Final Report to Martin County Commission
Contract # "EMERGY"

# EMERGY EVALUATION OF ENVIRONMENTAL ALTERNATIVES IN MARTIN COUNTY

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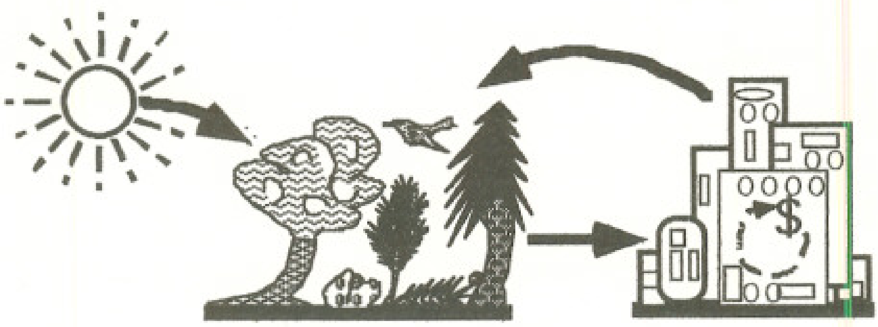

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## Executive Summary

The real wealth of Martin County is based on local environmental resources of land, waters, and ocean plus the raw materials, goods, services, fuels, and other resources purchased from outside the county. Emdollars measure the contribution of both to the economy on a common basis.

For example, if a flow of fresh water is evaluated as one million emdollars, this means that one million dollars of the gross economic product of the county is due to the use of that water directly or indirectly by the system of people and landscape.

A map view in Figure 1 shows some of the main features of environmental resources, especially the water flows from the west, urban development on the east, and marine beach and estuarine resources now impacted by water management practices in wet years.

Evaluations of the main resources, both from within and outside the county, are summarized in Figure 2 and Table 1. In Table 2 the resource base of the Martin County economy is compared with the state and the nation. Forty-two percent of the economy is from environmental resources. These are the attraction for economic developments and investments that contribute fifty-eight percent. The ratio of the purchased resources to the local environmental resource free from nature is about 1.4 to 1, much less than the ratio for Florida (7.1 to 1) and the United States (7 to 1) as a whole. This translates into a large potential for economic development in Martin County.

Freshwater resources of Martin County are summarized in Figure 3, with flows from Table 3 and storages from Table 4.

Alternatives for management of freshwater resources are summarized in Table 5. The fresh water available from Lake Okeechobee and the western part of Martin County in wet years is 30% greater than the normal water inputs and use. This represents a resource of potential value of 8.1 E7 emdollars. However, under the present arrangements, these water inputs are discharged through the central estuary, causing disturbance losses of 8.82 E8 emdollars, which includes the discharge of the valuable water to the sea without much contribution to the local economy. Several measures to prevent these losses are evaluated with estimated benefits 2 to 3 times higher than the costs of implementation.

The suggested measures are made not only to avoid the present losses associated with excess water years, but to avoid diverting a resource away from potential use in Martin County economic developments. The proposed measures allow restoration of marine resources estimated as 7.6 E7 emdollars per year.

Flows and storages of beach sands are drawn in Figure 4. In Table 6 evaluations were made of beaches, encroachment by the sea, and some alternatives for management of beaches and coastal sands. Three factors may be contributing to the encroachment by the sea: (1) a small amount from rising sea level due to higher temperatures; (2) a decrease of sands moving along the beach to replace those eroding from the beach; and (3) an invasion of the sea due to subsidence of the land due to diverted ground water recharge and removal of ground waters. Because the scientific data on the magnitude of the last two factors are not yet available, it is beyond the scope of this project to determine their relative causality. However, the emdollars involved in the encroachment is estimated for comparison with measures for reducing the possible impact of ground water diversion on land level at the shore.

The normal estuarine contributions of St. Lucie estuary (Figure 5) have been impacted by the surges of freshwater through the St. Lucie Canal in wet years. Figure 6 shows main features of that ecosystem and the contributions that are estimated from that ecosystem when it is allowed a normal Florida estuarine regime. Figure 7 shows the estuary in context with the rest of Martin County. Figure 8 shows more details within the estuary. Table 7b shows the emdollar value of restoring more normal estuarine functions that come from diverting the surges of freshwater discharge (Table 3).

Mangroves of Martin County (Figure 1) contribute to the marine resources, fisheries, land protection and coastal water quality but are affected by the alternatives for coastal water management. These values are given in Table 8.

Since the better economic use of fresh waters, estuarine values, marsh values, and beach values are dependent on restoring a more normal water discharge regimen, alternatives for holding excess waters within the county were evaluated in Table 9. The emdollar benefits far exceeded the emdollar costs of a changed pattern. In other words, future economic vitality of the county is increased by the investment in these environmental improvement measures.

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# Introduction, Environment, and Economy

The ultimate basis for a county economy is the real wealth processed and used, such as food, clothing, housing, information, culture, automobiles, clean air, water, beaches, land, education, population, etc. All of these, including human works, ultimately are based on the environmental resources made by nature's processes of earth, atmosphere, ocean, and biosphere. Understanding the resource basis of a county may be important for citizens and their representatives concerned with the future of their economy and environment.

A new measure: EMERGY spelled with an "m" puts all kinds of real wealth on a common basis. EMERGY of a product is calculated from the work previously required to make it. All kinds of work are expressed in units of one kind of energy (solar) previously used up directly and indirectly.

Solar EMERGY is used in this study to evaluate the real wealth basis for the economy of Martin County, Florida. Located between Lake Okeechobee and the east coast beaches, there are wetlands, agriculture, sand ridges, and a diversified economic activity centered in the city of Stuart, Florida (Figure 1).

After the total annual budget of real wealth of the county is evaluated in EMERGY units, we divide by the gross economic product in dollars to determine real-wealth-buying-power of the money (ratio of EMERGY to money). The dollar equivalent of the real wealth we call an emdollar. Thus, we can express the contributions to real wealth of Martin County, whether from nature or from human services, in EMERGY units (emjoules) or emdollars.

Money circulates among people paying for the services of bringing the real wealth into use. However, money is paid only to people, and not to nature for its work generating the real wealth, resources. Whereas we use market values as measures of what people are willing to pay other people for products and services, market values cannot be used to measure the contributions from environment because the money paid is only for the human part of the work of processing. However, we can use emdollars for everything, including human services.

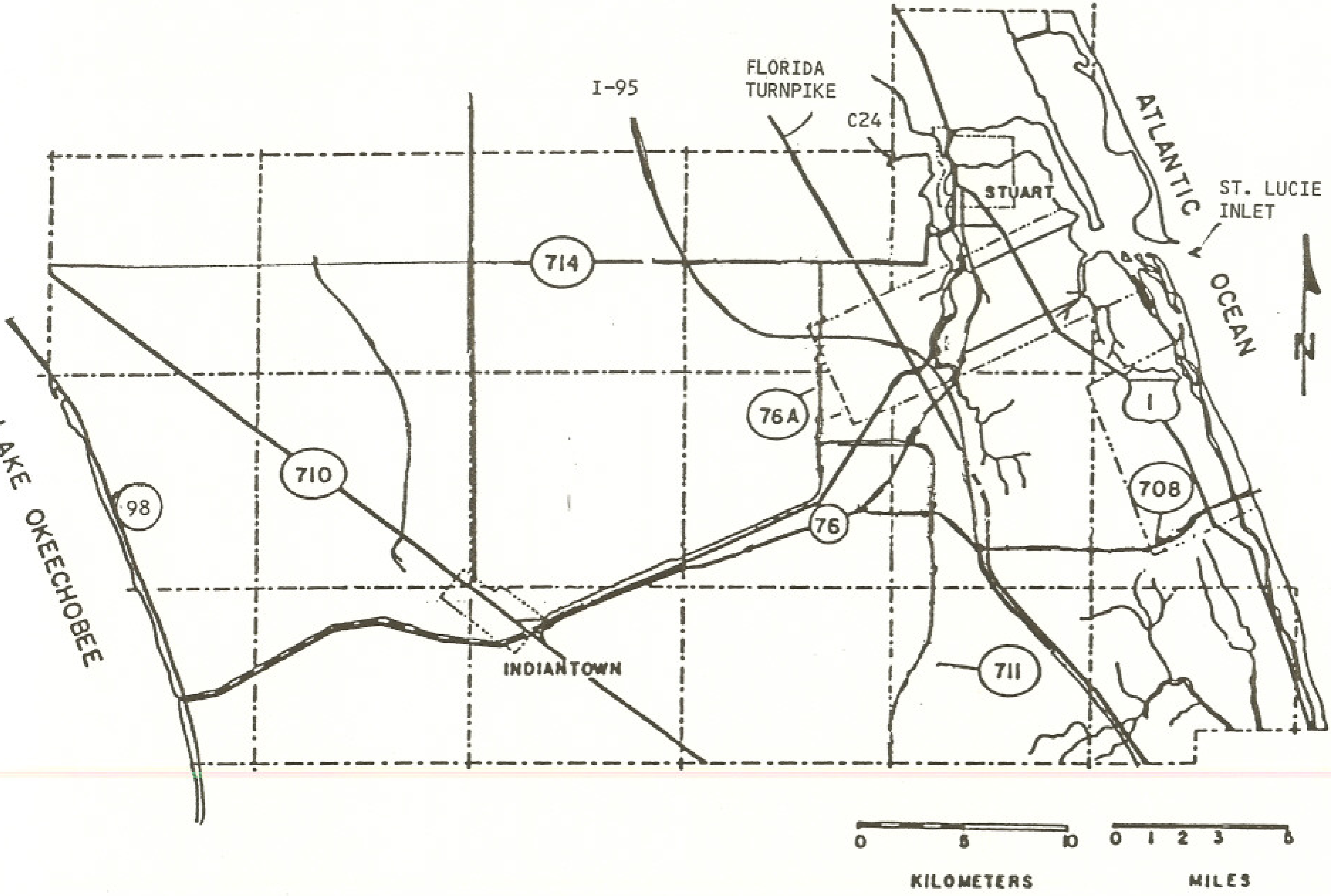



Figure 1. Map view of Martin County with the principal resources contributing to the environmental-economic system.

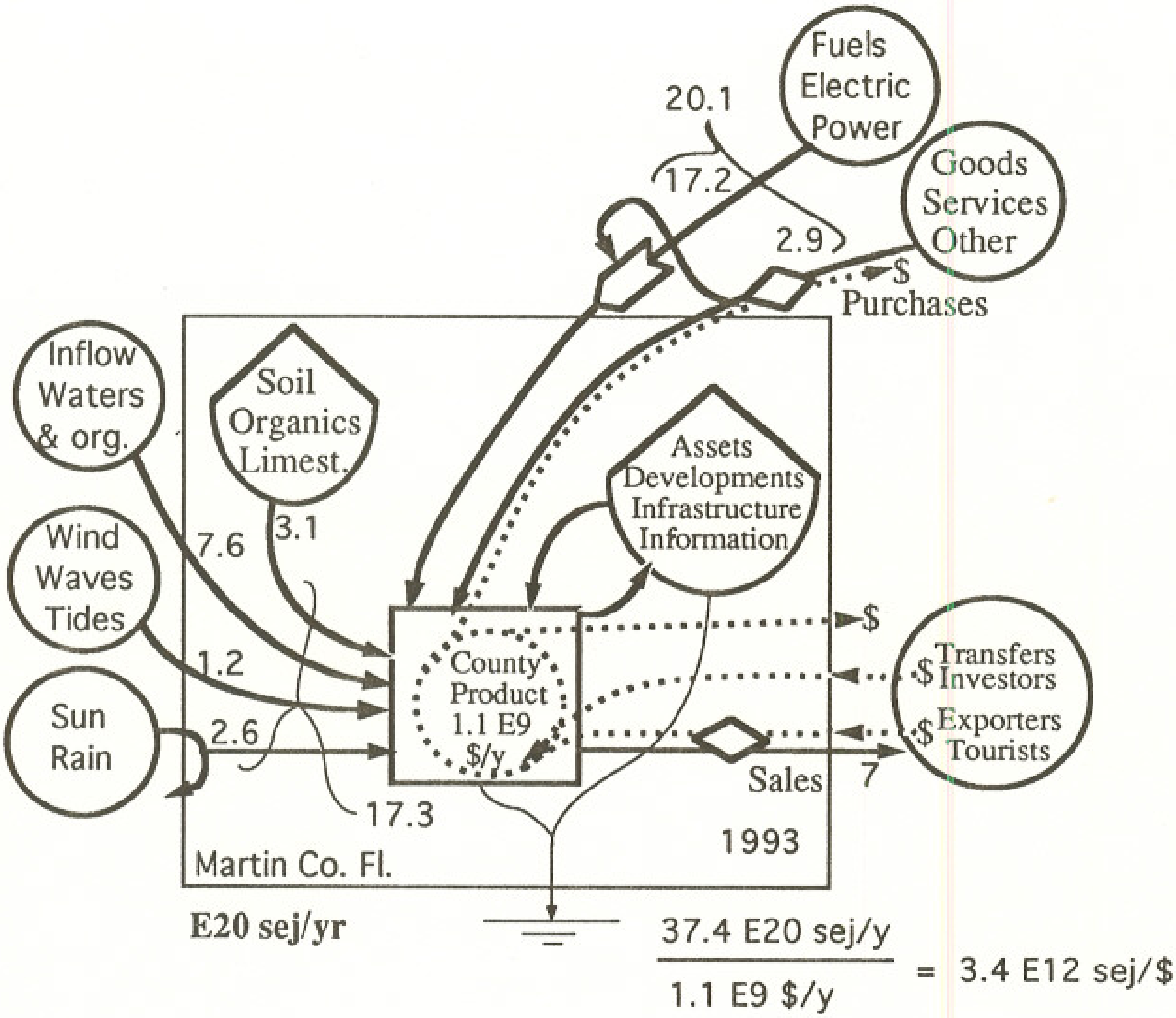
EMERGY Evaluation of the Economy of Martin County

The main resources contributing real wealth to the economy of Martin county are show in Figure 2. The numbers on the pathways are the annual flows of EMERGY as calculated in Appendix Table A2. Forty one percent of the real wealth comes free from the local environment as sun, rain, wind, waves, tides, rains, streams, soils, and minerals (14.5 E20 sej/yr in Figure 2). These resources are the necessary basis for the economic development that brings in 59% of the real wealth as fuels, electric power, goods, and services (20.1 E20 sej/yr).

Table 1a expresses the same data in their dollar equivalents (solar Emdollars). Notice the high values of real wealth inherent in the local free water resources (560.4 million emdollars per year) and in purchased electric power (535.8 million em$ per year) and fuels (360.1 million em$ per year). These Emdollar values indicate the direct and indirect contribution of these resources to gross economic product when they have been used. Table1b, based on incomplete data, has very approximate dollars estimated to cross into and out of the county. The EMERGY contribution of outside human services was estimated by multiplying the dollars paid for goods and services (Table 1b) by the ratio of EMERGY to money in the economy.

The characteristics of the overall Martin County evaluation are summarized in Table 2, and compared with the same indices calculated for Florida and for the United States as a whole. The top line shows Martin County annual total about 1% of that of Florida as a whole, a larger wealth than inferred from gross economic products in line 2. From line 3, money buys more than twice as much real wealth in Martin County than in Florida as a whole. The real wealth per person is higher than in Florida and the U.S. (line 4). The concentration per area of real wealth use is similar to that of Florida (line 5). Water contributes 11% of the county's real wealth (line 6).

The ratio of purchased resources from outside to local free resources (Line 7 of Table 2) is 1.4, much less than that of Florida and the U.S. In other words, the county is less developed relative to the state and nation. Line 8 of the table indicates 17 billion $/year potential economic development if the economic development in Martin County reaches the U.S. ratio.



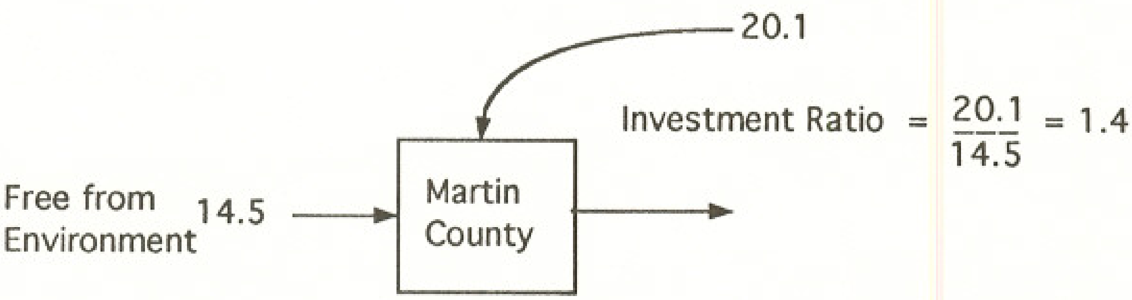




Figure 2. Overview of the environmental-economic system of Martin County: including the resource basis from nature's inside contribution and inputs purchased from outside. Evaluations of empower are given in solar emjoules per year.

Table 1a
Summary of Annual Inputs to Martin County, FL.
For details see Appendix Table A2.

| Resource | Million Emdollars per year | |
|---|---|---|
| 1. Local Environmental Input | | |
| a. Sun, Wind, Rain | 191.3 | |
| b. Water Inflows | 560.4 | |
| c. Waves and Tides | 84.0 | |
| d. Hurricanes | --- | |
| e. Soil, Limestone | 222.7 | |
| | 1058.4 | Total |
| 2. Purchased Inputs | | |
| a. Goods and Services | 116.0 | |
| b. Fuels | 360.1 | |
| c. Electric Power | 535.8 | |
| d. Automobiles, Machinery, Boats | --- | |
| 3. New People | | |
| a. Residents | 356.0 | |
| b. Tourists | 261.0 | |
| 4. Information | | |
| a. Television | 26.4 | |
| b. Books | --- | |
| | 1655.2 | Total 2-4 |

1a. Rain value only to avoid double counting (Appendix Table A2, #3)
1b. Runoff into Martin County (Canals 23, 24, Loxahatchee river, and discharge from Lake Okeechobee; see #6 in Appendix Table A2)
1c. see Appendix Table A2 #s 4, 5
1d. Indetermined
1e. Consumption of stored resources (see Appendix Table A2, #s 24, 28)

2a. see Appendix Table A2 # 18. After Brown, M.T. 1980, Figure 17.4 in Odum, H.T. Emergy and Public Policy
2b. Natural gas and gasoline/diesel (#s 15, 16 in Appendix Table A2)
2c. Electrical energy (Appendix Table A2, #17)
2d. Indetermined

3a. see Appendix Table A2 #14
3b. Metabolic energy and money provided by toursists (#s 20,21 in Appendix Table A2)

4a. Emergy of television transmittal and reception (#19 in Appendix Table A2)
4b. Indetermined

Table 1b
Estimates of Money Crossing the County Boundary*

| | Million $ per year |
|---|---|
| Crossing in: | |
| Export sales | $ 500 |
| From State Government | 10 |
| Federal Transfer Payments | $ 820 |
| Money from Tourists | $ 193 |
| Investment earnings | 8? |
| Total | $1531+ |
| Crossing out: | |
| Goods and Service Purchase (nomogram method) | $ 116 |
| State Taxes | $ 77 |
| Federal Taxes | $1153 |
| Investments out | ---?-- |
| Total | $1346+ |

*Details in Appendix Table A2.

Table 2
Comparisons between Martin County, Florida, and the United States

| Index | Martin Co. | Florida ** | U.S.A. |
|---|---|---|---|
| Annual Emergy Use (Empower) E20 sej/yr | 37.4 | 3546 | 87,500 |
| Gross Economic Product Billion $/yr | 1.13 | 240 | 6,378 |
| Emergy/money E12 sej/$ | 3.4 | 1.5 | 1.37 |
| EMERGY/person E15 sej/person | 36.7 | 26.8 | 29 |
| Empower Density E11 sej/m2/yr | 25 | 25 | 7 |
| Water Emergy Proportion | 11.0% | 9.5% | 5.1% |
| Emergy Investment Ratio | 1.4 | 7.1 | 7 |
| Economic Development Potential at the Florida-U.S. Matching Rate Billion $/yr | 17 | -- | -- |

1 Environmental inputs (#s 3, 4, 5, 6, 7, 24, 26, 28 in Appendix Table A2) plus Economic inputs (#s 12-20 in Appendiox Table A2) **

2 Total earned income including personal, farm, and manufacturing. From Florida Statistical Abstracts ($1.13 E9)

3 Total Empower Use divided by total earned income
4 Total Empower Use divided by population (102,000)
5 Total Empower Use divided by land area (1.51 E9 m2)
6 Rainfall, inflows, and groundwater withdrawals (#s 3, 6, 25 in Appendix Table A2)
7 Economic inputs (#s 12-20 in Appendix Table A2) divided by Environmental Inputs (#s 3, 4, 5, 6, 7, 24, 28 in Appendix Table A2)
8 (Emergy of Environmental inputs)*(7)(1.37 E12 sej/$)

** From Environment and Society in Florida (Odum, Odum and Brown, 1993)

In this study, an evaluation is first made of Martin County as a whole, identifying the main resources which are supplied locally by the environment and those which are brought into the county from outside by economic developments. Then special analysis is made of the freshwater flows of the county, especially the waters discharging into the estuarine system at Stuart. The beach system was also evaluated in relation to the encroachment of the sea and possible effect of water management.

Finally, policies for resource management are considered using the Maximum EMERGY Principle. The general idea is that policies can maximize public benefit by selecting alternatives that maximize production and use of EMERGY and emdollars.

## Methods

First, energy systems diagrams were made of the systems to be evaluated (Martin County, Estuary, etc.), combining information about what is important from as many people and sources as possible. The diagrams were used to identify for evaluation the main inputs from nature and from the economy outside the county. Evaluation tables were set up with line items for the main sources of real wealth, goods and services, etc. Data were obtained for annual inputs either in energy units, weight units, or dollars. Then these were multiplied by EMERGY per unit to get annual flows of EMERGY. Finally, EMERGY values were divided by EMERGY/money ratios to obtain solar emdollars.

Unlike traditional energy analysis where energies of various kinds are added together as if equivalent, with EMERGY evaluation the values of each kind of energy were multiplied by their solar transformities, which puts all the kinds of energy on the common basis of the solar EMERGY required for the product or service.

The transformities of different kinds of energy were obtained from previous evaluations of processes in which it was possible to add up the requirements (each expressed in solar EMERGY units). The methodology is given in detail with many applications in a new book (Odum, 1995). Tables and graphs in this report are in solar EMERGY units (solar emjoules) or in solar emdollars.

## Evaluation of Alternatives for Water Management

As shown in Tables 3 and 4 and Figure 3, the freshwaters that are locally and temporarily in excess, have a large emdollar value and potentially have 7 times that value in potential, if matched with economic development intensity average for Florida. If some of the waters that are in excess can be stored so that they are not discharged from the St. Lucie Estuary, some marine values are also restored and the freshwaters can be used in developments on land.

Because of their high emvalues and because most parts of Florida are developing shortages of water more and more often, periods of water excess may be less and less frequent. For example, the shortages of water in the Tampa-St Petersburg area may cause some of the waters to be diverted from the Kissimmee basin. Eventually, it may be rare to have excess waters in Lake Okeechobee. Also, as water demands increase, excess discharge from St. Lucie County canals into St. Lucie estuary may be expected to decrease too.

What is available to Martin County for water conservation is the high run-off from presently agricultural lands of the western part of the county. From the Martin County point of view, EMERGY value is maximized by retaining freshwaters on land, with less estuarine discharge, and without exporting to other counties, provided the measures for holding these waters do not require greater emvalue than their benefit. The first line in Table 5 provides estimates of annual emdollar benefit of the water saved for county use. The second line has the emvalue of these waters if matched with present intensity of economic development in Martin County. Line three has matching with the higher intensity of development of Florida (its average EMERGY investment ratio, 7.0). Similarly, Table 7b show the annual Em$ value of restored estuarine resources and a similar matching of economic development.

Since some of the excess runoff is due to higher runoff from agricultural and housing developments, and since the original transpiration was probably less than that now, this means there is less recharge now, potentially contributing to the danger of land subsidence and sea invasion. One solution is to arrange for reinjection of these waters into ground water at a number of sites scattered over the western part of the country. Slow recharge through wetland filters is the best, but direct injection may be next best, since land area for the wetland recharge is not easily available. The injection recharge is not uinlike the natural water entering in the past

Table 3
Emdollar Evaluations of Freshwater Flows in Martin County*

| Item | Annual flow 1993 Em$ (E6)/yr |
|---|---|
| 1. Rainfall | 190.7 |
| 2. Evapotranspiration | 238.5 |
| 3. Runoff | |
| a. Into Martin County | 102.9 |
| b. Drainage from Uplands | 139.8 |
| c. Lake Okeechobee through St. Lucie Canal | 23.5 |
| d. Discharge from St. Lucie Estuary | 316.9 |
| 4. Groundwater Exchange | |
| a. Recharge | 3.4 |
| b. Withdrawal | 11.4 |

* All values determined using the chemical energy of freshwater

1. Rainfall over entire County and offshore continental shelf
Total: 2.9 E9 m3; Transformity: 18199 sej/J

2. Evaporation and transpiration from inland areas
Total: 2.42 E9 m3; Transformity: 28261 sej/J

3a. Includes Loxahatchee, Canals 23, 24, and discharge from Lake Okeechobee
Total: 6.0 E8 m3; Transformity: 48460 sej/J

3b. Includes Loxahatchee flow, North and South Forks of St. Lucie River, and the difference in flow of Canal 44 between discharge at Lake Okeechobee and discharge at estuary. Total: 1.1 E9 m3; Transformity: 48460 sej/J

3c. Data obtained from U.S.G.S. data. Net flow to estuary during 1993 = 1.34 E8 m3; Transformity: 48460 sej/J

3d. Includes North and South Forks of St. Lucie river, Canals 23, 24, 44
Total: 1.65 E9 m3; Transformity: 48460 sej/J

4a. Estimated as 2% of rainfall over inland areas
Total: 5.27 E7 m3; Transformity: 18199 sej/J

4b. Data obtained from Florida Statistical Abstracts Table 8.41
Total: 7.7 E7 m3; Transformity: 41000 sej/J

Table 4
Evaluations of Water Storages in Martin County

| Item | Volume (E7 m3) | Replacement time | Million Emdollars |
|---|---|---|---|
| 1. Lake Okeechobee | ----- | ----- | -- |
| 2. Lake Okeechobee Rim Canal | ----- | ----- | ----- |
| 3. Drainage Canals | 1.6 | variable | 2.8 |
| 4. St. Lucie Estuary | 4.4 | 2 weeks | 7.7 |
| 5. Groundwater above sea level | 200 | 34 yrs | 350.0 |
| 6. Quarry Canal | ---- | ------ | ------ |
| 7. Northwest reservoir | 6.0 | 1 month | 10.5 |

1. Indetermined

2. Indetermined

3. Volume of water in Canals 23 and 44: estimated as 60 miles of canal length with an average depth of 15 feet and width of 120 feet converts to approximately 1.4 E7 m3. Replacement time variable depending on rainfall.

4. Estuary area: 2.206 E7 m2, estimated average depth of 2 m. Replacement time estimated as 2 weeks

5. Estimate porosity as 30% over the land area of 1.51 E9 m2, with an average elevation of groundwater of 4 m above NGVD. Volume/inputs equals replacement time:

1.81 E9 m3 / 5.27 E7 m3 = 34 yrs

6. Indetermined

7. Based on an estimated capacity of reservoir at 6.2 E7m3 (50,000 ac-ft); turnover time estimated by dividing volume by input rate from Canal 44 and runoff from uplands:

(6.2 E7 m3)/ (8.9 E8 m3/yr) = ~ 1 month

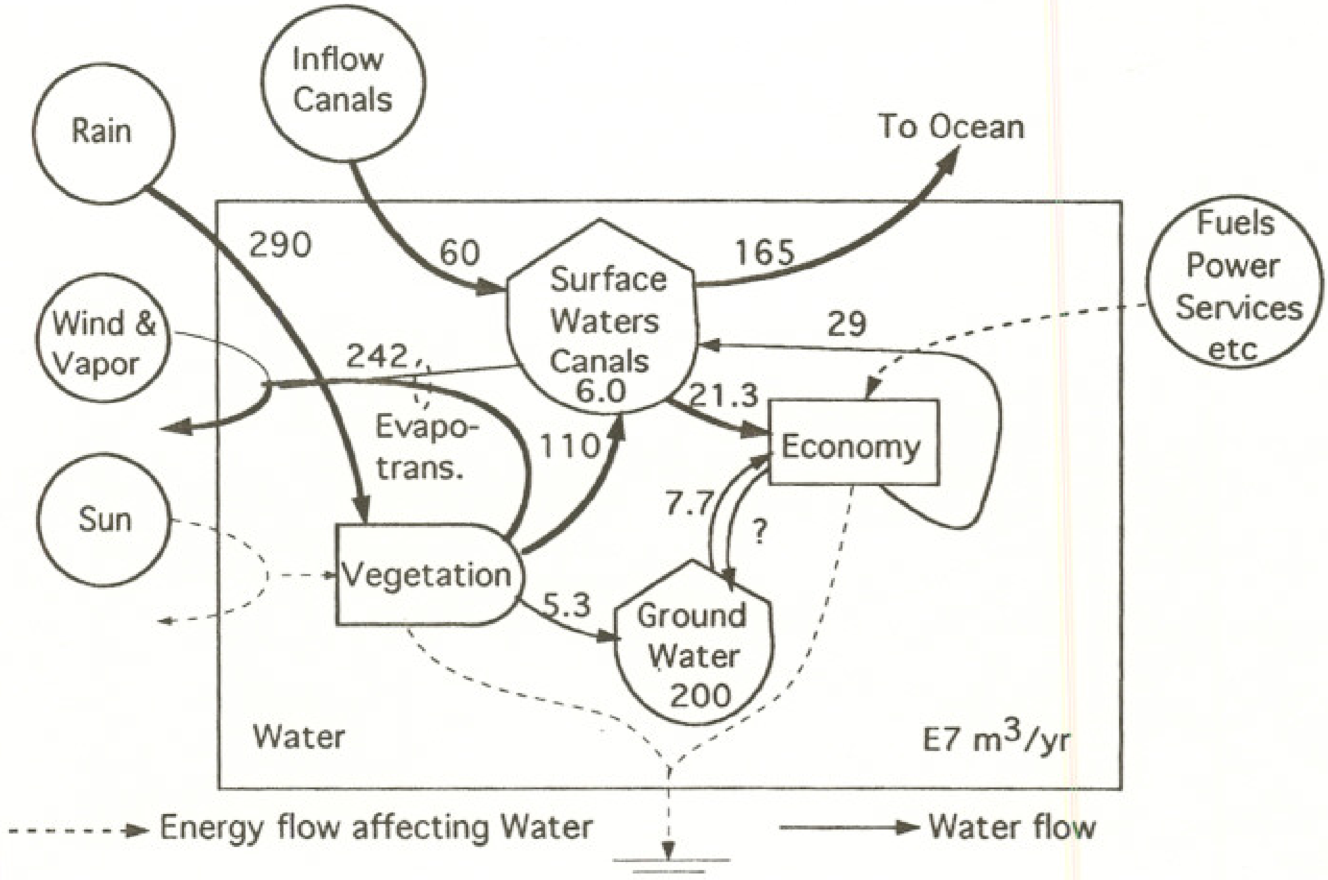



Figure 3. Principal fresh water inflows and storages in Martin County.

Table 5
Emdollar Values of Retaining 1 Billion Cubic Meters of Water per Year

| Item | Emdollars per year (Million) |
| --- | --- |
| 1 Value of Water | 150 million |
| 2 Value of water plus 1.4 matching | 360 million |
| 3 Value of water plus 7 times matching | 1200 million |

1 Chemical availability:
(1 E9 m3/yr)(1 E6 g/m3)(5 Joules/g)(4.1 E4 sej/J)/(1.37 E12sej/$)
= 150 E6 $/yr

2 Em$ from line1 plus matching obtained by multiplying by the EMERGY investment ratio 1.4 for Martin County as a whole (Table 2).

3 Em$ from line 1 plus matching obtained by multiplying by EMERGY investment ratio for Florida and the U.S., 7.0 (Table 2); possibly appropriate for the Stuart local area.

which also had low salts but considerable lignins (black waters), which have some water purification characteristics.

A change in water management to conserve these waters is a public benefit as long as the cost of the new water management is less than the benefits provided in this table. Whereas estimating economic costs of alternative water construction projects is not within the scope of this project, we can compare the emvalue benefits with those cost estimates that have been cited in the past for water conservation projects.

## Beaches and Sands

A major part of Martin County's real wealth is in the beaches and the budget of sands that maintain them. Operating on wave energy, tidal energy, and the inflow of sands in the long shore currents, the beach system is essential to maintain and protect the prominent economic values of Stuart and the tourist industry. Emdollar evaluations of the stock of sand in the beach and the annual budget are given in Table 6.

In recent studies (Erikson et al., 1995) the system of beach nourishment in Martin County was described and sand flows estimated based on 230,000 cubic yards per year of sand flowing from the north. Some of this is caught by the North Jetty, but much of this sand is diverted into the inlet, depositing on both the inflow and ebb tide areas, shoaling the inlet. As a regular part of maintaining the inlet channel for boats to 10 feet, sands are dredged and deposited in the beach zone, particularly on the south of the inlet. The budget estimated only 57,000 cubic yards per year going south, leaving the county by means of the long-shore current. The implication is that there is a net increase in sands in Martin County beaches. Figure 4 shows the system of sands and their interaction with waves, tides, and dredging.

However, it also may be that the beach between the high value beach buildings and the surf has been decreasing, even though the sea rise in recent years has been only a few inches. There seems to be a possible contradiction between a net increase in sand and a net loss in beach. there is a possibility that the land is sinking, perhaps from groundwater withdrawals, a phenomenon well known elsewhere, as in Taiwan and Venice, Italy. If there is subsidence of the land, it could account for a positive sand budget and a beach loss. Dean (1987) reviewed data from tide gauges on sea level rise relative to land and found that some land subsidence may be occurring in Florida.

The EMERGY value of the beach's protection is much larger than the value of sand in Table 6 because of its special location and protective role against hurricanes. The value of the groundwater withdrawals (Table 3-5) is small compared to the beach front property assets. Until more data become available, perhaps it is prudent not to withdraw more ground water than recharges each year. Perhaps restricting withdrawals to that for drinking purposes is part of public safety. The new satellite measurements of earth surface height are reported to be accurate to 4 millimeters. It should be possible in several years to determine from that data if the beach front at Stuart is sinking.

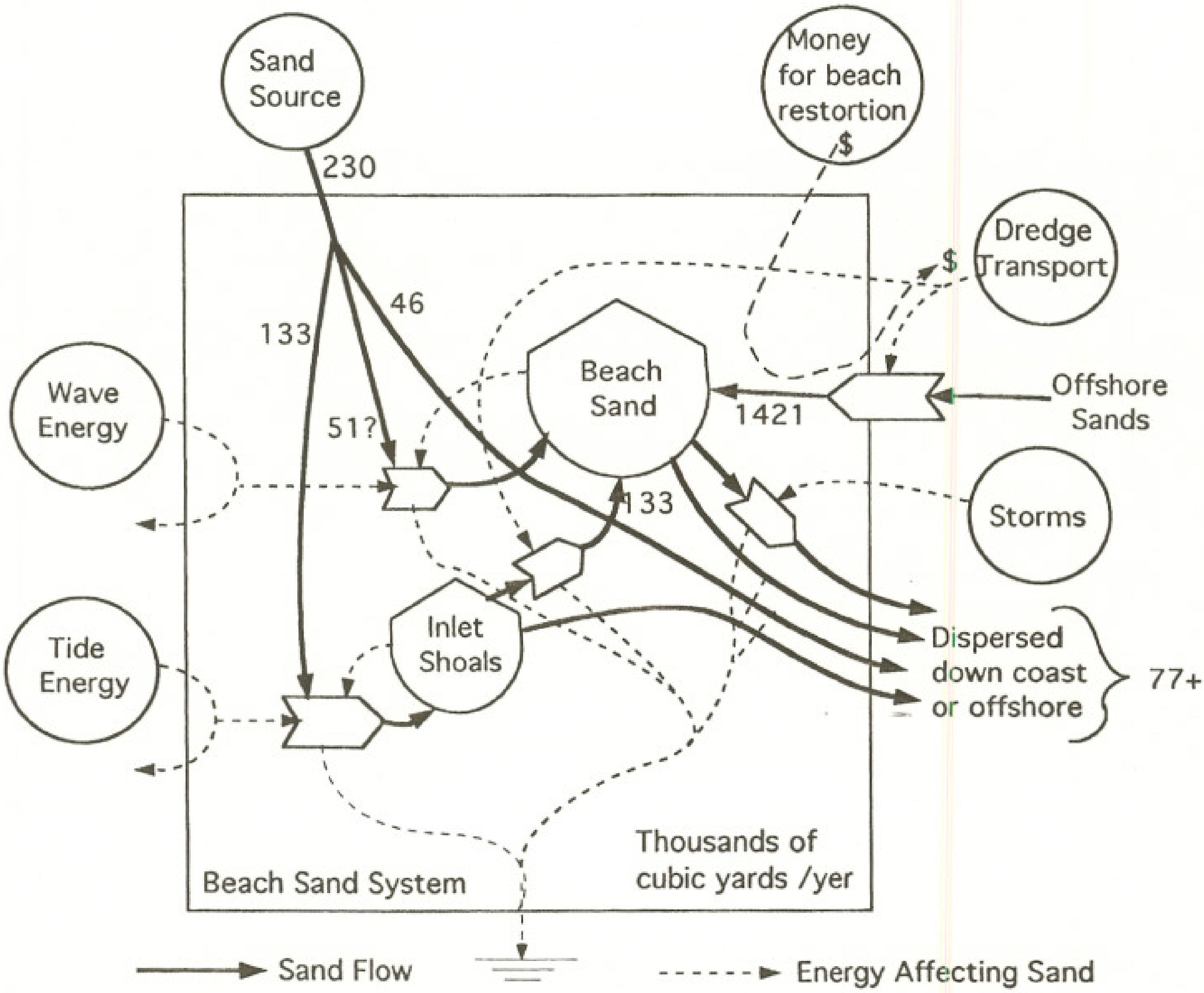



Figure 4. System of coastal sands.

Table 6
Emdollar Evaluations of Beaches, and Sands (See Figure 4)*

| Item | Volume Thsds Cubic Yards | Emdollars* |
|---|---|---|
| 1 Beach Sands | 11,000 | 1.8 E10 |
| Annual Flows: | | |
| | Thsds cubic yds/yr | Emdollars/'yr* |
| 2 Annual Beach Replenishment | 230 | 3.8 E8 |
| 3 Sands Dredged from inlet | 133 | 2.2 E8 |
| 4 Possible loss of sand from Beach | 77+ | 1.3 E8 |
| 5 Replenishment dredging from offshore | | |
| 6 Service Costs of Dredging | $ 3 E6 | ---- |
| 7 Fuels used in Dredging | ~6 E5 L | 1.1 E6 |

*EMERGY/mass used: 1.0 E9 sej/gram; EMERGY/$ used: 1.37 E12 sej/$.

1 Volume of beach sands above sea level and seaward of housing line
( 41 km county coastline)(50m width)(4 m high)(3? E6 g/m3)
(1 E9 sej/g)/1.37 E12 sej/$) = 1.8 E10 Em$/yr

2-4 Estimates from Erikson et al (1995)

5 (300,000 yd3/yr)*($10/yd3) = $3 E6/yr

6 see note 21 in Appendix Table A3

7 see note 18 in Appendix Table A3

## Estuarine Evaluation and Alternatives

The St. Lucie Estuary (Figures 5 through 8) accounts for more than two-thirds of the empower of Martin County but occurs on only 1% of the county area (Table 7a). The empower density is 23 times that of the county as a whole, but the investment ratio in the estuary is especially low. Only 16% of the empower is from estuarine-related industries. Although the low investment ratio for the county as a whole implies a high investment potential for Martin County, for the estuary, this low ratio may be the result of estuarine degradation that has caused economic development to lag. Most (53%) of the estuarine empower is from canal discharges of organic matter and fresh water. These are delivered in pulses, which cause frequent change in the species composition of animals and plants in the estuary, possibly preventing any one set from reaching its full development potential and is damaging to animals and plants (Haunert and Startzman 1985, Montague and Ley 1993). This is an example of poor matching of the frequency and intensity of an input resource to the natural ecological and economic cycles occurring within the estuary. For example, under current discharge regimes, few oysters occur in the St. Lucie Estuary. The state Division of Marine Fisheries commercial marine landings records for 37 years between 1951 and 1990 were analyzed. No oysters were commercially harvested in Martin County during that period and only negligible quantities in St. Lucie County (3,800 lbs in 37 years of records, with only 7 of 37 years reporting any oyster harvest at all). Too much freshwater too often may account for the lack of oysters (Haunert and Startzman 1985).

Moreover, the short residence time in the estuary of the bulk of the water and organics discharged through these canals prevents the ecological benefit of these emergy sources from being incorporated into the estuarine ecosystem. Instead, most of the potential benefit of this emergy is exported out the St. Lucie Inlet, perhaps to the benefit of near- and offshore ecosystems and economies outside Martin County.

It is possible that some offshore production is stimulated by the energy in the flowing water and organics as they pass beyond the inlet. This may result in increased fishing success in the waters near Martin County. This benefit, however, is diluted over a wide area once it leaves the St. Lucie Estuary and is considered negligible. A small amount of the potential energy in the large water flow probably helps scour sand from the St. Lucie Inlet and as such may reduce dredging costs to some degree. Furthermore, a small portion of the annual loading of organic matter accumulates in the estuary as muck, which over time has built a fairly

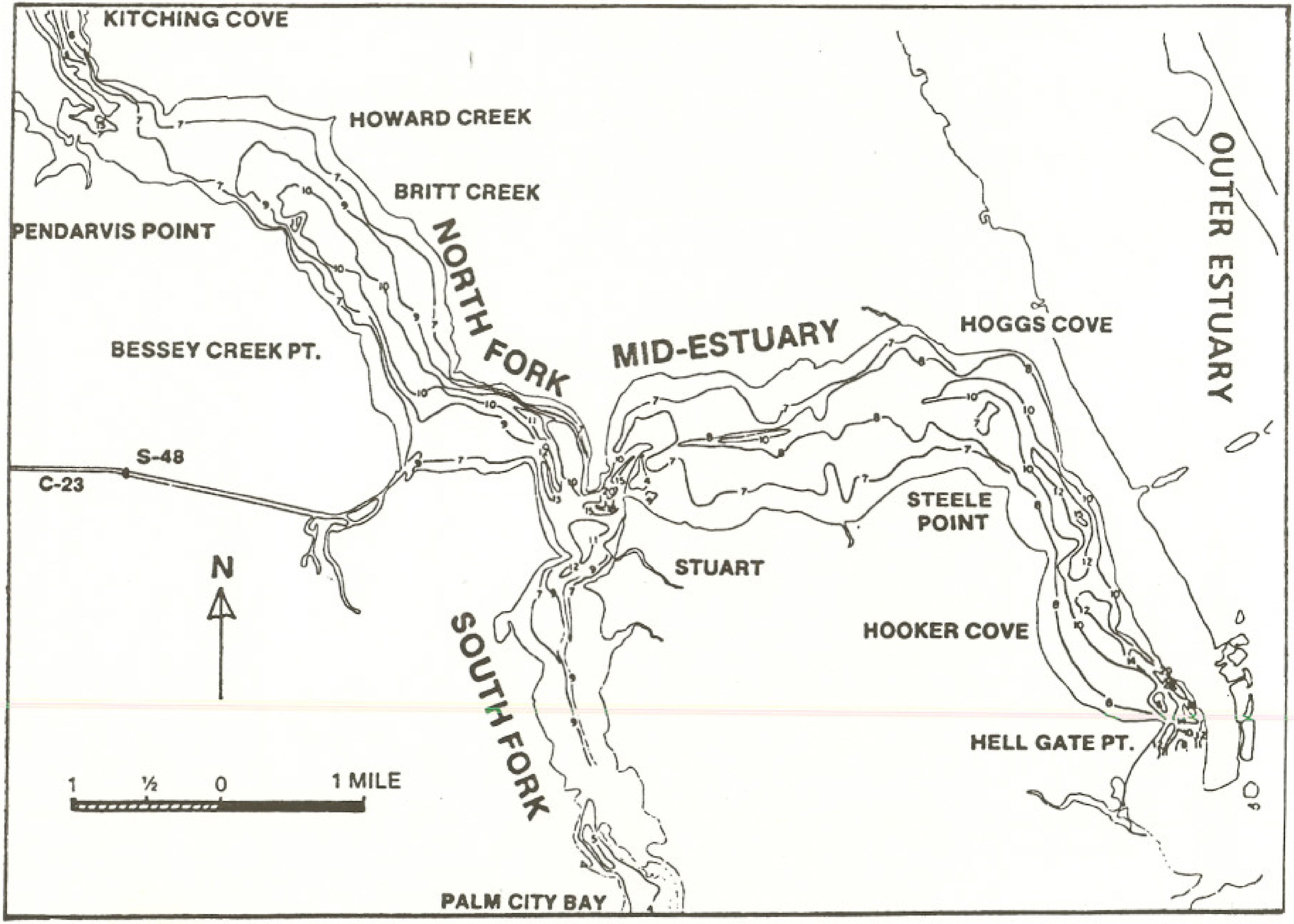



Figure 5. St. Lucie Estuary, with bottom contours in feet.

Table 7a
Summary Emergy and Emdollar Statistics for the St. Lucie Estuary (for data sources and computations, see Appendix A3)

| Energy Source | Emergy (x E20 sej/yr) | Emdollars (x E6) |
|---|---|---|
| Renewable Natural Resources | | |
| sun, wind, rain, waves | 0.033 | 2.4 |
| tides | 0.006 | 0.5 |
| river discharges | | |
| organic matter | 6.496 | 474.2 |
| freshwater | 1.462 | 106.7 |
| TOTAL renewable natural resources | 7.997 | 583.8 |
| Canal Discharges (% from C-44) | | |
| organic matter (59) | 11.324 | 826.6 |
| freshwater (58) | 2.413 | 176.1 |
| TOTAL canal discharges | 13.737 | 1002.7 |
| (TOTAL from C-44 | 8.081 | 589.8) |
| TOTAL FREE INPUTS | 21.77 | 1586.5 |
| Purchased Goods and Services from Estuarine Related Industries | | |
| tourism | 3.574 | 260.9 |
| boating | 0.546 | 39.9 |
| dredging | 0.010 | 0.7 |
| TOTAL purchased inputs | 4.13 | 301.5 |
| TOTAL Annual Empower | 25.90 (69% of Martin County's) | |
| Area of St. Lucie Estuary (km2) | 22 (1% of Martin County's) | |
| Empower Density* (xE11 sej/m2/yr) | 587 (23 times that of Martin Co.) | |
| Water Emergy Portion | 15% (1.4 times that of Martin Co.) | |
| Investment Ratio | 0.19 (14% of Martin County's) | |

*assumes a land area equal to that of the estuary is necessary to allow the estuarine related industries large muck layer along the bottom and contributed to the dark color and turbidity of the water (Haunert 1988; Schropp, et al., 1994). As this muck decomposes, it may subsidize production in the estuarine detrital food chain. However, this potential benefit to estuarine ecosystem production may be more than offset by a lack of both benthic and planktonic photosynthesis from the increased turbidity and color of the water.

The investment potential in Martin County in the vicinity of the estuary should be considerably enhanced by the restoration of biological production that can produce high emergy ecological products, such as crabs, fish, shrimp, and oysters (Figure 6). We hypothesize that the emergy value of the major primary producers can be matched by economic empower many times. This economic empower arises through an increase in fishing, tourism, and recreational opportunities and support services, and enhanced waterfront property values as waters become clearer and support seagrass beds and oyster reefs (Figure 7). These organisms not only are productive, but also help stabilize sediments and clarify water, and moreover are themselves nursery habitat for a diverse group of estuarine-dependent fish and shellfish.

Oyster reefs and seagrass beds are suitable indicators of the health of St. Lucie Estuary. Oyster reefs indicate considerable phytoplankton production. Seagrass beds occur when turbidity and color are sufficiently low. Not only do muck and stirred inorganic sediments reduce seagrass beds, but so do dense accumulations of phytoplankton. A healthy population of oysters and other filter feeders shunt most species of phytoplankton into animal production and keep the water clear. Healthy seagrass beds help to stabilize bottom sediments. Hence, once oyster reefs and seagrass beds become established, the estuarine ecosystem becomes self-maintaining.

On the other hand, however, if an estuary-wide perturbation occurs (such as a sudden and week-long release of a large volume of canal water), the self-maintenance loop is broken. When the sediment-stabilizing seagrasses and water-clarifying oyster reefs are killed, the water may become unsuitable for a long time because the resulting turbidity cannot allow light penetration to the bottom to support new seagrasses and may not be able to allow the production of phytoplankton that can support oyster growth. Furthermore, sudden drastic changes in water quality usually favor one species of opportunistic phytoplankton first. This then dominates the water. If it is not an appropriate food for oysters or zooplankton, this organism will simply contribute to turbidity (at the expense of seagrasses) without contributing to the production of the

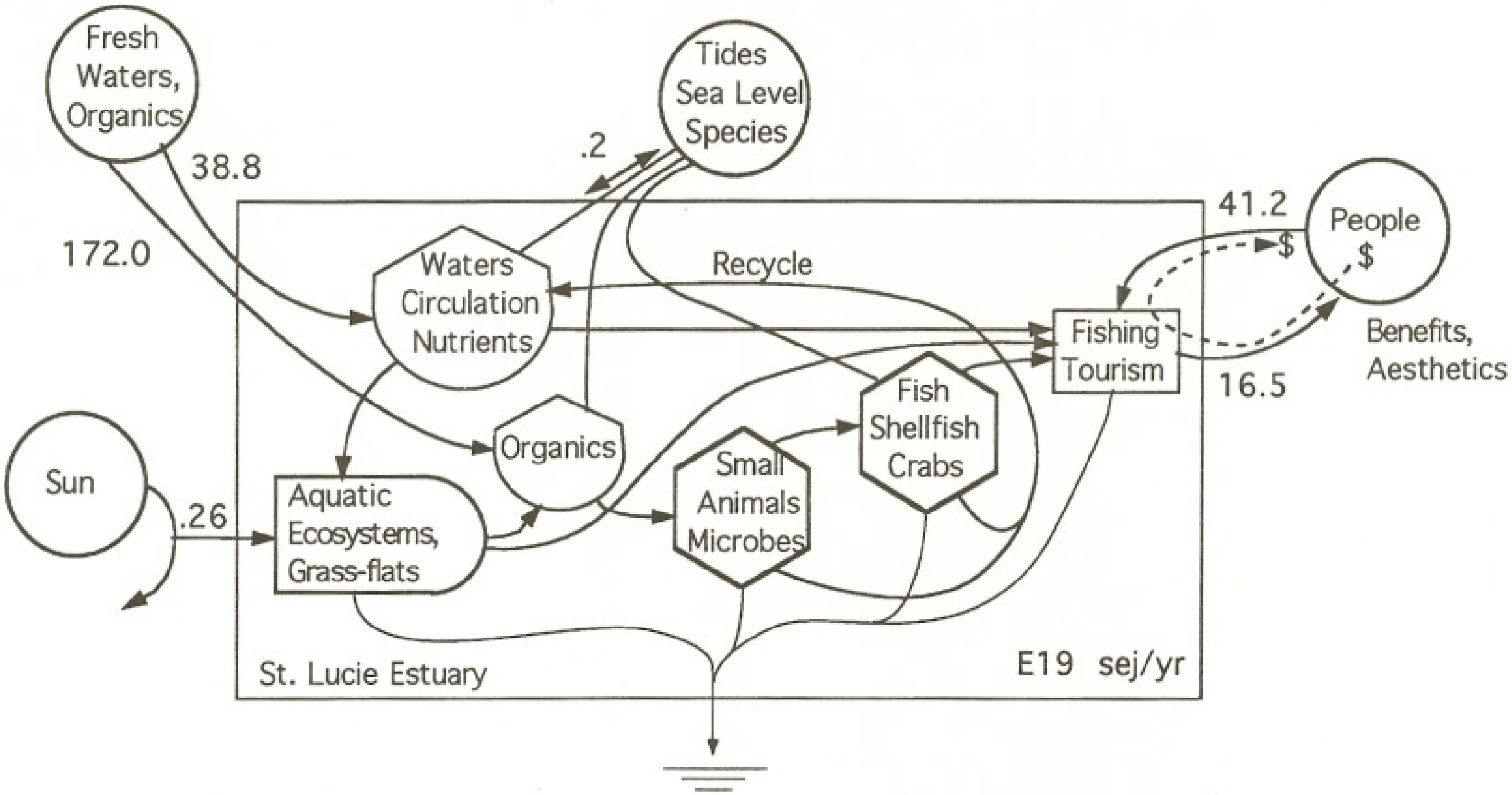



Figure 6. Main features of the St. Lucie estuarine ecological system when it operates without the destructive influences of excessive fresh-water discharges.

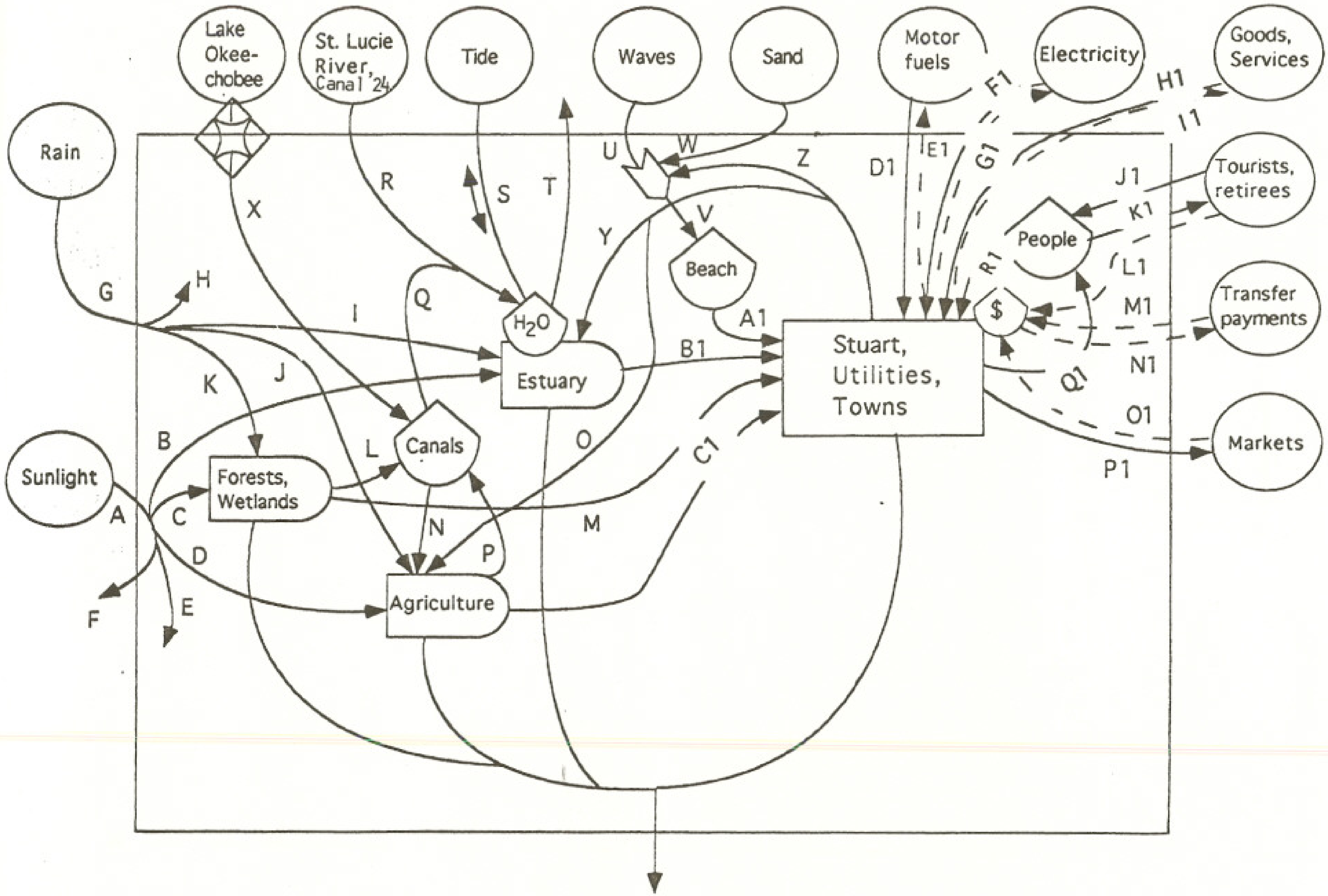



Figure 7. Systems diagram of Martin County with letters identifying the line items in the County Evaluation (Appendix Tables A1 and A2).

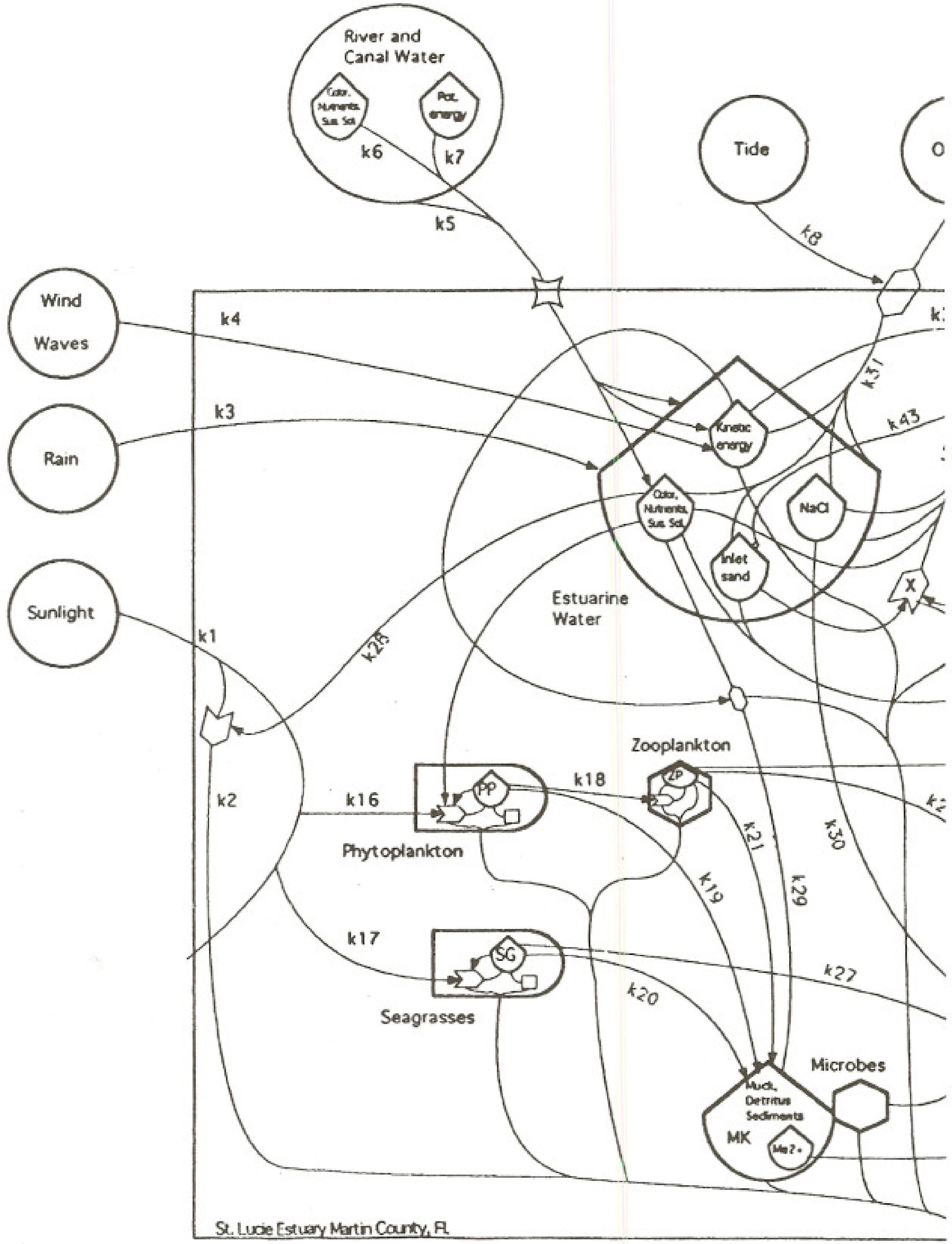
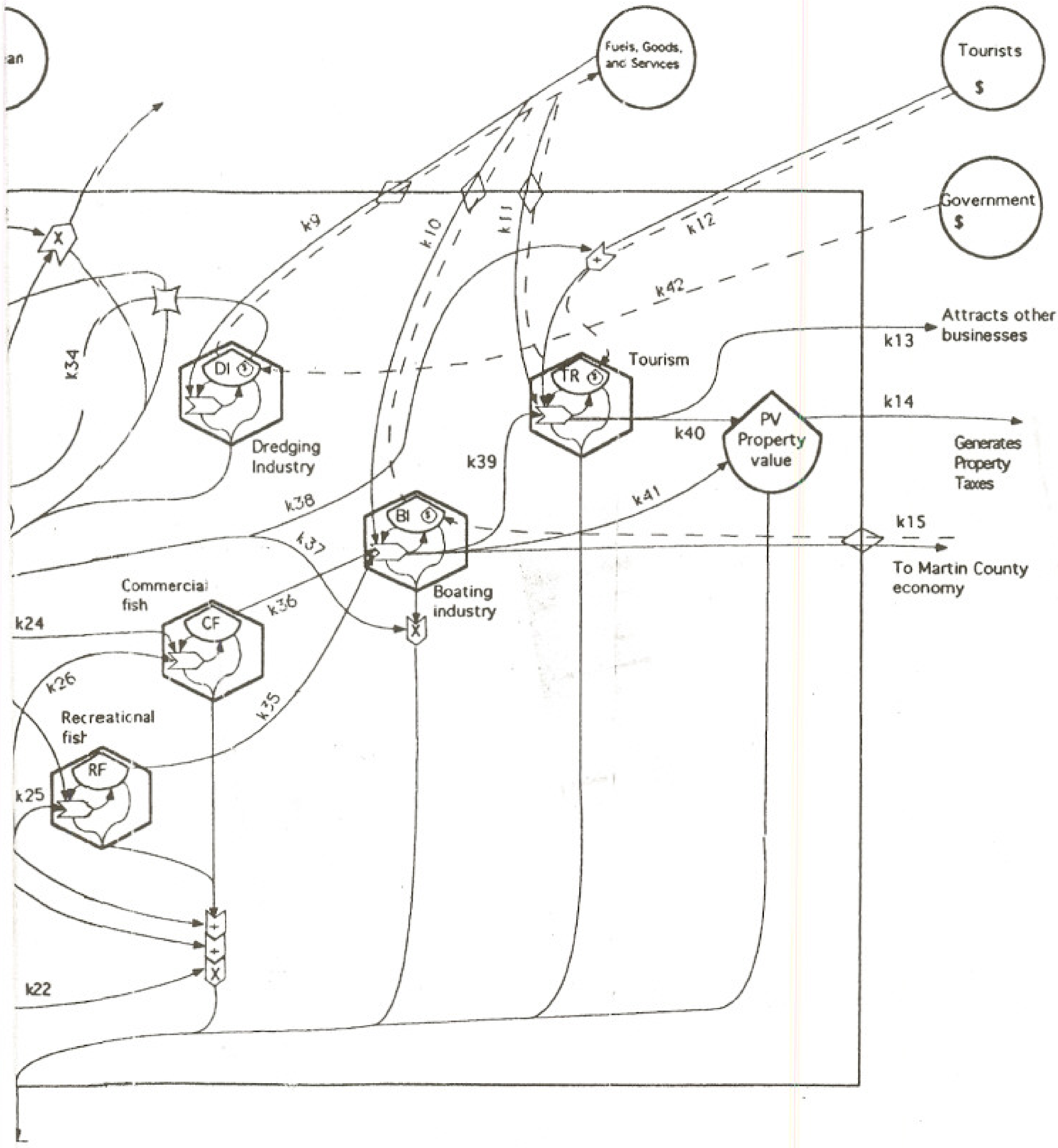
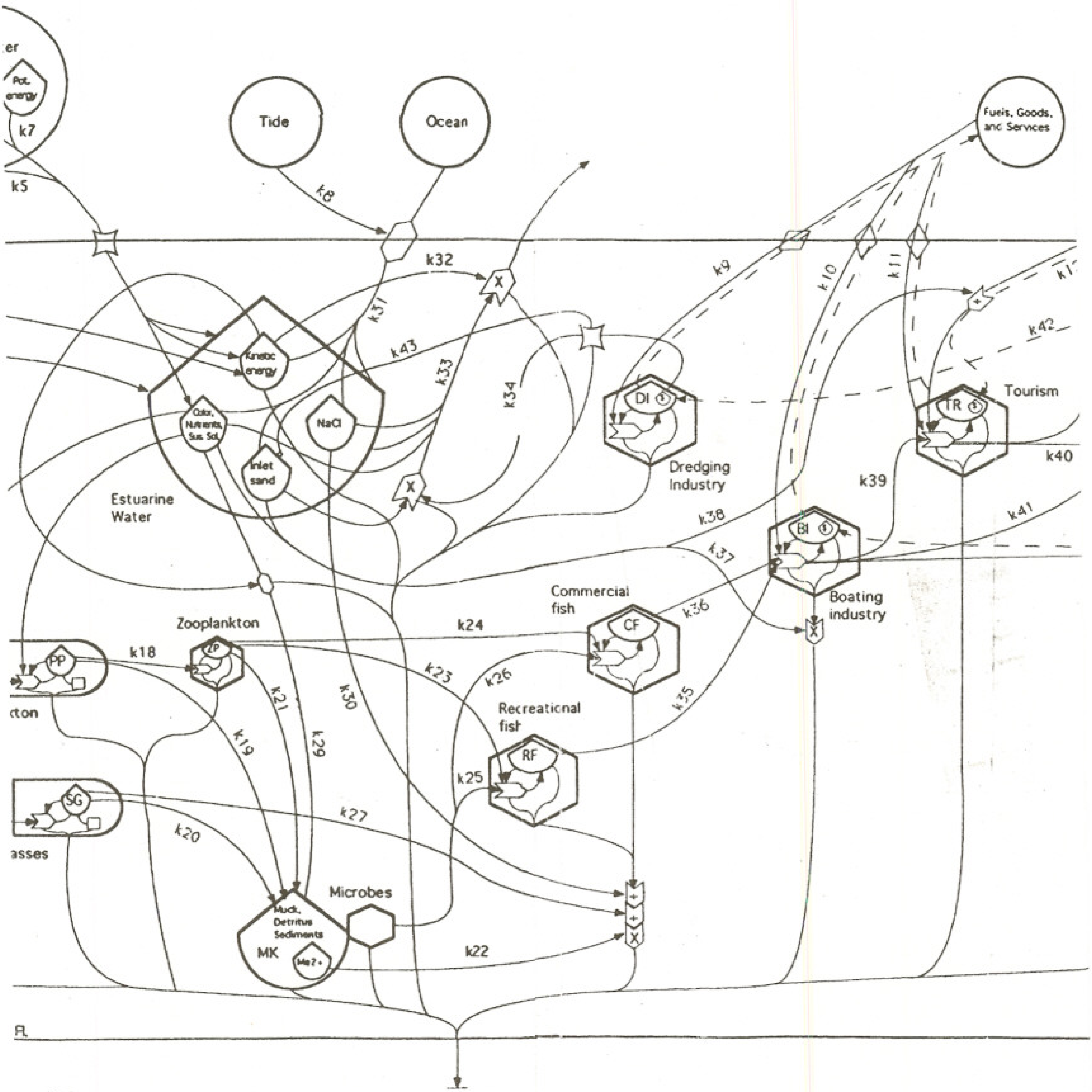



Figure 8. Estuarine ecosystem in detail.



Fuels, Goods, and Services
Tourists $
Government $
k9
k10
k11
k12
k42
k34
DI
Dredging Industry
TR
Tourism
Attracts other businesses
k13
k14
PV Property value
k40
Generates Property Taxes
k39
k38
k41
BI
k37
k15
To Martin County economy
Commercial fish
k36
CF
Boating industry
k24
k26
k35
Recreational fish
RF
k25
k22




e ecosystem in detail.

desired water-clarifying animals. Hence, habitat for many other species is lost, and estuarine ecological and matching economic production declines. This may be what has happened in the St. Lucie Estuary. Removing the perturbation is a necessary first step both to recovery of ecological production and diversity, and to overcoming the lag in economic investment in the vicinity.

Estimates of the current and restored emdollar values of ecosystem primary production in St. Lucie estuary are given in Table 7b. The current value of 5.1 million emdollars per year may increase by 50% with restoration. Moreover, this may be expected to be matched by economic development at least in proportion to the computed investment ratio for Martin County (1.4). It is likely that the matching will be much higher because of the proximity of the estuary to the city of Stuart. A matching of 50 times may be more appropriate. In this case, the 2.5 million emdollar per year increase in value of a restored estuarine primary production would stimulate 125 million emdollars per year of economic investment.

<u>Note on intertidal marshes and mangroves</u>. Intertidal marshes and mangroves account for 86% of the ecological empower associated with estuarine primary production in Martin County (Table 8). It is unlikely that any change in water management will impact the total area covered or the production of most of this area. Most of the vegetated intertidal zone is in the outer more saline estuary. Furthermore, although intertidal marsh plants closer to the discharges may be negatively impacted by the sudden salinity change, in general they are not very sensitive and unlike many seagrasses even grow better in fresh water (they occur in saltwater because they tolerate salt; they are rare in continuously fresh water because they are outcompeted by even better growing plants). Changes in the mean water level may impact the total area if the slope of the land above or below the present intertidal zone is different, however, this has been assumed not to be an issue for the control of canal discharges, though could be an issue in water management scenarios tied to land subsidence.

The economic matching expected by having these natural intertidal areas in proximity to a city could be considerable (Table 8). Assuming an investment ratio in such cases of 50, the total value of intertidal marshes and mangroves in the ecological-economic emergy system is 220 million emdollars per year. Salt marshes and mangroves above mean high water, however, can produce significant quantities of saltmarsh mosquitoes. These can be a pest, especially within 6.5 km (4 miles) of population centers. Less than 2% of intertidal marshes and mangroves are intensively managed at present by the Martin County Mosquito Control District (Les

Table 7b
Emdollar Value of Restored Estuarine Ecosystems in St. Lucie Estuary, and Estimated Economic Matching That May Result

| | | | |
|---|---|---|---|
| Value of current* estuarine ecosystem (million em$/yr) | | | |
| intertidal wetland ecosystem | 4.4 | | |
| planktonic ecosystem | 0.7 | | |
| seagrass ecosystems | $\leq$0.1 | | |
| TOTAL | 5.1 | | |
| Value of restored** estuarine ecosystem (million em$/yr) | | | |
| intertidal wetland ecosystem | 4.4 | | |
| planktonic ecosystem | 2.0 | | |
| seagrass ecosystems | 1.2 | | |
| TOTAL | 7.6 | | |
| Increase in value from restoration | 2.5 | Total value: | 7.6 |
| Increase times 1.4 investment ratio*** | 3.5 | Total value: | 11.1 |
| Increase times 7.0 investment ratio**** | 17.5 | Total value: | 25.1 |
| Increase times 50 investment ratio***** | 125.0 | Total value: | 132.6 |

* intertidal wetlands area from National Wetlands Inventory; planktonic production currently assumed to be similar to that of the Waccasassa River, Florida; seagrass currently assumed to cover about 0.2 $km^2$ with low average production (see Appendix A3).

** in restored ecosystem, planktonic system assumed to become similar to that of Apalachicola Bay (2.97E14 J/yr in Day et al., 1989), an increase of 2.7 times current assumed planktonic production; seagrass area assumed to cover 5.7 $km^2$, and production to increase 4 times over current assumed production (see Appendix B); intertidal wetlands assumed to remain similar.

*** investment ratio computed for Martin County as a whole (Table 2)

**** investment ratio for the United States as a whole (Table 2)

***** investment ratio assumed for natural areas within a city

Table 8
Emdollar Evaluation of Martin County Intertidal Marshes and Mangroves and Their Management Alternatives.

| Item | | Emdollars (Million) |
|---|---|---|
| 1 | Annual contribution of salt marshes-mangroves | 4.4 |
| 2 | Values inferred from economic matching | 220.0 |
| 3 | Inferred values lost from area with mosquito problems | -2.1 |

1 (1.47 E7 m2 area)(5.45 E3 g/m2/yr)(4.2 kcal/g)(4186 J/kcal)(4280 sej/J) = 6.03 E18

2 times 50

3 (2.8 E5 m2: area affected by mosquitoes)(fraction of investment matching lost: 0.5)(empower density in natural marsh area: 4.1 E11 sej/m2/yr)(50: economic matching)

Area of intertidal marsh and mangroves from USFWS National Wetlands Inventory, gross production from Day et al. (1989), assuming 1/3 riverine, 1/3 basin and 1/3 scrub mangroves, transformity from Odum (1995, in press) for gross photosynthesis of Spartina alterniflora. Area of intertidal marsh subject to mosquito control courtesy of Mr. Les Scherer of Martin Co., Mosquito Control District.

Scherer, pers. comm.) and this amount is not expected to increase. Current management trends are to restore formerly managed areas as much as possible and to use new less obtrusive methods of mosquito control. Nevertheless, if mosquito control practices reduce the investment matchin of affected intertidal areas by half, the resulting loss presently in Martin County is equivalent to 2.1 million emdollars per year, or less than 1% of the direct and inferred intertidal marsh and mangrove empower of Martin County. Thus, overall, the benefits of these intertidal zones far exceed the costs of the level of mosquito control now deemed necessary in Martin County intertidal marshes and mangroves.

## Value of the Excess Water to the Martin County Economy

Some of the very large values of the waters discussed in this report to the gross economic product are given in Table 9. Wasting the waters or sending them to other areas is equivalent to removing several hundred million dollars each year from the real wealth of the county. Counting the attracted developments that this much water generates on the average, there are several billion dollars of gross economic product at stake. Clearly, provision to keep the waters recharging and restoring the hydrological pattern may be the first choice.

Table 9
Summary of Values for Alternative Water Management Plans

| Plan | Emdollars (E6) |
| --- | --- |
| 1. Values lost with present plan | 1039.0 |
| 2. Net change in values with water sent out of County | - 420.3 |
| 3. Net change of values with water storage plan | 280.0 |

1. Determined by adding the chemical and organic matter EMergy of freshwater from Canals 23, 24, 44 discharged thru the inlet (see notes 28 and 29 in Appendix Table A2), plus the EMergy of potential seagrass production (see footnote 1c in Table 7), plus current dredging costs (note 21 in Appendix Table A3), plus loss of potential 25% increase (estimate) in tourists, money from tourists, boating, fishing, and property value (see see footnote 1d in Table 7).

2. Net change of EMergy in Martin county determined by adding EMergy of increases (25%) in estuarine related storages and processes (see footnote 1d in Table 7); phosphorous and inorganic solids runoff (notes 31 and 34 in Appendix Table A2) minus the chemical and organic material EMergy of discharge from Canals 23, 24; the discharge from Lake Okeechobee to Canal 44; increases in inlet dredging costs (see footnote 2 in Table 7).

3. EMergy costs associated with construction of a reservoir: Volume of water estimated as 6.2 E7 m3 (50,000 acre-feet) at $2/yd3 ($2.65/m3)excavation costs yields a total cost of $1.6 E8 emdollars; lost agricultural production of 5000 hectares (estimated area of reservoir at 4ft depth) and 3 kg/yr/m2 production:
(50 E6 m2)*(3000 g/m2/yr)*(4 kcal/g)*(4186 J/kcal)*(2E5 sej/J)/(1.37 E12 sej/$) = 3.6 E8 emdollars; increased estuary dredging costs estimated as double current costs: 1.46 E6 emdollars; Total costs: 5.24 E8 emdollars

EMergy benefits associated with reservoir: Chemical (1.16 E8 emdollars) and organic matter (6.06 E8 emdollars) EMergy of retained water from Canal 23 and drainage from uplands entering Canal 44 (see Appendix Table A2); increased benefits of estuary totalling 7.6 E7 emdollars (see Table 7 note 1d); retained phosphorous and inorganic solids previously discharged through Canals total of 5.33 E6 emdollars; Total benefits: 8.03 E8 emdollars

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APPENDIX A
Martin County Energy Systems Flows

**Appendix Table A1. Verbal Explanations of Flows in Martin County Energy Systems Diagram (Figure 7)**

**note: These flows are evaluated with line items in Appendix Table A2**

A Total sunlight

B Sunlight falling directly on estuary

C Sunlight falling directly on forests, wetlands, and unimproved rangeland

D Sunlight falling directly by crops, and improved pasture

E Sunlight falling on all other land and water areas in the county, such as urban and offshore areas

F Reflected sunlight

G Total rainfall, EMERGY values combine Gibbs free energy with EMERGY of nitrogen and phosphorous. Rainfall contributions to other sectors determined by their area

H Rainfall falling directly on developed areas and offshore

I Rainfall falling on the estuary

J Rainfall utilized directly by crops and improved pasture

K Rainfall utilized directly by forests, wetlands, and natural areas

L Surface and ground water drained from natural areas by Okeechobee waterway

M EMERGY contribution of natural areas to local economy in the form of timber, hunting, tourism ($ and people), diversity, image

N Canal water utilized by agriculture (oranges, sugarcane, vegetables) Total water requirements - utility water- rainfall -groundwater

O EMERGY contribution of local economy to agriculture, including labor, fertilizer, pesticides, fuels, machinery

Appendix Table A1

P Runoff from agriculture into Okeechobee waterway, including organic matter, Gibbs free energy, and sediment

Q Discharge from Okeechobee waterway into estuary. EMERGY includes organic matter, Gibbs free energy, geopotential, pesticides, suspended solids, heavy metals.

R Discharge from north into estuary.

S Tidal exchange with estuary; energy absorbed by tidal fluctuations

T Discharge of freshwater and organic matter from estuary inlet.

U Wave energy absorbed along shoreline.

W Sand/sediment pumped, dredged or deposited by the longshore current along the coastline of county. V is the EMERGY sum of flows W and U.

X Freshwater inputs from Lake Okeechobee to the St. Lucie canal, including organic matter, sediment load.

Y Contribution of local economy to estuary, including fuels, labor.

Z Dredging activities associated with channel maintenance and beach renourishment.

A1 Contribution of Beach ecosystems to local economy, including tourism ($ and people), property value (taxes)

B1 Contribution of estuary to local economy, including fisheries landings, tourism ($ and people), boating activities, property values.

C1 Contribution of agriculture to local economy, including exports

D1 Import of gasoline, diesel and natural gas into county economy.

E1 Money paid to outside economies for gasoline, diesel, and natural gas. Based on the amount of fuel consumed and average prices.

F1 Electricity purchased from outside sources

G1 Money paid for electricity. Based on average prices.

H1 Goods and services imported into the county, including migrant farm workers, and durable goods.

I1 Money paid for goods and services.

J1 Yearly flux of tourists and retirees, includes metabolic energy consumed during visit and/or residence.

K1 Migration of residents out of Martin county

L1 Money spent by tourists in Martin county, also includes foreign investments

M1 Money supplied by federal and state governments in transfer payments.

N1 Money paid for taxes to state and federal government.

O1 Money obtained from the sale of manufactured and agricultural products.

P1 Export of agricultural and manufactured products.

Q1 EMERGY contribution of economy to population

R1 EMERGY contribution of populace to economy. Metabolic energy and average transformity.

**Appendix Table A2.**
**Annual EMERGY flows for Martin County Florida**

**Physiography**

| | | | |
|---|---|---|---|
| Land Area | 1.51E+09 m2 | Population | 102,000 |
| Water Area | 5.36E+08 m2 | Agriculture and | |
| Offshore distance to 60ft depth | 5.95 km | Improved pasture | 4.52E8 m2 |
| Shoreline length | 41 km | | |
| Continental Shelf Area | 2.44E+08 m2 | Forestland, and | |
| Total Area | 2.29E+09 m2 | Rangeland | 9.5E8 m2 |

| | Data Units J, g, or $ | Solar Emergy/Unit sej/unit | Solar Emergy (E18) | Em$, 1993 E6 $/yr |
|---|---|---|---|---|
| **Environmental Inputs** | | | | |
| 1. Sunlight absorbed at surface | 1.36E+19 J | 1 | 13.6 | 9.93 |
| 2. Wind absorbed at the surface | 3.09E+17 J | 620 | 191.58 | 139.84 |
| 3. Rainfall, chemical | 1.44E+16 J | 18199 | 262.07 | 191.29 |
| 4. Tidal energy | 5.04E+14 J | 16842 | 8.49 | 6.20 |
| 5. Wave energy | 3.59E+15 J | 30550 | 109.67 | 80.05 |
| 6. Streams | | | | |
| Organic matter | 2.10E+14 J | 2.98E+06 | 625.80 | 456.79 |
| Chemical potential energy | 2.90E+15 J | 48460 | 140.53 | 102.58 |
| Geopotential | 1.10E+14 J | 27806 | 3.06 | 2.23 |
| 7. Geologic uplift | | 3.22E+10 | | |
| 8. Phosphorous in rain | 4.80E+08 g | 4.21E+09 | 2.02 | 1.48 |
| 9. Nitrogen in rain | 3.70E+08 g | 4.21E+09 | 1.56 | 1.14 |
| **Economic Inputs** | | | | |
| 10. Capital investments and purchases | 7.70E+06 $ | 1.37E+12 | 10.55 | 7.70 |
| 11. Federal transfer payments | 8.20E+08 $ | 1.37E+12 | 1123.13 | 819.80 |
| 12. Imported fertilizers | | | | |
| Nitrogen | 1.55E+09 g | 3.45E+09 | 5.35 | 3.90 |
| Phosphorous | 2.70E+08 g | 6.88E+09 | 1.86 | 1.36 |
| 13. Imported pesticides | 2.90E+08 g | 1.48E+10 | 4.29 | 3.13 |
| 14. Immigrants, retirees | 6.67E+12 J | 7.33E+07 | 488.91 | 356.87 |
| 15. Natural gas | 3.07E+14 J | 48000 | 14.74 | 10.76 |
| 16. Motor fuels | 7.25E+15 J | 66000 | 478.50 | 349.27 |
| 17. Electricity | 3.67E+15 J | 200000 | 734.00 | 535.77 |
| 18. Goods and Services | 1.16E+08 $ | 1.37E+12 | 158.92 | 116.00 |
| 19. Information (TV) | 51000 sets | 7.10E+14 | 36.21 | 26.43 |
| 20. Tourists | 1.26E+12 J | 7.33E+07 | 92.36 | 67.41 |
| 21. Money from tourists | 1.93E+08 $ | 1.37E+12 | 264.41 | 193.00 |
| 22. Money from exports | 5.00E+08 $ | 1.37E+12 | 685.00 | 500.00 |
| 23. Financial support from Florida | 9.94E+06 $ | 1.37E+12 | 13.62 | 9.94 |

Appendix Table A2 continued

| | | | | |
|---|---|---|---|---|
| **Consumption of Environmental Resources** | | | | |
| 24. Soils | 1.53E+15 J | 73750 | 112.84 | 82.36 |
| 25. Groundwater | 3.81E+14 J | 4.10E+04 | 15.62 | 11.40 |
| 26. Surface water | 1.03E+15 J | 255242 | 262.90 | 191.90 |
| 27. Phosphorous in soils | 5.60E+09 g | 4.21E+09 | 23.58 | 17.21 |
| 28. Limestone | 1.93E+10 g | 1.00E+10 | 192.50 | 140.51 |
| **Important Interior Flows** | | | | |
| 29. Water runoff to estuary | 7.99E+15 J | 48460 | 387.20 | 282.62 |
| 30. Organic runoff to estuary | 5.78E+14 J | 2.98E+06 | 1722.44 | 1257.26 |
| 31. Phosphorous runoff to estuary | 3.17E+08 g | 6.88E+09 | 2.18 | 1.59 |
| 32. Heavy metal runoff to estuary | 1.10E+07 g | 1.00E+09 | 1.10E-02 | 8.03E-03 |
| 33. Pesticide runoff to estuary | 3707 g | 1.48E+10 | 5.49E-05 | 4.00E-05 |
| 34. Inorganic solids to estuary | 3.00E+11 g | 1.71E+07 | 5.13 | 3.74 |
| 35. Evapotranspiration from land | 8.54E+15 J | 28261 | 241.35 | 176.17 |
| 36. Evaporation | 3.02E+15 J | 28261 | 85.35 | 62.30 |
| 37. Groundwater recharge and injection | 3.20E+14 J | 1.10E+05 | 35.20 | 25.69 |
| 38. Exchanges with Lake Okeechobee | 6.60E+14 J | 48460 | 31.98 | 23.35 |
| 39. Sand pumped/deposited on shore | 2.80E+11 g | 2.00E+09 | 560.00 | 408.76 |
| 40. Nutrient uptake by wetlands | | | | |
| Nitrogen | 7.55E+09 g | 4.21E+09 | 31.79 | 23.20 |
| Phosphorous | 2.00E+09 g | 4.21E+09 | 8.42 | 6.15 |
| 41. Freshwater discharge through inlet | 8.04E+15 J | 48460 | 389.62 | 284.39 |
| 42. Fish landings | 1.80E+13 J | 8.00E+06 | 144.00 | 105.11 |
| 43. Boat traffic | 7.90E+14 J | 66000 | 52.14 | 38.06 |
| **Exports and Outflows** | | | | |
| 44. Manufactured products | | | | |
| 45. Agricultural products | 2.60E+16 J | 200000 | 3133.00 | 3795.62 |
| 46. Exchanges betweeen shelf and open sea | | | | |
| 47. State taxes | 7.71E+07 $ | 1.37E+12 | 105.60 | 77.08 |
| 48. Federal Taxes | 1.15E+09 $ | 1.37E+12 | 1580.67 | 1153.78 |
| 49. Money paid for goods and services | 1.10E+08 $ | 1.37E+12 | 150.70 | 110.00 |
| 50. Money paid for electricity | 9.18E+07 $ | 1.37E+12 | 125.77 | 91.80 |
| 51. Money paid for fuels, gas | 6.84E+07 $ | 1.37E+12 | 93.65 | 68.36 |

1. SUNLIGHT ABSORBED AT SURFACE:

| | |
|---|---|
| Annual energy= | ((area)*(insolation)*(1-albedo)) |
| Area= | 2.29E9 m2 (Fla. Statistical Abstracts, 1993) |
| Insolation = | 6.90E9 J/m2/yr (Vishner, 1954) |
| Albedo= | 0.14 (% given as decimal) (Odum, 1987) |
| Annual energy= | 1.36 E19 J/yr |
| Transformity= | 1 sej/J by definition (Odum, 1995) |

2. WIND ABSORBED AT SURFACE:

| | |
|---|---|
| Annual energy= | (height)*(density)*(diffusion coefficient)*(wind gradiant)*(area) |
| Height= | 1000m |
| Density= | 1.23 kg/m3 |
| Diffusion coefficient= | 2.25 m3/m2/sec |
| Wind gradient= | 1.9E-3 m/sec/m |
| Area = | 2.29 E9 m2 |
| Conversion | 3.154E7 sec/yr |
| Annual energy = | 3.09 E17 J/yr |
| Transformity= | 620 sej/J (Odum, 1995) |

3. RAIN, CHEMICAL:

| | |
|---|---|
| Annual energy = | (area)*(rainfall)*(Gibbs free energy) |
| Area = | 2.29 E9 m2 |
| Rainfall = | 1.27 m/yr (~50 in. from Fla. Statistical Abstract, 1994) |
| Gibbs energy = | 4.94 J/g (from Odum, 1995) |
| Conversion= | 1m3 H2O = 1E6 g |
| Annual energy = | 1.44E16 J/yr |
| Transformity= | 18199 sej/J (Odum, 1995) |

4. TIDAL ENERGY:

| | |
|---|---|
| Annual energy = | (area elevated)*(0.5)*(# tides/yr)*(height)$^2$*(density)*(gravity constant) |
| Area elevated = | 2.206E7 m2 estuary area + 1/2 shelf area: 1.07 E8 m2 |
| # tides /yr = | 706 tides/yr (semi-diurnal cycle) |
| Height = | 0.7 m (from NOAA tide tables) |
| Density = | 1.025 E3 kg/m3 |
| Gravity constant = | 9.8 m/sec2 |
| Annual energy = | 5.03 E14 J/yr |
| Transformity= | 16842 sej/J (Odum, 1995) |

5. WAVE ENERGY

| | |
|---|---|
| Annual energy = | (shore length)*(1/8)*(density)*(gravity)*(velocity)*(3.15 E7 sec/yr)*(height)$^2$ |
| Shore length = | 41000 m (estimated from Rand-McNally map) |
| Density of water = | 1.025E3 kg/m3 |
| Gravity constant = | 9.80 m/sec2 |
| Velocity = | (gravity constant * depth)^1/2 assume depth of gauge equals 3 m (9.80 m/sec2 *3m)^1/2 = 5.4 m/sec |
| Height = | 0.64 m (St. Lucie Estuary Management Plan, Table II.G.1) |
| Annual energy = | 3.59 E15 J/yr |
| Transformity= | 30550 sej/J (Odum, 1995) |

6. STREAMS

ORGANIC MATTER

Annual energy = (organic matter conc.)*(volume of flow)*(4 kcal/g)*(4186 J/kcal)

| | Organic matter conc. | Flow | Total organic matter |
|---|---|---|---|
| Canals 23,24 | avg. 18.75 mg/L | 4.32E8 m3/yr | 8.1E9 g/yr |
| Okee - Canal 44 | 22.5 mg/L | 1.34 E8 m3/yr | 3.0 E9 g/yr |
| Loxahatchee | 37.5 mg/L | 3.57 E7 m3/yr | 1.34 E9 g/yr |
| | | Total | 1.25 E10 g/yr |

(from STORET, 1993)

Annual energy = 2.1 E14 J/yr
Transformity= 2.98E6 sej/J (Odum, 1995)

CHEMICAL POTENTIAL ENERGY

Annual energy = (Volume of flow)*(density of water)*(G)
where G is Gibbs free energy relative to seawater

$$G = \frac{(8.33\ J/mol/deg)*(300\ deg\ C)}{(18g/mol)} \ln \frac{(1E6 - S)ppm}{(965{,}000)ppm} J/g$$

S = dissolved solids in ppm

| | Dissolved solids (ppm) | Gibbs free energy | Flow | Energy |
|---|---|---|---|---|
| Canals 23,24 | 1027.5 | 4.80 J/g | 4.32 E8 m3/yr | 2.08 E15 J/yr |
| Okee - Canal 44 | 440 | 4.89 J/g | 1.34 E8 m3/yr | 6.8 E14 J/yr |
| Loxahatchee | 923 | 4.82 J/g | 3.57 E7 m3/yr | 1.72 E14 J/yr |
| | (from STORET) | | Total | 2.9 E15 J/yr |

Dissolved solids determined by multipying conductivity measurements (Storet) by 0.65
Transformity= 48460 sej/J (Odum, 1995)

GEOPOTENTIAL

Annual energy = (flow volume)*(density)*(height canal entry)*(gravity constant)
Flow volume = 1.89 E9 m3/yr (STORET, 1993)
Density = 1E3kg/m3
Height of canals = 6m (Quackenbos, 1993)
Estimated change in height of rivers= 6m
Gravity constant = 9.8m/sec2
Annual energy = 1.11 E14 J/yr
Transformity= 27806 sej/J (Odum, 1995)

7. GEOLOGIC UPLIFT

Annual energy= (area)(uplift rate)*(density)*(0.5)*(uplift)*(gravity)
Area= 2.29 E9 m2 (Fla. Statistical Abstracts, 1993)
Uplift rate=
Density= 1500 kg/m3 (estimate)
Uplift=
Gravity= 9.8 m/sec2
Annual energy=
Transformity= 3.22E10 sej/J

8. PHOSPHOROUS IN RAIN

| | |
|---|---|
| Annual amount= | (area)*(rainfall rate)*(average concentration) |
| Area= | 2.29 E9 m2 |
| Rainfall rate= | 1.27 m/yr (~50 in. from Fla. Statistical Abstract, 1994) |
| Concentration= | 0.167 g/m3 Total P (Brezonik, 1969 in Allen and Kramer eds. Nutrients in Natural Waters p. 12) |
| Annual amount= | 4.86 E8 g/yr |
| Transformity= | 4.21E9 sej/g (Odum, 1995) Needs confirmation |

9. NITROGEN IN RAIN

| | |
|---|---|
| Annual amount= | (area)*(rainfall rate)*(average concentration) |
| Area= | 2.29 E9 m2 |
| Rainfall rate= | 1.27 m/yr (~50 in. from Fla. Statistical Abstract, 1994) |
| Concentration= | 0.129 g/m3 NH3-N (Brezonik, 1969 in Allen and Kramer eds. Nutrients in Natural Waters p. 12) |
| Annual amount= | 3.75 E8 g/yr |
| Transformity= | 4.21E9 sej/g (Odum, 1995) Needs confirmation |

## ECONOMIC INPUTS

10. CAPITAL INVESTMENTS AND PURCHASES
1988 Acreage of foreign owned farmland: 26,345 acres, which equals 7.95% of total
1990 Acreage of foreign owned farmland: 31,767 acres, which equals 11.43% of total
(Fla. S.A. 1992, Table 9.45)

| | |
|---|---|
| Price of farmland: | Estimated as \$3000/acre |
| Capital investment: | \$7.7 E6/yr |
| Transformity: | 1.37 E12 sej/\$ |

11. FEDERAL TRANSFER PAYMENTS

| | |
|---|---|
| Total 1992= | Direct expenditures + grants + Wages and Salaries + Transfer payments \$ 819,803,000 (Fla. Stat. Abstracts, 1994) |
| Transformity= | 1.37 E12 sej\$ |

12. IMPORTED FERTILIZERS
1992- Commercial fertilizer used on a total of 31014 ha
Average applicatin rate = 50 kg/ha for N, and 20 kg/ha for $P_2O_5$ (Mudahar, M. and Hignett, T.P.)
Totals= 1.55 E9 g N; and (6.2 E8 g $P_2O_5$)*(62/142) = 2.7 E8 g P
(1992 Fla. Census of Agriculture Table 10)

13. IMPORTED PESTICIDES
1992- Commercial pesticide used on a total of 1.93E8 m2
Application rate: 1.5 g/m2 (estimate)
Total use:2.9E8 g/yr

14. IMMIGRANTS, RETIREES
Annual energy: (population change)*(2000 kcal/day)*(4186 J/kcal)*(365 days/yr)

| | |
|---|---|
| Population change 1991-92: | 2183 people |
| Total energy: | 6.67 E12 J/yr |
| Transformity: | 7.33 E7 |

15. NATURAL GAS

| | |
|---|---|
| Total annual use: | 8.07 E6 m3 (Fla. Statistical Abstracts, 1993), at 9077 kcal/m3 |
| Annual energy: | (8.07 E6 m3)*(9077 kcal/m3)*(4186 J/kcal) = 3.07 E14 J/yr |

16. MOTOR FUELS

| | |
|---|---|
| Gallons sold (1991): | 4.9321 E7 gallons of gasoline (Fla. Statistical Abstracts, 1993)<br>5.466 E6 gallons of diesel (Fla. Statistical Abstracts, 1993) |
| Energy: | (4.9321 E7 gal/yr)*(124000 Btu/gal)*(1055 J/Btu) = 6.45 E15 J/yr<br>(5.466 E6 gal/yr)*(1 bbl/ 42 gal)*(5.825 E6 Btu/bbl)*(1055 J/Btu) = 8 E14 J/yr |
| Total: | 6.45 E15 + 8 E14 = 7.25 E15 J/yr |

17. ELECTRICITY

| | |
|---|---|
| Kilowatt hours/capita: | 10,000 kWh/capita/year (est. from data in Fla. Statistical Abstracts 1991, Table 15.27) |
| Population: | 102,000 |
| Total electricity use: | (10000 kWh/cap/yr)*(102,000 pop.)*(3.6 E6 J/kWh) 3.67 E15 J/yr |

18. GOODS AND SERVICES

| | |
|---|---|
| Income density per square mile: | 2 E6 $/sq. mile |
| Money crossing boundary: | 2 E5 $/sq. mile (after Brown, M.T. 1980; in Odum, H.T. Environmental Accounting, 1995) |
| Transformity: | 1.37 E12 sej/$ |

19. INFORMATION (TV)

| | |
|---|---|
| Number of television sets: | 1 set/2 people = 51000 sets |
| Transformity: | 7.1 E14 sej/set-yr (Brown, M., Woithe, R. et al. 1993) |

20. TOURISTS

| | |
|---|---|
| Annual energy = | (# of visitors)*(avg duration of visit)*(energy of metabolism/day) |
| Total visitors = (Martin County) | ~25,000/yr (Fla. Statistical Abstracts, 1994) |
| Avg duration/stay = | 6 days |
| Energy of metabolism = | 2500 kcal/day |
| Annual energy/yr = | (25000 people)*(6 days)*(2000 kcal/day)*(4186 J/kcal) = 1.256 E12 J/yr |
| Transformity= | 7.33E7 sej/J (Odum, 1995) |

21. MONEY FROM TOURISTS

| | |
|---|---|
| Total sales tax prod. tourism industry = | $ 11.6 E6 (Fla. Statistical Abstracts, 1994) |
| Sales tax rate = | 6% |
| Total expenditures = | $11.6 E6/.06 = $1.93 E8 |
| Transformity= | 1.37E12 sej/$ (Odum, 1995) |

22. MONEY FROM EXPORTS

| | |
|---|---|
| Agriculture: | Cash and marketings and "other" incomes: $ 1.92 E8 (Fl. S.A. Table 9.22) |
| Manufacturing: | Value of shipments: $3.078 E8 (Fl. S.A. Table 12.06)<br>*(manufact. may include double counting of shipments between producers) |
| Total: | 5.0 E8 $/yr |
| Transformity= | 1.37 E12 sej/$ (Odum, 1995) |

23. FINANCIAL SUPPORT FROM STATE OF FLORIDA

| | |
|---|---|
| Total state aid: | $9,941,000 (Fl. S.A. Table 23.48) |
| Transformity= | 1.37E12 sej/$ (Odum, 1995) |

## CONSUMPTION OF ENVIRONMENTAL RESOURCES

24. SOILS

| | |
|---|---|
| Organic matter: | Consumption equals runoff plus oxidation rate due to draining of wetlands and agriculture. Runoff: 4.16 E10 g/yr<br>Oxidation rate: 1 cm/yr ; bulk density 0.15 g/cm3; organic content 1/2; estimated area affected = area of sugarcane production (13,000 acres) therefore total loss to oxidation: 3.95 E10 g/yr, and total consumption equals: 8.11 E10 g/yr |
| Annual energy: | (8.11 E10 g /yr)*(4.5 kcal/g)*(4186 J/kcal)= 1.53 E15 J/yr |

25. GROUNDWATER

Annual energy= (Volume of flow)*(density of water)*(G)
where G is Gibbs Free Energy relative to seawater

$$G = \frac{(8.33\ J/mol/deg)*(300\ deg\ C)}{(18g/mol)} \ln \frac{(1E6 - S)ppm}{(965{,}000)ppm}\ J/g,$$ S = dissolved solids in ppm

G= 4.95 J/g

| | |
|---|---|
| Volume of flow= | 55.71 mgd; (1990, Fla. S.A. TABLE 8.41) which equals 7.7E7 m3/yr |
| Density = | (1E6 g/m3) |
| Energy= | 3.8 E14 J/yr |
| Transformity= | 41000 (Odum, 1995) |

26. SURFACE WATER

Annual energy= (Volume of flow)*(density of water)*(G)
where G is Gibbs Free Energy relative to seawater

$$G = \frac{(8.33\ J/mol/deg)*(300\ deg\ C)}{(18g/mol)} \ln \frac{(1E6 - S)ppm}{(965{,}000)ppm}\ J/g,$$ S = dissolved solids in ppm

| | |
|---|---|
| Volume of flow= | 153.9 mgd; (1990, Fla. S.A. TABLE 8.41) which equals 2.13E8 m3/yr |
| Density = | (100770 g/m3) weighted avergae taken from surface water data |
| Energy= | 1.03 E15 J/yr |
| Transformity= | 255242 (Odum, 1995) |

27. PHOSPHOROUS IN SOILS

| | |
|---|---|
| Total P in soils: | Estimate 0.1 g P/100g soil (Brady, 1990); average density of soils 1.5 E3 kg/m3 volume of soils in Martin county to 2m: 2.05 E9 m2 land and water area* 2 m = 4.09 E9 m3 therefore, total P = (0.1/100)*(1.5 E6 g/m3)*(4.09 E9 m3) = 6.14 E12 g |
| Mass balance: | Additions - withdrawals = $\Delta$storage |
| Additions: | Fertilizer: 2.7 E8 g/yr; precipitation: 4.34 E8 g/yr using land and water area not including continental shelf |
| Withdrawals: | Runoff to estuary: 3.17 E8 g/yr; Uptake rate: estimated as 4 gP/m2/yr multiplied by land area = 6 E9 g/yr |
| $\Delta$Storage: | 5.6 E9 g/yr |

28. LIMESTONE

| | |
|---|---|
| Average concentration of groundwater: | 100 mg/L Ca |
| Groundwater withdrawals: | 7.7E7 m3/yr |
| Annual consumption | (100 g/m3)*(7.7E7 m3)*(100 g/mol CaCO3/40 g/mol Ca) = 1.93 E10 g/yr |

## IMPORTANT INTERIOR FLOWS

29. WATER RUNOFF TO ESTUARY

Annual energy = (Volume of flow)*(density of water)*(G)
where G is Gibbs free energy relative to seawater

$$G = \frac{(8.33\ \text{J/mol/deg})*(300\ \text{deg C})}{(18\text{g/mol})} \ln \frac{(1E6 - S)\text{ppm}}{(965{,}000)\text{ppm}}\ \text{J/g}$$

S = dissolved solids in ppm

Density = (1E6 g/m3)

| | Dissolved solids | Gibbs free energy | Flow | Energy |
|---|---|---|---|---|
| Canals 23,24 | avg. 1027.5 | 4.80 J/g | 4.32E8 m3/yr | 2.08 E15 J/yr |
| North fork | 1091.4 | 4.79 J/g | 3.144E8 m3/yr | 1.50 E15 J/yr |
| South fork | 855.4 | 4.83 J/g | 3.144E8 m3/yr | 1.52 E15 J/yr |
| Canal 44 | 440 | 4.89 J/g | 5.93E8 m3/yr | 2.9 E15 J/yr |
| | (from STORET) | | Total | 7.99 E15 J/yr |

30. ORGANIC MATTER RUNOFF TO ESTUARY

Annual energy = (organic matter conc.)*(flow rate)*(4 kcal/g)*(4186 J/kcal)

| | Organic matter conc. | Flow | Total organic matter |
|---|---|---|---|
| Canals 23,24 | avg. 18.75 mg/L | 4.32E8 m3/yr | 8.1E9 g/yr |
| North Fork | 15.0 mg/L | 3.144E8 m3/yr | 4.72E9 g/yr |
| South Fork | 26.3 mg/L | 3.144E8 m3/yr | 8.3E9 g/yr |
| Canal 44 | 22.5 mg/L | 5.93E8 m3/yr | 1.34E10 g/yr |
| | (from STORET, 1993) | Total | 3.45 E10 g/yr |

Annual energy = 5.78 E14 J/yr
Transformity= 2.98E6 sej/J (Odum, 1995)

31. PHOSPHOROUS RUNOFF TO ESTUARY
Annual amount = (concentration)*(flow rate)

| | Phosphorous conc. | Flow | Total Phosphorous |
|---|---|---|---|
| Canals 23,24 | 0.19 mg/L | 4.32E8 m3/yr | 8.21 E7 g/yr |
| North Fork | 0.23 mg/L | 3.144E8 m3/yr | 7.23 E7 g/yr |
| South Fork | 0.19 mg/L | 3.144E8 m3/yr | 5.97 E7 g/yr |
| Canal 44 | 0.13 mg/L | 5.93E8 m3/yr | 7.73 E7 g/yr |
| | (from STORET, 1993) | Total | 3.17 E8 g/yr |

Transformity = 6.88 E9

32. HEAVY METAL RUNOFF TO ESTUARY

| | |
|---|---|
| Average concentration in estuary sediment: | 25 mg/kg soil (SFWMD pub. # 88-10, Table 2); |
| Density : | 1.5 E3 kg/m3 |
| Volume of sediment to 1m: | 2.206 E7 m3 |
| Total metals: | (25 mg/kg)*(1.5 E3 kg/m3)*(2.206 E7 m3)*(1 g/1000mg) = 8.27 E8 g |
| Estimated 75 yrs impact: | (8.27 E8 g)/(75 yrs) = 1.1 E7 g/yr |

33. PESTICIDE RUNOFF TO ESTUARY

| | |
|---|---|
| Average concentration in estuary sediment: | 8.4 μg/kg soil (SFWMD pub. # 88-10, Table 4); |
| Density : | 1.5 E3 kg/m3 |
| Volume of sediment to 1m: | 2.206 E7 m3 |
| Total pesticides: | (8.4 μg/kg)*(1.5 E3 kg/m3)*(2.206 E7 m3)*(1 g/1E6μg) = 8.27 E8 g |
| Estimated 75 yrs impact: | (2.78 E5 g)/(75 yrs) = 3707 g/yr |

34. INORGANIC SOLIDS TO ESTUARY

| | |
|---|---|
| Canal 23: | 1.49E12 g/yr (estimate based on Storet data) |
| Canal 24: | 2.98E12 g/yr (estimate based on Storet data) |
| Canal 44: | 3.33E11 g/yr (estimate based on Storet data) |
| North and South Fork: | 3E11 g/yr (estimate) |

35. EVAPOTRANSPIRATION FROM LAND
Estimated as approximately 1.1m/yr (90% of precipitation amount)

| | |
|---|---|
| Land Area: | 1.51 E9 m2 |
| Total: | (1.73 E9 m3/yr)*(1 E3 kg/m3)*(1000 g/kg) = 1.73 E15g |
| Energy: | (1.73 E15g)*(4.95 J/g) = 8.54 E15 J/yr |
| Transformity: | Determined by adding Solar Emergy necessary for vaporization: 13488 sej/g and 90% of the total Emergy of rainfall in Martin County, then dividing by chemical energy of evaporated water. |

Given (58 kcal/mol for vaporization)/(18 g/mol)*(1E6 g/m3)*(1.51E9 m2)*(1.1 m/yr)*(1 sej/J) = 5.35 E18 sej
(.9)*(2.62 E20 sej) = 2.36 E20 sej
(5.35 E18 + 236 E18)/(8.54 E15 J) = 28261 sej/J

36 EVAPORATION FROM INLAND WATERS AND OFFSHORE
Evaporation rate: 1.14 m/yr (Quackenbos, 1993)
Inland water

| | |
|---|---|
| Area: | 5.36 E8 m2 |
| Total: | 6.11 E8 m3/yr |
| Energy: | (6.11 E8 m3)*(1E3 kg/m3)*(1000 g/kg)*(4.95 J/g) = 3.02 E15 J |
| Transformity: | 28261 sej/J |

37. GROUNDWATER RECHARGE AND INJECTION

| | |
|---|---|
| Total recharge: | Estimated as 2% of rainfall over inland areas<br>5.27 E7 m3 |
| Free energy: | 4.95 J/g |
| Transformity: | 1.1 E5 sej/J |

38. EXCHANGES WITH LAKE OKEECHOBEE
1993 Net exchange
Lake Okeechobee to

| | |
|---|---|
| Canal 44: | 1.34 E8 m3 |
| Free energy: | 4.95 J/g |
| Transformity: | 48460 |

39. SAND PUMPED/DEPOSITED ON SHORE

| | |
|---|---|
| Total volume: | from St. Luice Estuary Management Plan. 102,859 yd3 beach volume change at N. end of Jupiter Island and sum of beach renourishment program from town of Jupiter Island (Table II.E.1); 18050 yd3 (Table II.E.3;Total /5) and 22496 yd3 (Table II.E.3;Total /7) from dredge records along St. Lucie Inlet North Channel Bank and Interior inlet channels near sailfish point |
| Density: | Estimate 1.95 E6 g/yd3 (1.5 E3 kg/m3) |
| Total: | (143,405 yd3)*(1.95 E6 g/yd3) = 2.8 E11 g/yr |

40. NUTRIENT UPTAKE BY WETLANDS

| | |
|---|---|
| Annual uptake: | (Wetland area)*(Uptake rate) |
| Wetland Area: | Estimate as 1/4 of total land area is wetland, therefore 3.775 E8 m2 |
| Uptake rate: | Est. 20g N/m2/yr, and 5.3 gP/m2/yr for freshwater marshes (Mitsch and Gosselink, 1987 p. 362 and 363) |
| Total withdrawals: | 7.55 E9 g N/yr, and 2.0 E9 g P/yr |
| Transformity: | |

41. FRESHWATER DISCHARGE THROUGH INLET
(assume equal to inputs, note 31)
Annual energy = (Volume of flow)*(density of water)*(G)
where G is Gibbs free energy relative to seawater

$$G = \frac{(8.33\ J/mol/deg)*(300\ deg\ C)}{(18g/mol)} \ln \frac{(1E6 - S)ppm}{(965{,}000)ppm} J/g$$, S = dissolved solids in ppm

Density = (1E6 g/m3)
Transformity= 48460 sej/J (Odum, 1995)

| | Dissolved solids | Gibbs free energy | Flow | Energy |
|---|---|---|---|---|
| Canals 23,24 | avg. 1027.5 | 4.80 J/g | 4.32E8 m3/yr | 2.08 E15 J/yr |
| North fork | 1091.4 | 4.79 J/g | 3.144E8 m3/yr | 1.50 E15 J/yr |
| South fork | 855.4 | 4.83 J/g | 3.144E8 m3/yr | 1.56 E15 J/yr |
| Canal 44 | 440 | 4.89 J/g | 5.93E8 m3/yr | 2.9 E15 J/yr |
| | (from STORET) | | Total | 8.04 E15 J/yr |

42. FISH LANDINGS
Annual energy = (Biomass)*(5.4 kcal/g)*(4186 J/kcal)
Total landings = 1,753,322 lbs (Fla. Statistical Abstracts, 1994)
Annual energy = 1.8E13 J/yr
Transformity= 2E6 sej/J (Odum, 1995).

43. BOAT TRAFFIC
# registrered boats: 12080 pleasure, 534 commercial
Fuel use: 500 U.S. gal./yr boat (estimate)
Total energy use: (6.307 E6 gal/yr)*(124000 Btu/gal)*(1054 J/Btu) = 7.9 E14 J
Transformity: 66000 sej/J (Odum, 1995).

## EXPORTS AND OUTFLOWS

44. MANUFACTURED PRODUCTS

45. AGRICULTURAL PRODUCTS
1991-92 citrus production: 13644000 boxes (Fla. S.A. Table 9.2)
sugarcane: 4.13 E11g (Fla. S.A. Table 9.2 )
milk: 1.9 E10 g (Fla. S.A. Table )
vegetables: 5.05 E9 g/yr, based on an acreage and estimated yield of 500 g/m2/yr exportable goods (1992 Census of Ag. Table 1)
cattle and calves sold: 14349 * 500 lbs/cow (est) = 3.25 E9 g (1992 Census of Ag. Table 1)
hogs and pigs sold: 414 * 200lbs/pig (est) = 3.76 E7 g (1992 Census of Ag. Table 1)
hay: 6.8 E9 g (1992 Census of Ag. Table 1)
Total Energy: 2.6 E16 J/yr
Transformity: 2 E5 sej/J

46. EXCHANGES BETWEEN SHELF AND OPEN SEA
use salinity gradients

47. STATE TAXES

| | |
|---|---|
| Total: | $77,080,000 (Fla. S.A. Table 23.45) |
| Transformity: | 1.37E12 sej/$ |

48. FEDERAL TAXES

| | |
|---|---|
| Total Earnings 1993: | $1,153,776,000 (Fla. S.A. Table 5.26) |
| Estimated federal tax rate: | 20% |
| Total fed. taxes: | $2.88 E8 |
| Transformity: | 1.37E12 sej/$ |

49. MONEY PAID FOR GOODS AND SERVICES

| | |
|---|---|
| Income density/sq. mile: | 2 E6$/ sq. mile |
| Money crossing boundary: | 2E5 $/sq.mile (aftr Brown, M.T. 1980; in Odum, H.T. Environmental Accounting, 1995) |
| Transformity: | 1.37 E12 sej/$ |

50. MONEY PAID FOR ELECTRICITY

| | |
|---|---|
| Total use: | 1.02 E9 kWh/yr |
| Price: | $45/500 kWh (Fla. S.A. Table 24.76) |
| Money paid: | $9.18 E7 |
| Transformity: | 1.37E12 sej/$ |

51. MONEY PAID FOR GAS, FUELS

| | |
|---|---|
| Total use gasoline/diesel: | 5.48 E7 gal/yr |
| Avg. Price: | $1.20/gal (Fla. S.A. Table 24.76) |
| Money paid gas/diesel: | $6.57 E7 |
| Transformity: | 1.37E12 sej/$ |

| | |
|---|---|
| Total use natural gas: | 3.07 E14 J/yr = 2.9E11 Btu |
| Avg. Price: | $36.5/40 therms (Fla. S.A. Table 24.76) |
| Conversion: | 1E5 Btu/therm; |
| Money paid gas/diesel: | $2.66 E6 |
| Transformity: | 1.37E12 sej/yr |

Appendix Table A3. Annual EMERGY flows for the St. Lucie Estuary

| Note Item | Raw Units (J, $, or g) | | Trans-formity (sej/unit) | Solar EMERGY (E19 sej) |
|---|---|---|---|---|
| RENEWABLE RESOURCES | | | | |
| 1. Sunlight | 1.31E+17 | J/yr | 1 | 0.01 |
| 2. Wind, kinetic | 2.21E+15 | J/yr | 1496 | 0.33 |
| 3. Rain, chemical | 1.38E+14 | J/yr | 18199 | 0.25 |
| 4. Tidal Energy | 3.80E+13 | J/yr | 16842 | 0.06 |
| 5. Waves at inlet | 6.17E+13 | J/yr | 30550 | 0.19 |
| INDIGENOUS RENEWABLE ENERGY | | | | |
| 6. Phytoplankton production | 3.68E+14 | J/yr | 9.00E+03 | 0.33 |
| 7. Seagrass production | 1.85E+12 | J/yr | 9.00E+03 | 1.67E-03 |
| 8. Fish production | 2.00E+13 | J/yr | 2.00E+06 | 4.00 |
| NATURAL INPUTS OF STORED MATERIALS | | | | |
| 9. Chemical energy/freshwater input | | | | |
| Canals 23, 24 | 2.08E+15 | J/yr | 4.85E+04 | 10.08 |
| North Fork, St. Lucie River | 1.50E+15 | J/yr | 4.85E+04 | 7.27 |
| South Fork, St. Lucie River | 1.52E+15 | J/yr | 4.85E+04 | 7.35 |
| Canal 44 (Okee. Waterway) | 2.90E+15 | J/yr | 4.85E+04 | 14.05 |
| 10. Organic matter/freshwater inputs | | | | |
| Canals 23, 24 | 1.56E+14 | J/yr | 2.98E+06 | 46.49 |
| North Fork, St. Lucie River | 7.90E+13 | J/yr | 2.98E+06 | 23.54 |
| South Fork, St. Lucie River | 1.39E+14 | J/yr | 2.98E+06 | 41.42 |
| Canal 44 (Okee. Waterway) | 2.24E+14 | J/yr | 2.98E+06 | 66.75 |
| 11. Geopotential/freshwater inputs | | | | |
| Canals 23, 24 | 2.54E+13 | J/yr | 2.78E+04 | 0.07 |
| North Fork, St. Lucie River | 1.85E+13 | J/yr | 2.78E+04 | 0.05 |
| South Fork, St. Lucie River | 1.85E+13 | J/yr | 2.78E+04 | 0.05 |
| Canal 44 (Okee. Waterway) | 4.70E+13 | J/yr | 2.78E+04 | 0.13 |
| STORED RESOURCES | | | | |
| 12. Organic matter/muck | 2.50E+17 | J | 1.10E+04 | 275.00 |
| 13. Property value | 9.45E+07 | $ | 1.37E+12 | 12.95 |
| IMPORTS | | | | |
| 14. Tourists | 3.23E+09 | J/yr | 7.33E+07 | 0.02 |
| 15. Money from tourists | 1.45E+08 | $ | 1.37E+12 | 19.87 |

Appendix Table A3 continued

| | | | | |
|---|---|---|---|---|
| **Goods and fuels** | | | | |
| 16. Tourism industry/electricity | 1.01E+15 | J/yr | 2.00E+05 | 20.20 |
| 17. Boating industry/gasoline | 8.24E+14 | J/yr | 6.60E+04 | 5.44 |
| 18. Dredging industry | 2.37E+12 | J/yr | 6.60E+04 | 0.02 |
| **Services** | | | | |
| 19. Tourism industry | 1.13E+08 | $ | 1.37E+12 | 15.54 |
| 20. Boating industry | 1.23E+05 | $ | 1.37E+12 | 0.02 |
| 21. Dredging industry | 6.16E+05 | $ | 1.37E+12 | 0.08 |
| EXPORTS | | | | |
| 22. Fish landings | 1.80E+13 | J/yr | 2.00E+06 | 3.60 |
| 23. Organic material/through inlet | 5.98E+14 | J/yr | 2.98E+06 | 178.20 |

** EMERGY VALUES FOR ST. LUCIE ESTUARY

1. SUNLIGHT ABSORBED AT SURFACE:

| | |
|---|---|
| Annual energy= | ((area)*(insolation)*(1-albedo)) |
| Area= | 2.206E7 m2 (Stuart Comp. Growth Plan, 1990) |
| Insolation = | 6.90E9 J/m2/yr (Vishner, 1954) |
| Albedo= | 0.14 (% given as decimal) (Odum, 1987) |
| Annual energy= | 1.31E17 J/yr |
| Transformity= | 1 sej/J by definition (Odum, 1995) |

2. WIND ABSORBED AT SURFACE:

| | |
|---|---|
| Annual energy= | 1E8 J/m2/yr (estimated from Woithe, 1992 |
| Area = | 2.206E7 m2 (estuary) |
| Annual energy = | 2.206E15 J/yr |
| Transformity= | 620 sej/J (Odum, 1995) |

3. RAIN, CHEMICAL:

| | |
|---|---|
| Annual energy = | (area)*(rainfall)*(Gibbs free energy) |
| Area = | 2.206E7 m2 |
| Rainfall = | 1.27 m/yr (~50 in. from Fla. Statistical Abstract, 1994) |
| Gibbs energy = | 4.94 J/g (from Odum, 1995) |
| Annual energy = | 1.38E14 J/yr |
| Transformity= | 18199 sej/J (Odum, 1995) |

4. TIDAL ENERGY:

| | |
|---|---|
| Annual energy = | (area elevated)*(0.5)*(# tides/yr)*(height)$^2$*(density)*(gravity constant) |
| Area elevated = | 2.206E7 m2 |
| # tides /yr = | 706 tides/yr (semi-diurnal cycle) |
| Height = | 0.7 m (from NOAA tide tables) |
| Density = | 1.025 E3 kg/m3 |
| Gravity constant = | 9.8 m/sec2 |
| Annual energy = | 3.8 E13 J/yr |
| Transformity= | 16842 sej/J (Odum, 1995) |

5. WAVE ENERGY AT INLET:

| | |
|---|---|
| Annual energy = | (shore length)*(1/8)*(density)*(gravity)*(velocity)*<br>(3.15 E7 sec/yr)* (height)$^2$ |
| Shore length = | 800 m = est.width of inlet channel (from City of Stuart Comp.Plan) |
| Density of water = | 1.025E3 kg/m3 |
| Gravity constant = | 9.80 m/sec2 |
| Velocity = | (gravity constant * depth)^1/2 assume avg. depth equals 300 cm at inlet<br>(9.80 m/sec2 *3m)^1/2 = 5.42 m/sec |
| Height = | 0.6 m (estimated) |
| Annual energy = | 6.17 E13 J/yr |
| Transformity= | 30550 sej/J (Odum, 1995) |

6. PHYTOPLANKTON PRODUCTION:

| | |
|---|---|
| Annual energy = | (biomass production rate)*(4 kcal/g)*(4186 J/kcal)*(area) |
| Area = | 2.206E7 m2 |
| Prod. rate = | 292 g/m2/yr ; estimate of average (Day et al. 1989, assumes similar to Waccassassa River, FL) |
| Annual energy = | 1.08 E14 J/yr |
| Transformity= | 9E3 sej/J (Odum, 1995) |

7a. CURRENT SEAGRASS PRODUCTION

| | |
|---|---|
| Annual energy = | (biomass production rate)*(4 kcal/g)*(4186 J/kcal)*(area) |
| Area = | 2.206E5 m2 (estimate 1/100 of total estuary area) |
| Prod. rate = | 500 g/m2/yr ; estimate of average (Day et al. 1989) |
| Annual energy = | 1.85 E12 J/yr |
| Transformity= | 9E3 sej/J (Odum, 1995) |

7b. CURRENT INTERTIDAL MARSHES AND MANGROVE PRODUCTION

| | |
|---|---|
| Annual energy = | (gross production rate)*(4.2 Kcal/g)*(4186 J/Kcal)*(area) |
| Area = | 1.47 E7 m2 (National Wetlands Inventory) |
| Gross Production Rate = | 5.43 E3 g/m2/yr (Day et al., 1989, assuming 1/3 riverine, 1/3 basin, and 1/3 scrub mangroves) |
| Annual energy = | 1.40 E15 |
| Transformity = | 4.28 E3 sej/J (Odum, 1995, in press) assuming same as for <u>Spartina alterniflora</u>) |

8. FISH PRODUCTION

| | |
|---|---|
| Annual energy = | (biomass production rate)*(5.4 kcal/g)*(4186 J/kcal)*(area) |
| Area = | 2.206E7 m2 |
| Prod. rate = | 50 g/m2/yr ; estimate of average (Day et al. 1989 |
| Annual energy = | 2.0 E13 J/yr |
| Transformity= | 2E6 sej/J (Odum, 1995) |

## NATURAL INPUTS OF STORED MATERIALS

9. WATER RUNOFF TO ESTUARY

Annual energy = (Volume of flow)*(density of water)*(G)
where G is Gibbs free energy relative to seawater

$$G = \frac{(8.33\ \text{J/mol/deg})*(300\ \text{deg C})}{(18\text{g/mol})} \ln \frac{(1E6 - S)\text{ppm}}{(965{,}000)\text{ppm}}\ \text{J/g},\quad S = \text{dissolved solids in ppm}$$

Density = (1E6 g/m3)

| | Dissolved solids | Gibbs free energy | Flow | Energy |
|---|---|---|---|---|
| Canals 23,24 | avg. 1027.5 | 4.80 J/g | 4.32E8 m3/yr | 2.08 E15 J/yr |
| North fork | 1091.4 | 4.79 J/g | 3.144E8 m3/yr | 1.50 E15 J/yr |
| South fork | 855.4 | 4.83 J/g | 3.144E8 m3/yr | 1.52 E15 J/yr |
| Canal 44 | 440 | 4.89 J/g | 5.93E8 m3/yr | 2.9 E15 J/yr |
| | (from STORET) | | Total | 7.99 E15 J/yr |

**10.** ORGANIC MATTER RUNOFF TO ESTUARY

Annual energy = (organic matter conc.)*(flow rate)*(4 kcal/g)*(4186 J/kcal)

| | Organic matter conc. | Flow | Total organic matter |
|---|---|---|---|
| Canals 23,24 | avg. 18.75 mg/L | 4.32E8 m3/yr | 8.1E9 g/yr |
| North Fork | 15.0 mg/L | 3.144E8 m3/yr | 4.72E9 g/yr |
| South Fork | 26.3 mg/L | 3.144E8 m3/yr | 8.3E9 g/yr |
| Canal 44 | 22.5 mg/L | 5.93E8 m3/yr | 1.34E10 g/yr |
| | (from STORET, 1993) | Total | 3.45 E10 g/yr |

Annual energy = 5.78 E14 J/yr
Transformity= 2.98E6 sej/J (Odum, 1995)

**11.** GEOPOTENTIAL IN INCOMING WATER

Annual energy = (flow volume)*(density)*(height canal entry)*(gravity constant)
Flow volume = Canals 23, 24, 44: 1.21E9 m3/yr (STORET, 1993)
Density = 1E3kg/m3
Height of canal = 6m (Quackenbos, 1993)
Gravity constant = 9.8m/sec2
Annual energy = 7.1 E13 J/yr
Transformity= 27806 sej/J (Odum, 1995)

## STORED RESOURCES

**12.** ORGANIC MATTER IN SEDIMENTS

Total energy = (Volume of material)*(density)*(organic fraction)*(4 kcal/g)*(4186 J/kcal)
Volume of sediment = For 1m depth over 2.206 E7 m2 = 2.206E7 m3
Density = 1.5E6 g/m3 (estimate)
Organic fraction = 45% wt/wt (estimate of average based on data from Haunert, 1988)
Total energy = 2.5E17 J
Transformity= 1.1E4 sej/J (Odum, 1995)

**13.** PROPERTY VALUE ($)

Total value = (Shoreline length)*(Value/ft)
Shoreline length = 28.8 km (City of Stuart Comp. Growth Plan, 1991)
converts to 94493 ft
Value/ft = $1000 (estimate)
Total value = ~$ 9.45 E7
Transformity= 1.37 E12 sej/$ (Odum, 1995)

## IMPORTS

**14.** TOURISTS

| | |
|---|---|
| Annual energy = | (# of visitors)*(avg duration of visit)*(energy of metabolism/day) |
| Total visitors = | ~25,000/yr (Fla. Statistical Abstracts, 1994) |
| (Martin County) | Estimate 3/4 related to estuary, therefore 18750 people/yr |
| Avg duration/stay = | 6 days |
| Energy of metabolism = | 2500 kcal/day |
| Annual energy/yr = | (18750 people)*(6 days)*(2500 kcal/day)/(365 days/yr)*(4186 J/kcal) = 3.23 E9 J/yr |
| Transformity= | 7.33E7 sej/J (Odum, 1995) |

**15.** MONEY FROM TOURISTS

| | |
|---|---|
| Total sales tax prod. tourism industry = | $ 11.6 E6 (Fla. Statistical Abstracts, 1994) |
| Sales tax rate = | 6% |
| Total expenditures = | $11.6 E6/.06 = $1.93 E8 |
| For estuary = | estimate 3/4 tourism related to estuary therefore, $ 1.45 E8 |
| Transformity= | 1.37 E12 sej/$ (Odum, 1995) |

**Goods and Fuels:**

**16.** TOURIST INDUSTRY:

| | |
|---|---|
| Average per capita electricity consumption = | ~10,000 KWH/yr (Fla. Statistical Abstracts, 1991) |
| Number of tourists= | ~25,000/yr (Fla. Statistical Abstracts, 1991) |
| Average duration of stay= | 6 days |
| Total electricty= | 2.8E8 KWH/yr |
| Annual energy = | (2.8E8 KWH/yr)*(3.606E6 J/KWH) = 1.10E15 J/yr |
| Transformity= | 2E5 sej/J (Odum, 1995) |

**17.** BOATING INDUSTRY

| | |
|---|---|
| Total registered boats (Martin County) = | Pleasure: 12,080; Commercial : 534 |
| Fuel used = (gal/boat/yr) | 500 U.S. gallons/yr (estimate) |
| Total energy consumption = | (6.307E6 gal/yr)*(124,000 Btu/gal)*(1054 J/BTU) = 8.24 E141J/yr |
| Transformity= | 66000 sej/J (Odum, 1995) |

18. DREDGING INDUSTRY

| | |
|---|---|
| Annual fuel use: | 62,320 L/yr diesel fuel (Bousted and Hanerk) |
| Conversion factors: | 44.8 E6 J/kg; . 85kg/L |
| Total energy: | 2.37E12 J/yr |
| Transformity: | 6.6E4 sej/J |

**Services:**

19. TOURISM INDUSTRY

| | |
|---|---|
| Gross income = | $1.45 E8 (estimate based on sales tax receipts, see note 15) |
| Sales tax receipts = | $11.6 E6 (Fla. Statistical Abstracts, 1994) |
| Real income = | Profit margin : 15% (estimate)<br>(.15)*($1.334E8 gross - sales tax) = 2.001E7 $ |
| Remainder equals money paid for fuels, goods, serv.= | $1.334E8 - 2.001E7 = $1.134E8 |
| Transformity= | 1.37 E12 sej/$ (Odum, 1995) |

20. BOATING INDUSTRY

| | |
|---|---|
| Gross $ from fishing = | $876,660 (estimate based on landings (lbs) and avg. $.50/lb) |
| Profit margin = | 15% (estimate) |
| Money paid for fuels, goods, serv. = | ($876,660) - (.15)*(876,660) = $745,161 |
| Payroll for ship and boat manuf. = | $343,000 (Fla. Statistical Abstracts, 1994)<br>Estimate payroll equals 60% of gross income |
| Gross income = | ($343,000)/(.6) = $571,667; profit margin 15% (estimate) |
| Money paid for fuels, goods, serv. = | ($571667) - (.15)*(571667) = $485,917 |
| Total for Boating Industry (fuels, goods, serv) = | $745,161 + $485,917 = $1,231,078 |
| Transformity= | 1.37 E12 sej/$ (Odum, 1995). |

21. DREDGING INDUSTRY

| | |
|---|---|
| Annual expenditures: | $616,020/yr (Bousted and Hanerk) |
| Transformity= | 1.37 E12 sej/$ (Odum, 1995). |

## EXPORTS

**22.** FISH LANDINGS

| | |
|---|---|
| Annual energy = | (Biomass)*(5.4 kcal/g)*(4186 J/kcal) |
| Total landings = | 1,753,322 lbs (Fla. Statistical Abstracts, 1994) |
| Annual energy = | 1.8E13 J/yr |
| Transformity= | 2E6 sej/J (Odum, 1995). |

**23.** ORGANIC MATERIAL

| | |
|---|---|
| Annual energy = | Estimate as equal to inputs from canals and rivers<br>5.78 E14 J/yr (see note 10) |
| Transformity= | 2.98E6 sej/J (Odum, 1995). |

APPENDIX B

# ESTIMATE OF AMOUNT OF SEAGRASS RETURNING TO THE ST. LUCIE ESTUARY IF CANAL-CAUSED TURBIDITY AND COLOR IS ELIMINATED

by
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12 May 1995

In the Loxahatchee River estuary near Jupiter, Florida (to the south), seagrasses occur between 0 and 0.6 m (2 ft) depth (Mehta et al. 1991). If reduction of turbidity in St. Lucie estuary were to become comparable to that now in the Loxahatchee River, a similar distribution and density of seagrass might be expected. The bathymetric map given in Haunert and Startzman (1985), which excludes the outer estuary (Indian River Lagoon portion), was used to estimate the bottom area between 0 and 0.6 m depth by integrating the area between the shoreline and the 2.1m (7 ft) contour on that map and by linearly interpolating the area between 0 and 0.6 m (29% of the area between 0 and 2.1 m). By this method, approximately 2.85 $km^2$ (700 acres) of the St. Lucie estuary may become suitable for seagrasses. The density of seagrasses in seagrass beds in the Loxahatchee River estuary averages about 165 g $m^{-2}$ (Mehta et al. 1991). If this applies also to a less turbid St. Lucie estuary, 4.7 E8 g of seagrass would be expected in the estuary.

The Loxahatchee River estuary is a small estuary that also receives some canal drainage. It is possible that the canal there creates some turbidity. Hence, Loxahatchee River estuary conditions may underestimate the possible extent and density of seagrasses that might return to the St. Lucie estuary. Both the density and the depth of seagrasses could perhaps be doubled to achieve an upper estimate. This would result in four times the previous estimate or about 18.8 E8 g of seagrass.

Typically seagrass biomass in southeastern Florida turns over perhaps 3 to 4 times per year (Zieman 1982). This can be used to provide a rough estimate of net primary production. Gross production may be double that, assuming that half of gross production is respired by the plants themselves.

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