Areal Empower Density and Landscape Development Intensity (LDI) Indices for Wetlands of the Bayou Meto Watershed, Arkansas

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by

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EXECUTIVE SUMMARY

A primary goal of United States Environmental Protection Agency's National Wetland Program is to report on the ecological condition of the wetlands in the nation (USEPA 2003). A successful wetland monitoring program might include landscape-level assessments (Level 1), rapid assessments through on-the-ground surveys (Level 2), and intensive field surveys (Brooks et al. 2004, Fenessy et al. 2004). Level 1 assessment methods are designed to provide information on the condition of wetlands relying on remote-sensing imagery and Geographic Information Systems (GIS). These may include information from the National Wetlands Inventory (NWI), synoptic assessments (Brooks et al. 2004), and various indices of landscape disturbance. The Landscape Development Intensity (LDI) index (Brown and Vivas 2005) is an example of a Level 1 assessment method. It is a measure of human activity based on a development intensity measure that is derived from non-renewable energy use in the surrounding landscape. The LDI index has been used to predict ecosystem condition based on the intensity of human activities in the surrounding landscape and under the premise that ecological communities are affected by the direct, secondary, and cumulative impacts in the surrounding landscape (Brown and Vivas 2005).

The first objective of this research was to compute areal empower densities for land use classes of the Bayou Meto Watershed (BMW) in Arkansas, using existing land

use/land cover (LU/LC) data. Areal empower density was computed for a total of 20 land use types using a modified version of the method originally proposed by Brown and Vivas (2005). Values for the non-renewable and purchased areal empower density varied for land use types between 5.75 E15 sej/ha/yr for open space/recreational lands and 6289.55 E15 sej/ha/yr for high-density multiple residential areas. The average areal empower density for the BMW was 61.47 E15 sej/ha/yr. The largest areal empower densities occurred in the urban areas in the northern portion of the watershed. The middle and southern portions of the BMW were dominated by intermediate areal empower densities that characterize agricultural lands. In general, non-renewable and purchased areal empower density values for land uses in Arkansas were in agreement with those reported elsewhere (Odum et al. 1998) and Florida (Brandt-Williams 2001, Brown and Vivas 2005).

A second objective of this study was to calculate LDI scores for floodplain forested wetlands in the BMW. A total of 29 wetlands were investigated, and were selected from within various landscape settings including natural, agricultural, and urban land uses. The *a priori* selection of wetlands provided a range of landscapes that represented a gradient from undeveloped to highly developed lands. Wetlands within natural landscapes (n = 12), generally exhibit non-renewable and purchased areal empower densities of 0.00 sej/ha/yr to 3.00 E15 sej/ha/yr, which are characteristic of natural lands. For wetlands within agricultural landscapes (n = 9), empower density values ranged between 7.40 E15 sej/ha /yr and 26.71 E15 sej/ha /yr. Wetlands within urban landscapes (n = 8) were characterized by areal empower density values between 342.80 E15 sej/ha /yr and 1910.85 E15 sej/ha /yr.

The final objective was to correlate the LDI scores with three independent measures of wetlands condition: the Wetland Rapid Assessment Procedure (WRAP) used in South Florida, Hydrogeomorphic Functional Capacity Indices (HGM), and the Florida Department of Environmental Regulation's Uniform Mitigation Assessment Method (UMAM). Correlation between the LDI and the WRAP was highly significant, especially when the LDI was estimated for an area of 300 meters around the wetland study plots (Spearman's r = -0.81). The strongest correlation between the LDI and the HGM was reported for the habitat index and also for the 300-meter area immediately surrounding the study plots (Spearman's r = -0.73). The UMAM had the weakest correlation with the LDI (Spearman's r = -0.50), with very similar results for all four landscape scales considered.

The main findings of this research, which constitute a contribution to the development of a landscape procedure for the assessment of wetland ecologic condition in the BMW, can be summarized in three main points:

1. Since the existing LU/LC coverages for the BMW (and for the state of Arkansas) were developed with different goals in mind than those for this research, identifying a set of LU/LC classes that satisfies the requirements for the calculation of areal empower densities may require extensive spatial data manipulation to identify functional LDI classes. To that end, we are providing a set of 20 LDI classes with their corresponding non-renewable and purchased areal empower density values that may be used in other regions within Arkansas for similar studies.

2. The LDI index showed fair to good correlations with three multivariate independent measures of ecosystem condition for wetlands, confirming the validity and usefulness of the LDI.
3. Correlations between the LDI and the WRAP and between the hydrological and habitat categories of the HGM were highest when the LDI was calculated for the area immediately surrounding wetland study plots, initially suggesting that a landscape assessment of wetlands condition using the LDI may only need to consider the impact caused by the nearest land uses over other more distant land uses.

CHAPTER 1
INTRODUCTION AND OVERVIEW

The United States Environmental Protection Agency (USEPA) has recognized three categories of wetland assessment procedures that can be used to assess the ecological condition of wetlands. The criteria for the three different assessment levels are determined based on the scale and intensity of the assessment method, ranging from landscape-scale computer-based analyses to intensive field sampling of biological, physical, and chemical measures. The three procedures are described as Landscape Scale Assessment (Level 1), Rapid Field Methods (Level 2), and Intensive Biological and Physico-Chemical Measures (Level 3) (Fennessy et al. 2004).

The assessment of the ecological condition of wetlands based on the landscape approach is usually carried out using a Geographic Information System (GIS) and remote sensing data. It may also include the use of various indices of landscape composition and configuration and indices of landscape development intensity. The Landscape Development Intensity (LDI) index (Brown and Vivas 2005) is an example of a Level 1 assessment method. The LDI index (referred to as "LDI") is a measure of human activity based on a development intensity measure that is derived from non-renewable energy use in the surrounding landscape. The LDI has been used to predict ecosystem condition based on the intensity of human activities in the surrounding landscape and under the premise that ecological communities are affected by the direct, secondary, and cumulative impacts in the surrounding landscape (Brown and Vivas 2005). Examples of the application of the LDI are Lane (2003), Fore (2004; 2005), Reiss (2004; 2006), Reiss and Brown (2005), Surdick (2005), and Mack (2006).

The metric used in the LDI to quantify human activity is emergy use per unit area per time (or areal empower density). Emergy is an expression of all of the energy used in the work processes that generate a product or service, in units of one type of energy. The solar emergy of a product is the emergy of the product expressed in equivalent solar energy required to generate it (Odum 1996). The units of emergy are emjoules (for emergy joules) and the units of solar emergy are solar emjoules (abbreviated sej). Areal empower density (usually expressed as solar emergy per hectare per year [sej/ha/yr]) is calculated as average values for land use categories. Since the LDI is a measure of human activity, non-renewable energies are the primary source of areal empower density used in the calculation of the index. The LDI scale encompasses a gradient from undeveloped to highly developed land use intensity. Landscapes dominated by more intense activities such as commercial, industrial, and multi-family residential land uses receive higher LDI scores. Less developed lands and rural areas dominated by areas of forests, wetlands, and open lands receive a lower LDI score. The LDI score does not account for any individual causal agents directly, but instead represents the combined actions of air and water pollutants, physical damage, changes in the suite of environmental conditions (e.g., groundwater levels and increased flooding), or a combination of such factors, all of which enter the natural ecological system from the surrounding developed landscape (Brown and Vivas 2005).

Previous Studies Using Landscape Development Intensity

Emergy flows are organized hierarchically into spatial patterns with emergy flows per area more concentrated in hierarchical centers such as cities (Brown 1980; Odum 1996). Based on this observation, Brown and Vivas (2005) suggested that the impacts of human activities might be related spatially to the intensity of energy use and that areal empower density might serve as a measure of the level of human-induced impacts on ecological systems. Using land use data and areal empower density for land uses in Florida, Brown and Vivas (2005) computed LDI indices for watersheds and related them to water quality data and measures of wetland condition.

Parker (1998) used preliminary versions of the LDI based on physical and emergy measurements to correlate them with model results from a spatial pollutant model for total phosphorus (TP) for sub-watersheds of the St. Marks Watershed in Northern Florida. The LDIs showed a good amount of association with the TP loads above background levels, particularly an imperviousness LDI and the empower density LDIs. This study showed that despite the fact that predicting TP loads at low-development intensities are difficult, at higher levels of human development the LDI in its various forms may be a good predictor of nutrients accumulation that can result from more intense human activities.

Cohen et al. (2004) used the LDI calculated by Brown and Vivas (2005) as a measure against which an expert-based floristic quality assessment index (FQAI) could be compared and provide evidence of its importance in the assessment of the ecological condition of small isolated herbaceous wetland systems. Strong associations between the LDI and the FQAI provided evidence of the relevance of the floristic index for biological assessment studies and the LDI as a measure of the human disturbance gradient.

Using the LDI, Lane (2003) developed three indices as quantitative measures of biological integrity based on measurable attributes of diatoms, macrophytes, and macroinvertebrates for isolated herbaceous depressional wetlands in Florida. Similarly, Reiss (2004) developed a Wetland Condition Index (WCI) using measurable metrics for the same groups of organisms for isolated forested wetlands in Florida; Reiss and Brown (2005) developed a Florida Wetland Condition Index (FWCI) for forested strand and floodplain wetlands. In all three cases the LDI was used as the human disturbance gradient along which the change in the composition of biological communities of wetlands were evaluated. Fore (2004, 2005) used modified versions of the LDI to assess the biological condition of streams and lakes in Florida.

Surdick (2005) analyzed how human land uses of varying intensities surrounding isolated forested wetlands in Florida affect the species composition of birds and amphibians. A strong relationship between land use intensity and amphibian and avian species composition was found. Differences between species composition in less developed landscapes and highly developed landscapes were significant, following a gradient of increasing dissimilarity from undeveloped lands to silviculture, agriculture, and urban land uses, respectively. Surdick (2005) pointed out the relevance of the LDI for ecological studies involving changes along a disturbance gradient.

Mack (2006) tested the robustness of the LDI as a wetland condition assessment procedure using a large reference wetland data set in Ohio. The LDI was significantly correlated with the Ohio Rapid Assessment Method for Wetlands (ORAM), an independent measure of the human disturbance gradient. The LDI was also correlated with Ohio's Vegetation Index of Biotic Integrity (VIBI), a multi-metric index of wetland integrity. The most significant relationships were found between the LDI and metrics from emergent wetlands, followed by forested wetlands, and shrub wetlands. Mack (2006) emphasized the robustness of the LDI as a measure of the human disturbance gradient given its theoretical foundations and quantitative nature.

Project Overview

Overall, there were three inter-related objectives of this study: 1) develop areal empower density values for land use classes based on existing LU/LC coverages of the BMW; 2) compute LDI values at four different spatial scales for 29 floodplain forested wetlands chosen by the Arkansas Soil and Water Conservation Commission for which three field based measures of "ecosystem integrity" or wetland condition had been quantified; and 3) statistically determine if the LDI can be used as a predictor of wetland condition.

Energy systems diagrams, and concepts and methods of the environmental accounting methodology developed by H. T. Odum and colleagues at the University of Florida's Center for Environmental Policy (UF-CEP) were used to satisfy the first objective as the basis for calculating the areal empower density for land use types. To accomplish this objective it was first necessary to evaluate the emergy flows for Arkansas in order to apportion emergy to individual land use types. An emergy evaluation of Arkansas developed earlier by Odum et al. (1998) for 1990 was updated, and the resulting energy resource basis for the state was described (this analysis is presented in an appendix to this report). Next, LU/LC classification schemes of existing coverages were reviewed to determine their utility for calculating areal empower densities and recommendations were made for aggregating and disaggregating LU/LC categories to improve the functionality of classes. Once LU/LC classes were determined, systems diagrams were developed for 20 LU/LC classes. These classes served as an inventory guide for collecting material and energy flow data from a variety of sources including federal, state, and local agencies. Data on energy and material flow were used to develop emergy tables to compute areal empower density. The areal empower density of the non-renewable and purchased inputs was then used to derive LDI scores for individual wetland study plots.

The second objective was to compute LDI values at four landscape scales for a set of study wetlands in the BMW (n = 29). The four scales are called Levels of analysis and correspond to the following: Level 1- the entire upstream watershed of the study wetland plot, Level 2a - a 300-meter buffer of contiguous upstream wetlands, Level 2b - a 100-meter buffer of contiguous upstream wetlands, and Level 3 - a 300-meter buffer around the wetland study plot. To accomplish this objective, wetland study sites were sought in three *a priori* landscape settings: natural, agricultural, and urban. This selection allowed a range of landscapes that represented a gradient from undeveloped to highly developed land use intensity. Final LDI values for each wetland were computed using a GIS and based on the average areal empower density for land uses within each of the three landscape scales.

To accomplish the final objective, correlations between the LDI computed for wetland study plots and independent measures of wetlands condition were explored. The indices used were: a Wetland Rapid Assessment Procedure (WRAP) developed and used in South Florida, the Florida Department of Environmental Regulation's Uniform Mitigation Assessment Method (UMAM), and the Hydrogeomorphic Functional

Capacity Index (HGM). The indices were field-calculated by a research team of the Arkansas Multi Agency Wetland Planning Team (MAWPT) and scores were supplied to the UF team.

CHAPTER 2
METHODS

This chapter presents the steps followed in the computation of areal empower density for the different land use types and then LDI scores for each of the study wetlands of the Bayou Meto Watershed (BMW), Arkansas. First a brief description of the study area is given, followed by detailed methods for evaluation of land uses, computation of areal empower density for land uses, application of LDI values to the study wetlands, and finally analysis of relationships between LDI and wetland condition.

Study Area

The State of Arkansas

Arkansas is located in the southern/central U.S. and includes as its major geographic features the Ozark mountain highlands to the northwest, the Ouachita Mountains to the south, and the Mississippi River alluvial plain to the east. The latter includes the floodplain and old channels of the Mississippi River, as well as a complex web of streams, tributaries, and artificial drainage ditches and canals. The Mississippi River valley is a fertile agricultural area and is home to most of the crop agriculture in the state.

The Bayou Meto Watershed

The BMW is located in eastern Arkansas between the Arkansas River and the White River (Figure 2-1) and almost wholly within the Mississippi Alluvial Plain. The BMW flows southeast and is part of the Arkansas River watershed. The land forms within the BMW include backswamps, natural levees and meander belts, oxbow lakes or cutoffs, and terraces (MAWPT, unpublished report available at http://www.mawpt.org/products.asp). Except for the northern portion of the BMW that lies within the Ouachita Mountains ecoregion (Level III, according to Omermik's classification[1]), most of the BMW is contained within the Mississippi Alluvial Plain ecoregion (Level III) with a rather flat topography. The eastern portion of the BMW is within the Grand Prairie sub-ecoregion (Level IV), which lies between 6 to 12 meters above the Bayou Meto floodplains. Most of the wetlands under investigation in this study were located within the Grand Prairie sub-ecoregion.

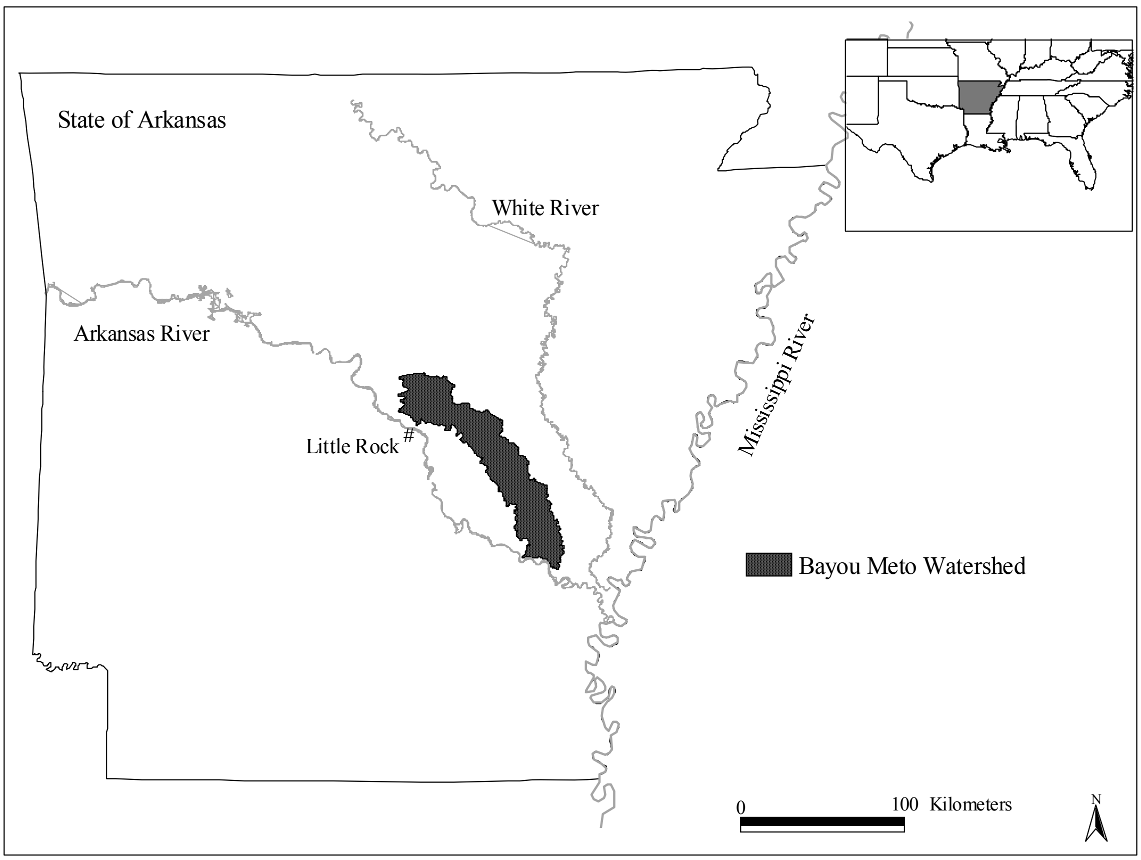

Figure 2-1. Location of the Bayou Meto Watershed, Arkansas.

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[1] Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). Annals of the Association of American Geographers 77(1):118-125.

Once rich in forests and wetlands, agriculture is currently the predominant land use within the BMW. Only 25% of the BMW is forested and it is estimated that from 1950 to 1990 approximately 50% of the natural wetlands present in the BMW were lost to land development (Arkansas MAWPT, unpublished report available at http://www.mawpt.org/products.asp). Urban land uses account for only 3% of the total landscape.

Emergy Evaluations of Arkansas and Land Uses in the Bayou Meto Watershed

The emergy evaluations of the state of Arkansas and of land use types within the BMW were performed following the principles and procedures of the emergy analysis methodology. The emergy analysis methodology consists of three general steps: (1) development of energy systems diagrams for the system of interest, (2) development of emergy tables, and (3) calculation of emergy indices that describe the system and its potential. Detailed methods for the evaluations are given in the Appendix.

Land Use Areal Empower Densities

Land Use / Land Cover (LU/LC) Data

A 1999 Arkansas LU/LC: Summer (1999 AR-LU/LC) GIS coverage, developed by the Center for Advance Spatial Technologies (2001) was used to identify the main land uses present in the BMW. The 1999 AR-LU/LC coverage is available through GeoStor, a web-based database containing all publicly available geodata for the state of Arkansas and available at http://www.cast.uark.edu/cast/geostor/. This coverage is the most recent state-wide LU/LC data set available for Arkansas and the study area. It was derived from Landsat TM 5 scenes and ground-truth information with a 30 x 30-meter cell resolution.

The 1999 AR-LU/LC coverage has a hierarchical system of categories with two levels ranging from general to specific. Level 1 consists of six classes (urban, barren, water, forests, agricultural, and herbaceous lands) which are further subdivided into finer detail (Level 2) with a total of 46 classes. Level 2 categories were used as the basis for identifying the land uses for which areal empower densities coefficients were calculated, and were included in the development of LDI values for the watersheds of the study wetlands. Level 2 category codes and labels for the 1999 AR-LU/LC coverage are summarized in Table 2-1.

Definition of Land Use Categories: aggregations and disaggregations

The 1999 AR-LU/LC coverage emphasizes agricultural land uses and forest classes, with only general descriptions provided for urban land uses and surface water cover. As a result of the uneven description of land uses in the coverage, it was necessary to aggregate some categories and disaggregate others to fit the requirements needed for LDI calculations. Aggregation was easily accomplished; however, disaggregation required the use of aerial photo interpretation and the construction of new coverages. New coverages were then merged to the 1999 AR-LU/LC to obtain a final LU/LC coverage that allowed describing LDI-LU/LC categories and performing LDI calculations.

The 1999 AR-LU/LC focuses primarily on agricultural land uses. It also includes forest categories that were initially developed by the 1992 Arkansas Gap Project, which had among its objectives mapping the distribution of vegetation types in the state. Water systems and urban lands were only generally classified in the 1999 AR-LU/LC. Since this research emphasized defining human disturbance as measured by areal empower density

Table 2-1. Level 2 category codes and labels for the 1999 AR-LU/LC coverage (after CAST 2001).

LULC Code	LULC Label	LULC Code	LULC Label
11	Urban Level 1	114	Forest 14
12	Urban Level 2	115	Forest 15
13	Urban Level 3	116	Forest 16
14	Urban Other (Park, Golf Course, Cemetery, etc.)	117	Forest 17
21	Major Roads	118	Forest 18
22	Railroads	119	Forest 19
23	Airports/Landing Strips	120	Forest 20
31	Barren Land (Sand Bars/Mining Operations/Exposed Rock)	121	Forest 21
41	Perennial Water	122	Forest 22
42	Flooded	123	Forest 23
101*	Forest 1	124	Forest 24
102	Forest 2	125	Forest 25
103	Forest 3	126	Forest 26
104	Forest 4	127	Forest 27
105	Forest 5	128	Forest 28
106	Forest 6	201	Soybeans
107	Forest 7	202	Rice
108	Forest 8	203	Cotton
109	Forest 9	204	Wheat/Oats
110	Forest 10	205	Sorghum/Corn
111	Forest 11	208	Bare Soil/Seedbed/Fallow
112	Forest 12	209	Warm Season Pasture
113	Forest 13	210	Cool Season Pasture

* Forest categories (101-128) were originally labeled with the name of specific species given after the 1992 Arkansas Gap Project.

primarily from urban and agricultural land uses, all of the forest classes on the 1999 AR-LU/LC coverage were aggregated into two categories: upland forests and wetlands.

The 1999 AR-LU/LC coverage had only two categories for describing the surface waters in the BMW: Perennial Waters and Flooded with codes 41 and 42, respectively. These were disaggregated to distinguish between the different freshwater ecosystems present in the study area, and to identify land uses such as managed ponds and dike/impounded waters systems. A new spatial layer, available through Geostor, was created based on spatial data for rivers/streams, lakes, and wetlands, and merged with the 1999 AR-LU/LC coverage to provide more detail regarding the surface waters within the BMW. After these changes, undefined water areas remained. A visual identification of these areas using aerial photographs showed that these areas most likely correspond to rice fields and managed ponds (aquaculture). As a result, a new land use category was created that combined aspects of both land uses.

Urban land use categories from the 1999 AR-LU/LC coverage were disaggregated by photo interpretation of aerial photographs in combination with vector GIS coverages for selected urban areas in the BMW provided by Metroplan, Arkansas. Urban lands were defined in the 1999 Arkansas LU/LC: Summer data set as three general classes labeled Urban 1, Urban 2, and Urban 3. These were reclassified to eight classes that distinguished between residential, commercial, and industrial areas. Residential areas were disaggregated into five categories that account for the different housing densities that might be present in an urban landscape. To determine housing densities for residential areas, houses were counted within one-hectare plots laid on aerial photos. This was done only for delineated sub-basins within the BMW. Commercial areas were disaggregated into two categories that distinguish between commercial strips and community shopping centers. Industrial areas were included in only one category. Institutional land uses such as public buildings, schools, and churches were assumed to be equivalent to commercial strips in terms of their level of energy usage and were assigned to the same land use category. Urban areas such as city parks, playgrounds, golf courses, and urban lands that have been cleared and prepared for construction and/or development were assigned to a unique category. Urban areas were completed by adding a data layer for roads (interstates and U.S. highways) and obtained from Geostor.

The resulting LU/LC categories were reclassified using functional LDI-LU/LC classes. The land use category 208 (bare soil/seedbed/fallow) from the 1999 AR-LU/LC coverage was not considered since it was only present in the northern portion of the BMW and only accounted for approximately 24.3 hectares. Land use categories 23 (airports/landing strips) and 204 (wheat/oats) were also not considered since the 1999 Ar-LU/LC: Summer coverage reported no such land use for the BMW. Definitions for the LDI-LU/LC classes are given in Table 2-2.

Areal Empower Densities

Detailed analyses for each LU/LC category were undertaken using data from the literature and the evaluation of the state of Arkansas (see Appendix). A look-up table was developed for each LU/LC category then the LDI-LU/LC coverage was reclassified assigning areal empower densities to each land use type. The result was an LDI-emPower coverage where each land use category was assigned its appropriate areal empower density.

Table 2-2. Development intensity land use categories and definitions.

Land Use	LULC* Code	Definition
Forests	101-128	Upland forests with low manipulations.
Wetlands	101-128	Forested wetlands with low manipulations.
Open Water	41, 42	Lakes, ponds, and streams with low manipulations.
Hay Crop	209-210	Areas devoted to the production of hay. Also applies to pasture lands (without livestock), which are defined as areas where the natural vegetation has been altered by drainage, irrigation, etc., for the grazing of domestic animals.
Soybeans	201	Areas devoted to the production of soybeans.
Rice	202	Areas devoted to the production rice.
Cotton	203	Areas devoted to the production cotton.
Sorghum/Corn	205	Areas devoted to the production of sorghum/corn.
Aquaculture	41	Fish farms. Can also apply to high-intensity agriculture land uses such as dairy farms and large-scale cattle feed lots, chicken farms, and hog farms, if present.
Rice/Aquaculture	41, 202	Undefined agricultural areas. Average of rice and aquaculture.
Open Space/Recreational	14, 31, 41	Areas with grassy lawns in urban landscapes including recreational lands such as playgrounds, ball fields, and golf courses. Also applies to land that has been cleared and prepared for construction and/or development, dirt roads, barren land, and open areas surrounding by paved roads and power lines. Includes human-created water bodies (retention ponds, canals, reservoirs, etc.) other than for aquaculture.
Low Intensity Single Family Residential	11	Areas that are predominantly residential units with a density less than 5 units/ha.
Medium Intensity Single Family Residential	11	Areas that are predominantly residential units with a density between 5 and 10 units/ha.
High Intensity Single Family Residential	11	Areas that are predominantly residential units with a density of more than 10 units/ha.
Low Intensity Multi-family Residential	11	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings up to 2 stories.
High Intensity Multi-family Residential	11	Areas that are predominantly multi-family residential units such as condominiums and apartment buildings with 3 or more stories.
Low Intensity Commercial/Institutional	12-13	Commercial strips with associated storage buildings and parking lots. Schools, universities, religious, military, medical and professional facilities, and government buildings.
High Intensity Commercial	12-13	Community shopping center with associated storage buildings and parking lots.
Industrial	12,13, 31	Land uses include manufacturing, assembly or processing of materials/products and associated buildings and grounds. Also includes extractive areas and mining operations, water supply plants, and solid waste disposal.
Low Intensity Transportation	21-22	Paved road with no more than 2 lanes, and railroads.
High Intensity Transportation	21	Paved road with more than 2 lanes, railroad terminals, bus and truck terminals, and large auto parking facilities when not directly related to other land uses.

* Level 2 category codes for the 1999 Arkansas Land-use/Land-cover: Summer.

LDI Index for Study Wetlands at Four Spatial Scales

Selection of Wetlands Sites

Study sites were selected with the aid of aerial photography and through a joint field visit made by the UF team and the Arkansas MAWPT in August 2005. The locations of the wetland study plots were determined in the field by the MAWPT staff using a Global Positioning System (GPS). The location of the wetland sites (n = 29) is shown in Figure 2-2 and is indicated by generalized *a priori* land use categories (reference, rural, and urban). Hereafter wetlands embedded in primarily undeveloped landscapes are called reference wetlands; wetlands embedded in primarily agricultural land uses are called rural wetlands; and wetlands embedded in primarily urban land uses are called urban wetlands. Information on each site is summarized in Table 2-3.

Spatial Areas of Influence

LDI indices for each study wetland were computed at four different spatial areas of influence (see Figure 2-3): 1) the drainage basin or total watershed upstream from the wetland study plots, 2) a 300-meter buffer around the riparian zone immediately upstream of the study wetland, 3) a 100-meter buffer around the riparian zone immediately upstream of the study wetland, and 4) a 300-meter buffer surrounding and immediately adjacent to the study wetland. Upstream riparian systems that were connected to the study wetlands were delineated using aerial photographs and GIS coverages. The buffer areas for riparian systems and buffer areas around each study wetland were delineated using buffer command in ArcView GIS 3.2 (Environmental Systems Research Institute, Inc. 1999).

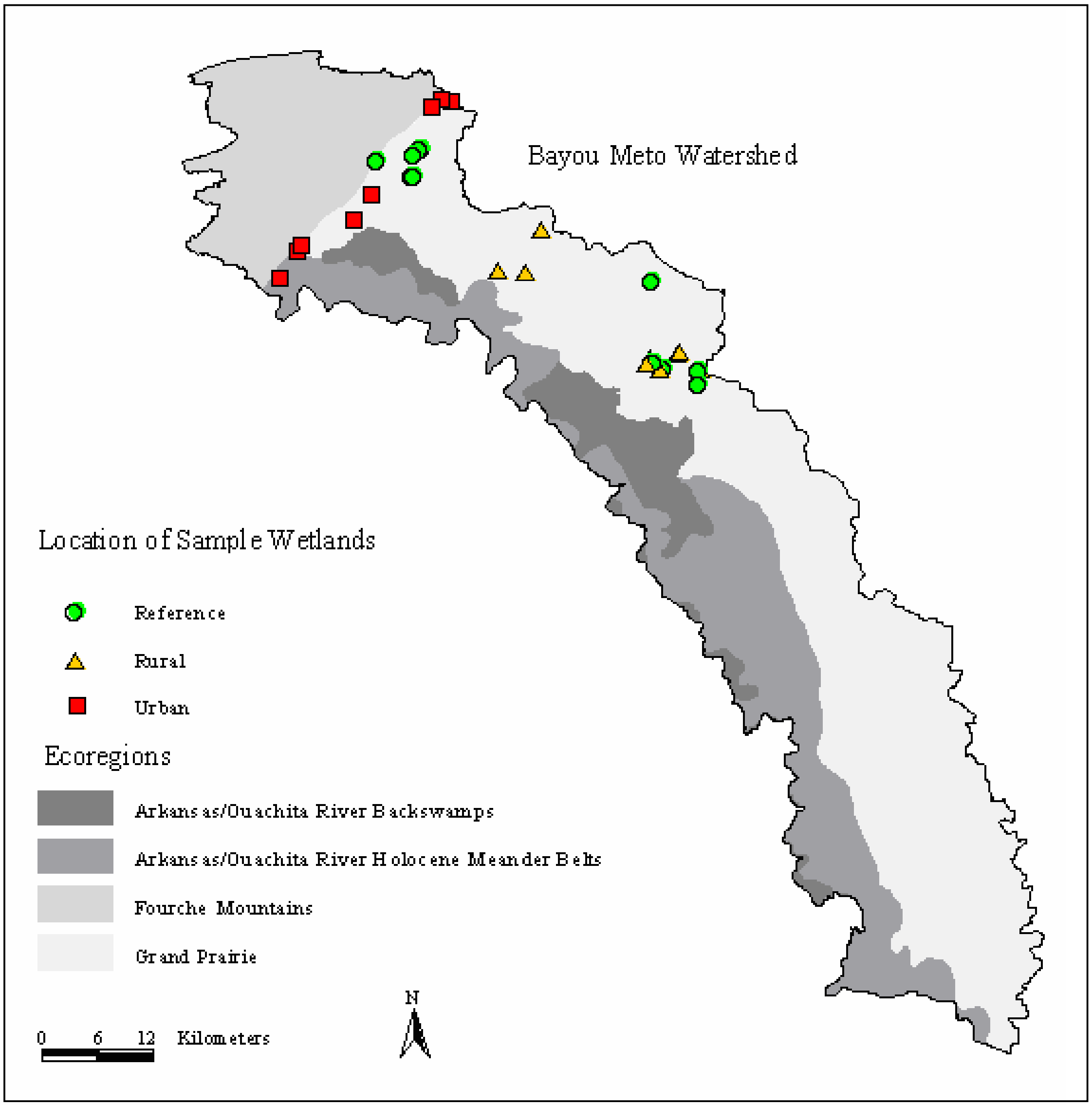


Figure 2-2. Approximate location of the Bayou Meto watershed forested wetland study sites.

Delineation of Drainage Basins

The areas draining to the locations where forested wetlands of the flood zone of the BMW and its tributaries were sampled, as well as the stream networks within the drainage areas, were determined using the Better Assessment Science Integrating Point and Nonpoint Sources 3.0 (BASINS 3.0) environmental analysis system. The BASINS computer program was developed by the Office of Water of the USEPA to support

Table 2-3. Summary information for the Bayou Meto Watershed forested wetlands study.

Site Number	Site Name	Type*	Size of Watershed (ha)	# of Sampling Plots
1	Fina Woods	Urban	437.1	1
2	Old Highway 69 Woods	Reference	3284.3	2
3	Church Woods	Urban	14.5	1
4	Strip Mall Woods	Urban	49.2	2
5	Cabot Park Woods	Urban	45.7	1
6	Gander Mtn. Sporting Goods	Urban	1721.7	2
7	Manson Rd. Woods	Urban	66.5	1
8	Harvest Foods Woods	Urban	45.0	1
9	Jacksonville Ball Field	Urban	221.7	3
10	Gentry Rd West	Rural	188.7	2
11	Gentry Rd East	Rural	530.1	1
12	Fairview	Rural	400.7	2
13	Winrock Hwy 13 West	Rural	154.2	1
14	Winrock Hwy 13 East	Rural	109.7	1
15	Winrock CR 923 East	Reference	2790.1	2
16	Winrock CR 923 West	Rural	2728.0	2
17	Merlin Mission	Rural	46.3	3
18	Winrock CR 915 East B	Reference	41.8	1
19	Winrock CR 915 East C (beaver)	Reference	105.2	1
20	Winrock CR 915 West	Rural	910.0	3
21	I-40 Woods	Reference	1386.2	3
22	North Holland Bottoms 1	Reference	28.3	2
23	North Holland Bottoms 2	Reference	8.0	4
24	North Holland Bottoms 3	Reference	5.9	1
25	Prairie Bayou WMA 1	Rural	21.8	1
26	Prairie Bayou WMA 2	Reference	30.2	2
27	Prairie Bayou WMA 3	Reference	171.4	1
28	Lower Holland Bottoms 1	Reference	109.1	2
29	Lower Holland Bottoms 2	Reference	39.2	2

*Wetlands were classified as reference, rural, or urban if they were embedded in primarily undeveloped landscapes, embedded in primarily agricultural land uses, or embedded in primarily urban land uses, respectively.

environmental and ecological studies at the watershed level (USEPA 2001). The assessment tools used in the BASINS system are integrated into the GIS software ArcView 3.2 (ESRI ®1992-1999), the computer program used for the spatial analyses performed during this study.

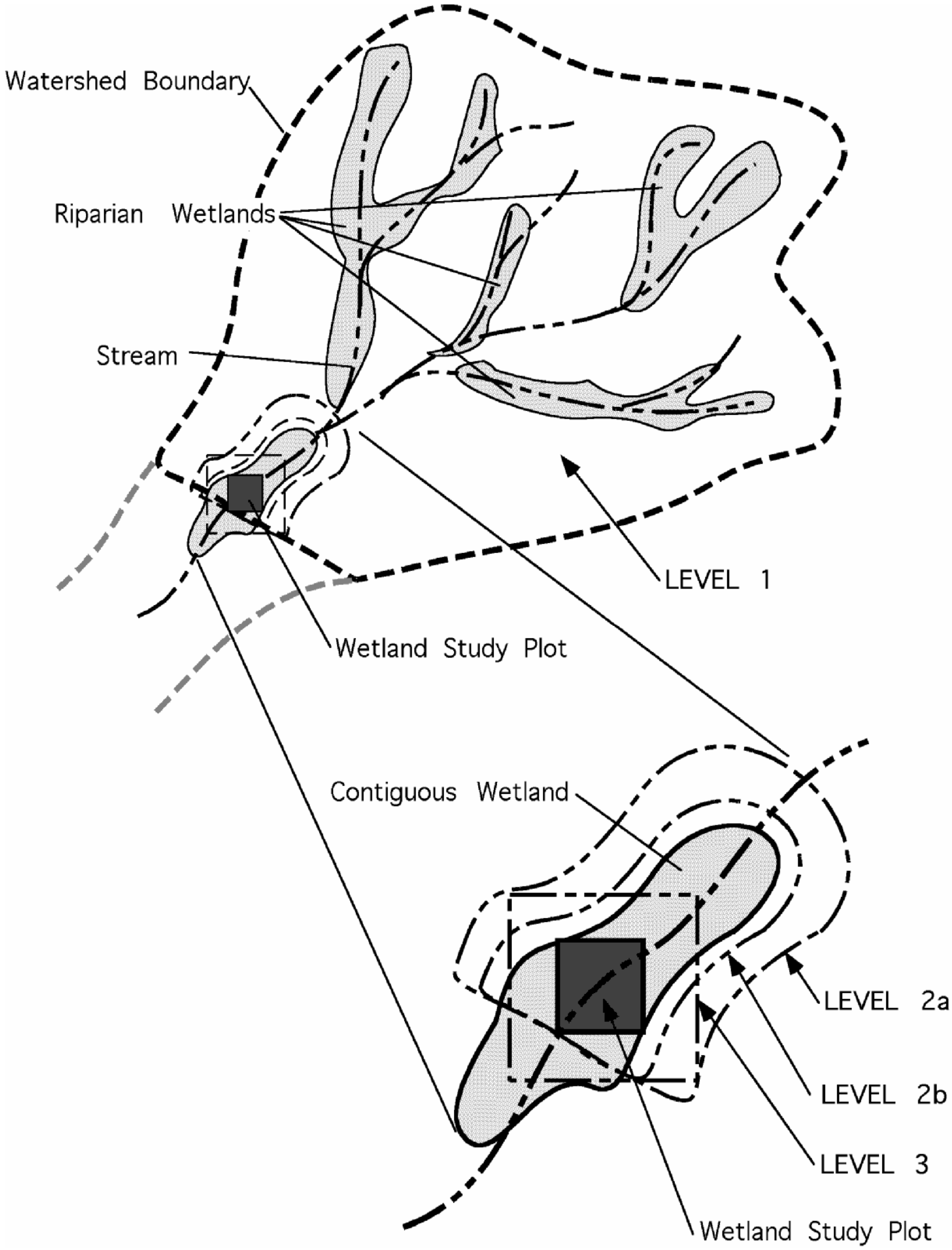


Figure 2-3. Landscape scales used to calculate LDI values for the study wetlands. LEVEL 1: watershed upstream of wetland study plot; LEVEL 2a: a 300-meter buffer around the riparian zone immediately upstream of the study wetland; LEVEL 2b: a meter buffer around the riparian zone immediately upstream of the study wetland; and LEVEL 3: a 300-meter buffer surrounding and immediately adjacent to the study wetland.

The delineation of drainage basins and the stream networks required the use of a digital terrain model (DTM), a grid map that masks the DTM, and a pre-digitized stream network. A state-wide digital elevation model (DEM) available through Geostor was used as the preferred DTM. The DEM has a 30 x 30-meter cell resolution and was developed by the United States Geological Survey (USGS) as part of the National Elevation Dataset (USGS 1999).The DEM for each drainage basin was masked using state-wide watershed boundaries coverage. The pre-digitized stream network used was a state-wide coverage also available through Geostor. Where data for streams were missing, the streams were delineated on-screen with the aid of aerial photography and the elevation terrain model. The final calculation of the drainage basin boundary was done using a stream outlet closest to the wetlands' sampling locations.

Landscape Development Intensity Index

The land uses within each of the four areas of spatial influence were clipped from the LDI-emPower coverage and the LDI index value was calculated for each study wetland as:

$$LDI = 10 * \log (empPD_{Total}/emPD_{Ref}) \qquad \text{(Eq. 1)}$$

where LDI is the Landscape Development Intensity index for a given landscape unit; $empPD_{Total}$ is the total areal empower density (including the background environment) within the buffer; and $emPD_{Ref}$ is the areal empower density of the background environment (2.20 E15 sej/ha-yr; average areal empower density for natural systems in the BMW). The total areal empower density ($empPD_{Total}$) was calculated as:

$$emPD_{total} = emPD_{Ref} + \sum(\%LU_i * emPD_i) \qquad \text{(Eq. 2)}$$

where $\%LU_i$ is the percent of the area of influence in land use i; and $emPD_i$ is the non-renewable areal empower density for land use i. This is a modification of the LDI published by Brown and Vivas (2005) and used by Vivas (2006).

Analysis of Relationships between the LDI and Wetland Condition

Spearman's rank order correlation, the non-parametric measure of correlation (Dytham 1999), was used to assess the relationship between the LDI and three different measures of wetland condition: WRAP (Miller and Boyd 1999), UMAM (62-345.100(6), Florida Administrative Code [F.A.C.]), and HGM procedure (Brinson 1993).

The WRAP (Miller and Boyd 1999), is a rapid assessment procedure consisting of a rating index that can be used to evaluate wetland condition based on six variables: wildlife utilization, wetland overstory/shrub canopy, wetland vegetative ground cover, adjacent upland support/wetland buffer, field indicators of wetland hydrology, and water quality input and treatment systems. Each variable is scored from 0.0 to 3.0, in increments of 0.5. The final index score is expressed on a scale ranging from 0.0 to 1.0. A score of 1.0 indicates an undisturbed wetland, whereas a score of 0.0 indicates a wetland with a reduced functional capacity. The WRAP was originally developed by the South Florida Water Management District (SFWMD) to assist in the regulatory evaluation of mitigation sites. The variable for adjacent land support and wetland buffer was not included in the calculation final WRAP score.

The Florida Department of Environmental Regulation (FDEP) developed the UMAM to assess impacts and mitigation requirements for wetlands and other protected waters (F.A.C 62-345.100(6)). UMAM provides a standardized procedure for assessing the functions provided by wetlands and other waters of the state, the amount those functions are reduced by proposed impacts, and the amount of mitigation necessary to off set that loss. Bardi et al. (2005) provided a summary of the method as follows: the area of study is evaluated based on both a qualitative description and quantitative evaluation of the assessment area. For the quantitative section, sites are evaluated according to three variables: location and landscape support, which examines the ecological context within which the system operates; water environment, a rapid assessment of hydrologic alteration and water quality impairment; and community structure, more specifically vegetation and structural habitat. Each indicator is scored numerically on a scale from 0 to 10 (where 10 indicates a minimally impaired system).The final UMAM score is determined by summing the scores of each of the three variables assessed and dividing that value by 30 to yield a number between 0 and 1. The variable on location and landscape support was not included in the calculation of the final UMAM scores in this study.

The HGM (Brinson 1993) is a procedure for measuring wetland functional capacity. The procedure was designed to satisfy the technical and programmatic requirements of the Clean Water Act Section 404 (Section 404). The HGM is based on three fundamental factors that influence wetland function: the position of the wetland in the landscape (geomorphic setting), the water source (hydrology), and the flow and fluctuation of the water within the wetland (hydrodynamics). Only three of the HGM categories were evaluated and used in this study: (a) hydrological category, (b) biogeochemical category, and (c) habitat category.

CHAPTER 3
RESULTS

Land Use / Land Cover of the Bayou Meto Watershed

Figure 3-1 is a map produced from the LU/LC coverage of the BMW showing the extent of coverage by the various land uses. The vast majority of the watershed is dominated by agricultural uses with the northern portions of the watershed dominated by urban uses. Based on the LU/LC classes shown in Figure 3-1, 20 functional land use categories for LDI calculations were defined for the BMW.

Emergy Evaluation of Selected Land Uses

A summary of areal empower densities for land use classes in the BMW is given in Table 3-1 and shown in Figure 3-2. The average areal empower density for the BMW was 61.47 E 15 sej/ha/yr. The largest areal empower densities (darker areas) occurred in the urban areas in the northern portion of the watershed (Figure 3-2). The middle and southern portions of the BMW were dominated by intermediate areal empower densities that characterize agricultural lands. Details of individual land use classes beginning with forested ecosystems are given in the following paragraphs.

Emergy evaluations of upland forest and forested wetlands ecosystems (see Appendix) revealed that the total solar emergy flow for a hectare of mixed hardwood forest was 1.82 E15 sej/yr, while that of a bottomland hardwood forest was 2.58 E15 sej/yr. Six crops that constitute the most common agricultural crops grown in the BMW were also evaluated. Total solar emergy values for a hectare of crop ranged between

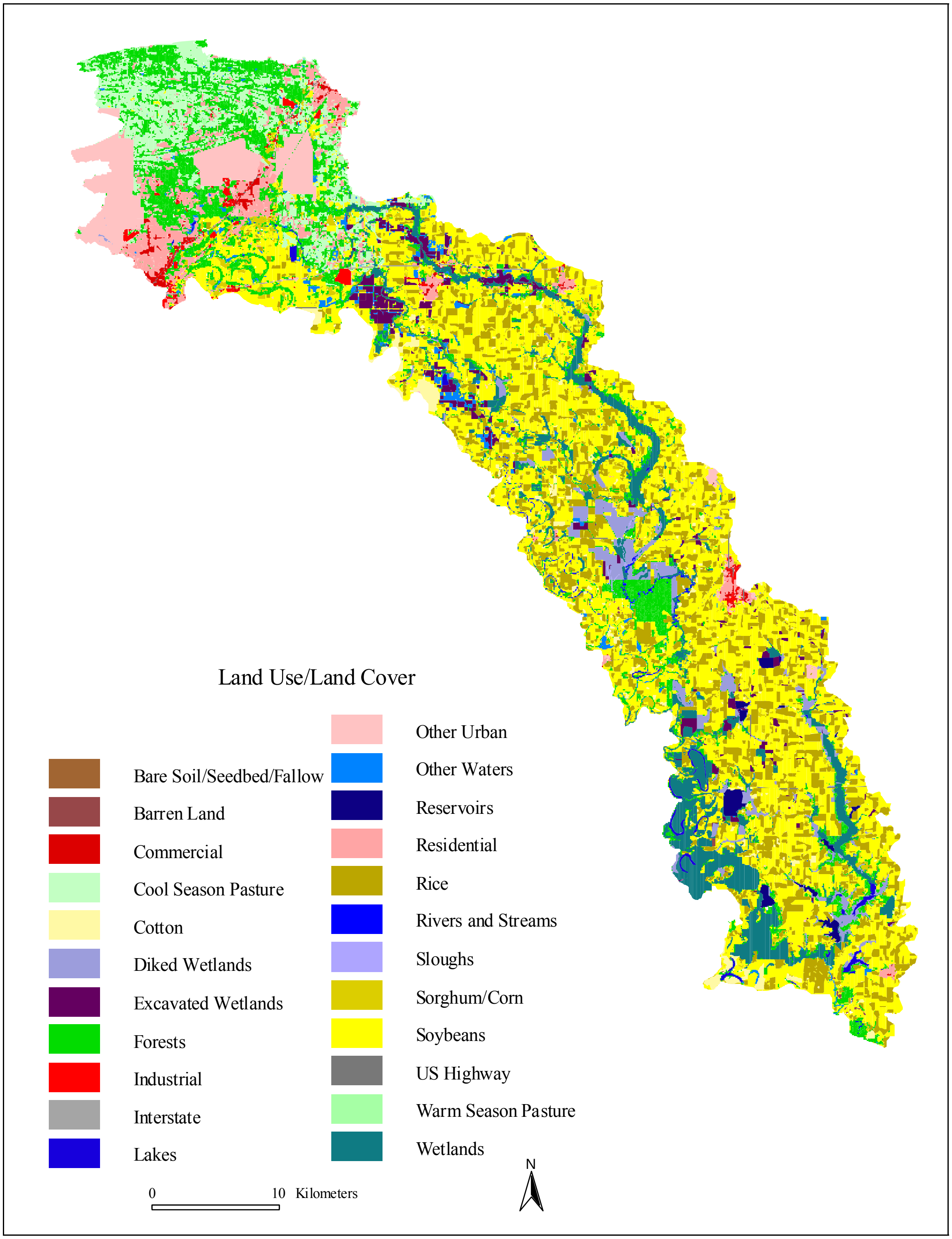


Figure 3-1. Base map of LU/LC classes for the BMW used to identify functional LDI-LU/LC classes.

7.87 E15sej/yr (sorghum) and 19.5 E15 sej/yr (cotton). Intermediate values included 9.61 E15 sej/yr (soybeans), 10.5 E15 sej/yr (hay), 11.7 E15 sej/yr (rice), and 12.3 E15 sej/yr (corn). Also common on the landscape of the BMW are fish ponds for raising catfish and baitfish. On a per hectare basis, the emergy evaluation of six 2-acre ponds for catfish resulted in a total solar emergy flow of 109.4 E15 sej/yr. A general energy systems

Table 3-1. Areal empower density for land use classes in the Bayou Meto Watershed.

Notes	Land Use Classes	Total Areal empower Density (E15 sej/ha/yr)	NR + PI* Areal empower Density wo/services (E15 sej/ha/yr)
1	Forests	1.82	0.00
2	Background Environment	2.17	0.00
3	Wetlands	2.58	0.00
4	Open Space/Recreational	7.91	5.75
5	Sorghum	7.87	6.16
6	Hay Crop	10.46	6.95
7	Soybeans	9.61	7.73
8	Corn	12.33	9.34
9	Rice	11.66	9.40
10	Cotton	19.52	15.84
11	Rice/Aquaculture	60.55	49.33
12	Aquaculture	109.44	89.25
13	LI-Single Family Residential	218.18	162.48
14	MI-Single Family Residential	610.91	454.94
15	LI-Transportation	494.50	494.50
16	HI-Single Family Residential	872.73	649.92
17	LI-Multi Family Residential	2815.27	2096.52
18	LI-Commercial/Institutional	5174.31	2444.43
19	HI-Transportation	2533.69	2533.69
20	Industrial	5235.02	3654.73
21	HI-Commercial	8372.42	4103.62
22	HI-Multi Family Residential	8445.80	6289.55

* Non-renewable and purchased inputs (wo = with out services)

Notes:

2 Weighted average of 1 and 3 - Based on the proportion of each in the BMW.

11 Average of 9 and 12.

diagram and the emergy evaluation tables for each agriculture system and for catfish production are included in the Appendix.

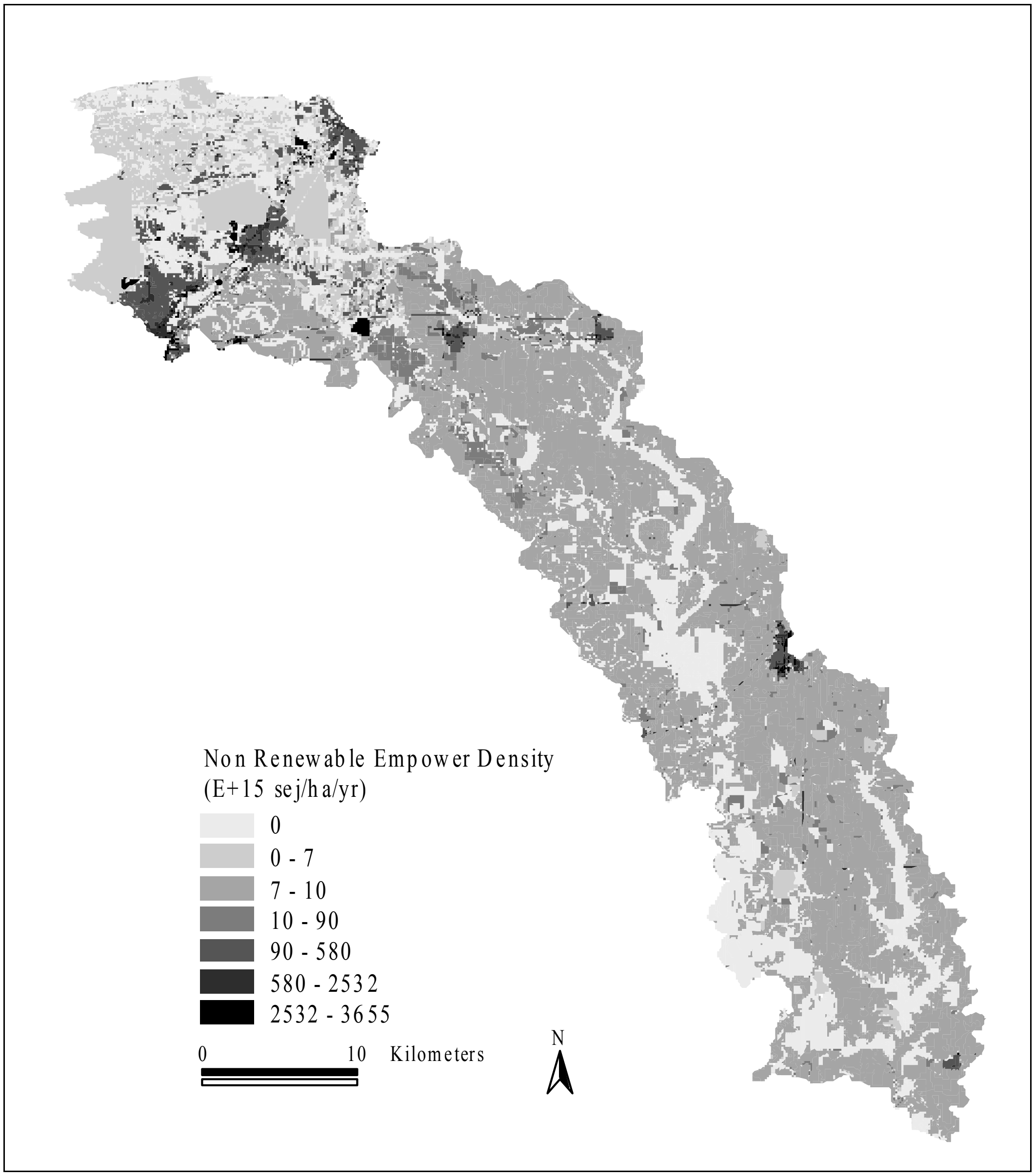


Figure 3-2. Non-renewable and purchased areal empower density for the Bayou Meto Watershed. The range of the areal empower density values are based on the LU/LC classes from Figure 3-1.

The baseline emergy evaluation for residential land uses was a single-family residential area with a density of 2.5 houses per hectare with an annual emergy flow of

2.18 E17 sej/ha/yr, and classified as low-intensity single-family residential. Other housing densities used were 7, 10, 32, and 97 units per hectare and were classified as medium-intensity single-family residential, high-intensity single-family residential, low-intensity multi-family residential, and high-intensity single-family residential, respectively. A general energy systems diagram for a residential area and the emergy evaluation tables for each residential density are included in the Appendix. The emergy evaluation of an urban lawn was also developed and used as a measurement for urban open spaces and urban recreational facilities after "dispersing" the energy usage over the landscape based on Robbins and Birkenholtz (2003)'s estimate of 23% coverage of lawns in the urban landscape. The annual emergy flow for a hectare of urban lawn was calculated as 7.91 E15 sej/ha/yr; this emergy evaluation is included in the Appendix.

Other urban land uses that were evaluated were commercial and industrial areas and transportation corridors (highways). The energy system diagrams and emergy evaluation tables for these urban land uses are provided in the Appendix. Commercial land uses had annual solar emergy flows of 5.17 E18 sej/ha/yr and 8.37 E18 sej/ha/yr for low-intensity and high-intensity areas, respectively. The annual solar emergy flows for an industrial area were calculated as 5.24 E18 sej/ha/yr. A hectare of an interstate highway (I-40) had an annual solar emergy flow of 2.53 E18 sej/ha/yr, while a less intense highway (U.S. Highway 70) had an annual solar emergy flow of 4.94 E17 sej/ha/yr.

LDI and Wetland Condition

LDI Scores for Study Wetlands

Table 3-2 lists each of the wetland study sites, their *a priori* classes, and the areal empower density and computed LDI for each of the four spatial scales. Urban sites had higher areal empower densities and LDI scores than rural and reference sites. The purpose of computing four different LDI scores for each wetland was to test which scale is most appropriate within watersheds. The Level 3 scale is the smallest scale consisting of a 300-meter buffer around each of the wetland study sites, while Level 1 is the largest scale consisting of the entire upstream watershed. There was general agreement between LDI scores for the four scales in urban and rural study sites. However, three *a priori* reference sites had unusual areal empower density values. Sites # 2 and 27 had Level 1, 2a, and 2b areal empower densities that were not indicative of reference conditions, while their Level 3 scores were well within reference conditions. Site # 21 had areal empower densities that were not indicative of reference conditions at all scales considered. This was due primarily to the fact that these study sites were embedded in watersheds that had relatively intense upstream urbanization.

LDI scores for the different scales were compared across each study site to determine if there were significant differences from one scale to the next. A Kruskal-Wallis non-parametric statistical test used to compare the computed LDI values at the four spatial scales showed no significant differences between the different scales ($H = 2.70$, $p = 0.439$). A comparison of LDI scores of the four spatial scales, as shown in Figure 3-3, suggests that there are relatively strong correlations between LDIs for wetland study plots computed for Levels 1, 2a, and 2b ($r^2 = 0.98$). LDI indices for Level 3 differ slightly from those calculated for Levels 1, 2a, and 2b but still have relatively strong correlations ($r^2 = 0.88$). It is obvious from the scatter plots in Figure 3-3 that wetland study sites with intermediate LDI values are absent from the data set.

Table 3-2. Non-renewable and purchased areal empower density and LDI index scores for 29 forested floodplain wetlands. Development intensity measurements were completed for four spatial scales.

			Level1:Watershed		Level 2a: 300-m Stream Buffer		Level 2b: 100-m Stream Buffer		Level 3: 300-m Adjacent to Wetland	
Site No.	Site Name	Type*	NR+P EmpDen (E+15 sej/ha/yr)	LDI	NR+P EmpDen (E+15 sej/ha/yr)	LDI	NR+P EmpDen (E+15 sej/ha/yr)	LDI	NR+P EmpDen (E+15 sej/ha/yr)	LDI
1	Fina Woods	Urb	603.38	24.40	1255.01	27.57	1335.57	27.84	1498.96	28.34
2	Old Highway 69 Woods	Ref	28.24	11.41	25.27	10.96	22.41	10.49	0.07	0.14
3	Church Woods	Urb	1312.54	27.76	1315.36	27.77	1374.84	27.97	1211.80	27.42
4	Strip Mall Woods	Urb	1910.85	29.39	1711.64	28.92	704.81	25.07	1844.90	29.24
5	Cabot Park	Urb	634.64	24.62	623.25	24.54	221.56	20.07	820.07	25.73
6	Gander Mtn. Sporting Goods	Urb	342.80	21.95	307.78	21.49	248.83	20.57	2566.80	30.67
7	Manson Rd. Woods	Urb	1470.33	28.26	1547.29	28.48	2108.05	29.82	2380.05	30.35
8	Harvest Foods Woods	Urb	1501.21	28.35	1871.77	29.30	1491.62	28.32	1588.39	28.59
9	Jacksonville Ball Field	Urb	789.90	25.56	665.24	24.82	428.26	22.92	231.04	20.25
10	Gentry Rd West	Rur	16.20	9.22	7.34	6.37	6.10	5.77	4.67	4.94
11	Gentry Rd East	Rur	26.71	11.19	9.02	7.07	8.01	6.67	5.59	5.49
12	Fareview	Rur	9.81	7.37	8.41	6.83	7.04	6.23	7.61	6.49
13	Winrock Hwy 13 West	Rur	8.78	6.98	8.73	6.96	7.94	6.64	9.25	7.16
14	Winrock Hwy 13 East	Rur	8.49	6.87	8.59	6.90	7.95	6.64	6.19	5.81
15	Winrock CR 923 East	Ref	9.42	7.23	9.05	7.09	8.62	6.92	5.51	5.45
16	Winrock CR 923 West	Rur	9.45	7.24	9.12	7.11	8.69	6.95	8.19	6.74
17	Merlin Mission	Rur	8.86	7.01	7.72	6.54	6.25	5.84	5.84	5.63
18	Winrock CR 915 East A	Ref	5.89	5.66	4.90	5.09	0.75	1.27	0.31	0.58
19	Winrock CR 915 East B&C	Ref	8.02	6.67	7.41	6.40	6.66	6.05	0.52	0.92
20	Winrock CR 915 West	Rur	9.46	7.24	9.10	7.11	8.44	6.85	3.43	4.08
21	I-40 Woods	Ref	13.25	8.46	14.19	8.72	13.35	8.49	98.66	16.61
22	North Holland Bottoms 1	Ref	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	North Holland Bottoms 2	Ref	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	North Holland Bottoms 3	Ref	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Prairie Bayou WMA 1	Rur	7.40	6.40	6.71	6.07	2.26	3.07	2.56	3.35
26	Prairie Bayou WMA 2	Ref	6.47	5.95	6.35	5.90	2.71	3.49	0.31	0.58
27	Prairie Bayou WMA 3	Ref	38.72	12.70	25.02	10.92	13.97	8.66	1.75	2.54
28	Lower Holland Bottoms 1	Ref	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Lower Holland Bottoms 2	Ref	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* Urb = Urban; Ref = Reference; Rur = Rural

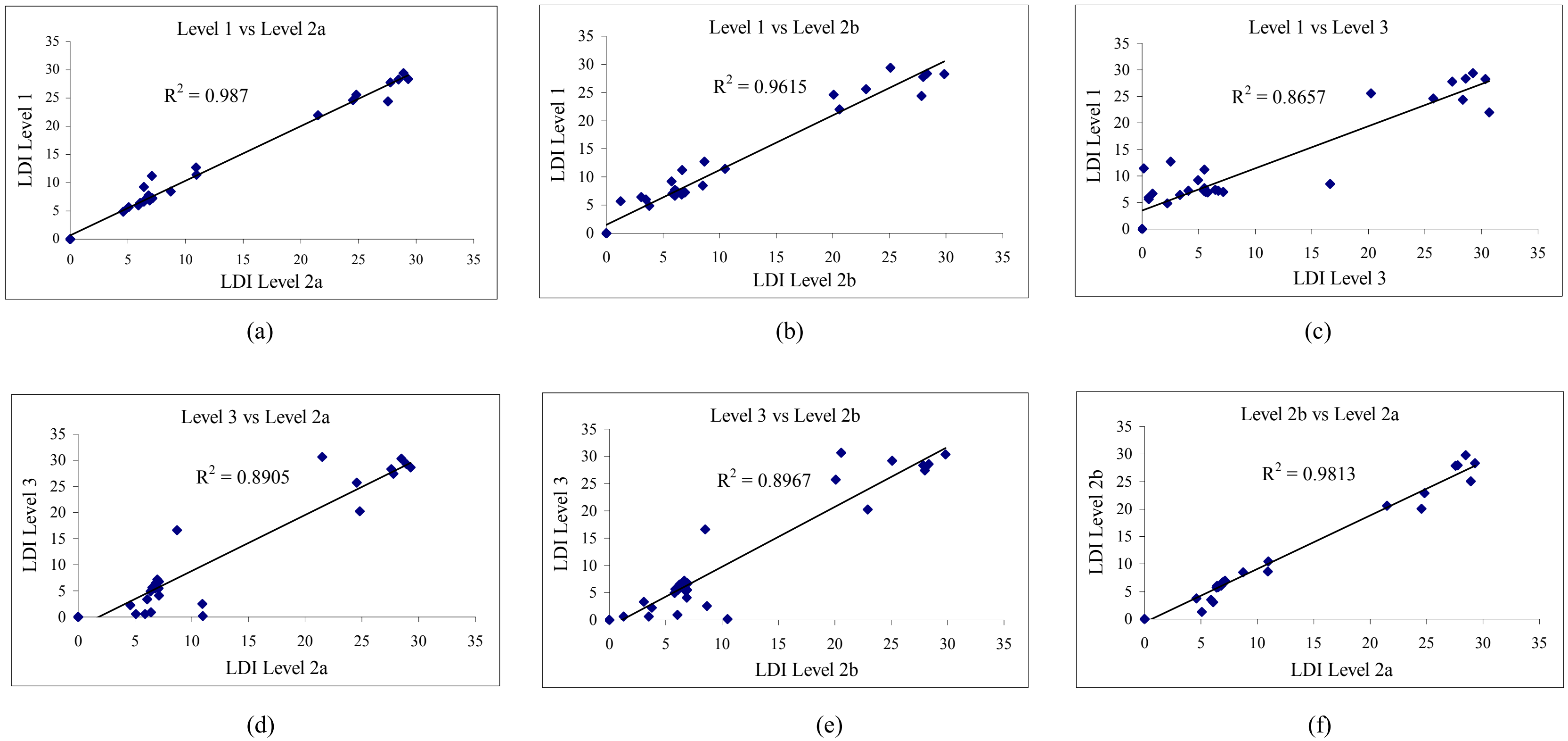


Figure 3.3 Scatter plots of study wetland LDI indices at various scales. a). Level 1 vs. Level 2a; b) Level 1 vs. Level 2b; c) level 1 vs. Level 3; d) Level 3 vs. Level 2a; e) Level 3 vs. Level 2b; and f) Level 2b vs. Level 2a. See text for explanations of the spatial scales corresponding to each of the levels of analysis.

Wetland Condition Indices for Wetland Study Sites

Table 3-3 lists each of the wetland study sites, their *a priori* classes, and their wetland condition index scores. Each of the three components of the HGM score is listed separately. Table 3-3 is a summary of the data for the *a priori* classes of wetland sites showing the mean LDI values for each of the four spatial scales and the corresponding mean wetland condition indices. The small sample size for each *a priori* class of wetland sites makes statistical comparisons among LDI groups and among groups of the wetland condition indices not relevant. However, the inspection of the data suggests that there are important differences in LDI scores and wetland condition indices scores among the *a priori* classes.

Table 3-3 Summary of LDIs and Wetland condition indices for a priori classes.

A priori Class	Level 1 LDI	Level 2a LDI	Level 2b LDI	Level 3 LDI	WRAP	UMAM	HGM-Hydrological	HGM-Biogeochemical	HGM-Habitat
Reference Sites	4.84	4.59	3.78	2.24	0.98	0.96	0.90	0.87	0.92
Rural Sites	7.72	6.77	6.07	5.52	0.84	0.81	0.89	0.83	0.87
Urban Sites	26.29	26.61	25.32	27.57	0.72	0.81	0.71	0.67	0.82

In general, mean LDI scores decreased as the spatial scale decreased. This held true for reference and rural sites; however, urban sites did not follow this trend. The Level 3 mean LDI scores for reference sites (n = 12) were less than half those of the Level 1 score, while the Level 3 mean LDI score for rural sites was about 30% lower than the Level 1 score.

Relationships between the LDI and Measurements of Wetland Condition

The LDI was correlated with three independent measurements of anthropogenic disturbance: WRAP, UMAM, and HGM. The scores for each of these indices for each wetland study plot are presented in Table 3-4; the correlation results are shown in Table 3-5. All correlations were statistically significant (p-level of 0.05). WRAP had the strongest correlations with LDI at all scales of analysis, followed by the HGM. The habitat component of the HGM had the highest correlations with LDI at all scales of analysis.

The strongest correlation was found between the LDI and the WRAP at the Level 3 spatial scale (Spearman's $r = -0.81$, $p < 0.001$). The habitat component of HGM correlated strongest with the LDI at the Level 3 spatial scale. The hydrological component of the HGM also showed the strongest association with the LDI at the same scale (Level 3). The biogeochemical component of HGM showed the strongest association with the LDI at the Level 2a and Level 2b scales (100-meter buffer and 300-meter buffer around the stream, respectively). Correlations between the UMAM and the LDI were very similar among the four spatial scales considered. Graphs showing the relationship between the LDI and the WRAP, HGM, and UMAM are shown in Figures 3-4, 3-5, and 3-6, respectively. Variables were graphed in rank order form.

Level of impairment, evaluated by means of the WRAP, increased as the development intensity of the surrounding landscape increased. The results seem to suggest that, for all scales, the levels of disturbance for the wetland study sites were influenced by their surrounding (or upstream) landscape and that areal empower density was a measure of the disturbance gradient (see Figure 3-4). Differences between the Spearman's correlations for the four scales (see Table 3-5), suggest that the landscape immediately adjacent to the wetlands (Level 3) may be more important in determining wetland condition than lager scale areas (i.e., Levels 1, 2a, and 2b).

Table 3-4. Final scores for three measurements of wetland condition for the sample floodplain wetlands.

Site No.	Site Name	Type*	WRAP	UMAM	HGM Hydrological Category	HGM Biogeochemical Category	HGM Habitat Category
1	Fina Woods	Urb	0.75	0.86	0.54	0.42	0.76
2	Old Highway 69 Woods	Ref	1.00	0.99	0.86	0.81	0.86
3	Church Woods	Urb	0.54	0.72	0.78	0.71	0.79
4	Strip Mall Woods	Urb	0.65	0.87	0.61	0.57	0.80
5	Cabot Park Woods	Urb	0.75	0.81	0.73	0.64	0.88
6	Gander Mtn Sporting Goods	Urb	0.61	0.78	0.78	0.90	0.76
7	Manson Rd. Woods	Urb	0.85	0.84	0.78	0.76	0.90
8	Harvest Foods Woods	Urb	0.88	0.83	0.74	0.78	0.81
9	Jacksonville Ball Field	Urb	0.69	0.78	0.69	0.58	0.82
10	Gentry Rd West	Rur	0.61	0.68	0.96	0.89	0.83
11	Gentry Rd East	Rur	0.84	0.85	0.94	0.83	0.91
12	Fairview	Rur	0.90	0.84	0.88	0.83	0.91
13	Winrock Hwy 13 West	Rur	0.83	0.78	0.97	0.86	0.92
14	Winrock Hwy 13 East	Rur	0.83	0.78	0.76	0.75	0.82
15	Winrock CR 923 East	Ref	0.88	0.81	0.94	0.87	0.95
16	Winrock CR 923 West	Rur	0.75	0.63	0.84	0.78	0.81
17	Merlin Mission	Rur	0.89	0.82	0.84	0.82	0.85
18	Winrock CR 915 East A	Ref	0.94	0.90	0.88	0.88	0.92
19	Winrock CR 915 East B&C	Ref	0.92	0.89	0.85	0.79	0.87
20	Winrock CR 915 West	Rur	0.93	0.92	0.92	0.85	0.88
21	I-40 Woods	Ref	0.99	0.96	0.90	0.83	0.87
22	North Holland Bottoms 1	Ref	1.00	0.99	0.89	0.86	0.92
23	North Holland Bottoms 2	Ref	1.00	0.99	0.91	0.91	0.92
24	North Holland Bottoms 3	Ref	1.00	1.00	0.92	0.97	0.95
25	Prairie Bayou WMA 1	Rur	1.00	0.98	0.94	0.87	0.92
26	Prairie Bayou WMA 2	Ref	1.00	0.96	0.91	0.89	0.96
27	Prairie Bayou WMA 3	Ref	1.00	0.97	0.98	0.92	0.98
28	Lower Holland Bottoms 1	Ref	1.00	1.00	0.94	0.86	0.96
29	Lower Holland Bottoms 2	Ref	1.00	1.00	0.84	0.85	0.92

Table 3-5. Spearman's correlations (r) between the LDI and measurements of wetland condition for the sample floodplain wetlands calculated at four different spatial scales.

LDI	WRAP		UMAM		HGM Hydrological Component		HGM Biogeochemical Component		HGM Habitat Component	
	r	p-value	r	p-value	r	p-value	r	p-value	r	p-value
Level 1: Watershed	-0.68	<0.001	-0.50	0.005	-0.49	0.007	-0.60	0.001	-0.67	<0.001
Level 2a: 300-m surrounding stream	-0.64	<0.001	-0.48	0.009	-0.54	0.002	-0.65	<0.001	-0.67	<0.001
Level 2b: 100-m surrounding stream	-0.64	<0.001	-0.49	0.008	-0.54	0.002	-0.64	<0.001	-0.67	<0.001
Level 3: 300-m adjacent to study wetland	-0.81	<0.001	-0.50	0.006	-0.57	0.001	-0.60	0.001	-0.73	<0.001

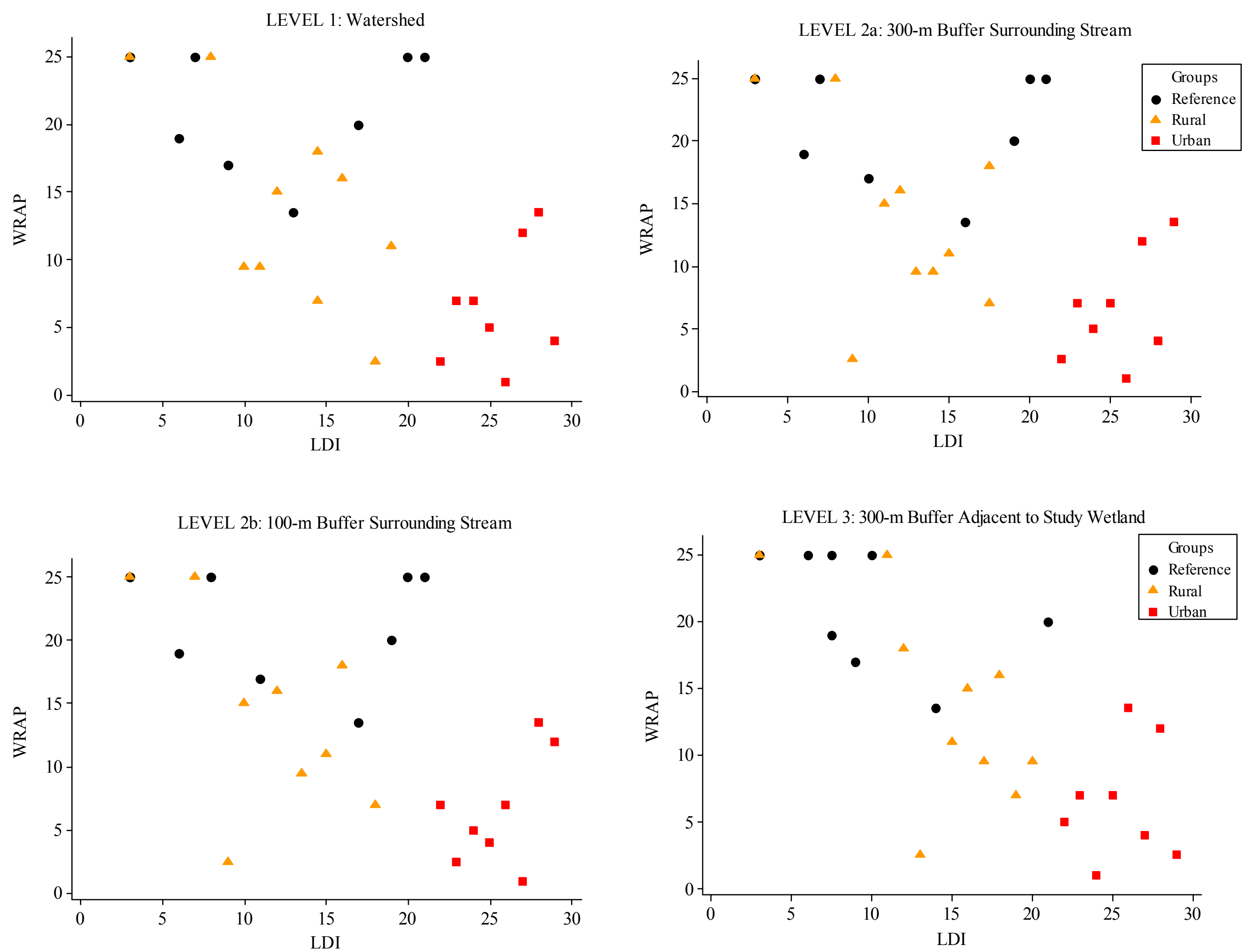
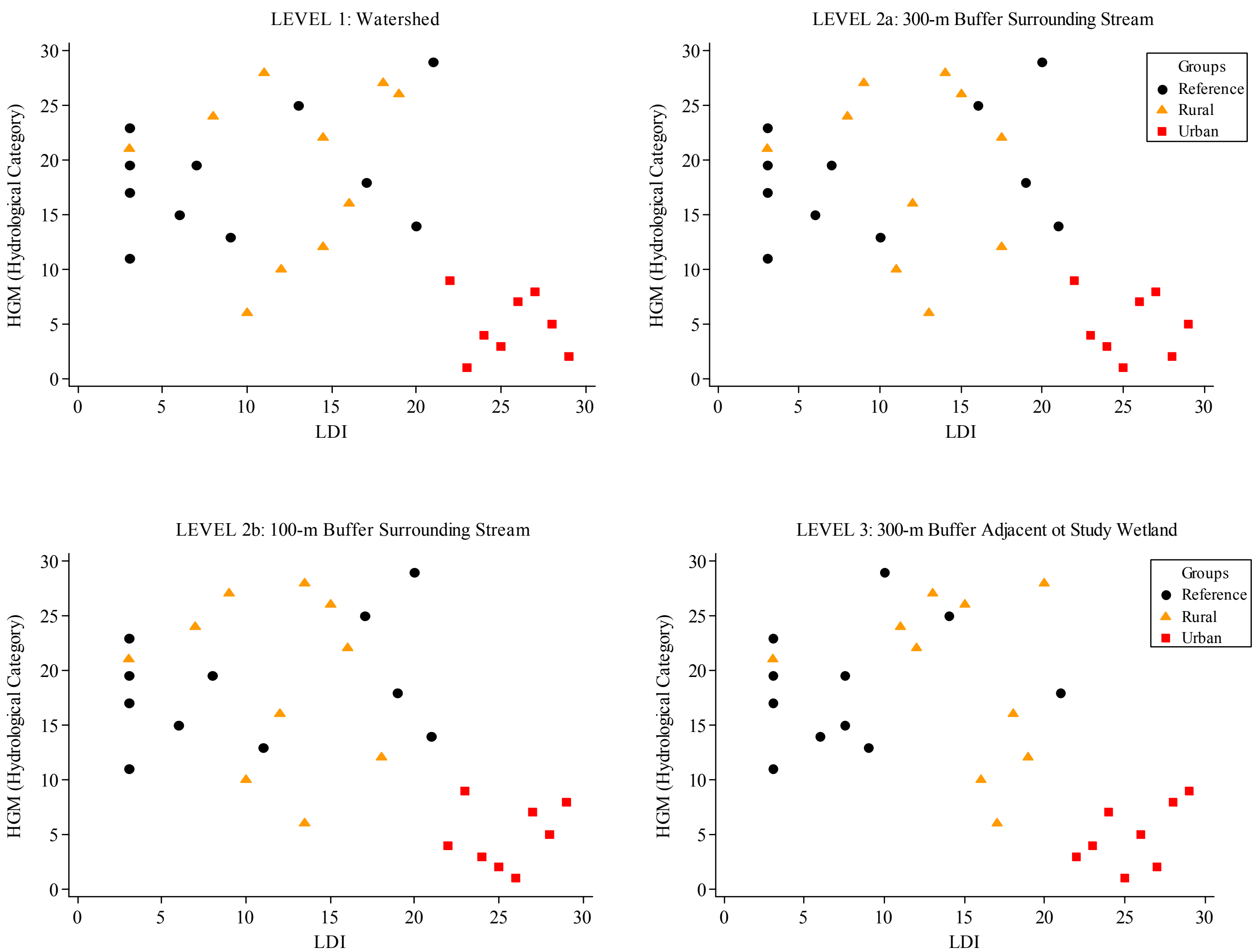
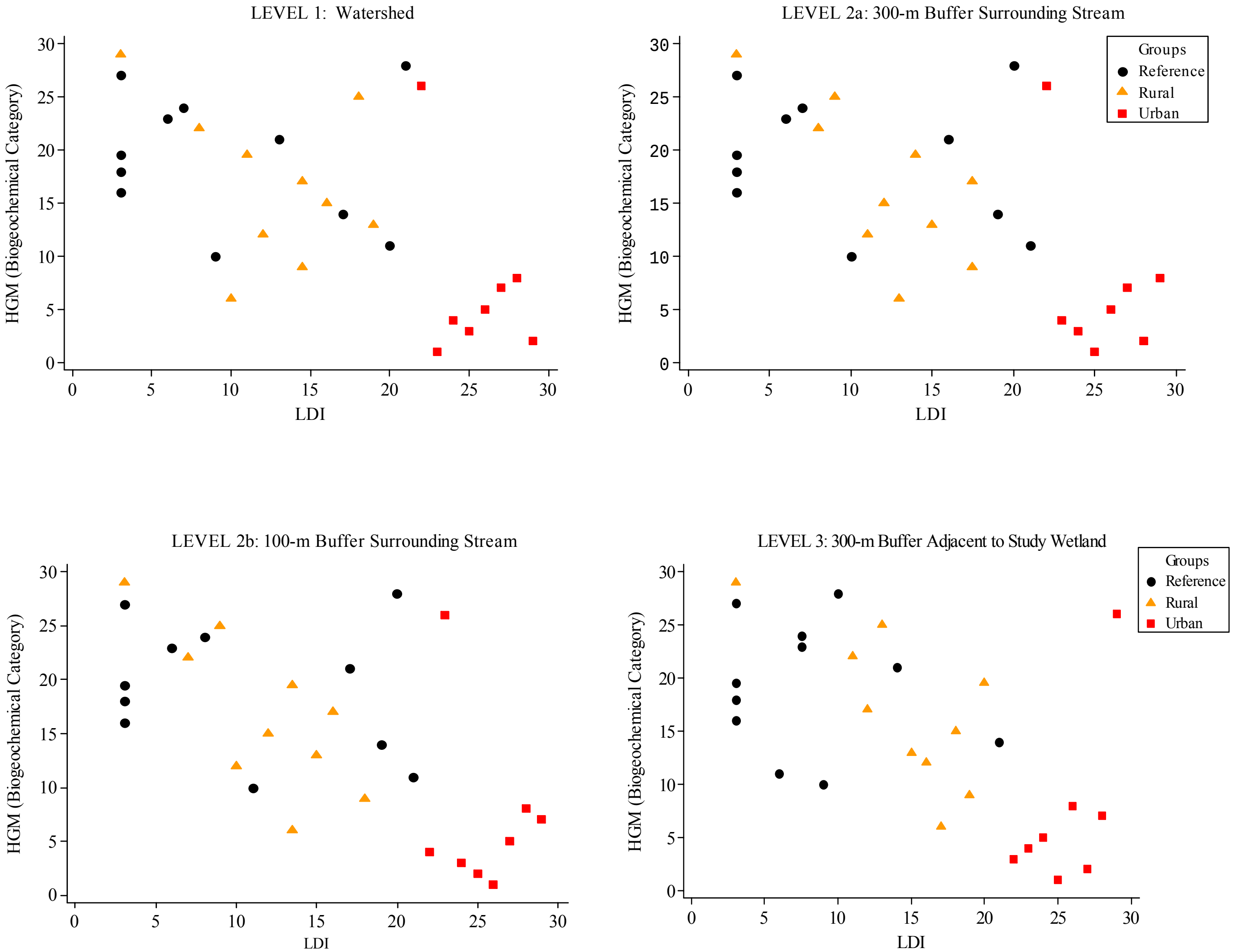


Figure 3-4. Scatterplots showing the relationship between the LDI and the WRAP for four different spatial scales. Data on both axes are shown as ranked scores.



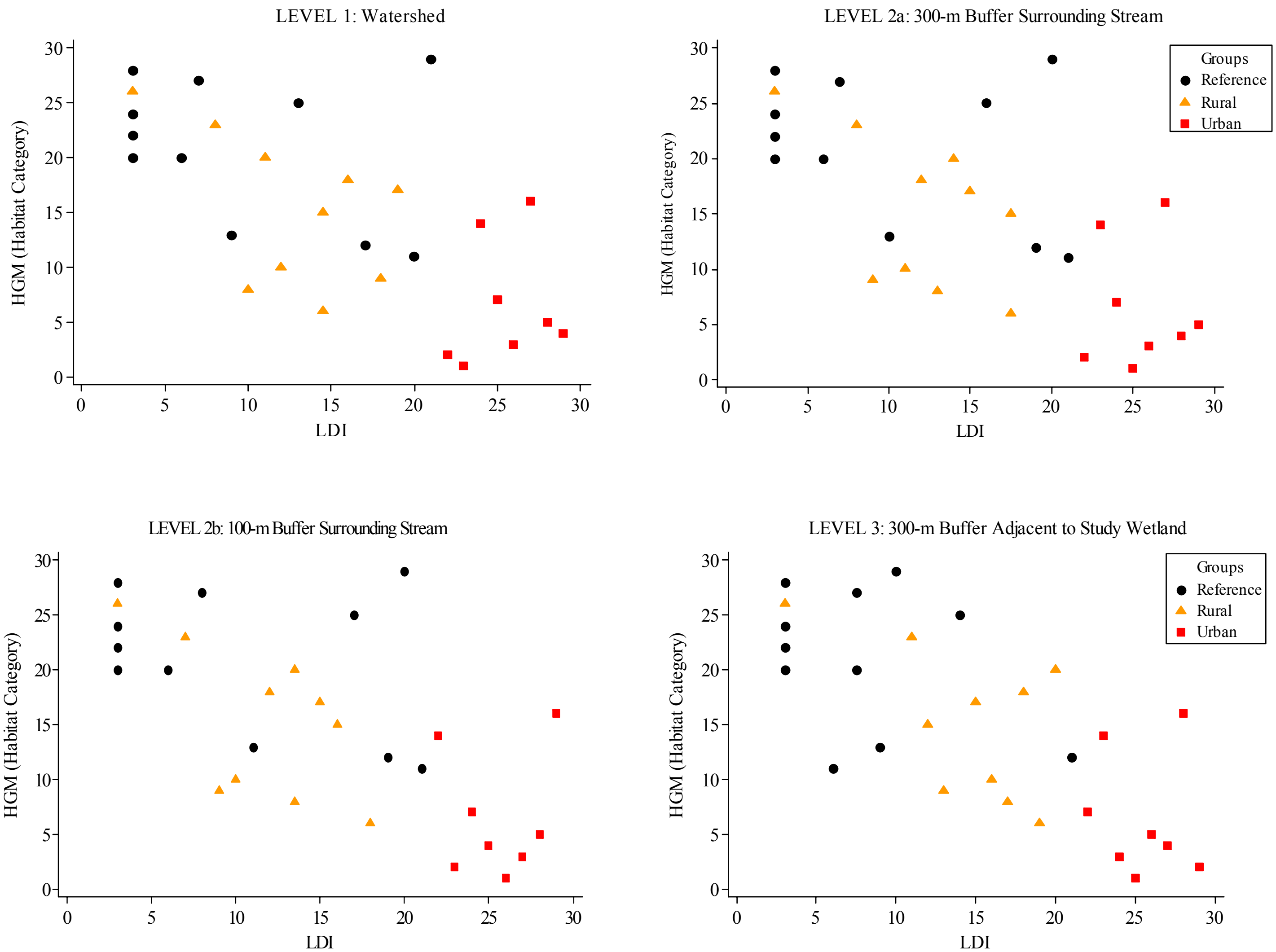
(a)

Figure 3-5a. Scatterplots showing the relationship between the LDI and the HGM hydrological category for four different spatial scales. Data on both axes are shown as ranked scores.



(b)

Figure 3-5b. Scatterplots showing the relationship between the LDI and the HGM biogeochemical category for four different spatial scales. Data on both axes are shown as ranked scores.



(c)

Figure 3-5c . Scatterplots showing the relationship between the LDI and the HGM habitat category for four different spatial scales. Data on both axes are shown as ranked scores.

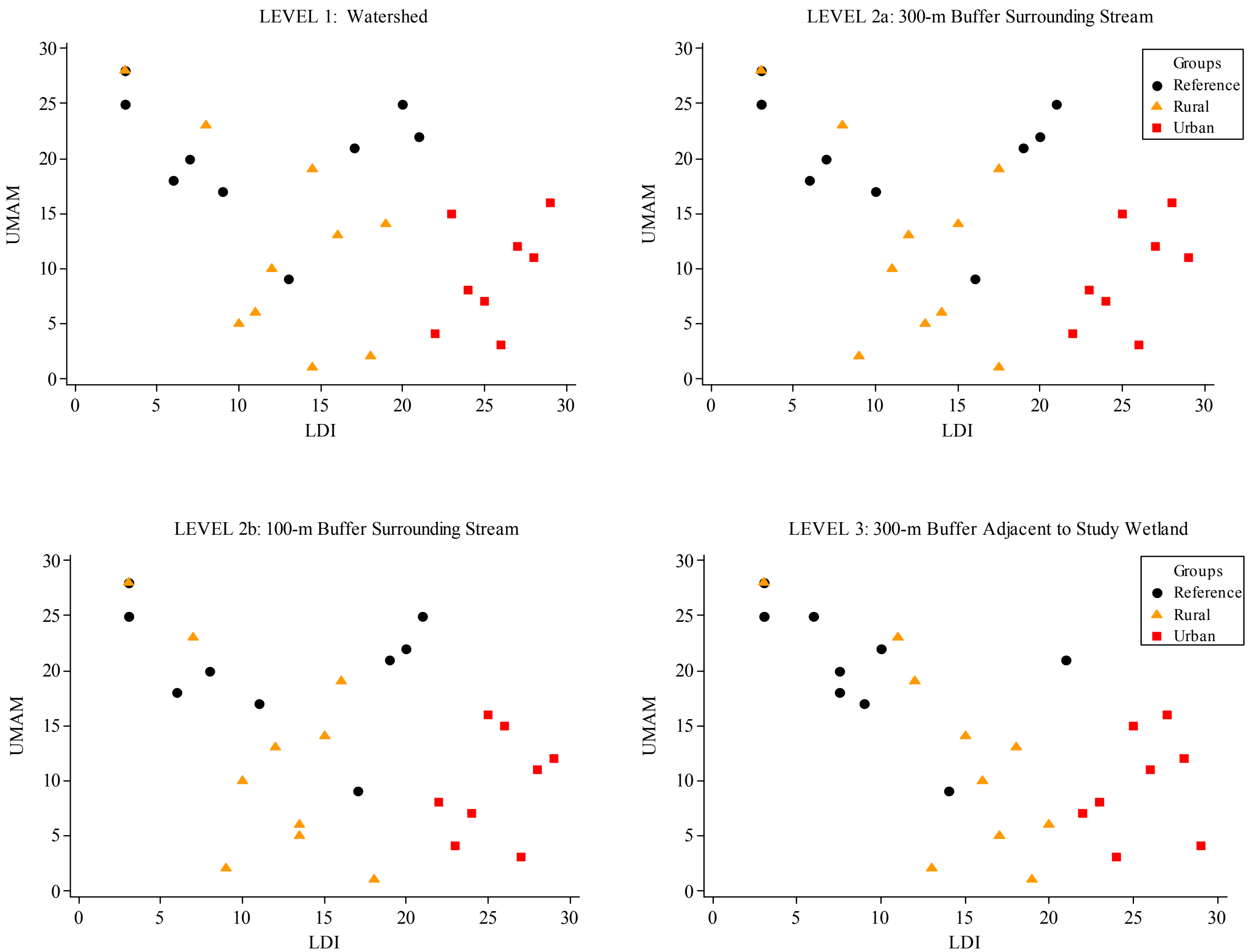


Figure 3-6. Scatterplots showing the relationship between the LDI and the UMAM for four different spatial scales. Data on both axes are shown as ranked scores.

CHAPTER 4
SUMMARY AND DISCUSSION

This study consisted of the following three inter-related objectives: 1) develop areal empower density values for land use classes based on existing LU/LC coverages of the BMW; 2) compute LDI values for floodplain forested wetlands for which three field based measures of wetland condition had been quantified; and 3) statistically determine if the LDI can be used as a predictor of wetland condition.

The first objective required three tasks: 1) a detailed evaluation of the emergy use of Arkansas to develop multipliers of emergy use for land uses, 2) integration of LU/LC coverages into a usable set of land uses classes for which detailed emergy flow data could be reasonably collected, and 3) detailed emergy evaluations of the land uses to compute areal empower density for each. The analysis of the state of Arkansas and the detailed analyses of individual land use types are presented in the Appendix.

The primary spatial data source for development of the land use classes was the 1999 Arkansas LU/LC: Summer (CAST 2001), referred to hereafter as 1999 AR-LC/LU coverage. The coverage consisted of 46 LU/LC classes, from which 20 LU/LC classes were defined and their areal empower density calculated. Systems diagrams were developed and used as an inventory guide for collecting material and energy flow data for each land use class. These data were used to develop emergy tables from which areal empower density was computed.

The second objective of this study was to calculate LDI scores for floodplain forested wetlands in the BMW. A total of 29 wetlands were selected from within various landscape settings including natural, agricultural, and urban land uses. The *a priori* selection of wetlands provided a range of landscapes that represented a gradient from undeveloped to highly developed lands, although intermediate disturbances were lacking in the data set.

The method of calculating LDI scores for wetlands differed somewhat from previous studies in Florida; LDIs are not calculated for individual land use and then averaged, but instead the areal empower density was computed for the entire area of influence of each wetland and then an LDI was calculated using a deci-log formula that included a reference state. The result is a more robust LDI score since it does not result from the averages of LDIs but instead from the average of the areal empower densities.

To test the appropriate spatial scale over which the LDI score should be calculated, LDI scores for each wetland study plot were computed for four different spatial scales. There were strong correlations between all four scales; however, the smallest scale (Level 3; 300-meter buffer surround the wetland study plot) seems to be a better predictor of wetland condition. LDI scores computed at the larger spatial scales had higher LDI scores than the Level 3 scores, reflecting the intense development in the large watershed. However, it appears that wetland condition responds to localized impacts more strongly than to conditions in upstream watersheds. This was also found in the earlier work on LDI in Florida (Brown and Vivas 2005; Lane et al. 2003; Reiss and Brown 2005; Reiss 2006).

The final objective was to correlate the LDI scores of the wetland study plots with several indices of wetland condition. Strong correlations between the LDI scores and the WRAP were found, especially at the Level 3 spatial scale. Correlations between the LDI scores and the HGM were also relatively high, particularly when the LDI scores were related to the habitat component of the HGM at the Level 3 spatial scale. Of the HGM categories, the habitat component had the strongest correlations with LDI scores. The relationship between the LDI and the UMAM was not as strong.

Land Use Land Cover Data Sources

The 1999 AR-LU/LC coverage emphasized agricultural land uses and forest classes providing only general descriptions for urban land uses and surface water cover. Because of the general description of urban land uses and water cover provided by the Arkansas LU/LC map, these categories had to be aggregated or disaggregated to fit the requirements needed for LDI calculations based on functional land use categories. This was done using partial coverages for urban centers in the BMW provided by Metroplan, Arkansas, through the MAWPT, and aerial photography. To determine housing densities for residential areas, houses were counted within one hectare plots laid on aerial photos. Aquatic systems, both natural and constructed, were determined using a combination of thematic coverages available through Geostor, a web-based database containing all publicly available geodata for the state of Arkansas (http://www.cast.uark.edu/cast/geostor/), and identification of land uses using aerial photography. Integrating all of these coverages using GIS allowed obtaining a working LU/LC coverage for the BMW.

The steps followed here to identify functional LDI land use classes can be replicated for other regions where similar LDI studies may be intended. In the absence of more detailed and recent data, the 1999 Arkansas LU/LC: Summer map provides detailed information on agricultural land uses. Information on forest classes can be easily aggregated with enough knowledge of the forest types used in the map into two classes, uplands and wetlands. For the purpose of areal empower density calculation these two forest categories may provide the level of detail needed. For urban areas, if more complete urban converges exist for other regions a more accurate representation of urban land uses will be possible. However, even with general spatial data for a given area as was the case for the BMW, LU/LC classes will be able to be identified that will fit LDI calculation needs. Baseline housing densities estimates from aerial photos can be easily determined, especially for urban areas with low tree cover. Finally, Geostor provides data that complements the 1999 Arkansas LU/LC: Summer map with coverages for aquatic (e.g., rivers, lakes, reservoirs, canals) and transportation systems (e.g., roads, railroads). Only a small set of land uses presented some difficulty for its accurate representation. The 1999 Arkansas LU/LC: Summer map presents a category for no data that was partially identified using aerial photography. After merging the 1999 Arkansas LU/LC: Summer map with the existing maps for aquatic systems from the Geostor database and those determined using remote data, some undefined water areas still remained. A visual identification of these areas using aerial photographs showed that these areas most probably corresponded to rice fields (wet stage) and managed ponds (aquaculture). These areas were incorporated in the final LU/LC map as a separate land use category. To accurately identify undefined land use areas, field visits to these areas are suggested. However, if the unidentified areas are relatively small and their identification though aerial photography suggests that these may belong to a well-defined land cover (e.g., agriculture), the areal empower density for a similar land use type (or a combination of land use types) may serve as a good approximation of energy flows within these areas.

Areal Empower Densities for Land Uses

Emergy evaluation results for each land use showed no major departures from similar studies in Arkansas and Florida. For Arkansas, Odum et al. (1998) developed emergy evaluations for land uses for the Cache River watershed in the northeastern portion of the state. These included an emergy evaluation of the Black Swamp and emergy evaluations for rice, soybeans, sorghum, and corn. Our results were similar to those reported by Odum and colleagues (1998). Where some differences were noted for the results of the study of the Cache River watershed and this study, they can be attributed to differences in data sources and number of inputs considered in the emergy evaluations. However, results for both studies were within the range of emergy values usually reported for agricultural crops for industrialized regions. In Florida, Brandt-Williams (2001) calculated the areal empower density of a variety of agricultural land uses. The results for the Florida study and for this research were very similar.

The areal empower densities computed for urban land uses were higher in this study than those reported by Brown and Vivas (2005) in the state of Florida. Among the residential land uses differences can be partially attributed to different housing densities used in the two studies and partially to differences in data sources. For non-residential land uses (i.e., commercial, institutional, industrial, and transportation) more complete data sources may account for most of the differences. The previous studies of Florida urban land uses were primarily completed in the 1980s and 1990s. Data sources nowadays are more completed and our methods of analysis have matured. So it is not unexpected that the more complete data and improved methods of analysis would result in slightly different emergy flow data for urban land uses. However, the areal empower densities computed in this study were within the range of values reported for urban land uses for developed regions.

A Landscape Assessment of Wetland Ecological Condition

Correlations between the LDI and indices of ecosystem condition, including wetland condition indices (Lane et al. 2003; Reiss and Brown 2005; Reiss 2006), the Stream Condition Index for Florida (Fore 2004), the Lake Vegetation Index (Fore 2005), rapid wetland assessment methods (Reiss 2004; Brown and Vivas 2005), and measures of the human disturbance gradient (Reiss 2004; Fore 2004; Mack 2006) suggest that the LDI may capture in one index the combined action of various factors that result from human activity that influence ecosystem structure and functioning.

In this study the LDI was correlated with three rapid field procedures for wetland condition: the WRAP, the HGM, and the UMAM to test the usefulness of the LDI as a Level 1 assessment method. The LDI was calculated for four areas of different sizes surrounding 29 floodplain wetlands in the BMW. The WRAP, UMAM, and HGM indices were computed for these wetlands by the MAWPT staff based on their field visits conducted in the Fall of 2005.

The wetland condition scores (see Table 3-3) when compared to the four LDI scores exhibited intermixing of reference wetlands and rural wetlands along the LDI disturbance gradient. Since there were very few natural areas within the BMW from which reference wetlands (low human-impacted sites) could be selected this result is not unexpected, as some of the reference sites had to be chosen from within agricultural landscapes and wetland study plots were located within local buffers of forested lands. This selection resulted in similar non-renewable and purchased areal empower density values for some of the reference and rural sites. This outcome was more evident at the broader landscape scales.

Correlations between the UMAM and LDI scores were the weakest correlation among the variables analyzed. In general, UMAM scores for the rural sites and the urban sites were approximately within the same range of values and did not show an alignment along the disturbance gradient. Inspection of the UMAN scores related to WRAP and HGM reveals that consistently, the UMAM scores were higher for urban wetland study plots and tended to be somewhat lower for reference and rural sites. The reason for this is not entirely clear. In this study, the functional component of the UMAM that assesses location and landscape support was not scored to avoid redundancy with the LDI, and only the water environment and community structure categories of the UMAM were measured. It should be noted that the HGM hydrological component also had the lowest correlation with LDI scores (see Table 3-4).

Among the different scales of landscapes considered in the calculation of LDI values for the wetland study plots, the Level 3 - 300 meters adjacent to the study plots, exhibited the strongest correlations with the WRAP and with the habitat and hydrological categories of the HGM. These results agree with Brown and Vivas (2005), who found that LDIs computed for 100-meter buffer areas surrounding small wetlands (< 2 hectares) had stronger correlations with wetland condition than larger areas.

Conclusions

Using existing LU/LC data for the BMW a group of 20 land use classes were identified for which the emergy use per unit area per time or areal empower density (units: sej/ha/yr) was calculated. The areal empower density values of the non-renewable and purchased energies for the 20 land use classes were comparable to those reported for similar land uses in Arkansas (Odum et al. 1998) and Florida (Brandt-Williams 2001; Brown and Vivas 2005). Thus, the areal empower densities calculated here can be used in other regions within Arkansas and possibly in other regions of the country.

LDI scores were computed from areal empower densities of land uses for four different scale landscape regions surrounding 29 floodplain wetlands in the BMW. LDI scores were correlated with three independent measures of wetlands condition: the WRAP, HGM, and the UMAM. The LDI showed fair to good correlations with these indices with the highest correlations reported with the WRAP and the habitat category of the HGM. Since the LDI has been developed and applied mostly in Florida, it has been suggested that it should be tested in other regions to further assess its validity and utility as an assessment tool (Mack 2006). Results from the use of the LDI in the BMW provide additional supportive evidence of the usefulness of the LDI as a Level 1 assessment procedure for the estimation of wetland condition.

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APPENDIX A
EMERGY EVALUATION OF THE STATE OF ARKANSAS AND LAND USES OF THE BAYOU METO WATERSHED

Introduction

Emergy and Emergy Analysis

Emergy analysis is an environmental accounting procedure for estimating the work required for a product or process in units of one kind of energy, and allows the relation of economic development with environmental change. It measures the contributions of nature to the regional economy. In this section a brief explanation of the emergy concepts and measures used in this project is provided. Emergy-related definitions are summarized in Table A-1.

Table A-1. Summary of emergy definitions (from Odum 1996).

Available Energy =	Potential energy capable of doing work and being degraded in the process (units: kilocalories, joules, British thermal units)
Useful Energy =	Available energy used to increase system production and efficiency
Power =	Useful energy flow per unit time
Emergy =	Available energy of one kind previously required directly and indirectly to make a product or service (units: emjoules)
Empower =	Emergy flow per unit time (units: emjoules per time)
Transformity =	The emergy of one type required to make a unit of energy of another type. A measure of energy quality (units: emjoule per joule)
Emdollar Value =	The dollars of gross economic product equivalent to the wealth measured in emergy
Wealth =	Usable products and services however produced

Emergy and energy hierarchy

Emergy is a measure of the available energy that was used in transformations and work to make a product or service (Odum 1996). It is calculated from data on energy flows that go into the product or process; its unit of measure is the solar emergy joule or emjoule (abbreviated sej).

Because of the second energy law, all of the processes of nature and the economy can be arranged in a series, representing the hierarchy of energy. In addition, all processes use up some of the available energy to do work, dispersing that energy as heat (degraded energy) and resulting in less available energy in its output than its inputs. Thus, processes may be arranged in an energy transformation series as shown in Figure A-1. Total energy flow (power) decreases from left to right, but becomes more concentrated. Also shown is how in each step of the hierarchy some of the available energy is dispersed. Food chains, stages in the hydrological cycle, and steps in the production sectors of the economy are examples with such an organization (Odum et al 1998).

Transformity

Transformity is a measure of the hierarchy of energy. Transformity is defined as the emergy per unit energy and is a measure of energy quality (Odum 1996). Unlike the energy flow, which decreases through an energy transformation series, the emergy flow remains the same or increases if more inputs are added. Transformities are used to calculate emergy from data on energy (i.e., solar emergy = energy * solar transformity; refer to Figure A-1).

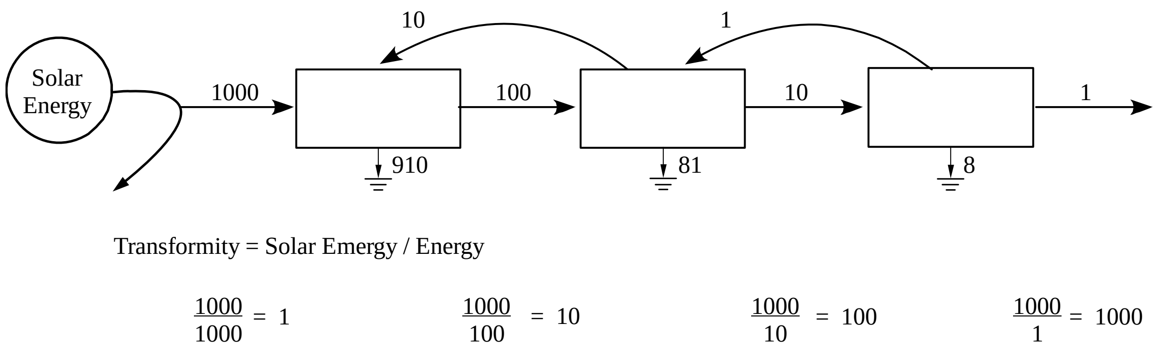


Figure A-1. A series of energy transformations forming an energy hierarchy from left to right with their corresponding transformities. Energy flow is measured as calories per time (modified from Odum et al. 1998).

Areal empower density

Power is defined as the rate of flow of energy into useful work (Odum 1994). When work is performed in a unit area we can speak of the energy flow as areal power density with units of power divided by area (e.g., watt/m^2). Similarly, a flow of emergy is empower (measured in solar emjoule per time); when it is applied in a unit area it is referred to as areal empower density and can be interpreted as a measure of work per area per time (units: sej/ha-yr) (Odum 1996). An area with high energy use, such as a city, will have a higher areal empower density than areas using less energy, such as rural areas. Since self-organizing systems develop centers of energy processing, a city is a hierarchical center with high concentrations of empower (Odum 1996).

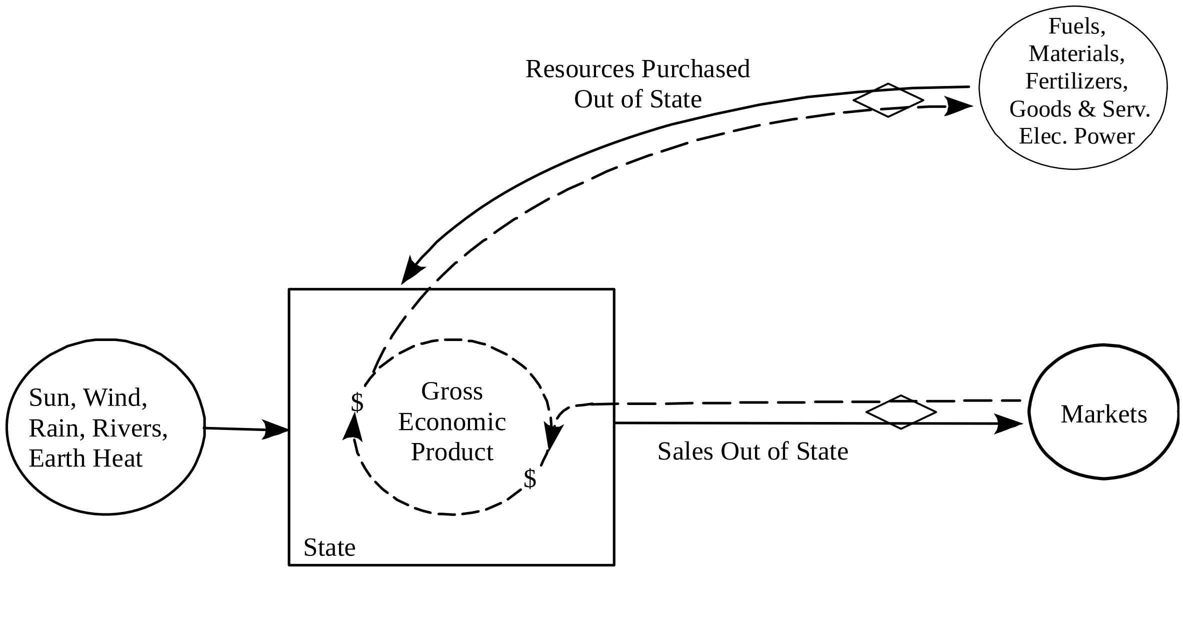
Emdollars and real wealth

The emdollar is defined as the emergy divided by the emergy/money ratio for an economy for a given year (Odum 1996). Emdollars allow the combination of environmental resource contributions on a common basis with contributions purchased by the economy. Since money is paid only to people for their contribution, money and market values cannot be used to evaluate the contribution of the environment to a process. The real wealth of an area or process includes inputs free from the environment and those purchased and transported in (Odum 1996). Emergy is a measure of real wealth since it allows evaluating the contributions from nature and those by humans on a common basis. As summarized in Figure A-2, dividing the annual emergy use by the gross economic product provides a useful measurement for relating real wealth to money.

Emergy indices

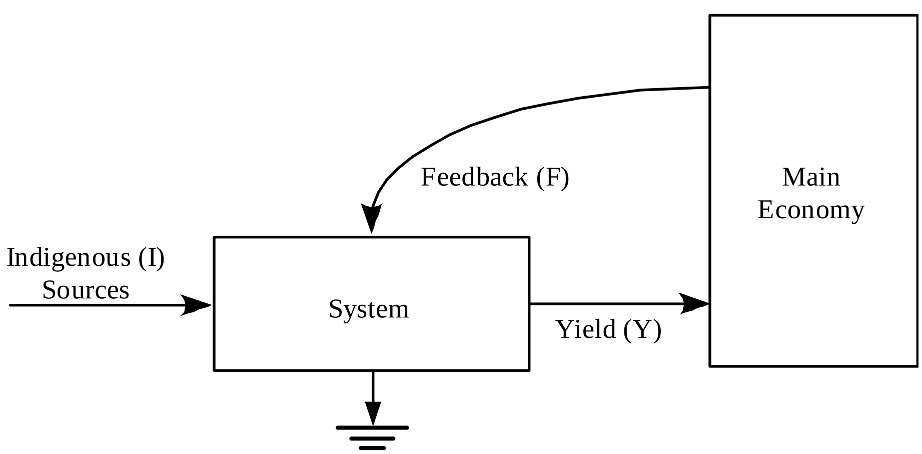
Emergy indices are useful for evaluating systems and their potential. Two commonly used ratios of emergy flows in environmental accounting are defined in Figure A-3. The emergy yield ratio is calculated by dividing the emergy of the yield (Y) flowing into the economy on the right by the emergy of all of the feedbacks (F) from the economy (e.g., fuels, fertilizers, services). The emergy yield ratio is a measure of the net contribution of a system to the economy (Odum 1996). A system with a large net emergy ratio contributes much more real wealth than is required for the process. Examples of this are rich mineral deposits and abundant fresh waters (Odum et al. 1998).

The emergy investment ratio allows the quantification of the intensity of regional economic development and the use of the environment. The emergy investment ratio is defined as the ratio of emergy purchased from the economy (F) to the emergy used free from the local environment (E). Less developed areas have lower ratio values than more developed ones. The U.S. has an investment ratio of 7, while Ecuador, which is a less developed country, has an investment ratio of less than 1 (Odum 1996).



$$\frac{\text{Empower Use}}{\text{Gross Economic Product}} = \text{Emergy/money ratio}$$

Figure A-2. Empower (emergy flow) and money circulation in a state. The emergy-to-money ratio allows evaluating emdollar of environmental contribution (modified from Odum et al. 1998).



Emergy Investment Ratio = $\frac{F}{I}$ Emergy Yield Ratio = $\frac{Y}{F}$

Figure A-3. Emergy indices used to evaluate environmental development (modified from Odum et al. 1998).

Background of Previous Studies using Emergy

Emergy accounting has allowed the relation of economic development with environmental change for a great variety of products and processes around the world. Most of this work is summarized in Odum (1996), and more recently in a series of folios published by the H.T. Odum Center for Environmental Policy of the University of Florida (Odum 2000; Odum et al. 2000; Brown and Bardi 2001; Brandt-Williams 2001; Kangas 2002), and in the proceedings of the biennial Emergy Synthesis Research Conferences initiated in 1999 (i.e., Brown 2000; Brown 2003, Brown 2005). The scientific basis of the emergy methodology is described in greater detail in Odum (1994).

The study of watersheds using emergy was begun more than 20 years ago. These studies have been directed to describe properties of watersheds, their patterns of development, and to propose management alternatives. Most of the earliest studies are summarized in Odum (1996). The work done by Odum et al. (1998) for the Cache River watershed in northeastern Arkansas is of particular relevance for the present study and seems to be the only reported case of similar studies for this state. Odum and colleagues (1998) found that environmental contributions within that system accounted for approximately half of the watersheds' wealth (measured in emergy units) while the other half was from inputs purchased from outside the system. The Cache River watershed, which is mostly an agricultural area based on indigenous soils and waters, proved to be a net emergy exporter. This study included an emergy evaluation of the Black Swamp and emergy evaluation of six production systems within the watershed: rice, soybeans, wheat, sorghum, corn, and poultry broiler production.

Odum et al. (1998) also evaluated the state of Arkansas using emergy and based on data for 1990. Arkansas was found to be 58% self-sufficient. With an emergy investment ratio of 0.73, Arkansas had a higher percentage of its economic basis supplied from the environmental emergy than more developed states like Florida or Texas. The emergy-to-money ratio was 3.45 E12 sej/$, compared to the same ratio of 1.55 E12 sej/$ for the U.S. for 1990 (Odum 1996).

For the Mississippi River Watershed, Diamond (1984) and Odum et al. (1987) evaluated the properties of stream orders based on their environmental and economic empower. These studies revealed that the geopotential energy fluxes were greatest at intermediate- to high-order levels while the delta and floodplain regions were found to be regions of emergy convergence.

Methods

Emergy evaluations are data intensive operations, requiring collection and cataloging of a variety of material and energy flows. The operation is organized into three related task; 1) drawing of system diagrams that capture the main flows of energy and materials supporting the system under study, 2) listing of data in an emergy evaluation table , and 3) summary of data through the use of indices of energy and material use that describe the system and its processes. The following provides details of each step in the methodology.

Energy System Diagramming

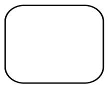
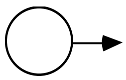
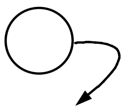
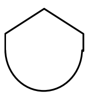
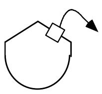
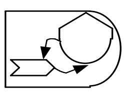
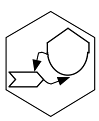
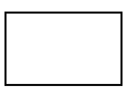
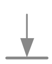
Energy system diagrams are useful since they allow the summarization of energy inputs and flows of a system and provide an overview of the main components, processes, problems, and contributing factors to a system (Odum 1996). An emergy evaluation starts with the drawing of a diagram of the system of interest. After defining the physical boundary, important outside sources are listed and drawn around the boundary from left to right in order of increasing transformity, which marks their position in the energy hierarchy (i.e., sun, wind, rain, geology, fuel, chemicals, goods, services, market, etc.). The main internal components and processes in the system are identified and drawn inside the system frame using energy system symbols. The system symbols that are commonly used are presented in Table A-2. In the diagramming process these symbols represent system components such as forests, agriculture and industrial producers, urban areas, and water and soil storages. The final step in the diagramming process is to connect pathways, interactions, and money transactions using arrows. A detailed discussion on the construction and mathematical description of energy systems diagrams and symbols is provided in Odum (1994).

Energy system diagrams showing primary components, sources, and flows were drawn for each of 20 different land uses within BMW. Diagrams were used as the basis for creating an inventory of the energy and material flows needed in emergy evaluations.

Emergy Tables

The second step in the emergy evaluation procedure is to develop emergy analysis tables. The main components of the emergy table are shown in Table A-3. A table consists of six columns: (1) the number of the line item and its footnote; (2) the name of the item to be estimated; (3) data in units of energy, mass, or cost; (4) emergy per unit (or transformities); (5) solar emergy; and (6) emdollars. Each input and output from the system were included in the table as a line item The solar emergy of each line item was estimated by multiplying the energy, mass, or money data in column 3 by the solar emergy per unit from column 4. Transformities were obtained from previous emergy studies and were referenced accordingly.

Table A-2. Primary symbols of the energy circuit diagramming.

Symbol	Name	Description
	System boundary	Defines the system being diagrammed. Lines that cross the system boundary indicate inflows and outflows of the system.
	Energy circuit	A pathway with a flow proportional to the quantity in the storage or source upstream.
	Source	A forcing function or outside source of energy delivering forces according to a program controlled from outside.
	Flow limited source	Outside source of energy with a flow that is externally controlled.
	Storage tank	A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows.
	Sensor	The sensor (small square box on storage) suggests the storage tank controls some other flow but does not supply the main energy for it.
	Producer	Unit that collects and transforms low-quality energy under the control of high-quality flows.
	Consumer	Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.
	Box	Miscellaneous symbol to use for whatever unit or function is needed.
	Heat sink	Dispersion of potential energy into heat that accompanies all real transformation processes and storages. Dispersed energy is no longer available to the system.

Separate emergy evaluation tables were prepared for each of the 20 different land uses in the BMW. Each land use was evaluated based on a spatial area of one hectare, therefore the areal empower density was derived directly from the table by summing the solar emergy for each line item.

Table A-3. Tabular format for an emergy evaluation.

Notes[a]	Item[b]	Data Units (J, g or $)	Solar Emergy/unit (sej/unit)	Solar Emergy (sej/yr)	Em$ ($/yr)
1	1				
2	2				
⋮	⋮				
n	n				

[a] Footnotes for each row of the table are placed here.
[b] One row for each source, process, or storage of interest.

Data Sources

The material flows, energy requirements, and economic data required for emergy evaluations were obtained from a variety of sources. Government sources were the first choice when the data were available, since these data are usually more reliable. As a result, a variety of federal and state publications and databases were consulted via library and electronic research. Academic sources were also widely consulted, particularly in the development of the emergy evaluations of agricultural land uses. Information provided by the agricultural extension services of different universities in Southern U.S., including the University of Arkansas, was used on multiple occasions. Published and unpublished academic documents were also widely used. Among these, a variety of documents such as reports, academic dissertations, and theses from the University of Florida were frequently used as sources for emergy-related data such as transformities, and to compare results with previous emergy evaluations and work.

When required, data were transformed to meaningful emergy units, usually mass, that can be easily converted to energy units. In all cases, data usage and conversions were reported in the footnotes for Column l of the emergy tables (see Table A-2). When required, assumptions about the data were made and also reported in the footnotes. Each source that was consulted was appropriately referenced in the footnotes section. All of the data were reported using the metric system since it is universally used and is the most convenient when data are obtained from many different sources.

Results

Emergy Evaluation of Arkansas

Energy systems diagram

The overview model of the state of Arkansas is shown in Figure A-4. The main outside environmental and purchase inputs are shown, as well as the main internal components and processes in the state. On the left of the diagram are the environmental and rural systems with their main energy sources (sun, wind, rain, rivers, and geological processes). These are production areas including forests, grasslands, wetlands, and agricultural crops. On the right side of the diagram are the consumer sectors. These are mainly located in towns and cities. Energy inputs purchased from outside including fuels, food, fertilizers, machinery, goods and services, together with inputs from within the state constitute the non-renewable resources basis used to power the economy. Arkansas exports include agricultural crops, machinery, chemicals, and meat. Additional energy flows outside the state include waste products. Summary diagrams with the aggregated pathways for evaluating the overall energy use in the state are presented in Figure A-5.

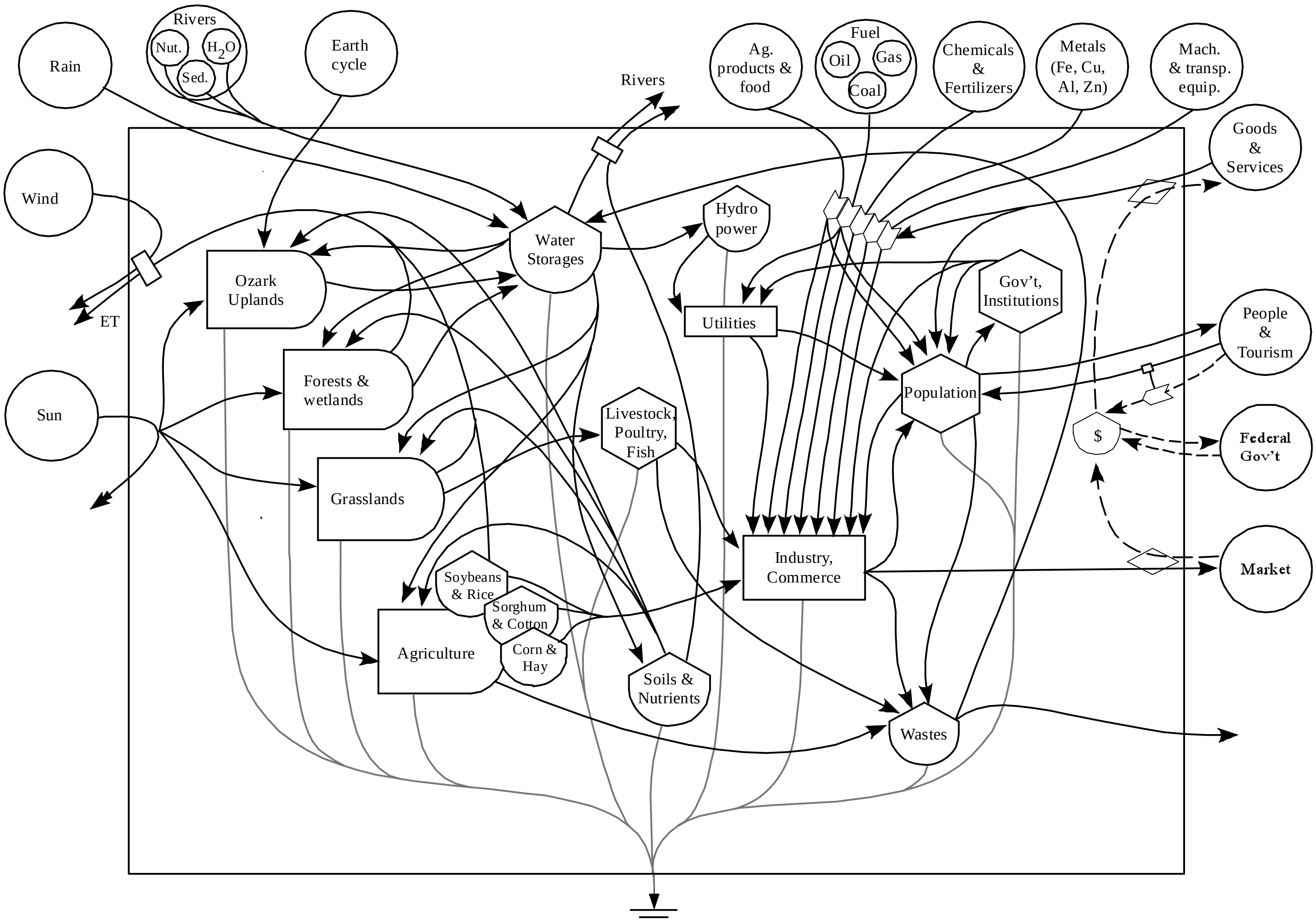


Figure A-4. Energy systems diagram for the state of Arkansas with main inputs, internal components, and pathways.

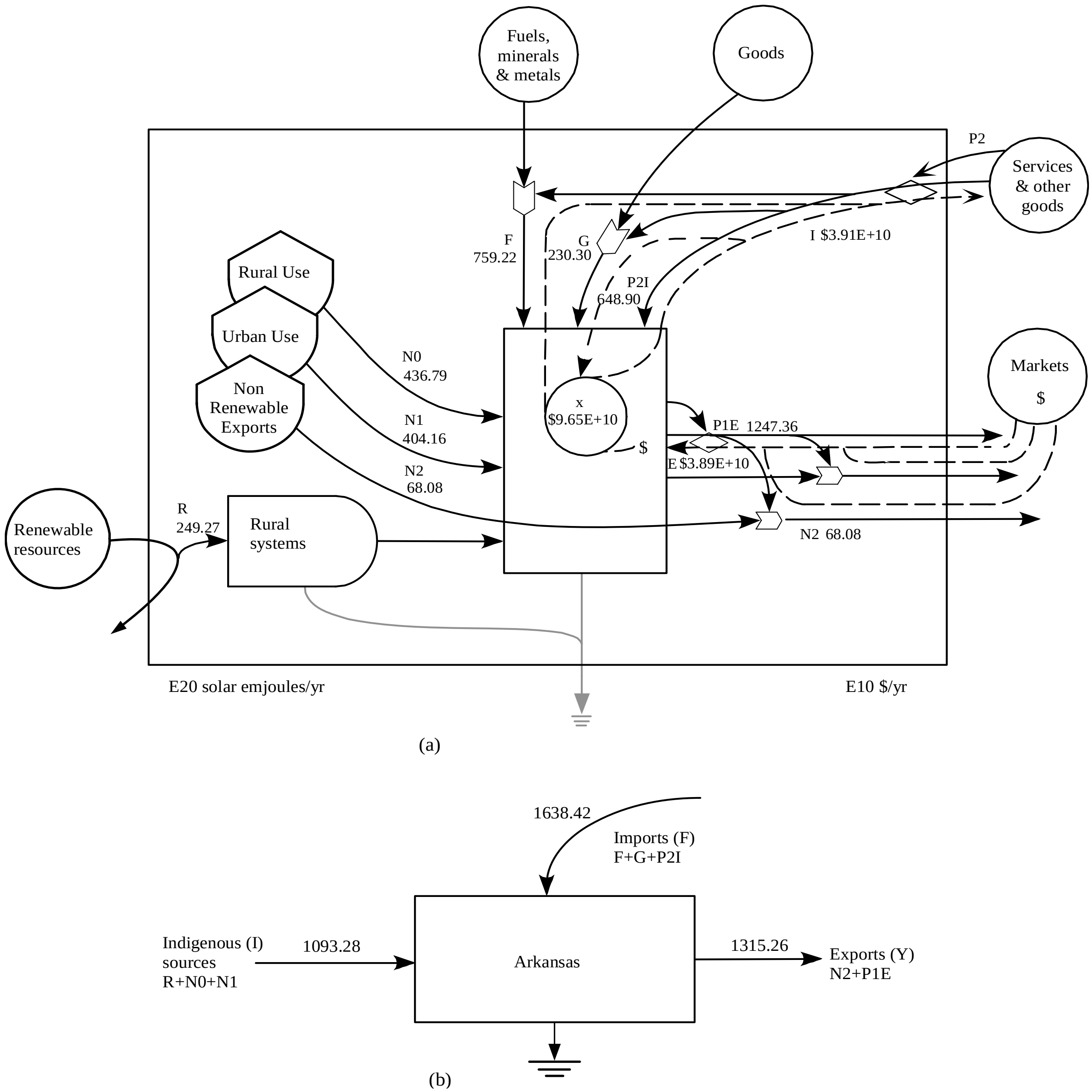


Figure A-5. Summary diagrams of emergy flows in the state of Arkansas in 2001. (a) aggregated diagram; (b) three-arm diagram aggregated further into threee flows: indigenous resources (I), imports (F), and exports (Y).

Emergy evaluation table

The emergy evaluation of the environmental inputs, imports, and exports for Arkansas are presented in Table A-4. For 2001 the total emergy used by the state's economy was 2.73 E23 sej. Contributions to the state's real wealth are shown in graph form in Figure A-6. The contributions are organized from left to right according to their position in the energy hierarchy.

The major environmental contribution to the state came from the rain's chemical potential energy, which accounts for 58% of the total renewable inputs into the system. Agriculture and livestock production (including poultry) accounted for 94% of the indigenous renewable energies. Soil losses were high, and together with electricity and natural gas, they were the most important non-renewable resources from within the system. Among the purchased inputs, fossil fuels (gas, coal, oil and its derivates) were the major inputs driving the economy together with the services of imports. Fuels represented 44% of the state's imports and services account for 38% of the total imports. Fuel imports reflect the increasing dependency on outside sources of fossil fuels, as the state's production of coal and oil has decreased over the last two decades.

Organic chemicals and meat were the top export products from the state; machinery and transportation equipment as well as agricultural products followed. The services associated with the state's exports accounted for 88% of the total exported emergy.

Emergy indices

The indices derived from the emergy evaluation table for Arkansas are presented in Table A-5 and Table A-6. Imported fuels and minerals accounted were the highest emergy imports in the state while the emergy value of goods and services was highest among exports (Table A-5). The solar emergy-to-money ratio was 2.83 E12 sej/$.

Table A-4. Emergy evaluation of resource basis for the state of Arkansas for 2001.

Note	Item	Raw Units		Transformity (sej/unit)*	Solar Emergy (E20 sej)	EmDollars (E9 US$)
RENEWABLE RESOURCES:						
1	Sunlight	6.48E+20	J	1.00E+00	6.5	0.2
2	Rain, Chemical	8.08E+17	J	3.05E+04	246.4	9.0
3	Rain, Geopotential	6.03E+15	J	4.70E+04	2.8	0.1
4	Wind, Kinetic Energy	1.38E+18	J	2.45E+03	33.9	1.2
5	Inflow River Geopotential	1.06E+17	J	4.70E+04	49.8	1.8
6	Inflow River Chemical Potential	6.44E+15	J	8.14E+04	5.2	0.2
7	Earth Cycle	1.38E+17	J	5.80E+04	79.9	2.9
INDIGENOUS RENEWABLE ENERGY:						
8	Hydroelectricity	9.17E+15	J	3.36E+05	30.8	1.1
9	Agriculture Production	1.34E+17	J	3.36E+05	448.8	16.3
10	Livestock Production	1.27E+16	J	3.36E+06	426.4	15.5
11	Fisheries Production	1.88E+14	J	3.36E+06	6.3	0.2
12	Fuelwood Production	0.00E+00	J	2.21E+04	0.0	0.0
13	Forest Extraction	9.09E+16	J	2.21E+04	20.1	0.7
						0.0
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:						
14	Natural Gas	1.84E+17	J	8.06E+04	148.3	5.2
15	Oil	4.63E+16	J	8.90E+04	41.2	1.5
16	Coal	5.08E+14	J	6.69E+04	0.3	0.0
17	Minerals (Bromine)	1.75E+11	g	2.20E+10	38.5	1.4
18	Soil Losses	1.94E+13	g	1.68E+09	325.7	11.8
19	Topsoil Losses	1.31E+16	J	7.40E+04	9.7	0.4
20	Groundwater	4.69E+16	J	1.60E+05	75.0	2.7
21	Electricity	5.32E+16	J	3.36E+05	178.8	6.3

Table A-3. Continued.

Note	Item	Raw Units		Transformity (sej/unit)*	Solar Emergy (E20 sej)	EmDollars (E9 US$)
IMPORTS AND OUTSIDE SOURCES:						
22	Fuels	8.79E+17	J	8.55E+04	751.3	26.5
23	Metals	1.02E+11	g	7.75E+09	7.9	0.3
24	Fertilizers	2.32E+11	g	2.19E+10	50.8	1.8
25	Agricultural Products	2.27E+15	J	3.36E+05	7.6	0.3
26	Meat, Fish & Related Foods	1.57E+14	J	3.36E+06	5.3	0.2
27	Plastics & Rubber	2.56E+15	J	1.11E+05	2.8	0.1
28	Chemicals (incl. pesticides)	1.92E+11	g	2.49E+10	47.6	1.7
29	Finished Materials	4.32E+11	g	1.89E+09	8.1	0.3
30	Machinery & Transportation Equipment	1.61E+12	g	6.70E+09	108.0	3.9
31	Services in Imports	3.91E+10	$	1.66E+12	648.9	23.6
32	Tourism	3.81E+09	$	1.66E+12	63.3	2.3
EXPORTS:						
33	Agricultural Products	3.92E+15	J	3.36E+05	13.2	0.5
34	Meat	1.06E+15	J	3.36E+06	35.6	1.3
35	Paper/Paperboard	2.16E+11	g	3.69E+09	8.0	0.3
36	Fuels	0.00E+00	J	0.00E+00	0.0	0.0
37	Metals	1.88E+11	g	6.13E+09	11.5	0.4
38	Minerals (bromine)	3.08E+10	g	2.20E+10	6.8	0.2
39	Organic Chemicals	2.00E+11	g	2.49E+10	49.8	1.8
40	Machinery & Transportation Equipment	2.91E+11	g	6.70E+09	19.5	0.7
41	Plastics	7.76E+14	J	1.11E+05	0.9	0.0
42	Services in Exports	3.89E+10	$	2.75E+12	1071.4	38.9

* Transformity based on a global renewable emergy flow of 15.83E24 sej/yr (Odum et al. 2000).

Table A-3. Continued

Footnotes:

RENEWABLE RESOURCES:					**References:**
1	SOLAR ENERGY:				
	Cont Shelf Area =	0.00E+00	m^2		
	Land Area =	1.38E+11	m^2		(AGC; www.state.ar.us/agc)
	Insolation =	1.41E+02	$Kcal/cm^2/yr$		(Odum et al. 1998)
	Albedo =	0.20	(% given as decimal)		(After www.nasa.gov)
	Energy(J) =	(area incl. shelf)(avg. insolation)(1-albedo)			
	=	(__m^2)(__$Cal/cm^2/y$)(E+04cm^2/m^2)(1-albedo)(4186J/kcal)			
	=	6.48E+20	J/yr		
	Transformity =	1.00+00	sej/J		(Odum 1996)
2	RAIN, CHEMICAL POTENTIAL ENERGY:				
	Land Area =	1.38E+11	m^2		
	Cont Shelf Area =	0.00E+00	m^2		
	Rain (land) =	1.21	m/yr		(www.noaa.gov)
	Rain (shelf) =	0.00	m/yr		
	Evapotranspiration rate =	1.19	m/yr		(Odum et al. 1998)
	Energy (land) (J) =	(area)(Evapotranspiration)(Gibbs no.)			
	=	(__m^2)(__m)(1000kg/m^3)(4.94E3J/kg)			
	=	8.08E+17	J/yr		
	Energy (shelf) (J) =	(area of shelf)(Rainfall)(Gibbs no.)			
	=	0.00E+00	J/yr		
	Total energy (J) =	8.08E+17	J/yr		
	Transformity =	3.05E+04	sej/J		(Odum et al. 2000)
3	RAIN, GEOPOTENTIAL ENERGY:				
	Area =	1.38E+11	m^2		
	Rainfall =	1.21	m		
	Avg. Elev. =	198.12	m	(650 feet)	(Carpenter & Provorse 1998)
	Runoff rate =	0.02	%	(percent, given as a decimal)	
	Energy(J) =	(area)(rainfall)(% runoff)(avg. elevation)(gravity)			
	=	(__m^2)(__m)(__%)(1000kg/m^3)(_m)(9.8m/s^2)			
	=	6.03E+15	J/yr		
	Transformity =	4.70E+04	sej/J		(Odum 2000)
4	WIND ENERGY:				
	Area =	1.38E+11	m^2		
	Density of air =	1.23E+00	kg/m^3		(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps		(Data for Little Rock, 2000; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps		(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03			(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)($velocity^3$)			
	=	(__m^2)(1.3 kg/ m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)			
	Energy(J) =	1.38E+18	J/yr		
	Transformity =	2.45E+03	sej/J		(Odum et al. 2000)
5	RIVER GEOPOTENTIAL:				
	Major inflowing rivers: Arkansas and Mississippi rivers				
	Flow in Arkansas River =	1.02E+03	m^3/s		(At Dardanelle, AR, data for 2001; www.usgs.gov)
	Elevation in =	2.10E+02	m		(Odum et al. 1998)
	Elevation out =	3.05E+01	m		
	Energy (J) =	(volume)(density)(height in-height out)(gravity)			
	=	(__m^3)(1.0E3kg/m^3)(__m - __m)(9.8 m/sec^2)			
	Energy (J) =	5.66E+16	J/yr		
	Flow in Mississippi River =	1.33E+04	m^3/s		(Odum et al. 1998)
	Elevation in =	4.50E+01	m		(Odum et al. 1998)

	Elevation out =	2.10E+01	m	
	Energy (J) =	(volume)(density)(height in-height out)(gravity)		
	=	(__m^3)(1.0E3kg/m^3)(__m - __m)(9.8 m/sec^2)		
	Energy =	9.86E+16	J/yr	
	Energy used in the State =	4.93E+16	J/yr	(Assumed 1/2 used after Odum et al. 1998)
	Total energy =	1.06E+17	J/yr	
	Transformity =	4.70E+04	sej/J	(Odum et al. 2000)
6	RIVER CHEMICAL POTENTIAL:			
	Gibbs free energy =	[(8.3143 J/mol/deg)(288 K)/(18 g/mol)] * ln [(1e6 - Solutes)ppm)/965000]		
	Dissolved solids in =	2.00E+02	ppm	(Odum et al. 1998)
	Dissolved solids out =	4.00E+02	ppm	(Odum et al. 1998)
	Gibbs free energy in =	4.71E+00	J/g	
	Gibbs free energy out =	4.69E+00	J/g	
	Flow in Arkansas River =	1.02E+03	m^3/s	
	Energy (J) =	(volume)(density)(Gibbs free energy)		
	=	(__m^3/s)(1.0E3 kg/ m^3)(__J/g)		
	Energy in =	1.52E+17	J/yr	
	Energy out =	1.51E+17	J/yr	
	In- Out =	8.57E+14	J/yr	
	Flow in Mississippi River =	1.33E+04	m^3/s	
	Energy in =	1.98E+18	J/yr	
	Energy out =	1.97E+18	J/yr	
	In- Out =	1.12E+16	J/yr	
	Energy Used in the State =	5.58E+15	J/yr	(Assumed 1/2 used)
	Total Energy =	6.44E+15	J/yr	
	Transformity =	8.14E+04	sej/J	(Odum 1996)
7	EARTH CYCLE:			
	Land area =	1.38E+11	m^2	
	Heat flow =	1.00E+06	J/ m^2	(Odum et al. 1998)
	Energy (J) =	(area)(Heat flow)		
	Energy (J) =	(__m^2)(1.00E6 J/ m^2)		
	=	1.38E+17	J/yr	
	Transformity =	5.80E+04	sej/J	(Odum 2000)

INDIGENOUS RENEWABLE ENERGY

8	HYDROELECTRICITY:			
	Kilowatt Hrs/yr =	2.55E+09	KwH/yr	(APSC, 2001 data; www.arkansas.gov/psc)
	Energy (J) =	(Energy production)(energy content)		
	Energy (J) =	(__KwH/yr)(3.6 E6 J/KwH)		
	=	9.17E+15	J/yr	
	Transformity =	3.36E+05	sej/J	(Odum 1996)
9	AGRICULTURAL PRODUCTION:			
	Rice =	4.67E+06	MT/yr	(USDA, 2001data; www.nass.usda.gov/ar)
	Sorghum =	3.71E+05	MT/yr	
	Cotton =	3.99E+05	MT/yr	
	Soybeans =	2.48E+06	MT/yr	
	Corn =	6.81E+05	MT/yr	
	Wheat =	1.37E+06	MT/yr	
	Total production =	9.97E+06	MT/yr	(dry mass, 20% humidity)
	Energy (J) =	(Total production)(energy content)		
	Energy (J) =	(__ MT/yr)(1E06 g/MT)(80%)(4.0 kcal/g)(4186 J/kcal)		
	=	1.34E+17	J/yr	
	Transformity =	3.36E+05	sej/J	(Brown & McClanaham 1996)

10 LIVESTOCK PRODUCTION:
Cattle = 3.36E+05 MT/yr (USDA, 2001data; www.nass.usda.gov/ar)
Pigs = 5.13E+04 MT/yr
Poultry = 2.64E+06 MT/yr
Livestock production = 3.03E+06 MT/yr (80% humidity)
Energy (J) = (Total production)(energy content)
Energy(J) = (__MT/yr)(1E+06 g/MT)(20%)(5.0 KCal/g)(4186 J/KCal)
= 1.27E+16 J/yr
Transformity = 3.36E+06 sej/J (Brown & McClanaham 1996)

11 FISHERIES PRODUCTION:
Fish Catch = 4.49E+04 MT/yr (80% humidity) (USDA, 2001data; www.nass.usda.gov/ar)
Energy (J) = (Total production)(energy content)
Energy (J) = (__MT)(1E+06 g/MT)(5.0 KCal/g)(20%)(4186 J/KCal)
= 1.88E+14 J/yr
Transformity = 3.36E+06 sej/J (Brown & McClanaham 1996)

12 FUELWOOD PRODUCTION:
Fuelwood Prod = 0.00E+00 m^3
Energy (J) = (Total production)(energy content)
Energy (J) = (__m^3)(0.5E6g/ m^3)(3.6 kcal/g)(80%)(4186 J/kcal)
= 0.00E+00 J/yr
Transformity = 2.21E+04 sej/J (Romitelli 2000)

13 FOREST EXTRACTION:
Harvest = 1.51E+07 m^3 (After Mehmood & Pelkki 2005)
Energy (J) = (Total production)(energy content)
Energy (J) = (__m^3)(0.5E+06 g/ m^3)(80%)(3.6 kcal/g)(4186 J/kcal)
= 9.09E+16 J/yr
Transformity = 2.21E+04 sej/J (Romitelli 2000)

NONRENEWABLE RESOURCE USE FROM WITHIN THE STATE

14 NATURAL GAS:
Consumption = 4.90E+06 m^3/yr (ADED 2003)
Energy (J) = (__m^3/yr)(energy content)
Energy (J) = (__m^3/yr)(8966 kcal/ m^3)(4186 J/kcal)
= 1.84E+14 J/yr
Transformity = 4.80E+04 sej/J (Odum 1996)

15 OIL:
Consumption = 7.59E+06 barrels (ADED 2003)
Energy (J) = (__barrel/yr)(energy content)
Energy (J) = (__barrel/yr)(6.1E9 Joules/barrel)
= 4.63E+16 J/yr
Transformity = 8.90E+04 sej/J (Odum 1996)

16 COAL:
Consumption = 1.75E+04 MT/yr (AGC; www.state.ar.us/agc)
Energy (J) = (__MT/yr)(energy content)
Energy (J) = (__MT/yr)(2.9E+10 J/MT)
= 5.08E+14 J/yr
Transformity = 6.69E+04 sej/J (Odum 1996)

17 MINERALS (Bromine):
Consumption = 1.75E+05 MT/yr (AGC; www.state.ar.us/agc)
Mass (g) = (__E5 MT)(1E6 g/MT)
= 1.75E+11 g/yr
Transformity (weighed) = 2.20E+10 sej/g (Odum et al. 1998)

18/19 TOPSOIL AND SOM:

Harvested cropland =	3.88E+10	m^2	(www.ers.usda.gov)
Soil loss =	5.00E+02	$g/m^2/yr$	(Odum et al. 1998)
Average organic content (%) =	3	%	
Energy (J) =	(__ g/ m^2/yr)(__ m^2)(% organic)(5.4 Kcal/g)(4186 J/Kcal)		
=	1.31E+16	J/yr	
Mass (g) =	1.94E+13	g/yr	
Transformity Soil =	1.68E+09	sej/g	(Odum 1996)
Transformity SOM =	7.40E+04	sej/J	(Brown & Bardi 2001)

20 GROUNDWATER:

Groundwater consumption =	6.92E+03	Mgal/day	(http://water.usgs.gov, data for 2000)
=	9.57E+09	m^3/yr	
Energy (J) =	chemical potential of groundwater		
Energy (J) =	(volume)(density)(Gibbs no.)		
=	(__m^3/yr)(1.0E6 g/ m^3)(4.94J/g)		
=	4.69E+16	J/yr	
Transformity =	1.60E+05	sej/J	(Odum et al. 1998)

21 ELECTRICITY:

Kilowatt Hrs/yr =	1.48E+10	KwH/yr	(EAI, 2001 data; www.arkansas.gov/psc)
Energy (J) =	(Energy production)(energy content)		
Energy (J) =	(__KwH/yr)(3.6 E6 J/KwH)		
=	5.32E+16	J/yr	
Transformity =	1.60E+05	sej/J	(Odum 1996)

IMPORTS OF OUTSIDE ENERGY SOURCES:

22 FUELS: (EIA, State Energy Data 2001; www.eia.doe.gov)

			Transformity		
Total natural gas used =	7.11E+09	m^3/yr			
Used-produced =	7.10E+09	m^3/yr			
Energy (J) =	(__m^3/yr)(8966 kcal/m^3)(4186 J/kcal)				
Total oil used =	7.10E+07	barrels			
Used-produced =	6.34E+07	barrels			
Energy (J) =	(__ barrel/yr)(6.1E9 Joules/barrel)				
Total coal used =	1.41E+07	MT/yr			
Used-produced =	1.41E+07	MT/yr			
Energy (J) =	(_ MT/yr)(2.9E10 J/Mt)				
Natural gas =	2.67E+17	J/yr	5.88E+04	sej/J	(Romitelli 2000)
Oil derived fuels =	3.87E+17	J/yr	1.11E+05	sej/J	(Odum 1996)
Coal =	4.09E+17	J/yr	6.69E+04	sej/J	(Odum 1996)
=	1.06E+18	J/yr			
Transformity (weighed) =	8.09E+04	sej/J			

23 METALS:

Estimates as fraction of US imports of metals in 2001. (Data from UN Statistics Division; http://unstats.un.org)

			Transformity		
Aluminum unwrought =	2.68E+06	MT/yr	1.43E+09	sej/g	(Odum 1996)
Aluminum worked =	8.77E+05	MT/yr	1.25E+10	sej/g	(Brown & Buranakam 2000)
Iron ore =	4.68E+06	MT/yr	1.44E+09	sej/g	(Odum 1996)
Steel =	2.18E+06	MT/yr	4.13E+09	sej/g	(Brown & Buranakam 2000)
Copper wire =	3.16E+05	MT/yr	1.66E+11	sej/g	(Odum 1996)
US imports =	1.07E+07	MT/yr	7.75E+09	sej/g	
Fraction =	9.50E-03		(Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)		
State imports =	1.02E+05	MT/yr			
Mass (g) =	(__MT/yr)(1E6 g/MT)				
=	1.02E+11	g/yr			
Transformity (weighed) =	7.75E+09	sej/g			

24 FERTILIZERS:

Estimates were done considering the use of fertilizer per crop and the area planted by crop in the State.

Fertilizer used/ha	N	P2O5	K2O	Area	
	Kg/ha	Kg/ha	Kg/ha	ha	
Sorghum	37.8	3.4	0.9	7.08E+04	(Odum et al. 1998)
Wheat	89.7	1.12	0	4.45E+05	
Rice	134.5	0	33.6	6.60E+05	(www.nass.usda.gov/ar)
Cotton	40	16	17	4.37E+05	
Soybeans	5.61	0	33.6	1.17E+06	

	Consumption		Transformity		
Phosphorus =	7.73E+03	MT/yr	2.99E+10	sej/g	(Odum 1996)
Potash =	6.91E+04	MT/yr	2.92E+09	sej/g	(Odum 1996)
Nitrogen =	1.55E+05	MT/yr	7.73E+09	sej/g	(Odum 1996)
Total consumption =	2.32E+05	MT/yr	2.19E+10	sej/g	

Mass (g) = (__E6 MT/yr)(1E6 g/MT)
= 2.32E+11 g/yr
Transformity (weighed) = 2.19E+10 sej/g

25 AGRICULTURAL PRODUCTS:

Estimates were done as fraction of US imports of agricultural products in 2001.

US imports = 2.04E+07 MT/yr (UN Statistics Division; http://unstats.un.org)
Fraction = 9.50E-03 (Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports = 1.94E+05 MT/yr
Energy (J) = (__ MT/yr)(1E6g/MT)(3.5 Kcal/g)(4186 J/Kcal)(80%)
= 2.27E+15 J/yr
Transformity = 3.36E+05 sej/J (Brown & McClanaham 1996)

26 MEAT, FISH & RELATED FOODS:

Estimates were done as fraction of US imports of meat and fish products in 2001.

US imports = 3.58E+06 MT/yr (UN Statistics Division; http://unstats.un.org)
Fraction = 9.50E-03 (Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports = 3.41E+04 MT/yr
Energy (J) = (__MT/yr)(1E6 g/MT)(5 Kcal/g)(4186 J/Kcal)(0.22 protein)
= 1.57E+14 J/yr
Transformity = 3.36E+06 sej/J (Brown & McClanaham 1996)

27 PLASTICS & RUBBER:

Estimates were done as fraction of US imports in 2001.

Imports = 3.01E+10 $/yr (UN Statistics Division; http://unstats.un.org)
Average price = 3.34E+03 $/MT
Imports = 8.99E+06 MT/yr
Fraction = 9.50E-03 (Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports = 8.54E+04 MT/yr
Energy (J) = (__ MT/yr)(1000 Kg/MT)(30.0E6J/kg)
= 2.56E+15 J/yr
Transformity = 1.11E+05 sej/J (Odum 1996)

28 CHEMICALS:

Estimates were done as fraction of US imports in 2001.

Imports = 2.02E+07 MT/yr (UN Statistics Division; http://unstats.un.org)
Fraction = 9.50E-03 (Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports = 1.92E+05 MT/yr

Mass (g) = (__MT/ yr)(1E6g/MT)
= 1.92E+11 g/yr
Transformity = 2.49E+10 sej/g (as pesticides) (Brown and Arding 1991, in Brandt-Williams 2001)

29 FINISHED MATERIALS (lumber, paper, textiles, glass, others):

Estimates were done as fraction of US imports in 2001.

Imports (lumber) =	2.92E+07	MT/yr			(UN Statistics Division; http://unstats.un.org)
Fraction =	9.50E-03				(Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports =	2.77E+05	MT/yr			
Imports (paper) =	1.57E+10	$/yr			
Price =	9.62E+02	$/MT			
Imports (paper) =	1.63E+07	MT/yr			
Fraction =	9.50E-03				(Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State imports =	1.55E+05	MT/yr			
			Transformity		
Lumber =	2.77E+05	MT/yr	8.80E+08	sej/g	(Brown & Buranakam 2000)
Paper =	1.55E+05	MT/yr	3.69E+09	sej/g	(Luchi & Ulgiati 2000)
Others =	0.0	MT/yr	5.85E+09	sej/g	(Brown & Buranakam 2000)
Imports =	4.32E+05	MT/yr	1.89E+09	sej/g	
Energy (J) =	(__ MT/yr)(1E6g/MT)				
=	4.32E+11	g/yr			
Transformity (weighed) =	1.89E+09	sej/g			

30 MACHINERY, TRANSPORTATION, EQUIPMENT:

Estimates were done as fraction of US imports in 2001.

Imports =	5.09E+11	$/yr	(UN Statistics Division; http://unstats.un.org)
Price =	3.00E+03	$/MT	(Assumed)
Imports =	1.70E+08	MT/yr	
Fraction =	9.50E-03		(Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
State Imports =	1.61E+06	MT/yr	
Mass (g) =	(___E4 MT/yr)(1E6g/MT)		
=	1.61E+12	g/yr	
Transformity =	6.70E+09	sej/g	(Brown & Bardi 2001)

31 IMPORTED SERVICES:

Estimates were done as fraction of US imports in 2001.

Dollar value (US) =	1.18E+12	$/yr	(UN Statistics Division; http://unstats.un.org)
Fraction =	9.50E-03		(Based on Population: State/US; US Census Bureau; http://quickfacts.census.gov)
Foreign state imports =	1.12E+10	$/yr	
Relative imports from other states =	1.12E+10	$/yr	(Estimated based on a 2.51 times increase between 1992 and 2001. Data for 1992 from Odum et al (1998))
Federal spending received =	1.67E+10	$/yr	(Tax Foundation 2004; http://www.taxfoundation.org/taxdata/)
Total $ value of imports =	3.91E+10	$/yr	
World Emergy/$ ratio =	1.66E+12	sej/$	

32 TOURISM :

Dollar Value =	3.81E+09	$US	(ADPT; http://www.arkansas.com)
World Emergy/$ ratio =	1.66E+12	sej/$	

EXPORTS OF ENERGY, MATERIALS AND SERVICES

33	AGRICULTURAL PRODUCTS:					
	Average price for US					(Estimated as raw cereals after UNSD;
	exports (2001) =	2.74E+02	$/MT			http://unstats.un.org)
	State exports =	9.17E+07	$/yr			(ADED 2003)
	State exports =	3.35E+05	MT/yr			
	Energy (J) =	(__MT)(1E+06 g/MT)(80%)(3.5 Cal/g)(4186 J/Cal)				
	=	3.92E+15	J/yr			
	Transformity =	3.36E+05	sej/J			(Brown & McClanaham 1996)
34	MEAT:					
	Average price for US					(Estimated after UN Statistics Division;
	exports (2001) =	2.08E+03	$/MT			http://unstats.un.org)
	State exports =	4.78E+08	$			(ADED 2003)
	State exports =	2.30E+05	MT/yr			
	Energy (J) =	(__MT)(1E+06 g/MT)(5 Cal/g)(4187 J/Cal)(0.22 protein)				
	=	1.06E+15	J/yr			
	Transformity =	3.36E+06	sej/J			(Brown & McClanaham 1996)
35	PAPER & PAPERBOARD:					
	Average price for US					
	exports (2001) =	9.62E+02	$/MT			(UN Statistics Division; http://unstats.un.org)
	State exports =	2.08E+08	$			(ADED 2003)
	State exports =	2.16E+05	MT/yr			
	Energy (J) =	(__MT)(1.0E+06 g/MT)				
	=	2.16E+11	g/yr			
	Transformity =	3.69E+09	sej/g			(Luchi & Ulgiati 2000)
36	FUELS:					
	Natural gas =	0.00E+00	m^3/yr			
	Energy (J) =	(__ m^3/yr)(8966 kcal/m^3)(4186 J/kcal)				
	Oil derived fuels =	0.00E+00	L/yr			
	Energy (J) =	(__L/yr)(1.14E4kcal/L)(4186 J/kcal)				
	Coal =	0.00E+00	MT/yr			
	Energy (J) =	(__MT/yr)(2.9E10 J/MT)		Transformity		
	Natural gas =	0.00E+00	J/yr	5.88E+04	sej/J	(Romitelli 2000)
	Oil derived fuels =	0.00E+00	J/yr	1.11E+05	sej/J	(Odum 1996)
	Coal =	0.00E+00	J/yr	6.69E+04	sej/J	(Odum 1996)
	=	0.00E+00	J/yr			
	Transformity =	0.00E+00	sej/J			
37	METALS:					
	Price US exports					(UN Statistics Division;
	aluminum (2001) =	6.15E+02	$/MT	(Aluminum hydroxide)		http://unstats.un.org)
	State exports =	3.97E+07	$/yr			(ADED 2003)
	State exports =	6.46E+04	MT/yr			
	Price US exports Iron					(UN Statistics Division;
	(2001) =	5.74E+02	$/MT	(Primary form of iron)		http://unstats.un.org)
	State exports =	3.54E+07	$/yr			(Assumed 50% of State's exports; ADED 2003)
	State exports =	6.17E+04	MT/yr	(Reported for iron and steel)		
	Price US exports steel					(UN Statistics Division;
	(2001) =	5.74E+02	$/MT	(Primary form of steel)		http://unstats.un.org)
	State exports =	3.54E+07	$/yr			(Assumed 50% of State's exports; ADED 2003)
	State exports =	6.17E+04	MT/yr	(Reported for iron and steel)		
				Transformity		
	Aluminum ore (Bauxite) =	0.00E+00	MT/yr	1.43E+09	sej/g	(Odum 1996)
	Aluminum =	6.46E+04	MT/yr	1.25E+10	sej/g	(Brown & Buranakam 2000)
	Iron =	6.17E+04	MT/yr	1.44E+09	sej/g	(Odum 1996)
	Steel =	6.17E+04	MT/yr	4.13E+09	sej/g	(Brown & Buranakam 2000)
	Copper wire =	0.00E+00	MT/yr	1.66E+11	sej/g	(Odum 1996)

	Others =	0.00E+00	MT/yr	1.68E+09	sej/g	(Odum 1996)
	Exports =	1.88E+05	MT/yr	6.13E+09	sej/g	
	Mass (g) =	(__MT)(1E6 g/MT)				
	=	1.88E+11	g/yr			
	Transformity (weighed) =	6.13E+09	sej/g			
38	MINERALS (Bromine):					
	Exports =	3.08E+04	MT/yr	(15% of production)		(AGC; www.state.ar.us/agc)
	Mass (g) =	(__E5 MT)(1E6 g/MT)				
	=	3.08E+10	g/yr			
	Transformity =	2.20E+10	sej/g			(Odum et al. 1998)
39	CHEMICALS (ORGANIC):					
	Average price for US exports (2001) =	8.92E+02	$/MT			(Estimated after UN Statistics Division; http://unstats.un.org)
	State exports =	1.79E+08	$/yr			(ADED 2003)
	State exports =	2.00E+05	MT/yr			
	Mass (g) =	(__MT)(1E6 g/MT)				
	=	2.00E+11	g/yr			
	Transformity =	2.49E+10	sej/g	(as pesticides)		(Brown and Arding 1991, in Brandt-Williams 2001)
40	MACHINERY, TRANSPORTATION, EQUIPMENT:					
	Average price =	3.00E+03	$/MT			(Assumed)
	State exports =	8.72E+08	$/yr			(Machinery, aircrafts, vehicles, 2001; ADED 2003)
	State exports =	2.91E+05	MT/yr			
	Mass (g) =	(__MT/yr)(1E6g/MT)				
	=	2.91E+11	g/yr			
	Transformity =	6.70E+09	sej/g			(Doherty 1995 in Brown and Bardi 2001)
41	PLASTICS:					
	Average price for US exports (2001) =	3.34E+03	$/MT			(UN Statistics Division; http://unstats.un.org)
	State exports =	8.65E+07	$			(ADED 2003)
	State exports =	2.59E+04	MT/yr			
	Energy (J) =	(__MT/yr)(1000 Kg/MT)(30.0E6J/kg)				
	=	7.76E+14				
	Transformity =	1.11E+05	sej/J			(Odum 1996)
42	SERVICES IN EXPORTS:					
	Foreign exports =	2.91E+09	$/yr			(ADED 2003)
	Relative exports to other states =	3.60E+10	$/yr			(Estimated based on a 2.21 times increase between 1992 and 2001. Data for 1992 from Odum et al [1998])
	Federal tax paid =	1.24E+10	$/yr			(Tax Foundation 2004; http://www.taxfoundation.org/taxdata/)
	Total $ value of exports =	3.89E+10	$/yr			

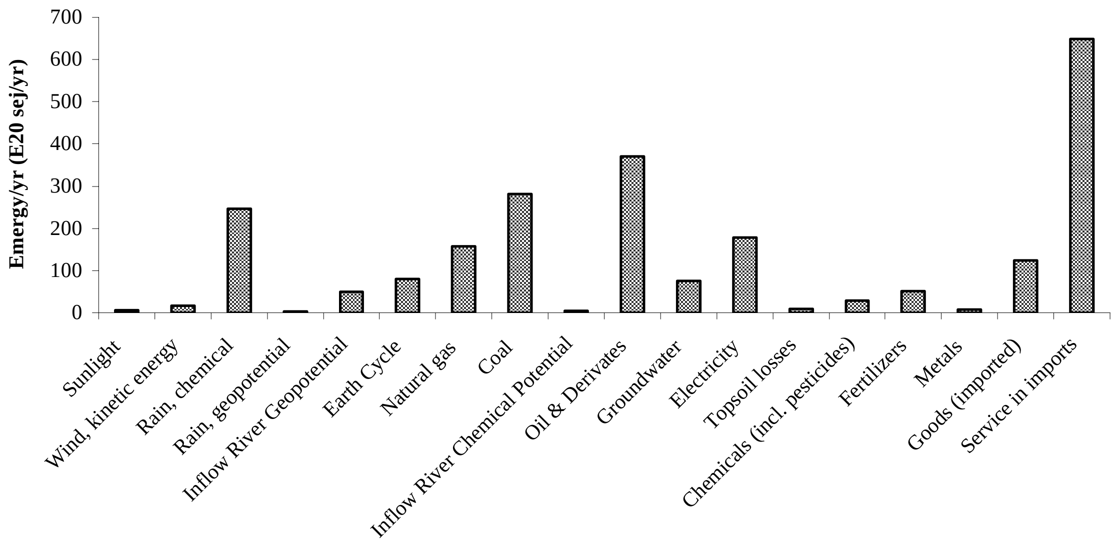


Figure A-6. Emergy signature of the environment and the economy of Arkansas in 2001.

The same ratio for the U.S. for 2001 was estimated at about 1.00 E12 sej/$. Since the U.S. as a whole is more developed than the state of Arkansas alone, the differences in values reflect this distinction.

The emergy used from home sources index showed that Arkansas is only 40% sufficient depending mostly on imported emergy (Table A-5).The emergy use per person is a measure of the standard of living in emergy terms. A person living in a rural environment may have a higher emergy use than a person living in a city. For Arkansas this ratio was 1.01 E17 sej/person, which is higher than for the average person for the entire U.S. in the year 20001. Again, since the U.S. as a whole is more developed than the state of Arkansas alone, the different values reflect this difference. On a per area basis, the emergy use for the state was 1.98 E16 sej/ha.

[1] Unpublished data, H.T. Odum Center for Environmental Policy, University of Florida.

Table A-5. Summary of flows for Arkansas, 2001.

Variable	Item	Solar Emergy (E20 sej/yr)	Dollars
R	Renewable sources (rain, tide, earth cycle)	249.27	
N	Non-renewable resources from within State	264.50	
N0	Dispersed Rural Source	436.79	
N1	Concentrated Use	407.16	
N2	Exported without Use	68.08	
F	Imported Fuels and Minerals	759.22	
G	Imported Goods	230.30	
I	Dollars Paid for Imports		3.91E+10
P2I	Emergy of Services in Imported Goods & Fuels	648.90	
E	Dollars Received for Exports		3.89E+10
P1E	Emergy Value of Goods and Service Exports	1247.36	
X	Gross State Product		9.65E+10
P2	World emergy/$ ratio, used in imports	1.66E+12	
P1	State Emergy/$ ratio	2.83E+12	

The emergy yield ratio (Y/F) was calculated as 0.80 (see Figure A-4[b]), which indicates that Arkansas uses much more resources from the economy than it contributes to it; Arkansas is a net importer of emergy. The emergy investment ratio (F/I) was 1.50. This index measures the intensity of the economic development and the loading of the environment. The reference value usually used for comparison is the investment ratio for the U.S., which tends to be 7 or higher. High values suggest a more developed economy and a high level of environmental stress. Accordingly, and since the loading ratio for Arkansas is relatively low, the free contributions from the environment to the state's economy are relatively large. A more developed state like Florida has an emergy investment ratio of about 7.

Table A-6. Emergy indices for Arkansas.

Item	Name of Index	Expression	Quantity
1	Renewable emergy flow	R	2.49E+22
2	Flow from indigenous non-renewable reserves	N	2.64E+22
3	Flow of imported emergy	F+G+P2I	1.64E+23
4	Total emergy inflows	R+N+F+G+P2I	2.15E+23
5	Total emergy used, U	N0+N1+R+F+G+P2I	2.73E+23
6	Total exported emergy	P1E	1.25E+23
7	Fraction emergy use derived from home sources	(NO+N1+R)/U	0.40
8	Imports minus exports	(F+G+P2I)-(N2+B+P1E)	3.23E+22
9	Export to Imports	(N2+P1E)/(F+G+P2I)	0.80
10	Fraction used, locally renewable	R/U	0.09
11	Fraction of use purchased	(F+G+P2I)/U	0.60
12	Fraction imported service	P2I/U	0.24
13	Fraction of use that is free	(R+N0)/U	0.25
14	Ratio of concentrated to rural	(F+G+P2I+N1)/(R+N0)	2.98
15	Use per unit area, Empower Density	U/(area ha)	1.98E+16
16	Use per person	U/population	1.01E+17
17	Renewable carrying capacity at present living standard	STATE POPULATION = (R/U) (population)	2.70E+06 2.46E+05
18	Developed carrying capacity at same living standard	8(R/U)(population)	1.97E+06
19	Ratio of use to GSP, emergy/dollar ratio	P1=U/GSP	2.83E+12
20	Ratio of electricity to use	(el)/U	1%
21	Fuel use per person	fuel/population	2.78E+16

Emergy Evaluation of Resource Basis for the State of Arkansas

With an annual rainfall of 1.21 meters in 2001, the rain-chemical potential energy was the highest source of natural renewable energy in Arkansas. Odum et al. (1998) also pointed out the significance of this source of energy to the state's economy and noted the high rates of evapotranspiration during the summer and early fall months due to the abundant rain usually present in the state.

The relative richness in non-renewable resources of Arkansas was also noted by Odum et al. (1998) and was confirmed by this study. The results showed that even though Arkansas has a significant amount of resources, there were no marked changes in the quantities of indigenous renewable and non-renewable resources used in the state over a period of 10 years. Both agricultural and livestock products (including poultry) remained the most important components of the annual indigenous renewable emergy flow in the state. Fossil fuels and electricity from within the state had total annual emergy flows of 189.9 E20 sej and 232.68 E20 sej, respectively. These values are similar to those reported by Odum et al. (1998).

The agricultural cost in terms of soil erosion continued to be high. This study reported a total of 325.7 E20 sej in soil losses, which is more than twice that reported in Odum et al. (1998). The difference might be the result of on increase in croplands between the two time periods. Overall, in 2001 soil losses represented 40% of all the non-renewable emergy used from within the state, suggesting that Arkansas agricultural production and its contribution to its economic growth comes at the expense of this important natural stock.

The Arkansas gross state product increased from 39 billion dollars in 1990 to 96.5 billion dollars in 2001. Since there was little change to the resources basis of the

Arkansas economy from within the state during these years, the growth of the state's economy was possibly mostly due to an increase in the imports of non-renewable resources, particularly of fossil fuels that accounted for 44% of all the emergy brought in to the system in 2001. The ratio of exports to imports for 2001 was 0.80. The emergy used from state sources was 40% of the total emergy used and the emergy used from home sources index showed that Arkansas was only 39% sufficient in 2001, depending mostly on imported emergy. Together these figures show that Arkansas is a net emergy importer state. This is a significant change from that reported by Odum et al. (1998). Using 1990 data, Odum et al.'s study showed that Arkansas was a net emergy exporter state.

The results for exported emergy that were reported by Odum et al. (1998) and the results of this study show some difference in the number of items included in the analysis and in the way total energy values were calculated. This study included more items. We used the exports dollar value of each product from state-level data and the average price for U.S. exports for each item in 2001 to obtain data on quantities exported. As such, emergy exports accounted only for the emergy in the international trade, excluding exports to other states. However, when calculating the emergy of the services in exports, a relative dollar value of the exports to other states was considered. The total emergy reported as exports in the Odum et al. (1998) study was 1231 E20 sej, while the total emergy exported according to this study was 1247.18 E20 sej. The services in exports accounted for 77% and 88% of total exports, respectively.

The emergy investment ratio for 1990 was 0.73. In 2001 this ratio was 1.50. The ratio value for the state is still lower than that for the U.S., which has an emergy investment ratio of around 7.0 and the state may still be considered a mostly rural or less developed state. However, the difference in the ratio value between the two time periods suggest that Arkansas is receiving less of their emergy as free contributions from the environment and that the state is slowly moving towards a more developed economy. In 2001 the economic system invested more emergy from sources outside the state. The changes in the fraction of emergy used which is locally renewable was 0.15 in 1990 and 0.09 in 2001, also seem to support this trend.

The solar emergy-to-money ratio for Arkansas in 1990 was 3.45 E12 sej/$ and 2.83 E12 sej/$ in 2001. Despite the normal decrease in its value[2], the emergy-to-money ratio of Arkansas was still higher than the ratio for the U.S. in 2001, which was estimated as about 1.00 E12 sej/$. Once again this value confirms the rather rural nature of the state of Arkansas. This ratio is an indication of the real wealth (in emergy terms) that a dollar can buy.

In summary, Arkansas has a diversified economy and is increasingly becoming more dependent on imported emergy. The emergy evaluation for Arkansas suggests that the state is slowly moving towards a more developed economy.

Emergy Evaluation of Land Uses of the Bayou Meto Watershed

In the following pages systems diagrams, and emergy evaluation tables of land uses and land cover systems of the Bayou Meto Watershed are presented.

[2] Generally, emergy-to-money ratios decrease over time due to inflation, the increase in money circulation year to year, and to the increasing efficiency in resource use (Odum 1996).

Mixed hardwood forest

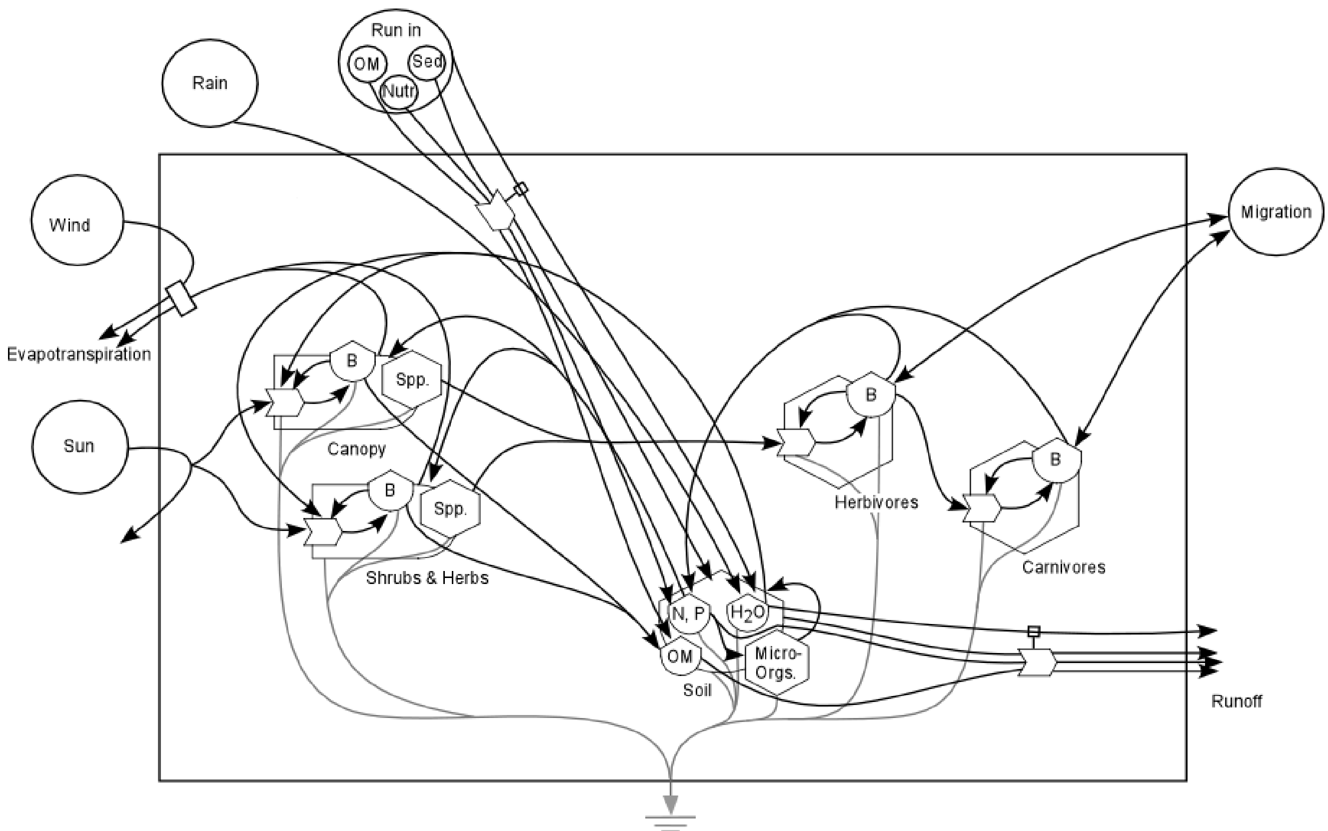


Figure A-7. Energy systems diagram of a mixed hardwood forest.

Table A-7. Emergy evaluation table of a mixed hardwood forest, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	4.72E+13	J	1.00E+00	5
2	Wind	5.02E+10	J	2.45E+03	12
3	Rain chemical potential	5.98E+10	J	3.05E+04	182
4	Run-in chemical potential	0.00E+00	J	8.24E+04	0
5	Water use (Transpiration)	2.62E+10	J	4.38E+04	115
Flows					
6	Gross primary production	7.80E+11	J	1.47E+03	115
7	Total EMERGY				182
Calculated ratios					
8	Empower Density	1.82E+15	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(____m^2)*(____Cal/cm^2/y)*(E+04cm^2/m^2)* (1-albedo)*(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	0.2		(After www.nasa.gov)
Annual energy =	4.72E+13	J	
Emergy per unit input =	1	sej/J	(Odum 1996)

2 **Wind, J**

Annual energy =	(area)(air density)(drag coefficient)(velocity^3)		
=	(_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)(3.14 E7 s/yr)		
Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	1.00E-03		(Garrat 1977)
Annual energy =	5.02E+10	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

3 **Rain chemical potential, J**

Annual energy =	(Avg. precip.)*(Area)*(1 E6 g/m^2)*(4.94J/g)		
Avg. precipitation =	1.21	m	
Area =	1.00E+04	m^2	
Annual energy =	5.98E+10		
Emergy per unit input =	3.05E+04	sej/J	(Odum 2000)

4 **Run-in chemical potential, J**

Annual energy =	0		(Southern mixed hardwood forest complex is not net sink for run-in; Orrell 1998)
Emergy per unit input =	8.24E+04	sej/J	(Bardi and Brown 2001)

5 **Water use (Transpiration), J**

Annual energy =	(Transpiration)*(area)*(1E6 g/m^3)*(4.94 J/g))		
Transpiration =	5.30E-01	m/yr	(Orrell 1998)
Annual energy =	2.62E+10	J/yr	

	Emergy per unit input =	4.38E+04	sej/J	(Bardi and Brown 2001)
6	**Gross primary production, J**			
	Annual energy =	(GPP)*(1E6 g/ton)*(8 kcal/g)*(4186 J/kcal)		
	Gross primary production =	2.33E+01	ton C/ha-yr	(Orrell 1998)
	Annual energy =	7.80E+11	J/yr	
	Emergy per unit input =	1.47E+03	sej/J	(Solar emergy of item # 6/Annual energy)
7	**Total Emergy -** Highest renewable input			
8	**Empower Density -** emergy per hectare per year			

Bottomland hardwood forest

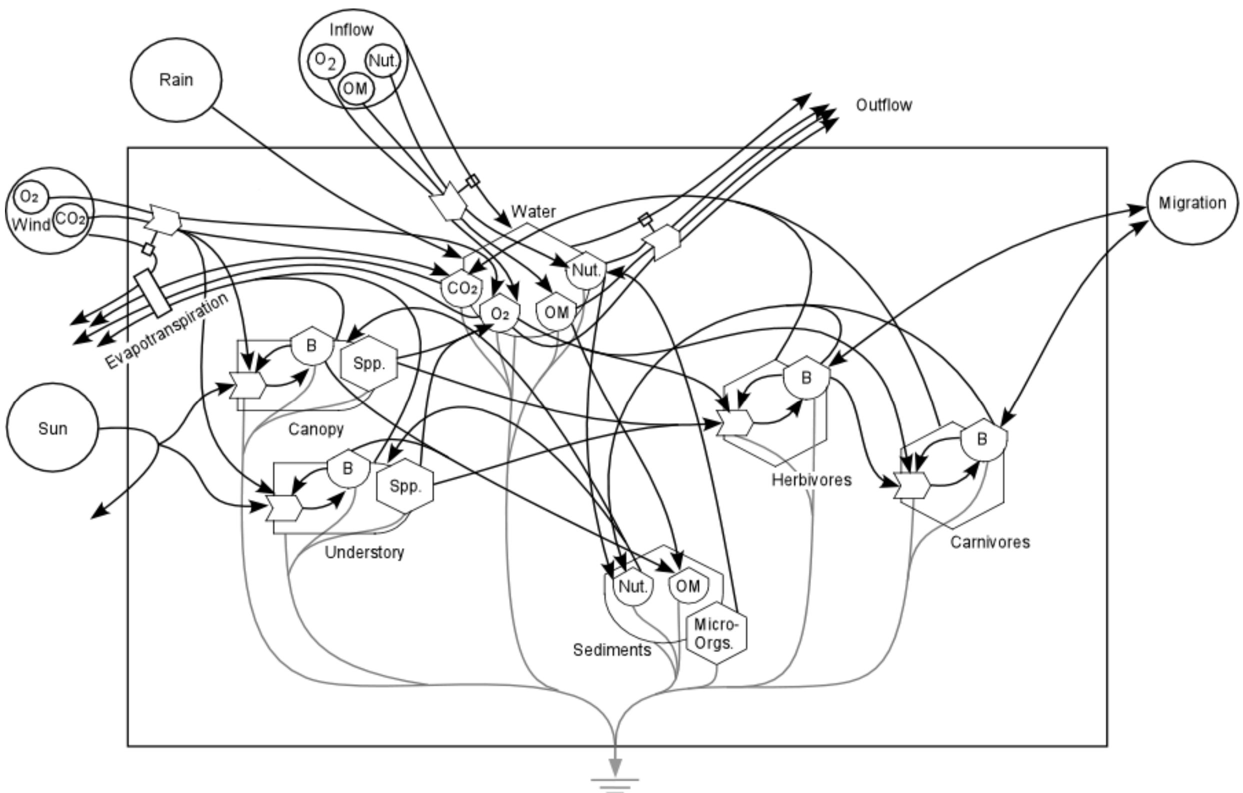


Figure A-8. Energy systems diagram of a bottomland hardwood forest.

Table A-8. Emergy evaluation table of a bottomland hardwood forest, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	4.72E+13	J	1.00E+00	5
2	Wind	5.02E+10	J	2.45E+03	12
3	Rain chemical potential	5.98E+10	J	3.05E+04	182
4	River geopotential	5.95E+08	J	4.70E+04	3
5	River chemical potential	1.51E+10	J	8.14E+04	123
6	Water use (Transpiration)	5.88E+10	J	4.38E+04	258
Flows					
7	Gross primary production	6.28E+10	J	4.15E+04	261
8	Total EMERGY				258
Calculated ratios					
9	Empower Density	2.58E+15	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(____m^2)*(____Cal/cm^2/y)*(E+04cm^2/m^2)* (1-albedo)*(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	0.2		(After www.nasa.gov)
Annual energy =	4.72E+13	J	
Emergy per unit input =	1	sej/J	(Odum 1996)

2 **Wind, J**

Annual energy =	(area)(air density)(drag coefficient)(velocity^3)		
=	(_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)(3.14 E7 s/yr)		
Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	1.00E-03		(Garrat 1977)
Annual energy =	5.02E+10	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

3 **Rain chemical potential, J**

Annual energy =	(Avg. precip.)*(Area)*(1 E6 g/m^2)*(4.94J/g)		
Avg. precipitation =	1.21	m	
Area =	1.00E+04	m^2	
Annual energy =	5.98E+10		
Emergy per unit input =	3.05E+04	sej/J	(Odum 2000)

4 **River geopotential, J**

Annual energy =	(volume)*(1.0E3 kg/m^3)*(height in-height out)*(gravity)		
Mean annual river flow =	6.99E+00	m^3/sec	(Estimated from daily data for 2000-2001 from USGS; available at http://nwis.waterdata.usgs.gov)
Mean annual river flow =	2.20E+08	m^3/yr	
Average elevation change =	1.07E+02	m	(www.mawpt.org; Bayou Meto WPA Report)
Area Bayou Meto Watershed =	3.88E+05	ha	(www.mawpt.org; Bayou Meto WPA Report)

	Annual energy =	5.95E+08	J/yr		
	Emergy per unit input =	4.70E+04	sej/J		(Odum et al. 2000)
5	**River chemical potential, J**				
	Gibbs free energy =	[(8.3143 J/mol/deg)(288 K)/(18 g/mol)]*ln[(1e6 - Solutes)ppm)/965000]			(Campbell et al. 2005)
	Dissolved Solids in =	2.00E+02	ppm		(Odum et al. 1998)
	Dissolved Solids out =	4.00E+02	ppm		(Odum et al. 1998)
	Gibbs Free Energy in =	4.71E+00	J/g		
	Gibbs Free Energy out =	4.69E+00	J/g		
	Mean annual river flow =	2.20E+08	m^3/yr		
	Energy(J) =	(volume)(density)(Gibbs free energy)			
	=	(____m^3/s)*(1.0E3 kg/m^3)(__J/g)			
	Energy in =	1.04E+18	J/yr		
	Energy out =	1.03E+18	J/yr		
	Annual energy (In- Out) =	1.51E+10	J/yr		
	Emergy per unit input =	8.14E+04	sej/J		(Odum, 1996)
6	**Water use (Transpiration), J**				
	Annual energy =	(Transpiration)*(area)*(1E6 g/m^3)*(4.94 J/g)			
	Transpiration =	1.19E+00	m/yr		(Odum et al. 1998)
	Annual energy =	5.88E+10	J/yr		
	Emergy per unit input =	4.38E+04	sej/J		(Bardi and Brown 2001)
7	**Gross primary production, J**				
	Annual energy =	(GPP)*(1E6 g/ton)*(4 kcal/g)*(4186 J/kcal)			
	Gross primary production =	3.75E+00	ton/yr		(Data for the Black Swamp, AR; Odum et al. 1998)
	Annual energy =	6.28E+10	J/yr		
	Emergy per unit input =	4.15E+04	sej/J		(Sum of solar emergy for item #4 and #6/Annual energy)
8	**Total Emergy** - Highest renewable input				
9	**Empower Density** - emergy per hectare per year				

Agricultural land uses

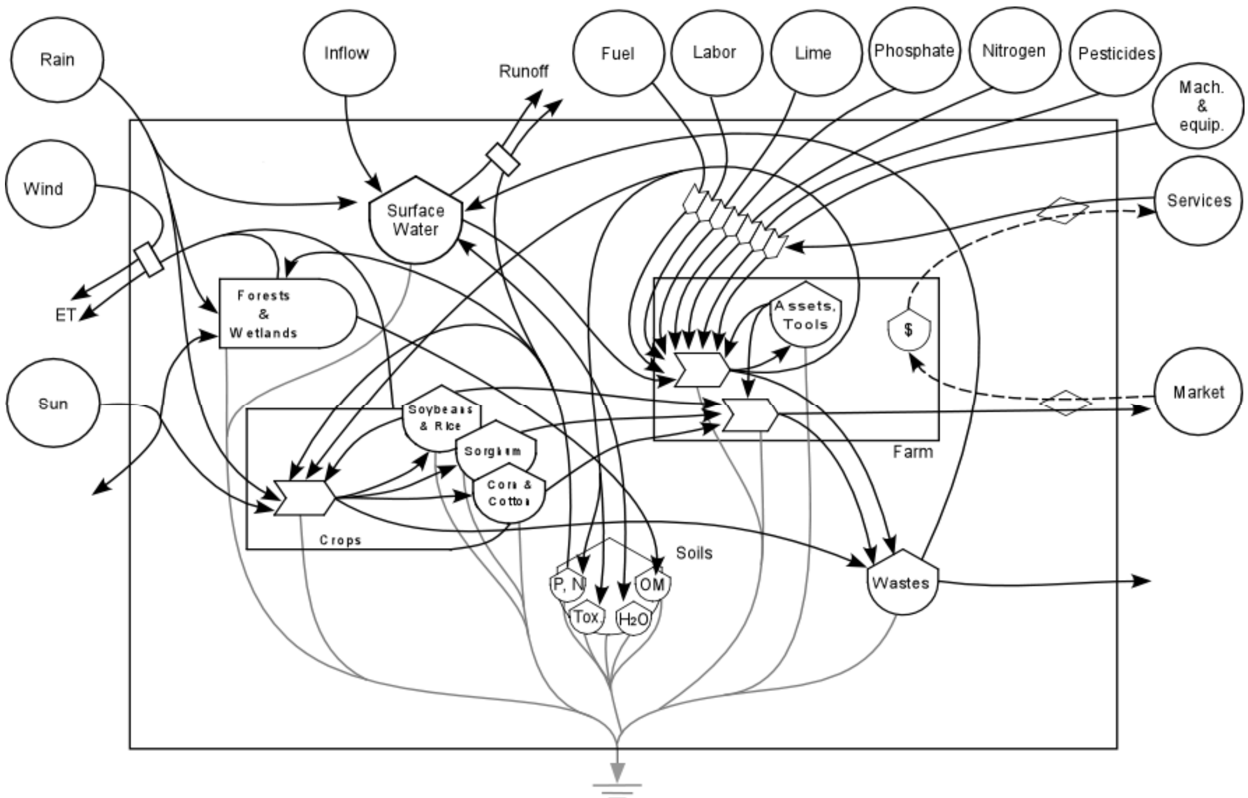


Figure A-9. Energy systems diagram of agriculture in the Bayou Meto Watershed.

Table A-9. Emergy evaluation table of sorghum, per ha per year

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	9.04E+09	J	1.24E+05	112
5	Groundwater	3.55E+09		2.69E+05	96
Purchased Inputs					
6	Fuel	4.92E+09	J	1.11E+05	55
7	Phosphorus	7.74E+04	g	1.45E+10	112
8	Nitrogen	1.29E+05	g	1.59E+10	205
9	Potassium	1.01E+05	g	1.85E+09	19
10	Pesticides	6.44E+03	g	2.52E+10	16
11	Labor	4.21E+06	J	4.45E+06	2
12	Services	4.23E+02	$	2.83E+12	120
13	Total EMERGY			2.8E+12	787
Yields					
14	Total Yield, dry weight	5.40E+06	g		
15	Total Yield, energy	7.91E+10	J		
Calculated ratios					
16	Emergy per mass	1.46E+09	sej/g		
17	Transformity w/services	9.95E+04	sej/J		
18	Transformity wo/services	8.43E+04	sej/J		
19	Empower Density	7.87E+15	sej/ha/yr		
20	NR + PI Empower Density w/services	7.36E+15	sej/ha/yr		
21	NR + PI Empower Density wo/services	6.16E+15	sej/ha/yr		

Notes: Grain Sorghum, Flood Irrigated, Loamy Soils

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Growing season =	3.30E-01	yr	(www.uaex.edu)
Area =	1.00E+04	m^2	
Albedo =	2.00E-01		(After www.nasa.gov)
Annual energy =	1.56E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Evapotranspiration, J**

Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Evapotranspiration =	1.20E+00	m^3/m^2/yr	(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr	
Volume (4 months) =	4.00E+03	m^3/yr	
Annual energy =	1.98E+10	J	
Emergy per unit input =	1.54E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.00E+03	$g/m^2/yr$	(After Odum et al. 1998)
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil =	(farmed area)(erosion rate)		
	OM in topsoil used up =	(total mass of topsoil)(% organic)		
	Energy loss =	(loss of organic matter)(5.4 kcal/g)(4186 J/kcal)		
	Annual energy =	9.04E+09	J	
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Ground water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater irrigation =	7.00E+00	acre inch/yr	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Groundwater irrigation =	7.20E+02	m^3/yr	
	Annual energy =	3.55E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Fuel, J**			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Gallons/acre =	1.51E+01		(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Gallons/ha =	3.73E+01		
	Annual energy =	4.92E+09	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Phosphorus, g**			
	Annual consumption =	6.90E+01	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	7.74E+04	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
8	**Nitrogen, g**			
	Annual consumption (as Urea 46%) =	1.15E+02	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption (as Urea) =	1.29E+05	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams 2001)
9	**Potassium, g**			
	Annual consumption =	9.00E+01	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	1.01E+05	g/ha	
	Emergy per unit input =	1.10E+09	sej/g	(Odum 1996)
10	**Pesticides, g** (fungicides and herbicides)			
	Annual consumption =	5.74E+00	lb/acre	(Assumed one pint of pesticide = 1.0375 lbs)
	Annual consumption =	6.44E+03	g/ha	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
11	**Labor, J** (operation and irrigation)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	1.30E+00	hr/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Labor =	3.21E+00	hr/ha	
	Annual energy =	4.21E+06	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
12	**Services, $**			
	Value =	3.56E+00	$/CWT	(www.nass.usda.gov/ar/)
	Value =	3.56E-02	$/lb	
	Value =	4.23E+02	$/ha	
	Annual emergy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
13	**Total Emergy** - Sum of inputs 2 through 12			
14	**Yield, g**			
	Yield =	8.60E+01	Bushel/acre	(www.auex.edu)
		5.60E+01	lb/bushel	(www.muextension.missouri.edu)
	Yield =	5.40E+06	g/ha	
15	**Product in Joules**			
	Energy =	(__g)(3.5 kcal/g)(4186J/kcal)		(Odum et al.1998)
	Energy content =	7.91E+10	J	
16	**Emergy per mass** - Total emergy divided by yield in grams			
17	**Transformity w/services** - Total emergy yield divided by yield in joules			
18	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
19	**Empower Density** - sum of emergy per hectare per year			
20	**NR + PI Empower Density w/services** - sum of non renewable and purchased inputs emergy per hectare per year			
21	**NR + PI Empower Density wo/services** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-10. Emergy evaluation table of hay (Bermuda grass), per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	6.33E+07	J	1.24E+05	1
5	Groundwater	6.12E+09	J	2.69E+05	164
Purchased Inputs					
6	Fuel	8.81E+09	J	1.11E+05	98
7	Phosphorus	6.73E+04	g	5.67E+09	38
8	Nitrogen	2.35E+05	g	1.59E+10	374
9	Potassium	6.73E+04	g	1.85E+09	12
10	Labor	1.49E+07	J	4.45E+06	7
11	Services	1.06E+03	$	2.83E+12	301
12	Total EMERGY				1046
Yields					
13	Total Yield, dry weight	1.70E+07	g		
14	Total Yield, energy	1.85E+11	J		
Calculated ratios					
15	Emergy per mass	6.16E+08	sej/g		
16	Transformity w/services	5.66E+04	sej/J		
17	Transformity wo/services	4.03E+04	sej/J		
18	Empower Density	1.05E+16	sej/ha/yr		
19	NR + PI Empower Density w/services	9.95E+15	sej/ha/yr		
20	NR + PI Empower Density wo/services	6.95E+15	sej/ha/yr		

Notes: Northwest Arkansas Bermuda Round Bales

				References:
1	**Sunlight, J**			
Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)			
=	(__m^2)(__$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)			
Insolation =	1.41E+02	$kcal/cm^2/yr$		(Odum et al. 1998)
Growing season =	3.30E-01	yr		(www.uaex.edu)
Area =	1.00E+04	m^2		
Albedo =	2.00E-01			(After www.nasa.gov)
Annual energy =	1.56E+13	J		
Emergy per unit input =	1.00E+00	sej/J		(Odum 1996)
2	**Evapotranspiration, J**			
Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)			
Evapotranspiration =	1.20E+00	$m^3/m^2/yr$		(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr		
Volume (4 months) =	4.00E+03	m^3/yr		
Annual energy =	1.98E+10	J		
Emergy per unit input =	1.54E+04	sej/J		(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	7.00E+00	$g/m^2/yr$	(After Pimentel et al. 1995)
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil =	(farmed area)(erosion rate)		
	OM in topsoil used up =	(total mass of topsoil)(% organic)		
	Energy loss =	(loss of organic matter)(5.4 kcal/g)(4186 J/kcal)		
	Annual energy =	6.33E+07	J	
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Ground water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater irrigation =	1.20E+01	acre inch/yr	(After Duble, R.L.; http://aggie-horticulture.tamu.edu/)
	Groundwater irrigation =	1.24E+03	m^3/yr	
	Annual energy =	6.12E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Fuel, J**			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Gallons/acre =	2.70E+01		(Rainey et al. 2005; www.aragriculture.org/famplanning/budgets)
	Gallons/ha =	6.68E+01		
	Annual energy =	8.81E+09	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Phosphorus, g (P2O5)**			
	Annual consumption =	6.00E+01	lb/acre	(Sandage & Chapman 1999; http://www.uaex.edu)
	Annual consumption =	6.73E+04	g/ha	
	Emergy per unit input =	5.67E+09	sej/g	(Brandt-Williams 2001)
8	**Nitrogen, g**			
	Annual consumption =	2.10E+02	lb/acre	(Sandage & Chapman 1999; http://www.uaex.edu)
	Annual consumption =	2.35E+05	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams 2001)
	Annual consumption =	6.00E+01	lb/acre	(Sandage & Chapman 1999; http://www.uaex.edu)
	Annual consumption =	6.73E+04	g/ha	
	Emergy per unit input =	1.10E+09	sej/g	(Odum 1996)
10	**Labor, J** (operation and irrigation)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	4.60E+00	hr/acre	(Rainey et al. 2004; www.aragriculture.org/famplanning/budgets)
	Labor =	1.14E+01	hr/ha	
	Annual energy =	1.49E+07	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)

11	**Services, $**			
	Value =	6.25E+01	$/ton	(www.nass.usda.gov/ar/)
	Value =	1.06E+03	$/ha	
	Annual emergy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
12	**Total Emergy** - Sum of inputs 2 through 11			
13	**Yield, g** (Midland 99, Tifton 44, Midland, Greenfield)			
	Average Yield =	6.88E+00	ton/acre	(Sandage & Cassida 2001; http://www.uaex.edu)
	Yield =	1.70E+07	g/ha	
14	**Product in Joules**			
	Energy =	(__g)(2.6 kcal/g)(4186J/kcal)		(Pimentel 1980)
	Energy content =	1.85E+11	J	
15	**Emergy per mass** - Total emergy divided by yield in grams			
16	**Transformity w/services** - Total emergy yield divided by yield in joules			
17	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
18	**Empower Density** - sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services** - sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-11. Emergy evaluation table of soybeans, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.26E+10	J	1.24E+05	404
5	Groundwater	6.60E+09	J	2.69E+05	177
Purchased Inputs					
6	Fuel	8.67E+09	J	1.11E+05	96
7	Phosphorus	4.04E+04	g	1.45E+10	59
8	Potassium	8.07E+04	g	1.85E+09	15
9	Pesticides	7.48E+03	g	2.52E+10	19
10	Labor	6.88E+06	J	4.45E+06	3
11	Services	4.86E+02	$	2.83E+12	137
12	Total EMERGY				961
Yields					
13	Total Yield, dry weight	3.03E+06	g		
14	Total Yield, energy	5.11E+10	J		
Calculated ratios					
15	Emergy per mass	3.17E+09	sej/g		
16	Transformity w/services	1.88E+05	sej/J		
17	Transformity wo/services	1.61E+05	sej/J		
18	Empower Density	9.61E+15	sej/ha/yr		
19	NR + PI Empower Density w/services	9.10E+15	sej/ha/yr		
20	NR + PI Empower Density wo/services	7.73E+15	sej/ha/yr		

Notes: Soybeans, Flood Irrigated, Following Rice, Loamy Soils

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	$kcal/cm^2/yr$	(Odum et al. 1998)
Growing season =	3.30E-01	yr	(www.uaex.edu)
Area =	1.00E+04	m^2	
Albedo =	2.00E-01		(After www.nasa.gov)
Annual energy =	1.56E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Evapotranspiration, J**

Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Evapotranspiration =	1.20E+00	$m^3/m^2/yr$	(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr	
Volume (4 months) =	4.00E+03	m^3/yr	
Annual energy =	1.98E+10	J	
Emergy per unit input =	1.54E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area = 1.00E+04 m^2

Density of air = 1.23E+00 kg/m^3 (Odum et al. 1998)

Avg. annual wind velocity = 3.04E+00 mps (Data for Little Rock, 2001; www.noaa.gov)

Geostrophic wind = 5.07E+00 mps (Observed winds are about 0.6 of geostrophic wind)

Drag coeff. = 2.00E-03 (Garrat 1977)

Energy (J) = (area)(air density)(drag coefficient)(velocity^3)

= (__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)

Annual energy = 1.00E+11 J

Emergy per unit input = 2.45E+03 sej/J (Odum et al. 2000)

4 **Net Topsoil Loss, J**

Erosion rate = 3.60E+03 $g/m^2/yr$ (After Pimentel et al. 1995)

Organic fraction in soil = 4.00E-02 (Pimentel et al. 1995)

Energy cont./g organic = 5.40E+00 kcal/g

Net loss of topsoil = (farmed area)(erosion rate)

OM in topsoil used up = (total mass of topsoil)(% organic)

Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Annual energy = 3.26E+10 J

Emergy per unit input = 7.38E+04 sej/J (Odum 1996)

5 **Ground water, J**

Annual energy = Chemical potential of groundwater

Annual energy = (Volume)(1E6 g/m^3)(4.94 J/g)

Groundwater irrigation = 1.30E+01 acre inch/yr (Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

Groundwater irrigation = 1.34E+03 m^3/yr

Annual energy = 6.60E+09 J

Emergy per unit input = 1.60E+05 sej/J (Odum et al 1998)

6 **Fuel, J**

Annual energy = (Gallons fuel)(1.32E8 J/gal)

Gallons/acre = 2.66E+01 (Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

Gallons/ha = 6.57E+01

Annual energy = 8.67E+09 J

Emergy per unit input = 6.60E+04 sej/J (Odum 1996)

7 **Phosphorus, g**

Annual consumption = 3.60E+01 lb/acre (Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

Annual consumption = 4.04E+04 g/ha

Emergy per unit input = 1.45E+10 sej/g (Brandt-Williams 2001)

8 **Potassium, g**

Annual consumption = 7.20E+01 lb/acre (Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

Annual consumption = 8.07E+04 g/ha

Emergy per unit input = 1.10E+09 sej/g (Odum 1996)

9 **Pesticides, g** (herbicides)

Annual consumption = 6.67E+00 lb/acre (Assumed one pint of pesticide = 1.0375 lbs)

Annual consumption = 7.48E+03 g/ha (Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)

Emergy per unit input = 1.50E+10 sej/g (Brown and Arding 1991, in Brandt-Williams 2001)

10	**Labor, J** (operation and irrigation)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	2.13E+00	hr/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Labor =	5.26E+00	hr/ha	
	Annual energy =	6.88E+06	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
11	**Services, $**			
	Value =	4.37E+00	$/bushel	(www.nass.usda.gov/ar/)
	Value =	4.86E+02	$/ha	
	Annual energy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
12	**Total Emergy -** Sum of inputs 2 through 11			
13	**Yield, g**			
	Yield =	4.50E+01	Bushel/acre	(www.auex.edu)
		6.00E+01	lb/bushel	(www.muextension.missouri.edu)
	Yield =	3.03E+06	g/ha	
14	**Product in Joules**			
	Energy =	(__g)(4.03 kcal/g)(4186 J/kcal)		(Odum et al.1998)
	Energy content =	5.11E+10	J	
15	**Emergy per mass** - Total emergy divided by yield in grams			
16	**Transformity w/services** - Total emergy yield divided by yield in joules			
17	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
18	**Empower Density -** sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-12. Emergy evaluation table of corn, per ha per year

Notes	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	1.81E+10	J	1.24E+05	224
5	Groundwater	5.08E+09	J	2.69E+05	137
Purchased Inputs					
6	Fuel	6.95E+09	J	1.11E+05	77
7	Phosphorus	9.03E+04	g	1.45E+10	131
8	Nitrogen	1.97E+05	g	1.59E+10	314
9	Potassium	1.18E+05	g	1.85E+09	22
10	Pesticides	1.10E+04	g	2.52E+10	28
11	Labor	4.88E+06	J	4.45E+06	2
12	Services	8.73E+02	$	2.83E+12	247
13	Total EMERGY				1233
Yields					
14	Total Yield, dry weight	9.11E+06	g		
15	Total Yield, energy	1.33E+11	J		
Calculated ratios					
16	Emergy per mass	1.35E+09	sej/g		
17	Transformity w/services	9.24E+04	sej/J		
18	Transformity wo/services	7.39E+04	sej/J		
19	Empower Density	1.23E+16	sej/ha/yr		
20	NR + PI Empower Density w/services	1.18E+16	sej/ha/yr		
21	NR + PI Empower Density wo/services	9.34E+15	sej/ha/yr		

Notes: Corn, Flood Irrigated, Loamy Soils

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Growing season =	3.30E-01	yr	(www.uaex.edu)
Area =	1.00E+04	m^2	
Albedo =	2.00E-01		(After www.nasa.gov)
Annual energy =	1.56E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Evapotranspiration, J**

Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Evapotranspiration =	1.20E+00	m^3/m^2/yr	(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr	
Volume (4 months) =	4.00E+03	m^3/yr	
Annual energy =	1.98E+10	J	
Emergy per unit input =	1.54E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	2.00E+03	$g/m^2/yr$	(Pimentel et al. 1995)
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil =	(farmed area)(erosion rate)		
	OM in topsoil used up =	(total mass of topsoil)(% organic)		
	Energy loss =	(loss of organic matter)(5.4 kcal/g)(4186 J/kcal)		
	Annual energy =	1.81E+10	J	
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Ground water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater irrigation =	1.00E+01	acre inch/yr	(Windham & Marshall 2005; www.aragriculture.org/famplanning/budgets)
	Groundwater irrigation =	1.03E+03	m^3/yr	
	Annual energy =	5.08E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Fuel, J**			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Gallons/acre =	2.13E+01		(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Gallons/ha =	5.27E+01		
	Annual energy =	6.95E+09	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Phosphorus, g**			
	Annual consumption =	8.05E+01	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	9.03E+04	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
8	**Nitrogen, g**			
	Annual consumption (Liquid 32%) =	1.76E+02	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption (Liquid 32%) =	1.97E+05	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams 2001)
9	**Potassium, g**			
	Annual consumption =	1.05E+02	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	1.18E+05	g/ha	
	Emergy per unit input =	1.10E+09	sej/g	(Odum 1996)
10	**Pesticides, g** (insecticides and herbicides)			
	Annual consumption =	9.85E+00	lb/acre	(Assumed one pint of pesticide = 1.0375 lbs)
	Annual consumption =	1.10E+04	g/ha	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)

11	**Labor, J** (operation and irrigation)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	1.51E+00	hr/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Labor =	3.73E+00	hr/ha	
	Annual energy =	4.88E+06	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
12	**Services, $**			
	Value =	2.02E+00	$/bushel	(www.nass.usda.gov/ar/)
	Value =	8.73E+02	$/ha	
	Annual energy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
13	**Total Emergy** - Sum of inputs 2 through 12			
14	**Yield**			
	Yield =	1.45E+02	Bu/acre	(www.auex.edu)
		5.60E+01	lb/bu	(www.muextension.missouri.edu)
	Yield =	9.11E+06	g/ha	
15	**Product in Joules**			
	Energy =	(__g)(3.5 kcal/g)(4186J/kcal)		(Odum et al.1998)
	Energy content =	1.33E+11	J	
16	**Emergy per mass** - Total emergy divided by yield in grams			
17	**Transformity w/services** - Total emergy yield divided by yield in joules			
18	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
19	**Empower Density** - sum of emergy per hectare per year			
20	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year			
21	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-13. Emergy evaluation table for rice, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	9.04E+09	J	1.24E+05	112
5	Groundwater	1.22E+10	J	2.69E+05	328
Purchased Inputs					
6	Fuel	1.19E+10	J	1.11E+05	132
7	Phosphorus	4.04E+04	g	1.45E+10	59
8	Nitrogen	1.70E+05	g	1.59E+10	271
9	Potassium	8.07E+04	g	1.85E+09	15
10	Pesticides	8.63E+03	g	2.52E+10	22
11	Labor	6.33E+06	J	4.45E+06	3
12	Services	6.16E+02	$	2.83E+12	174
13	Total EMERGY				1166
Yields					
14	Total Yield	7.12E+06	g		
15	Total Yield, energy	1.04E+11	J		
Calculated ratios					
16	Emergy per mass	1.64E+09	sej/g		
17	Transformity w/services	1.12E+05	sej/J		
18	Transformity wo/services	9.50E+04	sej/J		
19	Empower Density	1.17E+16	sej/ha/yr		
20	NR + PI Empower Density w/services	1.11E+16	sej/ha/yr		
21	NR + PI Empower Density wo/services	9.40E+15	sej/ha/yr		

Notes: Rice, Silt Loam Soils, Eastern Arkansas **References:**

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Growing season =	3.30E-01	yr	(www.uaex.edu)
Area =	1.00E+04	m^2	
Albedo =	2.00E-01		(After www.nasa.gov)
Annual energy =	1.56E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Evapotranspiration, J**

Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Evapotranspiration =	1.20E+00	m^3/m^2/yr	(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr	
Volume (4 months) =	4.00E+03	m^3/yr	
Annual energy =	1.98E+10	J	
Emergy per unit input =	1.54E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.00E+03	$g/m^2/yr$	(Odum et al. 1998)
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil =	(farmed area)(erosion rate)		
	OM in topsoil used up =	(total mass of topsoil)(% organic)		
	Energy loss =	(loss of organic matter)(5.4 kcal/g)(4186 J/kcal)		
	Annual energy =	9.04E+09	J	
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Groundwater, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater irrigation =	2.40E+01	acre inch/yr	(Windham & Marshall 2005; www.aragriculture.org/famplanning/budgets)
	Groundwater irrigation =	2.47E+03	m^3/yr	
	Annual energy =	1.22E+10	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Fuel, J**			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Gallons/acre =	3.65E+01		(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Gallons/ha =	9.02E+01		
	Annual energy =	1.19E+10	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Phosphorus, g**			
	Annual consumption =	3.60E+01	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	4.04E+04	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
8	**Nitrogen, g**			
	Consumption (as Urea 46%) =	1.52E+02	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Consumption (as Urea) =	1.70E+05	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams 2001)
9	**Potassium, g**			
	Annual consumption =	7.20E+01	lb/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	8.07E+04	g/ha	
	Emergy per unit input =	1.10E+09	sej/g	(Odum 1996)
10	**Pesticides, g** (includes fungicides and herbicides)			
	Annual consumption =	7.70E+00	lb/acre	(Assumed one pint of pesticide = 1.0375 lbs)

	Annual consumption =	8.63E+03	g/ha	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991)
11	**Labor, J** (operation and irrigation)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	1.96E+00	hr/acre	(Windham & Marshall 2004; www.aragriculture.org/famplanning/budgets)
	Labor =	4.84E+00	hr/ha	
	Annual energy =	6.33E+06	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
12	**Services, $**			
	Value =	3.93E+00	$/CWT	(www.nass.usda.gov/ar/)
	Value =	6.16E+02	$/ha	
	Annual emergy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
13	**Total Emergy** - Sum of inputs 2 through 12			
14	**Yield, g**			
	Yield =	6.35E+03	lb/acre	(www.nass.usda.gov/ar/)
	Yield =	7.12E+06	g/ha	
15	**Product in Joules**			
	Energy =	(__g)(3.5 kcal/g)(4186 J/kcal)		(Odum et al.1998)
	Energy content =	1.04E+11	J	
16	**Emergy per mass** - Total emergy divided by yield in grams			
17	**Transformity w/services** - Total emergy yield divided by yield in joules			
18	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
19	**Empower Density -** sum of emergy per hectare per year			
20	**NR + PI Empower Density w/services - s**um of non renewable and purchased inputs emergy per hectare per year			
21	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-14. Emergy Evaluation of cotton, per ha per year

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	1.56E+13	J	1	2
2	Rain transpired	1.98E+10	J	2.59E+04	51
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	8.23E+10	J	1.24E+05	1020
5	Groundwater	6.09E+09	J	2.69E+05	164
Purchased Inputs					
6	Fuel	8.86E+09	J	1.11E+05	98
7	Phosphorus	3.36E+04	g	1.45E+10	49
8	Nitrogen	1.12E+05	g	1.59E+10	178
9	Potassium	1.01E+05	g	1.85E+09	19
10	Pesticides	2.13E+04	g	2.52E+10	54
11	Labor	6.79E+06	J	4.45E+06	3
12	Services	1.12E+03	$	2.83E+12	316
13	Total EMERGY				1952
Yields					
14	Total Yield	1.81E+06	g		
15	Total Yield, energy	3.03E+10	J		
Calculated ratios					
16	Emergy per mass	1.08E+10	sej/g		
17	Transformity w/services	6.44E+05	sej/J		
18	Transformity wo/services	5.39E+05	sej/J		
19	Empower Density	1.95E+16	sej/ha/yr		
20	NR + PI Empower Density w/services	1.90E+16	sej/ha/yr		
21	NR + PI Empower Density wo/services	1.58E+16	sej/ha/yr		

Notes: **Cotton, Conventional till, furrow irrigation, 8 row equipment**

				References:
1 **Sunlight, J**				
Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)			
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)			
Insolation =	1.41E+02	kcal/cm^2/yr		(Odum et al. 1998)
Growing season =	3.30E-01	yr		(www.uaex.edu)
Area =	1.00E+04	m^2		
Albedo =	2.00E-01			(After www.nasa.gov)
Annual energy =	1.56E+13	J		
Emergy per unit input =	1.00E+00	sej/J		(Odum 1996)
2 **Evapotranspiration, J**				
Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)			
Evapotranspiration =	1.20E+00	m^3/m^2/yr		(Odum et al. 1998)
Volume/year =	1.20E+04	m^3/yr		
Volume (4 months) =	4.00E+03	m^3/yr		
Annual energy =	1.98E+10	J		
Emergy per unit input =	1.54E+04	sej/J		(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	9.10E+03	$g/m^2/yr$	(After Pimentel et al. 1995)
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil =	(farmed area)(erosion rate)		
	OM in topsoil used up =	(total mass of topsoil)(% organic)		
	Energy loss =	(loss of organic matter)(5.4 kcal/g)(4186 J/kcal)		
	Annual energy =	8.23E+10	J	
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Ground water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		(Hogan et al. 2005); www.aragriculture.org/famplanning/budgets
	Groundwater irrigation =	1.20E+01	acre inch/yr	
	Groundwater irrigation =	1.23E+03	m^3/yr	
	Annual energy =	6.09E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Fuel, J**			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Gallons/acre =	2.72E+01		(Hogan et al. 2005); www.aragriculture.org/famplanning/budgets
	Gallons/ha =	6.71E+01		
	Annual energy =	8.86E+09	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Phosphorus, g**			
	Annual consumption =	3.00E+01	lb/acre	(Bourland et al. 2003; data for the Southeast Branch Experiment Station at Rohwer)
	Annual consumption =	3.36E+04	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
8	**Nitrogen, g**			
	Annual consumption (Liquid 32%) =	9.98E+01	lb/acre	(Hogan et al. 2005; www.aragriculture.org/famplanning/budgets)
	Annual consumption =	1.12E+05	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
9	**Potassium, g**			
	Annual consumption =	9.00E+01	lb/acre	(Bourland et al. 2003; data for the Southeast Branch Experiment Station at Rohwer)
	Annual consumption =	1.01E+05	g/ha	
	Emergy per unit input =	1.10E+09	sej/g	(Odum 1996)
10	**Pesticides, g** (fungicides, insecticides and herbicides)			
	Annual consumption =	1.90E+01	lb/acre	(Assumed one pint of pesticide = 1.0375 lbs)
	Annual consumption =	2.13E+04	g/ha	(Hogan et al. 2005); www.aragriculture.org/famplanning/budgets
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)

11	**Labor, J** (operation, irrigation, and hand labor)			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	2.10E+00	hr/acre	(Hogan et al. 2005; www.aragriculture.org/famplanning/budgets)
	Labor =	5.19E+00	hr/ha	
	Annual energy =	6.79E+06	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
12	**Services, $**			
	Value =	2.80E-01	$/lb	(www.nass.usda.gov/ar/)
	Value =	1.12E+03	$/ha	
	Annual energy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
13	**Total Emergy -** Sum of inputs 2 through 12			
14	**Yield, g**			
	Yield =	1.62E+03	lb/acre	(Bourland et al. 2003; data for the Southeast Branch Experiment Station at Rohwer)
	Yield =	1.81E+06	g/ha	
15	**Product in Joules**			
	Energy =	(__g)(4.0 kcal/g)(4186J/kcal)		(Odum et al.1998)
	Energy content =	3.03E+10	J	
16	**Emergy per mass** - Total emergy divided by yield in grams			
17	**Transformity w/services** - Total emergy yield divided by yield in joules			
18	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
19	**Empower Density -** sum of emergy per hectare per year			
20	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year			
21	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Aquaculture

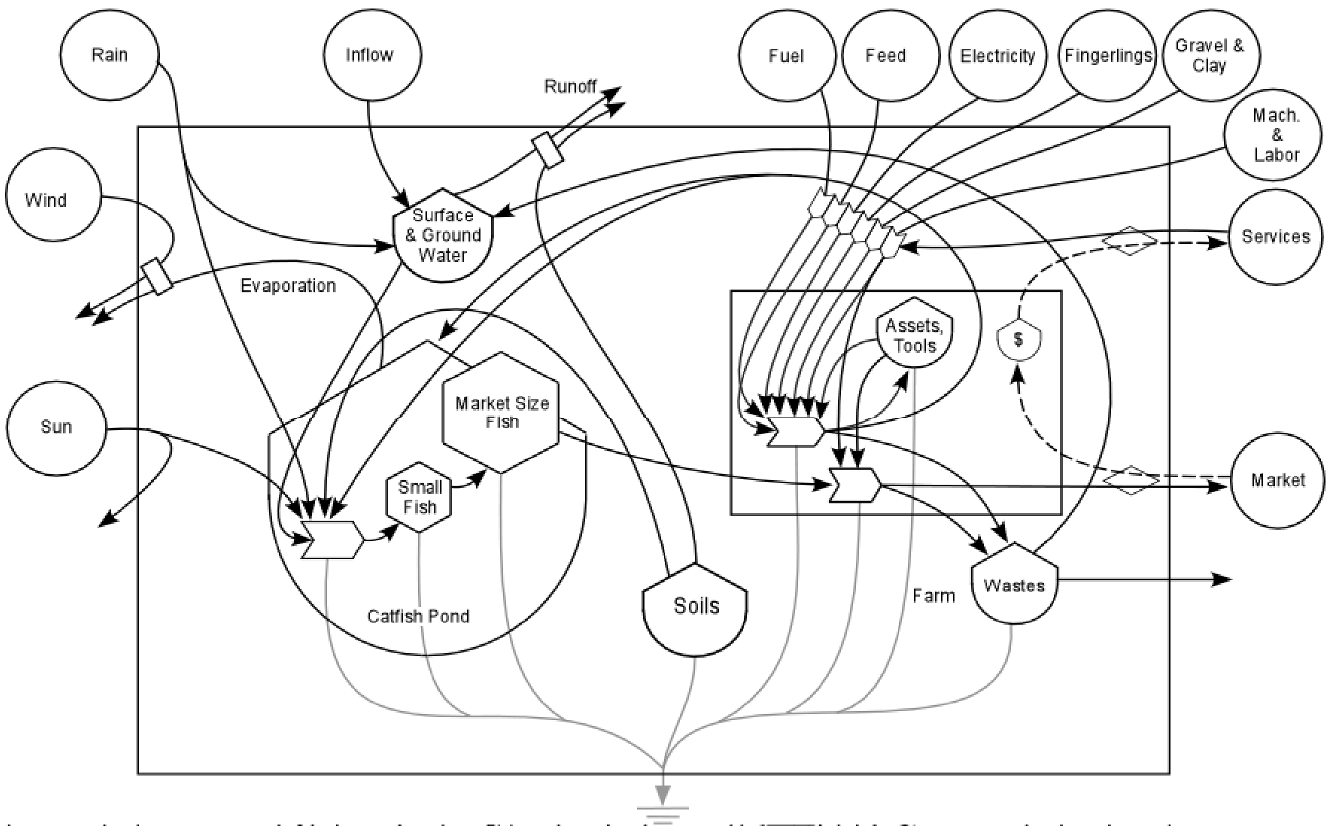


Figure A-10. Energy systems diagram of a catfish farm.

Table A-15. Emergy evaluation table for a catfish farm, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.31E+13	J	1	5
2	Rain	5.98E+10	J	3.02E+04	181
3	Wind	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Groundwater	2.49E+10	J	2.69E+05	669
Purchased Inputs					
5	Fish Fingerlings	5.82E+09		3.36E+06	1954
6	Fuel	1.34E+09	J	1.11E+05	15
7	Electricity	4.64E+09	J	2.69E+05	125
8	Feed	1.50E+11	J	3.36E+05	5056
9	Clay (pond construction)	1.52E+06	g	1.71E+09	260
10	Gravel (pond construction)	2.49E+06	g	1.71E+09	426
11	Machinery	1.32E+03	$	2.83E+12	374
12	Labor	2.79E+08	J	4.45E+06	124
13	Services	6.22E+03	$	2.83E+12	1762
14	Total EMERGY				10944
Yields					
15	Total Yield	3.92E+06	g		
16	Total Yield, energy	1.94E+10	J		
Calculated ratios					
17	Emergy per mass	2.79E+10	sej/g		
18	Transformity w/services	5.65E+06	sej/J		
19	Transformity wo/services	4.74E+06	sej/J		
20	Empower Density	1.09E+17	sej/ha/yr		
21	NR + PI Empower Density w/services	1.08E+17	sej/ha/yr		
22	NR + PI Empower Density wo/services	9.00E+16	sej/ha/yr		

Notes: **Small-scale Catfish Production (Six 2-acre ponds)**

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m²)(__Cal/cm²/y)(1E+04cm²/m²)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm²/yr	(Odum et al. 1998)
Area (pond) =	1.00E+04	m²	
Albedo =	1.00E-01		(Assumed)
Annual energy =	5.31E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain, J**

Annual energy =	(__m/yr)(__m²)(1E6g/m³)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area (pond) =	1.00E+04	m²	
Annual energy =	5.98E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag Coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
	Annual energy =	1.00E+11	J	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Groundwater, J**			
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Used =	1.67E+00	acre-ft	
	Used =	5.08E+03	m^3/yr	
	Annual energy =	2.49E+10	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al. 1998)
5	**Fish Fingerlings, J**			
	Annual energy =	(grams fish)(5 kcal/gr)(4186 J/kcal)		
	Stock =	3.75E+03	fish/acre	
	Stock =	9.26E+03	fish/ha	
	Average weight =	3.00E+01	g/fish	(Chapman 2000; http://edis.ifas.ufl.edu)
	Total weight =	2.78E+05	g	
	Annual energy =	5.82E+09	J	
	Emergy per unit input =	2.00E+06	sej/J	(Brown et al. 1992)
6	**Fuel, J** (fuel/oil/lube)			
	Annual energy =	(Gallons fuel)(1.32E8 J/gal)		
	Tractor =	4.12E+01	h/yr	(Engle & Stone 2002; http://srac.tamu.edu)
	Tractor fuel consumption =	4.20E-02	gal/h	(Grisso et al. 2003)
	Total tractor fuel consumption =	1.73E+00	gal/yr	
	Tractor annual energy =	2.28E+08	J	
	ATV =	9.37E+01	h/yr	
	ATV fuel consumption =	8.97E-02	gal/h	(Assumed based on 2.3 L/100 km, 15 km/h)
	Total ATV fuel consumption =	8.40E+00	gal/yr	
	ATV annual energy =	1.11E+09	J	
	Total annual energy =	1.34E+09	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Electricity, J**			
	Based on usage of a 1.5 HP/acre electric aerator			
	1 HP =	2.69E+06	J/h	
	Usage/yr =	7.00E+02	h/acre	(Engle & Stone 2002; http://srac.tamu.edu)
	Usage/yr =	1.73E+03	h/ha	
	Annual energy =	4.64E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
8	**Feed, J**			
	Annual energy =	(__grams)(__Kcal/g)(4186 J/kcal)		
	Weight =	4.95E+00	ton/acre	(Engle & Stone 2002; http://srac.tamu.edu)
	Weight =	1.22E+07	g/ha	
	(30% protein; 6% fat; 30% carbohydrates)			(Robinson & Li 1996; http://msucares.com/pubs/bulletins/b1041.htm)
	(protein = 4.0 kcal/g; fat = 9.0 kcal/g; carbohydrates = 4.0 kcal/g)			(FAO 2003)
	Annual energy =	1.50E+11	J	

	Emergy per unit input =	2.00E+05	sej/J	(Ortega et al. 2000)
9	**Clay, g** (pond construction, 20 yr useful life)			
	(Volume clay 50%, volume gravel 50%)			(Assumed)
	Volume clay =	1.38E+01	cu yd/acre	(www.uaex.edu/aquaculture2/FSA/FSA9077.htm)
	Weight(dry) clay =	7.25E+01	lb/cu ft	(www.sodsolutions.com/turfmgt/metric.html)
	Weight clay =	1.52E+06	g/ha	
	Emergy per unit input =	1.71E+09		(Odum 1996)
10	**Gravel, g** (pond construction, 20 yr useful life)			
	Volume gravel =	1.38E+01	cu yd/acre	(www.uaex.edu/aquaculture2/FSA/FSA9077.htm)
	Weight (dry) gravel =	1.19E+02	lb/cu ft	(www.epa.gov/ttn/chief/ap42/appendix/appa.pdf)
	Weight gravel =	2.49E+06	g/ha	
	Emergy per unit input =	1.71E+09		(Odum 1996)
11	**Machinery, $**			
	(Average useful life 7 yrs)			(Assumed after Engle & Stone 2002; www.srac.tamu.edu)
	Total Investment =	3.74E+03	$/acre	(Engle & Stone 2002; www.srac.tamu.edu)
	Total Investment =	1.32E+03	$/ha-yr	
	Emergy per unit input =	2.29E+12	sej/$, 2001	(This study, see Table A-5)
12	**Labor, J**			
	Annual energy =	(pers-hours/ha/yr)(2500 kcal/day)(4186J/Cal) / (8 pers- hrs/day)		
	Labor =	8.63E+01	h/acre	(Engle & Stone 2002; http://srac.tamu.edu)
	Labor =	2.13E+02	h/ha	
	Annual energy =	2.79E+08	J	
	Emergy per unit input =	4.45E+06	sej/J	(Migrant labor, Brandt-Williams 2001)
13	**Services, $**			
	Value =	7.20E-01	$/lb	(Engle & Stone 2002; http://srac.tamu.edu)
	Value =	6.22E+03	$/yr	
	Annual emergy =	($ /yr)(sej/$)		
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
14	**Total Emergy** - Sum of inputs 3 through 13			
15	**Yield, g**			
	Total Yield =	3.50E+03	lb/acre	(Chapman 2000: http://edis.ifas.ufl.edu)
	Total Yield =	3.92E+06	g/ha	
16	**Product in Joules**			
	Energy =	(__grams)(__Kcal/g)(4186 J/kcal)		
	Energy content =	1.18E+02	kcal/100g (raw tissue)	(Robinson et al. 2001)
	Energy content =	1.94E+10	J	
17	**Emergy per mass** - Total emergy divided by yield in grams			
18	**Transformity w/services** - Total emergy yield divided by yield in joules			
19	**Transformity wo/services** - Total emergy yield minus services divided by yield in joules			
20	**Empower Density** - sum of emergy per hectare per year			
21	**NR + PI Empower Density w/services** - sum of non renewable and purchased inputs emergy per hectare per year			
22	**NR + PI Empower Density wo/services** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Residential land uses

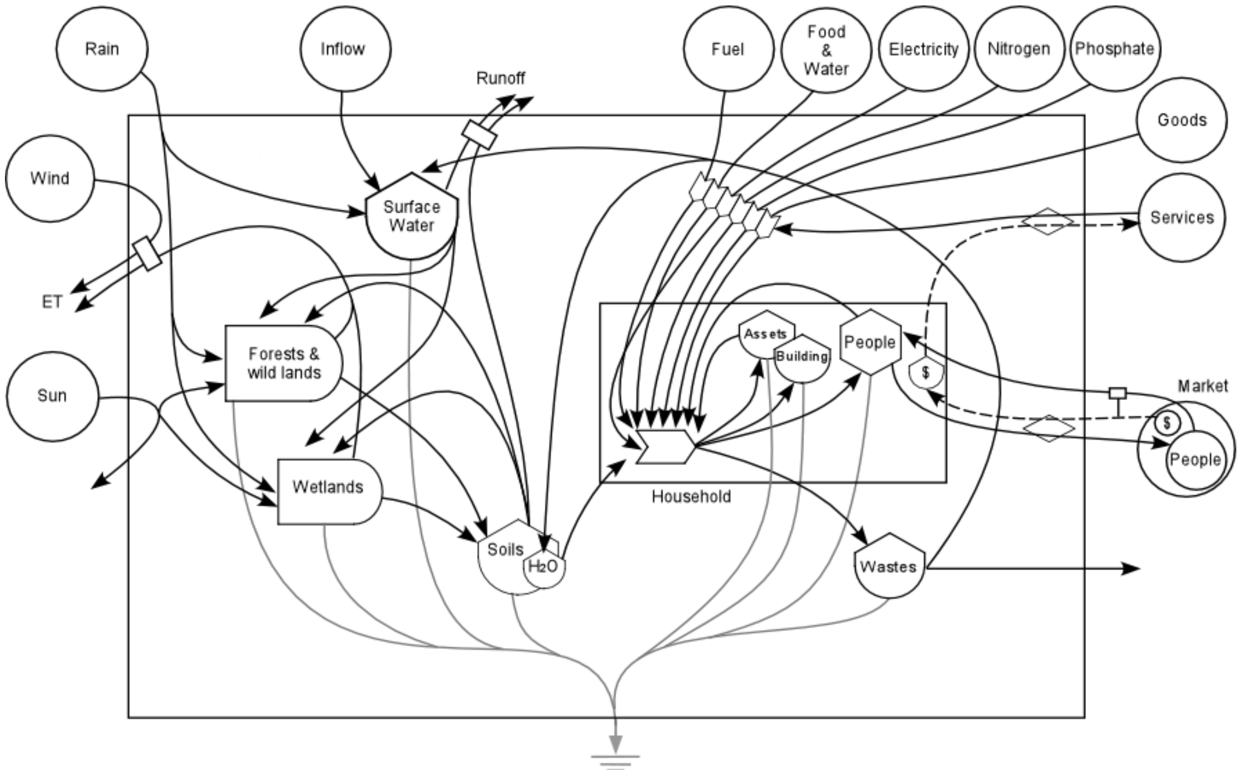


Figure A-11. Energy systems diagram of a single-family residential land use.

Table A-16. Emergy evaluation table for a low-density single-family residential land use, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Water	3.07E+09	J	2.69E+05	82
6	Fuel	1.01E+10	J	1.11E+05	112
7	Natural Gas	3.68E+10	J	8.06E+04	297
8	Electricity	4.54E+10	J	2.69E+05	1222
9	Pesticides	5.10E+03	g	2.52E+10	13
10	Nitrogen	2.27E+04	g	1.59E+10	36
11	Phosphate	8.43E+03	g	1.45E+10	12
12	Food	2.62E+07	J	3.36E+06	9
13	Construction Materials	3.04E+07	g	1.55E+09	4712
14	Goods & Services	7.55E+03	$	2.83E+12	2138
15	Total EMERGY				8727
			Units/ha =	2.5	21818
Calculated ratios					
16	Empower Density	8.73E+16	sej/ha/yr		
17	NR + PI Empower Density w/services	8.64E+16	sej/ha/yr		
18	Empower Density (2.5 units/ha)	2.18E+17	sej/ha/yr		
19	NR + PI Empower Density w/services (2.5 units/ha)	2.16E+17	sej/ha/yr		
20	NR + PI Empower Density wo/services (2.5 units/ha)	1.62E+17	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)
Energy (J) =	(area)(air density)(drag coefficient)($velocity^3$)		
=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
Energy (J) =	1.00E+11	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

4 **Net Topsoil Loss, J**

Erosion rate =	1.00E+00	lb/acre/day	(Corbitt 1990)
Erosion rate =	4.09E+01	$g/m^2/yr$	
Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
Energy cont./g organic =	5.40E+00	kcal/g	

Net loss of topsoil = (farmed area)(erosion rate)

Organic matter in topsoil used up = (total mass of topsoil)(% organic)

Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Annual energy =	3.70E+08		
Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)

5 **Water, J**

Annual energy =	Chemical potential of groundwater		
Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Groundwater consumption =	1.11E+02	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
Groundwater consumption =	1.53E+08	m^3/yr	
Population =	6.15E+05		(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
Per capita groundwater consumption =	2.48E+02	m^3/yr	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Groundwater consumption =	6.21E+02	$m^3/unit$	
Annual energy =	3.07E+09	J	
Emergy per unit input =	1.60E+05	sej/J	(Odum et al. 1998)

6 **Fuel, J** (Kerosene and LPG)

Annual energy =	(Btu)(1055 J/Btu)		
Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
Total residential fuel use (Y2001) =	1.03E+13	Btu	(www.eia.gov)
Per capita fuel consumption =	3.81E+06	Btu	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Fuel consumption =	9.54E+06	Btu/ha	
Annual energy =	1.01E+10	J	
Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)

7 **Natural Gas, J**

Annual energy =	(Btu)(1055 J/Btu)		
Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
Total residential gas use (Y2001) =	3.77E+13	Btu	(www.eia.gov)
Per capita gas consumption =	1.40E+07	Btu	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Gas consumption =	3.49E+07	Btu	
Annual energy =	3.68E+10		
Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)

8	**Electricity, J**				
		Annual Energy =	(___KwH/yr)(3.6 E6 J/KwH)		
		Electricity consumption =	1.26E+04	KwH/yr	(Entergy Arkansas, Inc. 2001)
		Annual energy =	4.54E+10	Btu	
		Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
9	**Pesticides, g** (includes herbicides, insecticides, fungicides)				
		Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
		Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
10	**Nitrogen, g of N**				
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)				
		g =	1.07E+05		(Brown and Vivas 2005)
		Annual consumption =	2.27E+04	g/ha	
		Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
11	**Phosphate, g of P**				
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)				
		g =	3.59E+04		(Brown and Vivas 2005)
		Annual consumption =	8.43E+03	g/ha	
		Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
12	**Food, J**				
		Annual consumption =	(2500 Cal/day)(4186 J/Cal)		
		Persons/household (Y2000)=	2.50E+00		(www.census.gov)
		Annual energy =	2.62E+07	J	
		Emergy per unit input =	3.36E+06	sej/J	(After Brown & Vivas 2005)
13	**Construction Materials, g**				
		Mass (g) =	(Total weight)/(50 yrs)		
		Total weight =	1.52E+09	g	(Haukoos 1995)
		Mass =	3.04E+07	g	
		Emergy per unit input =	1.55E+09	sej/g	(After Brown & Vivas 2005)
14	**Goods, $**				
		Per capita income Y2001 =	2.29E+04	$	(ADED, www.1800arkansas.com)
		Fraction of income into goods=	3.30E-01		(ACCRA Cost of Living Index – Misc. - in ADED 2005)
		Annual consumption =	7.55E+03	$	
		Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
15	**Total Emergy -** Sum of inputs 2 through 14				
16	**Empower Density -** sum of emergy per hectare per year				
17	**NR + PI Empower Density -** sum of non renewable and purchased inputs emergy per hectare per year				
18	**Empower Density (2.5 units/ha)** - sum of emergy per hectare per year				
19	**NR + PI Empower Density w/services (2.5 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year				
20	**NR + PI Empower Density wo/services (2.5 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year minus services				

Table A-17. Emergy evaluation table for a medium-density single-family residential land use, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Water	3.07E+09	J	2.69E+05	82
6	Fuel	1.01E+10	J	1.11E+05	112
7	Natural Gas	3.68E+10	J	8.06E+04	297
8	Electricity	4.54E+10	J	2.69E+05	1222
9	Pesticides	5.10E+03	g	2.52E+10	13
10	Nitrogen	2.27E+04	g	1.59E+10	36
11	Phosphate	8.43E+03	g	1.45E+10	12
12	Food	2.62E+07	J	3.36E+06	9
13	Construction Materials	3.04E+07	g	1.55E+09	4712
14	Goods & Services	7.55E+03	$	2.83E+12	2138
15	Total EMERGY				8727
			Units/ha =	7	61091
Calculated ratios					
16	Empower Density	8.73E+16	sej/ha/yr		
17	NR + PI Empower Density	8.64E+16	sej/ha/yr		
18	Empower Density (7 units/ha)	6.11E+17	sej/ha/yr		
19	NR + PI Empower Density w/services (7 units/ha)	6.05E+17	sej/ha/yr		
20	NR + PI Empower Density wo/services (7 units/ha)	4.55E+17	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)

Avg. annual wind velocity = 3.04E+00 mps (Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind = 5.07E+00 mps (Observed winds are about 0.6 of geostrophic wind)
Drag coeff. = 2.00E-03 (Garrat 1977)
Energy (J) = (area)(air density)(drag coefficient)(velocity^3)
= (___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)
Energy (J) = 1.00E+11 J/yr
Emergy per unit input = 2.45E+03 sej/J (Odum et al. 2000)

4 **Net Topsoil Loss, J**

Erosion rate = 1.00E+00 lb/acre/day (Corbitt 1990)
Erosion rate = 4.09E+01 g/m^2/yr
Organic fraction in soil = 4.00E-02 (Pimentel et al. 1995)
Energy cont./g organic = 5.40E+00 kcal/g
Net loss of topsoil = (farmed area)(erosion rate)
Organic matter in topsoil used up = (total mass of topsoil)(% organic)
Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)
Annual energy = 3.70E+08
Emergy per unit input = 7.38E+04 sej/J (Odum 1996)

5 **Water, J**

Annual energy = Chemical potential of groundwater
Annual energy = (Volume)(1E6 g/m^3)(4.94 J/g)
Groundwater consumption = 1.11E+02 Mgal/day (Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.usg.gov)
Groundwater consumption = 1.53E+08 m^3/yr
Population = 6.15E+05 (Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
Per capita groundwater consumption = 2.48E+02 m^3/yr
Persons/household (Y2000) = 2.50E+00 (www.census.gov)
Groundwater consumption = 6.21E+02 m^3/unit
Annual energy = 3.07E+09 J
Emergy per unit input = 1.60E+05 sej/J (Odum et al. 1998)

6 **Fuel, J** (Kerosene and LPG)

Annual energy = (Btu)(1055 J/Btu)
Population Arkansas (Y2001) = 2.70E+06 (Est. based on 1% increase for Y2000; ADED 2003)
Total residential fuel use (Y2001) = 1.03E+13 Btu (www.eia.gov)
Per capita fuel consumption = 3.81E+06 Btu
Persons/household (Y2000) = 2.50E+00 (www.census.gov)
Fuel consumption = 9.54E+06 Btu/ha
Annual energy = 1.01E+10 J
Emergy per unit input = 6.60E+04 sej/J (Odum 1996)

7 **Natural Gas, J**

Annual energy = (Btu)(1055 J/Btu)
Population Arkansas (Y2001) = 2.70E+06 (Est. based on 1% increase for Y2000; ADED 2003)
Total residential gas use (Y2001) = 3.77E+13 Btu (www.eia.gov)
Per capita gas consumption = 1.40E+07 Btu
Persons/household (Y2000) = 2.50E+00 (www.census.gov)
Gas consumption = 3.49E+07 Btu
Annual energy = 3.68E+10
Emergy per unit input = 4.80E+04 sej/J (Odum 1996)

8 **Electricity, J**

Annual Energy = (___KwH/yr)(3.6 E6 J/KwH)
Electricity consumption = 1.26E+04 KwH/yr (Entergy Arkansas, Inc. 2001)
Annual energy = 4.54E+10 Btu

	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
9	**Pesticides, g** (includes herbicides, insecticides, fungicides)			
	Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
10	**Nitrogen, g of N**			
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)			
	g =	1.07E+05		(Brown and Vivas 2005)
	Annual consumption =	2.27E+04	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
11	**Phosphate, g of P**			
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)			
	g =	3.59E+04		(Brown and Vivas 2005)
	Annual consumption =	8.43E+03	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
12	**Food, J**			
	Annual consumption =	(2500 Cal/day)(4186 J/Cal)		
	Persons/household (Y2000)=	2.50E+00		(www.census.gov)
	Annual energy =	2.62E+07	J	
	Emergy per unit input =	3.36E+06	sej/J	(After Brown & Vivas 2005)
13	**Construction Materials, g**			
	Mass (g) =	(Total weight)/(50 yrs)		
	Total weight =	1.52E+09	g	(Haukoos 1995)
	Mass =	3.04E+07	g	
	Emergy per unit input =	1.55E+09	sej/g	(After Brown & Vivas 2005)
14	**Goods, $**			
	Per capita income Y2001 =	2.29E+04	$	(ADED, available at www.1800arkansas.com)
	Fraction of income into goods=	3.30E-01		(ACCRA Cost of Living Index – Misc., ADED 2005)
	Annual consumption =	7.55E+03	$	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
15	**Total Emergy -** Sum of inputs 2 through 14			
16	**Empower Density** - sum of emergy per hectare per year			
17	**NR + PI Empower Density** - sum of non renewable and purchased inputs emergy per hectare per year			
18	**Empower Density (7 units/ha)** - sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services (7 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services (7 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-18. Emergy evaluation table for a high-density single-family residential land use, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Water	3.07E+09	J	2.69E+05	82
6	Fuel	1.01E+10	J	1.11E+05	112
7	Natural Gas	3.68E+10	J	8.06E+04	297
8	Electricity	4.54E+10	J	2.69E+05	1222
9	Pesticides	5.10E+03	g	2.52E+10	13
10	Nitrogen	2.27E+04	g	1.59E+10	36
11	Phosphate	8.43E+03	g	1.45E+10	12
12	Food	2.62E+07	J	3.36E+06	9
13	Construction Materials	3.04E+07	g	1.55E+09	4712
14	Goods & Services	7.55E+03	$	2.83E+12	2138
15	Total EMERGY				8727
			Units/ha =	10	87273
Calculated ratios					
16	Empower Density	8.73E+16	sej/ha/yr		
17	NR + PI Empower Density	8.64E+16	sej/ha/yr		
18	Empower Density (10 units/ha)	8.73E+17	sej/ha/yr		
19	NR + PI Empower Density w/services (10 units/ha)	8.64E+17	sej/ha/yr		
20	NR + PI Empower Density wo/services (10 units/ha)	6.50E+17	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
	Energy (J) =	1.00E+11	J/yr	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.00E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	$g/m^2/yr$	
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater consumption =	1.11E+02	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
	Groundwater consumption =	1.53E+08	m^3/yr	
	Population =	6.15E+05		(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
	Per capita groundwater consumption =	2.48E+02	m^3/yr	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Groundwater consumption =	6.21E+02	$m^3/unit$	
	Annual energy =	3.07E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al. 1998)
6	**Fuel, J** (Kerosene and LPG)			
	Annual energy =	(Btu)(1055 J/Btu)		
	Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
	Total residential fuel use (Y2001) =	1.03E+13	Btu	(www.eia.gov)
	Per capita fuel consumption =	3.81E+06	Btu	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Fuel consumption =	9.54E+06	Btu/ha	
	Annual energy =	1.01E+10	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Natural Gas, J**			
	Annual energy =	(Btu)(1055 J/Btu)		
	Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
	Total residential gas use (Y2001) =	3.77E+13	Btu	(www.eia.gov)
	Per capita gas consumption =	1.40E+07	Btu	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Gas consumption =	3.49E+07	Btu	
	Annual energy =	3.68E+10		
	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)

8	**Electricity, J**			
	Annual Energy =	(___KwH/yr)(3.6 E6 J/KwH)		
	Electricity consumption =	1.26E+04	KwH/yr	(Entergy Arkansas, Inc. 2001)
	Annual energy =	4.54E+10	Btu	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
9	**Pesticides, g** (includes herbicides, insecticides, fungicides)			
	Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
10	**Nitrogen, g of N**			
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)			
	g =	1.07E+05		(Brown and Vivas 2005)
	Annual consumption =	2.27E+04	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
11	**Phosphate, g of P**			
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)			
	g =	3.59E+04		(Brown and Vivas 2005)
	Annual consumption =	8.43E+03	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
12	**Food, J**			
	Annual consumption =	(2500 Cal/day)(4186 J/Cal)		
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Annual energy =	2.62E+07	J	
	Emergy per unit input =	3.36E+06	sej/J	(After Brown & Vivas 2005)
13	**Construction Materials, g**			
	Mass (g) =	(Total weight)/(50 yrs)		
	Total weight =	1.52E+09	g	(Haukoos 1995)
	Mass =	3.04E+07	g	
	Emergy per unit input =	1.55E+09	sej/g	(After Brown & Vivas 2005)
14	**Goods, $**			
	Per capita income Y2001 =	2.29E+04	$	(ADED, available at www.1800arkansas.com)
	Fraction of income into goods =	3.30E-01		(ACCRA Cost of Living Index - Miscellaneous - in ADED 2005)
	Annual consumption =	7.55E+03	$	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
15	**Total Emergy -** Sum of inputs 2 through 14			
16	**Empower Density -** sum of emergy per hectare per year			
17	**NR + PI Empower Density -** sum of non renewable and purchased inputs emergy per hectare per year			
18	**Empower Density (10 units/ha) -** sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services (10 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services (10 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-19. Emergy evaluation table for a low-rise (1 story) multi-family residential land use, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Water	3.07E+09	J	2.69E+05	82
6	Fuel	1.01E+10	J	1.11E+05	112
7	Natural Gas	3.68E+10	J	8.06E+04	297
8	Electricity	4.54E+10	J	2.69E+05	1222
9	Pesticides	5.10E+03	g	2.52E+10	13
10	Nitrogen	2.27E+04	g	1.59E+10	36
11	Phosphate	8.43E+03	g	1.45E+10	12
12	Food	2.62E+07	J	3.36E+06	9
13	Construction Materials	3.04E+07	g	1.55E+09	4712
14	Goods & Services	7.55E+03	$	2.83E+12	2138
15	Total EMERGY				8727
			Units/ha =	32	281527
Calculated ratios					
16	Empower Density	8.73E+16	sej/ha/yr		
17	NR + PI Empower Density	8.64E+16	sej/ha/yr		
18	Empower Density (32 units/ha)	2.82E+18	sej/ha/yr		
19	NR + PI Empower Density w/services (32 units/ha)	2.79E+18	sej/ha/yr		
20	NR + PI Empower Density wo/services (32 units/ha)	2.10E+18	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)
Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
Energy (J) =	1.00E+11	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

4 **Net Topsoil Loss, J**

Erosion rate =	1.00E+00	lb/acre/day	(Corbitt 1990)
Erosion rate =	4.09E+01	$g/m^2/yr$	
Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
Energy cont./g organic =	5.40E+00	kcal/g	

Net loss of topsoil = (farmed area)(erosion rate)

Organic matter in topsoil used up = (total mass of topsoil)(% organic)

Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)

Annual energy =	3.70E+08		
Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)

5 **Water, J**

Annual energy =	Chemical potential of groundwater		
Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
Groundwater consumption =	1.11E+02	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
Groundwater consumption =	1.53E+08	m^3/yr	
Population =	6.15E+05		(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
Per capita groundwater consumption =	2.48E+02	m^3/yr	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Groundwater consumption =	6.21E+02	$m^3/unit$	
Annual energy =	3.07E+09	J	
Emergy per unit input =	1.60E+05	sej/J	(Odum et al. 1998)

6 **Fuel, J** (Kerosene and LPG)

Annual energy =	(Btu)(1055 J/Btu)		
Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
Total residential fuel use (Y2001) =	1.03E+13	Btu	(www.eia.gov)
Per capita fuel consumption =	3.81E+06	Btu	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Fuel consumption =	9.54E+06	Btu/ha	
Annual energy =	1.01E+10	J	
Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)

7 **Natural Gas, J**

Annual energy =	(Btu)(1055 J/Btu)		
Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for data for Y2000; ADED 2003)
Total residential gas use (Y2001) =	3.77E+13	Btu	(www.eia.gov)
Per capita gas consumption =	1.40E+07	Btu	
Persons/household (Y2000) =	2.50E+00		(www.census.gov)
Gas consumption =	3.49E+07	Btu	
Annual energy =	3.68E+10		

	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)
8	**Electricity, J**			
	Annual Energy =	(___KwH/yr)(3.6 E6 J/KwH)		
	Electricity consumption =	1.26E+04	KwH/yr	(Entergy Arkansas, Inc. 2001)
	Annual energy =	4.54E+10	Btu	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
9	**Pesticides, g** (includes herbicides, insecticides, fungicides)			
	Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
10	**Nitrogen, g of N**			
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)			
	g =	1.07E+05		(Brown and Vivas 2005)
	Annual consumption =	2.27E+04	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
11	**Phosphate, g of P**			
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)			
	g =	3.59E+04		(Brown and Vivas 2005)
	Annual consumption =	8.43E+03	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
12	**Food, J**			
	Annual consumption =	(2500 Cal/day)(4186 J/Cal)		
	Persons/household (Y2000)=	2.50E+00		(www.census.gov)
	Annual energy =	2.62E+07	J	
	Emergy per unit input =	3.36E+06	sej/J	(After Brown & Vivas 2005)
13	**Construction Materials, g**			
	Mass (g) =	(Total weight)/(50 yrs)		
	Total weight =	1.52E+09	g	(Haukoos 1995)
	Mass =	3.04E+07	g	
	Emergy per unit input =	1.55E+09	sej/g	(After Brown & Vivas 2005)
14	**Goods, $**			
	Per capita income Y2001 =	2.29E+04	$	(ADED, available at www.1800arkansas.com)
	Fraction of income into goods=	3.30E-01		(ACCRA Cost of Living Index - Miscellaneous - in ADED 2005)
	Annual consumption =	7.55E+03	$	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
15	**Total Emergy -** Sum of inputs 2 through 14			
16	**Empower Density -** sum of emergy per hectare per year			
17	**NR + PI Empower Density -** sum of non renewable and purchased inputs emergy per hectare per year			
18	**Empower Density (32 units/ha)** - sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services (32 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services (32 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-20. Emergy evaluation table for a high rise (3 story) multi-family residential land use, per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Water	3.07E+09	J	2.69E+05	82
6	Fuel	1.01E+10	J	1.11E+05	112
7	Natural Gas	3.68E+10	J	8.06E+04	297
8	Electricity	4.54E+10	J	2.69E+05	1222
9	Pesticides	5.10E+03	g	2.52E+10	13
10	Nitrogen	2.27E+04	g	1.59E+10	36
11	Phosphate	8.43E+03	g	1.45E+10	12
12	Food	2.62E+07	J	3.36E+06	9
13	Construction Materials	3.04E+07	g	1.55E+09	4712
14	Goods & Services	7.55E+03	$	2.83E+12	2138
15	Total EMERGY				8727
			Units/ha =	97	844580
Calculated ratios					
16	Empower Density	8.73E+16	sej/ha/yr		
17	NR + PI Empower Density	8.64E+16	sej/ha/yr		
18	Empower Density (97 units/ha)	8.45E+18	sej/ha/yr		
19	NR + PI Empower Density w/services (97 units/ha)	8.36E+18	sej/ha/yr		
20	NR + PI Empower Density wo/services (97 units/ha)	6.29E+18	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
	Energy (J) =	1.00E+11	J/yr	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.00E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	$g/m^2/yr$	
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume)(1E6 g/m^3)(4.94 J/g)		
	Groundwater consumption =	1.11E+02	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
	Groundwater consumption =	1.53E+08	m^3/yr	
	Population =	6.15E+05		(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
	Per capita groundwater consumption =	2.48E+02	m^3/yr	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Groundwater consumption =	6.21E+02	$m^3/unit$	
	Annual energy =	3.07E+09	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al. 1998)
6	**Fuel, J** (Kerosene and LPG)			
	Annual energy =	(Btu)(1055 J/Btu)		
	Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
	Total residential fuel use (Y2001) =	1.03E+13	Btu	(www.eia.gov)
	Per capita fuel consumption =	3.81E+06	Btu	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Fuel consumption =	9.54E+06	Btu/ha	
	Annual energy =	1.01E+10	J	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Natural Gas, J**			
	Annual energy =	(Btu)(1055 J/Btu)		
	Population Arkansas (Y2001) =	2.70E+06		(Estimated based on 1% increase for Y2000; ADED 2003)
	Total residential gas use (Y2001) =	3.77E+13	Btu	(www.eia.gov)
	Per capita gas consumption =	1.40E+07	Btu	

	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Gas consumption =	3.49E+07	Btu	
	Annual energy =	3.68E+10		
	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)
8	**Electricity, J**			
	Annual Energy =	(___KwH/yr)(3.6 E6 J/KwH)		
	Electricity consumption =	1.26E+04	KwH/yr	(Entergy Arkansas, Inc. 2001)
	Annual energy =	4.54E+10	Btu	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
9	**Pesticides, g** (includes herbicides, insecticides, fungicides)			
	Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
10	**Nitrogen, g of N**			
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)			
	g =	1.07E+05		(Brown and Vivas 2005)
	Annual consumption =	2.27E+04	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams, 2001)
11	**Phosphate, g of P**			
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)			
	g =	3.59E+04		(Brown and Vivas 2005)
	Annual consumption =	8.43E+03	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
12	**Food, J**			
	Annual consumption =	(2500 Cal/day)(4186 J/Cal)		
	Persons/household (Y2000)=	2.50E+00		(www.census.gov)
	Annual energy =	2.62E+07	J	
	Emergy per unit input =	3.36E+06	sej/J	(After Brown & Vivas 2005)
13	**Construction Materials, g**			
	Mass (g) =	(Total weight)/(50 yrs)		
	Total weight =	1.52E+09	g	(Haukoos 1995)
	Mass =	3.04E+07	g	
	Emergy per unit input =	1.55E+09	sej/g	(After Brown & Vivas 2005)
14	**Goods, $**			(ADED, available at www.1800arkansas.com)
	Per capita income Y2001 =	2.29E+04	$	
	Fraction of income into goods=	3.30E-01		(ACCRA Cost of Living Index - Miscellaneous - in ADED 2005)
	Annual consumption =	7.55E+03	$	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
15	**Total Emergy** - Sum of inputs 2 through 14			
16	**Empower Density -** sum of emergy per hectare per year			
17	**NR + PI Empower Density -** sum of non renewable and purchased inputs emergy per hectare per year			
18	**Empower Density (97 units/ha)** - sum of emergy per hectare per year			
19	**NR + PI Empower Density w/services (97 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year			
20	**NR + PI Empower Density wo/services (97 units/ha)** - sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-21. Emergy evaluation table for a turf grass - house lawn, per ha per year

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.08E+13	J	1	5
2	Rain (chemical potential)	2.99E+10	J	3.02E+04	90
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
4	Water use (Transpiration)	7.16E+10	J	3.02E+04	217
Nonrenewable Storages Used					
5	Net Topsoil Loss	6.33E+07	J	1.24E+05	1
Purchased Inputs					
6	Water (irrigation)	1.91E+10	J	2.69E+05	513
7	Pesticides	5.10E+03	g	2.52E+10	13
8	Nitrogen	2.27E+04	g	1.59E+10	36
9	Phosphate	8.43E+03	g	1.45E+10	12
10	Total EMERGY				791
Calculated ratios					
11	Empower Density	7.91E+15	sej/ha/yr		
12	NR + PI Empower Density	5.75E+15	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(____m^2)(____$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	$kcal/cm^2/yr$	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.40E-01		(Odum 1987, referenced by Brown and Vivas 2005)
Annual energy =	5.08E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Percent transpiration =	5.00E-01		(Parker 1998)
Annual energy =	2.99E+10	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)
Energy (J) =	(area)(air density)(drag coefficient)($velocity^3$)		
=	(__m^2)(1.3 kg/m^3)(1.00 E-3)(__mps)(3.14 E7 s/yr)		
Energy (J) =	1.00E+11	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

4 **Water use (Transpiration), J**

Annual energy =	(Transpiration)(area)(1E6 g/m^3)(4.94 J/g))		
Transpiration =	1.45E+00	m/yr	(R.L. Duble, Texas Cooperative Extension; http://aggie-horticulture.tamu.edu)

	Annual energy =	7.16E+10	J/yr	
	Emergy per unit input =	1.50E+05	sej/J	(Average transformities for rain and groundwater)
5	**Net Topsoil Loss, J**			
	Erosion rate =	7.00E+00	$g/m^2/yr$	(Pimentel et al. 1995)
	Organic fraction in soil =	0.04		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	6.33E+07		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
6	**Water, J**			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume) (1E6 g/m^3) (4.94 J/g)		
	Groundwater consumption =	1.11E+02	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
	Groundwater consumption =	1.53E+08	m^3/yr	
	Population =	6.15E+05		(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000; www.usg.gov)
	Per capita groundwater consumption =	2.48E+02	m^3/yr	
	Persons/household (Y2000) =	2.50E+00		(www.census.gov)
	Groundwater consumption =	6.21E+02	m^3/unit	
	Fraction of groundwater used for irrigation =	5.80E-01		(After AWWARF 2000; www.awwarf.org)
	Ground water used for irrigation =	3.60E+02	m^3/unit	
	Number of units =	1.07E+01	unit/ha	(Assumed 65% of residential unit as lawn, and 23% of landscape as lawn after Robbins and Birkenholtz 2003)
	Annual energy =	1.91E+10	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
7	**Pesticides, g** (includes herbicides, insecticides, fungicides)			
	Annual consumption =	5.10E+03	g/ha	(Robbins and Birkenholtz 2003)
	Emergy per unit input =	1.50E+10	sej/g	(Brown and Arding 1991, in Brandt-Williams 2001)
8	**Nitrogen, g of N**			
	(g fertilizer active ingredient)(28 gmol P/132 gmol DAP)			
	g =	1.07E+05		(Brown and Vivas 2005)
	Annual consumption =	2.27E+04	g/ha	
	Emergy per unit input =	1.59E+10	sej/g	(Brandt-Williams 2001)
9	**Phosphate, g of P**			
	(g fertilizer active ingredient)(31 gmol P/132 gmol DAP)			
	g =	3.59E+04		(Brown and Vivas 2005)
	Annual consumption =	8.43E+03	g/ha	
	Emergy per unit input =	1.45E+10	sej/g	(Brandt-Williams 2001)
10	**Total Emergy -** Sum of inputs 4 through 9			
11	**Empower Density -** sum of emergy per hectare per year			
12	**NR Empower Density -** sum of non renewable emergy per hectare per year			

Commercial land uses

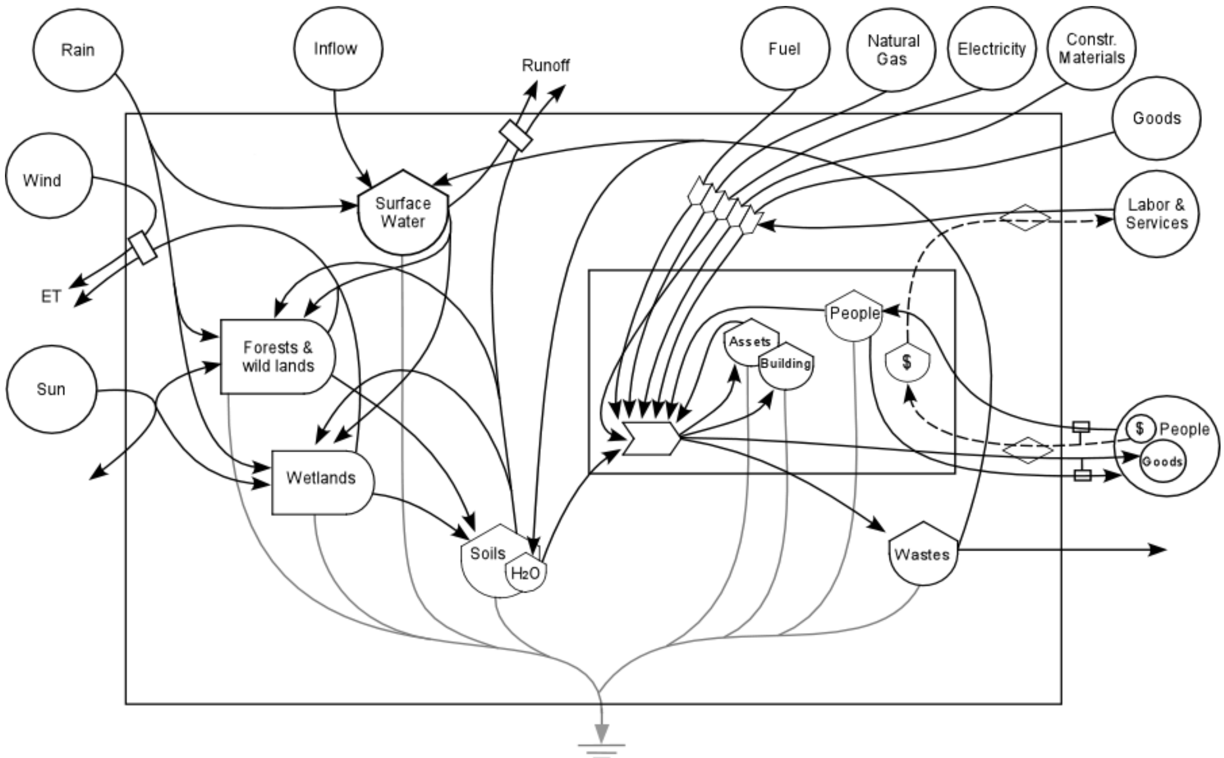


Figure A-12. Energy systems diagram of a commercial land use.

Table A-22. Emergy evaluation table for a low-intensity commercial land use (commercial strip), per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.19E+13	J	1	5
2	Rain (chemical potential)	2.99E+09	J	3.02E+04	9
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Fuel	3.26E+11	J	1.11E+05	3610
6	Natural Gas	1.92E+12	J	8.06E+04	15513
7	Electricity	2.01E+12	J	2.69E+05	53906
8	Construction Materials	1.50E+08	g	2.25E+09	33769
9	Labor	3.33E+10	J	4.13E+07	137642
10	Services	9.64E+05	$	2.83E+12	272963
11	Total EMERGY				517431
Calculated ratios					
12	Empower Density	5.17E+18	sej/ha/yr		
13	NR + PI Empower Density w/services	5.17E+18	sej/ha/yr		
14	NR + PI Empower Density wo/services	2.44E+18	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.20E-01		(Assumed)
Annual energy =	5.19E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Fraction transpired =	5.00E-02		(Parker 1998)
Annual energy =	2.99E+09	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)
Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
Energy (J) =	1.00E+11	J/yr	

	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.50E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	$g/m^2/yr$	
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Fuel, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area commercial/industrial LU in AR =	3.56E+08	m^2	(Calculated using a GIS based on the 1999 AR LU/LC: Summer; available at www.cast.uark.edu/cast/geostor/)
	Total area commercial LU in AR =	1.78E+08	m^2	(Assumed 1/2 of total area for commercial/industrial land use)
	Fuel used in AR (2001) =	5.50E+12	Btu	(www.eia.gov)
	Annual energy =	3.26E+11	J/ha	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
6	**Natural Gas, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area commercial LU in AR =	1.78E+08	m^2	
	Natural gas used in AR (2001) =	3.25E+13	Btu	(www.eia.gov)
	Annual energy =	1.92E+12	J/yr	
	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)
7	**Electricity, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area commercial LU in AR =	1.78E+08	m^2	
	Electricity used in AR (2001) =	3.39E+13	Btu	(www.eia.gov)
	Annual energy =	2.01E+12	J/yr	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
8	**Construction Materials, g**			
	Construction volume calculations based on municipal code specifications for North Little Rock, 2004 (www.municode.com)			
	Calculations based for 11 units/ha and 50% shared materials.			
	Commercial lot area =	1.00E+04	sq. ft.	(City Council, North Little Rock, Arkansas 2004; www.municode.com)
	Concrete and wood, assumed 50% each in construction volume			
	Mass (g) =	(Total weight)/(50 yrs)		
	Building structure (concrete) =	2.70E+03	m^3	
	Weight (concrete) =	2.40E+03	kg/m^3	
	Mass =	1.30E+08	g	
	Emergy per unit input =	1.28E+09	sej/g	(Haukoos 1995)
	Building structure (wood) =	2.70E+03	m^3	
	Weight (wood) =	3.80E+02	kg/m^3	
	Mass =	2.05E+07	g	
	Emergy per unit input =	1.40E+09	sej/g	(Haukoos 1995)
	Total mass =	(concrete) + (wood)		
	Total mass =	1.50E+08	g	
	Emergy per unit input =	1.34E+09	sej/g	(Average of transformities for concrete and wood)

9	**Labor, J**			
	Annual energy =	(pers/ha/yr)*(2500 kcal/day)*(4186J/Cal)*(250 days/person-yr)*(fraction day worked)		
	# persons employed by sector (2001) =	3.69E+05	person/yr	(AESD 2001; www.arkansas.gov)
	# persons employed non-shopping centers (2001) =	6.74E+05	person/yr	(Estimated based on employment data for shopping centers in Arkansas for 2004; ICSC 2005)
	Total area non-shopping center LU in AR =	1.75E+08	m^2	(Estimated based on data for shopping centers in Arkansas for 2004; ICSC 2005)
	# persons employed per area =	3.86E+01	person/ha	
	Total annual energy =	3.33E+10	J	
	Emergy per unit input =	2.46E+07	sej/J	(Transformity of education through high school, Odum 1996)
10	**Services (labor), $/ha**			
	Annual emergy =	($ /yr)*(sej/$)		
	Per capita income for sector (2001) =	2.50E+04	$/yr	(Estimated from AESD 2001; www.arkansas.gov)
	# persons employed non-shopping centers (2001) =	3.86E+01	person/ha	
	Dollar value =	9.64E+05	$/ha	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
11	**Total Emergy -** Sum of inputs 3 through 10			
12	**Empower Density -** sum of emergy per hectare per year			
13	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year			
14	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Table A-23. Emergy evaluation table for a high intensity commercial land use (shopping center), per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.19E+13	J	1	5
2	Rain (chemical potential)	2.99E+09	J	3.02E+04	9
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Fuel	3.26E+11	J	1.11E+05	3610
6	Natural Gas	1.92E+12	J	8.06E+04	15513
7	Electricity	2.01E+12	J	2.69E+05	53906
8	Construction Materials	2.82E+08	g	3.40E+09	95871
9	Labor	5.84E+10	J	4.13E+07	241459
10	Services	1.51E+06	$	2.83E+12	426856
11	Total EMERGY				837242
Calculated ratios					
12	Empower Density	8.37E+18	sej/ha/yr		
13	NR + PI Empower Density w/services	8.37E+18	sej/ha/yr		
14	NR + PI Empower Density wo/services	4.10E+18	sej/ha/yr		

Notes:

References:

1 **Sunlight, J**

Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
=	(__m^2)(__$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
Insolation =	1.41E+02	$kcal/cm^2/yr$	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.20E-01		(Assumed)
Annual energy =	5.19E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Fraction Transpired =	5.00E-02		(Parker 1998)
Annual energy =	2.99E+09	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock,2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)
Energy (J) =	(area)(air density)(drag coefficient)($velocity^3$)		
=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
Energy (J) =	1.00E+11	J/yr	

	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.50E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	$g/m^2/yr$	
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Fuel, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area comm./indust. LU in AR =	3.56E+08	m^2	(Calculated with a GIS based on the 1999 AR LU/LC: Summer; available at www.cast.uark.edu/cast/geostor/)
	Total area commercial LU in AR =	1.78E+08	m^2	(Assumed 1/2 of total area for comm./industrial land use)
	Fuel used in AR (2001) =	5.50E+12	Btu	(www.eia.gov)
	Annual energy =	3.26E+11	J/ha	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
6	**Natural Gas, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area commercial LU in AR =	1.78E+08	m^2	
	Natural gas used in AR (2001) =	3.25E+13	Btu	(www.eia.gov)
	Annual energy =	1.92E+12	J/yr	
	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)
7	**Electricity, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area commercial LU in AR =	1.78E+08	m^2	
	Electricity used in AR (2001) =	3.39E+13	Btu	(www.eia.gov)
	Annual energy =	2.01E+12	J/yr	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)
8	**Construction Materials, g**			
	Construction volume calculations based on municipal code specifications for North Little Rock, 2004 (www.municode.com)			
	Concrete and steel, assumed 50% each in construction volume.			
	Mass (g) =	(Total weight)/(50 yrs)		
	Building structure (concrete) =	5.06E+03	m^3	
	Weight (concrete) =	2.40E+03	kg/m^3	
	Mass =	2.43E+08	g	
	Emergy per unit input =	2.15E+09	sej/g	(Haukoos 1995)
	Building structure (steel) =	5.06E+03	m^3	
	Weight (steel) =	3.80E+02	kg/m^3	
	Mass =	3.85E+07	g	
	Emergy per unit input =	4.65E+09	sej/g	(Haukoos 1995)
	Total mass =	2.82E+08	g	
	Emergy per unit input =	3.40E+09	sej/g	(Average of transformities for concrete and steel)
9	**Labor, J**			
	Annual energy =	(pers/ha/yr)*(2500 kcal/day)*(4186J/Cal)*(250 days/person-yr)*(fraction day worked)		
	# persons employed =	8.06E+04	person/yr	(Data for 2004; ICSC 2005)
	Total leasable retail area =	3.57E+06	m^2	(Data for 2004; ICSC 2005)
	# persons employed per area =	6.77E+01	person/ha	
	Annual energy =	5.84E+10	J	

	Emergy per unit input =	2.46E+07	sej/J	(Transformity of education through high school, Odum 1996)
10	**Services (labor), $/ha**			
	Annual emergy =	($ /yr)(sej/$)		
	Per capita income for sector (2001) =	2.23E+04	$/yr	(Estimated from AESD 2001; www.arkansas.gov)
	# Persons employed per area =	6.77E+01	person/ha	
	Dollar value =	1.51E+06	$/ha	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
11	**Total Emergy -** Sum of inputs 3 through 10			
12	**Empower Density -** sum of emergy per hectare per year			
13	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year			
14	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services			

Industrial land use

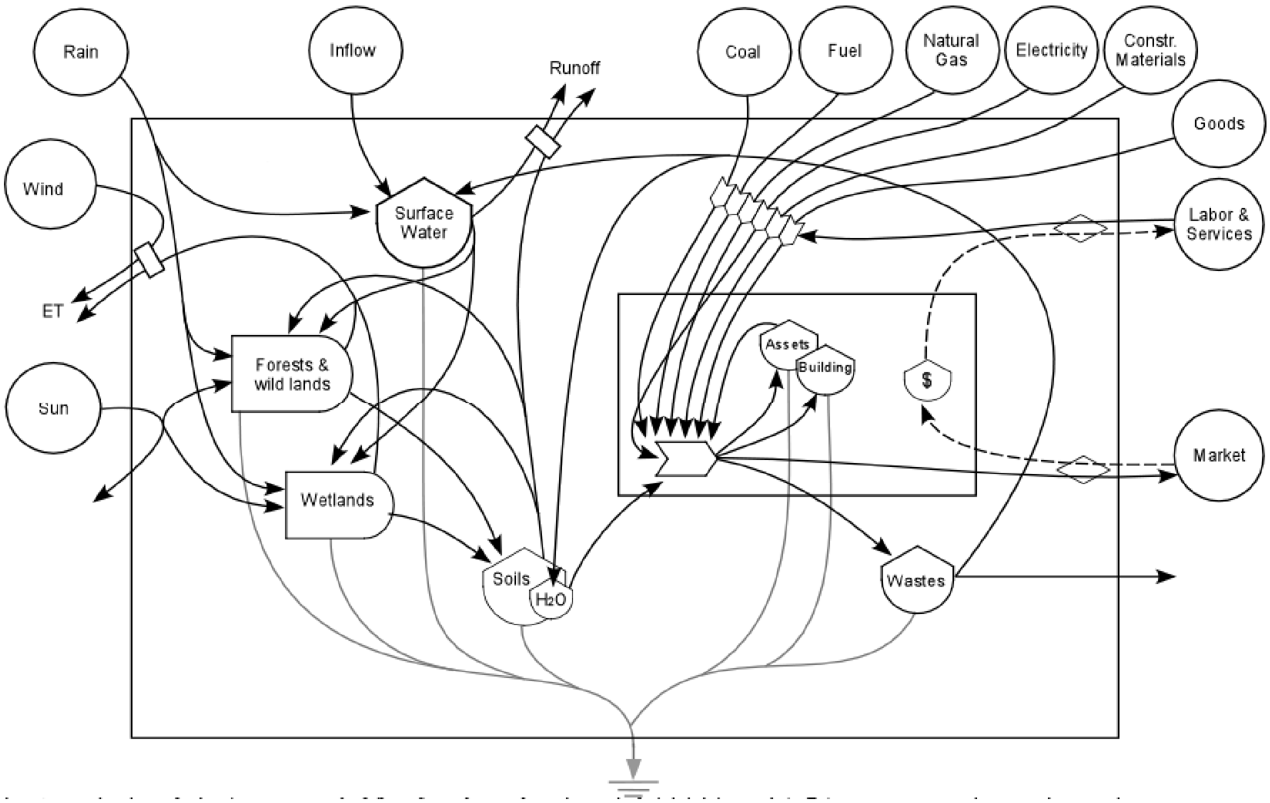


Figure A-13. Energy systems diagram of an industrial land use.

Table A-24. Emergy evaluation table for an industrial land use, per ha per year

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.19E+13	J	1	5
2	Rain (chemical potential)	2.99E+09	J	3.02E+04	9
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
5	Groundwater	1.45E+10	J	2.69E+05	390
Purchased Inputs					
6	Coal	6.45E+11	J	1.11E+05	7154
7	Fuel	5.03E+12	J	6.69E+04	33640
8	Natural Gas	7.43E+12	J	8.06E+04	59903
9	Electricity	3.38E+12	J	2.69E+05	90848
10	Construction Materials	3.18E+08	g	3.40E+09	108264
11	Labor	1.58E+10	J	4.13E+07	65269
12	Services	5.58E+05	$	2.83E+12	158004
13	Total EMERGY				523502
Calculated ratios					
14	Empower Density	5.24E+18	sej/ha/yr		
15	NR + PI Empower Density w/services	5.23E+18	sej/ha/yr		
16	NR + PI Empower Density wo/services	3.65E+18	sej/ha/yr		

Notes:

					References:
1	**Sunlight, J**				
	Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)			
	=	(__m^2)(__$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)			
	Insolation =	1.41E+02	$kcal/cm^2/yr$		(Odum et al. 1998)
	Area =	1.00E+04	m^2		
	Albedo =	1.20E-01			(Assumed)
	Annual energy =	5.19E+13	J		
	Emergy per unit input =	1.00E+00	sej/J		(Odum 1996)
2	**Rain (chemical potential), J**				
	Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)			
	Annual rainfall =	1.21E+00	m/yr		(www.noaa.gov)
	Area =	1.00E+04	m^2		
	Fraction transpired =	5.00E-02			(Parker 1998)
	Annual energy =	2.99E+09	J		
	Emergy per unit input =	1.80E+04	sej/J		(Odum 1996)
3	**Wind (kinetic energy), J**				
	Area =	1.00E+04	m^2		
	Density of air =	1.23E+00	kg/m^3		(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps		(Data for Little Rock,2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps		(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03			(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)($velocity^3$)			

	=	(___m²)(1.3 kg/m³)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
	Energy (J) =	1.00E+11	J/yr	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.50E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	$g/m^2/yr$	
	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Water, J** (groundwater)			
	Annual energy =	Chemical potential of groundwater		
	Annual energy =	(Volume) (1E6 g/m^3) (4.94 J/g)		
	Total area comm./indust. LU in AR =	3.56E+08	m^2	(Calculated with a GIS based on the 1999 AR LU/LC: Summer; available at www.cast.uark.edu/cast/geostor/)
	Total area industrial LU in AR =	1.78E+08	m^2	(Assumed 1/2 of total area for commercial/industrial land use)
	Groundwater consumption =	3.79E+01	Mgal/day	(Data for Arkansas, Faulkner, Jefferson, Lonoke, Prairie, and Lulaski counties, Y 2000: www.water.usg.gov)
	Groundwater consumption =	5.24E+07	m^3/yr	
	Groundwater Consumption =	2.94E+03	m^3/ha	
	Annual energy =	1.45E+10	J	
	Emergy per unit input =	1.60E+05	sej/J	(Odum et al 1998)
6	**Coal, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area industrial LU in AR =	1.78E+08	m^2	
	Coal used in AR (2001) =	1.09E+13	Btu	(www.eia.gov)
	Annual energy =	6.45E+11	J/ha	
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
7	**Fuel, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area industrial LU in AR =	1.78E+08	m^2	
	Fuel used in AR (2001) =	8.50E+13	Btu	(www.eia.gov)
	Annual energy =	5.03E+12	J/ha	
	Emergy per unit input =	3.98E+04	sej/J	(Odum 1996)
8	**Natural Gas, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total Area Commercial LU in AR =	1.78E+08	m^2	
	Natural gas used in AR (2001) =	1.26E+14	Btu	(www.eia.gov)
	Annual energy =	7.43E+12	J/yr	
	Emergy per unit input =	4.80E+04	sej/J	(Odum 1996)
9	**Electricity, J**			
	Annual energy =	(Btu)*(1055 J/Btu)		
	Total area of industrial LU in AR =	1.78E+08	m^2	
	Electricity used in AR (2001) =	5.71E+13	Btu	(www.eia.gov)
	Annual energy =	3.38E+12	J/yr	
	Emergy per unit input =	1.60E+05	sej/J	(Odum 1996)

10	**Construction Materials, g**				
	Construction volume calculations based on municipal code specifications for North Little Rock, 2004 (www.municode.com).				
	Concrete and steel, assumed 50% each in construction volume.				
	Mass (g) =	(Total weight)/(50 yrs)			
	Building structure (concrete) =	5.72E+03	m^3		
	Weight (concrete) =	2.40E+03	kg/m^3		
	Mass =	2.75E+08	g		
	Emergy per unit input =	2.15E+09	sej/g		(Haukoos 1995)
	Building structure (steel) =	5.72E+03	m^3		
	Weight (steel) =	3.80E+02	kg/m^3		
	Mass =	4.35E+07	g		
	Emergy per unit input =	4.65E+09	sej/g		(Haukoos 1995)
	Total mass =	3.18E+08	g		
	Emergy per unit input =	3.40E+09	sej/g		(Average of transformities for concrete and steel)
11	**Labor, J**				
	Annual energy =	(pers/ha/yr)*(2500 kcal/day)*(4186J/Cal)*(250 days/person-yr)*(fraction day worked)			
	# persons employed =	3.26E+05	person/yr		(Estimated from AESD 2001; www.arkansas.gov)
	# persons employed per area =	1.83E+01	person/ha		
	Annual energy =	1.58E+10	J		
	Emergy per unit input =	2.46E+07	sej/J		(Transformity of education through high school, Odum 1996)
12	**Services (labor), $/ha**				
	Annual emergy =	($ /yr)(sej/$)			
	Per capita income for sector (2001) =	3.05E+04	$/yr		(Estimated from AESD 2001; www.arkansas.gov)
	# persons employed per area =	1.83E+01	person/ha		
	Dollar value =	5.58E+05	$/ha		
	Emergy per unit input =	2.83E+12	sej/$, 2001		(This study, see Table A-5)
13	**Total Emergy -** Sum of inputs 3 through 12				
14	**Empower Density** - sum of emergy per hectare per year				
15	**NR + PI Empower Density w/services -** sum of non renewable and purchased inputs emergy per hectare per year				
16	**NR + PI Empower Density wo/services -** sum of non renewable and purchased inputs emergy per hectare per year minus services				

Transportation land uses

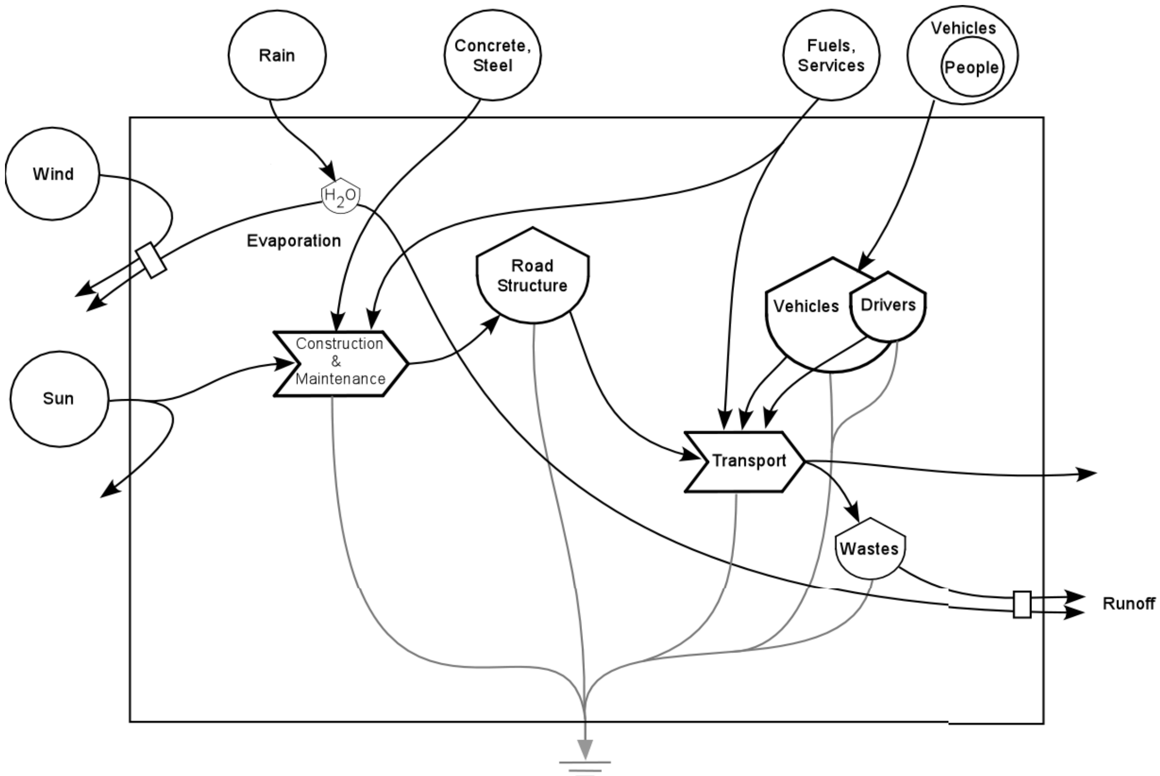


Figure A-14. Energy systems diagram of a transportation corridor (highway).

Table A-25: Emergy evaluation table for a low-intensity transportation corridor (2 lane road), per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.19E+13	J	1	5
2	Rain (chemical potential)	2.99E+09	J	3.02E+04	9
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Fuel	4.31E+12	J	1.11E+05	47844
6	Vehicles	1.75E+05	g	4.28E+10	749
7	Construction Materials	3.03E+02	$	2.83E+12	86
8	Maintenance & Operation	2.62E+03	$	2.83E+12	742
9	Total EMERGY				49450
Calculated ratios					
10	Empower Density	4.94E+17	sej/ha/yr		
11	NR + PI Empower Density	4.94E+17	sej/ha/yr		

Notes: Data on purchased inputs for US Highway 70; assumed 2 lanes.

References:

1 **Sunlight, J**

Annual energy (J) = (Avg. Total Annual Insolation J/yr)(Area)(1-albedo)
= (__m^2)(__$Cal/cm^2/y$)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)

Insolation =	1.41E+02	$kcal/cm^2/yr$	(Odum et al. 1998)
Area =	1.00E+04	m^2	
Albedo =	1.20E-01		(www.epa.gov)
Annual energy =	5.19E+13	J	
Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)

2 **Rain (chemical potential), J**

Annual energy = (__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)

Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
Area =	1.00E+04	m^2	
Fraction transpired =	5.00E-02		(Parker 1998)
Annual energy =	2.99E+09	J	
Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)

3 **Wind (kinetic energy), J**

Area =	1.00E+04	m^2	
Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
Drag coeff. =	2.00E-03		(Garrat 1977)

Energy (J) = (area)(air density)(drag coefficient)($velocity^3$)
= (___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)

Energy (J) =	1.00E+11	J/yr	
Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)

4 **Net Topsoil Loss, J**

Erosion rate =	1.50E+00	lb/acre/day	(Corbitt 1990)
Erosion rate =	4.09E+01	$g/m^2/yr$	

	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Fuel, J**			
	(Data for US Highway 70)			
	Annual energy =	(Gallons fuel)*(1.32E8 J/gal)		
	Average number of cars =	3.28E+03	vehicles/day	(AHTD 1999; www.ahtd.state.ar.us)
	Average number of cars =	1.20E+06	vehicles/yr	
	Average KPG =	4.03E+01	km/gal	(Assumed)
	US H-70 length in the BMW =	3.61E+01	km	(Calculated using a GIS)
	Total fuel use =	1.07E+06	gal/yr	
	Total annual energy =	1.42E+14	J/yr	
	Total annual energy/1111m length =	4.31E+12	J/yr	(Lane width = 15 feet/4.6m; 2 lanes)
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
6	**Vehicles, g**			
	Average number of cars =	1.20E+06	vehicles/yr	
	Average speed =	8.86E+01	km/hr	(Assumed)
	Time spent on road segment =	1.25E-02	hr	
	Average useful life of a vehicle =	8.76E+04	hr	(Assumed)
	Fraction of life spent on road segment =	1.43E-07		
	Average weight of a vehicle =	1.02E+03	kg/vehicle	(McGrane 1994)
	Vehicle use on road segment =	1.46E-04	kg/vehicle	
	Total vehicle use on road segment =	1.75E+05	g/yr	
	Emergy per unit input =	4.28E+10	sej/g	(After McGrane 1994)
7	**Construction Materials, $**			
	Cost ($) =	(Cost of 1111m length)/(50 yrs)		
	Cost/mile =	2.20E+04	$/yr	(Assumed as 1/2 the cost of Interstate mile, see Table A-26)
	Cost/1111m length =	3.03E+02	$/yr	
	Emergy per unit input =	2.83E+12	sej/$, 2001	
8	**Maintenance & Operation, $**			
	Cost/mile =	3.81E+03	$/yr	(Assumed as 1/2 the cost of Interstate mile, see Table A-26)
	Cost/1111m length =	2.62E+03	$/yr	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
9	**Total Emergy** - Sum of inputs 3 through 8			
10	**Empower Density -** sum of emergy per hectare per year			
11	**NR + PI Empower Density** - sum of non renewable and purchased inputs emergy per hectare per year			

Table A-26: Emergy evaluation table for a high-intensity transportation corridor (4 lane road), per ha per year.

Note	Description	Data (per ha^{-1} yr^{-1})		Emergy/unit (sej/unit)	Solar EMERGY (E13 sej/yr)
Renewable Inputs					
1	Sunlight	5.19E+13	J	1	5
2	Rain (chemical potential)	2.99E+09	J	3.02E+04	9
3	Wind (kinetic energy)	1.00E+11	J	2.45E+03	25
Nonrenewable Storages Used					
4	Net Topsoil Loss	3.70E+08	J	1.24E+05	5
Purchased Inputs					
5	Fuel	2.25E+13	J	1.11E+05	249672
6	Vehicles	6.64E+05	g	4.28E+10	2840
7	Construction Materials	3.03E+02	$	2.83E+12	86
8	Maintenance & Operation	2.62E+03	$	2.83E+12	743
9	Total EMERGY				253369
Calculated ratios					
10	Empower Density	2.53E+18	sej/ha/yr		
11	NR + PI Empower Density	2.53E+18	sej/ha/yr		

Notes: Data on purchased inputs for Interstate-40 (4 lanes).

				References:
1	**Sunlight, J**			
	Annual energy (J) =	(Avg. Total Annual Insolation J/yr)(Area)(1-albedo)		
	=	(__m^2)(__Cal/cm^2/y)(1E+04cm^2/m^2)(1-albedo)(4186J/kcal)		
	Insolation =	1.41E+02	kcal/cm^2/yr	(Odum et al. 1998)
	Area =	1.00E+04	m^2	
	Albedo =	1.20E-01		(www.epa.gov)
	Annual energy =	5.19E+13	J	
	Emergy per unit input =	1.00E+00	sej/J	(Odum 1996)
2	**Rain (chemical potential), J**			
	Annual energy =	(__m/yr)(__m^2)(1E6g/m^3)(% Transpiration)(4.94J/g)		
	Annual rainfall =	1.21E+00	m/yr	(www.noaa.gov)
	Area =	1.00E+04	m^2	
	Fraction transpired =	5.00E-02		(Parker 1998)
	Annual energy =	2.99E+09	J	
	Emergy per unit input =	1.80E+04	sej/J	(Odum 1996)
3	**Wind (kinetic energy), J**			
	Area =	1.00E+04	m^2	
	Density of air =	1.23E+00	kg/m^3	(Odum et al. 1998)
	Avg. annual wind velocity =	3.04E+00	mps	(Data for Little Rock, 2001; www.noaa.gov)
	Geostrophic wind =	5.07E+00	mps	(Observed winds are about 0.6 of geostrophic wind)
	Drag coeff. =	2.00E-03		(Garrat 1977)
	Energy (J) =	(area)(air density)(drag coefficient)(velocity^3)		
	=	(___m^2)(1.3 kg/m^3)(1.00 E-3)(___mps)(3.14 E7 s/yr)		
	Energy (J) =	1.00E+11	J/yr	
	Emergy per unit input =	2.45E+03	sej/J	(Odum et al. 2000)
4	**Net Topsoil Loss, J**			
	Erosion rate =	1.50E+00	lb/acre/day	(Corbitt 1990)
	Erosion rate =	4.09E+01	g/m^2/yr	

	Organic fraction in soil =	4.00E-02		(Pimentel et al. 1995)
	Energy cont./g organic =	5.40E+00	kcal/g	
	Net loss of topsoil = (farmed area)(erosion rate)			
	Organic matter in topsoil used up = (total mass of topsoil)(% organic)			
	Energy loss = (loss of organic matter)(5.4 kcal/g)(4186 J/kcal)			
	Annual energy =	3.70E+08		
	Emergy per unit input =	7.38E+04	sej/J	(Odum 1996)
5	**Fuel, J**			
	Annual energy =	(Gallons fuel)*(1.32E8 J/gal)		
	Average number of cars =	3.38E+04	vehicles/day	(AHTD 1999; www.ahtd.state.ar.us)
	Average number of cars =	1.23E+07	vehicles/yr	
	Average KPG =	4.03E+01	km/gal	(Assumed)
	I-40 length in the BMW =	6.17E+01	km	(Calculated using a GIS)
	Total fuel use =	1.89E+07	gal/yr	
	Total annual energy =	2.50E+15	J/yr	
	Total annual energy/556m length =	2.25E+13	J/yr	(Lane width = 15 feet/4.6m)
	Emergy per unit input =	6.60E+04	sej/J	(Odum 1996)
6	**Vehicles, g**			
	Average number of cars =	1.23E+07	vehicles/yr	
	Average speed =	1.21E+02	km/hr	(Assumed)
	Time spent on road segment =	4.60E-03	hr	
	Average useful life of a vehicle =	8.76E+04	hr	(Assumed)
	Fraction of life spent on road segment =	5.26E-08		
	Average weight of a vehicle =	1.02E+03	kg/vehicle	(McGrane 1994)
	Vehicle use on road segment =	5.38E-05	kg/vehicle	
	Total vehicles use on road segment =	6.64E+05	g/yr	
	Emergy per unit input =	4.28E+10	sej/g	(After McGrane 1994)
7	**Construction Materials, $**			
	Cost ($) =	(Cost of 556m length)/(50 yrs)		
	Cost/mile =	4.39E+04	$/yr	(AHC 2002; www.ahtd.state.ar.us)
	Cost/556m length =	3.03E+02	$/yr	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
8	**Maintenance & Operation, $**			
	Cost/mile =	7.61E+03	$/yr	(AHC 2002; www.ahtd.state.ar.us)
	Cost/556m length =	2.62E+03	$/yr	
	Emergy per unit input =	2.83E+12	sej/$, 2001	(This study, see Table A-5)
9	**Total Emergy -** Sum of inputs 3 through 8			
10	**Empower Density -** sum of emergy per hectare per year			
11	**NR + PI Empower Density -** sum of non renewable and purchased inputs emergy per hectare per year			

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