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CYPRESS SWAMPS FOR NUTRIENT REMOVAL

AND WASTEWATER RECYCLING*

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INTRODUCTION

Many communities throughout the country are facing increases in utility costs as new water pollution laws come into effect. Installation of advanced wastewater treatment systems is prohibitively expensive for smaller communities in particular. A project undertaken by the Center for Wetlands at the University of Florida has been investigating for nearly five years the consequences of use of cypress wetlands for sewage recycling. Secondarily treated sewage has been discharged at the rate of 2.5 cm/wk into two cypress domes which are small swamps. The main study area (Figure 1) is located near Gainesville, Florida, where cypress domes are commonly found in pine flatwoods and plantations. Three experimental cypress domes are located next to a trailer park. Two of these were accidentally burned in a fire early in the project; one has been receiving sewage and another groundwater since March, 1974. A third, unburned dome has been receiving sewage since March, 1975. A fourth dome located in the university's Austin Cary Forest is surrounded by a natural stand of slash pine and longleaf pine. No experimental treatments have been applied to this dome.

CYPRESS ECOSYSTEMS IN FLORIDA

Cypress trees are commonly found where water levels fluctuate: in floodplain forests; around the fringes of lakes; in domes, which are small, circular swamps with internal drainage; and in extensively meandering, shallow, slowly moving streams called strands. The greatest extent and density of cypress trees in north-central Florida occur in domes and strands, which are often underlain by clay (Spangler et al., 1976). Peat and limestone of varying depths are found beneath these ecosystems in south Florida, however, where optimum growth rates for cypress occur in strands at a hydroperiod of 286 to 296 days (Duever et al., 1977). In this area, wetland habitats occur in areas with hydroperiods of at least 223 days, and peat accumulation begins when hydroperiod exceeds 241 days. Peat depth and consequently vegetation composition and growth rates may vary if fire burns through an area with any frequency, however. While early growth rates may be faster where peat is deepest (Duever et al., 1977), trees rooted in these areas may be more easily killed by fires (Ewel and Mitsch, 1978).

Gross primary productivity rates in cypress ecosystems are very low in domes but comparable to Puerto Rican rain forest rates in floodplain forests and in a sewage-enriched dome (Brown, 1977). A relationship seems to exist between gross primary productivity of cypress ecosystems and available phosphorus. Net primary productivity rates of cypress are reflected in the species composition of a swamp. Cypress in association with hardwoods grows most rapidly, while cypress in pure stands or in association with pine trees grows more slowly (Mitsch and Ewel, 1978). Drainage conditions appear to have a strong influence on growth rates in these swamps (Figure 2).

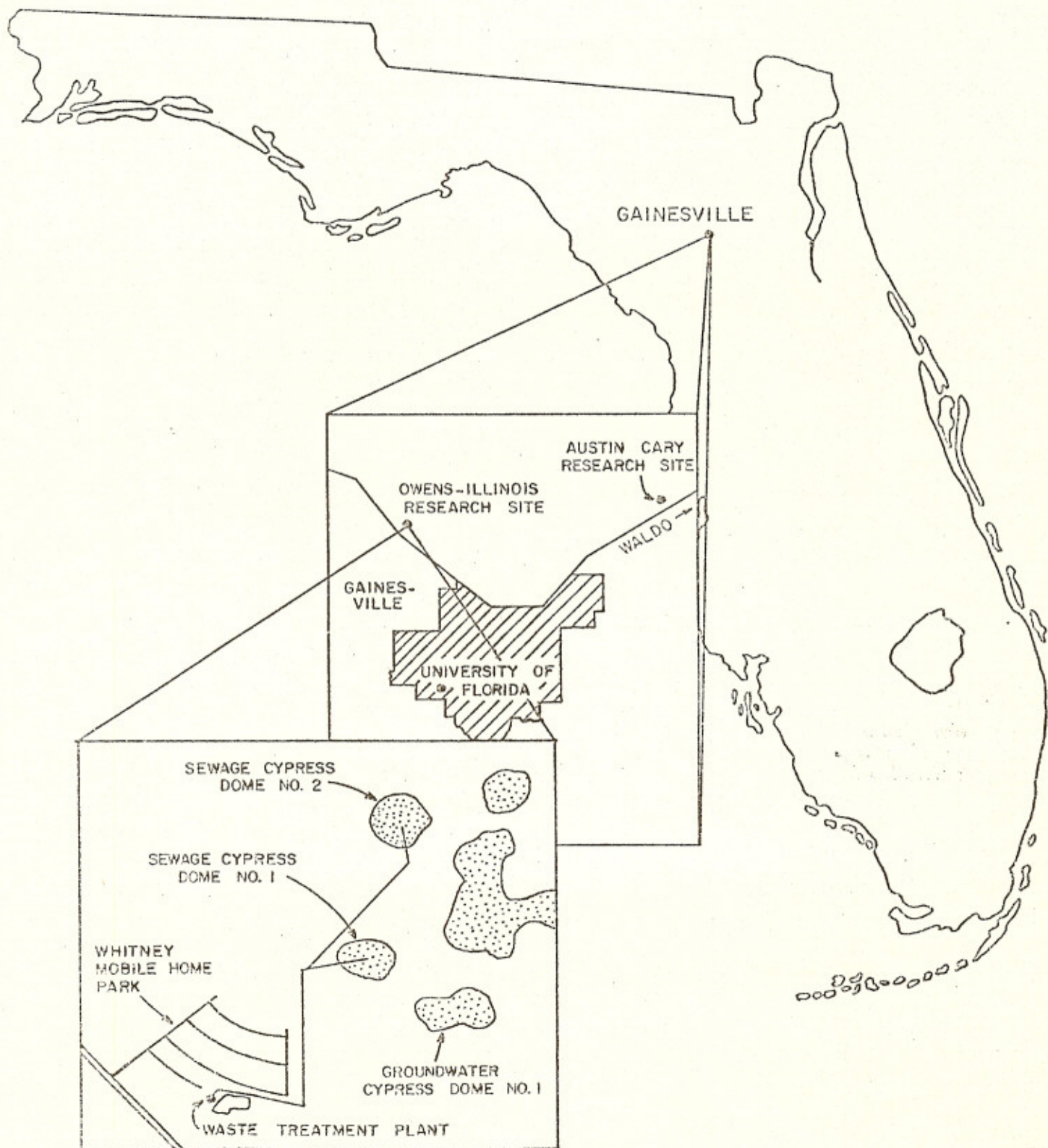


Fig. 1. Map of sewage recycling research sites.

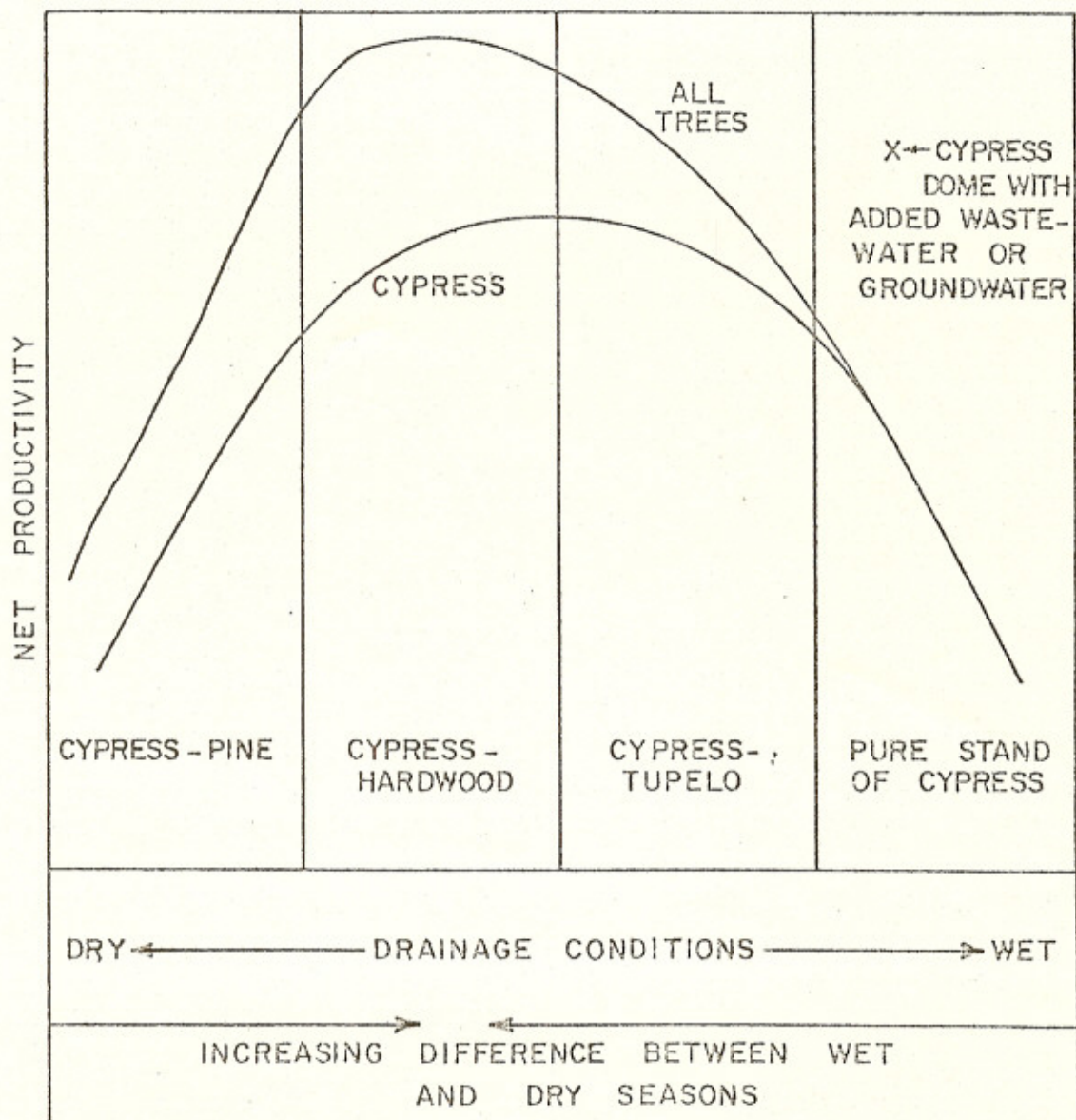


Fig. 2. Relationship between net productivity and drainage in several wetland ecosystems (Mitsch and Ewel, 1978).

EFFECT OF SEWAGE ON VEGETATION

Cypress dome vegetation is usually distinct from vegetation in the surrounding pine flatwoods. Species composition appears to be affected primarily by fluctuating water levels. Ferns are common in the shallower edges of the dome, small floating plants such as duckweed may grow in the deeper interior pool, and shrubs and herbs may be rooted in the organic matter that accumulates around the bases of trees and on cypress knees.

Application of secondarily treated sewage to cypress domes increases biomass of understory vegetation (Figure 3), primarily because of the proliferation of small, floating plants (*Lemna perpusilla*, *Spirodela oligorhiza*, and *Azolla carolinensis*) (Ewel, 1977). Bald cypress, pond cypress, and black tupelo seedlings planted in the cypress domes showed varying degrees of success. Seedlings of pond cypress, which is the variety of cypress found in domes, grow at approximately the same rate in both Sewage dome 1 and the Groundwater dome (Figure 4). Because these domes had been previously burned, light penetration to the water surface is greater than in the other sites. Growth rates of seedlings planted at Austin Cary are significantly lower. The mortality rate of seedlings planted in the sewage domes was considerably higher in the sewage domes than in either of the control domes (Deghi, 1977). Increases in tree diameter, on the other hand, have been greater in the experimental domes than in the control dome (Table 1). Although the effects of the fire have compounded the results, the concentrations of nutrients in trees appear to increase initially but to return eventually to normal (Straub and Post, 1977).

Similarly, increased productivity rates in sewage-enriched cypress domes are apparently due more to increases in leaf biomass than to increases in weight-specific photosynthetic rates (Brown, 1977).

NITROGEN AND PHOSPHORUS RELATIONSHIPS ;

Phosphorus budgets calculated for the unburned sewage dome and for the control dome are shown in Figure 5 (Deghi, 1977). In the sewage dome, at least 72% of the incoming phosphorus is estimated to percolate from the surface water either directly downward or through the sands immediately surrounding the dome; 9% of this amount is retained in the layer of organic material lining the basin. Increased uptake of phosphorus by faster-growing trees only accounts for 2% of the incoming phosphorus in this study, leaving approximately 25% of the incoming phosphorus unaccounted for. However, in an analysis of a nearby sewage-enriched cypress strand, high concentrations of phosphorus were found in the roots of cypress (Lugo et al., 1977). In this swamp, it was estimated that as much as 43% of the phosphorus taken up by the ecosystem may have been stored in the root tissue.

Neither nitrogen nor phosphorus appears to be moving laterally from underneath the domes. The presence of chloride ions in shallow wells surrounding the domes indicates that the water entering the dome from the sewage treatment plant is infiltrating the shallow water table (Dierberg and Brezonik, 1977). However, the sediments, sands, and clays underlying the dome are retaining many of the other elements, particularly nitrogen and phosphorus (Figure 6).

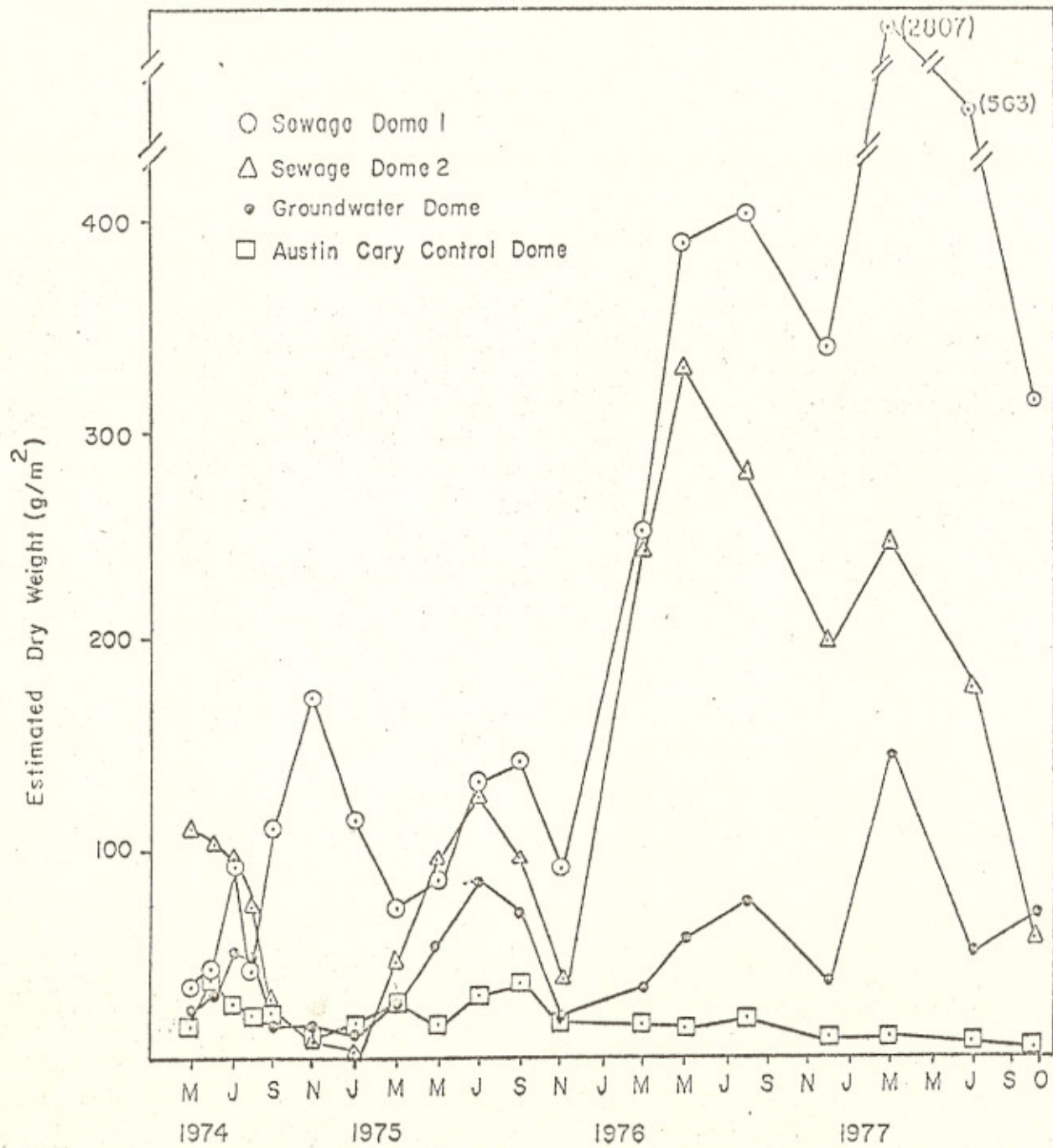


Fig. 3. Changes in biomass of understory vegetation at four experimental cypress domes. Sewage was added to Sewage Dome 1 in March 1974 and to Sewage Dome 2 in March 1975.

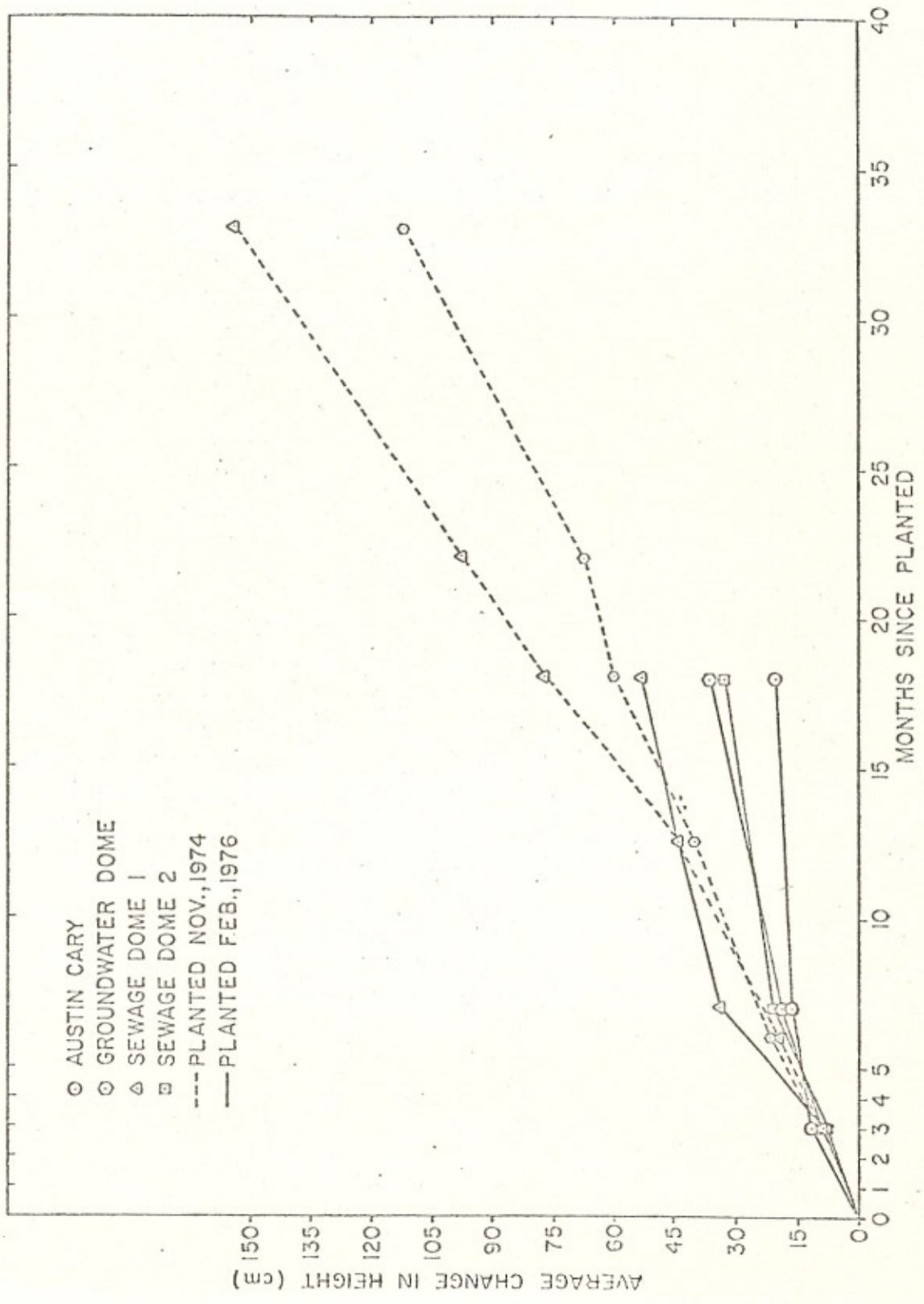


Fig. 4. Growth rates of pond cypress seedlings planted in four experimental cypress domes.

Table 1. Average^a Annual Increase^b in Diameter of Taxodium distichum
var nutans (6/26/76 - 6/15/77).

Sewage Dome 1 ^c	Sewage Dome 2 ^d	Groundwater Dome 1 ^e	Austin Cary Control Dome ^f
0.33 ± 0.03	0.36 ± 0.03	0.36 ± 0.03	0.08 ± 0.01

^aValues are the mean and plus or minus the standard error of the mean.

^bValues listed are in centimeters.

^cValues are based on 94 trees.

^dValues are based on 97 trees.

^eValues are based on 98 trees.

^fValues are based on 195 trees.

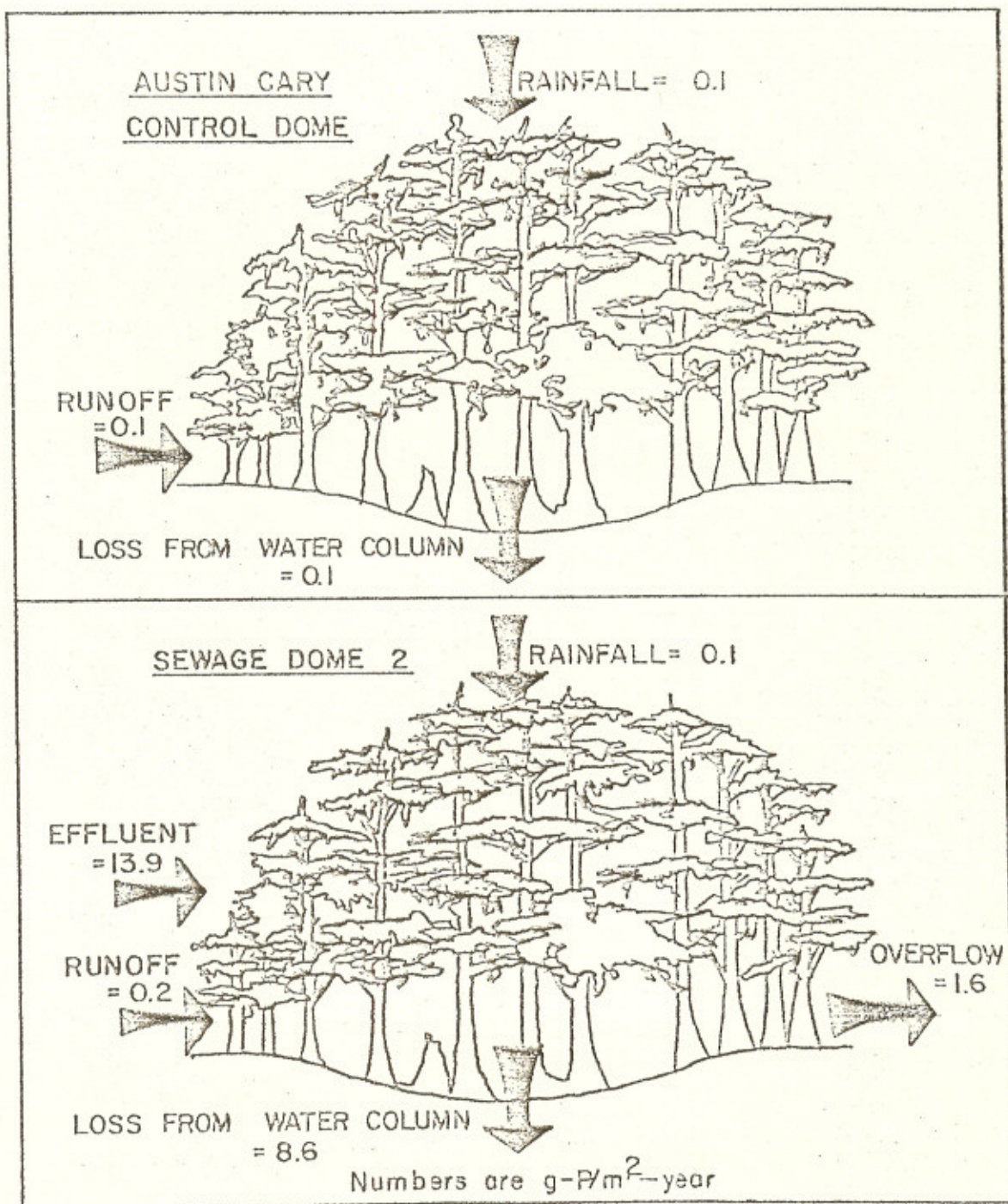


Fig. 5. Major phosphorus flows in a natural cypress dome and in a sewage-enriched cypress dome.

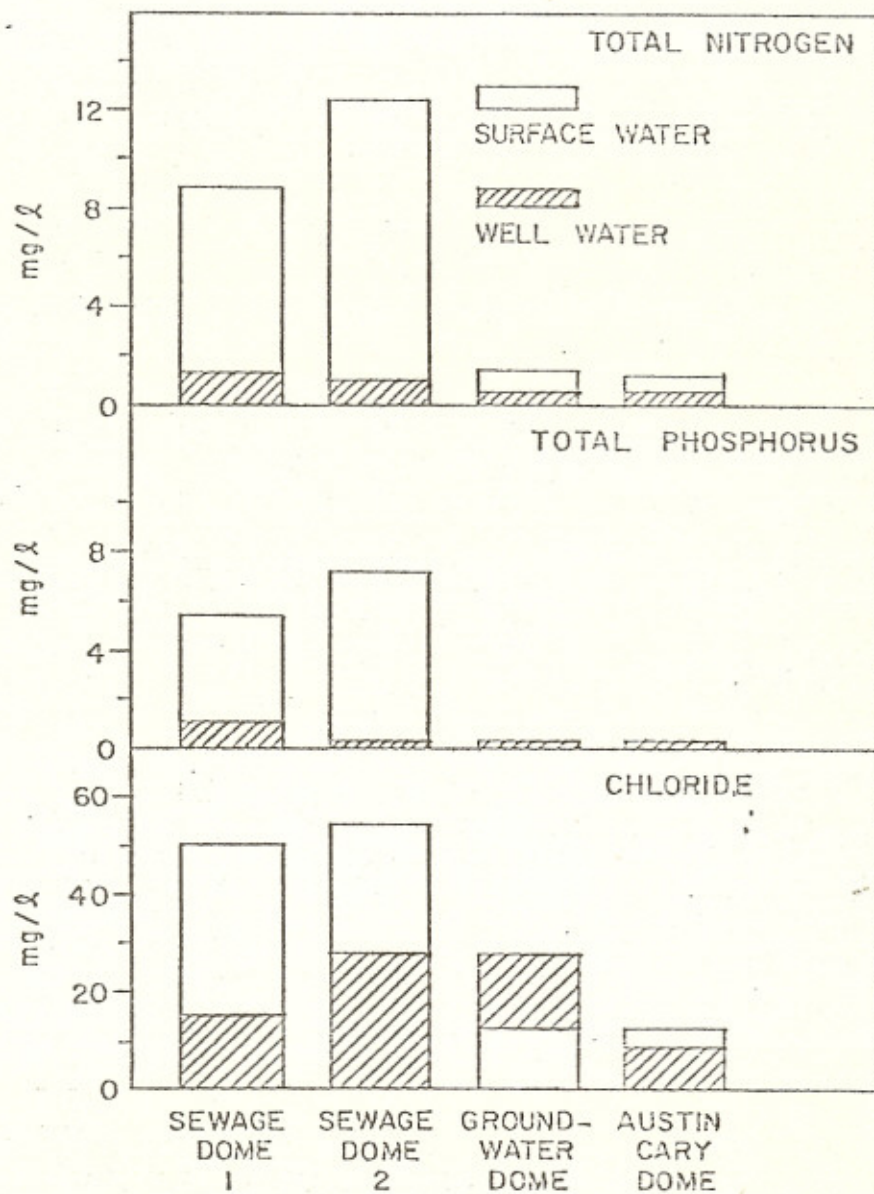


Fig. 6. Concentrations of three elements in surface water and surrounding wells of four experimental cypress domes.

Dierberg and Brezonik (1977) conclude that nitrogen rather than phosphorus is the principal limiting factor in the sewage-enriched cypress domes. They present four observations to support their conclusions: 1.) low N:P ratio relative to the ratio for the control dome; 2.) lack of constancy of nitrogen levels over time relative to phosphorus; 3.) the fact that most of the nitrogen in the dome exists in inorganic form; and 4.) correlation of BOD with total nitrogen.

ANIMAL POPULATIONS IN CYPRESS DOMES

Figure 7 illustrates the effect of sewage disposal into cypress swamps on leopard frogs: the sewage domes act as a sink, whereas the groundwater dome, representing an experimental control, is an exporter of amphibian biomass (Jetter and Harris, 1976). Fish populations are greatly reduced, but are seldom an important component in cypress domes because of fluctuating water levels and low aquatic productivity. Ramsay (1977) found that diversity of bird species was greater in a sewage dome than a control dome. Moreover, the number of bird sightings in the sewage dome was 150% greater than the number of sightings in the control dome. Part of this increase is due to higher numbers of migrating birds.

An extensive sampling effort by McMahan and Davis (1977) showed that insect biomass was greater in the sewage domes than in the control domes, although all domes show a high level of diversity with little similarity between them. The diversity was as high as values measured in the Puerto Rican rain forest using the same technique. Davis (1977) found no significant differences between the domes in mosquito populations, particularly of economically or medically important species. Nor did he find that the sewage domes produced significantly higher levels of eastern or western equine encephalitis virus than other domes. Most of the virus activity is during the summer. However, 96% of the birds sighted in both the sewage dome and the natural dome were residents and winter visitors. The summer visitors comprised only 3% of the total in both cases. Fecal coliform levels in groundwater wells in the experimental domes and in the standing water at a nearby sewage-enriched strand were consistently low during a 1.5-year sampling program (Allinson and Fox, 1976).



FEASIBILITY

A preliminary study of the cost of three different methods of advanced wastewater treatment for the city of Waldo, Florida, resulted in the following estimates (Ordway, 1976):

Spray Irrigation	\$0.63/1000 gal
Advanced Waste Treatment	1.07/1000 gal
Wetland Recycling	0.42/1000 gal

These values do not include the cost of secondary treatment. Waldo is a small city, and now produces 20 to 30 thousand gallons of sewage per day. The estimates were based on an anticipated flow of 120,000 gallons per day by 1990. The wetland recycling scheme proposed impoundment of part of a larger nearby cypress wetland.

LEOPARD FROGS

 ENTERING PER METER OF EDGE
 LEAVING PER METER OF EDGE

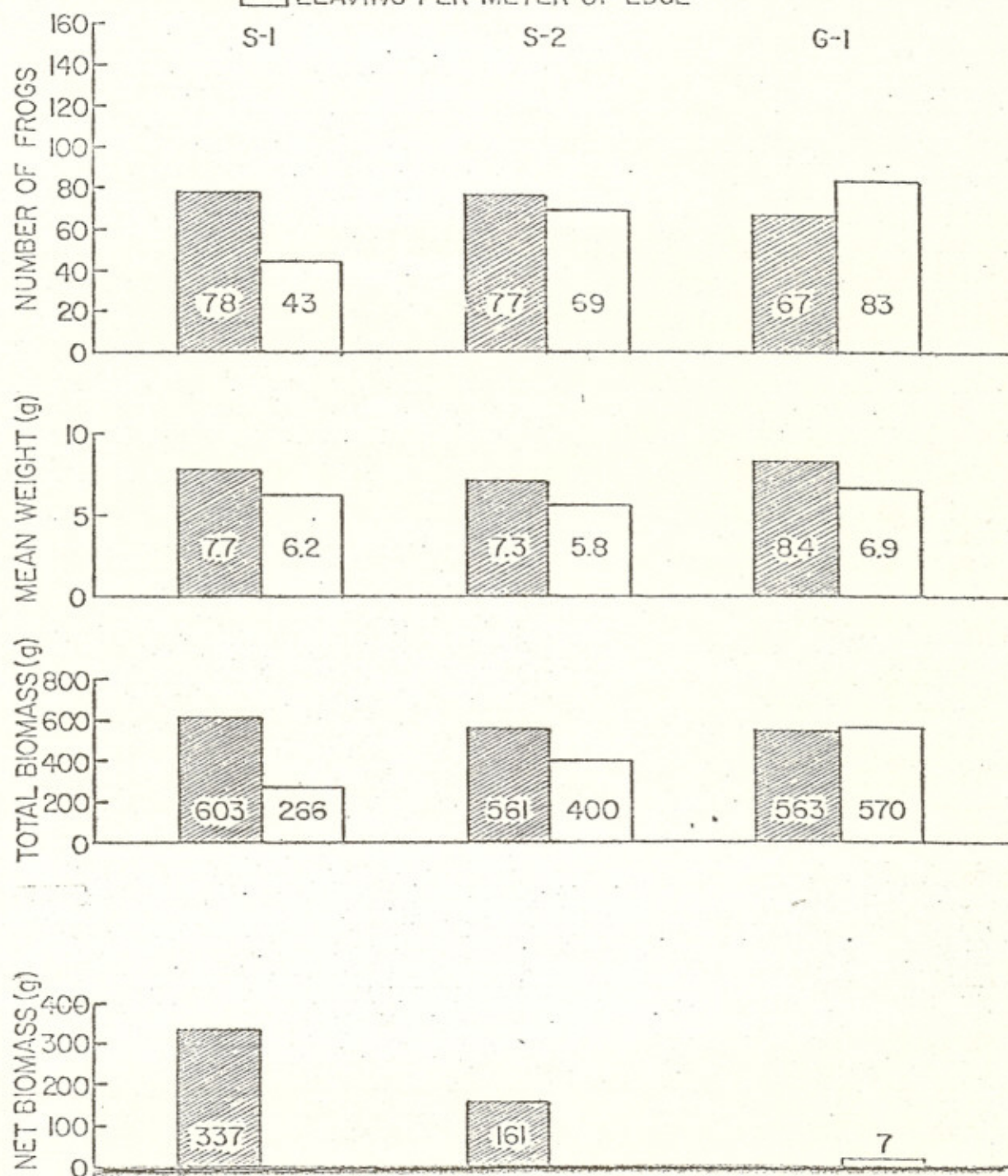


Fig. 7. Numbers and biomass of frogs captured at the edges of three experimental cypress domes.

A more general analysis by Fritz and Helle (1977) indicated that the extensive force main network and fencing costs needed for disposal from large sewage treatment plants into many small cypress domes would make disposal into domes more expensive than spray irrigation. They also found, however, that the cost of discharge into a single large cypress strand was competitive with spray irrigation for these larger disposal systems. Research into the structure and function of cypress strands is being continued along the ongoing cypress dome work in order to provide an analysis of the ability of these ecosystems to provide an important service to society which might be compatible with their normal ecological roles.

THE ROLE OF SWAMPS IN SAVING WATER

The hydrologic budget of an unburned cypress dome was studied by Heimburg (1977) who found 30% less evapotranspiration than in open water (Figure 8). Work done by Burns (1978) in a cypress strand showed the same conclusion. This relationship was not expected, since increases in productivity of a plant cover increase water loss over evaporation from bare soil (Arkley, 1963; McClurkin, 1965). Cypress swamps, however, have low leaf area indices and leaf biomass (Mitsch, 1975; Brown, 1978). Moreover, cypress trees drop their leaves in the dry season, stopping transpiration, while still shading the water and diminishing wind strength, thereby keeping evaporation rates low.

By transpiring less, cypress trees help maintain their own characteristic wetland habitat. The draining of cypress ponds in Florida is causing a loss of water that would otherwise be available for aquifer recharge or for economic use. A government memorandum circulated in Florida a decade ago advocated cutting swamp trees to save water. If implemented, this would clearly have hurt the economy of Florida.

ENERGY ANALYSIS

The role of cypress dome recycling can be measured with methods used in energy analysis. In Figure 9, the energy embodied in the work of the swamp is shown as an input from the left (I). Renewable energies directly and indirectly from the sun operate the treatment action without economic cost. To connect and process the wastewaters requires purchased goods and services which contain embodied energy from the main economy in proportion to the money spent. The ratio of economic cost to free environmental service, both expressed as coal equivalents, is 11.5:3, a factor of 3.8. This is slightly larger than the average ratio of fuel use to solar-based energy (in coal equivalents) in the U.S., which is 2.5.

From an environmental-protection point of view, this is an acceptable ratio, because it is no more dense in economic activity than the average pattern of the U.S. From an economic point of view, the contribution of free, environmental, renewable energy flow is substantial, providing matching energy and attraction for the economic activity to help make it competitive with systems requiring greater economic input.

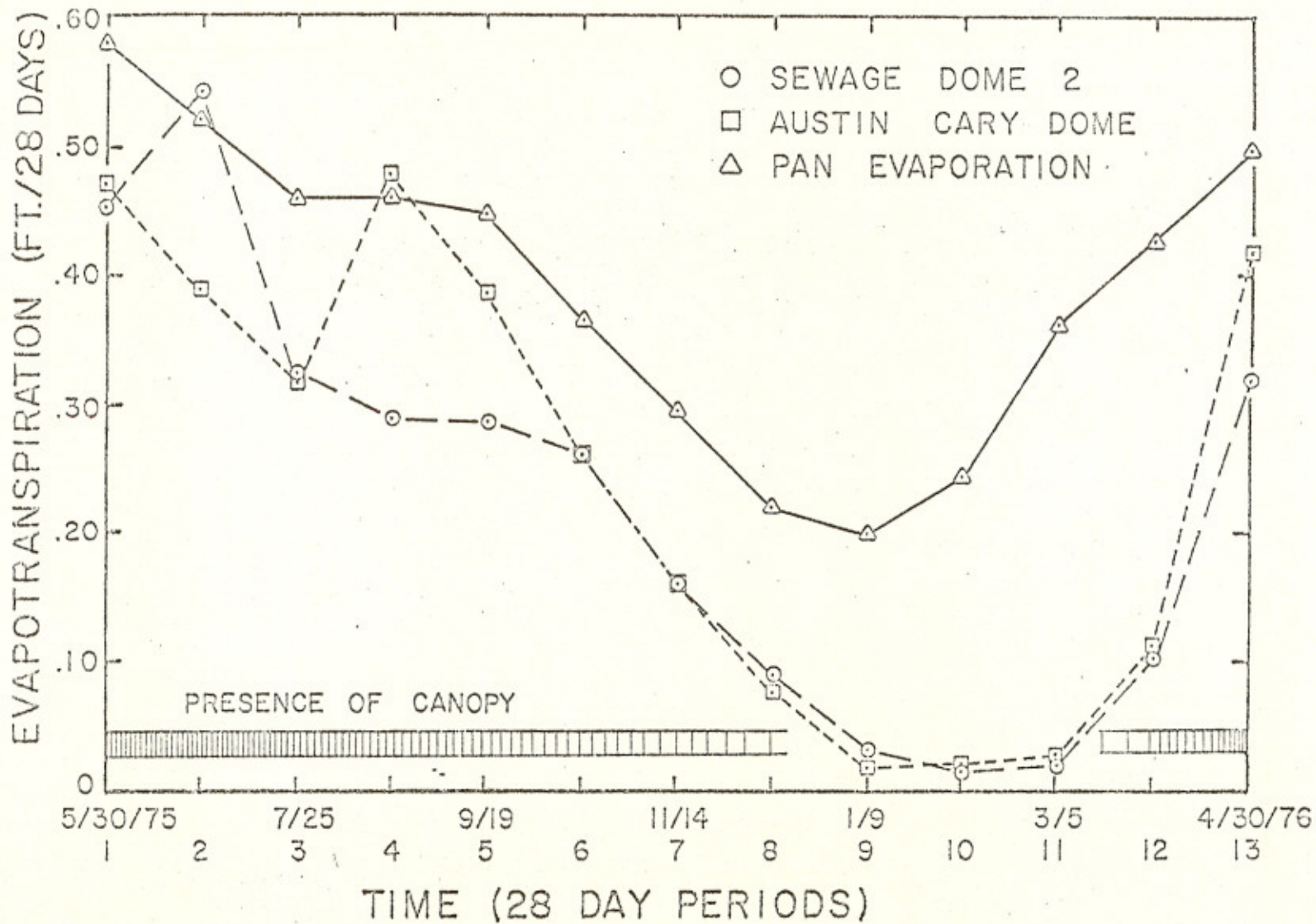
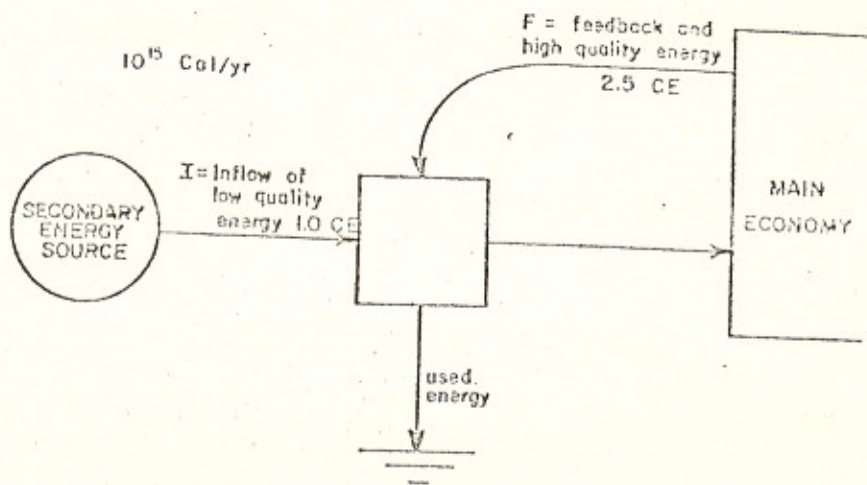


Fig. 8. Seasonal evapotranspiration rates from two cypress domes and corresponding pan evaporation rates (Heimburg, 1977).



$$\text{Energy Investment Ratio} = \frac{F}{I} = \frac{2.5}{1.0}$$

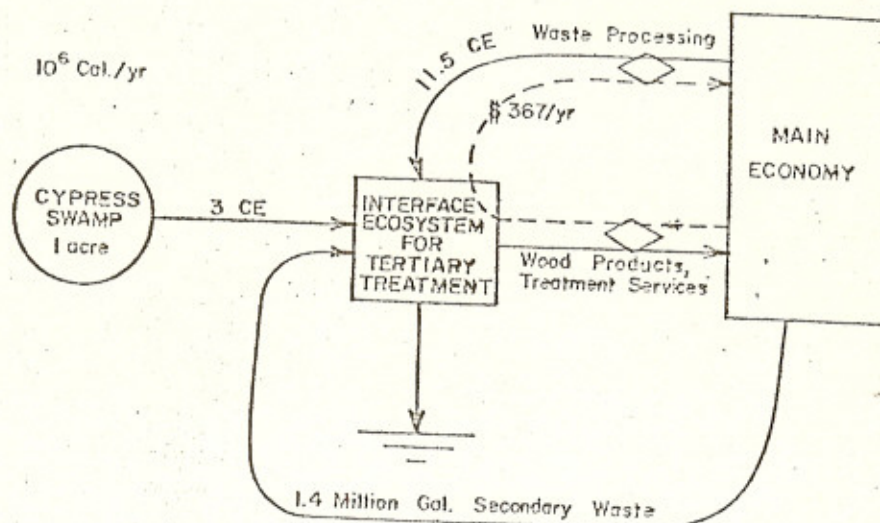


Fig. 9a. Diagram defining the investment ratio with values for the United States. Feedback of high quality energy is shown pumping an inflow of low quality energy from a secondary source. Numbers are coal equivalents.

b. Energy analysis summary of tertiary waste recycling that uses cypress swamp interface ecosystems in Florida. (Odum et al., 1976).

Technological tertiary treatment, for instance, has large dollar costs without much contribution from environmental processes. The combined system of man and nature is competitive ecologically and economically when the two aspects are reinforcing and cooperating. The economy benefits and conservation dollars are wisely spent when the investment ratio (Figure 9) is low.

ENERGY CONVERGENCE ON ITS WETLANDS WITHIN A LANDSCAPE

In the same sense that energy converges in food chains, runoff waters from landscapes help converge and concentrate the energy embodied in sunlight, rain, wind, and substances from the uplifted land. The embodied energy is the energy required to generate the flow. These flows contribute to the formation of the geomorphologic characteristics of the wetland basin, to the maintenance of the existing ecosystem, and to the perpetuation of its roles in service to the landscape as a whole (e.g., aquifer recharge). Wetlands comprise about 10 to 20% of the landscape in Florida. The convergence effect allows them to develop high-quality structures, analogous to the high-quality organisms found at the tops of food chains, using the embodied energy of the larger total area in which they are embedded. The nutrient-trapping basin of the cypress dome is an example of such a structure. Because of this convergence effect, the value of a swamp is greater than the landscape as a whole. This concept is illustrated in Figure 10.

When the capacity of the swamp to serve a recycling role for human society is considered, the value of the swamp may increase to a level 10 times greater than the general landscape. In systems that survive (both human and natural systems), structures with high energy inputs generally have special and important uses in that system. Economic benefits can result when these structures in natural systems can be tapped to serve human systems. If calculation of the investment ratio were to take into account the special role that wetlands play in the landscape, the investment ratio describing the use of swamps for sewage recycling would be even more favorable than that in Fig. 9b.

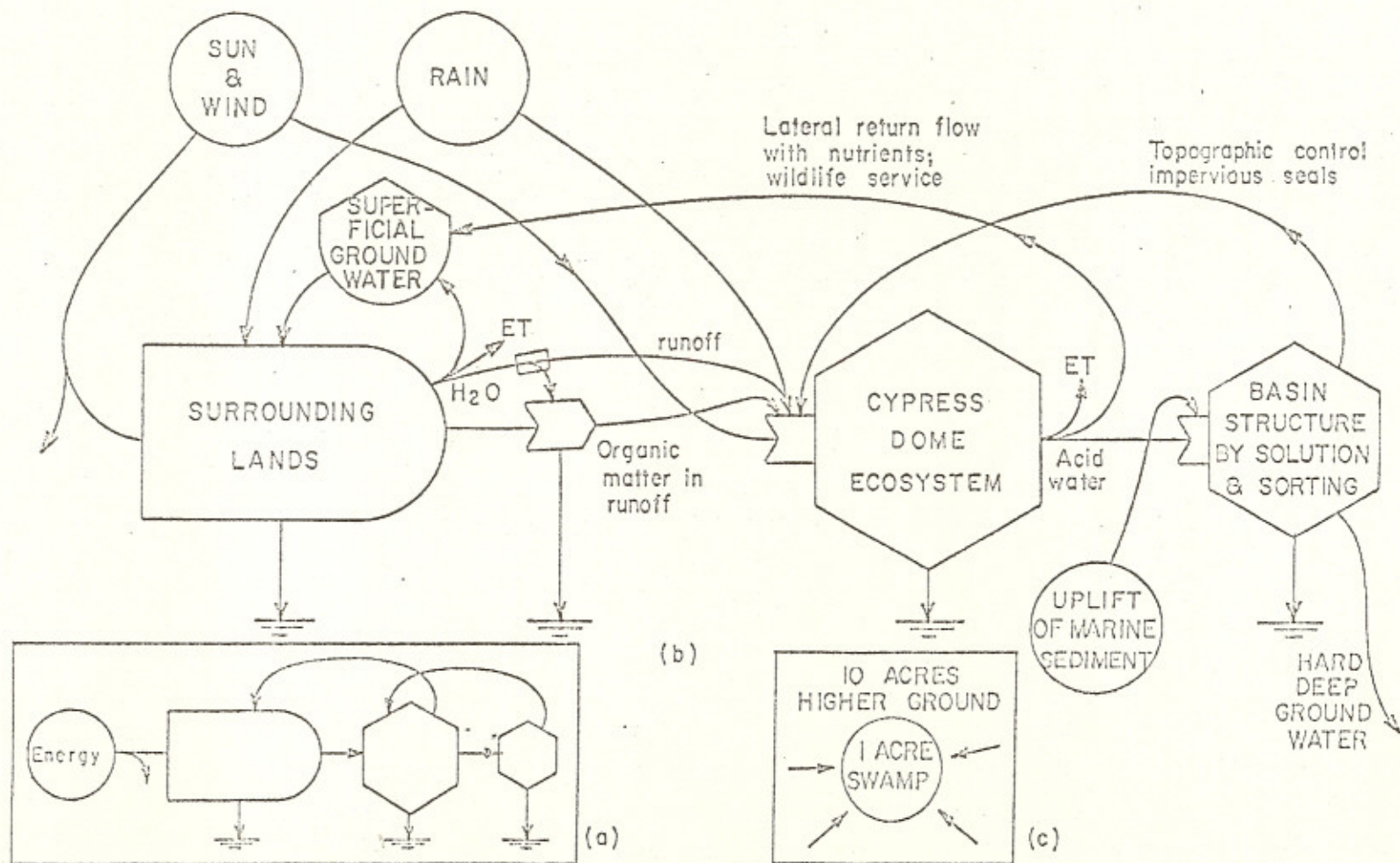


Fig. 10. Energy flow model illustrating the convergent effect of energy in a landscape on a cypress dome ecosystem.

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