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**RECYCLING TREATED SEWAGE THROUGH CYPRESS
WETLANDS IN FLORIDA**

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The burned, unburned, soft water, hard water, and wastewater variations represent major classes of conditions in Florida. Phases of research are measuring uptake of nutrients by the components of the ecosystem, heavy metal concentrations, changes in organic matter, microbial concentrations, tree growth, changes in ecological commu-

nities, microclimate, mosquito populations, and economic potentials in stimulating this type of land use as a replacement for tertiary treatment (Odum and Ewel, 1974).

Figure 2 is an aerial photograph of the experimental area six years prior to the study. The dark, isolated areas are cypress domes; the light areas are pine plantations. This

Fig. 2 Aerial view of cypress domes in pine plantations before forest fire or sewage disposal.



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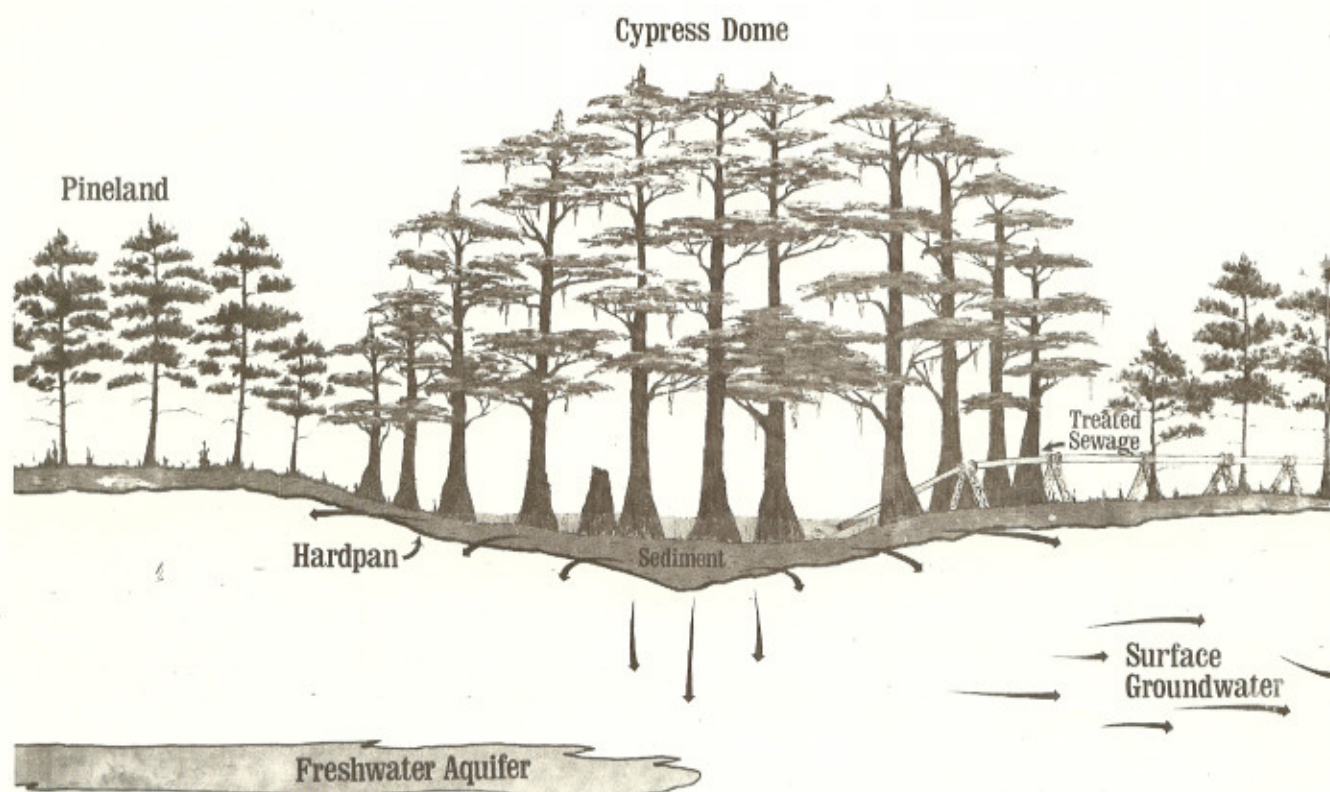


Fig. 1 Generalized profile of a cypress dome ecosystem showing surrounding pinelands and wastewater disposal scheme.

A natural water management system exists in Florida: its cypress wetlands catch and hold excessive rains, letting them percolate slowly to the ground water. The needles drop in the dry season and the dense trunk biomass shades the waters, reducing water loss during this critical time. A test of the feasibility of recycling treated sewage through cypress wetlands is in its second year in Gainesville, Florida (see Fig. 1). Wastewater from secondary sewage treatment plant at a trailer park is being routed into two of the cypress domes which are found in large numbers in many of the counties of Florida (40,000 in some counties). A dome

is a roughly circular cypress swamp, 1–25 acres in size, occupying a saucer-shaped depression which receives water from the surrounding higher ground. The trees are tallest in the center and shorter at the sides like an inverted bowl, or dome.

One of the domes receiving waste was severely burned prior to flow, and the other is typical of the wet ponds that have only been burned slightly. A normal acid-water pond is being used as a control, while another burned cypress dome is receiving hard ground water, such as is now found in many cypress ponds in disturbed areas in south Florida.

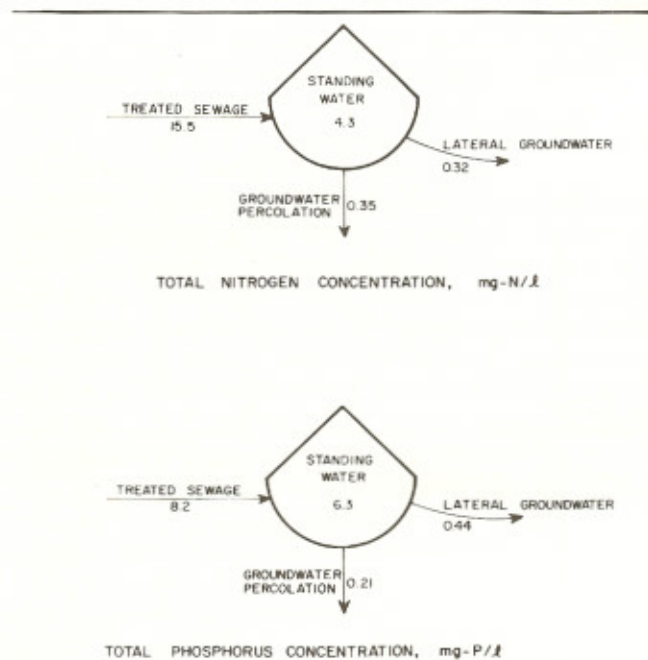
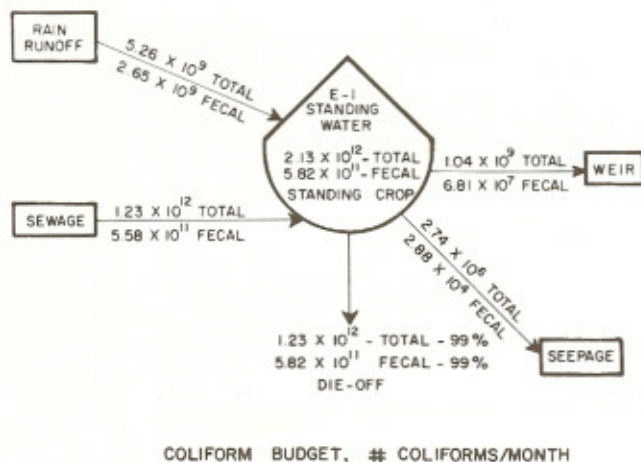


Fig. 5 Nutrient concentrations of treated sewage, standing water, and groundwater of cypress dome receiving sewage. Little or no surface outflow is assumed at an application rate of one inch per week. Groundwater percolation values are from a well 3 m directly below the dome while surface groundwater values are from a shallow well 50 m downstream of the dome.

Fig. 6 Coliform budget (total and fecal) for cypress dome receiving treated sewage (D. Price and J. Fox).



week in rainfall and two inches in runoff, and experimental domes receive an additional inch per week of wastewater or groundwater. The dome has some of the properties of a giant pressure filter: one inch per week is estimated to pass from the pool in the dome to the groundwater.

The diagram (Fig. 5) shows the nutrient concentrations in the wastewaters flowing into the dome, in the standing water, and in the groundwaters emerging from under the dome. Preliminary indications are that most of the nutrients are being taken out of the waters, although we don't know yet whether they are being routed from sediments to increased tree growth. Sediments below domes are calcareous and may be depositing phosphorus from percolating waters by differential precipitation, as shown by Gilliland (1973) for Florida ecosystems in general.

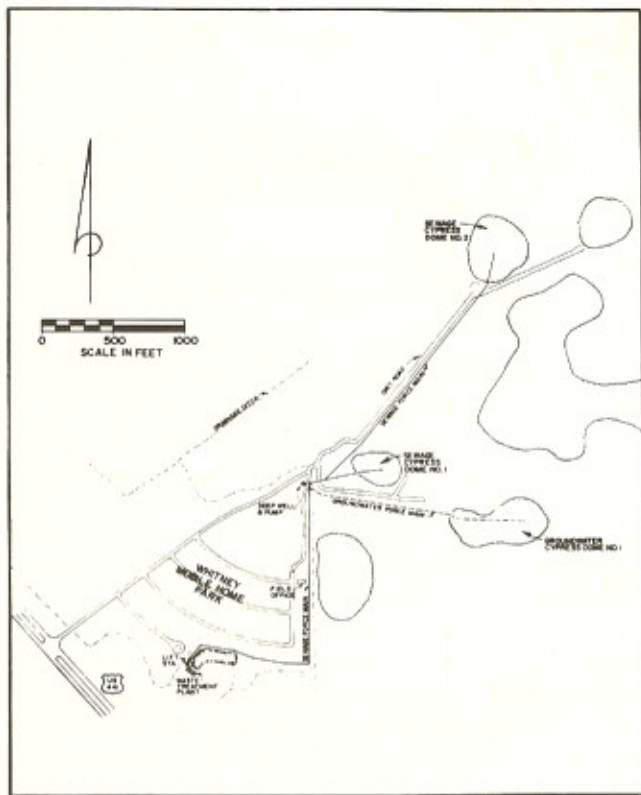
Similar changes in coliform bacteria counts are shown in Fig. 6. Some leakage of sewage around wells drilled into the first dome resulted in detectable bacterial concentrations in the groundwater; no wells or other deep installations were put into the second dome, preventing this artificial leakage.

Cooperative studies by Wellings et al., (1975) showed leakage of viruses as well into the groundwater. So far, none have appeared in the groundwater wells surrounding the unburned dome that has not been perforated.

The main features of the cypress dome ecosystem are shown in Fig. 7. The energy circuit symbols used (Odum, 1971) imply specific mathematical relationships. The major features shown include the autotrophic compartments of cypress, pine, and understory. Nutrients, water, and organic peat are important components in the sediments. Interactions with the outside include fire, logging, drainage, and nutrient loading.

The ecosystems with normal, acid water are fairly diversified with some aquatic plant growth; productivity in the pond is particularly high in the early spring before cypress leaves have reappeared. Dissolved oxygen is about one-fourth of saturation. After fire, a floating algal cover and then a duckweed growth appeared in the two burned domes, presumably stimulated by the released nutrients. The burned dome receiving treated sewage, however, retained a solid duckweed cover, causing near zero oxygen levels in the water. The duckweed in the burned groundwater dome decreased to scattered patches. Nitrogen was depleted there also, presumably due to denitrification by microbes in anaerobic water and uptake by duckweed growth.

Normal cypress domes are characterized by submerged aquatic vegetation, bladderwort (*Utricularia* sp.) in this case. Emergent vegetation is common in shallower areas,

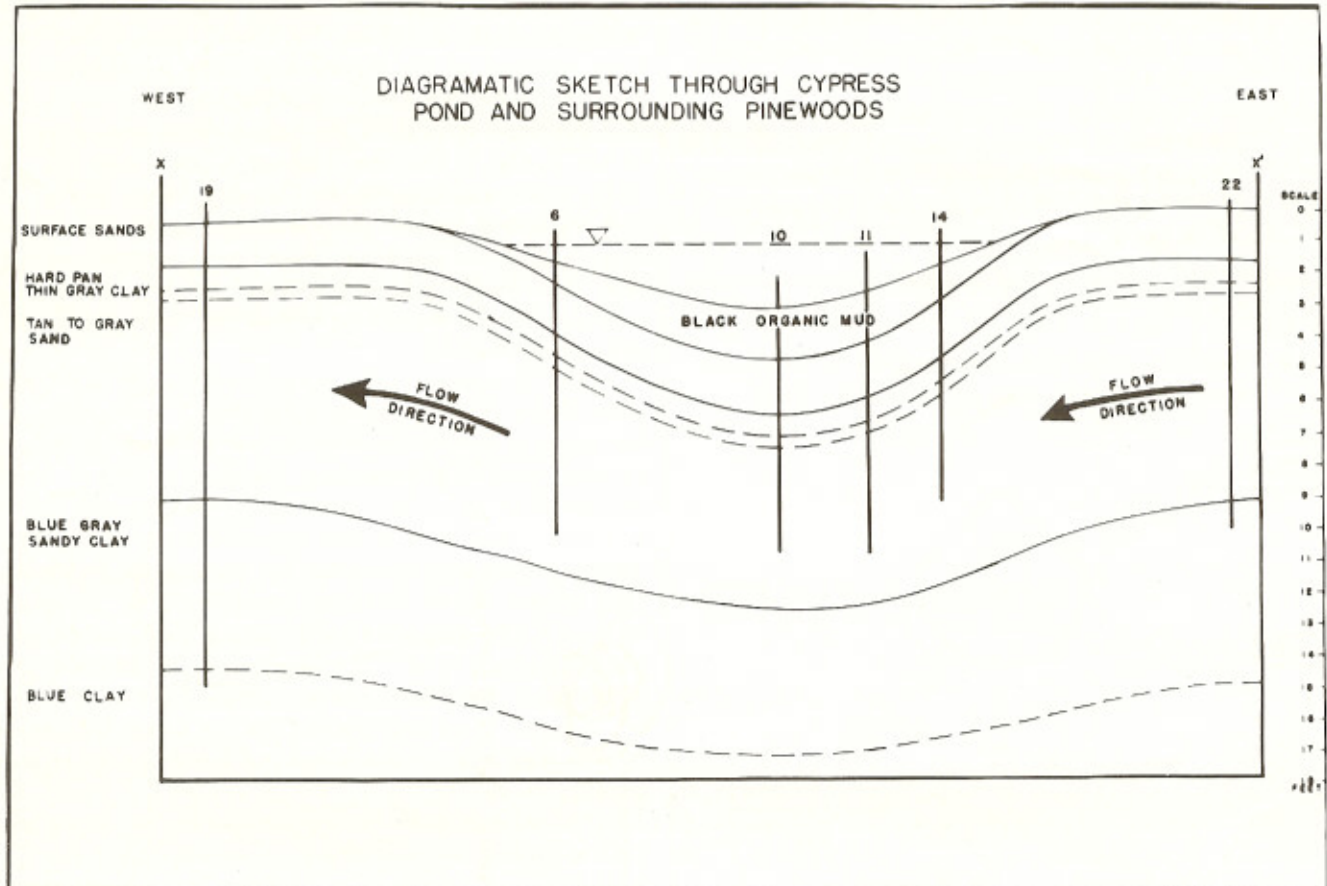


degree of interspersed of the two ecosystem types is very typical of the north Florida landscape. The current layout of the experimental areas is outlined in Fig. 3, which shows the location of the three domes affected by fire. The fourth is about ten miles from this site.

The geologic strata are described in a thesis by Cutright (1974), and are shown in Fig. 4. His studies showed the movement of superficial groundwater through the sands beneath the dome. During the winter dry season, the ponds of the cypress domes are perched several feet above the groundwater; in the summer rainy season, the groundwater contacts the lower surface of the dome. During the summer each dome receives about an inch per

Fig. 3 General site plan of cypress domes receiving treated sewage and groundwater.

Fig. 4 Idealized east-west cross-section through the cypress dome receiving sewage, showing geological strata, test wells, and general groundwater flow (Cutright, 1974).



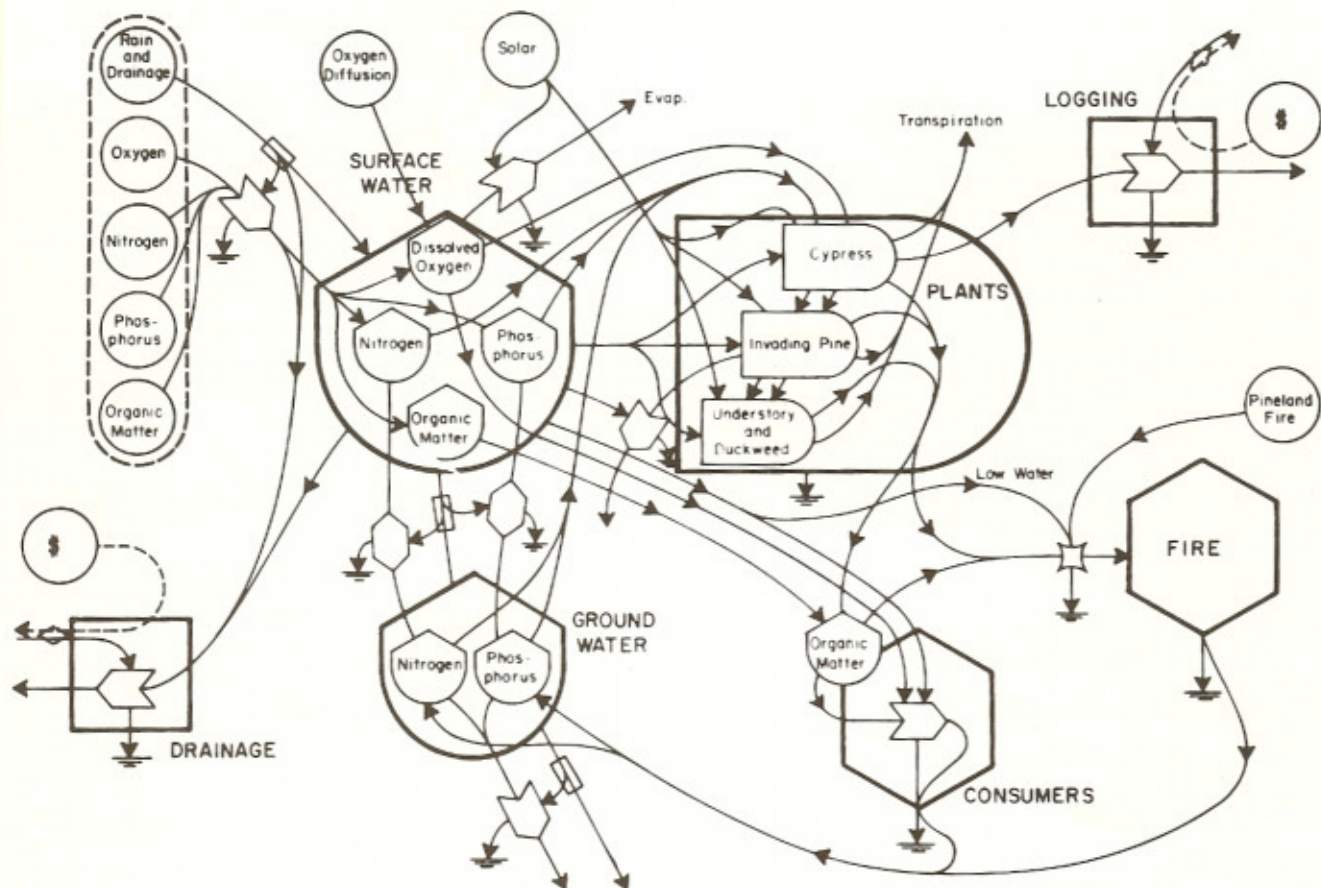
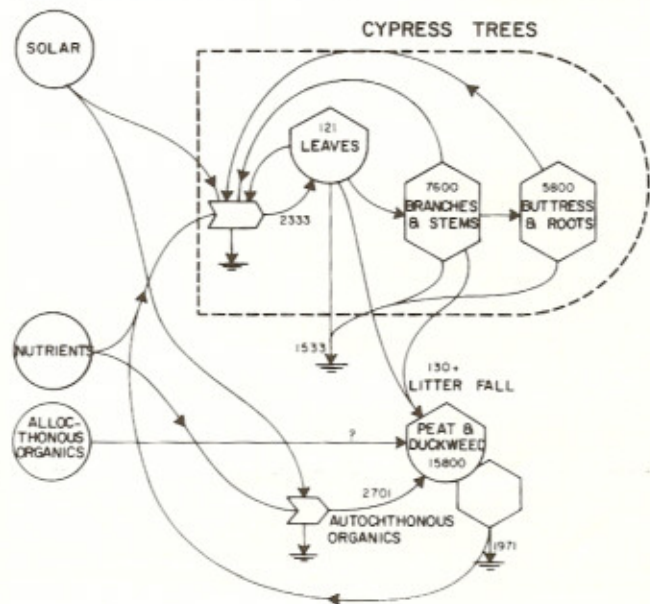


Fig. 7 Energy flow diagram of major compartments of a cypress dome ecosystem including interactions of fire, tree logging, and drainage.

Fig. 8 Major organic storages and flows in the cypress dome receiving sewage. Flows are in g-organic matter/m²-yr while storages are in g-organic matter/m².



while most of the vegetation is characteristically clumped around the bases of the trees and knees. The thick cover of duckweed soon disappeared in the dome receiving groundwater, but has persisted in the sewage dome and proliferated in the second dome receiving sewage almost as soon as flow began. One species of duckweed returned to the groundwater dome when a rookery of immature white ibis took up temporary residency. The duckweed fronds contain nitrogen concentrations of 5 to 6% – much higher than the other species of vegetation.

Baldcypress seedlings planted in all the domes grew more slowly at first in the sewage domes, but all seedlings

showed a high survival rate, and in the second year the seedlings in the sewage dome are growing faster than those in the groundwater dome (J.B. Murphy). Cypress seeds require drawdown to germinate, so natural regeneration may have stopped in the three experimental areas except around the edges. New tupelo seedlings have been found growing in the sewage dome.

The intensity of the fire, increased by considerable draining in the area during the last few years, was so great that most of the hardwoods and pines in the two badly burned domes were killed. Over 95% of the cypress trees survived, however. Foliage put out in the spring following the fire was very abnormal, springing adventitiously from the trunk and hanging close to the trunks, opening up the canopy considerably. New limbs were red-barked. The second year's growth has been more normal, however, and many of the branches show the spread of needles

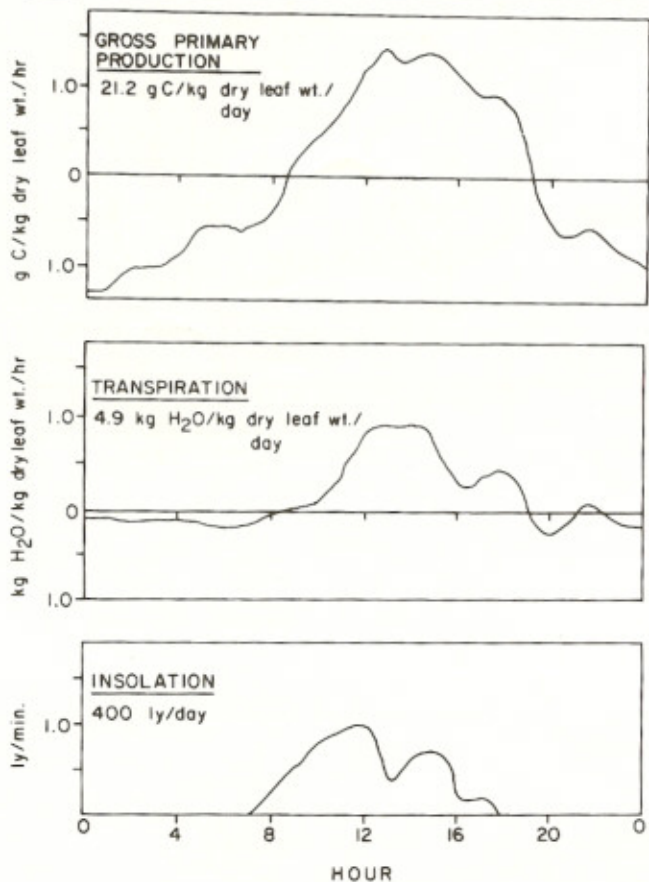


Fig. 9 Productivity and transpiration of cypress leaves as measured by CO₂ gas metabolism unit. Data are from October 1973 (Bayley, Burns and Burr, 1974).

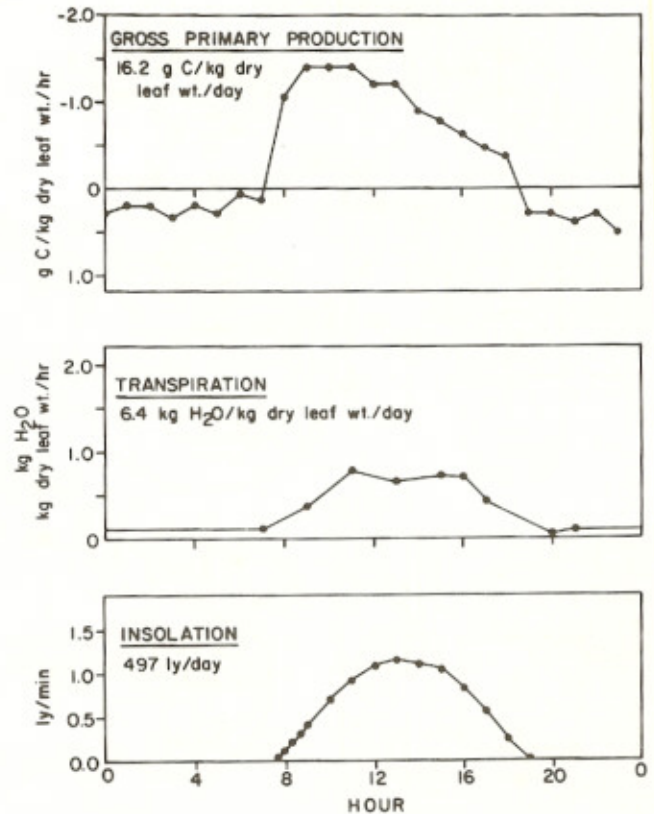


Fig. 10 Productivity and transpiration of cypress leaves as measured by CO₂ gas metabolism unit. Data are from October 1974 (Cowles, 1974).

characteristic of baldcypress rather than pondcypress.

The organic cycle within the dome is shown in Fig. 8. Measurements of litterfall and tree metabolism indicate that net primary productivity is greater than zero and that the trees are still growing. The high input to the pond from autochthonous organic materials is due to the proliferation and deposition of duckweed. Cypress has a small leaf biomass per unit area although the photosynthesis and transpiration per area of leaf is normal. Insolation and rates of photosynthesis for two consecutive years are shown in Fig. 9 (Bayley et al. 1974) and Fig. 10 (Cowles, 1974).

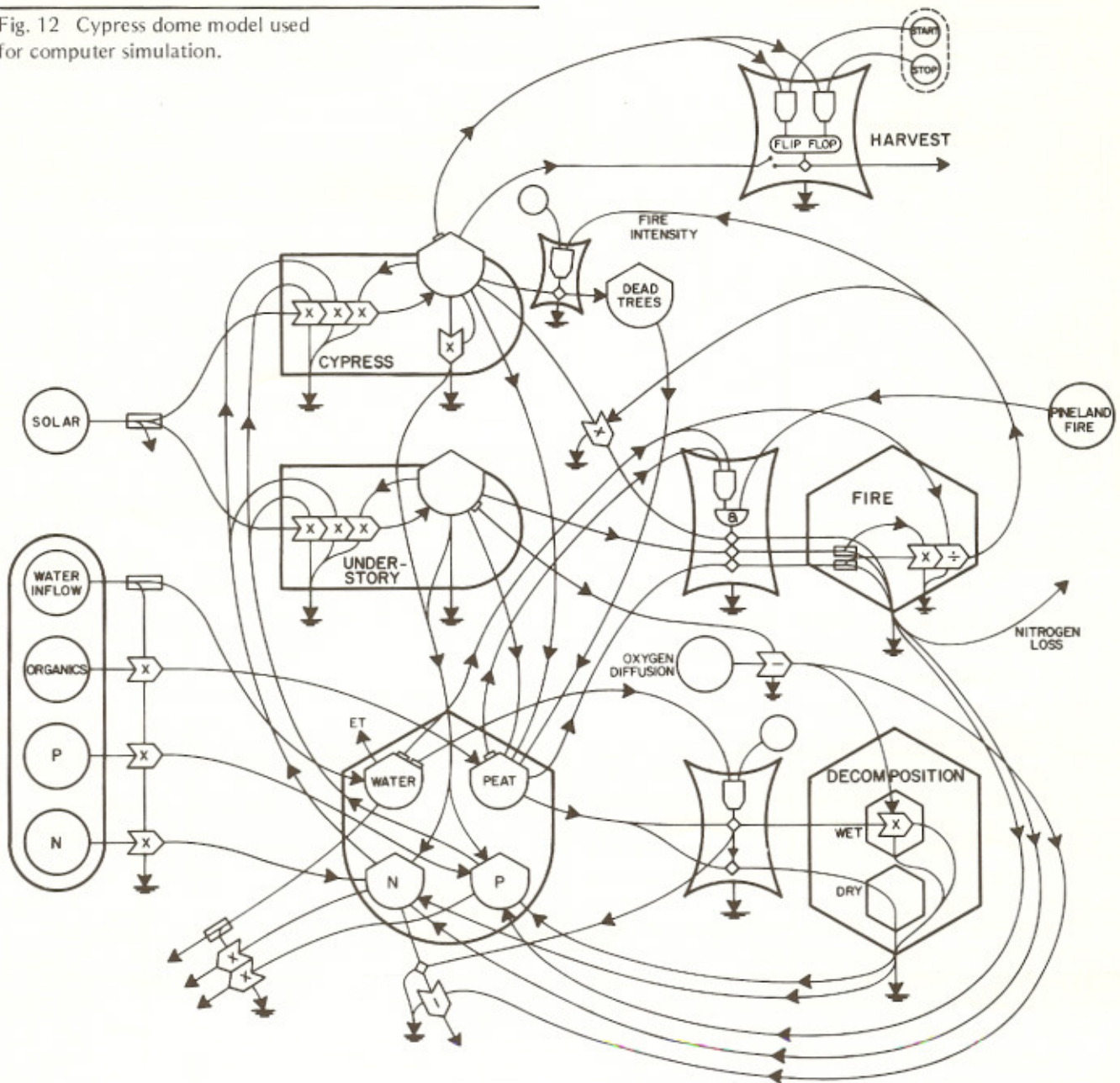
Mosquito fish as well as several other species are commonly found in cypress domes. All the experimental ponds are being seeded with a combination of common freshwater species. Self-design properties of the ecosystem may result in an interface ecosystem with organisms using all the resources; seeding will eliminate the delay caused by species having to gain access by natural means.

The duckweed cover is changing the insect population considerably, at present fostering moth and shore flies

go with cypress as contrasted with those that generate marshes, wet prairies and ponds without cypress (Fig. 18). The cypress are in the sites with the lower position and longer period of submergence.

At Wildwood, Florida, wastes from the town have passed into a floodplain swamp for 19 years. Recent analysis of these by Brown *et al.*, (1974) showed coliform reduction from 1.6 million MPN to 300 million MPN per

Fig. 12 Cypress dome model used for computer simulation.



which are common in sewage areas. Many migratory songbirds, potential carriers of viral encephalitis, were observed to be attracted by the flies in the sewage domes. The mosquito species with disease potentials are listed in Table 1.

Surrounding the domes are slash pine seedlings planted by Owens-Illinois Incorporated from whom the land is leased. One of the beneficial effects of maintaining domes

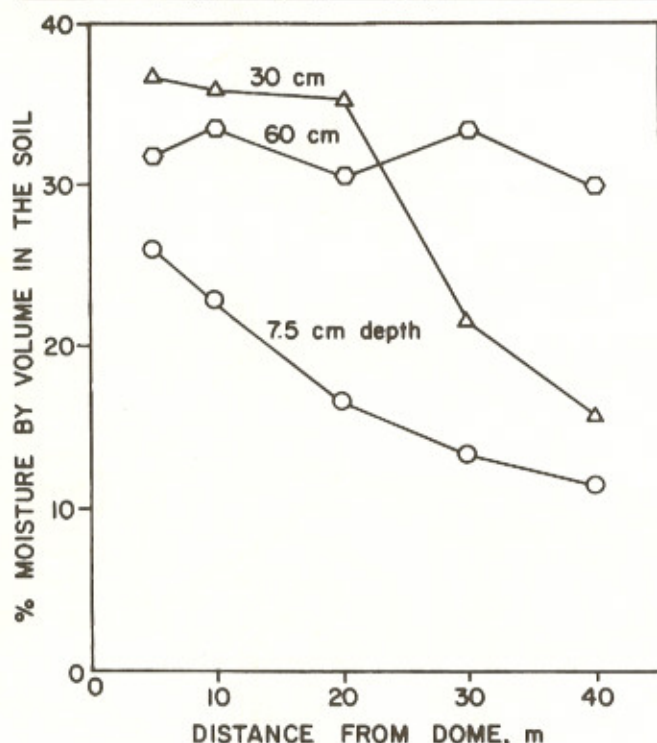


Fig. 11 Soil moisture as a function of distance from edge of cypress dome receiving sewage. Curves are for 3 depths in the soil (P. Okorie and C.M. Kaufman).

wet during the dry season, as natural domes tend to be, may be in keeping surrounding forests damp, reducing the damage by fire and increasing growth of pine trees. Preliminary data gathered by P. Okorie on the effects of the increased water levels on soil moisture in the surrounding area are shown in Fig. 11.

The possible interplay of sun, nutrients, water, fire, and harvesting over the long range was studied by W.J. Mitsch (1975) in computer simulation models which incorporated much of the information already discussed. The model simulated is in Fig. 12 and samples of the graphs are given in Figs. 13-15. Cutting and draining together increase the effects of fire, thereby reducing productivity,

whereas fire alone or cutting alone (without draining) is not a major effect and may accelerate the dominance of the taller trees.

Field workers on the project have commented on the pleasant microclimate within the dome; measurements are being made to determine the differences between radiation balance, temperature, saturation deficit and wind velocity, in the domes and surrounding pinelands (see Fig. 16.) Spectral signature from satellite photographs of Lee County (Capehart *et al.*, 1975) showed cypress as having higher reflectance in infrared than pine or *Melaleuca leucodendron*. Reflectance was higher in spring than in other months and higher in dry cypress.

Cypress lands are only half as expensive as uplands in Florida, and they are aesthetic attractions in many places. Savings in housing costs may be realized by building in or near cypress swamps. Architects associated with the project seized the need for an equipment shed as an opportunity to test the concept of building houses within domes. Houses have been built in Naples, Florida with cypress swamps as yards. They are elevated as well. Drainage ditches have lowered the groundwater in the vicinity to some extent.

Another part of the project is monitoring cypress growth and nutrient relations in swamps and strands where waters flow in from larger drainage areas and out again, more as in a river floodplain. Here, there are believed to be more nutrients available per tree, water levels may be more regular in dry season, and faster growth per tree can be shown (Fig. 17). Trees are of the baldcypress variety.

At the virgin Corkscrew Swamp site, Collier County, Florida (Duever *et al.*, 1974), as part of this project, have documented the hydroperiod and groundwater levels that

TABLE 1

Mosquitoes Caught in Ramp Traps in Sewage Dome (Over 1% of Catch)

(H. Davis, L. Berner and D. Dame)

Species	% of Catch		Disease Potential
	April	July	
<i>Aedes atlanticus</i>	—	4.9	
<i>Anopheles crucians</i>	16.6	7.5	pest
<i>Anopheles quadrimaculatus</i>	—	—	malaria
<i>Culex nigropalpus</i>	—	4.3	encephalitis virus
<i>Culex spp. (other)</i>	43.2	13.5	virus
<i>Culiseta melanura</i>	16.6	53.0	encephalitis in birds
<i>Mansoni perturbans</i>	3.3	1.8	
<i>Psorophora ferox</i>	6.6	1.1	
<i>Psorophora confinnis</i>	—	1.8	
<i>Uranotaenia sapphirina</i>	3.3	16.4	
<i>Uranotaenia lowii</i>	—	1.1	

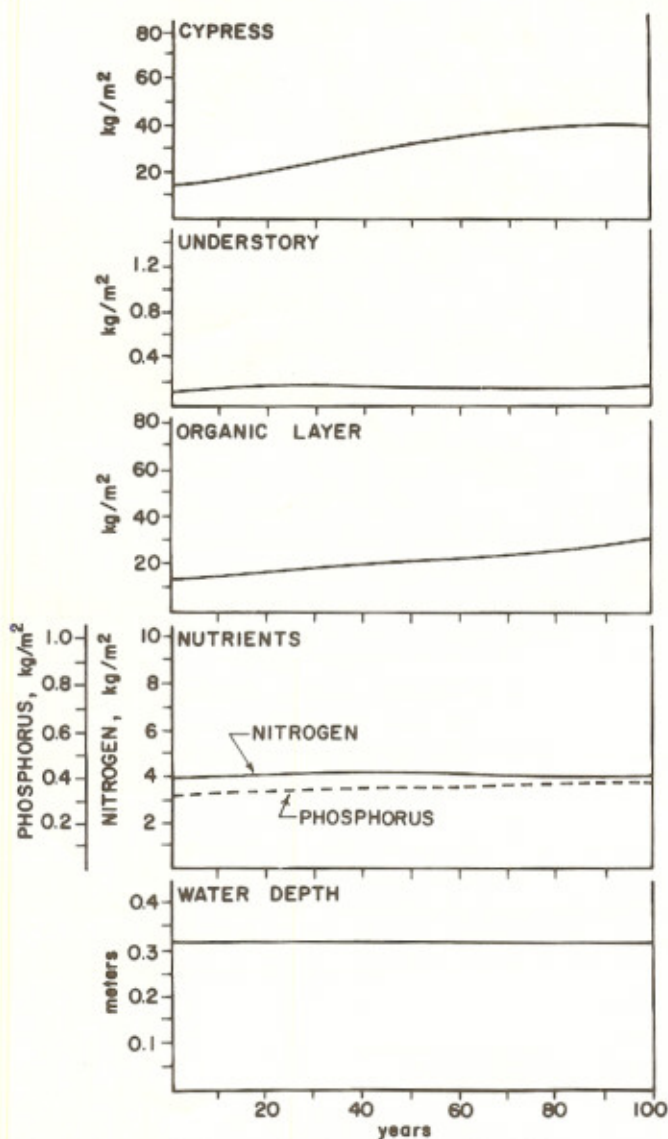


Fig. 13 Simulation results for model in Fig. 12 for undisturbed conditions.

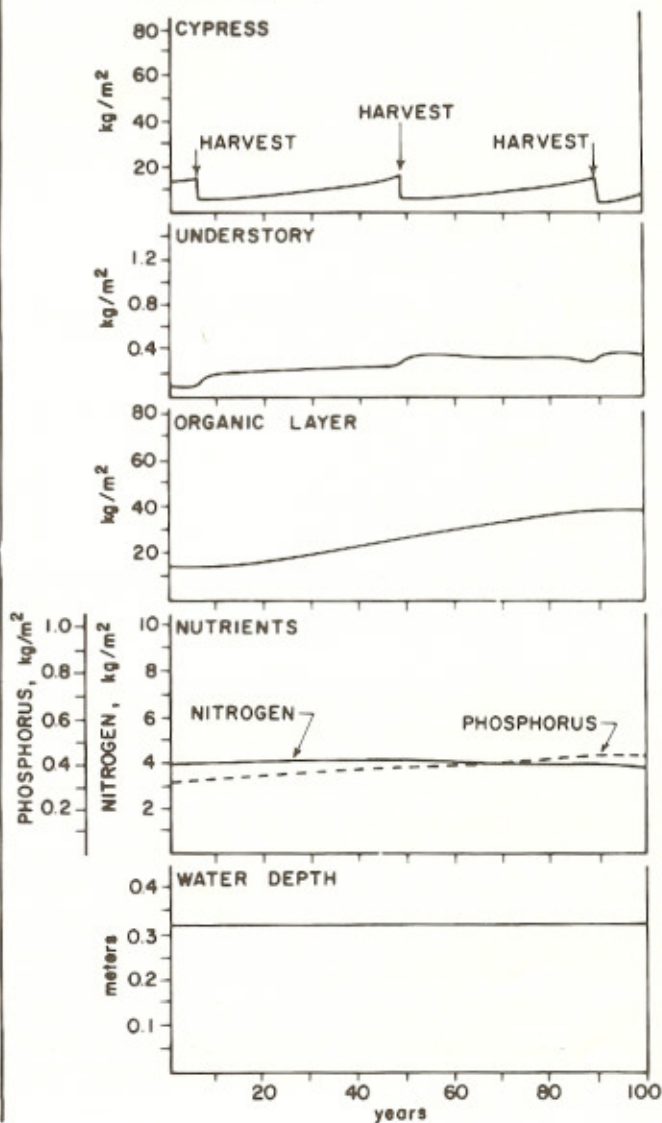
100 ml, phosphorus reduction from 7ppm to 0.1 ppm, and increased growth of the trees by a third.

A new energy investment ratio principle (Odum, 1975) can also be used to estimate economic worth (see Fig. 19a). The average purchased energy (in fossil fuel equivalents) that an area can attract depends on a free resident resource that supplements bought energy in generating a yield. It is the basis for attracting economic investment in the first place and the resident energy helps keep prices competitive. An activity that supplements bought energy with less than 1.0 kcal fossil fuel equivalent

(2000 kcal solar energy) for every 2.5 kilocalorie bought (directly or indirectly from 2.5 kcal of fossil fuel work) will not be competitive.

Based on the nation's economy as a whole, 1 kcal fossil fuel equivalent (FFE) of sunlight on the average has been attracting 2.5 kcal FFE of fossil fuels to the resident economy. The ratio will change as the nation's energy intensiveness changes. Figure 19 shows a general diagram for the disposal of 2.8 million gallons per day of nutrient wastewater. The high energy quality of the nutrients gives

Fig. 14 Simulation results for model in Fig. 12 in which cypress harvesting occurs when cypress biomass reaches 15 kg/m².



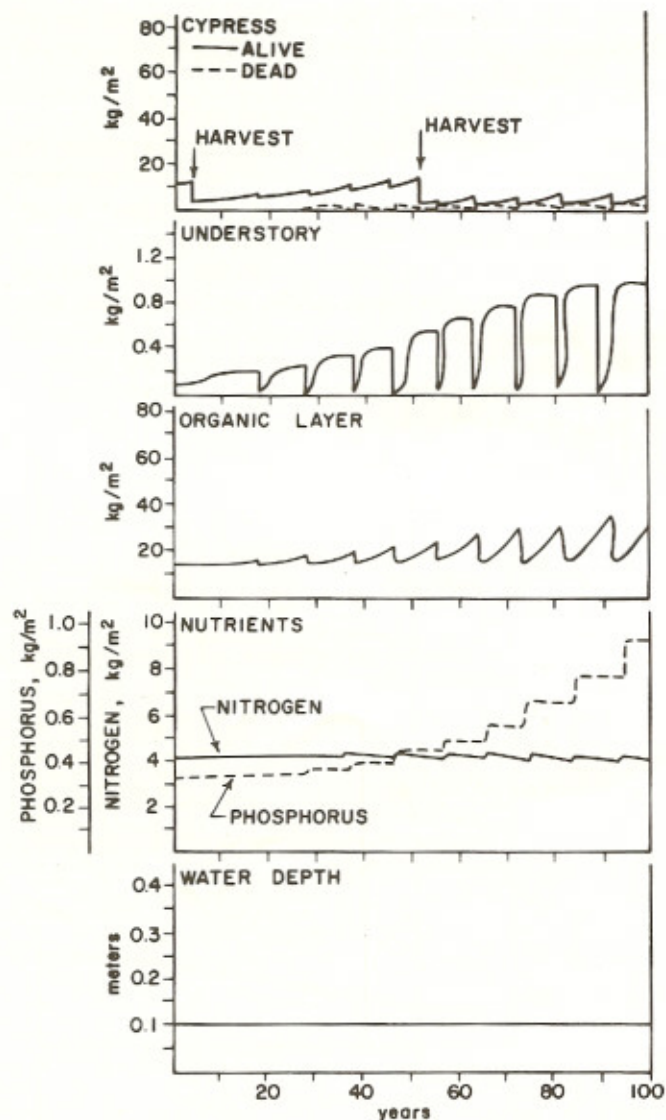


Fig. 15 Simulation results for model in Fig. 12 where cypress harvesting and 10 year fire occur, the latter due to low water conditions.

that flow a value of 8.0×10^8 kcal FFE/year if it is matched by enough sunlight (intensity \times area) to get a net increase in 8.0×10^8 kcal FFE/yr from the natural system. This increase in resident natural energy flow can therefore theoretically attract 20.0×10^8 kcal FFE/year from external sources. The model shows that the disposal of the 2.8 mgd of secondary sewage into a natural system has the capability of increasing the money flow in the local economy by \$80,000/year or approximately \$0.08/1000 gallons of secondary sewage.

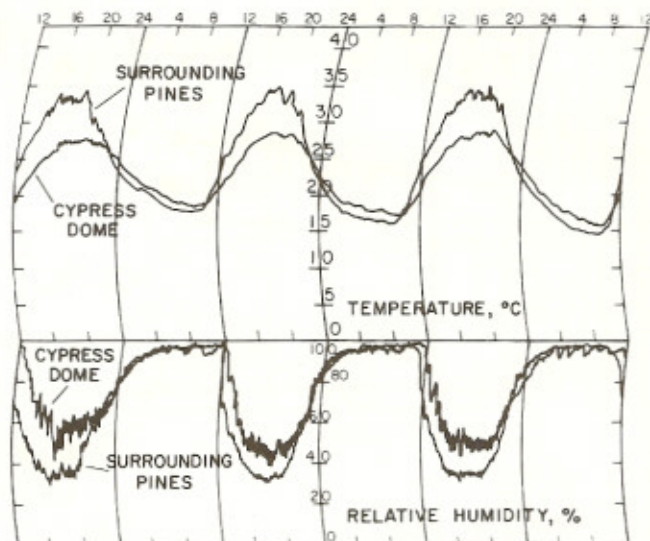


Fig. 16 Microclimate differences between interior of an undisturbed cypress dome and the interior of the surrounding pineland in March, 1975. (K. Heimburg).

In a cypress system disposal scheme (Fig. 20), a loading rate of one inch per week allows the water to percolate slowly through the soil to the aquifer, leaving nutrients behind. The nutrients increase the metabolism of the cypress trees over a large area, and the economic flow is amplified with the production of high quality cypress wood. The purchased energies attracted to this system include the work of harvesting, the work of finishing the wood, and possibly even the work of building a cypress

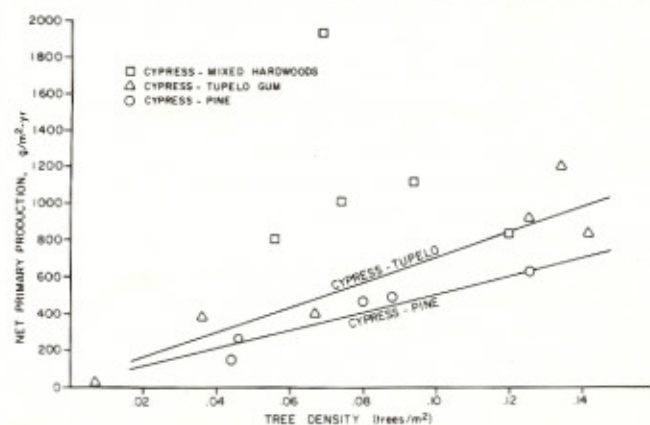


Fig. 17 Relationship between cypress net productivity and tree density for three different cypress associations in the Withlacoochee State Forest in west-central Florida. Cypress-mixed hardwood associates generally indicated riverine or strand swamps (Mitsch, 1975).

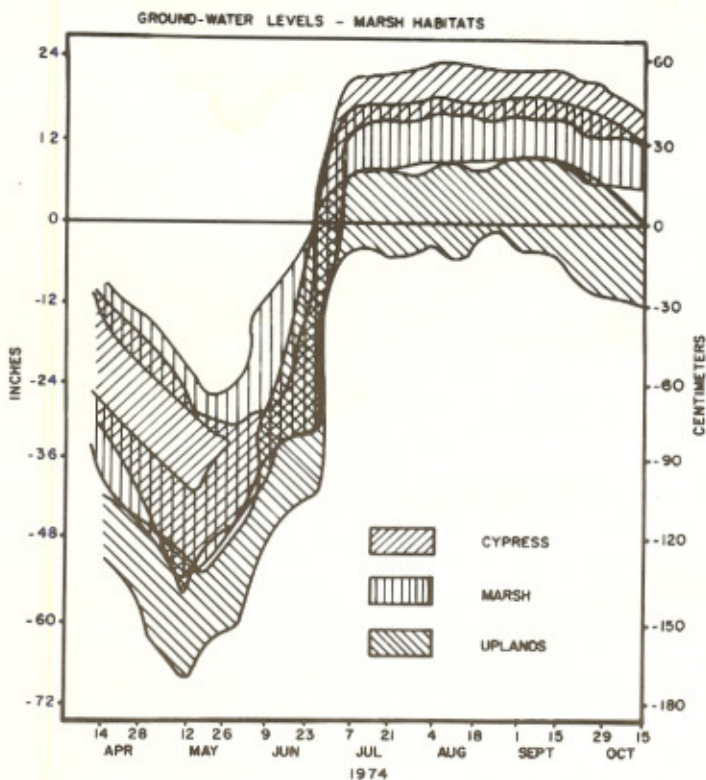


Fig. 18 Relationships between seasonal water levels and ecosystem type found in the Big Cypress Swamp in Southwest Florida (M. Duever, E. Carlson and L. Riopelle, 1974).

wood house or some other manufactured goods. Here the free work of the sun, water, wind, and land have supplemented the purchased economy. Preliminary calculations show the investment ratio in this case to be 2.1.

The Water Pollution Control Act of 1972 requires that cities throughout the country should be treating wastewater with the "best practicable treatment" by July 1, 1983, and to meet this goal the U.S. Environmental Protection Agency estimates that construction costs for advanced waste treatment plants will be over twenty billion dollars (Dobrzynski, 1975). The maintenance and operating costs of these physical-chemical plants (most conventional primary and secondary plants use biological processes) will also be high due to the large amounts of coagulating chemicals and energy needed for their operation. A cost analysis for a ten million gallon per day plant based on an "Engineering News-Record" Construction Cost Index of 2000 (the EN-R Construction Cost Index for October 2, 1975 was 2278.7) found that a 97% BOD removal and a 92% phosphorus removal would cost approximately \$.50

per 1000 gallons (Wallis, 1974) and a comparison of nutrient removal processes for domestic waste by Eliassen and Tchobanoglous (1969) found that for both nitrogen and phosphorus removal efficiencies of 80% or more the costs ranged from \$.17 to \$1.00 per 1000 gallons treated. Table 2 gives the unit cost for cypress wetland disposal at \$.25 per 1000 gallons, but it should be noted that using a higher loading rate with the existing system would lead to a much smaller unit cost. A loading rate of two inches per week for instance, would lead to a cost of approximately \$.13 per 1000 gallons.

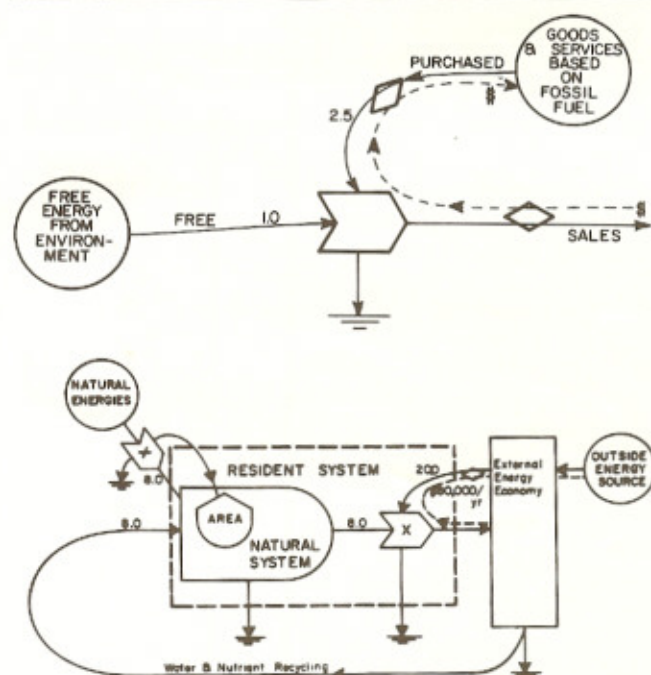


Fig. 19 (a) Definition of investment ratio: purchased feedback divided by free natural inflow where both are expressed in fossil fuel equivalents. Ratio for U.S.A. in fossil fuel equivalents is 2.5/1.

(b) Theoretical investment ratio model showing energy flows to be expected (in kcal fossil fuel equivalents $\times 10^8/\text{yr}$) for the disposal of 2.8 million gallons per day treated sewage into a natural system.

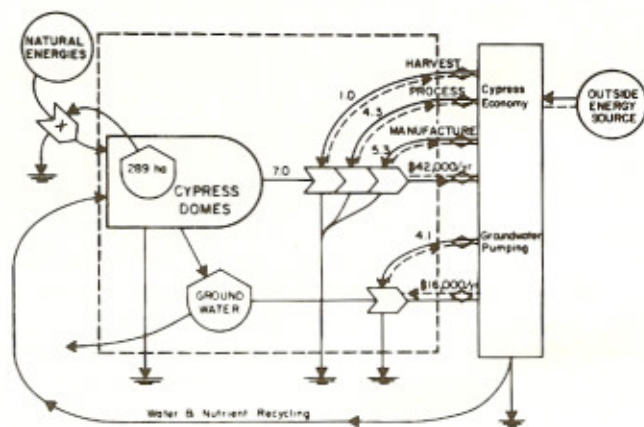


Fig. 20 Calculated natural and purchased energy flows applied to the disposal of 2.8 mgd treated sewage into cypress domes. For every natural calorie of fossil fuel equivalent of increased productivity, 2.1 calories fossil fuel equivalent are purchased in this case.

TABLE 2

Cost Analysis for Cypress Wetlands Disposal @ 25,000 GPD

Cost Items	Cost Data
Capital and Installation Cost	
Wetwell (6 ft. dia., 10 ft. deep)	\$ 1,200
Pumps (2 ea., 1-1/2 hp.)	2,000
6" P.V.C. Pipe and Fittings (1500 ft.)	4,500
4" P.V.C. Pipe and Fittings (3100 ft.)	7,750
	<u>\$15,450</u>
Annual Operating Cost	
Power @ 5 cents/kwh	75
Maintenance	
Parts	300
Labor (1-1/2 hrs./week @ \$10.75/hr.)	840
	<u>\$ 1,215</u>
Total Unit Costs	
Annual Capital Cost	
Wetwell and Pump (20 yrs. @ 6%)	279
P.V.C. Pipe (40 yrs. @ 6%)	815
Annual Operating Cost	1,215
	<u>\$ 2,309</u>
TOTAL UNIT COSTS	
\$/1000 gal.	\$ 0.25

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