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Value of Wetlands as Domestic Ecosystems

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Wetlands have always served the natural landscape as filters, as water conservation devices, and producers of high quality products, all on solar energy. Can scattered wetlands interspersed among urban, industrial, and agricultural activities of humans provide the human-dominated landscape low cost water quantity management, water quality, and other high values? Consciously and inadvertently wetlands are already being used as interfaces between human wastes and the public's domain of nature. Perhaps more wetlands can be preserved or newly replanted as domestic ecosystems to use solar energy for water management and the maximization of economic vitality.

In the last century a domesticated form of the natural gravel bed found in lakes and streams was placed within concrete tanks and called a sewage treatment plant. It was and is a domesticated ecosystem that filters water. In response to the inflow of organic resources of waste water an ecosystem of organisms grows among the gravel, reproducing and self organizing. The outflow is water of improved quality. Its energy source is the sewage organic matter. The trickling filter system is the basis for much of our national sewage treatment. There are a few salt water ones that develop ecosystems comparable to the natural ecosystem in the sea beach.

There is a general principle here. Why not use other ecosystems that have filtering, water quality roles, as domestic ecosystems wherever they are needed? This is a way to insure the protection of wetlands as they become coupled to the economic system serving and being served.

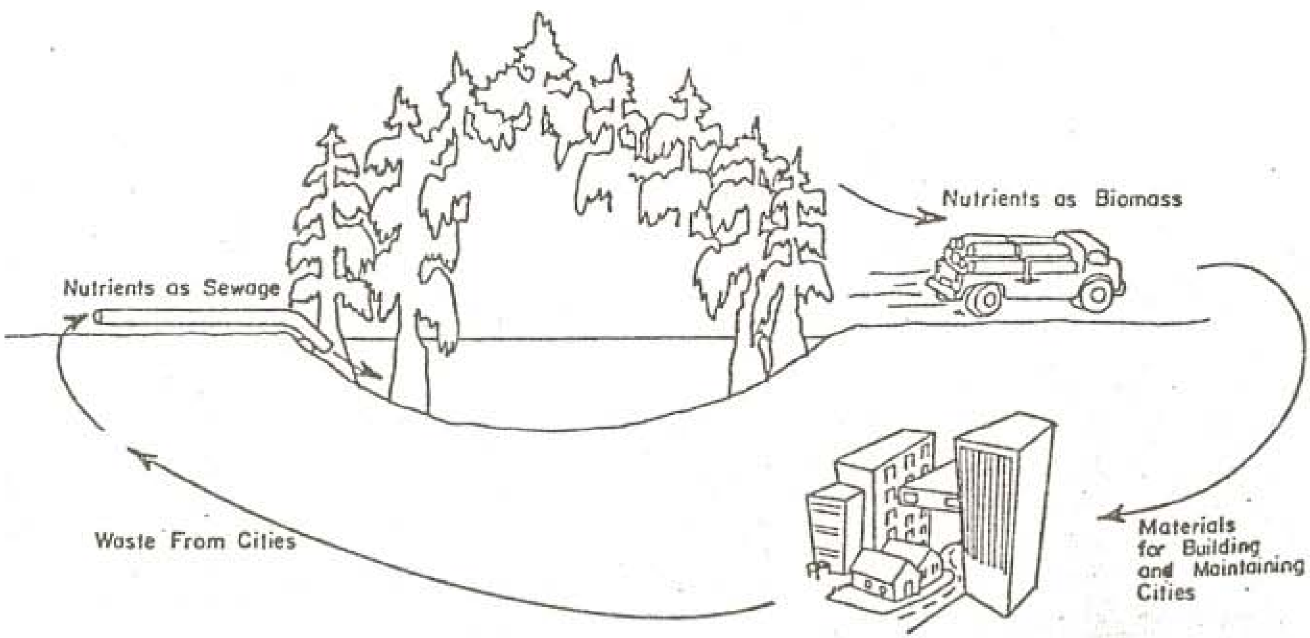

Figure 1. Cypress dome in Florida as an interface ecosystem recharging groundwater and yielding high quality wood and wildlife. (Wharton et al., 1977)

Under auspices of the Rockefeller Foundation and the Rann Division of the National Science Foundation, The Center for Wetlands has conducted an experiment now in its fourth year passing treated sewage into cypress swamps in Florida in lieu of tertiary treatment. We have also studied a situation where this has been done for more than 40 years. An interface ecosystem with most of the properties of the natural swamp filters out nutrients, microbes, grows valuable wood faster, and provides a wildlife greenbelt unit. The costs are primarily those of the pipe. The experimental sites are near Gainesville, Florida (Figure 1). Elsewhere, in many places in Florida, swamps are being used to accept stormwater runoff and drainage from housing areas and streets.

INTERFACE ECOSYSTEMS

An interface ecosystem is a natural or domesticated system of organisms and chemical processes that is compatible with the waste water of man and can use it as a resource, and which as its own output releases byproducts close enough to those of nature to be released to the public domain, helping the natural ecosystems.

Swamps and marshes are the interfaces used by nature as recycling intermediates, and these are the ecosystems most nearly adapted for interface functions between human developments and the environment. If the loads are not excessive and the contents not too toxic, natural wetlands can develop a modified association of organisms to process wastes of human developments. Wetlands can serve the same interface functions for man that similar wetlands have been doing for the natural landscape for millions of years. Recognition of the service work already being done by wetlands in maintaining water regimes with loads of urban waste is part of the purpose of this conference.

Somehow the law has to find a way to recognize the role of wetlands in the public good so that an individual's use of his own wetlands does not detract from its role in public life support.

An economy is vital when environment and economic developments are mutually reinforced and protected. Unfortunately, well meaning efforts to draft laws to protect the environment have not always been made with an understanding of the ecological principles of symbiosis and recycle by which nature and humanity are best combined. For example, in Florida current laws and practice allow, and in some cases require, the draining of swamps that are part of the public's water conservation system, but prohibit or at least make difficult the retention of swamps to receive recycling of waste waters. Action has been lacking partly because values of these alternatives have not been clear. In this article principles are given for determining these values with energy concepts. Tax credit is needed for private owners holding lands so as to allow continuation of wetlands functions.

EVALUATION WITH ENERGY COSTS EXPRESSED IN UNITS OF ONE ENERGY TYPE

Understanding the value of wetlands for their partnership with human activity cannot be done with traditional economic evaluations, because wetlands do not receive and deliver money for their outputs and inputs. Evaluating their contribution, however, can be done with energy units which are the common denominator of useful work both in the economic exchanges and environmental exchanges. To use energy values to evaluate the roles of the environment requires that the various kinds of energy be expressed in energy units of the same energy type such as solar energy or coal. Some energy types like solar energy are dilute; coal is moderately concentrated; and the energy embodied in water, human services, and high technology is very concentrated in the sense that much energy went through processes of making it. Different factors are used to indicate the energy of one type required to be transformed into another. The work of wetlands and the accumulated work in stored attributes in the soils and geological structure can be expressed in calories of one type and compared with work within the human economy expressed in the same way. Then effect on dollar flow is estimated.

ENERGY ROLE OF SWAMPS

First, consider the role of swamps in the landscape and the principles by which patterns prevail. One theory invoked to explain the organization of landscapes is the maximum power principle, which is stated as follows: Systems that become organized with mechanisms that contribute to the maximum possible flow of power (energy per time) are reinforced and prevail. The self-organizing effects of maximum power take many forms, producing the characteristic features observed in the organization of nature such as: feedbacks of service in exchange for receipts, recycle of materials, convergence of energy in food chain hierarchies, combination of various types of energy, and interdependent organization of land uses. How do swamps combine energies, feedback services, and contribute to the maximum power of a region?

LANDSCAPE UNITS AS A CHAIN OF ENERGY DEVELOPMENT

Species can be arranged according to their position in the food chain with a converging of many low quality plants to a very few high quality animals at the end. Landscape units also operate in such chains with energies of sun, wind, and rain that were incident on the general landscape, converging action through runoff to a relatively small area of wetlands. Wetlands, like consumers in food chains, are high quality receiving units that feed back even higher quality services to the larger surrounding area of land. Figure 2 suggests how these operate and lists some numbers which are appropriate.

The energy chain relationship explains the reason for the high value of wetlands in the life support system of man and nature and reinforces the general feelings about value of wetlands emphasized at this conference. The energy convergence is measurable by the ratio of energies of one type required to develop another and is roughly in relation to the ratio of areas in the working landscape.

The energy chain idea helps answer the question: How much wetlands are needed? To some extent one can look at the original landscape. However, where the energy flows of man from fossil fuel have been much increased, then the areas of wetlands needed to deal well with filtering water quality and control are larger than the natural. More, not less, wetlands may be needed in some urban areas.

HIGH VALUE IN NATURAL COUPLING

Often human planning considers one problem or factor at a time, making decisions, plans, and constructions based on this one factor. Natural systems, as they evolve a pattern of maximum power, have simultaneous interactions of all factors, using one process as a byproduct of another, solving more than one problem at a time in ways where one function is helped and not hindered by another. For example, sun, wind, and water interact in natural production building vegetation, soil, and landform structure all at once (Figure 2), each a byproduct and each with

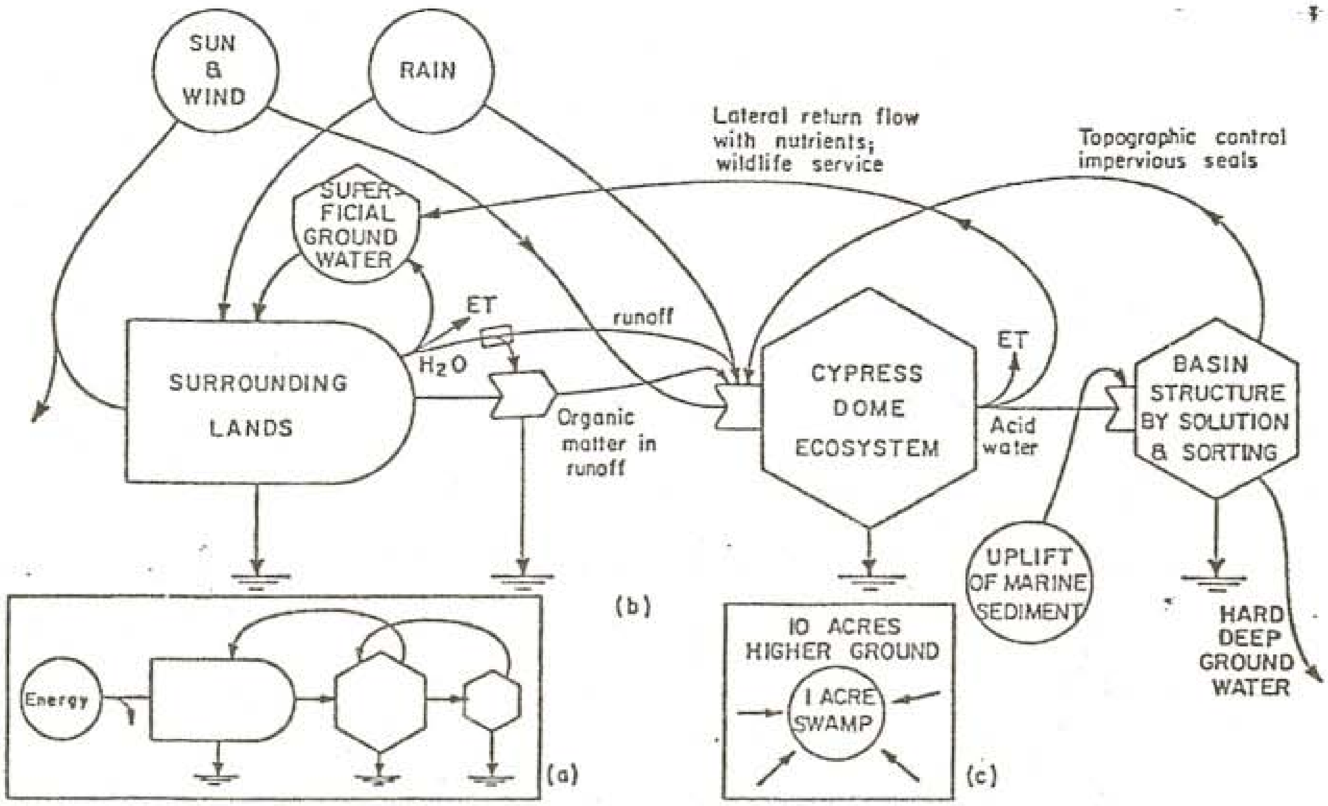

Figure 2. Swamps and wetlands basins as higher quality members of an energy chain of converging work and increasing quality: (a) general concept like that of a food chain, each step feeding back services and cycles; (b) diagram of converging work of sun and water generating water management structure; and (c) sketch of spatial convergence of work and products of work.

feedbacks to improve the process chain. Much of the unnecessary wastes from human systems come from the developing of one process without regard for the workings of the whole.

Thus, any proposed change of the landscape by man that is made on one basis is likely to be disharmonious and a more expensive way of doing the same thing than already evolved by the natural landscape in the trial and error business of developing maximum power. The energy spent by natural processes on maintaining water conservation, quality, and structures is likely to be less than that of human, monopurpose designs because there is less collaboration arranged between unit processes.

THE RANGE OF PRODUCTIVITY OF SWAMPS

One of the ways of measuring the product of the interactions of natural energies is to measure organic productivity, which is the organic matter produced per day. Swamps range from the lowest to the highest of productivity of ecosystems depending on their type and role in the landscape. In Figure 3 are sketches showing within Florida the types of cypress swamps that range from nutrient-impoverished, dwarf cypress vegetation characteristic of the Big Cypress area to the fast growing bald cypress (*Taxodium distichum*) found with a diversity of other swamp trees in river floodplains where nutrient flows are rich. Recent measurements by Bayley (1976), Cowles (1976), Brown (1977) and Burns (1977), have documented the wide range of gross productivity for similar sunlight regimes from 1 $g/m^2/day$ organic matter production to 30 $g/m^2/day$.

If organic production were the only measure of natural work, one would find some swamps of low value. However, when these are considered for their water processing role in the larger landscape of the region, a higher energy impact is found through the high quality of the water processing. The waterborne processes converge some of the products of work of the larger area concentrating their values in the wetlands (Figure 2).

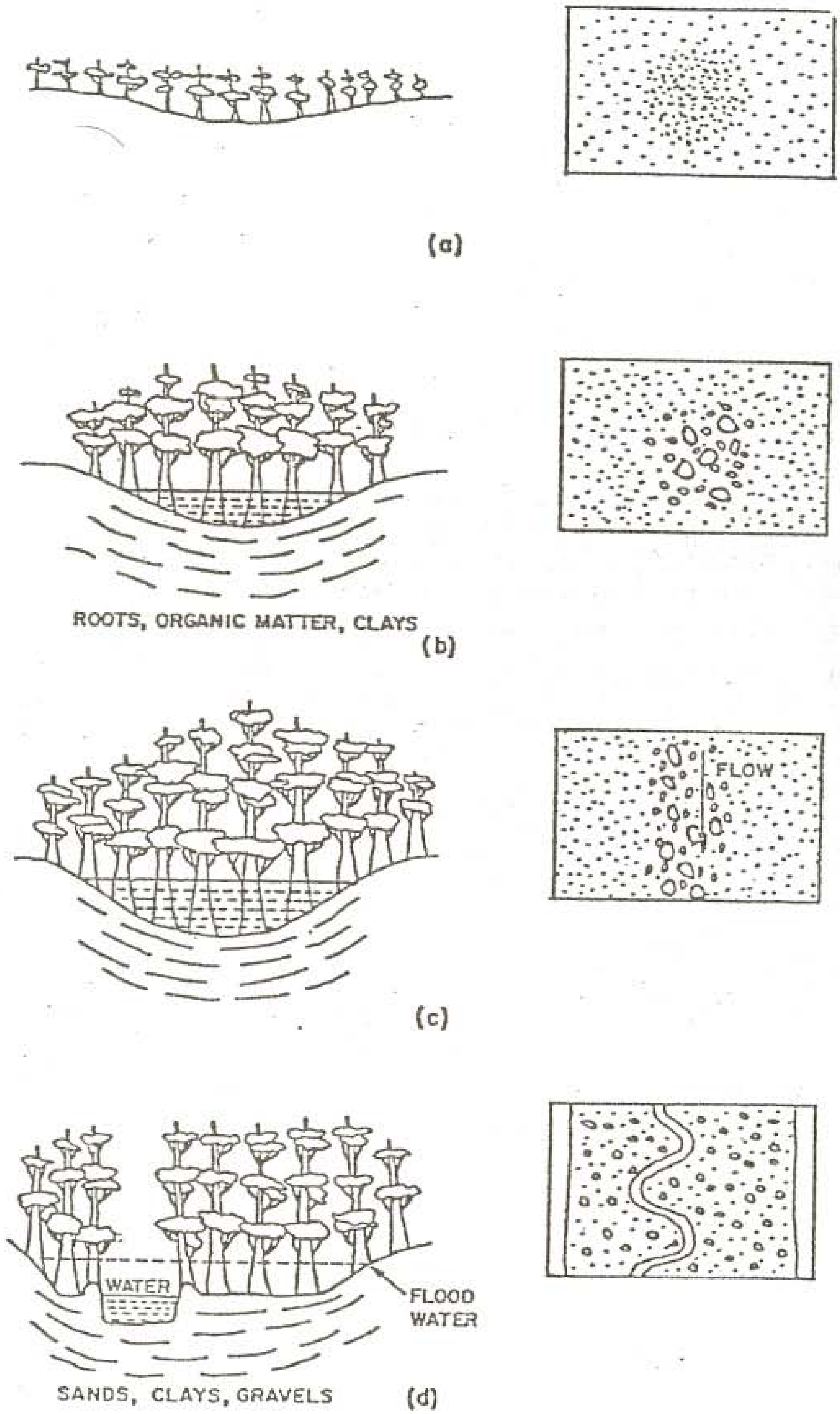

Figure 3. Comparison of Cypress swamps in Florida arranged in order of increasing productivity: (a) low fertility dwarf cypresses on leached sand, sparsely distributed; (b) cypress dome with some drainage from surrounding lands, pond cypress, many stems, slow growing; (c) cypress strand with slowly flowing water from a drainage basin, trees larger but spaced more, bald cypress; (d) floodplain forest with cypress only one of several dominants.

THE WATER CONSERVATION ROLE OF TABLELAND SWAMPS

In the studies of the water budgets of the cypress swamps near Gainesville, Heimburg (1976) found that the cypress domes (ponds) save 30 percent of the water that would have evaporated had the pond been an open one subject to regular evaporation. The trees drop their leaves in the dry season, but the high basal area shields the water from much of the sunlight and wind so that evaporation is retarded. In the growing season the leaf area index of the cypress domes is very low so that the transpiration is low compared to other vegetation. Satellite reflection studies showed a higher infrared heat radiation reflection from cypress than from other Florida forest vegetation. The idea of draining swamps and replacing them with reservoirs proposed earlier in Florida would have caused a major loss of water from recharge areas such as the Green Swamp of central Florida. These swamps operate to save water, perpetuating their existence, and saving water for recharge to groundwater and use by the landscape or humanity elsewhere.

The largest areas of cypress swamps are not lowlands but relatively high plateaus that receive only rain water. These areas have developed water storages in the form of scattered cypress basins and from these waters drain downward, being filtered to recharge the groundwater aquifers from which Florida draws its water supplies for the human economy. These areas include the Okeefenokee Swamp in Georgia, the tablelands of north Florida, the Green Swamp of central Florida and the Big Cypress wetland of south Florida. Smaller plateaus are found in almost every county. Helping to maximize the productive power of the region, the perched water tables serve as water reservoirs to keep the Florida landscape moist, the ground waters recharged, and the vegetational productivity outside the swamp areas more productive. Swamps are about 10 to 15 percent of the area. Plant productivity of highland swamps is smaller than average, but the energy embodied in the water saved and processed is high with a high amplifier effect on regional value.

The needs of human economic developments are the same as the former landscape so far as water processing, and the ready made water conservation and quality control system and its embodied energies of structure are very high indeed. Laws to permit recognition and saving of these values that are part of the public good are urgently needed. The education of the public to recognize the role of the wetlands in their economic vitality has begun (Browder, *et al*, 1976) but much more is needed.

THE FLOOD CONTROL AND WILDLIFE FUNCTIONS OF LOWLAND SWAMPS

As streams drain seaward to lower ground they develop the familiar floodplains. Water runs in a meandering channel at low water and at flood time rises into a broad sheetflow through the trees and vegetation, discharging excess water steadily, evenly, and slowly, held back by the thick population of trees. The floodplain at that time accepts and filters nutrients and sediments and stores means for a very productive ecosystem heavy with nuts and wildlife. The floodplain is being recognized as a much better floodplain device than the reservoir, one that saves more water from evaporation, one that never fills up, and one that provides a continuous corridor for wildlife, branching over the landscape. Ecosystem studies are showing that the larger animals and fishes gain their stability by having continuous connections between populations so that excess reproduction in one place at one time can balance the lower-reproduction and mortality in another place. Upstream and downstream movements of fishes are normal and necessary for most species.

VALUE EMBODIED IN LANDSCAPE STRUCTURE

The sculptured topography of the land as cut by sun, water, wind, geological transport, uplift, and vegetation interactions represents a large value. The land surface is the memory and the bank by which the flows of energy develop and maintain a capital of means for further processing of energy flows, some for maintaining the capital against depreciation, and some for developing other values that go out in exchange for inflows.

The large energy value stored in land configurations becomes obvious when one has to pay millions of dollars in bulldozer and truck operations to make a basin or other land form. Measuring the alternative energy that it takes to make such a basin is one way of estimating value and determining its equivalent value in the economic system. One may estimate the value by measuring the rates of energy flows which built it in the

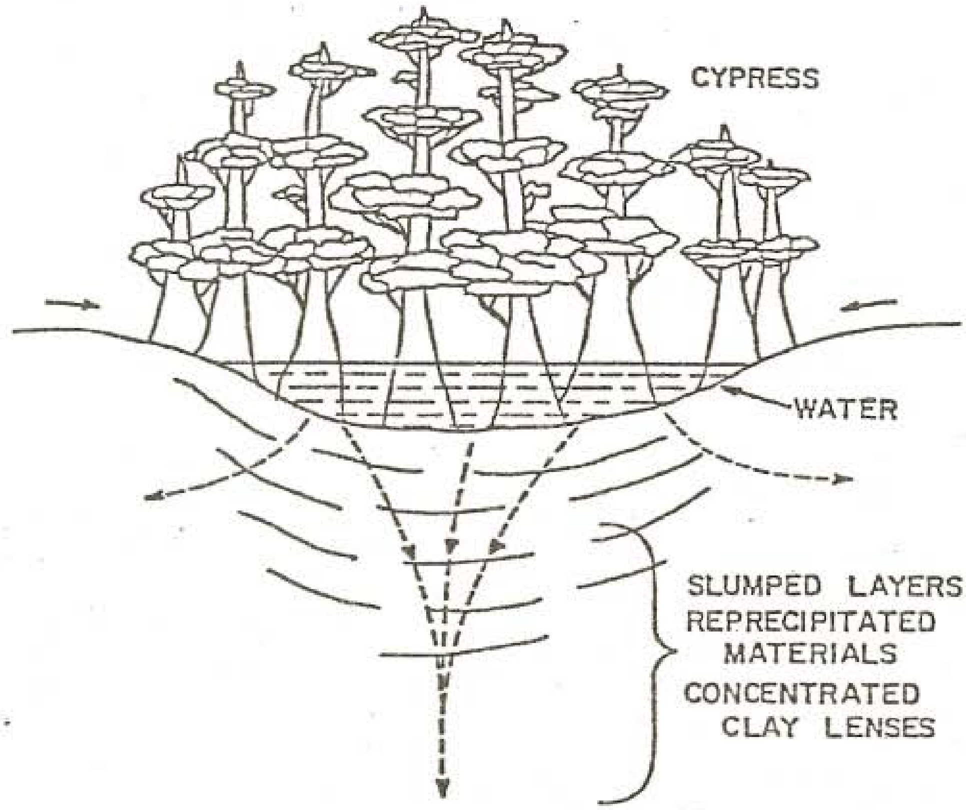

Figure 4. Diagram showing the work of percolating waters in developing a wetlands basin, dissolving some material, reprecipitating some substances such as phosphate, uranium, dolomite. and iron, and by selective solution concentrating clays into impermeable lenses. Clays and redepositions make a partial water seal.

Water percolates 1 inch (2.5 cm) per week. Water contains 40 g/m^3 organic carbon which forms 8.2 moles of acid $ions/m^3$ as it percolates and oxidizes. To form a basin, solution rate of lime-containing marine sediments is calculated per square meter by multiplying volume per year times moles of acid per volume. This is the moles of $CaCO_3$ dissolved which was multiplied by 100 g/mole to obtain the grams removed. Dividing by a density of 2 g/ml gives a volume of land removed per square meter per year. When divided by 10^4 cm^2/m^2 depth removal results.

$$\text{Depth per year} = \frac{(1\ in/wk)\ (52 wks)\ (2.54\ cm/in)\ (1\ m^3/100\ cm/m^3)\ (3.3\ moles/m^3)\ (100\ g\ CaCO_3/mole}{2\ g/ml)\ (10^4 cm^2/m^2)}$$

$$= .022\ cm/yr$$

To develop one meter: 100 cm divided by 0.022 cm/yr is 4545 years

$$\text{Cumulative energy cost is: } \frac{(1.5 \times 10^7\ Cal/m^2/yr)\ (4.1 \times 10^3 m^2/acre)\ (4545\ yrs)}{2000\ Cal\ coal/Cal\ sun}$$

$$= 1.4 \times 10^{11}\ \text{Calories coal equivalents}$$

At 20,000 Cal/$, cumulated production of value is 2.9 million dollars for the 10 acre (4 ha) basin with 1 acre (0.40 ha) swamp including the storage of structure.

first place and multiplying by the time for construction. For example, the cypress dome basins have an organized structure including a partial seal and slow filter bed that required a long time to develop. These represent a high capital investment of energy cost. The energy embodied in the final structure is found by evaluating energy flows in Figure 2 (See results in Figure 4).

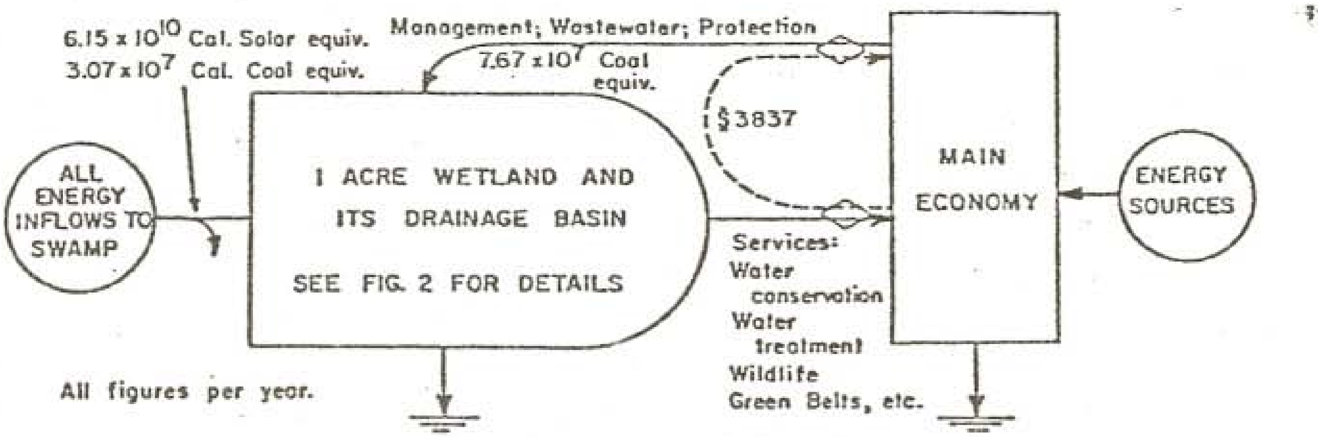

Figure 5. Energies of environment develop wetlands, yield services, products, and production that attract energy and dollar investments from outside. Estimate energy value of an acre of wetlands as solar energy of 10 acres (4 ha) divided by 20,000 to convert solar equivalents. This is a rough estimate of energy output of wetlands (in coal equivalents); then multiply by 2.5 (a usual ratio of outside energy attracted); then divide by current energy-dollar ratio of the economy.

Annual dollar value for work that converges on one acre (0.40 ha) of cypress wetland and its basin =

$$\frac{(10\text{ acres})\,(4.1\times10^{3}\text{m}^{2}/\text{acre})\,(1.5\times10^{6}\text{kcalories}/\text{m}^{2}/\text{yr sunlight})\,(2.5)}{(2000\text{ kcalories sunlight}/\text{kcalories coal})\,(20{,}000\text{kcalories}/\$)}$$

$$= \$3{,}837$$

Part of this remains when wetland is drained because the energy flow to the 10 acres (4 ha) still does some work but less than its full energy potential.

Recognizing the high values in existing landscapes and finding ways to fit man's further developments without waste of the previous landscape values is the challenge to modern culture to maximize the vitality of its economy by using all its values.

SUMMARY OF ENERGY METHOD OF EVALUATING DOLLAR VALUE PER YEAR

The evaluation of alternatives with the energy method is done by evaluating flows "F" in Figure 5 as follows:

- Determine the renewable, natural energy flows which are the resource basis. These resources are the free "externality."

- Determine the energy storages embodied in the land as form, elevation, geochemical constitution, and soil values.

- Express energy flows and flows from storages first in calories per time and then use energy quality factors to represent them in calories of the same quality such as solar calorie cost equivalents.

- Estimate the maximum production of energy of higher quality that has been or can be generated by the interaction of storages and flows ("Services" in Figure 5).

- From the potential production estimate the outside investment that can be attracted to interact with the potential production using a ratio characteristic of competing economies. One ratio used in our studies has been 2.5 Calories attracted per Calorie, where both are in Calories of the same type. The reference ratio was obtained from the ratio of United States sunlight (in coal equivalents) to United States fuel consumption.

- Having expressed the attracted investment energy flow in calories, estimate the accompanying dollar flow, or potential dollar flow. Note the counter flow of $ in Figure 5. Dollar flows of high quality feedbacks are largely for services from the final demand sectors of the economy and thus it is appropriate to use the ratio of gross national product to total energy flow of our economy (including natural energy flow). The ratio is about 20,000 coal Calories/ $ or 40 million solar Calories/$ (for 1975). The simple calculation in Figure 5 shows very high values for wetlands.

, Estimate stored values by multiplying annual flows by time for formation of structure.

, Compare the energy and dollar flows with alternatives that are proposed. This procedure allows an annual dollar value to be estimated from its ultimate casual basis which is energy transformation.

A critique of this method is forthcoming in Coastal Zone Management Journal, Fall, 1978, to be followed by a rebuttal written by E. P. Odum and myself.

COMPETITION FOR LANDFORMS

When a dam and reservoir is considered where there was a floodplain river channel or when a floodplain may be considered as desirable where an existing dam now exists, some evaluation is required as to the best alternative for the combined economy of man and nature including local and regional roles of the basin. The river had developed a valuable structural storage in its basin form which was operating a floodplain system and serving the region in water purification, soil development, forest production, wildlife production, recreational work, etc. The outputs of the system were high quality services that attracted many outside investments, often without conscious awareness by people that the floodplains were making the surroundings more valuable in terms of economic activities.

When these values are replaced with a dam and reservoir a new set of storages is provided which routes energies into alternative activities which may or may not be greater in total work done for the region. The amount of electricity and increased regularity of water may be more or less of a contribution to economic activity. Water quality may be worse, the evaporating water losses greater, and ultimately the flood protection patchy and intermittent. Quantitative evaluations are required and may be made with the energy method.

BUILDING NEW SWAMPS AND MARSHES

If an area has lost its wetlands or has too few wetlands to serve well in a role of filtering and recycle, more swamps can be constructed. One way is to restore the water regime and hydroperiod to a formerly drained area along with multiple seeding of species of trees and animals characteristic of swamps.

Another way is to sculpture the land in the manner that would eventually be done by rains and runoff so as to create wetlands topography and wetlands where there were none before.

If wetlands are needed in close proximity to outflows of waste waters from human activities, special swamps can be planted. One engineer asked if it would be all right if they were planted in rectangles and straight lines, a query that reflects the traditional directness and neatness characteristic of construction. Even if one did construct basins in such shapes for reasons of convenience, the flows of waters would tend to develop circular shapes where waters converge and curving meanders where they are flowing horizontally, although these curves could be allowed to operate within some larger rectangular bounds. Whatever structure is built should be formed so it is self maintaining.

MELALEUCA SWAMPS AS A DRYING AGENT

In Florida there is a fast growing exotic tree *Melaleuca* from monsoon climates which can survive heavy flooding but also survive intense droughts and fire. Where the water table has been dropped several feet as generally in south Florida, the greater extremes of water and drought cause *Melaleuca* to displace cypress. It has been shown to have much higher evapotranspiration, and its spread is beginning to have a major effect on the water budget of south Florida. Restoration of high water table is needed. Local diking is a better way to keep high water out of the activities of agriculture, housing and urban development. It has been pointed out that if there are instances where waste waters should be evaporated, these can best be arranged by using a *Melaleuca* swamp as a receiving agent.