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Emergy Analysis of Two Watersheds in the Mobile Bay National Estuary Program's Area

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ABSTRACT

Application of emergy accounting techniques was tested to two watersheds in south Alabama to demonstrate the utility of the methodologies for the Mobile Bay National Estuary Program. Using available land-use data and emergy accounting procedures, we have evaluated the renewable and non-renewable emergy signatures for the Dog River watershed located in Mobile County and the Fish River watershed located in Baldwin County. The emergy signatures were evaluated directly from existing landuse, elevation, soil, rainfall and population data using geographic information system software incorporating surface modeling techniques. The derived non-renewable and renewable emergy signatures were compared and evaluated using limited extant materials loading information from the literature. As another comparison, annual empower estimates derived for Florida landuse characteristics were found to be highly correlated to nutrient loading estimates for subwatersheds where available loading characteristics were available. This indicates that empower density estimates derived for similar Florida watersheds can be used as a surrogate for deriving local empower estimates when only limited or outdated information is available. In addition to the emergy calculations, we estimated the economic value of estuarine marsh wetland habitats in the Dog River watershed using emergy procedures and developed emdollar values for each habitat analyzed.

INTRODUCTION

The simultaneous evaluation of economic and environmental benefits in environmental planning are often hampered by the lack of a formal methodology to equate economic worth of man-made structures, public services and assets to the services and assets provided by the environment. In particular, the economic value of natural resources is typically underestimated by classic economic analyses. Because of this it is often difficult to justify the expenditures of large sums of monies for natural resource restoration projects for a perceived small return on investment. A full accounting of ecosystem services and the variable value of these services based on geographic position within the ecosystem construct must be identified if a true accounting of landscape value is to be determined. This accounting of economic values across a wide variety of resources, based on the energy signatures of these landscapes from both man-made and natural energy sources, is achievable using the formal process of Emergy Analysis (Odum, 1996, 1998, 2000). Emergy accounting is particularly well suited for "public works" projects involving environmental restoration, and comparison of land use types especially at the scale of the Mobile Bay National Estuary Program (MBNEP).

Emergy (spelled with an "m") is defined as a measure of the available energy required, directly and indirectly, to make a product or service. The quality of anything is measured by the emergy per unit and thus the real wealth of both man-made and environmental resources is measured directly. It is a way of calculating the value of both natural and man-made items on an equal basis and indicates their true contribution to the human economy. Emergy per unit of money measures real wealth buying power and is used to calculate emdollars, the economic equivalent used to compare ecosystem services.

Emergy flow and storages in a system can be used to evaluate several properties of the system including the basic measures of renewable resource use and non-renewable resource use (Figure 1). From these basic measures, several ratios can be derived to evaluate measures of system efficiency and sustainability. Compilation of renewable and non-renewable emergy signatures in watersheds is an important first step in evaluating energy use within those watersheds.

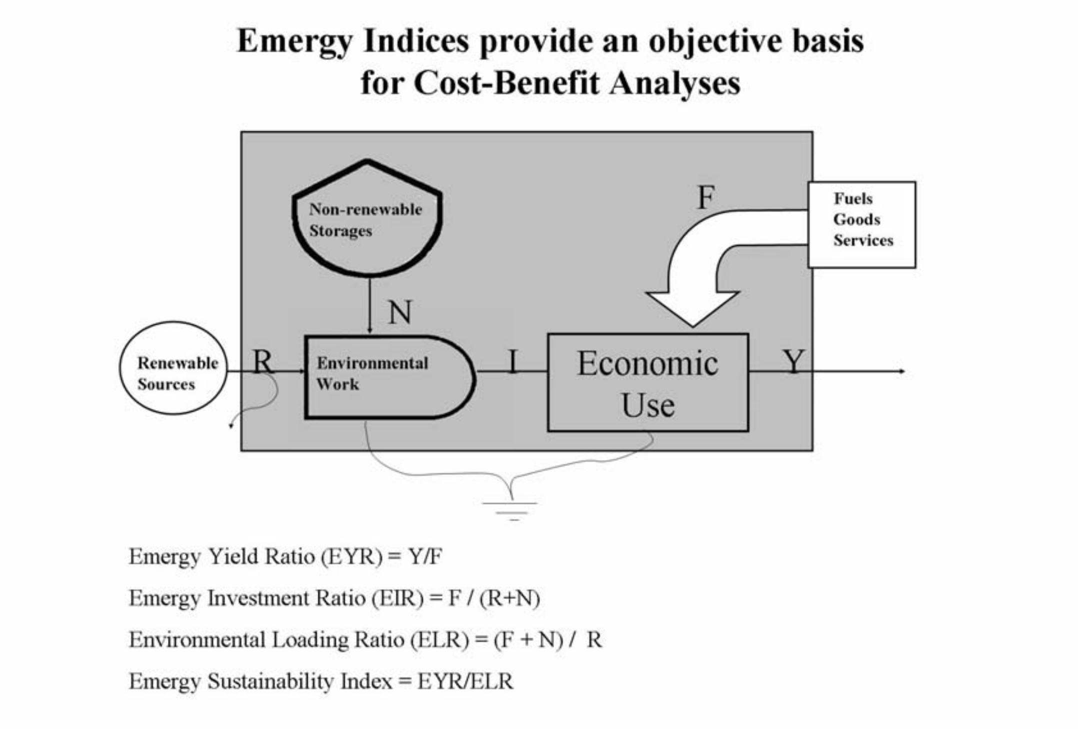

Figure 1. Emergy Metrics used to evaluate Systems.

Emergy accounting can also provide a basis for comparing watersheds as to the extent of development, and their energy (or emergy) intensity, thereby providing a basis for estimating environmental impacts resulting from the development activity. Indices based on the amount of renewable and non-renewable emergy use within a watershed can be an important measure of the environmental impacts a landscape is experiencing. Calculation of the amount of emergy use is an important first step for using this technique for a variety of planning purposes. Application of emergy accounting can thus be particularly useful if the resulting indices can be applied in areas where limited data exist for environmental quality indictors such as pollutant loads. Predictions of areas of impact based on emergy signatures of various landuse types can be an important tool for watershed managers with limited funds to measure

The real value of various habitat types such as wetlands, agricultural land and urban areas, is dependent upon the cost of developing the structures (from both natural and purchased sources) and on the services provided by those habitats. This concept has been utilized by Florida regulators to develop an index of landscape development intensity (LDI) which is being used in the planning process for the total maximum daily load (TMDL) program (see Brown, Parker and Foley, 1998). It has also been further extended in Florida to develop a landscape suitability index (LSI), based on non-renewable emergy signatures for landuse types that has been used in the relative assessment of ecosystem services provided by wetland habitats (Bardi, *et al*. 2005).

In this project we have applied emergy accounting procedures, along with other landuse characteristics to develop the landscape development intensity (LDI) for two MBNEP watersheds; the Dog River watershed located in Mobile County, Alabama and the Fish River watershed located in Baldwin County, Alabama. We have compared these indices with existing estimates of pollutant loading for metals for the Dog River watershed, and nutrient loadings estimates for both watersheds to assess their applicability to watersheds in coastal Alabama. In addition, we have also evaluated several wetland habitats in the Dog River watershed, using emergy procedures and have developed emdollar values for each habitat analyzed. The purpose of these comparisons was to provide the Mobile Bay NEP with an initial set of wetland values based on emergy accounting procedures. It should be noted that the objectives of this project were to evaluate the methodology, in terms of practicality and utility for future planning purposes. It was not meant to be an exhaustive evaluation of emergy use in the watershed but to evaluate its overall utility to the MBNEP.

METHODOLOGY

Source Data

The source data from the project were obtained from available sources on the internet, including USEPA Basins website (watershed boundaries, stream files and population from the BASINS (USEPA, 2005), the USGS website (elevation, landuse) and NRCS (soil type). The delineation of the watersheds had been previously compiled by Lehrter (2003) in developing watershed loadings and HSPF (Hydrologic Simulation Program – FORTRAN) modeling of the basins.

Procedure

Landscape Development Intensity Index

The procedure for developing a landscape development index, based on emergy analysis, is described in Brown, Parker and Foley (1998) and consists of deriving a series of areal based measures from the basic landuse-physical data described above. Once entered into the GIS

(ArcView) the data were transformed using the Spatial Analyst using the Spatial Modeling extensions.

The procedure used for the Dog River and Fish River-Weeks Bay Watersheds located adjacent to Mobile Bay Alabama (Figure 2) was as follows:

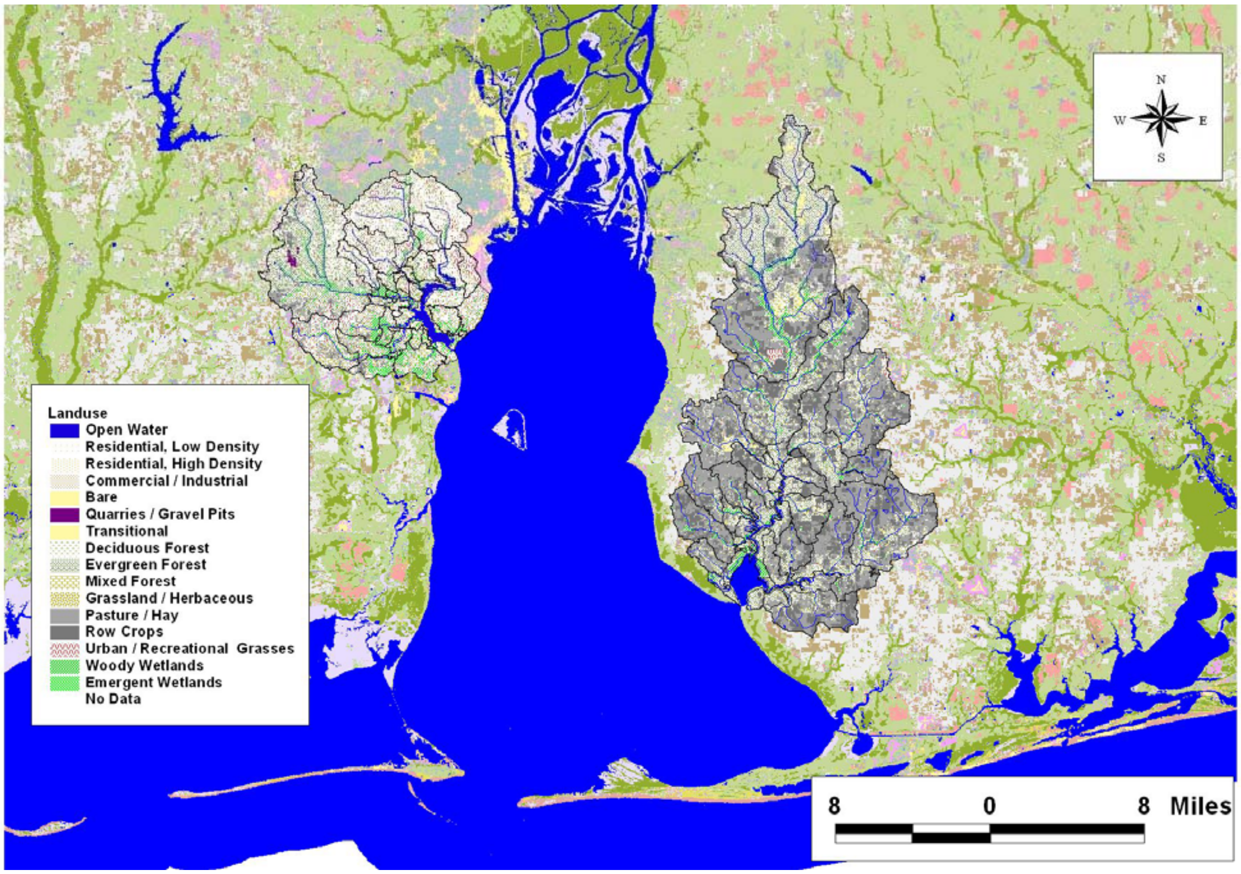

Figure 2. Location of the Study Areas adjacent to Mobile Bay Alabama (inset shows location on map of US)

- Compile landuse characteristics for each watershed from existing sources, and additional including elevations, rainfall, soils, roads, and population estimates (Figure 3).

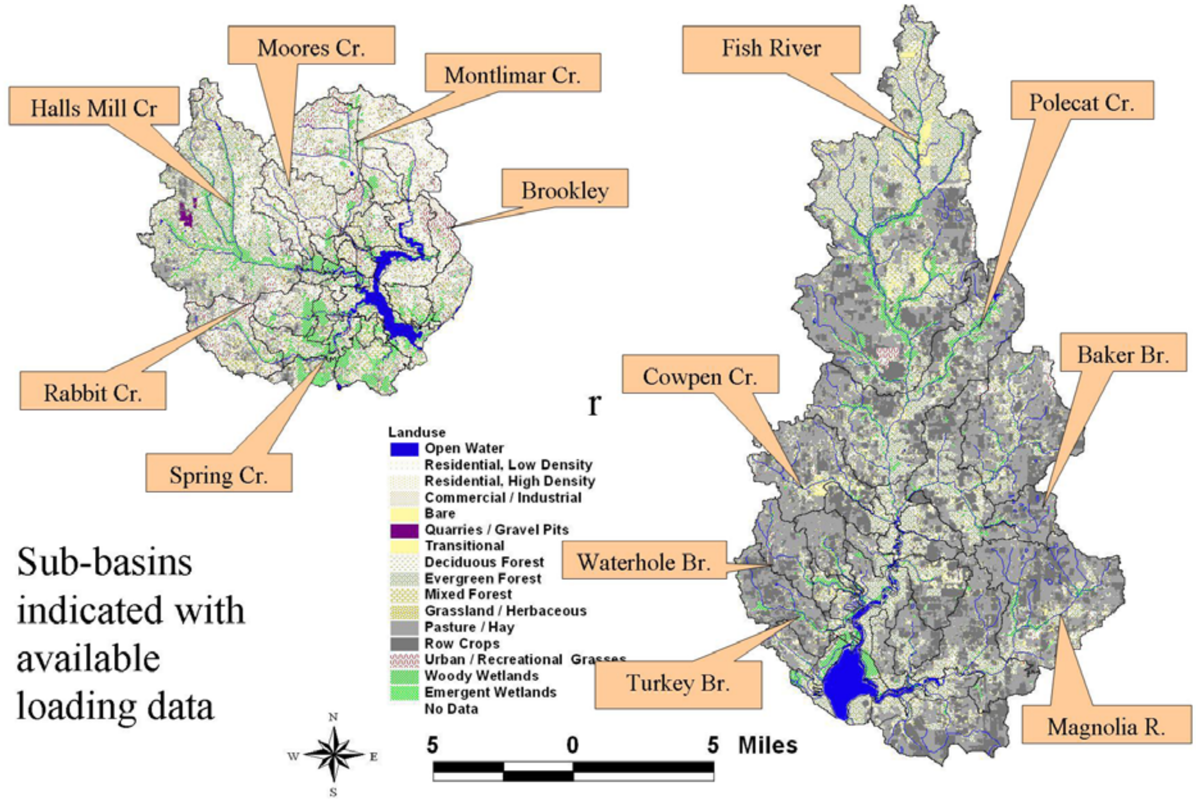

Figure 3. Dog River and Weeks Bay Watersheds adjacent to the Mobile Bay Estuary.

- Compile empower densities (emergy) for each landuse type based on the Brown-Parker-Foley model. Simple areal transforms for each landscape component follows the equations used by Brown, Parker and Foley (1998).   Transform these basic data into derived datasets to develop measures of transpiration and geopotential using spatial analyst to derive the more complex functions. These derived and basic data were then summed using ArcView Spatial Analysts spatial modeling extensions to evaluate measures of renewable and non-renewable resource use in each watershed (See Appendices for all flowcharts for spatial analyst modeling).
- Develop an overall Landscape Development Intensity (LDI) Index for each Watershed, based on total emergy use and compare emergy flow and storages. The LDI is defined as the log (log base 10) of 10 times the ratio of emPower (sej/yr) of the area (renewable and non-renewable) divided by emPower of a reference area (LDI = log(10 * (emP/emP_r)) and results in a scale from 1 (all natural systems) through 30 and perhaps even higher (Bardi, *et al.*

2005). We have also evaluated the Environmental Loading Ratio, based on empower flows. This is defined as the sum of the non-renewable and purchased emergy flows divided by the renewable flows (ELR=(N+P)/R in Figure 1)

These resulting non-renewable empower values for each applicable sub-basin were then compared to existing sediment metals data (4 sub-basins) and regressed to sub-basin annual loading data prepared by Lehrter (2003).

Some deficiencies were noted with the basic input data, particularly for soils where only very general soil types were available, and roadways (lack of statistical data on fuel use and road use intensity). Because of these deficiencies, empower density derived from roadways were not included in the resulting measures. The deficiencies in the soils data may have resulted in some errors in calculations that propagated through to the geopotential and soil loss calculations since these measures are dependent on the soils information. However, since the analyses presented here are a "first order" effort, we proceeded with the LDI development in spite of some missing data.

In addition to development of the Landscape Development Index directly from the derived data for the watersheds, we also investigated the applicability of existing non-renewable empower estimates used in Florida for calculating the Landscape Support Index (LSI) used for evaluating the wetlands functions under Florida's Uniform Mitigation Assessment Method (UMAM) program mandated by Florida statute (F.A.C. 62-345; Florida Department of State, 2006). The procedure involves calculating the area represented by each relevant landuse and multiplying by the appropriate empower density value (sej/HA/yr) specified by Bardi, et al. 2005. This results in an total empower estimate (sej/yr) which was then compared to loading estimates for each sub-basin prepared by Lehrter (2003).

Emergy evaluation and emDollar calculations

The purpose of this portion of the project was to provide an economic evaluation of several wetland habitats in the Dog River watershed. The procedure used was as follows:

- Compile acreage of each habitat within the watershed, using a sub-watershed approach.

- Using Emergy analysis, provide an economic evaluation in emdollars of each habitat, developing both a value of the habitat by acre, and the total emdollar value of each wetland habitat for the entire watershed. We chose to evaluate the systems based on the renewable emergy flows provided by the system.

RESULTS

Compilation of the emergy flows from the various sources for each watershed was accomplished and is provided in Table 1 and 2 for the Weeks Bay and Dog River watersheds, respectively. The calculations provide the basis for several comparisons between the various watersheds including sub-basin comparisons of renewable (R), non-renewable (NR) and purchased energy utilization (F), along with the Environmental Investment Ratio (EIR) and the Environmental Loading Ratio (ELR).

The resulting values can be used to demonstrate where development, as depicted by each sub-basin emergy ELR signature, can expect to show environmental impact associated with utilization of a higher level of non-renewable resources and fuels. It is a measure of development intensity and the resulting environmental degradation. An overall emergy signature, from renewable (R), non-renewable (NR) and purchased emergy (F), and corresponding LDI, EIR and ELR ratios in each major basin are given in Table 3. Overall, the LDI's were similar for each of the two watersheds.

Table 4 presents the ELR and the LDI for 4 sub-basins Dog River watershed (identified in Figure 3) and some corresponding environmental quality indicators, sediment metal content and water nutrient concentrations (ADEM, 1994, ADEM 1995). Of note is the increase in levels of the water and sediment contaminants at stations located within or immediately downstream of the sub-basins and the concomitant increase in the ELR. While there is some variation between the various contaminants, the indication of a positive correlation between the ELR and contaminant levels is evident. Further comparisons between the ELR and various environmental indicators are necessary before confident predictions are possible, but the evidence of the correlation is promising. It is not surprising, however, given similar correlations in Florida watersheds and apparent conformance to the theoretical basis of the ELR index.

Another application of the emergy measures for the watershed is to calculate not only the ELR but a measure of sustainability for emergy use in the two watersheds. By observing the contributions of renewable and non-renewable emergy and fuel use (purchased emergy) an indication of the different resource base between the two watersheds can be observed. Figure 4 presents the overall emergy signatures for the two watersheds showing the differences between the agricultural based (Weeks Bay) and urban dominated (Dog River) systems. On an areal basis, the Weeks Bay watershed is more reliant on non-renewable emergy sources (soils and elevation) than the Dog River watershed, because of its heavier agricultural base. Purchased emergy is higher in the Dog River watershed, owing to its more commercial and residential nature.

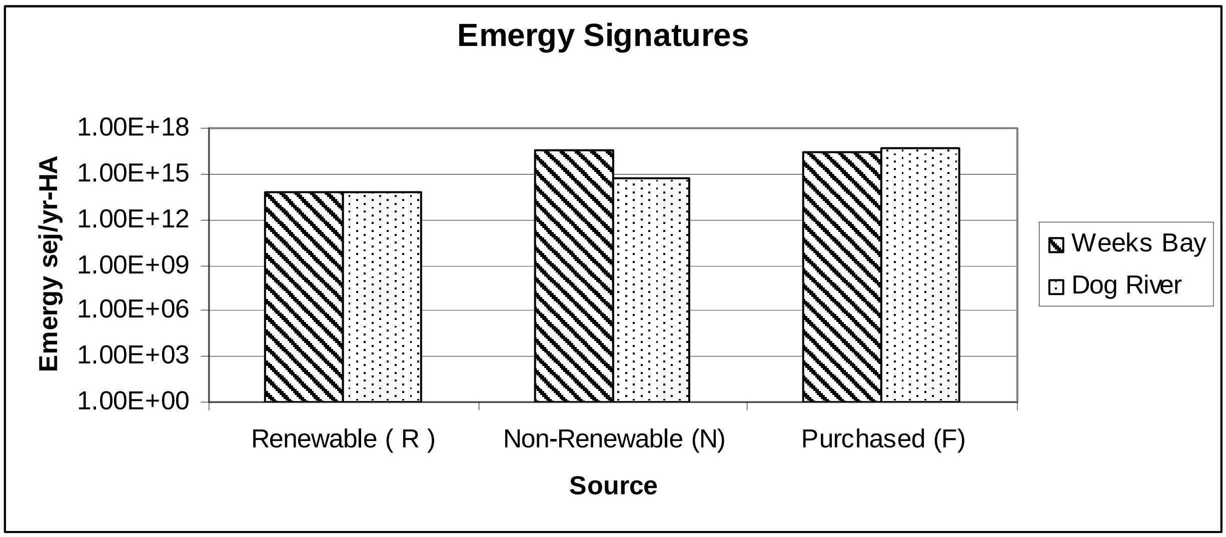

Figure 4. Overall Emergy Signatures for the Two Watersheds for Renewable (R), non-renewable (N) and purchased or fuel-based (F) emergy.

Comparison of non-renewable emergy and measured nutrient loads in subbasins of the Dog River and Weeks Bay watersheds.

Table 5 presents a summary of loadings and the renewable empower. The calculated emergy signatures for available sub-basins in (highlighted in Figure 3.) were compared to measured pollutant loading values using regression analysis. The results of curvi-linear regression (exponential fit) of the emergy values to total nitrogen and total phosphorus loadings showed moderate agreement as depicted in Figure 5. compared to the measured loads exported downstream from these sub-basins calculated by Lehrter (2003).

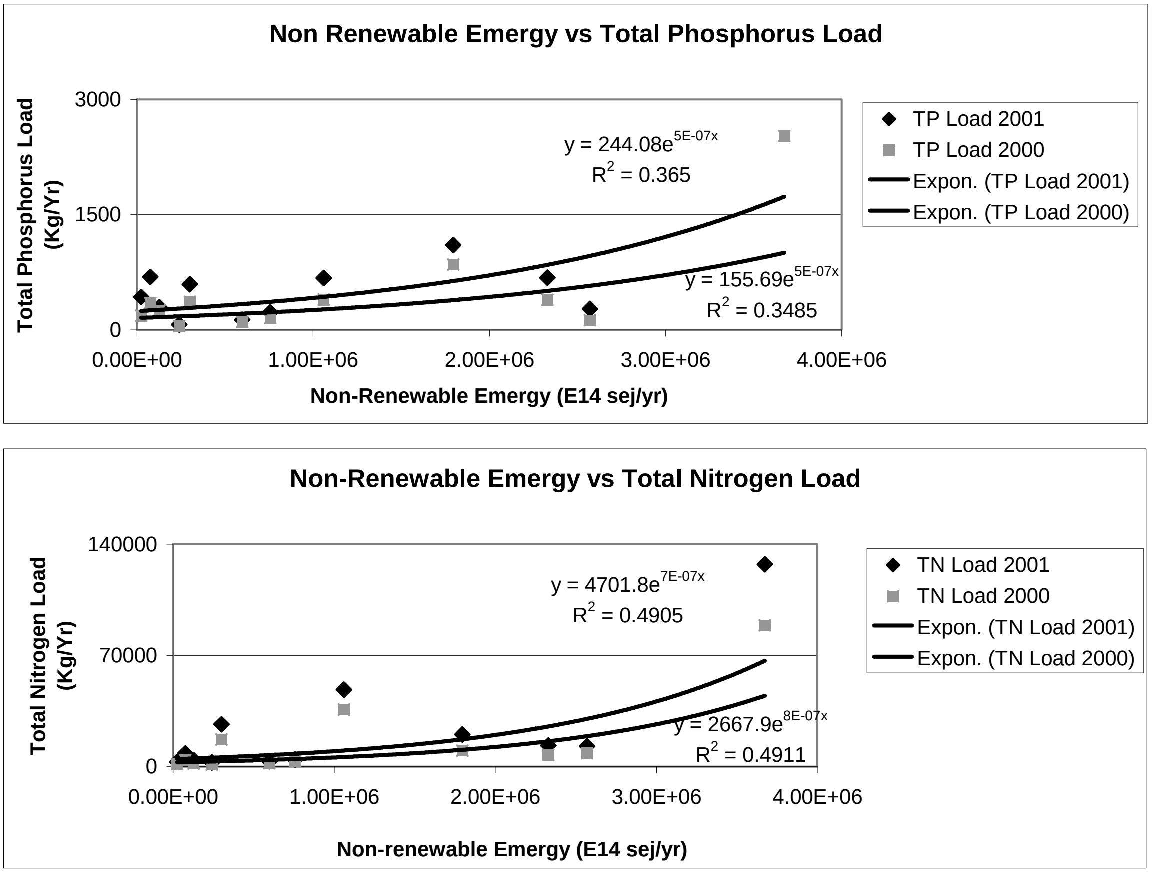

Figure 5. Results of Linear Regression on Non-renewable emergy from this study versus basin loads for Dog River and Weeks Bay watersheds

Recent estimates of non-renewable empower densities for different landuse types have also been prepared by Bardi et al. (2005) for Florida landscapes. The derivation performed for Florida systems is not expected to be greatly different than those that could be calculated for Alabama, given regional similarities in non-renewable emergy signatures. To test this hypothesis, we compared emergy signatures derived from the most recent Florida non-renewable emergy signatures for the various land uses and compared these to the Lehrter (2003) results. The results are presented in Table 5 and Figure 6 presents curvi-linear regression (exponential fit) results applied to these data. The relatively good agreement observed between the annual empower for each sub-basin and the corresponding nutrient loadings is supportive of the premise that non-renewable empower is predictive of potential environmental impact. The improved relationship observed using the non-renewable empower densities from the Florida studies probably are the result of more accurate data for such parameters such as soil type, urban and agricultural fuel use and population estimates. This indicates that an improvement in the relationship for the derived empower densities derived for this study may be improved by including improved data (particularly soils and fuel use) for the watershed

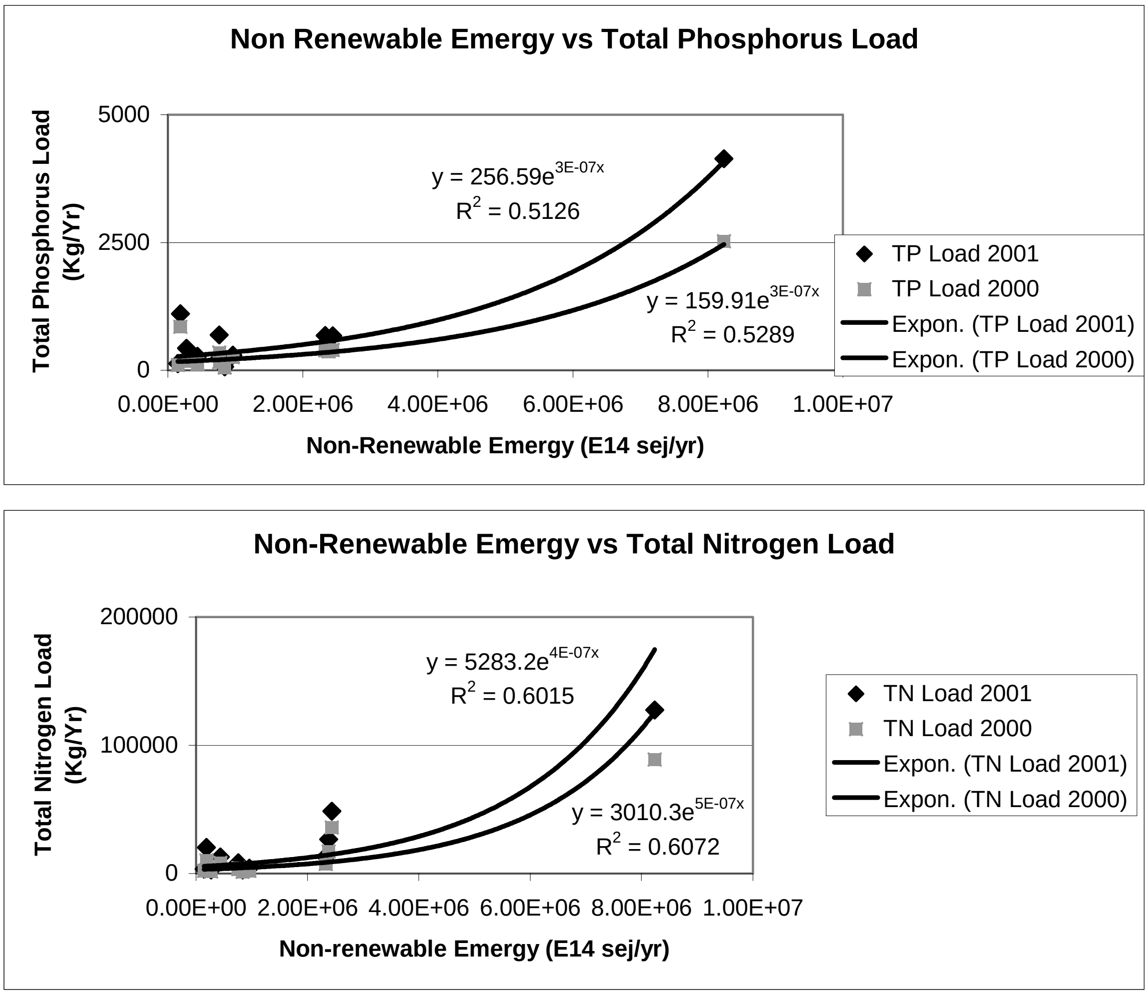

Figure 6. Results of Linear Regression on Non-renewable emergy using the Florida empower densities (Bardi et al. 2005)versus basin loads for Dog River and Weeks Bay watersheds.

Wetlands Evaluation

An important application of emergy analysis is the evaluation of wetlands areas, based on the emergy signatures of these valuable habitats. The wetlands in the Dog River watershed are extensive and support a wide variety of freshwater and estuarine organisms. These habitats also provide a variety of additional environmental services such as water quality enhancement and nursery to many commercially important estuarine organisms. An economic evaluation based on market value often misses many of these valuable ecological services.

The analysis provided here gives a first cut estimate of economic value for the wetlands in the Dog River watershed and looks at the value of incoming renewable emergy flows captured by these wetland systems. This gives a conservative estimate of evaluation, but an indication of the annual value in ecosystem services lost when these habitats are destroyed. An alternative estimate could be obtained by looking at the storages of the systems, but this would require more extensive data collection and analysis but possibly would result in significantly higher figures.

Table 6 presents an evaluation of the entire herbaceous and forested (woody) wetlands for the Dog River watershed. It is based on the emergy conversions and data presented in the following: 1. Folio #3 "Emergy of Ecosystems" (Brown and Bardi, 2001); 2. Folio #5 Emergy of Landforms (Kangas, 2002) (both folios available from the Center for Environmental Policy at the University of Florida - http://www.ees.ufl.edu/cep/publications.asp) and Odum, 1996.

The evaluation resulted in a value of em$9,236 (2000 basis) per hectare for herbaceous wetlands located within the Dog River watershed. The value for woody wetlands (swamp forests) was considerably higher at em$62, 615 (2000 basis) per hectare. These values are generally higher than values obtained based on local market values. It should also be noted that if the land area is converted to other use, the value attributed for loss the wetlands functions would be the net change in value based on an emergy valuation of its altered use.

DISCUSSION

Watershed Comparison

Emergy analysis of the two subject watershed provided good insight into the landscape activities between the two coastal counties. The urban dominated watershed (Dog River, Mobile) and the agricultural dominated watershed (Weeks Bay, Baldwin) trends consistent with emergy theory.

There was a strong relationship between several environmental impact indicators and non-renewable emergy use calculated using emergy signatures derived from the available Alabama data sources as well as those calculated for Florida (Brown, Parker and Foley. 1998). However, the emergy signatures calculated for Florida showed better agreement with the indicators. The reason for this outcome is related to the nature of the data relied upon for the values calculated for Alabama. Both the spatial soil type data and the transportation data used were available at a very coarse scale and likely did not represent enough detail to adequately define the actual emergy signatures of these watersheds.

The environmental impact data used for comparing the two watersheds was limited. A more comprehensive comparison would have been possible if additional consistent data were available on other environmental quality indicators for the two watersheds. While the nutrient loading data provided a good basis for comparison, additional consistent information, taken from both watersheds, on other parameters such as metals or other contaminates would have been useful. This underscores the continuing need for consistent data collection efforts between watersheds.

Another factor in the correlations was the high degree of variability observed in loads in watersheds with lower empower densities. Parker (1998) found that the correlation of LDI and Total Phosphorus showed a better fit for loading levels above background. This indicates that more data is needed for the sub-basins with higher loading values to help better define the relationship.

Wetlands Evaluation

The full accounting of economic benefits derived from ecological services provided by fully functioning wetland systems is related both to the flow of annual environmental services provided as well as the value of its storage of emergy, or natural capital, that has accumulated over time by the system. The initial estimates presented here only provide the value for a small portion of the emergy flows captured by these systems, i.e., the emergy captured from sunlight and chemical potential of rain water. Additional sources of emergy flows such as from tides, wind, runoff and other renewable emergy sources and from non-renewable storage utilization would increase these valuations. For example, Bardi and Brown's (2000) compilation including additional values for wind, geological inputs, gross primary production, transpiration and infiltration, for freshwater herbaceous and forested wetlands resulted in per hectare emDollar values of em$13,173 and em$231,880 respectively for ecosystem services (1998 basis).

We have not provided estimates for the environmental storages, or the natural capital of these local systems in this paper. Typically, the emergy used for the development of wetland landscapes result in additional value several orders of magnitude higher than the estimates of annual empower alone (Bardi and Brown, 2000; Kangas, 2002). Bardi and Brown (2000) estimated the value of natural capital for herbaceous and forested wetlands in central Florida to be em$6,170,664/ha and em$11,472,451/ha, respectively (1998 basis). Their estimates account for both the value stored in the live biomass, peat and water stored in these systems as well as an estimate of the value of the basin structure. In order to fully evaluate the emergy value of these local Alabama wetland systems, additional information on local emergy flows and storages would need to be compiled. Thus, the values presented in this paper are only partial estimates in an ongoing process designed to stimulate further analyses of these ecosystems in Alabama.

CONCLUSIONS

Compiling non-renewable and renewable emergy signatures for two watersheds in coastal Alabama provided a good demonstration of the utility of these measures derived from landuse data. The emergy signatures were evaluated directly from existing landuse, elevation, soil, rainfall and population data using geographic information system software incorporating surface modeling techniques. Annual empower estimates derived for Florida landuse characteristics were found to provide the best estimates and were highly correlated to nutrient loading estimates for sub-watersheds where available loading characteristics were available. This result indicates that empower density estimates derived for similar Florida watersheds can be used as a surrogate for deriving local empower estimates when only limited or outdated information is available. It also provides support for the use of regionally valid indices based on emergy.

Wetlands valuation of herbaceous and woody habitats based on minimal empower flows can also provide a first cut estimate of economic value for the wetland habitats. The value of incoming renewable emergy flows captured by these wetland systems as a reliable basis for estimating ecosystem services for environmental planners and ecologists.

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Protection Agency. The authors are also grateful for the kind assistance of two anonymous reviewers whose helpful suggestions improved the manuscript considerably.

Table 1. Emergy Synthesis for the Weeks Bay watershed showing empower estimates for major sources in each sub-basin.

	Subbasin	Area Hectares	Sunlight (1) (sej/yr)	Rain Geopotential (2) (sej/yr)	RainChemical (3) (sej/yr)	RENEWABLE (sej/yr)	EarthLoss (4) (sej/yr)	Direct (5) (sej/yr)	Agricultural (6) (sej/yr)	NON-RENEWABLE (sej/yr)	LDI (7)	EIR	ELR
WEEKS BAY WATERSHED	**1**	1940	1.15E+17	2.04E+07	3.69E+11	**1.15E+17**	4.92E+17	2.82E+18	1.76E+18	**5.07E+18**	**1.3**	**1.19**	**43.9**
	2	13658	8.13E+17	1.43E+08	3.55E+11	**8.13E+17**	2.29E+18	5.46E+19	3.10E+20	**3.67E+20**	**11.4**	**0.17**	**452.1**
	3	5668	3.37E+17	5.95E+07	1.00E+11	**3.37E+17**	1.14E+18	7.65E+18	2.12E+19	**3.00E+19**	**4.3**	**0.34**	**88.8**
	4	4071	2.42E+17	4.27E+07	6.65E+10	**2.42E+17**	9.75E+17	1.64E+19	4.63E+20	**4.80E+20**	**17.8**	**0.04**	**1983.0**
	5	2482	1.48E+17	2.60E+07	1.95E+11	**1.48E+17**	6.14E+17	1.01E+19	2.46E+20	**2.57E+20**	**17.2**	**0.04**	**1740.8**
	6	591	3.52E+16	6.20E+06	7.58E+10	**3.52E+16**	1.20E+17	9.58E+17	1.76E+18	**2.84E+18**	**3.9**	**0.50**	**80.8**
	7	525	3.12E+16	5.50E+06	1.95E+10	**3.12E+16**	8.84E+16	6.35E+17	9.70E+18	**1.04E+19**	**10.1**	**0.06**	**334.0**
	8	857	5.10E+16	8.99E+06	1.63E+11	**5.10E+16**	2.33E+17	1.38E+18	8.82E+17	**2.49E+18**	**1.8**	**1.18**	**48.9**
	9	2518	1.50E+17	2.64E+07	6.55E+10	**1.50E+17**	4.85E+17	5.48E+18	1.47E+20	**1.53E+20**	**14.9**	**0.04**	**1023.9**
	10	346	2.06E+16	3.63E+06	6.11E+09	**2.06E+16**	6.95E+16	8.17E+17	1.59E+19	**1.68E+19**	**13.9**	**0.05**	**817.4**
	11	836	4.97E+16	8.77E+06	1.37E+10	**4.97E+16**	2.13E+17	1.02E+18	0.00E+00	**1.23E+18**	**1.0**	**3.86**	**24.7**
	12	1088	6.48E+16	1.14E+07	8.56E+10	**6.48E+16**	2.93E+17	4.50E+18	0.00E+00	**4.79E+18**	**3.6**	**12.58**	**74.0**
	13	328	1.95E+16	3.44E+06	4.20E+10	**1.95E+16**	5.49E+16	2.41E+17	0.00E+00	**2.96E+17**	**1.0**	**3.24**	**15.2**
	14	1080	6.43E+16	1.13E+07	4.01E+10	**6.43E+16**	2.57E+17	7.80E+18	4.41E+18	**1.25E+19**	**7.7**	**1.65**	**194.0**
	15	73	4.34E+15	7.65E+05	1.39E+10	**4.34E+15**	8.21E+15	4.09E+16	0.00E+00	**4.91E+16**	**1.0**	**3.26**	**11.3**
	16	1586	9.44E+16	1.66E+07	4.13E+10	**9.44E+16**	4.19E+17	2.76E+18	4.41E+18	**7.59E+18**	**3.9**	**0.56**	**80.4**
	17	4298	2.56E+17	4.51E+07	7.59E+10	**2.56E+17**	1.08E+18	1.38E+19	3.68E+20	**3.83E+20**	**16.6**	**0.04**	**1496.9**
	18	803	4.78E+16	8.42E+06	1.31E+10	**4.78E+16**	1.89E+17	9.68E+17	0.00E+00	**1.16E+18**	**1.0**	**4.08**	**24.2**
	19	493	2.94E+16	5.17E+06	1.01E+11	**2.94E+16**	1.08E+17	6.04E+17	1.76E+18	**2.48E+18**	**4.1**	**0.32**	**84.4**
	20	1940	1.15E+17	2.04E+07	2.91E+10	**1.15E+17**	4.92E+17	2.82E+18	1.76E+18	**5.07E+18**	**1.3**	**1.19**	**43.9**
	21	2545	1.51E+17	2.67E+07	2.19E+10	**1.51E+17**	6.18E+17	6.50E+18	9.89E+19	**1.06E+20**	**13.3**	**0.07**	**700.0**
	22	506	3.01E+16	5.11E+06	2.04E+10	**3.01E+16**	2.47E+16	4.25E+17	3.00E+19	**3.04E+19**	**14.8**	**0.01**	**1010.3**
	23	809	4.81E+16	8.45E+06	8.47E+10	**4.81E+16**	9.47E+16	1.57E+18	4.76E+19	**4.93E+19**	**14.9**	**0.03**	**1024.0**
	24	398	2.37E+16	3.78E+06	2.27E+10	**2.37E+16**	2.78E+16	4.42E+17	2.65E+18	**3.12E+18**	**6.0**	**0.16**	**131.5**
	25	2310	1.37E+17	2.42E+07	1.22E+12	**1.37E+17**	3.20E+17	5.97E+18	1.16E+20	**1.22E+20**	**14.3**	**0.05**	**889.7**
	26	9	5.41E+14	9.53E+04	4.72E+09	**5.41E+14**	5.83E+14	9.02E+16	0.00E+00	**9.08E+16**	**7.1**	**80.21**	**167.8**
	27	1	6.43E+13	1.13E+04	8.00E+10	**6.43E+13**	8.08E+13	2.26E+14	0.00E+00	**3.07E+14**	**1.0**	**1.56**	**4.8**
	28	476	2.83E+16	5.00E+06	1.88E+11	**2.83E+16**	8.94E+16	6.27E+17	8.82E+17	**1.60E+18**	**2.4**	**0.63**	**56.4**

(1) Sunlight Using the Transformity of 1 sej/J Sun = 59.5 E 12 sej/ha/yr (Odum 1996; p114)

(2) Rain Geopotential using the Brown-Parker-Foley model (Brown, et al 1998) Data derived using ArcView GIS and Surface Modeler using DEM - Minimum Elevation * Runoff * 1E3 g/m3 * 9.8 m/s2. Transformity according to Odum 1996 = 10489 sej/J

(3) Earth Chemical From Brown, et al. 1998. Rain (sej) = 1 E 4M2/HA * 11.83 M/yr)* transpiration_map)*4.94 J/g * 1E6g/M3* Transformity 18.199 sej/J (Odum 1996)

(4) Earthloss from Corbitt, (1990) = (5.4 Kcal/g)*(4186 J/Kcal) = 22604 J/g; Transformitiy for Topsoil = 6.3 E4 sej/J (Odum 1996; p 194)

(5) Direct Emergy taken from Whitfield (1993) and applied to appropriate landuse

(6) Agriculture calculated for Row crops = Corn Crops (Brandt-Williams, 1998) 2.49 X E15 sej/ha/yr and for pasture using the calculated value for bahia pasture (Brandt-Williams, 1998) of 9.80 X E14 sej/ha/yr.

(7) LDI = 10 * (emP/emPr) (Brown 2005). We have used the regional background empower for Florida of 1.97 E 15 sej/ha/yr as the base background empower density. Our calculations nt represent total empower for the subbasins (ie. empower densities multiplied by the area of the sub-basin)

Table 2. Emergy Synthesis for the Dog River watershed showing empower estimates for major sources in each sub-basin.

	Subbasin	Area Hectares	Sunlight (1) (sej/yr)	Rain Geopotential (2) (sej/yr)	RainChemical (3) (sej/yr)	RENEWABLE (sej/yr)	EarthLoss (4) (sej/yr)	Direct (5) (sej/yr)	Agricultural (6) (sej/yr)	NON-RENEWABLE (sej/yr)	EIR	ELR
DOG RIVER WATERSHED	**1**	2030	1.21E+17	2.13E+11	3.69E+11	**1.21E+17**	8.14E+17	1.93E+20	8.55E+17	**1.95E+20**	**107.85**	1612.27
	2	1952	1.16E+17	2.05E+11	3.55E+11	**1.16E+17**	9.37E+17	2.46E+20	6.79E+17	**2.48E+20**	**142.01**	2131.61
	3	550	3.27E+16	5.77E+10	1.00E+11	**3.27E+16**	2.22E+17	5.19E+19	1.53E+17	**5.23E+19**	**127.19**	1597.55
	4	366	2.18E+16	3.83E+10	6.65E+10	**2.18E+16**	1.53E+17	3.78E+19	2.64E+17	**3.82E+19**	**86.11**	1756.69
	5	1073	6.38E+16	1.12E+11	1.95E+11	**6.38E+16**	3.35E+17	7.50E+19	4.61E+17	**7.58E+19**	**87.22**	1187.04
	6	417	2.48E+16	4.37E+10	7.58E+10	**2.48E+16**	9.04E+16	1.70E+19	1.35E+17	**1.72E+19**	**68.00**	694.38
	7	107	6.37E+15	1.12E+10	1.95E+10	**6.37E+15**	3.00E+16	6.42E+18	1.97E+16	**6.47E+18**	**114.54**	1015.93
	8	557	3.31E+16	5.84E+10	1.01E+11	**3.31E+16**	1.86E+17	4.26E+19	2.19E+17	**4.30E+19**	**97.20**	1297.29
	9	160	9.51E+15	1.68E+10	2.91E+10	**9.51E+15**	5.31E+16	1.18E+19	3.27E+16	**1.19E+19**	**123.77**	1249.42
	10	120	7.16E+15	1.25E+10	2.19E+10	**7.16E+15**	1.41E+16	1.55E+18	5.76E+16	**1.63E+18**	**19.71**	227.10
	11	112	6.68E+15	1.18E+10	2.04E+10	**6.68E+15**	4.61E+16	6.09E+18	8.97E+15	**6.15E+18**	**98.63**	919.58
	12	466	2.77E+16	4.88E+10	8.47E+10	**2.77E+16**	2.10E+17	4.49E+19	4.68E+17	**4.56E+19**	**63.70**	1646.44
	13	125	7.42E+15	1.31E+10	2.27E+10	**7.42E+15**	3.18E+16	4.41E+18	2.37E+16	**4.47E+18**	**70.14**	601.76
	14	6681	3.98E+17	7.01E+11	1.22E+12	**3.98E+17**	1.44E+18	1.73E+20	1.08E+18	**1.76E+20**	**59.46**	442.66
	15	26	1.54E+15	2.72E+09	4.72E+09	**1.54E+15**	3.96E+15	5.75E+17	7.52E+15	**5.87E+17**	**44.16**	380.39
	16	440	2.62E+16	4.52E+10	8.00E+10	**2.62E+16**	9.09E+16	1.26E+19	6.63E+16	**1.28E+19**	**68.97**	489.29
	17	53	3.13E+15	5.42E+09	9.58E+09	**3.13E+15**	1.45E+16	1.91E+18	1.28E+16	**1.94E+18**	**62.90**	619.47
	18	971	5.77E+16	1.02E+11	1.77E+11	**5.77E+16**	3.33E+17	5.99E+19	3.23E+17	**6.05E+19**	**83.94**	1048.00
	19	311	1.85E+16	3.27E+10	5.67E+10	**1.85E+16**	1.14E+17	1.63E+19	5.54E+16	**1.65E+19**	**87.12**	890.49
	20	77	4.61E+15	8.12E+09	1.41E+10	**4.61E+15**	6.48E+15	6.02E+17	2.82E+15	**6.11E+17**	**43.30**	132.70
	21	590	9.24E+15	1.63E+10	2.83E+10	**9.24E+15**	2.25E+16	2.41E+18	2.95E+15	**2.44E+18**	**69.42**	263.55
	22	1494	3.51E+16	6.19E+10	1.07E+11	**3.51E+16**	1.72E+17	2.38E+19	8.18E+16	**2.40E+19**	**82.23**	684.08
	23	899	8.89E+16	1.57E+11	2.72E+11	**8.89E+16**	4.17E+17	5.87E+19	6.34E+17	**5.97E+19**	**51.46**	671.86
	24	49	5.35E+16	9.43E+10	1.64E+11	**5.35E+16**	2.70E+17	4.17E+19	8.11E+16	**4.21E+19**	**103.12**	787.20
	25	485	2.89E+15	5.10E+09	8.84E+09	**2.89E+15**	1.90E+16	3.59E+18	3.12E+16	**3.64E+18**	**67.54**	1257.85
	26	282	2.88E+16	5.08E+10	8.81E+10	**2.88E+16**	1.56E+17	2.09E+19	8.77E+16	**2.11E+19**	**76.63**	731.74
	27	686	1.68E+16	2.95E+10	5.12E+10	**1.68E+16**	8.69E+16	1.43E+19	1.80E+16	**1.44E+19**	**117.70**	860.52
	28	152	4.08E+16	6.33E+10	1.25E+11	**4.08E+16**	2.24E+17	5.13E+19	3.61E+17	**5.19E+19**	**82.11**	1271.33
	29	62	9.02E+15	1.47E+10	2.76E+10	**9.02E+15**	3.12E+16	3.97E+18	8.48E+16	**4.08E+18**	**31.72**	452.60
	30	700	3.71E+15	6.49E+09	1.13E+10	**3.71E+15**	1.52E+16	3.58E+18	2.02E+16	**3.62E+18**	**91.64**	975.28
	31	199	4.16E+16	6.05E+10	1.27E+11	**4.16E+16**	1.37E+17	1.93E+19	1.81E+17	**1.96E+19**	**53.54**	470.31
	32	1036	1.18E+16	1.45E+10	3.61E+10	**1.18E+16**	5.92E+16	7.72E+18	2.06E+16	**7.80E+18**	**84.29**	659.14
	33	636	6.16E+16	7.07E+10	1.88E+11	**6.16E+16**	1.22E+17	1.75E+19	1.73E+17	**1.78E+19**	**48.99**	288.67

(1) Sunlight Using the Transformity of 1 sej/J Sun = 59.5 E 12 sej/ha/yr (Odum 1996; p114)

(2) Rain Geopotential using the Brown-Parker-Foley model (Brown, et al 1998) Data derived using ArcView GIS and Surface Modeler using DEM - Minimum Elevation * Runoff * 1E3 g/m3 * 9.8 m/s2. Transformity according to Odum 1996 = 10489 sej/J

(3) Earth Chemical From Brown, et al. 1998. Rain (sej) = 1 E 4M2/HA * 11.83 M/yr)* transpiration_map)*4.94 J/g * 1E6g/M3* Transformity 18.199 sej/J (Odum 1996)

(4) Earthloss from Corbitt, (1990) = (5.4 Kcal/g)*(4186 J/Kcal) = 22604 J/g; Transformity for Topsoil = 6.3 E4 sej/J (Odum 1996; p 194)

(5) Direct Emergy taken from Whitfield (1993) and applied to appropriate landuse

(6) Agriculture calculated for Row crops = Corn Crops (Brandt-Williams, 1998) 2.49 X E15 sej/ha/yr and for pasture using the calculated value for bahia pasture (Brandt-Williams, 1998) of 9.80 X E14 sej/ha/yr.

(7) LDI = 10 * (emP/emPr) (Brown 2005). We have used the regional background empower for Florida of 1.97 E 15 sej/ha/yr as the base background empower density. Our calculations represent total empower for the subbasins (ie. empower densities multiplied by the area of the sub-basin)

Table 3. Overall Emergy signatures for the Weeks Bay and Dog River Watersheds.

	R	N	F	LDI	EIR	ELR
Weeks Bay	3.11E+18	1.91E+21	1.51E+21	15.2	0.79	1100
Dog River	1.43E+18	1.40E+19	1.30E+21	14.5	84.26	920

Table 4. Comparison of Environmental Loading Ratio and Water/Sediment Quality Measurements for selected Dog River Sub-basins.

Subbasin	Dominant Landuse	Environmental Loading Ratio	Landscape Development Index	Sediment Lead (mg/kg)	Sediment Zinc (mg/kg	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)
Montlimar	Urban - Residential	68	16.9	142	336	1.311	0.128
Moores Creek	Urban - Residential	71	15.6	38	88	1.562	0.174
Brookley	Urban - Industrial	160	16	114	328	0.801	0.05
Halls Mill Creek	Mixed	13	12	46	138	0.673	0.029

Water and Sediment Quality data from ADEM Dog River Studies (1994 & 1995)

Table 5. Summary of nutrient loading and emergy signatures for selected sub-basins of the Weeks Bay and Dog River watersheds.

Watershed	Designation	Subbasin	Area (ha)	NON-RENEWABLE EMPOWER This Study sej/yr	NON-RENEWABLE EMPOWER Brown 2005 sej/yr	TP2001 (kg/yr)	TN2001 (kg/yr)	TN2000 (kg/yr)	TP2000 (kg/yr)
Weeks Bay	Fish River	1	13658	3.674E+20	8.238E+20	4141	127430	89040	2524
	Magnolia River	21	4298	1.060E+20	2.440E+20	675	48463	35876	396
	Cowpen Creek	5	2482	2.571E+20	4.360E+19	274	12874	8405	125
	Waterhole Branch	14 & 15	1924	1.276E+19	9.590E+19	295	4017	1952	253
	Turkey Branch	18	1586	7.588E+18	7.590E+19	688	8280	4206	348
	Polecat Creek	4	4071	2.996E+19	2.380E+20	594	26600	17046	367
	Baker Branch	9	2518	2.492E+18	2.730E+19	430	2802	1619	183
Dog River	Montlimar	1 & 4	2395	2.329E+20	2.331E+20	680	13204	7427	392
	Moore	5	1073	7.575E+19	7.582E+19	228	4500	3338	156
	Halls Mill	17 & 29	6730	1.796E+20	1.847E+19	1105	20260	10074	849
	Rabbit	27	1494	5.972E+19	1.443E+19	132	3336	2076	102
	Spring	21 & 22	1282	2.403E+19	8.388E+19	69	2614	1344	50.2

Table 6. Wetlands Economic Evaluation of Marshes and Swamp for the Dog River Watershed.

		Emergy Inflow sej/Yr	Em$ Value / Yr	Em$ / HA/Yr
Herbaceous Wetlands	Sunlight	1.88E+16	$ 17,534	$ 51
	Rain, Chem potential	3.36E+18	$ 3,141,206	$ 9,185
	Herbaceous Totals	**3.38E+18**	**$ 3,158,739**	**$ 9,236**
Woody Wetlands	Sunlight	1.27E+17	$ 118,870	$ 348
	Rain, Chem potential	2.28E+19	$ 21,295,623	$ 62,268
	Woody Totals	**2.29E+19**	**$ 21,414,493**	**$ 62,615**

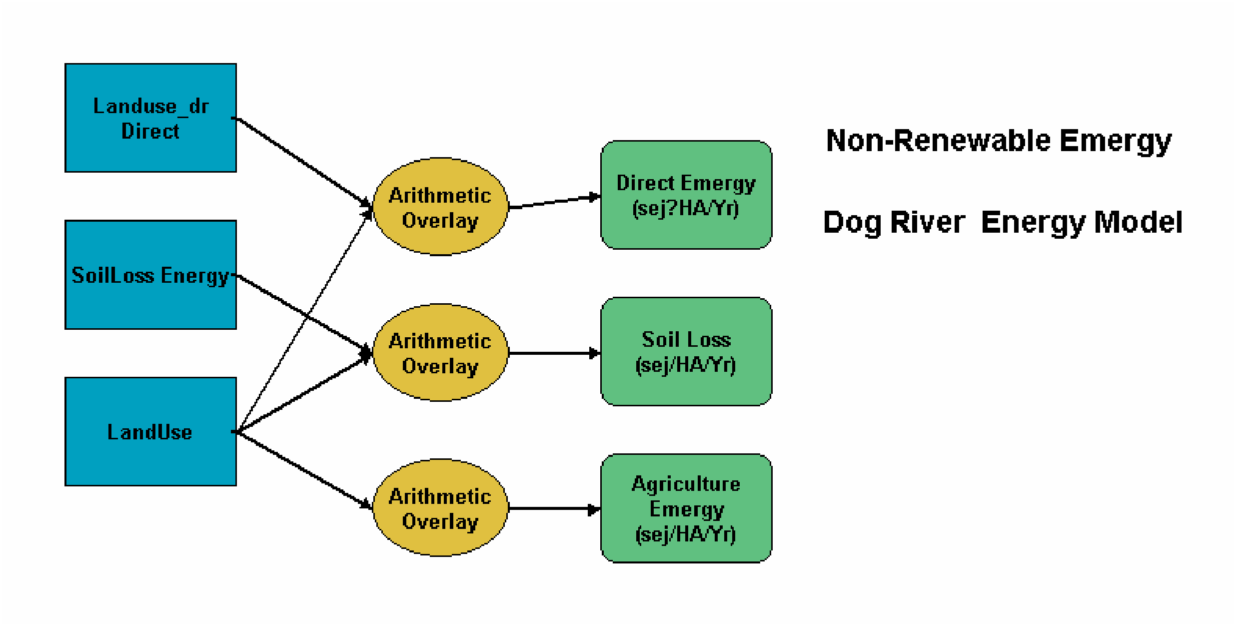
1. Solar Insolation for 2005 taken from http://www.srrb.noaa.gov/surfrad/pick.html for Goodwin Creek MS 0f 1.46 E6 kCal/m2/yr with 10% albedo. (1.46E6 kCal/m2/yr * 0.9 * 1X 10E4 m2/HA * 4186 J/kCal = 5.49 E 13 J/HA/yr)

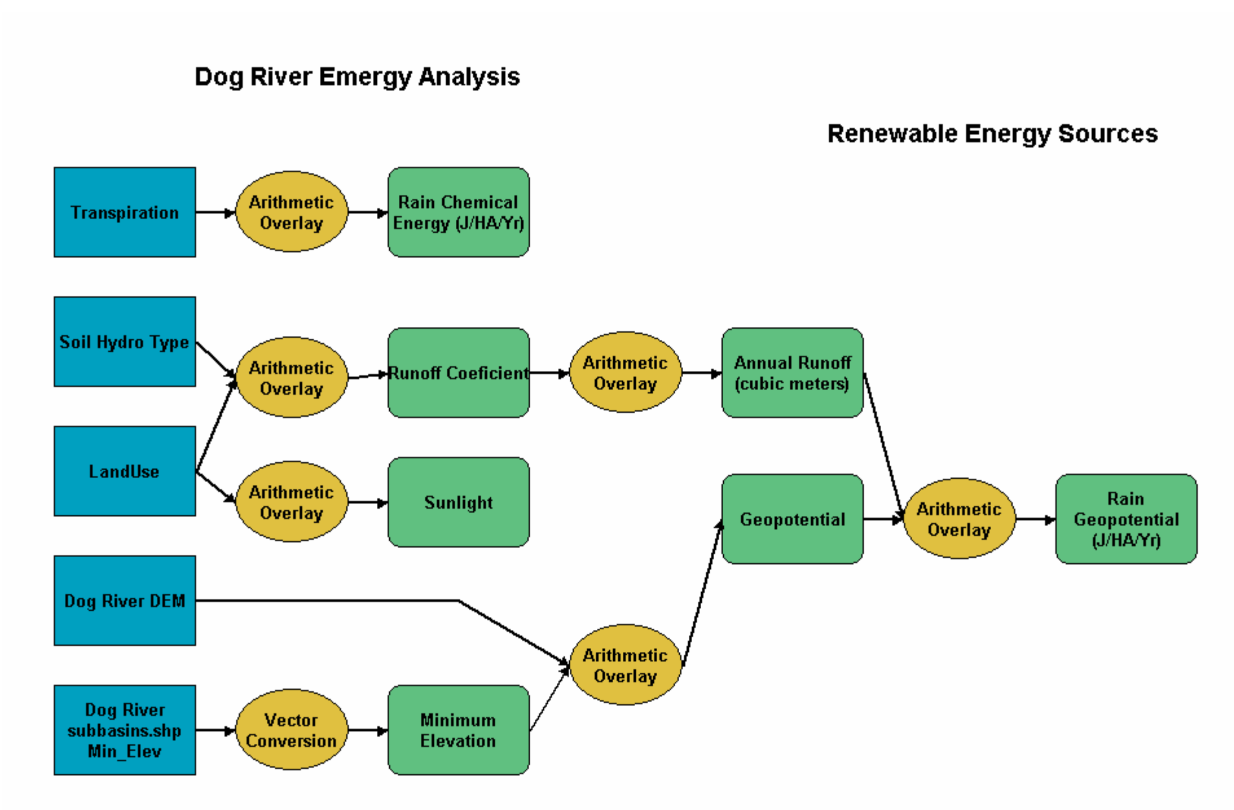
2. Area (1 E 4 m2/HA)* 1.81 M2/yr * Gibbs Free Energy (4.94 J/g) * 1.00 E 6 g/m3 * transformity 18199 (Odum, 1996).

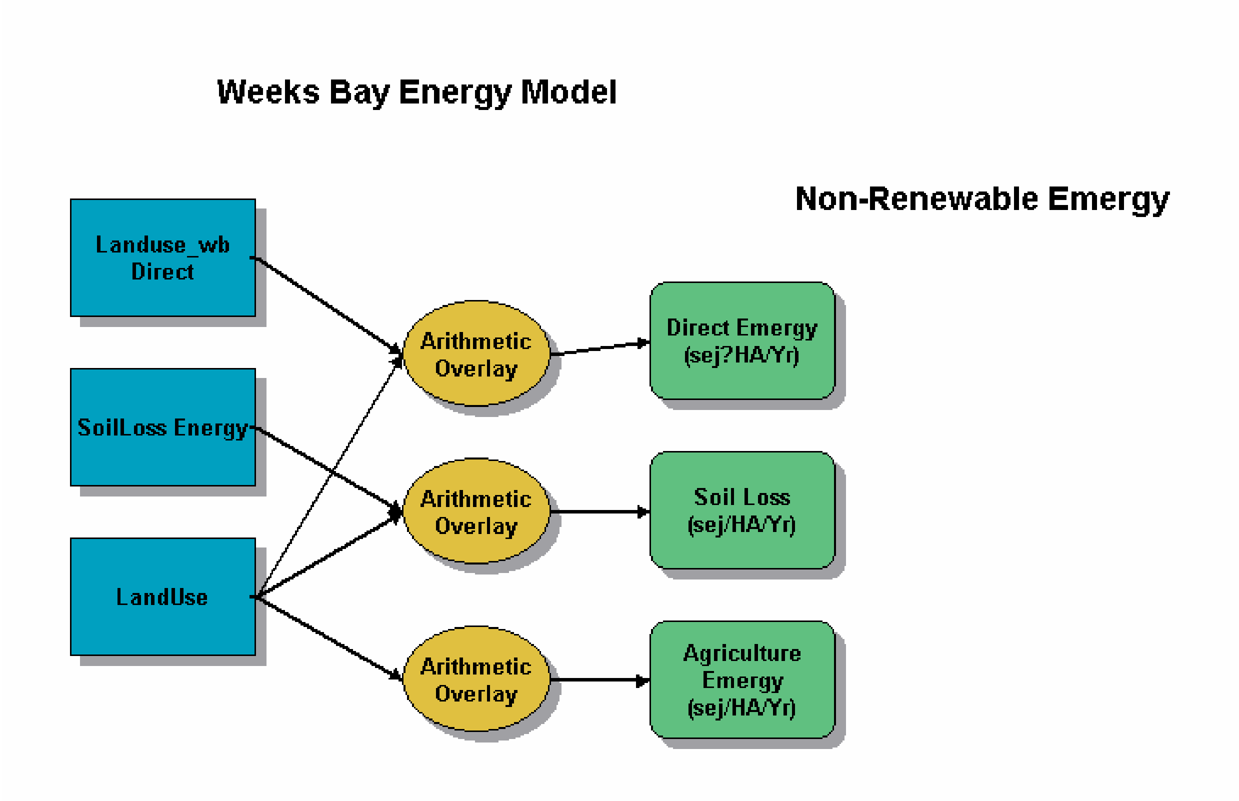
3. Emergy to Dollar Ratio for 2000. = 1.07 E 12 sej/$. Campbell 2005

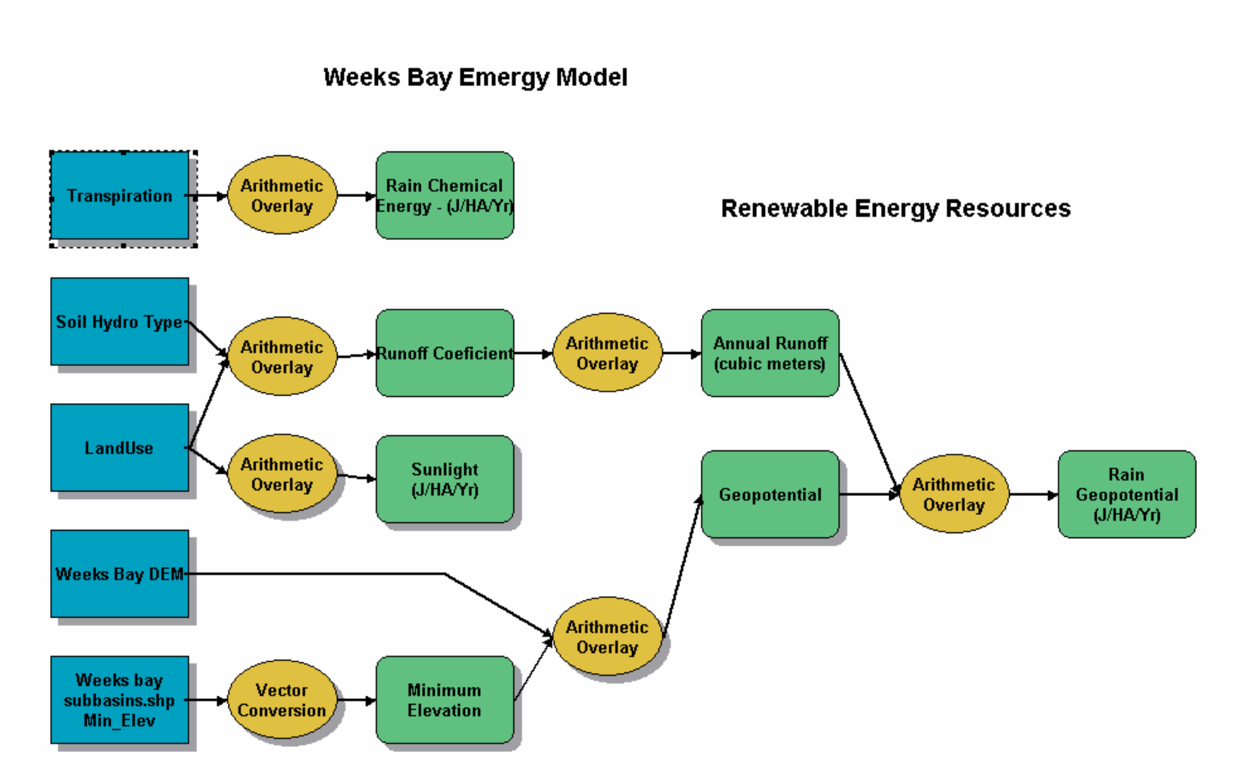
APPENDICES

A. Emergy Model Flowchart for ArcView Spatial Analyst – Dog River
B. Emergy Model Flowchart for ArcView Spatial Analyst – Weeks Bay


Non-Renewable Emergy
Dog River Energy Model
Landuse_dr Direct
SoilLoss Energy
LandUse
Arithmetic Overlay
Arithmetic Overlay
Arithmetic Overlay
Direct Emergy (sej?HA/Yr)
Soil Loss (sej/HA/Yr)
Agriculture Emergy (sej/HA/Yr)


Dog River Emergy Analysis
Renewable Energy Sources
Transpiration
Arithmetic Overlay
Rain Chemical Energy (J/HA/Yr)
Soil Hydro Type
LandUse
Arithmetic Overlay
Runoff Coeficient
Arithmetic Overlay
Annual Runoff (cubic meters)
Arithmetic Overlay
Sunlight
Geopotential
Arithmetic Overlay
Rain Geopotential (J/HA/Yr)
Dog River DEM
Arithmetic Overlay
Dog River subbasins.shp Min_Elev
Vector Conversion
Minimum Elevation


Weeks Bay Energy Model
Non-Renewable Emergy
Landuse_wb Direct
SoilLoss Energy
LandUse
Arithmetic Overlay
Arithmetic Overlay
Arithmetic Overlay
Direct Emergy (sej?HA/Yr)
Soil Loss (sej/HA/Yr)
Agriculture Emergy (sej/HA/Yr)


Weeks Bay Emergy Model
Renewable Energy Resources
Transpiration
Arithmetic Overlay
Rain Chemical Energy - (J/HA/Yr)
Soil Hydro Type
LandUse
Arithmetic Overlay
Runoff Coeficient
Arithmetic Overlay
Annual Runoff (cubic meters)
Arithmetic Overlay
Sunlight (J/HA/Yr)
Geopotential
Arithmetic Overlay
Rain Geopotential (J/HA/Yr)
Weeks Bay DEM
Weeks bay subbasins.shp Min_Elev
Vector Conversion
Minimum Elevation
Arithmetic Overlay