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Removal of nutrients from treated municipal wastewater by wetland vegetation

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Wildwood, Florida, population approximately 2 500, has been releasing secondarily treated wastewater effluent into a mixed hardwood swamp for 20 years. Wildwood is located in the central portion of Florida and is surrounded by the characteristically low, flat topography of the region. Because this land is often inundated, it is not readily adaptable to development. Natural waterways usually consist of the shallow streams which empty into a wetlands area, which in turn often borders a shallow lake. The swamp into which Wildwood releases its wastewater effluent extends about 8 km (5 miles) south of Wildwood and borders Lake Panasoffkee. Prior to and during this study, the Wildwood wastewater treatment facility consisted of a trickling filter plant with a capacity of 950 m^3/d (0.25 mgd). However, during the last few years, the plant has not operated properly and the effluent has received little more than primary treatment. At the start of this study a new activated sludge treatment plant was under construction. The Florida Department of Environmental Regulation was concerned that nutrients from the wastewater effluent might reach Lake Panasoffkee, making addition of tertiary treatment facilities at Wildwood desirable.

Recent studies [1,2] have shown that spray irrigation of wastewater effluent is one effective method of water recharge involving a natural system. This process, however, does involve some cost in elaborate transport and distribution equipment. In Florida these distribution costs can be reduced by using a wetlands system. Wetland systems are well suited for receiving large volumes of nutrient-laden water for two reasons: 1) the wetland system disperses water from a point source over a large area; 2) the vegetation itself is adapted to filter nutrients from the water. Swamp systems have been reported by Carter [3] to have a very high productivity of 990 to 1 170 $g/m^2 \cdot y$. 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 functions of swamps are characteristics comparable to a salt marsh.[4] Studies done in a North Carolina salt marsh by Marshall [5] 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 wastewater. Kitchens *et al.*[6] and Wharton [7] report that river floodplain swamps functioned effectively as a nutrient sink for both urban and agricultural waste.

METHODS

Description of study area. Sampling stations were numbered consecutively, with Number 1 located at the wastewater plant and Number 16 at the lake. Urban runoff from the city entered Marsh A at Station 5. Stations 10, 11, 13, and 14 did not receive wastewater and were located in the control area. Swamp D, on the Monarch Cattle Ranch. Marsh A and Swamps B and C received wastewater and jointly comprised the experimental swamp with a total area of 202 ha (500 acres). Marsh A received the wastewater directly from a diversion ditch leading from the wastewater plant. Marsh A is covered by *Lemna* sp. (duckweed); also present are *Typha latifolia* (cattail), *Salix* sp. (willow) and *Azolla* sp. The flow can be visually observed through this area and into Swamp B. Swamp B 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 ash), 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, the largest swamp. It is composed of *F. profunda, T. distichum, N. sylvatica, Acer rubrum* (maple), *Magnolia virginiana* (sweet bay), and *Liquidambar straciflua* (sweet gum), with an understory including *Itea virginica, Cornus foemina, Panicum sphagnicoal, Smilax walteria* (briar), *R. radicans, Sabel minor* (palmetto), and *Saururus cernuus* (lizard's tail). A culvert allowed the overflow of water during periods of high rainfall to flow from Swamp C through the northern corner of Swamp D, under Interstate 75, and then to Lake Panasoffkee. The control area was located in the southeastern portion of Swamp D. The control Swamp D was formerly part of the experimental Swamp C but was cut off from the experimental swamp by the Sunshine Parkway. The major portion of Swamp D is composed of the same tree species and understory as is found in Swamp C.

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 ortho-P, total P, NO_3^--N, NO_2^--N, NH_3-N, Kjeldahl N, inorganic and organic carbon. The tests were performed as described in "Standard Methods." [8] Total organic carbon (TOC) was measured with a TOC analyzer. At approximately 3-month intervals, temperature and dissolved oxygen (DO) were measured using a DO meter. Following the procedures in "Standard Methods" [8] the water samples were also analyzed for concentrations of magnesium, calcium, sodium, potassium, iron, zinc, copper, lead, and cadmium.

Bacteria. During the March, August, and December 1975 sampling, fecal coliforms and fecal streptococci were measured using the millipore filter techniques as described by "Standard Methods," [8] while for July 1974, fecal coliforms were determined by the MPN technique. The samples were diluted and filtered in the field using a millipore field kit, then returned to the laboratory for incubation.

Hydrological calculations. In order to construct a nutrient budget for the swamp, hydrological calculations concerning rainfall and runoff were needed to estimate water inflow and outflow for the swamp. Rainfall data were collected at the wastewater treatment plant by the operator and used to estimate runoff. Since the watershed was approximately 672 ha (1 660 acres), monthly rainfall data were used to compute runoff according to a method described by Chow.[9] The equations used were

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{1}$$

$$Cn = \frac{1\,000}{S + 10} \tag{2}$$

$$S = \frac{1\,000}{Cn} - 10 \tag{3}$$

where Q is the runoff in inches, P is the rainfall in inches, Cn is the curve number, and S is the potential infiltration in inches. For the study area a combination of the potentiometric map, soil map, and aerial photographs were used to determine a weighted average curve number based on soil type and vegetation.[9] The estimated average contained 34.8 percent urban land (Astatula-Tavares soil association) with a curve number of 60.2, and 65.2 percent improved pasture (Myakka-Wabasso soil association) with a curve number of 39. The resulting average curve number was 46.3.

The flow from the wastewater treatment plant was 570 m³/d (0.15 mgd). Some water was probably lost in the diversion ditch by evapotranspiration and did not enter the swamp, but these losses were not considered significant in estimating the water contribution of the wastewater effluent. In other areas of the swamp it was impossible to determine the flow, so only the depth of water was measured.

The rate of groundwater infiltration was determined using the relationship

$$V = Ki \tag{4}$$

where V is the velocity of infiltration, K is the permeability, and i is the potentiometric gradient.

Sediment analysis. Sediment cores were taken to a depth of 76 mm (3 in.) and analyzed for nitrogen and phosphorus according to the procedure outlined in "Standard Methods." [8] Deeper sediment cores also were taken so that a soil profile could be constructed.

A soil auger was used adjacent to the wastewater ditch at Station 3 to determine the different soil layers. 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 distance 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.

Biological evaluation of productivity. Tree growth data for both cypress and ash were collected with an increment coring device to measure the thickness of the growth rings, and a clinometer to determine height. The diameter at breast height (dbh) was also measured. The cores were split, examined carefully under a dissecting scope, and the width of the growth rings was determined with vernier calipers.

RESULTS AND DISCUSSION

Swamp effectiveness in nutrient uptake. After flowing through the experimental swamps, the concentration of nutrients was reduced to values equal to or less than those found in the control swamp or Lake Panosoffkee. The data are shown graphically in Figures 1 through 5. The concentrations of organic phosphorus were so low that only total phosphorus levels were graphed. Also the concentrations of nitrite nitrogen were too small to be shown graphically. The average concentration of nutrients in the water at Station 2, approximately 490 m (1 600 ft) from the wastewater treatment plant, was 6.4 mg/l total phosphorus and 15.3 mg/l total nitrogen. At Station 12, 3.7 km (2.3 miles) from the wastewater treatment plant, the average concentrations were 0.124 mg/l total phosphorus and 1.61 mg/l total nitrogen. The concentrations of nitrogen and phosphorus at the wastewater treatment plant outfall were not used as the basis of comparison because of their wide variability. The actual outfall averages were higher than those measured at Station 2.

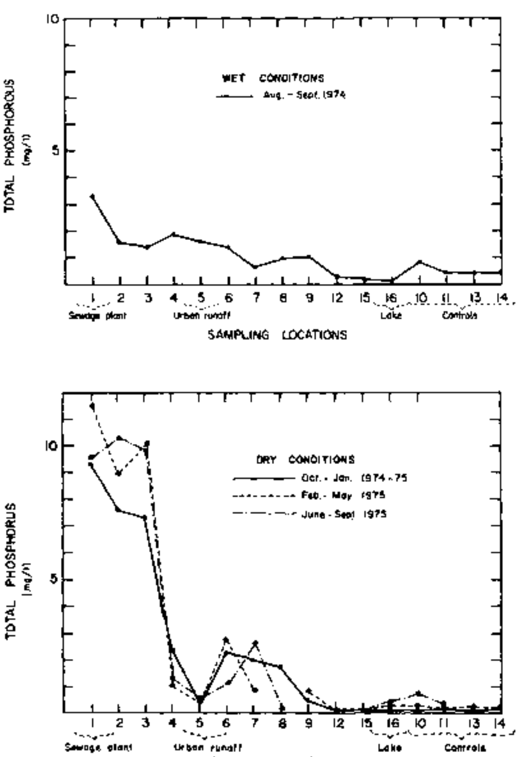

FIGURE 1. Concentration of total phosphorous at the various sampling locations.

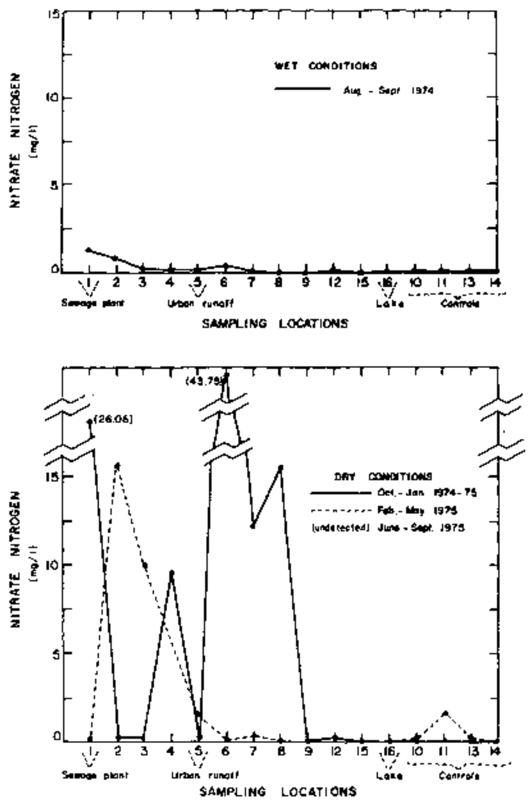

FIGURE 2. Concentration of nitrate nitrogen at the various sampling locations.

The concentration of total phosphorus declined from Station 1 to Station 12, as shown in Figure 1. The average concentration of total phosphorus in the experimental swamp over a 12-month period was 0.124 mg/l, while the average for all the control stations was 0.274 mg/l. The consistently rapid decline of total phosphorus from about 6.4 mg/l at the entrance to the swamp (Station 2) to below 1 mg/l by Station 9 showed that added phosphorus was quickly taken out of the water.

Figure 2 shows that the concentration of nitrate nitrogen varied during this study. During August and September 1974, the concentration of nitrate remained below 1.5 mg/l at all stations. However, from October 1974

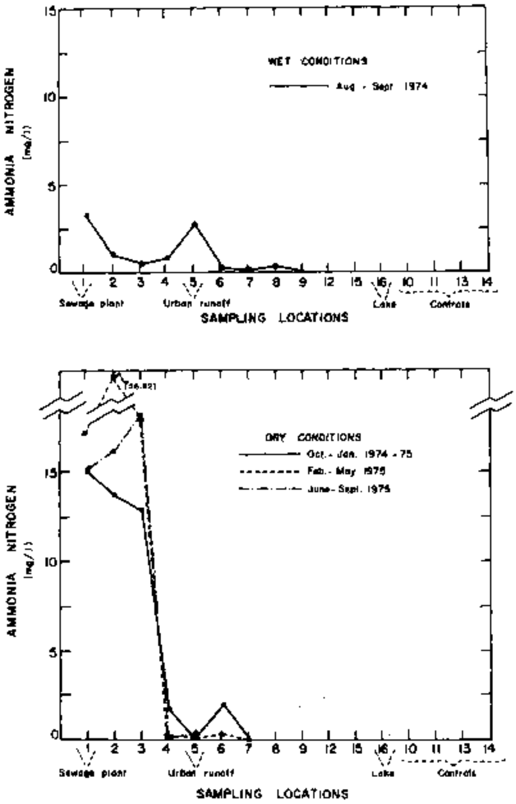

FIGURE 3. Concentration of ammonia nitrogen at the various sampling locations.

until January 1975 there were very high concentrations of nitrate nitrogen during this study at Stations 4, 6, 7, and 8. The increase in nitrate was probably caused in part by the microbial conversion of NH_3 to NO_2 and NO_3. The concentration of NH_3-N decreased steadily during the same sampling period (Figure 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 was not detectable at any of the experimental or control stations. Nitrate was not detectable at any of the experimental or control stations from June through September 1975, which was compatible with the low concentrations obtained in August and September of 1974. During these months the nitrate was probably rapidly used by various plants and phytoplankton.

Figure 3 shows that the concentration of ammonia nitrogen exhibited the same general response each month. The ammonia was high near the wastewater plant but was almost completely absent beyond Station 6 and in the control area. The slight rise in ammonia near Station 5 was probably caused by urban runoff, which generally had diluted wastewater treatment plant effluent. However, Figure 3 showed an increase of ammonia nitrogen at Station 5 during wet conditions, which illustrated that the effect of urban runoff was not consistent. With very large volumes of urban runoff the flow was probably rapid enough to cause some disturbance in the sediments, releasing ammonia produced by prior decomposition.

Figure 4 shows that organic nitrogen ranged from about 1.0 to 7.5 mg/l and exhibited less variation than other parameters. In general, the concentration of organic nitrogen exhibited an 85 percent reduction during wet conditions and a 75 percent reduction during dry conditions. Background levels of organic nitrogen were always attained by Station 12, 3.7 km (2.3 miles) from the wastewater treatment plant.

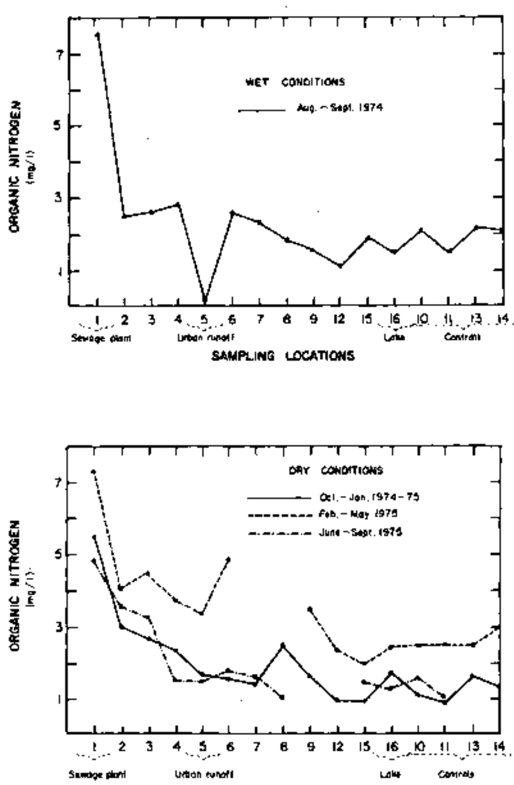

FIGURE 4. Concentration of organic nitrogen at the various sampling locations.

The organic carbon concentration shown in Figure 5 ranged from approximately 57.0 to 16 mg/l. Using a 95 percent confidence interval, no significant difference was found between organic carbon levels in the control and experimental swamps.

The effect of dilution from rain and runoff was noted in comparing the concentration of nutrients under both wet and dry conditions. During August and September 1974, the swamp contained about 1 m of standing water and the concentrations were more uniform throughout the experimental and control areas. The dryer conditions from October 1974 until September 1975 exhibited a higher concentration of nutrients in the experimental swamp, but frequently the level of nutrients continued to decline to below those levels observed in the control swamp. Often during dry conditions the wastewater effluent was completely contained within Marsh A and Swamp B, and no flow was observed into Swamp C. Under wet conditions the nutrients were diluted and carried farther into Swamp C.

Between Station 2 and Station 12 a 98.1 percent reduction in total phosphorus and an 89.5 percent reduction in total nitrogen was achieved. Advanced treatment of wastewater by a coagulation-sedimentation process usually results in 98 to 99.5 percent phosphorus removal, which is comparable to the removal efficiencies exhibited by the swamp. Nitrogen removals of 90 to 99 percent can be expected when a nitrification-denitrification process is employed for nutrient removal, which is greater than the 89.7 percent removal of nitrogen achieved in the swamp. However, it should be noted that the average total nitrogen concentration in the control swamp was 1.4 mg/l. Hence, concentrations of approximately 1.4 mg/l represent the lower limit for nitrogen removal in the swamp system.

Water quality other than nutrients. The concentrations of heavy metals were examined in June 1975, and the data is presented in Table I. Since the wastewater treatment plant in Wildwood received no industrial wastes, the concentration of heavy metals was low in the treatment plant effluent at Station 1, as well as in the experimental and control swamps. Copper and lead analyses were performed in February 1975 at all sampling stations. The data collected at that time showed that the lead

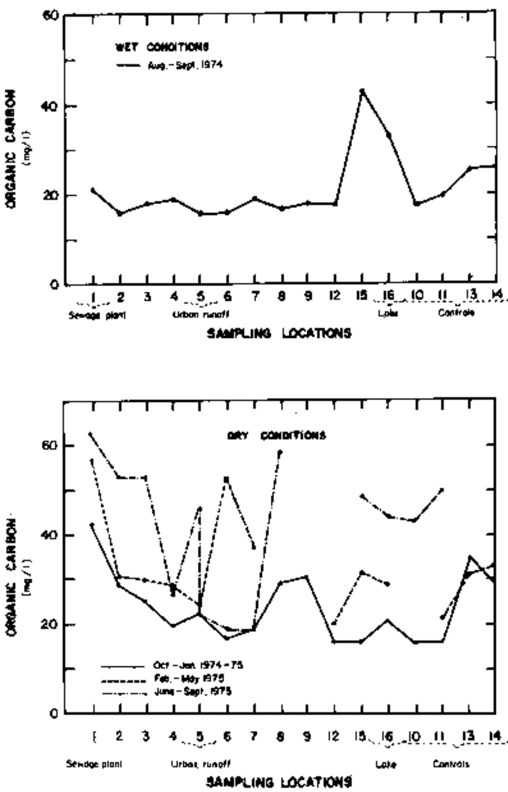

FIGURE 5. Concentration of organic carbon at the various sampling locations.

TABLE I. The concentrations of metals in water samples taken from a swamp in Wildwood, Florida.

Sampling Location	Metal Concentrations (mg/l)							
	Magnesium	Calcium	Sodium	Potassium	Iron	Zinc	Copper	Lead
1	4.1	92	4.4	8.8	0.17	0.048	0.02	0.03
2	3.8	81	55.2	7.6	0.06	0.042	0.015	0.03
3	3.6	69	55.2	7.2	0.06	0.042	0.02	0.03
5	3.2	121	29.9	6.4	0.19	0.015	0.01	0.02
10	4.1	85	4.6	2.8	0.32	0.01	0.01	0.02
15	5.8	113	3.45	0.4	0.026	0.008	0.015	0.01
16	5.2	95	4.6	1.7	0.05	0.113	0.005	0.15

TABLE II. Temperature (°C) and dissolved 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	0.45	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		
7	28.0	1.4	17.0	1.3			16.5	1.8		
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		
12	28.5	3.1	20.0	3.0	19.2	3.3	18.7	4.4		
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		
13	26.4	1.8	17.0	1.9	18.5	1.5	16.2	1.7		
14	27.0	3.1	17.0	1.0	20.0	1.8	16.7	2.2		

concentrations were all below 0.03 mg/l, and the copper concentrations were less than 0.02 mg/l.

Values for DO are shown in Table II. The average concentration of DO in the experimental swamp was 2.8 mg/l, with a range of from 0.3 to 6.3 mg/l. The values in the control swamp ranged from 2.0 to 4.0 mg/l, with an average of 2.4 mg/l. The only area which showed a marked deviation from these values was found in the ditch within a few hundred yards of the wastewater outflow. This area also exhibited the highest concentration of algae and the hydrogen sulfide odor was indicative of anaerobic decomposition. Under normally wet conditions the sediments were probably anoxic. Data by Brezonik *et al.*[10] indicated that anoxic conditions were most favorable for nutrient release, keeping the maximum concentration of nutrients in the water, and thereby available for uptake by plants.

Bacteria. Investigations were made to determine the presence and concentration of fecal bacteria. Table III shows that the concentration of fecal coliform bacteria rapidly declined before the effluent reached Station 3. However, the average fecal coliform concentration in the control area was 200 per 100 ml, which was above U. S. Public Health Service drinking water and recreational water standards. In order to differentiate between human and animal fecal contamination, the fecal coliform to fecal streptococci ratio (FC:FS) was determined. The data presented in Table IV shows that the FC:FS ratio was always less than 1.0 beyond Station 3. In human feces the FC:FS ratio is approximately 4.0, while for livestock it is less than 0.4. Based on this standard, the high fecal bacteria beyond Station 3 probably represented contamination from livestock feces rather than from human waste.

Role of sediments in storing nutrients within the swamp. Figure 6 shows the results of additional sediment cores that were taken to a depth of 7.6 cm (3.0 in.) and analyzed for nitrogen and phosphorus. Station 2, located about 91 m from the wastewater plant, exhibited high concentrations of phosphorus, 20.2 mg/g dry soil, and nitrogen, 27.0 mg/g dry soil. The concentrations of organic nitrogen at Stations 6, 9, 13, and 15 were 24.0, 66.0, 17.0, and 48.0 respectively. The phosphorus level remained high at Station 6 in Swamp B with a value of 15.2 mg/g dry soil, but then dropped to only 5.8 mg/g dry soil at Station 9 in Swamp C. The phosphorus concentration at control station 13 was 18.8 mg/g dry soil, which was only slightly less than at Station 2. On the basis of the data taken, there was no evidence of a greater buildup of nutrients in the sediments of the experimental swamp than in the control swamp.

Examination of the sediments gave some support to the assumption that there was no vertical movement of water in the swamp. A soil profile was constructed from the five sediment cores taken. Throughout Marsh A, and Swamps B and C the clay layer was found between 0.9 and 1.2 m (3.0 and 4.0 ft) below the surface. The clay layer most likely prevented an open exchange between surface water carrying treated wastewater and groundwater. The soil types found in the swamp were reported by the Soil Conservation Service to be Myakka-Wabasso, Panasoffkee-Bushnell and Terra Ceia-Placid. All of these soils were poorly drained. The dominant soil type was Panasoffkee-Bushnell association, which had a very slow filtration rate and a clay subsoil.[9] These characteristics, along with the sediment cores which showed the shallow clay layer, indicated that there was probably little groundwater recharge.

TABLE III. Fecal coliform bacteria found at various sampling locations in Wildwood, Florida.

Sampling Location	Count
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	2.11×10^6
6	9.8×10^1
9	1.3×10^1
13	5.3×10^1
15	4.9×10^1

TABLE IV. The fecal coliform : fecal streptococci ratio calculated for water samples taken in Wildwood, Florida. (The FC:FS ratio for various animals is man = 4.4; sheep = 0.4; cow = 0.2; turkey = 0.1; pig = 0.04).

	Sampling Location	FC/FS*
May 1975	1	3.63
	3	0.4
	15	0.084
August 1975	1	2.51
	3	4.91
	6	0.304
	13	0.88
	15	0.82
December 1975	1	8.63
	3	21.7
	6	0.383
	9	0.27
	13	1.06
	15	0.924

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

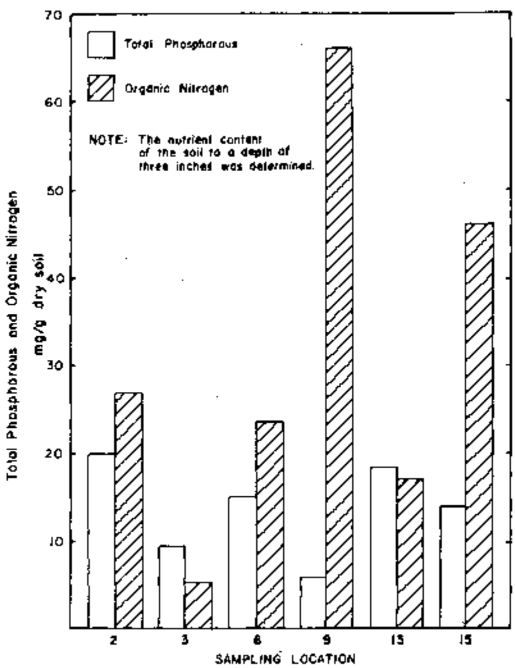

FIGURE 6. Total phosphorous and organic nitrogen content of the soil.

TABLE V. The tree growth data collected in experimental Swamp B for both ash and cypress trees.

Tree	dbh (cm)	Height (cm)	Last 20 rings (cm)
Ash	33.5	2 194.6	4.80
	28.7	1 950.7	3.74
	27.2	2 438.4	4.85
	42.5	2 499.4	4.28
	40.0	2 255.5	3.48
	36.2	2 316.5	3.81
	34.5	2 377.4	6.50
	50.0	2 682.2	5.34
	28.5	2 316.5	3.28
	28.5	2 011.7	3.30
	25.5	2 316.5	5.90
	41.1	1 341.2	7.48
			Average 4.73
Cypress	52.0	2 621.3	5.90
	28.2	1 341.1	5.70
	27.0	1 219.2	5.26
	63.4	2 255.5	7.10
	22.3	1 767.8	4.82
			Average 5.50

Biological uptake of nutrients within the swamp. Some of the nutrients added by the wastewater effluent were taken up by the trees in the swamp. The tree growth in Swamp B was greater than the tree growth in the control area. The average 20-year growth increment in Swamp B, which was receiving the wastewater effluent, was 5.5 cm/20 y for cypress, and 4.73 cm/20 y for ash. The average growth increment for the control swamp was 3.87 cm/20 y for cypress and 3.93 cm/20 y for ash. This data is summarized in Tables V and VI. The trees in Swamp B exhibited a significant increase in growth rate at a 95 percent confidence level for cypress and a 90 percent confidence level for ash. This increased growth rate implied that nutrients were being taken up at a faster rate in Swamp B, probably in response to the elevated nutrient concentrations from the wastewater effluent.

TABLE VI. The tree growth data collected in the control area Swamp D.

Tree	dbh (cm)	Height (cm)	20 rings (cm)
Ash	19.0	1 950.7	3.90
	27.0	2 555.5	2.98
	51.6	3 169.9	5.88
	37.7	2 987.0	2.50
	36.0	2 804.2	6.60
	21.0	2 316.5	2.67
	24.4	2 011.7	3.40
	41.3	2 621.3	5.64
	26.3	2 133.7	3.04
	24.8	2 255.5	3.10
	29.3	2 377.4	3.55
			Average 3.93
Cypress	26.7	1 889.8	3.27
	42.5	2 743.2	4.55
	36.2	2 438.4	3.80
	33.7	2 560.3	3.32
	49.6	2 743.2	4.40
			Average 3.87

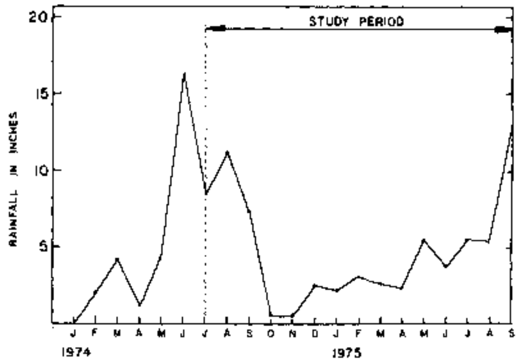

FIGURE 7. Monthly rainfall totals for 1974 and 1975 as collected by the plant operator at the Wildwood wastewater plant.

Hydrologic considerations. The hydrological characteristics of the swamp were important in constructing a nutrient budget. The inflows of water to the swamp were rainfall, runoff, and wastewater, all of which carried nutrients into the swamp. The rainfall for this area of Florida averages around 130 cm/y (51 in./y) with roughly 70 percent of it falling during June, July, and August. As mentioned earlier during periods of high rainfall such as the summer months, the nutrients from the wastewater were diluted and may have been flushed farther into Swamp C. The monthly rainfall totals for the time of this study were recorded at the Wildwood wastewater plant and are shown in Figure 7. When compared to past weather data, 1974 and 1975 represented a wide range of precipitation. In the past 12 years a monthly total of 38 cm (15 in.) or more was recorded only during 1964 and 1974, indicating that 1974 was a very wet year. However, 1975 was a very dry year with monthly totals for the summer months ranging from about 10 cm (4 in.) to 15 cm (6 in.).

A water budget for the swamp is shown in Figure 8. Since 1974 was a very wet year which would represent the maximum dilution and flushing of nutrients through the swamp, rain data for 1975 were used to calculate the water budget. The calculations for these flows are given in Appendix A. Rainfall represented 69 percent and the runoff total represented 26 percent of the total water inflow to the experimental swamp while the remaining 5 percent was contributed by the wastewater effluent.

Nutrient budget. The construction of a nutrient budget is shown in Figure 9 to give a better understanding of the approximate export of nutrients from the swamp. The inputs and outflow for phosphorus were estimated using the phosphorus concentration data collected and the hydrological calculations for 1974. The calculations are included in Appendix B. A nitrogen budget was not calculated due to the difficulty of measuring the effects of nitrification and denitrification.

The flows of phosphorus in Figure 9 were described in terms of total $g/m^2 \cdot y$. The phosphorus budget showed that the total export of phosphorus out of the experimental swamp was 0.115 $g/m^2 \cdot y$, which is only 13 percent of the total phosphorus inflow. This phosphorus export was probably supplied by the natural sources of rain and runoff since ambient nutrient concentrations were reached by Station 12 as shown previously (Figures 1 to 5). In a dry year such as 1975 the swamp was so dry that there was not a flow of water through the swamp which would flush the nutrients out.

The swamp as an alternative to tertiary treatment. As shown for this mixed hardwood swamp, wetland systems can be used as an

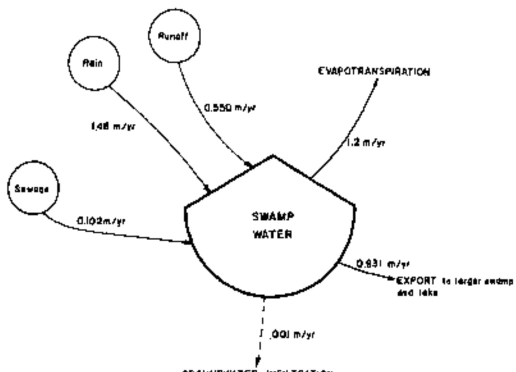

FIGURE 8. Water budget for the experimental and control swamps. Hydrological data for 1974 were used for the calculations.

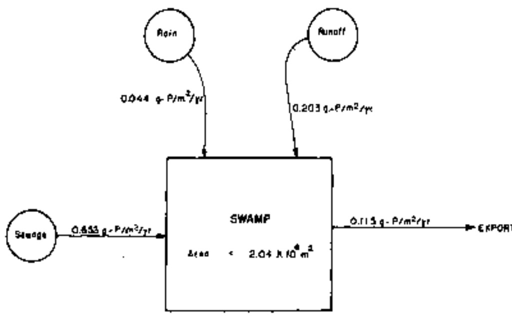

FIGURE 9. Flow of phosphorous through the swamp as summarized by an input-output nutrient model.

alternative to tertiary treatment. The wetlands disposal of wastewater did not pose a health problem, since the human fecal bacteria were removed after the effluent had traveled less than a mile. Also, within a fairly short distance from the wastewater treatment plant, the swamp removed most of the nutrient input from the plant effluent. This was partially accompanied by increased productivity of vegetation within the swamp. Since the nutrient concentrations at Station 12 were less than the control swamp, the wastewater effluent from Wildwood was not a major contributor of nutrients or pollutants to Lake Panasoffkee.

During most of the study, the high nutrient wastewater effluent was contained within Marsh A and Swamp B. This area represented about 3 percent of the total area, or roughly 6 ha (15 acres), in which more than 70 percent of the total phosphorus was usually removed. Although further research is needed to determine the precise relationship between wastewater flow and the swamp disposal area, a very conservative estimate can be made for Wildwood. With a 570-m^3/d (0.15-mgd) treatment facility providing little more than primary treatment, the wastewater required only about 8 ha (20 acres) of swamp during optimum conditions, with a buffer zone of 194 ha (480 acres) to handle the wastewater.

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. In order to incorporate tertiary treatment at the new 1 900-m^3/d (0.5-mgd) secondary plant in Wildwood, it was estimated that the extra cost would be $290 000,[11] or $32 000/y over 25 years at 10 percent interest. Maintenance costs for tertiary treatment estimated from Smith[12] to March 1975[13]

TABLE VII. The construction and maintenance costs for secondary and tertiary treatment are given for a 900-m^3/d wastewater plant.

	Amortized Construction cost, 25-y life at 10% yearly	Yearly Maintenance Costs	Yearly Total Costs	Total Costs (life of plant estimated to be 25 y)	Cost per 1 000 gal.
Secondary Treatment	$31 950	$39 850	$71 800	$1 800 000	$0.39
Tertiary	$31 950	$47 450	$79 400	$2 000 000	$0.44
Both	$63 900	$87 300	$151 200	$3 800 000	$0.83

would be $47 500/y. The total cost for tertiary treatment would be $79 500/y. Thus the swamp, as an alternative to the tertiary treatment method, would save $79 500/y for the residents of Wildwood. The savings for the entire 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 VII.

The swamp is a very valuable and renewable resource for Wildwood. The monetary value 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. Generally, 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.[14] The swamp represents an energy pathway which can be used by Wildwood in many ways for their mutual benefit and maximum power output. The fossil fuel which might have been used to build and maintain a tertiary treatment plant can be used for more important applications. The trees in the swamp can be selectively cut to provide timber, and the unpolluted water is available to flow into Lake Panasoffkee.

APPENDIX A

Calculations for Figure 8:

1. The wastewater flow was measured to be 568 m^3/d and the area of the experimental swamp 2.04×10^6 m^2. The wastewater inflow was

$$\frac{568\ m^3/d \times 365\ d/y}{2.04 \times 10^6\ m^2} = 0.102\ m/y$$

2. Rainfall for 1974 was 1.48 m (58.3 in.)

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

$$\frac{0.23\ m/y \times 4.88 \times 10^6\ m^2}{2.04 \times 10^6\ m^2} = 0.550\ m/y$$

4. Groundwater infiltration was estimated based on the permeability of clay being 1.21 ft/y.[15] The velocity was calculated from the equation

$$V = ki$$

where

V = velocity
k = permeability
i = potentiometric gradient

For the Wildwood area, i was calculated from a potentiometric map to be 0.001 58.

$$V = (1.21\ ft/y)(0.001\ 58) = 0.000\ 58\ m/y \quad 0.001\ m/y$$

5. The rate of evapotranspiration (ET) was estimated by ET = pan evaporation $\times$ 0.8.[16] Pan evaporation for 1974 was recorded to be 1.50 m/y.

$$ET = (1.50\ m/y)(0.8) = 1.20\ m/y$$

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

$$E = (0.102 + 1.48 + 0.550)\ m/y - (1.2 + 0.001)\ m/y = 0.931\ m/y$$

APPENDIX B

Calculations for Figure 9:

1. The average concentration of phosphorus during 1 year was 6.4 mg/l (6.4 g/m^3).

The flow of phosphorus into the swamp each year was equal to

$$\frac{(568\ m^3/d \times 6.4\ g/m^3 \times 365\ d/y)}{2.04 \times 10^6\ m^2} = 0.653\ g/m^2\cdot y$$

2. The rainfall for 1974 was approximately 1.48 m/y. The concentration of phosphorus in rainfall[10] was 0.03 g/m^3. Thus the flow of phosphorus into the swamp from rainfall was equal to

$$(1.48\ m^3/m^2\cdot y \times 0.03\ g/m^3) = 0.044\ g/m^2\cdot y$$

3. The runoff for 1975 was estimated as 0.550 m/y. The concentration of phosphorus in urban runoff[17] was approximately 0.3 g/m^3 and for pasture[17] the concentration was approximately 0.5 g/m^3. The runoff into the swamp was composed of 34.8 percent urban and 65.2 percent improved pasture. The input of phosphorus was computed as follows:

$$(0.550\ m^3/m^2\cdot y \times 0.348 \times 0.5\ g/m^3) + (0.550\ m^3/m^2\cdot y \times 0.652 \times 0.3\ g/m^3) = 0.203\ g/m^2\cdot y$$

4. The outflow was 0.998 m/y (See Figure 8). The average concentration of phosphorus for 1 year (from June 1974 to June 1975) at the overflow culvert at Station 12 was 0.124 g/m^3. The phosphorus exported was

$$0.931\ m^3/m^2\cdot y \times 0.124\ g/m^3 = 0.115\ g/m^2\cdot y$$

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