the sewage outflow are contained within marsh A and swamp B. In no case however were the nutrients carried beyond the experimental swamp or into the vicinity of Lake Panasoffkee.

Levels of Metals and Dissolved Oxygen in the Swamp

The concentrations of heavy metals were examined and the data are presented in Table 2. Since the sewage plant in Wildwood received no industrial wastes the concentration of heavy metals was low in the sewage effluent (station 1) as well as in the experimental and control swamps. Copper and lead analyses were done in February 1975 on all sampling stations. In the experimental and control swamps the lead concentrations were below 0.03 ppm and the copper concentrations were less than 0.02 ppm. The data in Table 2 was collected in June 1975 except for the lead and copper concentrations.

The dissolved oxygen values are shown in Table 3. The average concentration of dissolved oxygen in the experimental swamp was 2.8 mg/l, with a range of 0.3 to 6.3 mg/l. The values in the control swamp ranged from 2.0 to 4.0 ppm with an average of 2.4 mg/l. The only area which showed a marked deviation from these baseline control swamp values was found in the ditch within 100 m of the sewage outflow. Under normal wet conditions, the sediments were probably anoxic as indicated by the low dissolved oxygen measured throughout the swamp. Brezonik *et al.* (1969) indicate that anoxic conditions are most favorable for nutrient release, since the concentration of nutrients in the water and available for uptake by plants is at a maximum.

Bacteria Indicating Fecal Contamination

The presence of fecal bacteria was also briefly examined during this study. The concentration of fecal coliform bacteria rapidly declined

Table 2. The concentrations of metals in water samples taken from a swamp in Wildwood, Florida.

Sampling Location	Metal Concentrations (parts per million)							
	Magnesium	Calcium	Sodium	Potassium	Iron	Zinc	Copper	Lead
1	4.1	92	4.4	8.8	0.17	0.048	0.020	0.03
2	3.8	81	55.2	7.6	0.06	0.042	0.015	0.03
3	3.6	79	55.2	7.2	0.06	0.042	0.020	0.03
5	3.2	121	29.9	6.4	0.19	0.015	0.010	0.02
10	4.1	85	4.6	2.8	0.32	0.010	0.010	0.02
15	5.8	113	3.5	0.4	0.03	0.008	0.015	0.01
16	5.2	95	4.6	1.7	0.05	0.113	0.005	0.15

Table 3. Temperature (°C) and dissolves oxygen (mg/l) measured in samples from Wildwood, Florida.

Sampling Location	August 1974		November 1974		February 1975		April 1975		August 1975	
	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.	Temp.	D.O.
Sewage Plant 1	30.0	2.4	24.5	5.7	22.0	1.3	23.0	0.6	29.0	0.4
2	30.0	1.7	20.0	1.5	19.0	1.5	17.8	0.8	27.0	1.1
3	30.0	2.0	18.0	1.9	19.0	1.2	16.1	0.5	27.0	1.1
4	31.0	1.5	18.0	2.1	20.0	0.7	17.2	0.5	28.0	3.0
5	29.0	2.0	18.0	1.9	20.0	1.7	18.0	0.6	27.0	2.1
6	29.0	2.4	17.0	6.3	20.0	1.2	18.0	1.2	no water	
7	28.0	1.4	17.0	1.3			16.5	1.8	no water	
8	29.5	1.3	19.0	2.6						
9	27.5	1.7	20.0	2.7	20.0	1.8	17.6	1.8	no water	
12	28.5	3.1	20.0	3.0	19.2	3.3	18.7	4.4	no water	
15	29.5	3.5	20.0	4.7	20.0	4.6	20.2	1.4	29.0	4.9
Lake 16	29.0	3.0	20.0	7.6	20.0	3.0	19.9	4.5	29.0	1.0
Controls 10	27.0	2.1	16.0	3.6	18.0	4.1	17.5	4.7	26.0	1.1
11	28.0	1.8	19.0	2.8	19.5	1.5	17.3	4.5	no water	
13	26.4	1.8	17.0	1.9	18.5	1.5	16.2	1.7	no water	
14	27.0	3.1	17.0	1.0	20.0	1.8	16.7	2.2	no water	

by station 3 as shown in Table 4. However, the fecal coliform concentration in the control area was on the average 200 per 100 ml, which is above U.S. Public Health Service drinking water standards and recreational water standards. The high fecal coliform count was probably due to the pasture runoff into the swamp. To determine the influence of agricultural runoff, the ratio of fecal coliform to fecal streptococci was determined (Table 5). In human feces the ratio is approximately 4.0, while for livestock it is less than 0.7 (Geldreich and Kenner, 1969). Based on this standard, the high ratio at station 1 and sometimes station 3 indicated human fecal contamination as found in domestic waste. However the consistently lower ratio at station 6 and beyond indicated the fecal contamination was probably created by domestic livestock from nearby pastures.

Virus

The viral work done for this study was conducted by Dr. Flora Mae Wellings, Dr. A. L. Lewis, and Dr. C. W. Mountain at the Epidemiology Research Center in Tampa, Florida.

The viral concentrations being released in the Wildwood sewage plant chlorinated effluent were quite variable and range from 4 to more than 186 plaque forming units (pfu)/500 ml sample. The high virus concentrations are probably the result of poor treatment by the trickling filter. The levels found in the experimental swamp A, from station 3 to station 4, varied from 0 to 6 pfu in 500 ml water samples. The sediment samples from this area showed considerably higher levels of virus ranging from 1 to 61 pfu/≃400 g (wet weight), excluding one sample

Table 4. Fecal coliform bacteria found at the various sampling locations in Wildwood, Florida.

July 1974

Sampling Location	MPN/100 ml (most probable number/100 ml)
1	1.6×10^6
3	3.0×10^5
6	1.5×10^4
7	7.6×10^2
8	1.5×10^3
9	3.0×10^2
14	3.0×10^2
16	3.0×10^2

March 1975

Sampling Location	No. per 100 ml
1	5.3×10^4
3	6.9×10^3
9	1.6×10^3
13	2.5×10^2
16	4.0×10^1

May 1975

Sampling Location	No. per 100 ml
1	5.7×10^5
3	4.8×10^4
15	1.0×10^1

August 1975

Sampling Location	No. per 100 ml
1	1.2×10^6
3	1.7×10^5
6	1.4×10^3
13	5.9×10^3
15	1.7×10^2

December 1975

Sampling Location	No. per 100 ml
1	1.14×10^6
3	2.11×10^5
6	9.8×10^1
9	1.3×10^1
13	5.3×10^1
15	4.9×10^1

Table 5. The fecal coliform to fecal streptococci ratio, calculated for water samples taken in Wildwood, Florida.

	Sampling Location	FC/FS*
May 1975	1	3.63
	3	0.40
	15	0.08
August 1975	1	2.51
	3	4.91
	6	0.30
	13	0.88
	15	0.82
December 1975	1	8.63
	3	21.70
	6	0.38
	9	0.27
	13	1.06
	15	0.92

*No. of fecal coliform/no. of fecal streptococci.

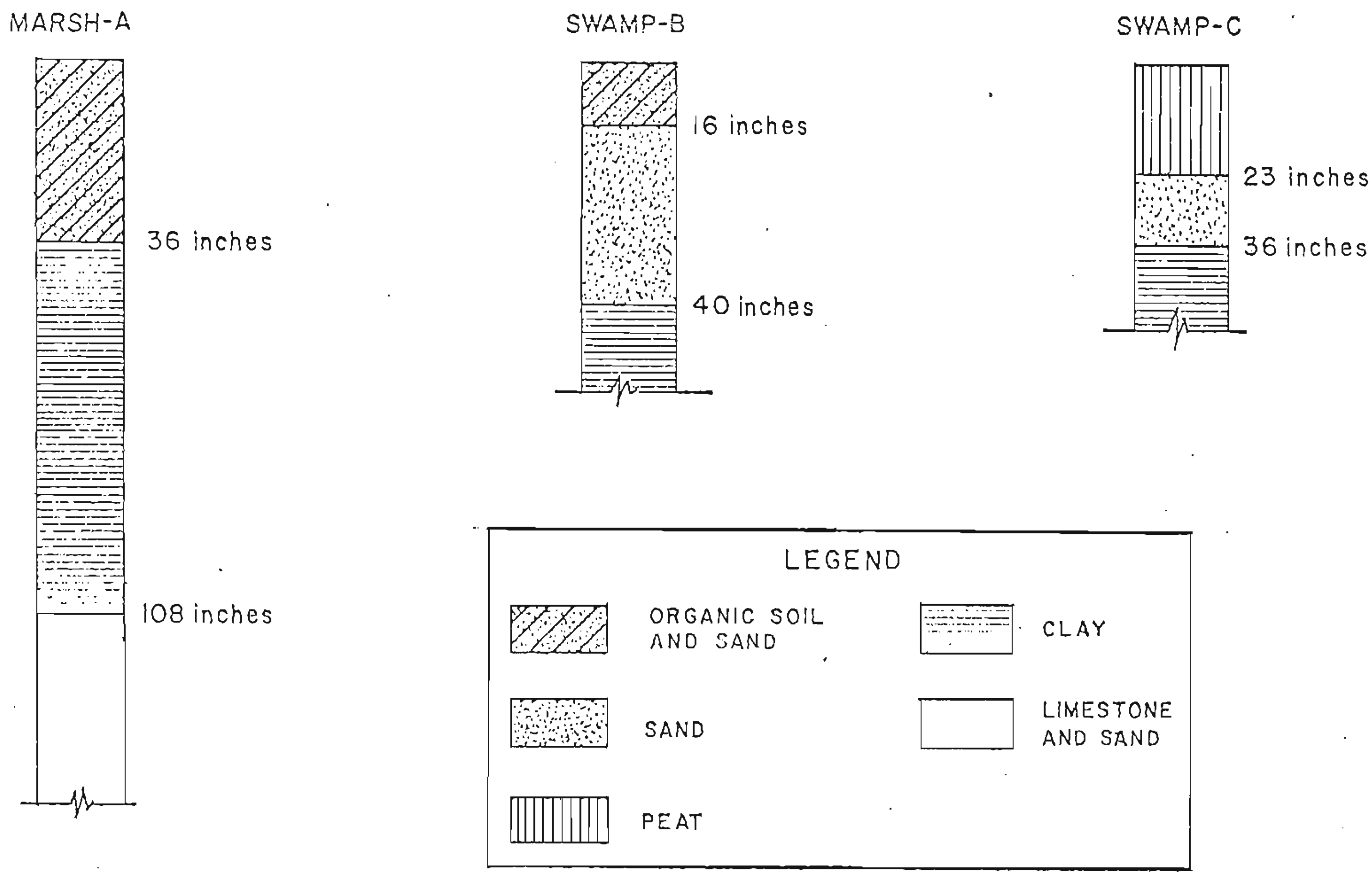
which contained too many virus to count. These data indicated that the virus settled out of the water and become associated with the sediment column. The data are summarized in Appendix B and were taken over an 8 month period, March - October, 1975.

Preliminary testing of groundwater wells, one 9 feet and the other 12 feet deep, produced negative viral results. However, the sampling was done only once in October 1975. At this time 100 gallon water samples were pumped from each of 2 wells located about 10 feet from the ditch carrying the sewage into swamp A. One hundred gallon water samples taken in the control swamp surface water also produced negative results.

Nutrient Levels in the Sediments

Examination of the sediments gave some support to the assumption that there was little vertical movement of water in the swamp. A soil profile was constructed from the five sediment cores 5 cm (2 in) in diameter taken (Figure 8). Throughout marsh A, swamps B, and C, a clay layer was found between 0.9 and 1.2 m (3-4 ft) below the surface. This layer probably prevented an open exchange between the surface water carrying treated sewage and the ground water. In addition, the soil types of the swamp were reported to be Myakka-Wabasso, Panasoffkee-Bushnell and Terra Ceia-Placid by the Soil Conservation Service. All of these soils are poorly drained with seasonal high water table between 0 and 30 in. The dominant soil type is Panasoffkee-Bushnell association, which has a very slow filtration rate and a clay subsoil (Chow, 1971). These characteristics, along with the sediment cores which showed the shallow clay layer, indicate that there was probably little groundwater recharge.

Figure 8. Soil layers found in the experimental area.


MARSH-A
36 inches
108 inches
SWAMP-B
16 inches
40 inches
SWAMP-C
23 inches
36 inches
LEGEND
ORGANIC SOIL AND SAND
CLAY
SAND
LIMESTONE AND SAND
PEAT

Additional sediment cores were taken to a depth of 7.6 cm (3 in) and analyzed for nitrogen and phosphorus (Figure 9). Station 2, located about 100 m from the sewage plant, exhibited large concentrations of phosphorus (20.2 mg/g-dry soil), and nitrogen (27.0 mg/g-dry soil). Stations 6, 9, 13, and 15 also exhibited high concentrations of organic nitrogen (24, 66, 17, and 48 mg/g-dry soil, respectively). The phosphorus level stayed high at station 6 in swamp B (15.2 mg/g-dry soil), but then dropped to 5.8 mg/g-dry soil at station 9 in swamp C. The phosphorus concentration was also high at the control station 13 with a value of 18.4 mg/g-dry soil. On the basis of the limited data taken there was no evidence of a larger build-up of nutrients in the sediments of the experimental swamp than in the control swamp.

Productivity and Uptake of Nutrients

A large portion of the nutrients was taken up by the trees in the swamp. The tree growth in swamp B (Table 6) was greater than the tree growth in the control area (Table 7). The average growth increment for cypress in swamp B, which was receiving the sewage effluent, was 5.5 cm/20 yr and for ash 4.73 cm/20 yr. The average increment for the control swamp was 3.87 cm/20 yr for cypress and 3.93 cm/20 yr for ash. The difference was significant at a confidence level for ash of 90% and for cypress at a confidence level of 95%. The productivity calculations showed that ash in the area receiving the additional nutrients from sewage had a greater ash productivity, 1101.5 g/m^2-yr, as compared to 882.4 g/m^2-yr in the control swamp. This represents a 20% increase in the experimental swamp B. For ash in swamp B the

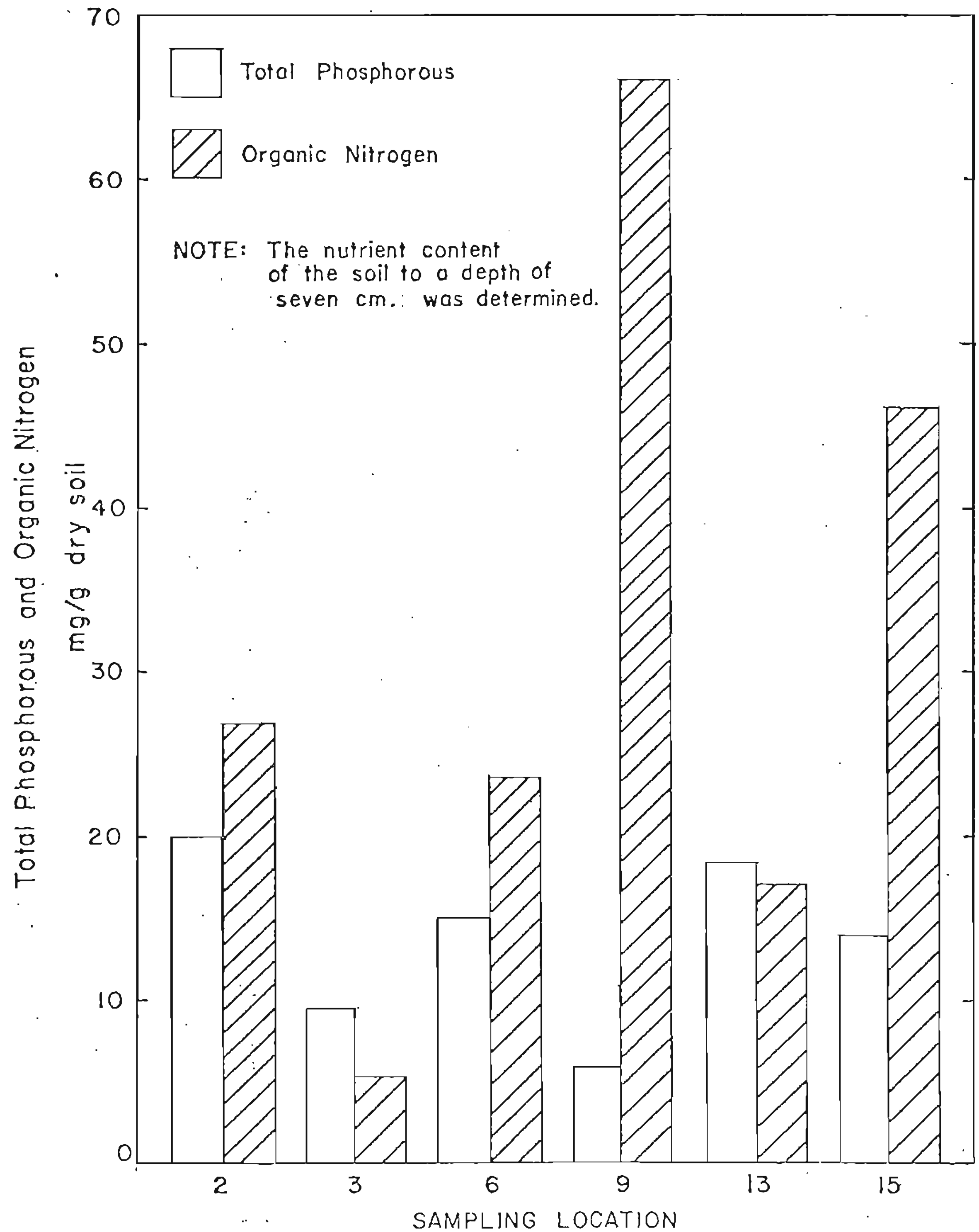
Table 6. The data recorded on tree growth in experimental Swamp B for both ash and cypress trees.

Tree	dbh (cm)	Height (cm)	Last 20 rings (cm)
Ash	33.5	2194.6	4.80
	28.7	1950.7	3.74
	27.2	2438.4	4.85
	42.5	2499.4	4.28
	40.0	2255.5	3.48
	36.2	2316.5	3.81
	34.5	2377.4	6.50
	50.0	2682.2	5.34
	28.5	2316.5	3.28
	28.5	2011.7	3.30
	25.5	2316.5	5.90
	41.1	1341.2	7.48
		Average	4.73
Cypress	52.0	2621.3	5.90
	28.2	1341.1	5.70
	27.0	1219.2	5.26
	63.4	2255.5	7.10
	22.3	1767.8	4.82
		Average	5.50

Table 7. The data collected on the growth of trees in the control area Swamp D.

Tree	dbh (cm)	Height (cm)	20 rings (cm)
Ash	19.0	1950.7	3.90
	27.0	2555.5	2.98
	51.6	3169.9	5.88
	37.7	2987.0	2.50
	36.0	2804.2	6.60
	21.0	2316.5	2.67
	24.4	2011.7	3.40
	41.3	2621.3	5.64
	26.3	2133.7	3.04
	24.8	2255.5	3.10
	29.3	2377.4	3.55
			Average 3.93
Cypress	26.7	1889.8	3.27
	42.5	2743.2	4.55
	36.2	2438.4	3.80
	33.7	2560.3	3.32
	49.6	2743.2	4.40
			Average 3.87

Figure 9. Nutrient content of the soil to a depth of 7.6 cm (3 in).


Total Phosphorous
Organic Nitrogen
NOTE: The nutrient content of the soil to a depth of seven cm. was determined.
Total Phosphorous and Organic Nitrogen
mg/g dry soil
70
60
50
40
30
20
10
0
2
3
6
9
13
15
SAMPLING LOCATION

phosphorus uptake was 0.184 g/m^2-yr while the rate in the control swamp was only 0.158 g/m^2-yr.

Data in Table 8 indicated that understory was also a large storage for nutrients in the experimental swamp. The average standing crop was 64.4 g/m^2 in swamp B, 1.0 g/m^2 in swamp C, and 9.53 g/m^2 in control swamp D. These values were calculated from the dry weight of the standing crop in September, which is not the peak growth period. Swamp B exhibited a large growth of understory during early spring, in an area which had been covered by water in August of 1974, had dried out by March 1975 but was wet again in September 1975. The growth was composed almost exclusively of *Polygonum punctatum* (smartweed) and was very dense. The understory in the other swamps was more variable with no one plant dominant. The understory was very responsive to moisture and nutrients. Throughout the summer of 1975 swamps C and D were dry with no standing water. However after a summer rainstorm the understory would rapidly frow and then die as the swamp began to dry out. Swamp B was kept moist by the constant inflow of sewage effluent and therefore able to support a large biomass of understory.

Hydrologic Considerations in the Swamp

The fate of nutrients within the swamp is highly dependent on the hydrologic cycle. During periods of high rainfall, more nutrients were flushed into the larger swamp; however, under dry conditions the nutrients were contained within experimental swamp B and were allowed time to be absorbed onto the sediments or utilized by the vegetation. Thus the feasibility of using the swamp as an alternative to tertiary wastewater

Table 8. The understory standing crop.

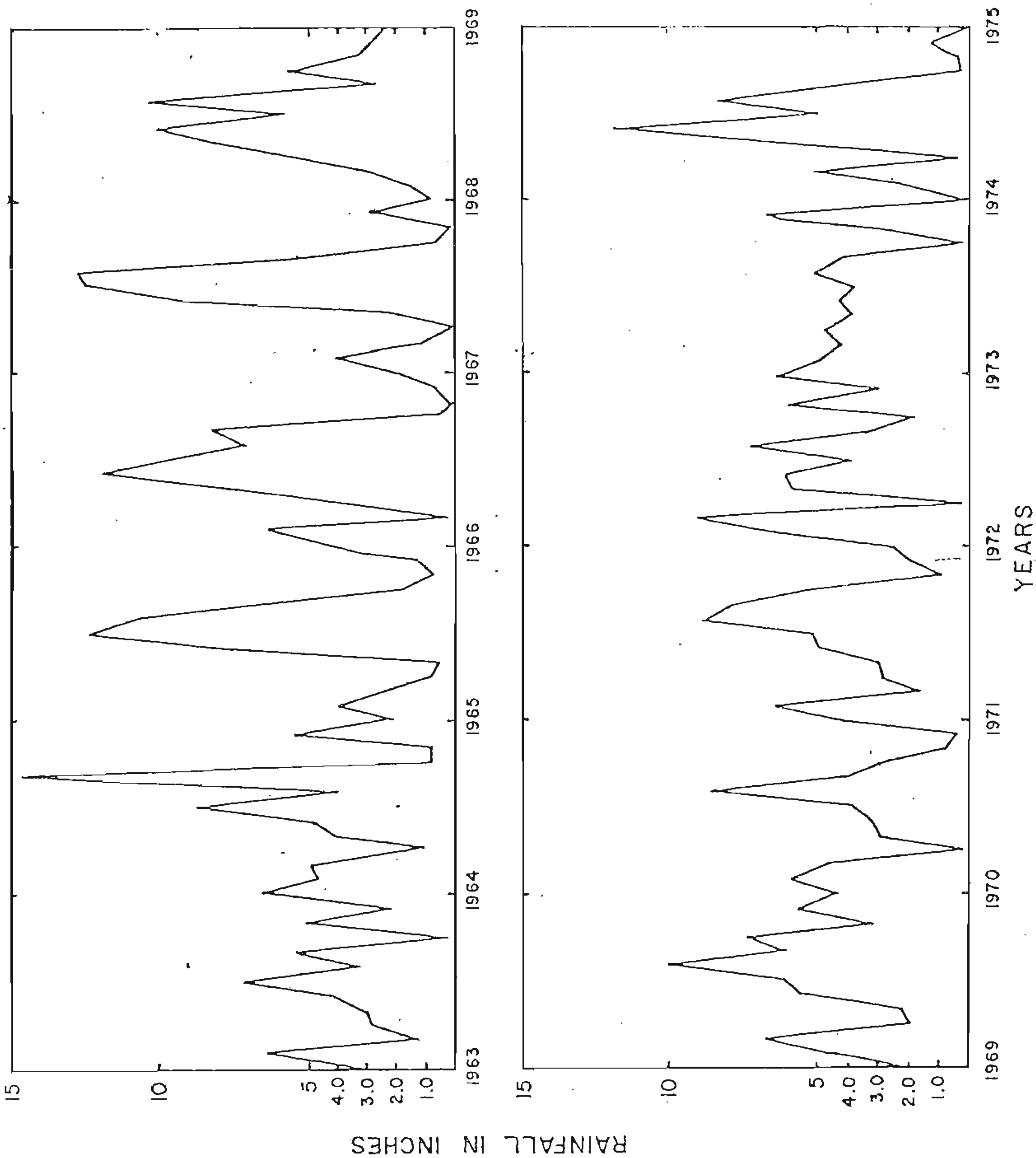
	Average Dry Weight g/m^2	S.D.	No. of Samples
Swamp B	64.4	74.2	8
Swamp C	1.0	1.3	8
Swamp D	9.5	10.8	8

treatment depends to some degree on the quantity of water received by the swamp. An approximation of the hydrologic cycle was used to develop a nutrient model so that the flow of nutrients through the swamp could be estimated.

Figures 10 and 11 show monthly rainfall patterns. Figure 10 presents data from the U.S. Weather Bureau Station in Bushnell, 15 miles southwest of Wildwood. These data were included as historical data so that rainfall trends for this area could be determined over a moderate time span. The years from 1964 through 1967 showed a very sharp peak of rainfall during the summer months. However, from 1968 until 1974, the precipitation was more irregular, but with peaks usually during the summer months. From 1968 until 1974 the rainfall did not go above 25.4 cm (10 in) per month until June of 1974, when 30.5 cm (12 in) was measured. The precipitation was measured at the Wildwood sewage plant by the operator for 1974 and 1975 and is plotted in Figure 11. In comparing the rainfall recorded at Bushnell to that recorded at Wildwood, the same type of pattern emerges. A peak rainfall occurs between June and August, with similar monthly totals. The historical data from Bushnell imply that the time of this study, July 1974 through September 1975, produced a wide range of precipitation, with 1974 being a very wet year, followed by the dry year of 1975. Therefore the results of this study show the response of the swamp to the highest and one of the lowest recorded monthly rainfall totals in the past 12 years.

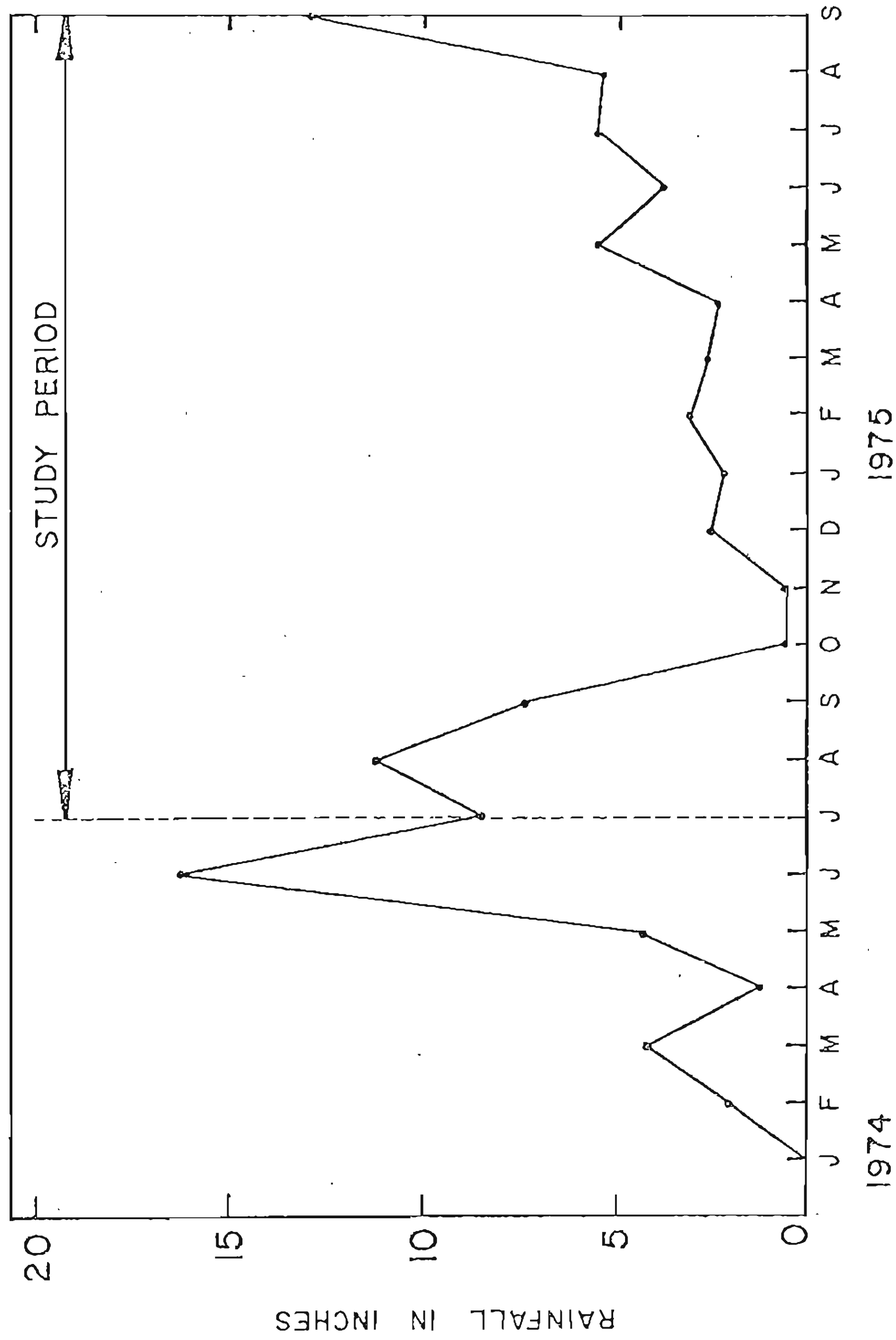
Since the nutrients are contained within the experimental swamp during dry conditions, but are more easily flushed out during a very wet year, 1974 was chosen for use in the construction of a water budget

Figure 10. The monthly rainfall totals over the past 13 yr recorded at the Bushnell U.S. Weather Station.



RAINFALL IN INCHES
YEARS
15
10
5
4.0
3.0
2.0
1.0
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975

Figure 11. The monthly rainfall totals for 1974 and 1975 as collected by the plant operator at the Wildwood sewage plant.


STUDY PERIOD
RAINFALL IN INCHES
20
15
10
5
0
J F M A M J J A S O N D J F M A M J J A S
1974
1975

so that the maximum flow from the swamp could be determined. During the summer of 1974 there was a continuous flow of water through the swamp to the lake. However, according to the computations, runoff into the experimental swamp occurred only during the months of June and July of 1974 when the rainfall was far above the storage capacity of the soil. The total rainfall for 1974 was 148 cm (58.3 in) with approximately 23 cm (9.1 in) of runoff received by the experimental swamp. Evapotranspiration was calculated to be 118.5 cm/yr (46.6 in/yr) in this area of Florida. Combining the rainfall received with the approximate runoff and the sewage flow, the total water input for the experimental swamp in 1974 was 171.2 cm (67.4 in). If the loss due to evapotranspiration was subtracted, then the amount of water left was 52.7 cm (20.8 in). A study done by Smith (1975) reported that the permeability of clay was between 0.369 m/yr (1.21 ft/yr) and 0.076 m/yr (0.25 ft/yr). The potentiometric gradient for the Wildwood swamp was found to be 0.00158. Thus the ground water infiltration was not more than 0.001 m/yr (3.3×10^{-6} ft/yr), so that most of the remaining 52.7 cm (20.8 in) was exported to the lake. The overall hydrological budget is summarized in Figure 12. Calculations are presented in Table 9.

Construction of a Nutrient Budget

The construction of a nutrient budget (Figure 13) gave a better understanding of the pathway of nutrients through the swamp. The inputs, uptake and outflow for phosphorus were estimated (Table 10) using the phosphorus concentration data collected and the hydrological calculations for 1974. A nitrogen budget was not constructed due to the difficulty of measuring the effects of nitrification and denitrification.

Table 9. Calculations for Figure 12.

1. The sewage flow was 568 m^3/day as measured at the plant and the area of the experimental swamp $2.04 \times 10^6 m^2$. The sewage outflow was

$$\frac{(568\ m^3/\mathrm{day})(365\ \mathrm{day/yr})}{2.04 \times 10^6\ m^2} = 0.102\ \mathrm{m/yr}$$

2. Rainfall for 1974 was 58.3 inches or 1.48 m.

3. Rainfall runoff for 1974 was calculated to be 0.23 m/yr. The area of the watershed was estimated to be $4.88 \times 10^6\ m^2$.

$$\frac{(0.23\ \mathrm{m/yr})(4.88 \times 10^6\ m^2)}{2.04 \times 10^6\ m^2} = 0.550\ \mathrm{m/yr}$$

4. Ground water infiltration was estimated based on the permeability of clay (Smith, 1975).

   For the Wildwood area i was calculated from a potentiometric map (Klein, 1971) to be 0.00158.

$$V = (1.21\ \mathrm{ft/yr})(0.00158) = 0.00058\ \mathrm{m/yr}$$
$$\simeq 0.001\ \mathrm{m/yr}$$

5. The rate of evapotranspiration (ET) was estimated at ET = pan evaporation x 0.8. Pan evaporation for 1974 was recorded to be 1.50 m/yr (Heinburg, unpub.).

$$ET = (1.50\ \mathrm{m/yr})(0.8) = 1.20\ \mathrm{m/yr}$$

6. To determine export (E) to swamp D and Lake Panasoffkee, the total evapotranspiration (ET) and ground water infiltration (V) were subtracted from the total inflow which included rainfall, runoff and sewage.

$$E = (0.102\ \mathrm{m/yr} + 1.48\ \mathrm{m/yr} + 0.550\ \mathrm{m/yr}) - (1.2\ \mathrm{m/yr} + 0.001\ \mathrm{m/yr})$$
$$= 0.931\ \mathrm{m/yr}.$$

Figure 12. The water budget for the experimental swamp.

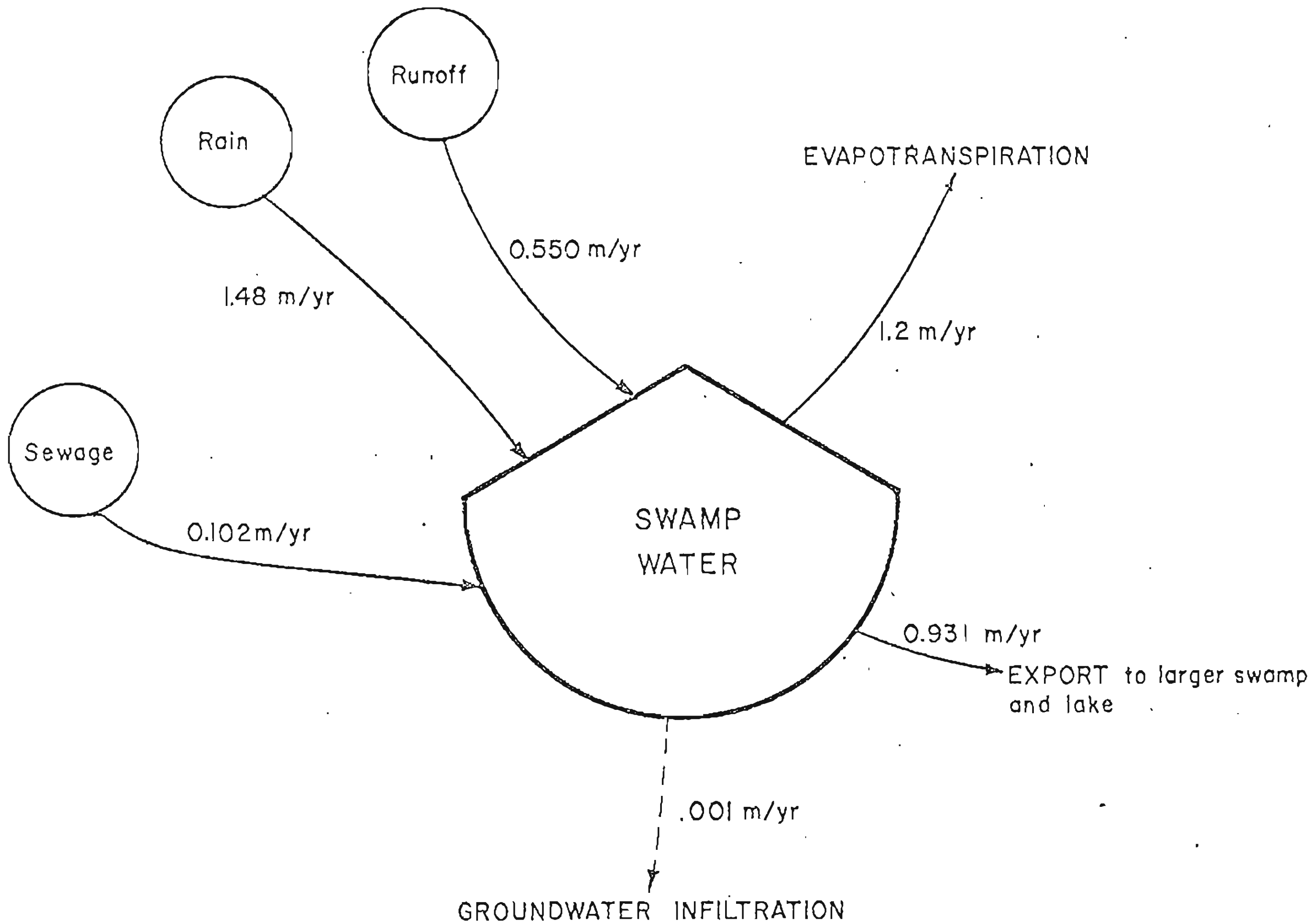

Runoff
Rain
Sewage
EVAPOTRANSPIRATION
0.550 m/yr
1.48 m/yr
1.2 m/yr
0.102m/yr
SWAMP
WATER
0.931 m/yr
EXPORT to larger swamp
and lake
.001 m/yr
GROUNDWATER INFILTRATION

Table 10. Calculations for Figure 13.

1. The estimated flow-rate of sewage into the swamp was based on the 0.25 mgd capacity of the plant. The average concentration of phosphorus during one year was 6.4 mg/l or 6.4 g/m^3. The flow of phosphorus into the swamp each year was equal to

$$\frac{(568\ m^3/day)(6.4\ g\text{-}P/m^3)(365\ days/yr)}{2.04 \times 10^6\ m^2} = 0.653\ g\text{-}P/m^2\text{-}yr$$

2. The rainfall for 1974 was approximately 1.48 m/yr. The concentration of phosphorus in rainfall was 0.03 g/m^3 (Brezonik *et al.*, 1969). Thus the flow of phosphorus into the swamp from rainfall was equal to

$$(1.48\ m^3/yr\ m^2)(0.03\ g\text{-}P/m^3) = 0.044\ g\text{-}P/m^2\text{-}yr$$

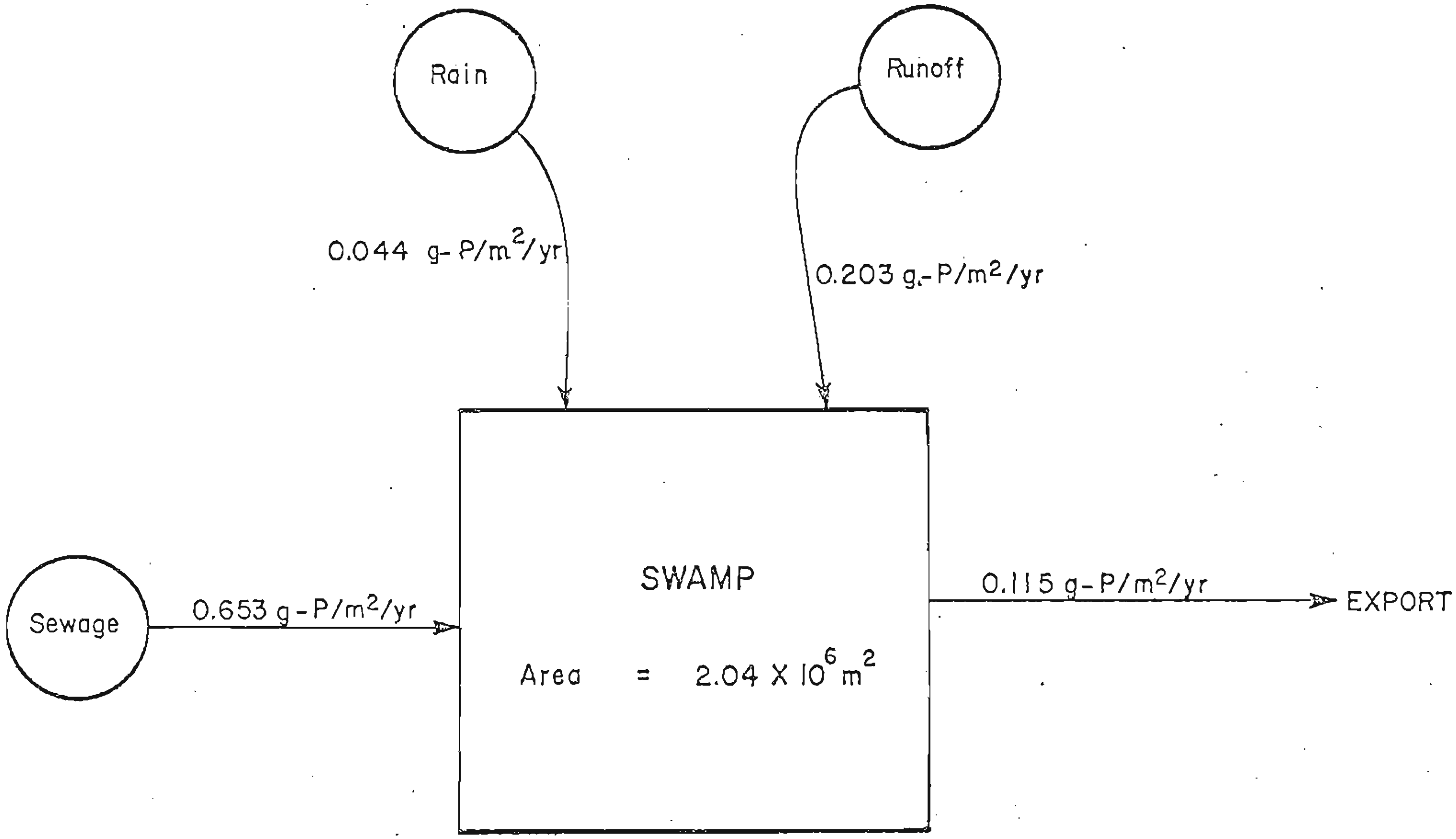
3. The runoff for 1975 was estimated as 0.550 m/yr. The concentration of phosphorus in urban runoff was approximately 0.3 $g\text{-}P/m^3$ and for pasture the concentration was approximately 0.5 $g\text{-}P/m^3$ (Shapiro and Odum, 1975). The runoff into the swamp was composed of 34.8% urban and 65.2% improved pasture. The input of phosphorus was computed as follows:

$$(0.550\ m^3/m^2\text{-}yr)(0.348)(0.5\ g/m^3) + (0.550\ m^3/m^2\text{-}yr)(0.652)(0.3\ g/m^3) = 0.203\ g\text{-}P/m^2\text{-}yr$$

4. The outflow was 0.931 m/yr(see Figure 10). The average concentration of phosphorus for one year (from June 1974 - June 1975) at the over-flow culvert at station 12 was 0.124 g/m^3. The phosphorus exported was

$$(0.931\ m^3/m^2\text{-}yr)(0.124\ g/m^3) = 0.115\ g\text{-}P/m^2\text{-}yr$$

Figure 13. Phosphorus model for the experimental swamp.



Rain
Runoff
0.044 g-P/m²/yr
0.203 g.-P/m²/yr
Sewage
0.653 g-P/m²/yr
SWAMP
Area = 2.04 X 10⁶ m²
0.115 g-P/m²/yr
EXPORT

Since all the pathways were described in terms of total g/m^2-yr, the effects of dilution through rain and runoff were included. Thus, the total export of phosphorus to the lake was low, only 0.115 g/m^2-yr.

In a dry year such as 1975, there was no export to the lake, since much of the swamp was dry. The water that did reach the swamp was lost by evapotranspiration or helped to maintain the water level at or near the soil surface. Throughout the study, the soil in the swamp was very moist. However, from December 1974 through September 1975 there was no water flow observed through the culvert at station 12.

DISCUSSION

Nutrient Uptake Effectiveness of the Swamp

Wetlands systems can be used as an alternative to tertiary treatment as was shown for this mixed hardwood swamp. In a fairly short distance from the sewage plant the swamp removed most of the nutrient input from the sewage effluent. After flowing through 3.7 km (2.3 mi) of swamp the concentrations of phosphorus showed a 98.1% reduction over the levels measured at the sewage ditch entering the wetlands system. In the same distance the total nitrogen concentration was reduced by 89.7%. A sedimentation-coagulation process of advanced waste water treatment removes approximately 98-99.5% of the phosphorus (Dobrzynski, 1975), which is in the same range as the phosphorus removal currently being effected by the swamp. The nitrogen removal rate using an extended biological decomposition method removes 90-99% of the nitrogen, which is above the 89.7% removal by the swamp. However, the natural concentration of nitrogen in the swamp was 1.4 mg/l. Thus, even if the nitrogen in the sewage effluent were completely removed, the concentration of nitrogen in the swamp would remain at about the same level. Even during the wet conditions when the largest export of nutrients occurs, the nutrient flow into swamp D and the lake was less than the nutrient inflow from rain and runoff. Thus the sewage effluent from Wildwood is not a major contributor to the eutrophication of Lake Panasoffkee.

The decrease in nutrient concentration was accompanied by an increase in the productivity of vegetation within the swamp. The cypress and ash grew more rapidly in swamp B than in swamp D. This elevated growth rate represented a 20% increase in the uptake rate of phosphorus by ash. Also the understory was most dense in swamp B probably in response to the extra water and nutrients provided by the sewage effluent. Smith and Post (1973) found a similar response of the understory in a pine community also being treated with secondary effluent.

A Detailed Nutrient Model of the Swamp

The model shown in Figure 14 summarizes the flow of nitrogen and phosphorus through the swamp. An explanation of the symbols is shown in Figure 15. The nutrients are carried into the swamp by the water. The standing water, shown as a tank, exchanges nutrients freely with the sediment tank. The nutrients in both of these tanks are available for uptake by the aquatic vegetation, however the trees depend mainly on nutrients from the sediments. The nitrogen is taken up by plants in the form of nitrate or ammonia, while the phosphorus utilized by plants is in the phosphate form. After being used by the producers the nutrients become part of the detritus. The microbes use oxygen in their respiration and convert the detritus back to its inorganic form. Also some microbes denitrify the nitrogen which then leaves the system as nitrogen gas. Since the sediments are usually saturated there is very little dissolved oxygen. However the water is shallow, allowing the diffusion of oxygen into the water. In addition many areas of the swamp were dry during part of the year which caused some oxidation of the sediments.

Phosphorus may be absorbed onto clay particles and precipitate in the form of $FePO_4$, $AlPO_4$, and $Ca_{10}(PO_4)_6F_2$ (variscite, strengite, and fluroapatite, respectively). The magnitude of this process is dependent

Figure 14. A detailed nutrient model for the experimental swamp.

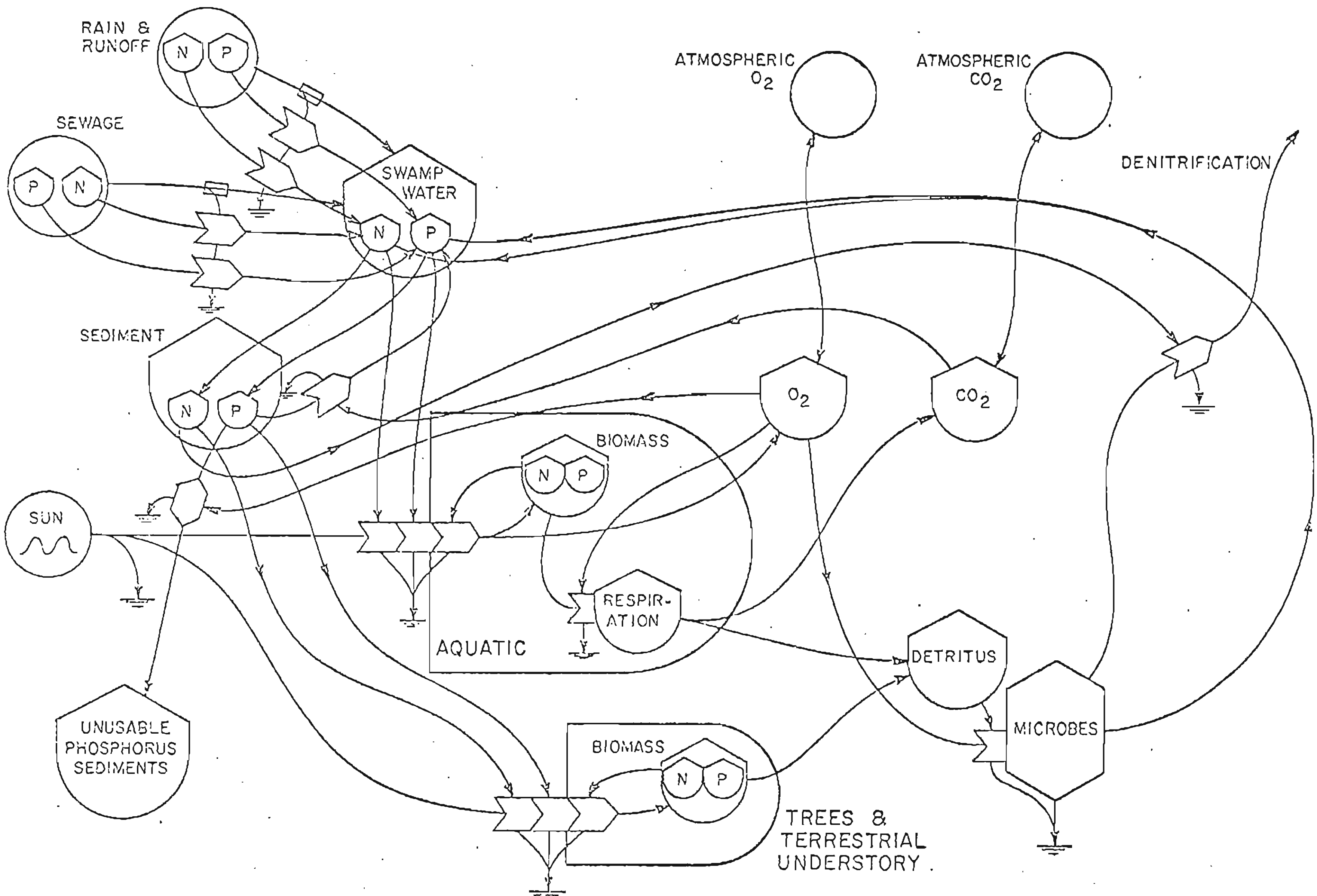

RAIN & RUNOFF
N
P
SEWAGE
P
N
SWAMP WATER
N
P
SEDIMENT
N
P
ATMOSPHERIC O_2
ATMOSPHERIC CO_2
DENITRIFICATION
O_2
CO_2
BIOMASS
N
P
SUN
RESPIR-ATION
AQUATIC
DETRITUS
MICROBES
UNUSABLE PHOSPHORUS SEDIMENTS
BIOMASS
N
P
TREES & TERRESTRIAL UNDERSTORY.

Figure 15. Description of Energese, an energy circuit language (Odum, 1971).

(a) External, unlimited energy source to the system.

(b) Heat sink as required by the second law of thermodynamics in order to do work.

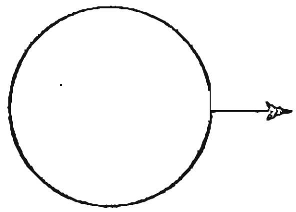
(c) Component of energy or matter storage in which quantity stored is the integral of the inflows and outflows.

(d) Autotrophic individual or community which has both anabolic and catabolic processes.

(e) Interaction in which output is some unspecified function of two input forces.

(f) Autocatalytic unit which by virtue of feedback mechanisms may enhance its ability to process energy.

(g) Force (X) acting to proportion of flow (J).

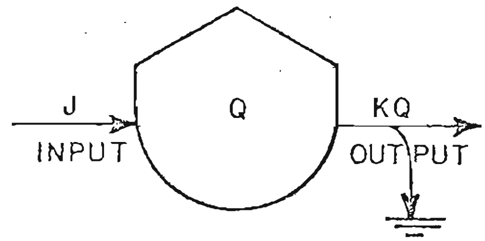


SOURCE

(a)

HEAT SINK

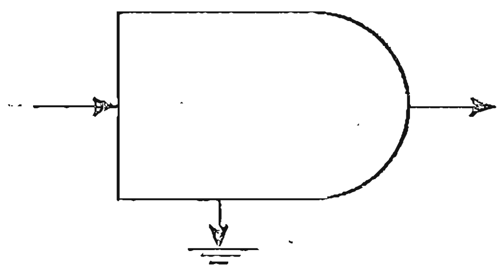
(b)



$\dot{Q} = J - KQ$

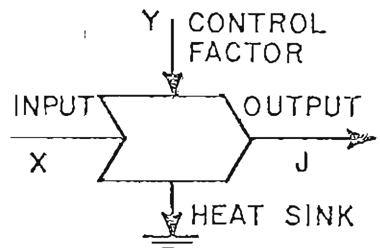
PASSIVE STORAGE

(c)



GREEN PLANT AND
OTHER PRODUCERS

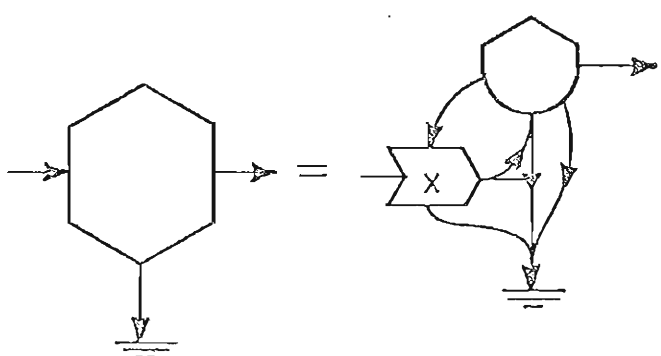
(d)



$J = f(X,Y)$

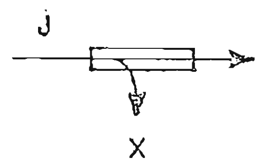
GENERALIZED WORKGATE

(e)



SELF MAINTAINING CONSUMER UNIT

(f)



FORCE FROM
A FLOW

(g)

on the oxygen level and pH. Brezonik *et al.* (1969) reported that under anerobic conditions more phosphorus was released by lake sediments. This conclusion concurred with a report by Stumm and Loecki (1970) which stated that the reduced $Fe(II)PO_4$ compound was soluble while $Fe(III)PO_4$ was not.

As mentioned above one sink for nitrogen is the atmosphere. In this process nitrate nitrogen is reduced to nitrogen gas. Favorable conditions for this process are an anaerobic environment, a neutral pH (Keeney, 1973), and the presence of organic matter. Both of these conditions are met by the Wildwood swamp indicating that denitrification is possibly an important mechanism in the nitrogen budget.

Since it was not feasible to measure the value of each flow shown in the model, the model itself cannot be used to extrapolate the effectiveness of the swamp under other conditions such as an increase in the sewage volume. However, the increased uptake of phosphorus by ash was observed only in swamp B, which is about 4% of the total area of the experimental swamp. The sewage flow is often contained within swamp B but if the flow were doubled then more nutrients probably would be carried into swamp C, where 194 ha (480 acres) of swamp are available. Based on the data from swamp B it seems likely that some increased productivity could occur in swamp C in response to the greater levels of water and nutrients. Because most of the nutrient and pathogen removal occurred within a small area, swamp C would probably continue to function effectively as an alternative to tertiary treatment even if Wildwood experienced some growth in population. The precise relationship between the area of swamp needed per volume of waste is very important and requires further research.

Public Health Aspects of Swamp Sewage Disposal

In addition to removing nutrients, the swamp appeared to be filtering bacteria out of the wastewater. Although bacterial measurements were not of major importance in this study the few measurements made probably are indicative of a general pattern. Other more intensive studies support this (Sopper and Kardos, 1973). Fecal coliform and fecal streptococci bacteria are always found in the excreta of warm-blooded animals. Their presence in natural waters signifies recent fecal pollution and possibly the presence of pathogens. The ratio of fecal coliforms to fecal streptococci was used to determine the origin of the fecal contamination. Throughout this study the ratio in swamp B and sometimes in marsh A was at or below 0.7 which is outside the range of human fecal contamination.

Another important public health consideration is the release of virus from sewage effluent. Dr. Flora Mae Wellings and her associates at the State Epidemiological Research Center, Tampa, Florida, performed virus analyses on the effluent and swamp water at Wildwood. Their results are summarized in Appendix B. They found that although many viruses were released in the sewage effluent, their concentration in the water declined so rapidly that none were found beyond marsh A. As expected (De Flora *et al.*, 1975) the viruses were concentrated in the sediments. Virus particles become bound up in the organic matter if there is a large amount of organics in the water, thus protecting them from the chlorine disinfectant (Schaub *et al.*, 1974). The Wildwood plant effluent was very turbid with a BOD reduction ranging from 30 to 80%. It contained a large amount of organic matter presumably carrying many virus. The new 0.5 mgd plant now under construction will hopefully eliminate these problems. A study done by Malina *et al.* (1975) found that an activated sludge treatment process was able to cause the inactivation of virus. Stokes and Hedenland (1974) reported that with a good activated sludge process 98% BOD removal was attained. When this treatment was coupled with a chlorine residual of 1 ppm of HOCl for 30 minutes, viruses were quite effectively controlled.

Virus standards have been very hard to develop due to the lack of reliable techniques for the concentration and detection of viruses in water. The "natural" or "tolerable" concentrations of virus have not been determined. However James McDermott, chief of EPA Water Supply Division (Taylor, 1974), proposed that 1 plaque forming unit (pfu) was equivalent to one infective dose and estimated that one out of every 100 to 1000 infected people would exhibit disease symptoms. However, the swamp water in Wildwood is used neither for drinking nor recreation, so higher viral levels might be permissible without causing a public health problem.

While negative results in the ground water wells do not prove that there is no viral contamination, the presence of a clay layer indicates that there probably is little vertical movement of water which would carry virus into the ground water. The virus particles are probably absorbed onto the soil surfaces in the top 0.6 m (2 ft) (Drewry and Eliassen, 1968). No conclusive evidence on the survival time of human pathogenic viruses in the soil has been reported, but Wellings *et al.*, (1975) reported 28 days survival in a cypress dome. The data collected on the ground water wells in Wildwood showed no virus present suggesting that there is not an excessive buildup of virus in the swamp even after 20 yr of receiving sewage effluent. With the new secondary activated sludge and the viral removal capacity of the swamp, it is suggested that additional virus treatment may be only a costly burden to the town without producing tangible benefits.

Economic Value of the Swamp

Since the swamp was shown to be an effective alternative to tertiary wastewater treatment, the economic benefits of this swamp disposal system were explored. The construction cost of a secondary treatment plant of 0.5 mgd capacity in the vicinity of the Wildwood area was estimated by Lochran (1975) to be $290,000. With a life expectancy of 25 years and an interest rate of 10%, the amortized yearly cost was $31,950 for construction alone. In order to extend the application of this thesis, the national cost figures from Smith (1968) were used to estimate the maintenance cost for a 0.5 mgd secondary activated sludge plant as $20,000 in 1967. Using the Engineering News-Record (1975) cost index, this figure was updated to $39,850 as of March, 1975. Thus the total yearly cost for secondary treatment including construction and maintenance would be $71,800 or $0.39/1000 gal.

To incorporate tertiary treatment, including biological nitrification-denitrification, chemical precipitation, and filtration, would double the construction cost (Lochran, 1975). Maintenance costs estimated from Smith (1968) would be an additional $47,450/yr for a 0.5 mgd tertiary treatment plant. The total cost for tertiary treatment would be $79,400. Thus the swamp as an alternative to the tertiary treatment method alone has a value of $79,400/yr to the residents of Wildwood. The savings for the 25 year life expectancy of the plant are nearly $2,000,000, which would more than pay for the land itself. These figures are summarized in Table 11.

The two mini models shown in Figure 16 represent the interaction between the swamp and the city with and without tertiary treatment. Model A shows the present interaction between the city and the swamp. The waste produced requires fossil fuel for secondary treatment but the product of this treatment still contains usable energy for the swamp producers in the form of nutrients. Once brought into the swamp the nutrients allow a higher productivity rate and produce timber more rapidly. Model B describes the case of using tertiary wastewater treatment requiring more fossil fuel input. During this process the water and nutrients are separated by precipitating the nutrients and then physically removing them from the system. Clean water is the only product of this system.

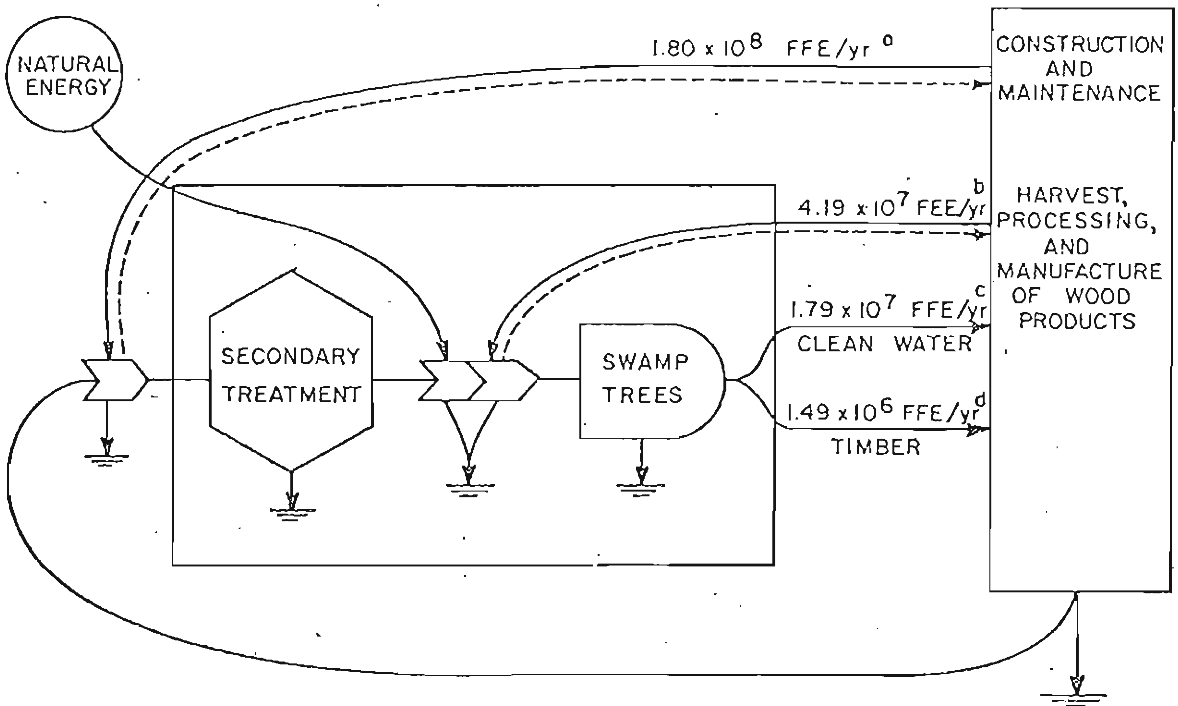
By converting all of the energy flows shown on the models into units having the same energy quality they can easily be compared. The technique by which this conversion can be made was developed by Odum and Brown (1975) using the fossil fuel equivalent (FFE) as the basic unit. The concept of energy quality is based on the fact that some energy forms such as electricity have more uses for mankind than the dilute energy of sunlight and therefore have a higher energy quality. Odum and Brown (1975) reported the energy quality factor of sunlight to fossil fuel is 2000, meaning that 1 kcal of fossil fuel (FFE) is equivalent to 2000 kcal of sunlight. Odum and Brown (1975) calculated the energy quality of net primary productivity to be 20 as compared to fossil fuel. Since 1 g of biomass is equivalent to 4.5 kcal of energy as determined by a bomb

Table 11. The construction and maintenance costs for secondary and tertiary treatment are given for an 0.5 million gallons per day sewage plant.

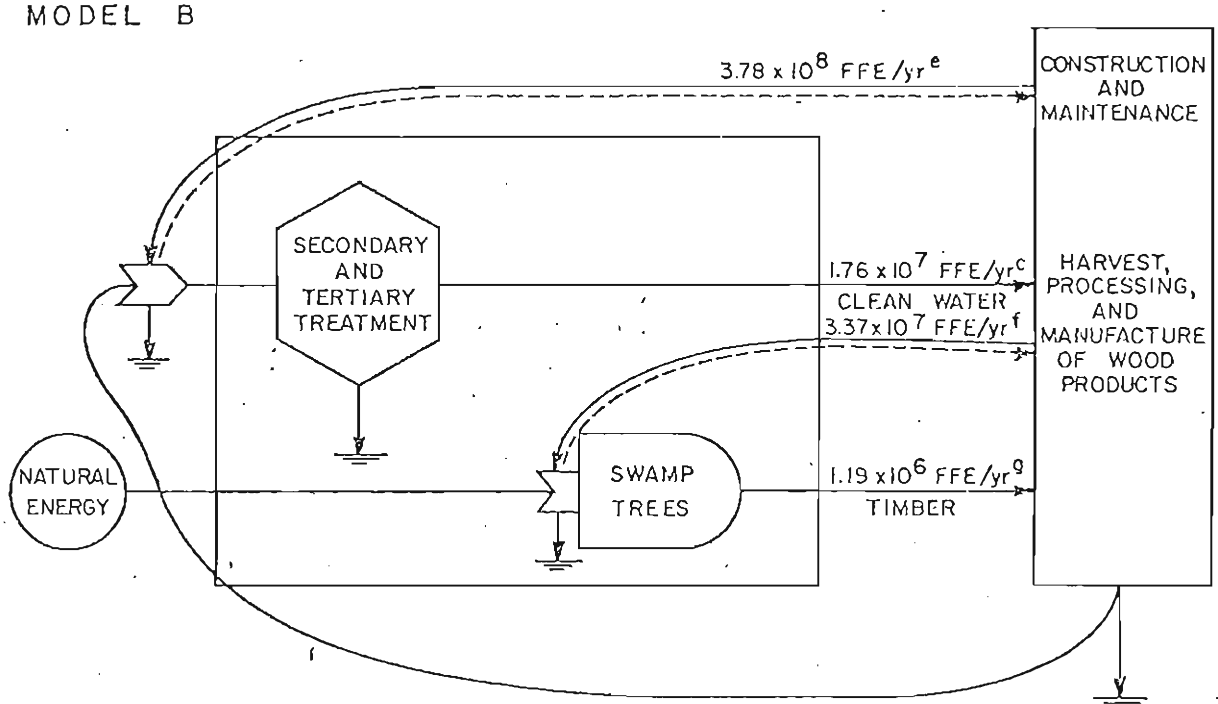
	Amortized Construction cost, 25 yr. life at 10% yearly	Yearly Maintenance Costs	Yearly Total Costs	Total Costs (life of plant estimated to be 25 years)	Cost per 1000 gal.
Secondary Treatment	$31,949	$39,850	$71,799	$1,794,975	$0.39
Tertiary	$31,949	$47,450	$79,399	$1,984,975	$0.44
Both	$63,898	$87,300	$151,198	$3,799,950	$0.83

Figure 16. Models A and B show the energetic evaluation of the two waste disposal methods.

MODEL A



MODEL B



Footnotes for Figure 16

a) Construction and maintenance costs for secondary sewage treatment = \$71,800; 20,000 FFE/dollar (Kylstra, 1975)

$$(\$71,800)(20,000\ \text{FFE/dollar}) = 1.80 \times 10^{8}\ \text{FFE/yr}$$

b) Assume selective harvest of net productivity with 75% merchantable lumber

$$\frac{(1101\ \text{g/m}^2\text{-yr})(600\ \text{m}^2)(0.75)}{(0.5\ \text{g/cm}^3)(2359.7\ \text{cm}^3/\text{bd-ft})} = 419.9\ \text{bd-ft/yr}$$

harvesting and rough cut cost = \$995/1000 bd-ft (Brown, 1976)

$$(\$995/1000\ \text{bd-ft})(419.9\ \text{bd-ft/yr})(20,000\ \text{FFE/dollar}) = 8.36 \times 10^{6}\ \text{FFE/yr}$$

processing cost = \$1095/1000 bd-ft (Brown, 1976)

$$\frac{\$1095 - \$995}{1000\ \text{bd-ft}}(419.9\ \text{bd-ft/yr})(20,000\ \text{FFE/dollar}) = 8.40 \times 10^{5}$$

manufacturing cost = \$5000/1000 bd-ft

$$\frac{\$5000 - \$1095}{1000\ \text{bd-ft}}(419.9\ \text{bd-ft/yr})(20,000\ \text{FFE/yr}) = 3.28 \times 10^{7}\ \text{FFE/yr}$$

total cost;
$$(8.36 \times 10^{6}\ \text{FFE/yr}) + (8.40 \times 10^{5}\ \text{FFE/yr}) + (3.28 \times 10^{7}\ \text{FFE/yr}) = 4.19 \times 10^{7}\ \text{FFE/yr}$$

c) Energy cost to cleanse water of approximately 200 mg/l of dissolved solids.

$$\Delta F = RT\ \ell n\ C1/C2$$
$$= (1.987\ \text{cal/mole-deg.})(300°)\ \ell n\ \frac{0.9999783}{1.0000004}$$
$$= 8.48 \times 10^{-4}\ \text{kcal/g}$$

Grams of water processed each year by sewage plant (568 m^3/day) (365 days/yr)(10^3 l/m^3) = 2.077×10^{11} g/yr

energy quality of water = 0.1 FFE/kcal of water (Costanza, 1976)

Energy value of clean water from sewage plant

$$(0.1\ \text{FFE/kcal})(2.07 \times 10^{11}\ \text{g/yr})(8.48 \times 10^{-4}\ \text{kcal/g}) = 1.76 \times 10^{7}\ \text{FFE/yr}$$

d) Net productivity for swamp B = 1101 g/m^2-yr; energy quality of wood to fossil fuel = 2.0 (Odum and Brown, 1975)

$$\frac{(1101\ \text{g/m}^2\text{-yr})(4.5\ \text{kcal/g})(600\ \text{m}^2)}{2\ \text{kcal/FFE}} = 1.49 \times 10^{6}\ \text{FFE/yr}$$

e) Construction and maintenance costs for both secondary and tertiary treatment = \$151,200

$(\$151{,}200/\text{yr})(20{,}000\ \text{FFE/yr}) = 3.78 \times 10^{8}\ \text{FFE/yr}$

f) Assume selective harvest of net productivity with 75% mechantable lumber.

$$\frac{(882\ \text{g/m}^2\text{-yr})(600\ \text{m}^2)(0.75)}{(0.5\ \text{g/cm}^3)(2359.7\ \text{cm}^3/\text{bd-ft})} = 336.4\ \text{bd-ft/yr})$$

harvesting cost and rough cut cost = \$995/1000 bd-ft (Brown, 1976)

$(\$995/1000\ \text{bd-ft})(336.4\ \text{bd-ft/yr})(20{,}000\ \text{FFE/dollar}) = 6.69 \times 10^{6}$ FFE/yr

processing cost = \$1095/1000 bd-ft (Brown, 1976)

$$\left(\frac{\$1095 - \$995}{1000\ \text{bd-ft}}\right)(336.4\ \text{bd-ft/yr})(20{,}000\ \text{FFE/dollar}) = 6.73 \times 10^{5}\ \text{FFE/yr}$$

manufacturing cost = \$5000/1000 bd-ft (Brown, 1976)

$$\left(\frac{\$5000 - \$1095}{1000\ \text{bd-ft}}\right)(336.4\ \text{bd-ft/yr})(20{,}000\ \text{FFE/dollar}) = 2.63 \times 10^{7}\ \text{FFE/yr}$$

Total cost:
$(6.69 \times 10^{6}\ \text{FFE/yr}) + (6.73 \times 10^{5}\ \text{FFE/yr}) + (2.63 \times 10^{7}\ \text{FFE/yr}) = 3.37 \times 10^{7}\ \text{FFE/yr}$

g) Net productivity for swamp without sewage effluent:

$$\frac{(882\ \text{g/m}^2\text{-yr})(4.5\ \text{kcal/g})(600\ \text{m}^2)}{2\ \text{kcal/FFE}} = 1.19 \times 10^{6}\ \text{FFE/yr}$$

calorimeter, then 1 g of biomass is equivalent to 4.5/20 FFE. Kylstra (1975) reported the value of money to be 20,000 FFE per dollar. These conversion factors were used to determine the kcal of fossil fuel represented by the timber productivity of the swamp, the cost of harvesting, processing, and manufacture of the wood, and the cost of waste treatment. Once all the values were converted into FFE, the two systems were easier to compare.

In Model A the waste is treated using money from the economy and natural energy. Under this system a total of 2.22×10^8 FFE/yr is required from the main economy of Wildwood and 1.91×10^7 FFE/yr is produced. This output represents approximately a 0.9% return on the energy invested from the economy. Therefore by matching this invested energy with the natural energy of the area, the system produces more timber.

However, as shown in Model B, the technological processes of waste treatment does not represent a very high return on the energy invested, only about 0.5%. In this system the local economy invests 4.12×10^8 FFE/yr but the system itself produces only 1.19×10^7 FFE/yr which is the value of the clean water produced and the lower timber yield.

The city of Wildwood retains a very valuable, and in one sense, renewable resource in the swamp. The monetary value alone of this wetlands system for just a tertiary treatment facility is quite high. This figure, however, does not begin to include the importance of the swamp as contributing to the regional energy flow through the management of water and timber. In nature, the system which is the most efficient in using all its energy sources for the maximum power output wins out in competition with other systems (Odum, 1971; Odum and Brown, 1975). The swamp represents an energy pathway which can be used by the city of Wildwood in many ways for their mutual benefit and maximum power output. The use of the swamp to reprocess wastewater enables the taxes of the city to remain low. In addition, the fossil fuel which might have been used to build and maintain a tertiary treatment plant can be used for more important tasks. Also, if the net productivity of the trees in the swamp is harvested for timber, then the system produces an additional economic gain while maintaining the swamp in its current successional stage. In addition, processed water is available to flow into Lake Panasoffkee.

The Wildwood area provides an excellent example of the interaction of man and nature in which both benefit. The City of Wildwood is not wealthy enough to support a high energy waste disposal system. It is, however, located in a largely natural area and small enough that the swamp is able to process its waste efficiently. Though the loading rate and the area of swamp needed will vary in other areas, the study of Wildwood shows that wetland systems can be used as an alternative to high cost, tertiary treatment facilities.

APPENDIX A

Table A1. Field sampling results of 19 August 1974.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-H mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l
1	1.48	1.90	0.40	0.750	1.77	4.43	23.5	25.0
2	1.02	1.28	0.05	0.230	0.00	---	22.5	21.5
3	0.80	1.00	0.04	0.000	0.00	2.43	21.5	20.0
4	1.48	1.72	0.27	0.000	trace	3.45	23.5	21.0
5	1.34	2.84	0.09	0.690	trace	4.80	23.0	24.0
6	1.06	1.28	0.07	0.000	0.00	3.41	20.5	23.5
7	0.88	1.10	0.09	0.000	0.00	3.59	19.0	22.8
8	0.88	1.16	0.28	0.000	0.00	---	19.0	24.0
9	0.92	1.28	0.25	0.000	0.00	1.77	25.0	28.0
12	0.16	0.32	0.44	0.000	0.00	1.21	21.5	19.5
15	0.16	0.20	0.13	0.000	0.00	2.52	7.7	> 72.0
16	0.10	0.12	0.13	0.000	0.00	1.12	30.0	45.0
10	0.28	0.40	0.42	0.000	0.00	2.15	11.5	24.5
11	0.26	0.46	0.28	0.000	0.00	2.10	15.5	28.5
13	0.40	0.48	0.18	0.000	0.00	2.15	8.5	29.0
14	0.34	0.38	0.36	0.000	0.00	2.24	38.5	> 41.0

Table A2. Field sampling results of 18 September 1974.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l
1	4.05	4.76	1.40	0.055	4.94	10.70	47.0	17.5
2	1.85	2.00	0.00	0.033	2.24	2.46	40.0	11.0
3	1.52	1.90	0.00	0.000	1.24	2.83	40.0	16.0
4	1.62	1.90	0.00	0.000	1.91	2.24	40.0	17.0
5	0.25	0.40	0.24	0.000	0.23	0.90	34.5	7.5
6	1.32	1.48	0.00	0.000	0.78	1.79	37.5	8.5
7	0.20	0.22	0.06	0.000	0.00	1.00	28.5	15.0
8	0.82	0.92	0.00	0.000	0.78	1.79	34.5	9.5
9	0.90	1.00	0.00	0.000	0.34	1.45	43.0	8.0
12	0.21	0.24	0.00	0.000	0.11	1.10	33.0	16.0
15	0.07	0.20	0.09	0.000	0.11	1.35	34.5	14.0
16	0.00	0.10	0.14	0.000	0.44	1.80	21.0	22.0
10	1.04	1.20	0.16	0.000	0.34	1.92	35.0	9.0
11	0.24	0.28	0.09	0.000	0.11	0.90	33.0	11.0
13	0.27	0.30	0.06	0.000	0.11	2.35	52.5	21.5
14	0.39	0.44	0.00	0.000	0.11	---	72.5	11.5

Table A3. Field sampling results of 15 October 1974.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-P mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l
1	8.60	7.90	0.20	0.004	12.50	5.60	54.0	37.5
2	4.10	4.10	0.20	0.003	7.16	2.37	48.0	22.5
3	3.64	3.80	0.20	0.003	5.39	2.12	45.0	22.5
4	2.64	2.30	0.20	0.008	3.59	1.00	43.5	15.5
5	0.26	0.41	0.20	0.000	0.00	1.12	36.0	19.0
6	1.13	1.36	0.00	0.000	2.35	1.07	47.5	15.5
7	1.16	1.24	0.00	0.000	2.63	1.55	43.0	13.5
8	0.92	0.90	0.00	0.004	1.96	0.00	43.5	16.5
9	1.20	0.92	0.00	0.000	0.00	1.00	52.5	18.0
12	0.07	0.10	0.20	0.000	0.00	0.78	46.0	15.0
15	0.05	0.05	0.00	0.000	0.00	0.67	34.5	12.5
16	0.04	0.09	0.20	0.000	0.00	3.13	26.0	25.5
10	0.06	0.13	0.00	0.000	0.00	1.57	39.5	17.0
11	0.08	0.09	0.00	0.000	0.00	0.78	48.0	13.0
13	0.10	0.14	0.00	0.000	0.00	1.35	65.0	35.0
14	0.13	0.16	0.00	0.000	0.00	1.12	67.0	31.5

Table A4. Field sampling results of 21 November 1974.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	8.25	8.60	All below detectable limits	4.600	14.90	5.60	52.0	46.0	
2	8.70	9.45		0.000	18.00	3.60	58.0	36.0	12 inches
3	7.75	8.50		0.000	16.50	3.47	61.0	28.0	8 inches
4	6.75	4.70		4.300	4.03	2.13	44.0	24.0	12 inches
5	0.21	0.38		0.000	0.00	2.56	36.0	29.0	
6	2.90	5.05		6.500	5.81	1.90	48.0	21.0	24 inches
7	3.33	4.30		7.300	3.47	1.79	42.0	27.0	11 inches
8	0.49	2.80		6.200	0.00	4.02	42.0	29.5	
9	0.11	0.16		0.000	0.00	2.52	59.0	31.0	
9a	4.10	5.00		9.000	4.92	2.24	44.0	27.0	
12	0.04	0.07		0.000	0.00	1.79	46.0	24.0	
15	0.03	0.09		0.000	0.00	1.68	30.0	17.0	23 inches
16	0.02	0.08		0.000	0.00	2.13	30.0	32.0	30 inches
10	0.03	0.07		0.000	0.00	1.79	42.0	22.0	30 inches
11	0.01	0.07		0.000	0.00	1.29	46.0	25.5	
13	0.05	0.08		0.000	0.00	2.01	69.0	37.0	8 inches
14	0.07	0.11		0.000	0.00	1.57	66.0	54.0	

Table A5. Field sampling results of 17 December 1974.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l
1	9.00	9.40	0.00	58.000	15.40	5.82	48.0	38.0
2	5.50	5.75	0.00	0.000	8.50	2.13	40.0	28.0
3	6.35	6.45	0.00	0.000	9.50	2.02	41.0	28.0
4	1.26	1.70	0.00	15.000	0.00	3.70	27.0	28.0
5	0.29	0.60	0.00	0.000	0.00	1.00	27.0	29.0
6	1.26	1.65	0.00	62.000	0.00	1.00	25.0	28.0
7	1.20	1.42	0.00	33.000	0.00	1.57	27.0	22.0
8	1.11	1.50	0.50	40.000	0.00	2.47	32.0	43.0
9	0.30	0.46	0.00	0.000	0.00	1.80	82.0	61.0
9a	0.55	0.64	0.00	0.000	0.00	1.57	43.0	45.0
12	0.01	0.04	0.00	0.000	0.00	0.67	38.0	24.0
15	0.10	0.14	0.00	0.000	0.00	1.00	23.0	20.0
16	0.01	0.02	0.00	0.000	0.00	0.90	32.0	23.0
10	0.04	---	0.00	0.000	0.00	0.79	38.0	24.0
11	0.03	0.05	0.00	0.000	0.00	0.90	41.0	24.0
13	0.11	0.10	0.00	0.000	0.00	1.80	52.0	47.0
14	0.05	0.09	0.00	0.000	0.00	1.35	55.0	28.0

Table A6. Field sampling results of 17 January 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	10.60	10.60	All below detec-able limits	0.000	17.50	5.15	63.0	49.0	
2	10.60	11.00		0.000	22.00	3.92	80.0	30.0	
3	10.60	11.00		0.000	20.40	3.14	78.0	24.0	
4	0.95	0.94		19.000	0.00	2.58	41.0	11.0	
5	0.23	0.32		0.000	0.00	1.34	38.0	14.0	
6	0.50	1.32		48.000	0.00	2.58	40.0	5.0	
7	1.06	1.15		9.000	0.00	1.00	47.0	13.0	
8									No water
9	0.35	0.46		0.000	0.00	1.46	98.0	16.0	
9a	0.21	0.34		0.000	0.00	1.23	66.0	18.0	
12	0.01	0.07		0.000	0.00	0.79	65.0	3.0	
15	0.06	0.09		0.000	0.00	1.23	44.0	15.0	
16	0.01	0.05		0.000	0.00	0.90	54.0	5.0	
10	0.02	0.10		0.000	0.00	0.79	58.0	3.0	
11	0.03	0.06		0.000	0.00	0.56	63.0	5.0	
13	0.04	0.05		0.000	0.00	1.40	76.0	23.0	
14	0.01	0.09		0.000	0.00	1.29	90.0	8.0	

Table A7. Field sampling results of 21 February 1975

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	10.70	13.20	All below detectable limits	0.000	15.00	5.50	74.0	61.0	2 inches
2	11.60	13.40		0.000	19.70	2.91	83.0	24.0	
3	10.20	10.80		0.000	19.30	2.46	81.5	22.5	11 inches
4	0.90	1.40		Trace	0.00	2.58	37.0	26.0	5 inches
5	0.42	0.66		0.000	0.00	1.68	34.0	21.0	11 inches
6	5.05	5.70		Trace	0.00	10.80	93.0	52.0	6 inches
7									No water
8									No water
9	0.80	1.14		0.000	0.00	1.80	85.0	9.0	
9a	0.50	0.69		0.000	0.00	0.90	56.0	27.0	18 inches
12	0.04	0.08		0.000	0.00	0.34	57.0	5.0	
15	0.02	0.05		0.000	0.00	1.12	46.0	19.0	22 inches
16	0.05	0.11		0.000	0.00	0.90	34.0	24.0	
10	0.05	0.11		0.000	0.00	1.12	51.0	12.0	41 inches
11	0.05	0.09		0.000	0.00	1.23	55.0	5.0	16 inches
13	0.07	0.13		0.000	0.00	0.56	70.0	20.0	5 inches
14	0.06	0.11		0.000	0.00	1.12	82.0	30.0	

Table A8. Field sampling results of 19 March 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	11.10	11.00	0.00	0.000	19.90	12.10	57.0	48.0	
2	0.77	11.19	0.83	100.000	0.24	7.73	11.0	16.0	
3	8.08	8.69	0.00	40.000	13.40	9.10	44.0	31.0	
4	1.15	0.16	0.00	34.000	0.00	8.30	27.0	27.0	
5	0.43	0.86	0.00	5.000	0.00	7.20	32.0	23.0	
6									No water
7									No water
8									No water
9	0.87	1.14	0.00	0.000	0.00	7.10	52.0	21.0	
9a	0.48	0.67	0.00	0.000	0.00	6.72	41.0	29.0	
12	0.08	0.17	0.05	0.000	0.00	6.50	26.0	22.0	
15	0.03	0.12	0.00	0.000	0.00	6.05	30.0	20.0	
16	0.02	0.28	0.00	0.000	0.00	6.50	24.0	19.0	
10	0.06	0.17	0.00	0.000	0.00	6.61	30.0	26.0	
11	0.75	0.17	0.05	7.000	0.00	7.20	26.0	22.0	
13	0.08	0.17	0.00	0.000	0.00	6.60	42.0	28.0	
14	0.09	0.23	0.00	0.000	0.00	6.60	54.0	22.0	

Table A9. Field sampling results of 17 April 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-H mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	9.90	10.40	All below detectable limits	All below detectable limits	18.60	7.40	57.0	70.0	
2	10.40	10.40			20.80	4.59	59.0	60.0	
3	10.20	10.30			20.60	4.93	65.0	45.0	
4	0.87	1.11			0.00	2.90	14.0	37.0	
5	0.34	0.43			0.00	1.70	11.0	34.0	
6	0.18	1.00			0.00	1.70	10.0	40.0	
7	0.78	0.98			0.00	1.46	8.0	37.0	
8	.								No water
9	0.23	0.27			0.00	1.60	25.0	40.0	
9a	0.17	0.23			0.00	1.46	22.0	46.0	
12	0.04	0.07			0.00	1.12	26.0	41.0	
15	0.15	0.16			0.00	1.20	12.0	48.0	
16	0.02	0.05			0.00	1.20	24.0	41.0	
10	0.09	0.19			0.00	1.12	29.0	33.0	
11	0.05	0.10			0.00	0.12	35.0	32.0	
13	0.04	0.05			0.00	1.60	34.0	51.0	
14	0.02	0.05			0.00	1.70	50.0	49.0	

Table A10. Field sampling results of 23 May 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	9.64	10.99	All below detectable limits	0.000	15.12	4.37	50.0	48.0	
2	10.00	10.60		0.000	18.10	1.00	60.0	25.0	13 inches
3	9.83	10.80		0.000	19.10	1.46	60.0	25.0	
4	2.03	2.14		0.000	0.45	1.23	30.0	25.0	10 inches
5	0.57	1.06		0.000	0.00	2.80	23.0	21.0	18 inches
6	1.37	1.64		0.000	0.45	2.40	26.0	28.0	2 inches
7									No water
8									No water
9									No water
9a	0.21	0.30		8.000	0.00	1.20	47.0	21.0	No flow
12	0.10	0.16		0.000	0.00	1.34	46.0	15.0	
15	0.10	0.17		0.000	0.00	0.80	15.0	15.0	21 inches
16	0.09	0.17		0.000	0.00	1.70	27.0	27.0	17 inches
10	0.56	0.79		0.000	0.00	1.23	30.0	17.0	33 inches
11	0.27	0.27		0.000	0.00	0.90	51.0	15.0	10 feet
13	0.09	0.15		0.000	0.00	1.50	71.0	25.0	
14									No water

Table A11. Field sampling results of 23 June 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	9.74	10.60	All below detectable limits	All below detectable limits	16.80	6.10	95.0	65.0	
2	10.30	10.40			19.80	4.88	91.0	39.0	
3	10.00	10.20			19.40	5.15	91.0	59.0	18 inches
4									No water
5	0.80	0.89			1.12	1.23	92.0	48.0	3 inches
6									No water
7									No water
8									No water
9									No water
9a									No water
12									No water
15	0.04	0.12				1.79	76.0	40.0	16 inches
16	0.17	0.25				1.46	61.0	51.0	39 inches
10	0.61	0.60				1.90	65.0	50.0	23 inches
11									No water
13									No water
14									No water

Table A12. Field sampling results of 17 July 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	10.02	10.02	All below detectable limits	All below detectable limits	15.10	5.54	Analyzer out of order	Analyzer out of order	
2	10.90	11.37			12.90	1.74			12 inches
3	11.95	9.83			19.60	2.97			17 inches
4	1.06	1.25			0.00	2.13			11 inches
5	1.42	1.45			0.00	2.13			14 inches
6	1.71	1.88			0.00	2.91			8 inches
7	2.86	5.25			0.00	2.41			3 inches
8									No water
9									No water
9a									No water
12									No water
15	0.17	0.36			0.00	2.07			18 inches
16	0.53	1.09			0.00	1.85			29 inches
10	0.58	1.18			0.00	1.57			29 inches
11	0.22	0.48			0.00	1.23			1 inch
13									No water
14									No water

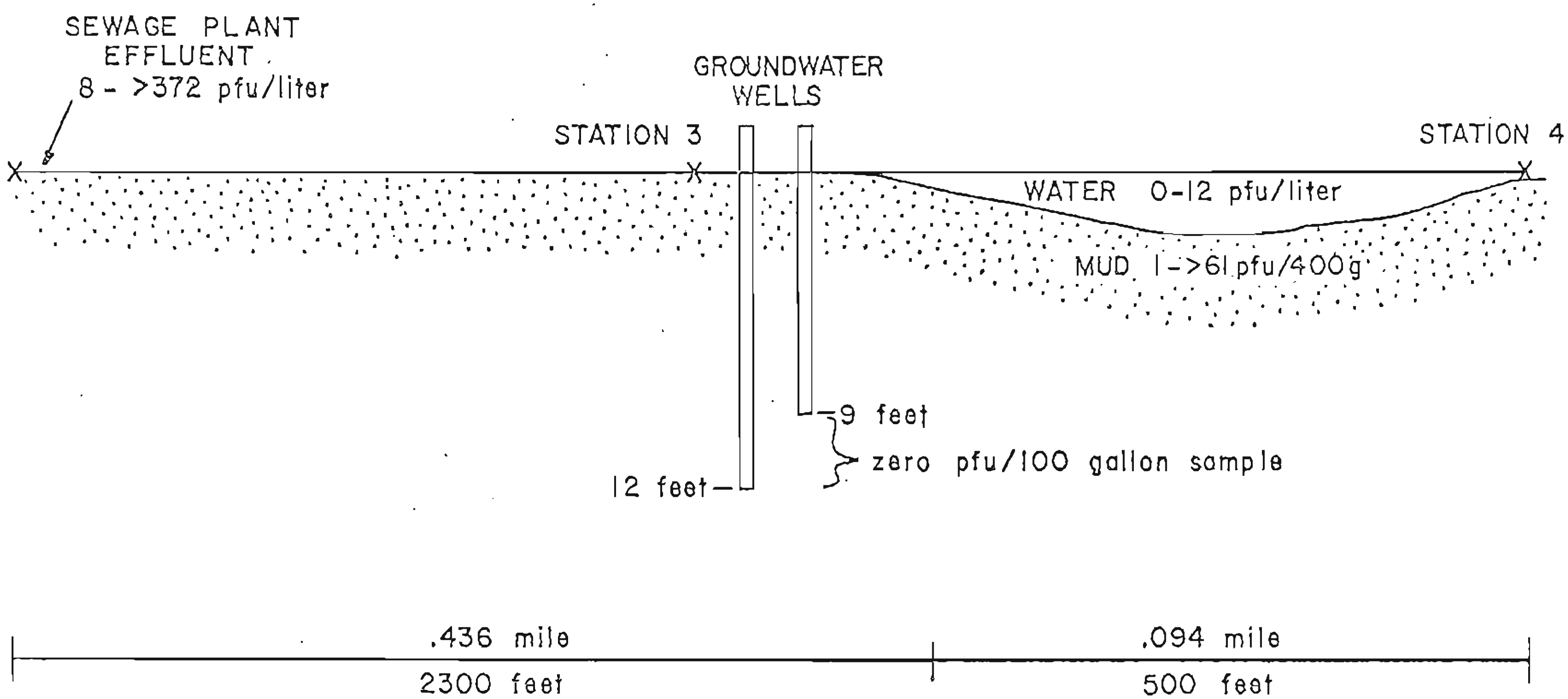
Table A13. Field sampling results of 26 August 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	9.80	10.10	All below detection limits	All below detection limits	16.70	3.60	60.0	50.0	
2	10.50	10.20			17.36	2.90	62.0	34.0	12 inches
3	10.30	10.20			17.92	3.00	62.0	28.0	15 inches
4	2.12	2.30			0.00	1.34	31.0	25.0	12 inches
5	0.66	1.35			0.00	1.80	29.0	28.0	15 inches
6									No water
7									No water
8									No water
9									No water
9a									No water
12									No water
15	0.11	0.35			0.00	1.34	50.0	34.0	17 inches
16	0.14	0.37			0.00	0.00	27.0	29.0	30 inches
10	0.69	0.90			0.00	0.00	35.0	26.0	24 inches
11									No water
13									No water
14									No water

Table A14. Field sampling results of 18 September 1975.

Sampling Location	PO_4-P mg/l	Total P mg/l	NO_3-N mg/l	NO_2-N mg/l	NH_3-N mg/l	Org. N mg/l	Inorg. C mg/l	Org. C mg/l	Remarks
1	7.10	7.70	All below detectable limits	All below detectable limits	13.50	4.30	43.0	45.0	
2	8.60	9.10			16.50	4.30	48.0	36.0	12 inches
3	9.10	9.40			15.60	3.58	46.0	40.0	27 inches
4	0.34	0.36			0.00	1.12	10.0	20.0	19 inches
5	0.38	0.28			0.00	1.00	10.0	20.0	20 inches
6	0.27	0.40			0.00	0.90	10.0	19.0	
7	0.38	0.40			0.00	1.00	10.0	19.0	10 inches
8									No water
9									No water
9a									No water
12	0.06	0.02			0.00	1.10	25.0	59.0	
15	0.04	0.26			0.00	0.90	30.0	39.0	26 inches
16	0.12	0.20			0.00	0.80	18.0	43.0	36 inches
10	0.29	0.33			0.00	1.60	17.0	30.0	30 inches
11	0.22	0.29			0.00	1.00	50.0	50.0	
13	0.16	0.00			0.00	1.10	23.0	42.0	
14									No water

APPENDIX B



*not drawn to scale

Figure B1. Location schematic of virus concentration ranges.

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

Suzanne E. Bayley

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