ENERGY ANALYSIS EVALUATION OF SANTA FE SWAMP

Bradford County, Florida

by

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SUMMARY

Values of the Santa Fe Swamp in Bradford County, Florida, were evaluated with an energy analysis procedure and expressed as macroeconomic dollar contribution to the public economy. The swamp serves the region as a major regulator and conserver of water quantity and quality, increasingly important to the public good as density of populations and urban activities increase in North Florida. Annual contribution to the regional economy was estimated as $3.4 million and the capital assets in the swamp's geological and ecological structure and storages was estimated as $2.2 billion.

Management measures are recommended that help natural succession to restore a canopy of larger trees that were cut earlier. By seeding and supplying nutrients, some of the wet scrub may be displaced more rapidly by succession, restoring a "bay-cypress-gum" swamp with additional ecological, aesthetic, wildlife, and recreational values that existed before clearcutting. With appropriate access trails and canoe access, the swamp should develop educational and recreational uses like the Okeefenokee Swamp.

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INTRODUCTION

Increasingly, the values of swamps to the regional economy of humanity and nature are becoming apparent with many questions raised about best utilization, values, appropriate laws, etc. Among the large swamps in Florida under discussion is the Santa Fe Swamp. This report uses energy systems methods to show ecological relationships and the role of the swamp in the regional economy. Calculations are made of the swamp's stored values and the annual contributions of the swamp to the regional economy.

Santa Fe Swamp

The Santa Fe Swamp is located in Bradford County, Florida, shown in Figure 1 and Figure 2. The swamp is an elevated plateau receiving rainwaters, waters from Lake Santa Fe and some drainages from sandy ridges to the east. The drainage canal from Lake Santa Fe to Lake Alto earlier in the century apparently lowered the water table of the swamp. It was clear-cut for timber and has experienced fires in dry periods that helped to arrest succession in a scrubby thicket stage. Fires and other oxidation tend to eliminate the peat above the water table in dry periods, especially after drainage efforts. Whether the swamp and peat level is in equilibrium with the present lower level of the swamp water table now is not known.

The pattern of the swamp in cross section is given in Figure 3 with water table and drainage shown.

Conceptual Background

Like Bogs found in more northern climates, bays and elevated swamps like the Okeefenokee Swamp and the Santa Fe Swamp in Bradford County receive rain waters, runoffs, and superficial ground water drainages from sandy

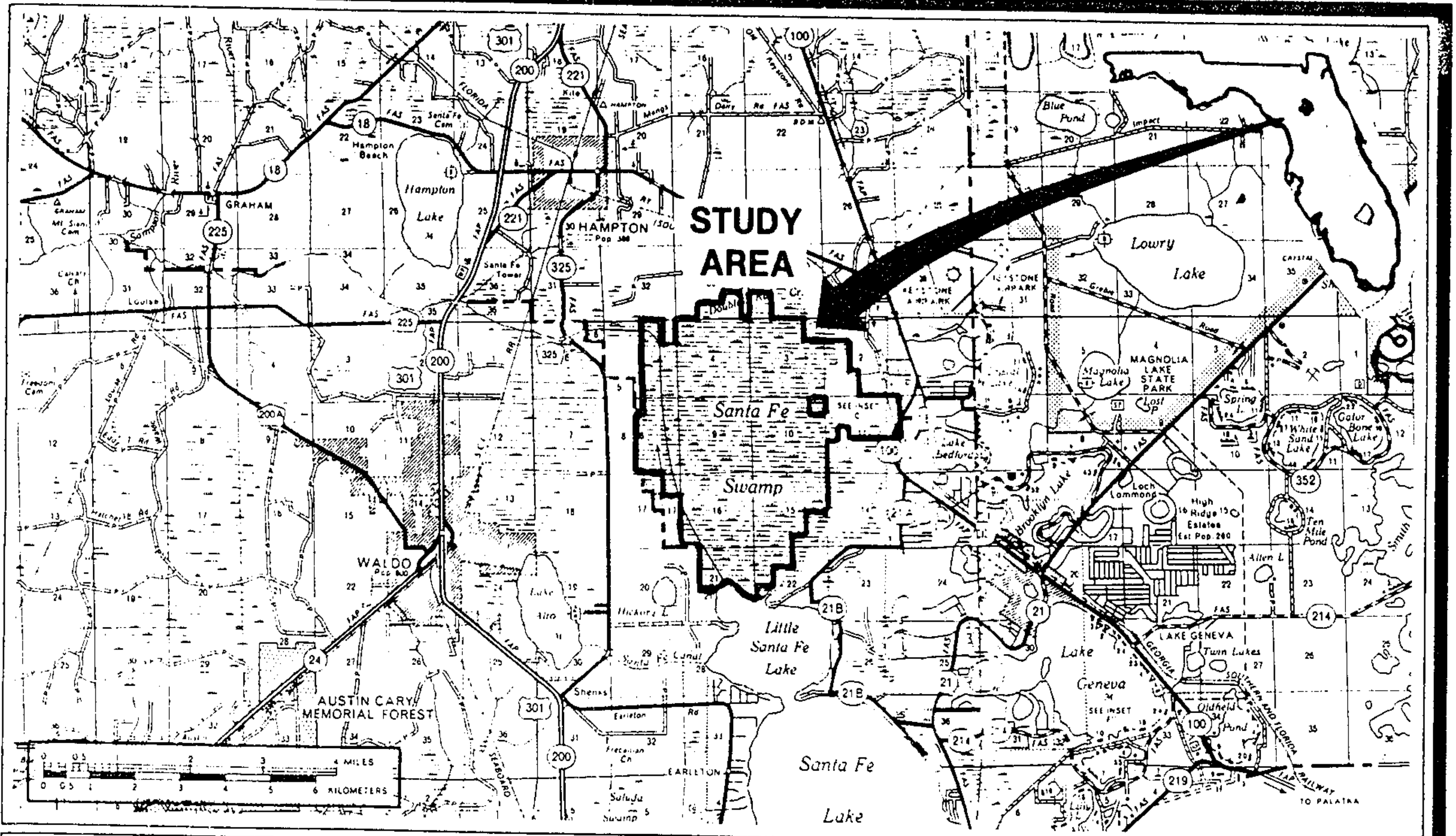

Figure 1

LOCATION OF GEORGIA-PACIFIC LITTLE SANTA FE TRACT

SOURCE: GEORGIA-PACIFIC, 1980.

Georgia-Pacific Corporation

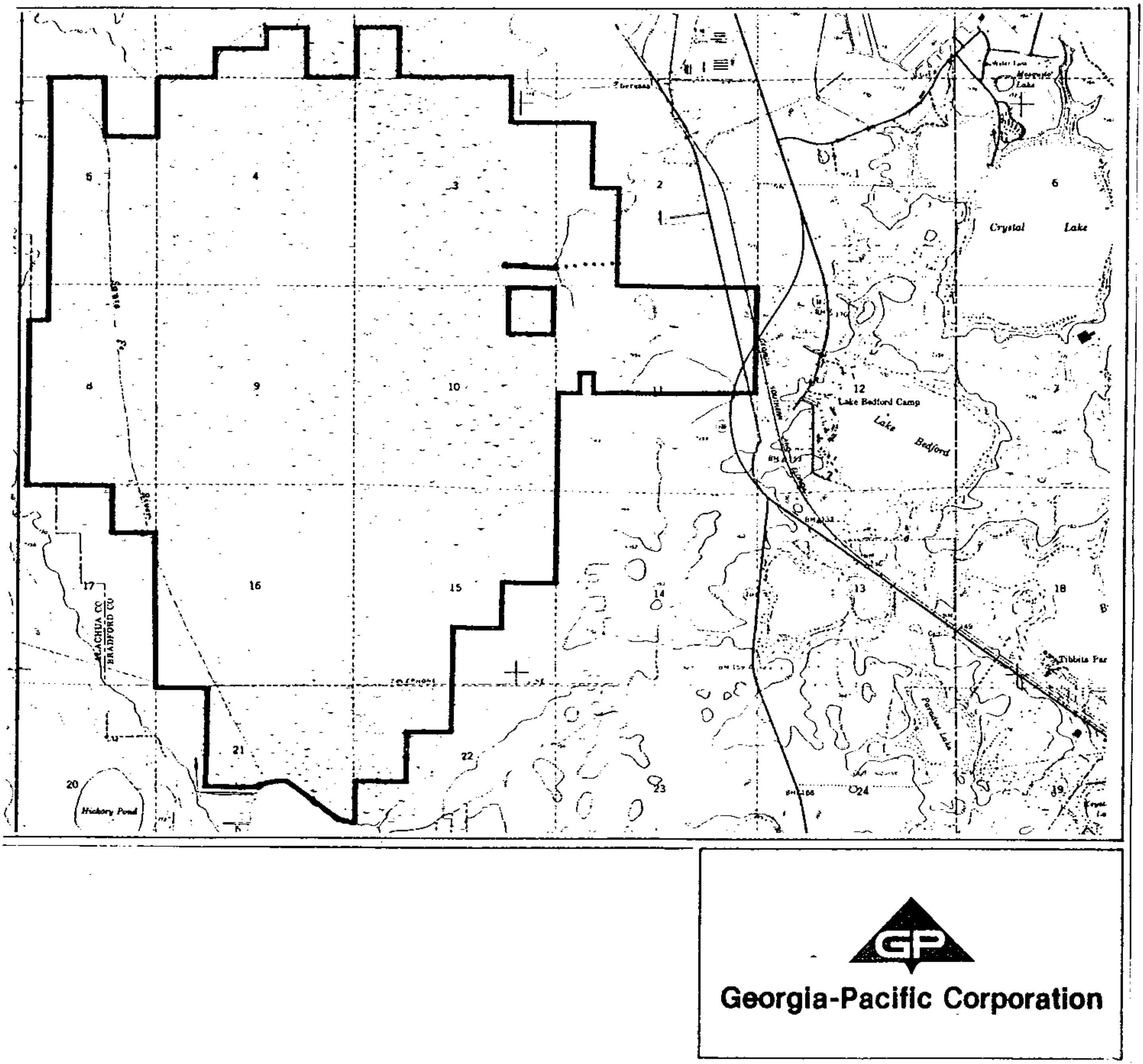

Figure 2. Area of the Santa Fe Swamp evaluated with energy-dollar analysis.

ridges without much nutrients. Under these low nutrient conditions a type of vegetation develops that makes abundant cellulose and lignin which is deposited as peat. Growth of living matter is slow and there are mechanisms for conserving nutrients within the living components such as evergreenness of many species such as the several species of "bay trees." The nutrient absence and acid condition may interfere with the consumers more than the plant producers so that peat accumulates. Whether this factor is more important in accounting for Santa Fe Swamp or its position as a filter across the outflow from the Santa Fe Lake network, or some other factor is more important is not known.

The following theory about the way elevated swamps operate and save water is gaining increasing support with considerable evidence now available. Because the nutrients are few and conserved, net growth is small, stomata are not opened for carbon-dioxide uptake as much, transpiration is less, and the heat budget of the sun is balanced by increased reflection and reradiation. Waters under the vegetation are shielded from sun and wind even in the dry periods. Water is stored in loose peaty colloidal solutions as well. Thus, the swamps of this type conserve water, evapotranspiring less than open waters of eutrophic lowland floodplain swamps.

The low nutrient swamps of the type described are elevated plateaus generally higher than the surrounding region so that the conserved waters tend to drain outward forming a headwater to strands that become stream floodplains at lower altitudes. Only local and temporary superficial water tables are higher and drain into the swamp. Since these perched water conservation swamps have a higher water table than the general regional aquifers, some of the waters recharge the aquifers underneath. The waters are initially organic laden and become acid due to carbon dioxide from decomposition and may also contain acid contributions from combustion stacks.

The downward percolation of such waters dissolves limestones over long geological periods, waters becoming neutral and hard of the reasonably good quality used by most municipalities by pumping from the deeper aquifers.

The action of the swamp helps develop the recharge pathways downward, but the percolating waters may concentrate clays. These and the beds of peat serve as natural kidneys, filtering nutrients, heavy metals, and many toxic organic substances (Jenkins et al., 1983). During growth periods, the waters held in peaty swamps help to maintain local stream flows and lake levels. During excessive rains, the swamp area acts as storm retention volume, the friction of the heavy vegetation helping to delay runoff surges.

Although not without controversy, these concepts suggest that the bays and upland swamps are important to regional water supplies, increasing quantity and protecting quality.

Other values of swamps are well known, as wildlife centers and recreational wilderness, becoming increasingly appreciated for aesthetic and educational values as population densities increase.

In general, this class of permanent swamps does not develop large numbers of nuisance mosquitoes that may develop in temporary waters, perhaps because of the small fishes that spread out when waters are high.

Over long periods of a hundred years or more moderately tall canopy trees of bay, cypress, and gum develop. Drier species such as slash pines develop on the elevated platforms that form of clustered root bases. Such swamps are beautiful, cool, generally mosquito-free, colorful with red lichens, the floor with sphagnum mosses, and somewhat open beneath. After this timber is clear cut and the sun reaches the swamp floor a massive abnormal thicket of the other species develops with intensive competition - a wet scrub develops. This scrub may take many years to develop its canopy again because of the nutrient shortages, the lack of seed trees, the vegetative competition, and repetitive fires caused in part by lowered water tables due to drainage canals. Such a scrub developed over part of the Santa Fe Swamp.

METHODS

After diagrams were developed to overview the systems of concern, energy storages and flows were calculated, expressed in solar equivalent joules and then dollar equivalents. Evaluations were made with existing conditions and for some management alternatives.

1. Energy Systems Diagrams. After assembly of information from various written sources and knowledgeable people two energy systems diagrams were developed, one showing the main features of the Swamp ecosystem and its processes, the other considering a large size scale represents the role of the swamp in the regional processes, hydrology, and human economy. These diagrams use energy language symbols that express energetic, hydrologic, material balance, mathematical, and economic aspects of the systems they represent. For full explanations see book (Odum, 1971; 1983; Odum and Odum, 1976, 1982; and Hall and Day, 1975). A brief explanation is included here in Appendix A.

The process of developing the diagrams identified the properties and processes to be numerically evaluated. The diagram also shows the interplay of causal factors within the swamp and between the swamp and the larger outside economy. The diagrams are a one page impact statement.

2. Energy Evaluation. Flows and storages which are believed important are listed in tabular form, and the actual energy flows and storages that accompany these were calculated with standard scientific formulae. A "cookbook" summary of these is given in two sources (Odum et al., 1983; Odum and Odum, 1983).

Next, the solar energy equivalent of each of the energy storages and flows was calculated by multiplying the actual energy by an appropriate energy transformation ratio (ETR). See Table 1. These ETR's were derived from previous calculations of the joules of solar energy required directly and indirectly to generate the joules of the type of energy of concern.

Simple proportion was used to determine the percent of the regional economic product of each flow or storage of interest. The fraction that the item is of the regional energy budget (in solar equivalent joules) is the fraction that the item is of the regional economic product. Care in examining the system diagrams helps avoid double counting where pathways are diverging byproducts of the same process. Results were given in tables and in summary diagrams.

3. Management Suggestions. Ways of increasing environmental services found to be important to the combined economy of humanity and nature were identified among values lost in earlier management.

RESULTS

Energy diagrams for system overview are given in Figures 3 and 4 and tables of energy and dollar equivalent evaluations are given in Tables 2 and 3.

Santa Fe Swamp Ecosystem

The Santa Fe Swamp ecosystem as defined in Figure 2 is diagrammed with its outside influences, its stored quantities and its pathways of interaction in Figure 3. The flows of sunlight interacting with the inflows and outflows

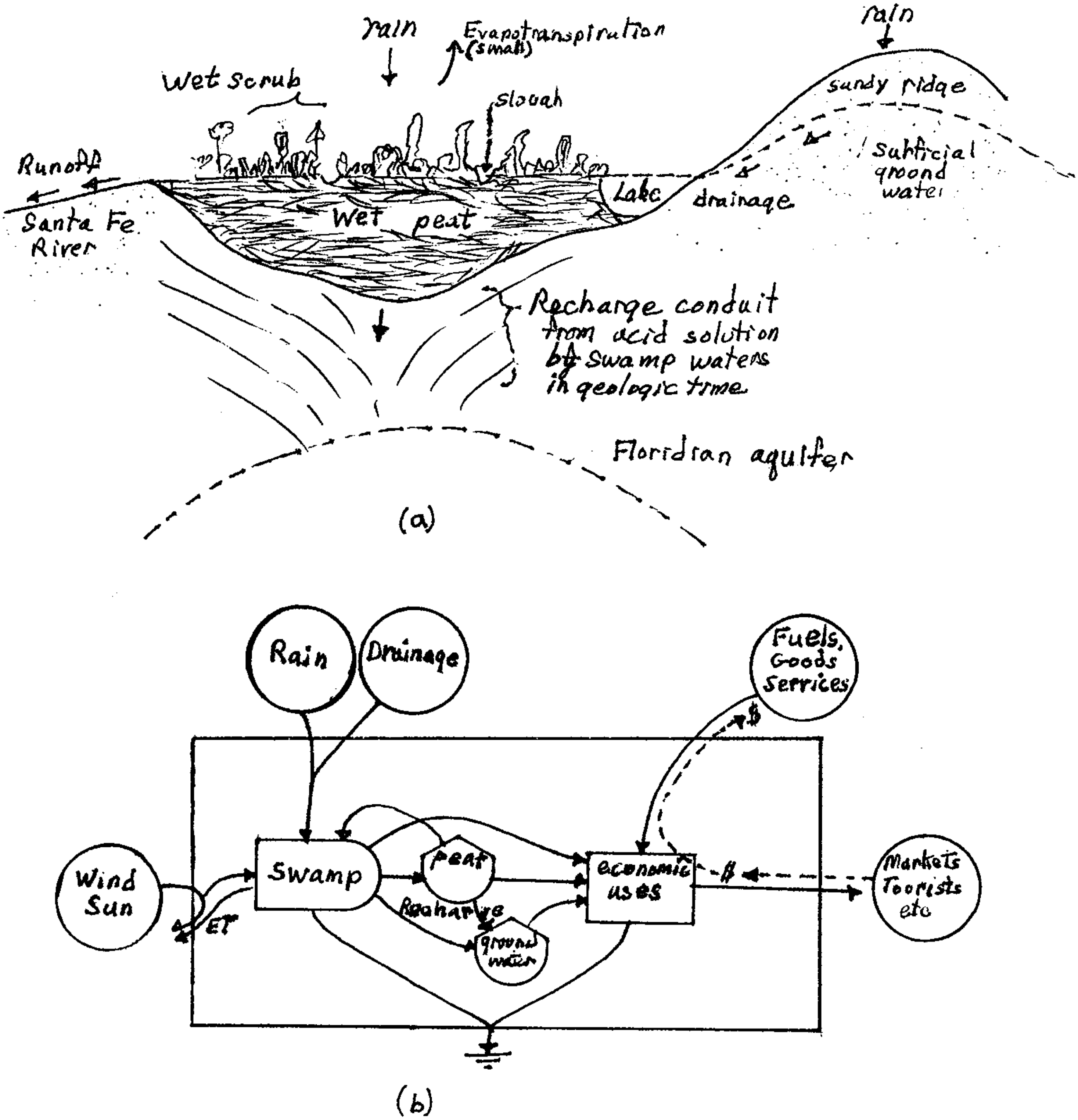

Figure 3. Santa Fe Swamp. (a) Cross sectional sketch; (b) energy diagram of energy and money relationships.

Table 1. Energy transformation ratios used.

Footnote	Item	Solar Equivalents SEJ/J
1	Water in peat	4.1 E4
2	Peat	3.5 E4
3	Wood in the field	3.0 E4
4	Sun	1.0
5	Rain	1.5 E4
6	Draining water	3.0 E4
7	Recharge to aquifer	4.5 E4

Footnotes for Table 1

ETR of water increases as it goes from rain into streams or storage since the quantity reaching these last stages is less.

1 Energy transformation ratio of rain (see Footnote 5) is increased by a factor of 2.7 assumed for the ratio of water processed through the swamp to maintain a unit of water stored in the peat zone.

2 Energy transformation ratio of peat collected for sale with partial drying. Input work in solar equivalent joules was summed and divided by actual output energy of one cubic yard. Deposition rate assumed 0.001 m/y so that one cubic yard (0.73 m^3) above a square meter requires 730 years.

<u>Environmental work</u> evaluated from water budget.

Rain, $(2.71 \text{ E7 } m^3/y)(1 \text{ E6 } g/m^3)(5 \text{ J/g})(\text{ETR}=1.5 \text{ E4})$

$= 2.0 \text{ E18 SEJ/y}$

Drainage, $(3.55 \text{ E7 } m^3/y)(1 \text{ E6 } g/m^3)(5 \text{ J/g})(\text{ETR}=3.0 \text{ E4})$

$= 5.3 \text{ E18 SEJ/y}$

$$\text{Total} = \frac{7.3 \text{ E18 SEJ/y}}{1.98 \text{ E7 } m^2} = 3.69 \text{ E11 SEJ}/m^2/y$$

$$(3.69 \text{ E11 SEJ}/m^2/y)(730 \text{ g}) = 26.9 \text{ E13 SEJ}/m^2$$

<u>Fuel use</u> estimated \$2/cu yd @ \$1/gal

(2 gal)(3.8 l/gal)(900 g/l)(10 kcal/g)(4186 J/kcal)(ETR=5.8 E4) =

1.66 E13 SEJ/cu yd.

<u>Goods and services input</u>, \$10/cu yd (Traxler Peat Co., 1984) half dry multiplied by U.S. ratio of solar embodied energy per \$:

(\$10)(2.2 E12 SEJ/\$) = 2.2 E13 SEJ/y

<u>Output</u>: $(1 \text{ cu yd})(0.73 \; m^3/\text{cu yd})(0.5 \text{ dry})(1 \text{ E6 } g/m^3)(5 \text{ kcal/g})(4186 \text{ J/kcal})$

$= 7.63 \text{ E9 J/cu yd}$

ETR for peat collected half dry:

[(26.9 + 1.66 + 2.2) E13 SEJ] / 7.63 E9 J = 3.5 E4 SEJ/J

= (30.76 E13 SEJ)/(7.63 E9 J) = 4.03 E4 SEJ/J

ETR for peat in field: (26.9 E13 SEJ/m^2)/(7.63 E9 J/cu yd)

= 3.53 E4 SEJ/J

3 Wood in the field; an ETR for tropical forest was used (Odum and Odum, 1983).

4 Direct sunlight has energy transformation ratio of one by definition.

5 Rain energy of global processes in ratio to Gibbs free energy of rainwater falling on/and relative to salt water (representing saltiness of leaves due to transpiration and/or salt of sea for runoffs reaching the sea (Odum and Odum, 1983).

6 Ratio for rain in Footnote 5 increased by factor of the rain to drainage-runoff taken as 2.

7 Ratio for rain in Footnote 5 increased by factor of rain to recharge of 3 (Hunn and Slack, 1983).

Table 2. Energy-dollar evaluation of stored quantities in Santa Fe Swamp.*

Footnote Number	Item	Energy Storage Joules	Energy Transformation Ratio† Solar Joules/ Joule	Embodied Solar Energy Solar Joules	\$ 10^6
1	Water storage	3.14 E14	4.1 E4	1.21 E19	5.9
2	Peat storage	1.4 E17	3.5 E4	4.9 E21	2227.0
3	Wood storage	3.52 E16	3.0 E4	1.06 E21	480.0
	Highest value includes others:		---	---	2227.0

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* 4896 acres belonging to Georgia Pacific.

Footnotes for Table 2

$ Calculated by dividing embodied solar energy by ratio of estimated embodied solar energy to dollars for the U.S. economy 1984, 2.2 E12 solar equivalent joules per $.

† See Table 1.

1 Volume of water held in swamp taken as the volume of peat, 8.65 E7 cubic yards; 89.6% moisture (Appendix C); Gibbs free energy of soft water, 5 joules/g.

$\text{(8.65 E7 cu yd)(0.729 m}^3\text{/yd}^3\text{)(1 E6 g/m}^3\text{)(5 J/g) = 3.15 E14 J}$

2 Peat storage, 8.65 E7 cu yd; dry weight 10.4%; heat content 9.2 E3 BTU/lb dry; reversible heat correction negligible and not included;

$\text{(8.65 E7 cu yd)(0.729 m}^3\text{/cu yd)(1 E6 g/m}^3\text{)(0.104 dry of wet)}$

= 6.56 E12 g dry

(9.2 E3 BTU/lg dry)(0.254 kcal/BTU)(4186 J/kcal)/(454 g/lb)

= 2.15 E4 J/g

(6.56 E12 g)(2.15 E4 J/g) = 1.4 E17 Joules

3 Wood storage based on timber cruise in 1981

$$\frac{\text{(2040 cds)(4 x 4 x 8 cu ft/cd)(0.027 cu m/cu ft)(0.7 E6 g dry/cu m)(3.5 Cal/g)(4186 J)}}{\text{(101 plots)(0.1 acre/plot)(4.05 E3 m}^2\text{/acre)}}$$

= 1.768 E9 J/m^2

$\text{(4896 acres)(4.05 E3 m}^2\text{/acre)(1.78 E9 J/m}^2\text{) = 3.52 E16 joules.}$

Table 3. Energy flows in Santa Fe Swamp. See Figure 3.

Footnote	Item	Energy Flow J/y	Energy Transformation Ratio SEJ/J	Embodied Energy E18 SEJ/y	Dollar Equivalence* Million $/y
1	Sun	1.04 E17	1.0	0.1	0.045
2	Rain	1.36 E14	1.5 E4	1.9	0.9
3	Drainage in	1.8 E14	3.0 E4	5.4	2.4
4	Recharge	4.5 E13	4.5 E4	2.0	0.9

Footnotes for Table 3

* Dollar equivalence calculated by dividing by ratio of embodied solar energy/dollars for U.S. in 1984, 2.2 E12 SEJ/$.

1 Direct solar energy (Gainesville)

(3446 kcal/m^2/d)(365 d/y)(1.98 E7 m^2)(4186 J/kcal) = 1.04 E17 J/y

2 Global solar energy embodied in a chemical purity of rain falling on Florida - calculated as 5 joules Gibbs free energy per gram of soft water. This item includes the direct solar energy in Footnote 1, since it is part of the global energy generating rain on land.

(54 in/y)(2.54 cm/in)(1 E4 cm^2/m^2)(1 g/cm^3)(5 J/g)(1.98 E7 m^2)

= 1.36 E14 J/y

3 Drainage into swamp

(20 sq mi)(640 acre/sq mi)(4.04 E3 m^2/acre)(1 E4 cm^2/m^2)(55 in/yr)(2.54 cm/in)

(0.5 draining)(5 J/g) = 1.81 E14 J/y

4 Recharge has the embodied energy of the rain and drainage.

(18 in/y)(2.54 cm/in)(1.98 E7 m^2)(1 E4 cm^2/m^2)(1 g/cm^3)(5 J/g)

= 4.5 E13 J/y

of water generate a swamp forest cover supported on a peat base in which scarce nutrients are bound and recycled. This diagram uses the energy language symbols that define the mathematical relationships so that the diagram is a computer simulation model.

Santa Fe Swamp in Regional System

Figure 4 is the regional system diagram that shows the way the Santa Fe Swamp participates in the regional processes and economy through control of hydrological budgets and other existing or potential activities.

Value Stored in Swamp

The embodied energy in the stored water, stored peat, and wood is given in Table 2 with dollar equivalents (1984 $), 2.2 billion dollars.

Annual Contributions of Value

Annual contributions to the economy, services of the swamp to the economic system through its work in hydrological and other environmental systems is given in Table 3, which enumerates main flows of the swamp also pictured in Figure 4. The global work embodied in the rain's work in generating a stable groundwater and stream headwater etc. is about $3.4 million/year.

Inferences from Fieldwork

Field examination was made along the transect in Figure 5 with entry to the swamp from the east side. See line in Figure 2 also. Peat samples were taken with a Hiller borer at three positions located approximately at 1, 2 and 3.

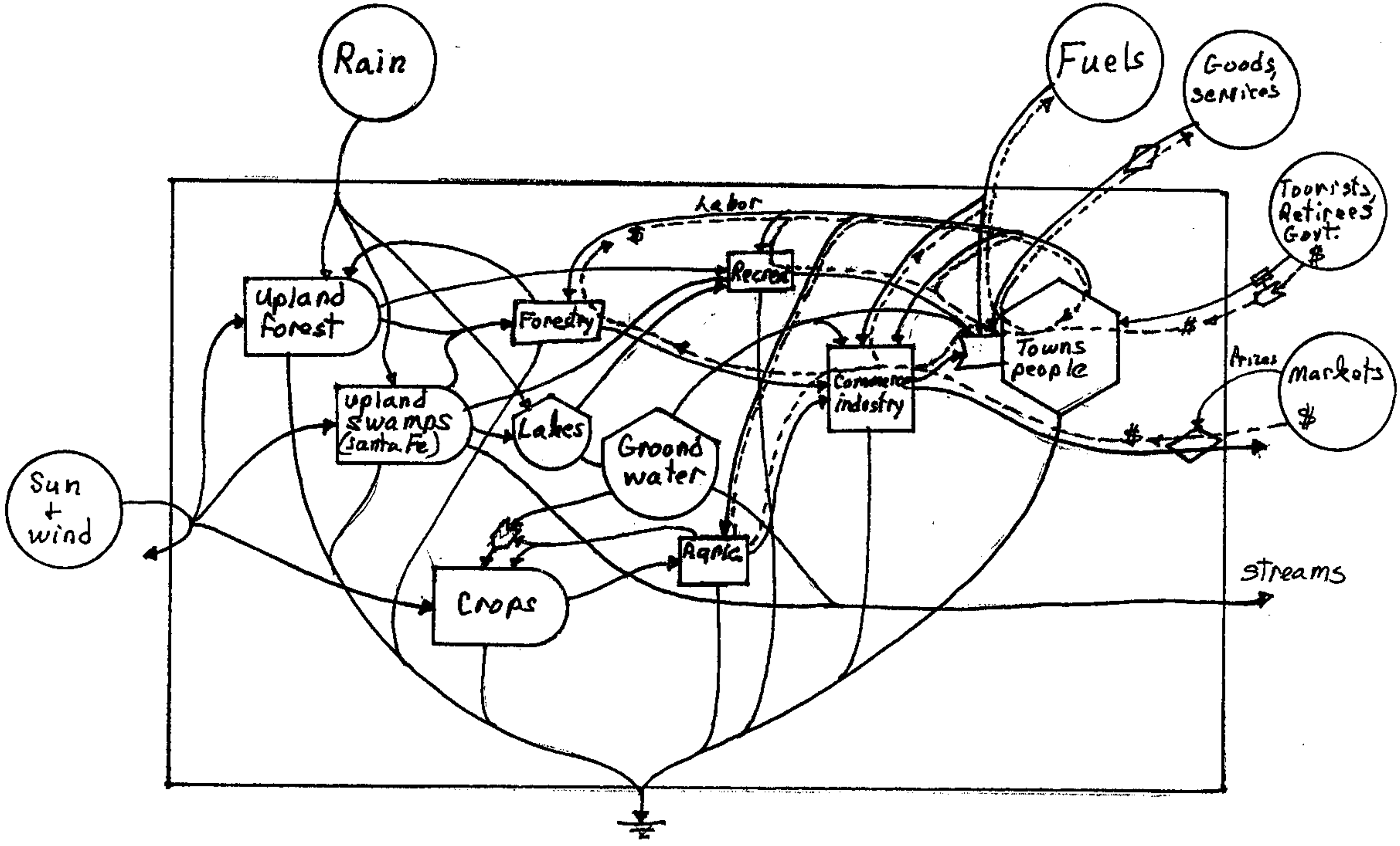

Figure 4. Energy-dollar diagram of regional economy and the central role of upland swamps.

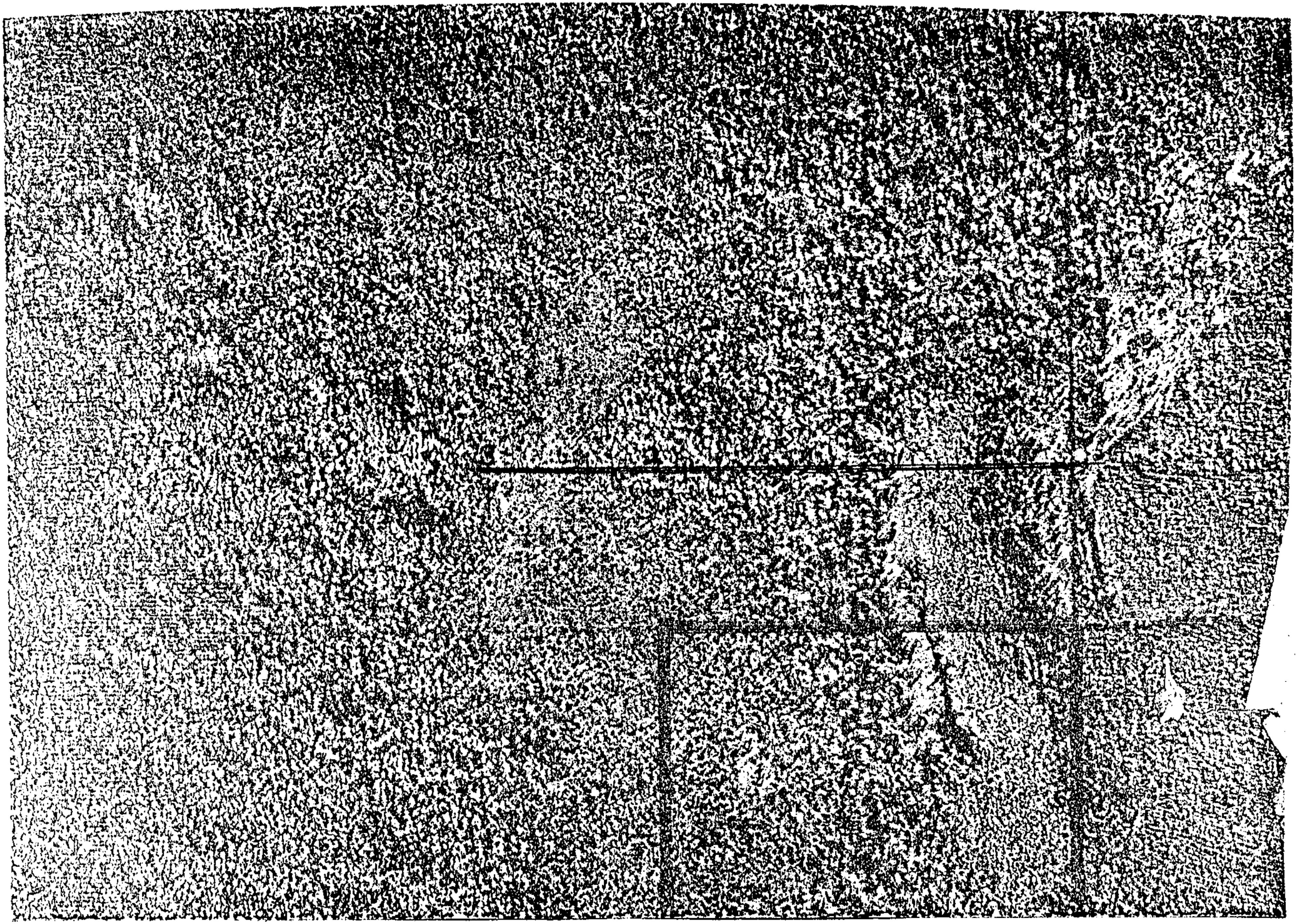

Figure 5. 1983 aerial view of eastern section of Santa Fe Swamp indicating field transect and peat core positions. Note predominance of bushy scrub vegetation.

The peat in samples examined is woody (estimated by P. White as Von Post 5) and heavily permeated with cypress pollen. The wet scrub now present over much of the area is quite different from the cypress swamp that may have existed before the clear cutting, lowering of water table, and fires. A restoration of the former swamp forest can be managed.

DISCUSSION

Distinction between Macro-economic Dollar Value and Micro-economic Market Value

The market price that one pays for wood or other products from a swamp is money paid to humans for their services in processing the environmental product. As a market price, effects of supply and demand help humans determine price according to utility. These prices are micro-economic values involving human contribution to the economic use of the environment.

The work that the environment does for the general economy directly and indirectly is much greater than the money paid for the first human service. By the time wood has been utilized, processed, reprocessed, transported, manufactured, and sold in wholesale and retail outlets, much more money has circulated than is involved in the first payment to the woodcutter. In addition the swamp's work in increasing quantity and quality of water for the area is a contribution to the economy that is generally unrecognized until it is lost and tax money has to be spent in substituting human work for the lost environmental work. These little recognized contributions to the economy are macro-economic values that are generally larger than the micro-economic market prices. These larger contributions to the economy are not in payment for services of land owners but are dollar recognition of nature's work. They may be a good predictor of the value of the swamp to society as a whole, expressed in dollars of the economic product.

Research Needed to Confirm Premises Used in Evaluation

Although reasonable estimates may have been developed for most of the calculations, the following are particularly important to calculations and conclusions and should be verified with further research:

(1) The role of low nutrient swamps in conserving water through adaptations with low rates of transpiration needs to be further confirmed with indirect measurements of water budget and with direct chamber measurements of transpiration.

(2) The time required to grow the peat base of the swamp needs to be verified with radiocarbon dating and other methods. One sample from 3 m has been sent to radiocarbon dating laboratory (Beta Analysis) in Coral Gables.

(3) The time required to grow larger canopy trees needs to be determined with tree core measurements.

Measures for Maintaining and Enhancing Public Values of Santa Fe Swamp

If the Santa Fe Swamp is to be managed for its direct and indirect multiple values to the public, the following suggestions are made for preservation and enhancement of its regional role.

(1) The very slow succession of regrowth of canopy trees such as cypress and gum can be accelerated by planting of seedlings of the larger species which may have been delayed from getting a restart because of inadequate seeding, germination, and survival, partly due to the competition

of the dense wet scrub of lesser vegetation that developed after taller trees were cut.

(2) Since regrowth is limited by the generally low nutrient content of bays that are mainly nourished by rainwater and drainages from sands poor in nutrients, effluents from agriculture, street runoffs, and treated municipal waters should be tested for their beneficial effects. Use of such runoffs in this way keeps them out of public waters, encourages their storage and recharge and allows the swamp to filter out many of the contained substances. There may be a limit to the use of such waters since with enough nutrients the consumption of the peat by micro-organisms may exceed the organic deposition. However, in the case of Santa Fe Swamp, waters that were diverted earlier from the swamp by canals lowering the level of Santa Fe Lake would be restored to earlier natural patterns by this mechanism.

(3) To facilitate the recreational and educational use, wilderness trails and canoe trails may be developed. These need to be done carefully so as not to appreciably short circuit the gradual water flows through the filtering vegetation and peat. Shallow canoe trails through existing sloughs may be arranged like the popular ones in the Okeefenokee Swamps. Walking trails of built-up coarse gravel interlaced with root networks may work in peripheral areas where peat is shallow. In other areas boardwalks may work if supported on natural platforms of root networks, on cross members lashed to trunks, or supported by driven posts. Some of these can be the expensive boardwalks found in such parks as Highlands Hammock, but others can be inexpensive one board width tracks for wilderness experience.

(4) Some kind of private or governmental park and water conservation management may be desirable to maintain the area as a wildlife nucleus, to support long term renewable contributions to the regional economy.

(5) Consideration should be given to restoring part or all of the Santa Fe drainage now diverted through canals, back to the swamp for water and conservation purposes. This alternative will require consideration of other consequences such as effect of water level changes on piers of riparian boat owners.

ACKNOWLEDGEMENTS

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APPENDIX A -- DESCRIPTION OF METHODS

APPENDIX B -- POLLEN COUNTS IN PEAT

Pollen counts in the four peat samples taken were made for preliminary survey purposes by Antonia Higuera. These counts are included in this appendix.

Santa Fe Swamp, Fl.

T A X A	Hole # 1 Z = 1.7 m		Hole # 2 Z= 2.5 m		Hole # 3 Z= 2.5 m		Hole #3 Z= 3m	
	No. of Grains	%	No. of grains	%	No. of grains	%	No of grains	%
Amaranthaceae/ Chenopodiaceae	1	0.4	3	1.2	-	-	5	2
Ambrosia	2	0.8	-	-	4	1.6	3	1.2
Compositae	4	1.6	4	1.6	21	8.4	15	6
Gramineae	10	4	9	3.6	8	3.2	18	7.2
Cyperaceae	6	2.4	12	4.8	30	12	31	12.4
Ericaceae	6	2.4	5	2	13	5.2	-	-
Melastomataceae	6	2.4	1	0.4	-	-	-	-
Legume type	-	-	-	-	-	-	1	0.4
Plantago	8	3.2	4	1.6	4	1.6	6	2.4
Palmae	-	-	-	-	2	0.8	4	1.6
Solanacea	-	-	--	-	-	-	2	0.8
Carpinus/ *Ostrya*	6	2.4	4	1.6	6	2.4	9	3.6
Myrica / *Casuarina*	6	2.4	8	3.2	8	3.2	16	6.4
Alnus	2	0.8	1	0.4	-	-	-	-
Ulmus	-	-	4	1.6	-	-	4	1.6
Potamogeton	-	-	7	2.8	1	0.4	6	2.4
Typha	3	1.2	-	-	3	1.2	-	-
Taxodium	187	75	179	72	131	52	120	48
Unidentified grains	9	3.6	9	3.6	19	7.6	10	4
Partial pollen sum (excludes *Pinus* and *Quercus*) =	250		250		250		250	

TAXA	Hole # 1 Z = 1.7 m		Z= 2.5 m		Z= 2.5 m		Z= 3m	
	# of grains	% of total pollen sum	# of grains	% of total pollen sum	# of grains	% of total pollen sum	# of grains	% of total pollen sum
<u>Pinus</u>	249	46	308	50	281	46	391	55
<u>Quercus</u>	39	7.2	59	9.6	77	12.6	72	10
TOTAL POLLEN SUM : INCLUDES ALL TAXA (250 grains) PLUS <u>Pinus</u> and <u>Quercus</u>	538		617		608		713	
* <u>Taxodium</u> percentage of the total pollen sum =		35		29		22		17