Emergy Evaluation of the Umpqua River Watershed in Oregon

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Abstract

Procedures are suggested for evaluating alternatives for management of a watershed containing anadromous fisheries and hydroelectric dams. In order to maximize the production of real wealth in a watershed, *emergy* (spelled with an "m") and its economic equivalent, emdollars, was used to put the work of environment, the work of the economy, and the exchanges with surroundings on a common basis. The analyses give environmental contributions their real economic significance by externalizing the internalities.

Alternative uses of a watershed may include harvest of migrating fish, hydroelectric dams, agricultural irrigation, urban water use, and oceanic harvest of coastal fishes, forest products, mining, tourist developments, and othrs. For an example, evaluation was made of the Umpqua River Watershed, Douglas County, Oregon. Maximum production of real wealth (defined here as emergy) requires favorable symbiosis of economy and environment on three scales: (1) scale of each system of environment and human settlement within the watershed; (2) whole watershed system of landscape, river, and regional economy; (3) role of watershed in and exchanges with the state and larger systems surrounding. Evaluations were made of alternative managements and totalled from the point of view of each of the three scales. Because of the changing net emergy that accompanies changing prices of fuels, the evaluations of the present state were compared with future scenarios of world energy prices.
Appendix A contains an evaluation of the emergy of the stages in the life cycle of salmon in a watershed, calculating the inputs from watershed and ocean. Appendix B Contains an emergy evalution of Oregon made by Peter Keller for 1990 (~~and updated to 1997 ?~~).

Introduction

Rising populations, increased demands for energy, anticipated shortages of water and environmental impacts of development are causing controversy and public discourse on the best management of watersheds. Several recent studies of watersheds used emergy, spelled with an "m" to put production of biological, hydrological and geological processes on a common basis with production of society within the human economy. Then choices in watershed management were recommended that maximize the production and efficient use of real wealth (in emergy units) by the whole system . It can be argued that human society either rationally or by trial and error eventually selects patterns that mazimize the combined performance of watershed and economy. A public policy with evaluation procedures is desirable means of anticipating what works in advance.

Concepts

Emergy, spelled with an "m" is defined as all the available energy that was used in the work of making a product expressed in units of one type of energy. The unit of emergy is the emjoule. If the type of emergy is solar than the unit of solar emergy is the solar emjoule. The concept was used in 1967b (Odum, 1967, 1971) and renamed in 1983 (Odum, 1986; Scienceman, 1987). Annual flows of environmental quantities, economic commodities, or money are expressed in empower units. Empower is defined as the solar emoules of emergy per time.

Transformity is defined as the emergy of one type required to make a unit of energy of another type. It is the quotient of emergy divided by the energy. The unit of transformity is emjoule per Joule. If the type of emergy is solar, then the unit of solar transformity is solar emjoule per Joule, abbreviated sej/J. The concept was defined in 1976 and renamed in 1983 (Odum,1976, 1986, 1988).

Emergy indices: gives insight:
The emdollar value (abbreviated em$) refers to the dollar flow generated directly and indirectly in the gross economic product by an emergy input. It is calculated by dividing the emergy input by the emergy/money ratio for that year. The emergy money ratio for Oregon in 1990 wass calculated in Appendix B and extrapolated to the present as about 3.8 Trillion solar emjoules per 1999 $.

The emergy yield ratio is the emergy of an output divided by the emergy of those inputs to the process that are fed back from the economy (see

Figure 5). This ratio indicates whether the process contributes more to the economy than is purchased from it for the processing. Ratios for typical agricultural products range from less than one to 6. (Values less than one may be obtained when the yield is calculated separately with a transformity from another source of data). Processes yielding close to one are not viable as primary energy sources (capable of supporting other sectors of the economy). The higher the yield ratio the higher the stimulus to the economy able to purchase the product. In recent years emergy yield ratio of fossil fuels ranged 3 to 12.

The <u>emergy investment ratios</u> relate the emergy fed back from the economy to the emergy inputs from the free environment. The ratio indicates if a process is economical in matching the economy's investments with free environmental inputs in comparison to alternatives. To be economical, the process should have a similar or lower ratio to its competitors. If the ratio is low, the environment provides more to the process, costs are less and its prices tend to be less so that the product competes well in outside markets. The typical ratio for the United States is 7.

The <u>emergy exchange ratio</u> is the ratio of emergy received for emergy delivered in a trade or sales transaction. For example, a trade of wood for oil can be expressed in emergy units. The area receiving the larger emergy receives the larger real wealth and has its economy stimulated more. Raw products usuall contribute more to the purchaser than is in the buying power of the money.

Previous Emergy Evaluations of Watersheds

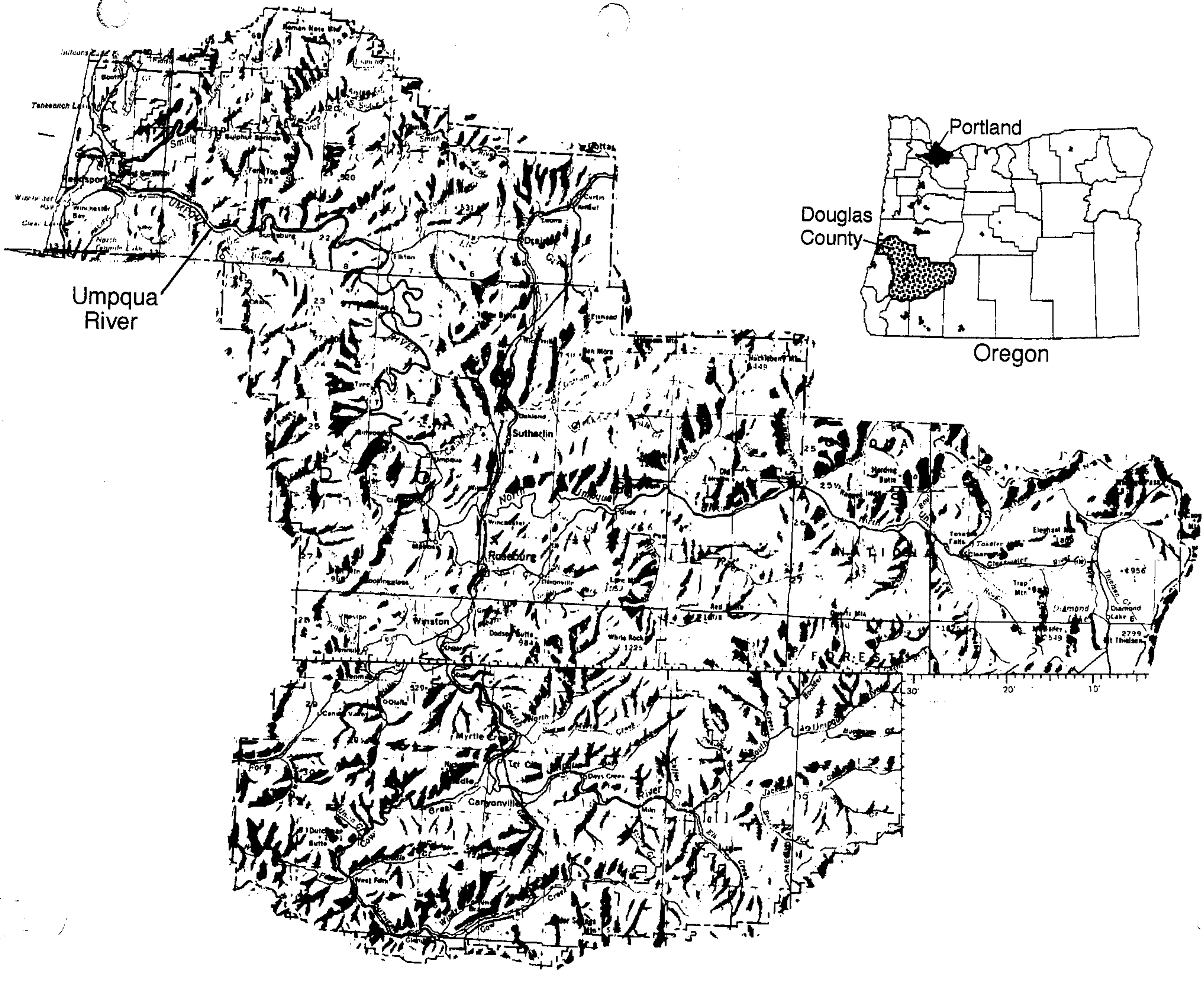
(brief paragraph here citing, Boggess, Bradt-Williams, Tilley, Romitelli, Doherty)

Study Area, Umpqua River Watershed

Issues of public discussion on the management of watersheds, anadromous fisheries, hydroelectric power, and watershed vegetation are illustrated in this study by evaluation of a a watershed example, the umpqua River Watershed in Southern Oregon (Figure 1)

Previous Studies in the Watershed

(a few paragraphs summarizing those studies that dealt with overviews of the watershed and its relation to Oregon. Papers on chemical, physical, and


Portland
Douglas County
Oregon
Umpqua River
Reedsport
Scottsburg
Elkton
Drain
Sutherlin
Oakland
Roseburg
Winston
Myrtle Creek
Riddle
Canyonville
Tri City
Glide
Winchester
Dixonville
Umpqua
North
South
Smith
Huckleberry Mtn
Diamond Lake
Mt Thielsen
White Rock
Dodson Butte
Dutchman Butte
West Fork
Days Creek
Elk
Creek
River
Toketee Falls
Clearwater
Elephant Mtn
Trap Mtn
Sulphur Springs
Winchester Bay
Tahkenitch Lake
Curtin
Yoncalla

economic details need not be mentioned here, but cited as used in footnotes to tables etc)

During the 1970's energy crisis Govenor Tom McCall arranged for the study of energy of resources in relation to growth and carrying capacity summarized by its director, Joel Schatz. This study did not distinguish kinds of energy, nor evaluate the environmental contributions on a basis comparable with the fuels and electric power studies.

Methods and Procedure

A systems overview is sought for the watershed and its surroundings. Then emergy evaluation tables are made of inputs, parts and processes. Then emergy indices are used to determine what is important, the effects of alternative managements and furture scenarios. Evaluaations are made to determine which choiceds maximize real wealth production and use in the local area, in the whole watershed, and in the effect of the watershed on the state economy. The following summarizes the procedure used.

(1) Systems Diagramming: Using many sources of information about the watershed, energy systems diagrams were prepared to identify the main parts, processes, and sources of the study area on several scales. Figure 1 represents main features and inputs to the Umpqua River Watershed of Oregon. Figure 2 represents the next larger scale showing the Oregon state system and the participating role of the small river watershed within. A part of the watershed system, the life cycle of the salmon was diagrammed as Appendix Figure A1.

(2) Emergy Evaluation Tables: Tables are prepared in which each line item is a source inflow, a production process, or exchange with the outside. Annual data in grams, joules, or dollars are multiplied by the appropriate Emergy per unit to obtain the emergy flow. These values of emergy per unit (g,J, or $) are derived from other evaluation studies. Those used in this study are listed in Table 1. Table 2 contains the annual emergy inflows contributing to the economy of humanity and nature in Umpqua River watershed. Table 3 contains the annual emergy production flows by the Umpqua River watershed, which is almost identical with Douglas County, Oregon. Some of the line items in these tables are included partly or entirely within other line items. Thus it would be double counting to simply add all the evaluated items. Table 4 totals and summaizes the important emergy flows for purposes of comparison and management choice.

In these tables salmon are first estimated according to their pre-colonization state. Appendix Table A1 evaluates salmon life cycle as it may have existed before economic development. The procedure for evaluating the life cycle may be useful as a guideline for the needed evaluation of emergy and transformities of life cycles of other wildlife and fishery species.

(3) Indices and Interpretation: For each scale of interpretation, a summary was prepared comparing emergy flows from environment and from the economy. The environmental-economic matching is interpreted with the emergy investment ratio = Purchased emergy/environmental free emergy. The net benefit of the environmental resources is evalauted with the net emergy ratio = Emergy yielded to economy/emergy required from the economy. The net benefit of sales outside of the area was evaluated with the emergy exchange ratio. Contributions of hydroelectric power was compared with salmon fishery. Impacts of alternative forest management were compared. For comparison with other areas, solar empower density and other indices are included in Table 5.

Results and Discussion

Emergy Overview of Oregon

Appendix B has an emergy overview of Oregon.
(Few sentences comparing Oregon to other States and the U.S.)

Emergy in the Umpqua River Watershed

The rains and the geologic contribution of the land are the main environmental sources of emergy used in the Umpqua River watershed (65.3 E20 sej/yr Tables 4). However before development salmon runs may have contributed 11% more(7.4 E20 sej/yr Table 2) from the sea in the returning runs of adult salmon. At present the environmental resources attract human economic inputs of 73+ E20 sej/yr , almost a one to one matching (Table 5), much less than the 7/1 for the United States as a whole. The emergy theories predict increased pressures for economic inputs and investments towards the higher ratios available to state or private investment initiatives.

The emergy per person is much higher than the average for the United States. The emergyof the original salmon run is higher than the existing hydroelectric development (Table 5), less than the electrical demand in the water shed, and much less than the total geopotential for hydroelectric development (Table 5).

Emergy Evaluation of Alternative Scenarios

Emergy of Alternate Scenarios
(using Table 6
Effect of Global increase in Fuel Costs
(using Table 6)
Differences due to Scale of View
(using Table 7)

Summary

This paper uses emergy methods to evaluate watershed management alternatives to maximize a regional economy, while maintaining their ecosystems, the necessary electric power, and equity in products in sales and service exchanges with the outside.----more to add

Table 1
Unit Emergy Values used in Calculations

Note	Item, Units	Solar Emergy per unit
1	Sunlight, J	1
2	Rain at 1000 m, g	2.5 E5
3	Rain geopotential at 1000 m, g	1.45 E5
4	Rain on the land, 1000 m, g	~~5.2~~ E5 6.5 E5
5	Umpqua River discharge, g	5.9 E5
6	Headwater streams, g	~~1.46 E6~~ 6.2 E5
7	Geopotential energy, 1000 m, J	6.1 E4
8	Stream sediments, g	3 E9
10	Electric Power	2.85 E5

UNFINISHED --- I need to add all transformities, Emergy/mass, and emergy /$ values used and their sources

*Letters refer to references marked in Literature Cited Section
1 Solar transformity of sunlight is 1 by definition

2 Emergy of rain at 1000 m =2.9 E4 sej/J from Table 4 in Folio #2

3 Emergy of rain geopotential at 1000 m = 14.5 E4 sej/g

4 For each cubic meter of rain per year on one square meter, emergy from rain is (4.1 E5 sej/g)(1 E6 g/yr) = 4.1 E11 sej/m3 water/yr
emergy from the mountain into that water from a square meter is
(1 m2 area/m3 rain)(32 E20 sej/yr/3.1 E10 m2) = 1.1 E11 sej/m2/yr
Sum of rain and geologic input = 4.1 + 1.1 = 5.2 E11 sej/m3 rain on land
(5.2 E11 sej/m3 rain on land)/1 E6 g/m3)= 5.2 E5 sej/g rain on land

5 (350 m3/sec)(3.15 E7 sec/yr)(1 E3 kg/m3) = 1.10 E13 kg/yr discharge

(65.3 E20 sej/yr)/(1.10 E16 g/yr) = 5.93 E5 sej/g

6 Emergy in headwater streams is concentrated from 3.1 E10 g/yr rain to 1.1 E10 g/yr of runoff: (3.1/1.1)(5.2 E5 sej/g water) = ~~1.46 E6~~ sej/g.

7 geopotential available, 1000 m; watershed emergy/discharge energy (1.10 E13 kg/yr discharge)(1000 m)(9.8 m2/sec2) = 1.07 E17 J geopot/yr
Transformity: (65.3 E20 sej/yr)/(1.07 E17 J geopot/yr) = 6.1 E4 sej/J

8 reference [G] increased 1.68 according to earth emergy in Folio #1

10 1.7 E5 sej/J from [G] increased by 1.68 based on revised earth emergy from Folio #1 [E]

Table 2
Annual Emergy Inputs to the Umpqua River Watershed in Oregon

Note	Item, Units	Data Units/yr	Solar Emergy per unit sej/unit	Solar Emergy per year E20 sej/yr
	Free Environmental Inputs			
1	Direct Sun, J	7.1 E19	1	0.71
2	Wind,kinetic energy, J	2.17 E17	1.5 E3	3.24
3	Tide absorbed, J	3.11 E15	4.9 E4	1.52
4	Ocean waves, J	4.6 E14	3.06 E4	0.14
5	Chem. Pot. in Rain, J			
	a Cont. shelf	1.95 E15	6.1 E4	0.56
	b Over mountain land	6.6 E16	6.1 E4	33.
	c Total			33.6
6	Geopotential in Runoff, J			
	a Upper area, 1000-500 m	3.1 E16	1.04 E4	18.9
	b Lower area, 500-0 m	5.4 E16	1.04 E4	32.9
	c Total			51.8
7	Geologic cycle, erosion, g			
	a Land, 1000 m	9.9 E11	2.5 E9	24.7
	b Land, 500 m	4.0 E11	2.0 E9	8.0
	c Total			32.0
8	Salmon return from ocean, ind	4.7 E4	9.1 E14?	0.42
9	Marine fish landed	5.9 E14	1 E6	5.9
10	Total of lines #5c,8c,~~9 & 10~~			78.9
	Inputs Purchased from Outside			
11	Fuels and electric power			
	a Use inside, J	4.75 E16	4 E4	19.0
12	Capital Equipment ?			
13	Outiside Services inferred	2.76 E8	3.4 E12	9.3
14	Services(Tourist-Government $)	1.58 E9	3.4 E12	53.7
15	Transfer - tax (State & Fed)		3.4 E12	

16	Sales, timber, and agricult.	?		
17	Total of lines 11,14,15,16	--	--	82+
18	Population immigration, persons	2,640	5.7 E18	151
	Net loss of Watershed stocks			
19	Soil, g organics			
20	Forest Timber, J	none	0	0
21	Mineral products, g			
22	Total non-renewed use: sum of lines 20-22			?
23	Total Emergy Inflows: sum of lines	10, 17,18 & 22		312+

Footnotes for Table 2 Emergy Inputs, Umpqua River Watershed, Oregon

Abbreviations: sec, second; yr, year; m, meter; g, gram; kcal, kilocalorie; J, Joule; kwh, kilowatt-hours; ind = individuals

Sources of Oregon data cited:
[A] = Atlas of the Pacific Northwest, ed by P.L. Jackson & A.J. Kimerling, 8th ed. Oregan State University Press, 152 pp. 1993
[B] = Atlas of Oregon, ed by W.G.Loy, S.Allen, C.P. Patton, and R.D. Plank Univ of Oregon Books, Eugene, Ore, 215 pp., 1976.
[C] = Statistical Abstract of the United States, The National Data Book 119th edition, U.S.Department of Commerce, 1005 pp., 1999
[D] =Energy Analysis o Environmental Value, Odum, H.T., F.C. Wang, J.F. Alezander, Jr, M. Gilliland, M. Miller, J. Sendzimier, Center for Wetlands, Univ. of Fl,91 pp.,1987
[E] = Odum, H.T. Emergy Evaluation of Earth Processes, Folio #2, Hanbook of Emergy, Center for Environmental Policy, University of Florida, 2000
[F] =Keller P., 1992 Emergy Evaluation of Oregon-1990 unpublished student report (Appendix B),
[G] = Odum, H.T. 1996 Environmental Accounting, Emergy and Decision Making, John Wiley, N.Y. 370 pp.
[H] Keisling, P. Oregon Blue Book 1999, Secretary of State, Salem, Ore., 431 pp

Charactertistics of study area used in calculations:
Area of Umpqua River Watershed System (Douglas County): Land, 1.31 E10 m^2 5057 squere miles (Blue book says Douglas County is 5071 sq miles)
Marine shelf assigned to the area (14 x 28 km), 0.039 E10 m^2; Total area, 1.34 E10 m^2= 1.34 E4 km2 = 5234 sq miles.
Douglas County, Oregon: population 26 people/sq mile[B];
(26/sqmi)(0.39 sqmi/ km2)(1.31 E4 km2) = 1.32 E5 people
per capita income: ? $20,000;
Gross economic product estimate: (1.32 E5 people?)(2 E4 $/person/yr) = 2.6 E9 $/yr
Income density:(26 people/sq mile)($20,000/person/yr) = 5.2 E5 $/sqmile/yr

Gravity, 9.8 m/sec^2.

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1 Direct sun: mean of winter 3.5 and summer 18 = 10.75 kiloLangleys/month {A}
(10.75 E3 gcal/cm2/mo)(1E4 cm2/m2)(4.186 J/gcal)(12 mo/yr) = 5.40 E9 J/m2/yr
(5.4 E9 J/m2/yr)(1.31 E10 m2) = 7.1 E19 J/yr

2 Wind kinetic Energy Absorbed D = r*C*V3; drag coefficient C =1,0E-3 (Regier 1969); air density r = 1.3 kg/m3; velocity, V = 10 miles/hr[B] = 4.44 m/sec; geostrophic wind= 10/6)* 4.44 m/sec = 7.4 mpsec
(1.3 kg/m3)(1.0E-3)(405 m3/sec3)(3.14 E7 sec/yr)(1.31 E10 m2) = 2.17 E17 J/yr

3 Tidal energy; assuming 90% absorbed on continental shelves (Campbell 1997) 2.5 m range, center of gravity 0.5, shelf area used 0.039 E10 m2)
(0.9)(0.5)(2.5m)(2.5 m)(0.039 E10 m^2)(1.025 E3 kg/m^3)(9.8 m/sec^2)(706 tides/yr) = 3.11 E15 J/y

4 Wave energy absorbed: calculated as energy of waves multiplied by length of coastline and shoreward velocity = $(gz)^{0.5}$ (g=square root of gravity; z = water depth) Assumed pending data: 3 m measured in 3 m water-depth (z); share of coastline facing wave fronts 100 km.

(1 E5 m)(1/8)(1.025 E kg/m^3)(9.8 m/sec^2) (3)(3)(3.154 E7 sec/yr)[(9.8 m/sec^2)(3.0 m)]$^{0.5}$ = 3.56 E13* 8.46 E16*[29.4]$^{0.5}$ = 4.6 E14 J/yr

5 Rain, 1.0 m/y; includes shelf
Chemical potential of rainwater
5a Shelf: (0.039 E10 m2)(1.0 m/yr)(1 E6 g/m^3)(5 J/g) = 1.95 E15 J/y
5b Land: (1.31 E10 m2)(1.0 m/yr)(1 E6 g/m3)(5 J.g) = 6.6 E16 J/yr

6 Geopotential energy of rain runoff, Total discharge, 350 m3/sec
calculation in two parts
6a Upper watershed
(200 m3/sec)(1 E3 kg/m^3)(1000-500 m)(9.8 m/sec2)(3.14 E7 sec/yr) = 3.1 E16 J/yr
6b Lower watershed
(350 m3/sec)(1 E3 kg/m^3)(500 m)(9.8 m/sec2)(3.14 E7 sec/yr) = 5.4 E16 J/yr

7 Geologic cycle, estimated from erosion, a function of altitude [E]
Half at 1000 m elevation; 0.15 E3 g/m2/yr, emergy/mass: 2.5 E9 sej/g
(0.66 E10 m2)(0.15 E3 g/m2/yr) = 9.9 E11 g/yr

Half at 500m elevation, by interpolation; 0.06 E3 g/m2/yr, emergy/mass: 2 E9 sej/g
.(0.66 E10 m2)(0.06 E3 g/m2/yr) = 4.0 E11 g/yr

8 Present salmon returning from the sea (personal communication from Steve Jacobs, Oregon Dept. of Wildlife), 47,000/yr (original salmon 408,000 /yr)
Transformity of the food of adult salmon from Appendix Table A1

9 Fishery landings [H} 260 E6 pounds/yr worth $70 E6.
(260 E6 lb/yr)(454 g/lb)(0.20 dry)(6 kcal/g)(4186 J/Kcal) = 5.9 E14 J/yr
Assumed transformity 1 E6 sej/J

10 Total of main indepent emergy sources (lines 5c,8c,8,& 10

11 Energy (Fuels and electricity)
11a energy use in Oregon: 341.6 E6 btu/capita [C]
(341.6 E6 btu/ind)(1.32 E5 people)(1054 J/btu) = 4.75 E16 J/yr

12 Capital Equipment ?

13 Services from outside:
Income density:(26 people/sq mile)($20,000/person/yr) = 5.2 E5 $/sqmile/yr
Dollar exchange across watershed boundary obtained
from graph of external $ inflow per area vs income density (Brown, 1980; see Env Acct, page 76): (5 E4 $/sq mi/yr)(5057 sq mile) = 2.52 E8 $/yr

Emergy/$ ratio for Oregon in 1990 changed in proportion to change in US values:
(4.8 E12 sej/$ Oregon 1990)(1.1 E12 USA 1997)/(1.55 E12 USA 1990) = 3.4 E12 sej/$)

14 Outside services purchased with money from vistor expenditures 1996 [H]: hunters $655 million; anglers $623 million; induced from state personnel $305 million.

15 State and Federal Government expenditures minus state and federal tax (__________$/yr)

16 Sales of timber ______; agricultural products; ______

17 Total of outside inflows from the economy: lines 11,14,15, & 16

18 Population In-migration
assumed 2%/yr: (1.32 E5 people)(.02) = 2640 people per year
Emergy per person, transformity for school-college educated: 50 E6 sej/J from [G p. 232] and age assumed 30 yrs
(30 yr ed&experience)(50 E6 sej/J)(10.47 E6 J metabolism/day)(365 d) = 5.7 E18 sej/person

19 Net soil erosion evaluated as erosion excess over that of mature forest land
(m2 of cleared land)(g/m2/yr erosion)(fraction organic)(5 kcal/g organic)(4186 J/kcal) =

20 No net loss of timber stocks: See footnote 2 in Table 3
Growth rate estimate (note 2a) exceeds harvest rate (note 2b)

21 (______g/yr mined)

22 Sum of decrease in stored environmental stocks (Timber, soil, minerals)

23 Sum of Emergy Inflows including free environmental, inputs from the economy, net change in educated people, net use-up of environmental capital stores.

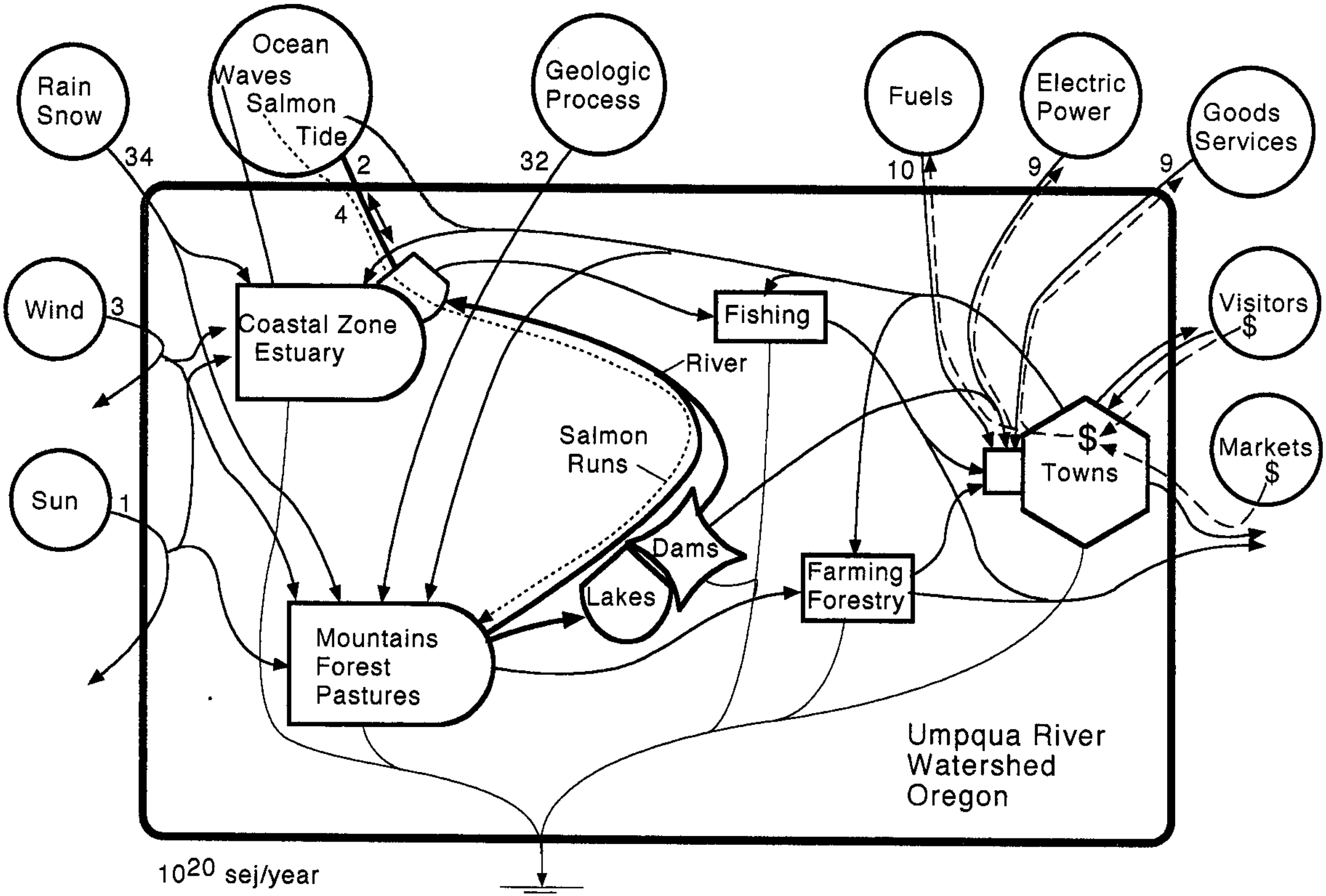

Rain
Snow
34
Ocean
Waves
Salmon
Tide
2
4
Geologic
Process
32
Fuels
10
Electric
Power
9
Goods
Services
9
Wind
3
Sun
1
Coastal Zone
Estuary
Fishing
River
Salmon
Runs
Visitors
$
Markets
$
$
Towns
Dams
Lakes
Farming
Forestry
Mountains
Forest
Pastures
Umpqua River
Watershed
Oregon
10^{20} sej/year

Table 3
Evaluation of Products and Exports from the Umqua River Watershed

Note	Item, Units	Data Units/yr	Solar Emergy per unit sej/unit	Solar Emergy per year E20 sej/yr
Environmental Production and Export				
1	Plant photosyn.,transpir,m3	--	--	58.1
2	Wood, J			
	a Growth	?1.3 E18	1 E3	13.0
	b Harvest	2.9 E16	1 E4	2.9
3	Fresh Water, m3/yr			
	a Transpiration	0.16 E10	2.7 E11	52.9
	b Runoff,ocean discharge	1.10 E10	5.4 E11	59.4
	c Local use from streams	4.05 E8	5.4 E11	2.2
4	Hydroelectric power, J			
	a Production	2.9 E15	1.7 E5	4.9
	b Local Use	5.3 E15	1.7 E5	9.0
	c Net (- = import)			-4.1
5	Sediments			
	a Runoff,mature forest	7.6 E14	3 E9	4.8
	b Runoff,disturbed areas	41. E11	3 E9	123
	c Export to sea	?22. E11	3 E9	?66
	d Local redeposition	?21. E11	3 E9	?63
6	Organic Matter, J			
	a Soil production	7.0 E16	1 E5	70
	b Runoff	3.0 E16	1 E5	30
	c Discharge to sea	?1.1 E16	1 E5	11
	d Local use,redeposit	1.9 E16	1 E5	19
7	Agricultural products			
	a Sales, 1974$	15 E6	6 E12	0.9
8	Services, 1998$	2 E9	1.2 E12	24
9	Fisheries			
9a	Salmon Returning	--	--	0.43
9b	Marine Fish Landings, 1972$	1 E6	7 E12	0.07

Some items are included in other items.

Footnotes for Table 3 Production in Umpqua River Watershed

1 Primary Plant Production based on emergy of transpired rain and the geologic basis for the landscape--Table 3, items 5 & 7
(0.9 green area)(32.6 + 32.0 E20 sej/yr) = 58.1 E 20 sej/yr

2 Wood
2a organic growth[B] (170 m3/ha/yr?)(0.50 forest)(1.3 E10 m2)(0.7 E6 g/m3)(4 kcal/g)(4186 J/kcal)/(1 E4 m2/ha) = 1.3 E18 J/yr

2b harvest: [A]: 800 million board-ft/yr
1 board-ft =(0.3m)(0.3m)(0.0254 m) = 0.002286 m3
(800 E6 bd-ft/yr)(2.286 E-3 m3/bd-ft)(0.85 E6 g/m3)(4.5 kcal/g)
(4186 J/kcal)= 2.9 E16 g/yr

3 Water flows
3a Transpiration = rain - local use - runoff; Rain (1.0 m/yr)(1.3 E10 m2); runoff and local use in notes 3b & 3c
1.3 - 1.10 -0.04 = 0.16 E10 m3/yr

Emergy/mass of unconcentrated rain for 1000 m elevation Folio #2 Table 4
25.1 E4 sej/g; for 500 m: 19.8 E4sej/g

3b Stream runoff = Umpqua discharge = 350 m3/sec;
(350 m3/sec)(3.15 E7 sec/yr) = 1.10 E10 m3/yr
(1.10 E10 m3/yr runoff)/(1.3 E10 m3 rain) = 0.846 fraction runoff

Emergy of Umpqua watershed: 33.6 E20 rain plus 32.0 E20 land cycle = 64.6 E20 sej/yr
(64.6 E20 sej/yr Umpqua)/(1.10 E10 m3/yr runoff) = 5.8 E11 sej/m3 H2O

3c Water withdrawals for agriculture 600 acre ft/day, for public use, 300acre-ft/day, and for industry-miing, 100 acre ft/day [B]
(900 acre-ft/day)(1233 m3/acre-ft)(365 d/yr) = 4.05 E8 m3/yr

4 Hydroelectric power
4a Eight hydroelectric plants on North Umpqua River
soda springs, Slide Creek, Fish Creek, Tokatee, Clearwater No 1, Clearwater No. 2, Lomolo no 1, Lomolo No 2; 100 Thsd megawatt-hrs each 1976 [B]
(8)(1 E8 kwatt-hrs/yr)(3.6 E6 J/Kw-hr) = 2.9 E15 J/yr electrical
4b Electrical use [B]:
Oregon: (47.6 E9 kw-hr/yr)/(3.3 E6 people) = 14,422 kw-hr/yr/person
Umpqua Watershed:
(1.02 E5 people/area)(1.44 E4 kw-hr/pers.)(3.6 E6 J/kw=hr) =5.3 E15 J/yr

5 Sediments: inorganic particulate: 500 kg/ha/yr[J]
5a (500 kg/ha/yr)(0.26)(1000 g/kg)/1E4 m2/ha) = 13 g/m2/yr;
(13 g/m2/yr)(0.40 mature forest)(3.1 E10 m2)= 1.6 E11 g/yr

5b Runoff disturbed forest, agriculture, 26 times more erosion [K]
(1.6 E11 g/yr mature forest)(26) = 4.1 E12 g/yr

5c (1.1 E10 m3/yr)(200 ? g/m3??) = 2.2 E12 g/yr??

5d Runoff sediments minus discharge sediments
(1.6 +41.0 E11 g/yr) - (22 ? E11 g/yr) = 20.6 E11 g/yr

6 Organic matter:
6a soil production: (1 g/m2/day)(365 d/yr)(1.3 E10 m2) (5 kcal/g)(4186 J/kcal)(0.7 forest) = 7.0 E16 J/yr

6b Runoff organics, forest area: organic leaching: 14% of 500 kg/ha/yr [J]
(500 kg/ha/yr)(0.14)(1000 g/kg)(5 kcal/g)(4186 J/Kcal)/(1 E3 m2/ha)
= 1.46 E5 J/m2/yr
Undisturbed area:
(1.46 E5 J/m2/yr)(0.4 forest)(1.3 E10 m2) = 7.6 E14 J/yr
Disturbed areas 26 faster [K]:
(1.46 E5 J/m2/yr)(26)(0.6)(1.3 E10 J/m2/yr) = 2.9 E 16 J/yr
(1.1 E10 m3/yr runoff)(?300 g/m3? org)(5 kcal/g)(4186) = 6.9 E16 J/yr
Organic runoff sum: (0.76 + 29)= 29.8 E15 J/m2/yr

6c (1.1 E10 m3/yr)(50 g/m3?)(5 kcal/g)(4186) = 1.1 E16 J/yr

6c Runoff organics minus discharge sediments:(3.0-1.1 E 16) = 1.9 E16 J/yr

7 Agricultural products, cattle
Sales $15 E6 1974$ [B]

8 Income: (102,000 people)($20,000/pers./yr) = 2 E9 1998$

9 Fisheries
9a Calculated from number of fish line 8, Table 2and emergy/fish from Appendix A.
9b Marine fish landings [B]: winchester Bay 1 E6 1972$

Table 4

Summary of the Annual Emergy Use by the Umpqua River Watershed#

Note	Input	Solar Emergy per year E20 sej/yr	1997 Em$* (Oregon) Million $
	Renewable Environmental Input		
1	Rains generating streams	32.7	988
2	Land, mountains, geological process	32.0	941
3	Oceanic contributions	8.0	235
4	Subtotal	78.9	2,164
	Non-renewed Uses of Watershed Stores		
5	Net loss of soil, timber, minerals		
	Economic Inputs		
6	Outside fuels, electrical power, equipment	19	558
7	Outside Services ?	54+	1588+
8	Subtotal	73+	2147+
9	Immigration of educated people	151	4441
10	Total Emergy Use by the Umpqua Watershed (lines 4,5,8, & 9)	304	8752

#Summary of line itms in Tables 2 and 3.

*Annual contribution of solar emergy divided by 3.4 E12 sej/$
962Emergy/$ ratio for Oregon in 1990 (Appendix B)changed in proportion to the change in US values from 1990 to 1997:
(4.8 E12 sej/$ Oregon 1990)(1.1 E12 USA 1997)/(1.55 E12 USA 1990) = 3.4 E12 sej/$)

Footnotes for Table 4 Summary of Emergy Use by the Umpqua Watershed

1 Area rain times emergy per unit rain
emergy per gram from Folio #2 Table 4 1000 m elevation
(1.0 m/yr rain)(1.31 E10 m2)(1 E6 g/m3)(25 E4 sej/g) = 32.7 E20 sej/yr

2 Geologic cycle, estimated from erosion, a function of altitude
Half at 1000 m elevation;
0.15 E3 g/m2/yr, emergy/mass: 2.5 E9 sej/g
(0.66 E10 m2)(0.15 E3 g/m2/yr)(2.5sej/g) = 24.7 E20 sej/yr
Half at 500m elevation, by interpolation;
0.06 E3 g/m2/yr, emergy/mass: 2 E9 sej/g ;
(0.66 E10 m2)(0.06 E3 g/m2/yr)(2 E9 sej/g) =7.9 E20 sej/yr
Sum: (24.7 +7.9 = 32.6 E20 sej/yr emergy support of land
Per area: (32.6 E20 sej/yr)/(1.31 E10 m2)=2.48 E11 sej/m2

3 Contribution of Returning Salmon from Table 2 (0.42 E20 sej/yr) plus tide and wave inflows in Table 2 (1.52 + 0.14 =1.66 E20 sej/yr) plus marine fish landed 5.9 E20 sej/yr (Table 2) = 8.0 E20 sej/yr

4 Sum of lines 1-3

5 Non-renewed Resource use within the watershed
Sum of net soil erosion, net loss of timber stock, and mined minerals from lines 15-17 in Table 2

6 Lines 11-12 in Table 2. Includes electrical power use that exceeds the hydroelectric power generated within the watershed

7 Tourist money, sales, transfers-tax, Table 2 Line 17

8 Total emergy input purchased from the economy outside of the watershed based on money coming in to thewatershed: sum: lines 6 & 7

9 Emergy added to the area in the form of already educated people immigrating permanently. Line 18 Table 2

10 Total of lines 4,5,8, and 9

Table 5
Evaluation Indices for the Systems of Umpqua Watershed

Note	Category		Index
1	Emergy sources:	External recurring	48%
		Indigenous	52%
	Ratio of outside to inside sources		0.92
2	Emergy per person		149 E15 sej/yr
3	Emergy Use/money circulating		5.8 E12 sej/$
4	Areal Empower density		11.6 E11 sej/m2/yr
5	Ratio of Emdollar use to dollar circulation		4.4
6	Ratio of present salmon runs to original		11 %
7	Salmon proportion of emergy use		
		Present salmon	0.27 %
		Original salmon	2.4 %
8	Ratio of Salmon emergy to geopotential emergy		
		Present salmon	0.65 %
		Original salmon	5.7 %
9	Ratio of Salmon emergy to existing		
	Hydroelectric emergy:	Present salmon	8.6 %
		Original salmon	75 %
10	Ratio of Salmon emergy to electric power use		
		Present salmon	4.7%
		Original salmon	41%
11	Emergy ratio of products sold to those purchased		
12	Ratio of products sold to watershed total		
13	Ratio of withdrawals to total river flow		3.7 %

Fooootnotes for Table 5

1 Total recurring 78.9+ indigenous (Table 2 line 10) plus 73 E20 sej/yr external (Table 4, line 8) = 152 E20 sej/yr (not including information in immigration of people)

2 (152 E20 sej/yr)/(102,000 people)= 149 E15 sej/person/yr

3 (152 E20 sej/yr)/(2.6 E9 $/yr) = 5.8 E12 sej/$

4 (152 E20 sej/yr)/(1.3 E10 m2/area) = 11.6 E11 sej/m2/yr

5 8.7 E9 Emdollars from Table 4, line 10; area income, 2 E9 $/yr footnote 8 Table 3

6 Present salmon returning, 0.42 E20 sej/yr from Line 9, Table 2; Estimate of original by Steve Jacobs of Oregon Wildlife Dept. is 408,000 fish per year. (4.08 E5 ind/yr)(9.1 E14 sej/ind Table A1) = 3.7 E20 sej/yr

7 Emergy of returning salmon, 0.42 E20 sej/yr from Table 2 divided by total 152 E20 sej/yr from Table 4, lines 4 and 8 (omiting immigration). Original salmon: 3.7 E20/152 E20 =

8 Emergy of returning salmon, 0.42 E20 sej/yr from line 9 in Table 2 divided by emergy of the geopotential = sum of rain and geologic input =64.5 E20 sej/yr (Note 3b in Table 3); Orignal salmon: 3.7 E20 sej/yr/64.5 E20 sej/yr

9 Emergy of returning salmon, 0.42 E20 sej/yr from line 9 in Table 2 divided by hydroelectric emergy 4.9 E20 sej/yr from line 4 Table 3; Original salmon: 3.7 E20 sej/yr/ 4.9 E20 sej/yr

10 Emergy of returning salmon, 0.42 E20 sej/yr from Table 2 divided by hydroelectric emergy 9.0 E20 sej/yr from line 4 Table 3; Original salmon: 3.7 E20 sej/yr/9.0 E20 sej/yr

11 & 12 (need better figures for sales)

13 emergy of local withdrawals 2.2 E20 sej/yr (Line 3c in table 3) Runoff, 59.4 E20 sej/yr 2.2/59.4 = 3.7%

Table 6 Emergy-emdollar evaluation of Alternative Scenarios

Note	Item	Environ.* Contribution	Matched#
Contributions of streams			
1	Maximum salmon, no hydroelectric power		
2	Same as #1 without salmon harvest at sea		
3	Maximum hydroelectric power		
Contributions of the land			
3	Protected forests, no harvest, 90% of land		
4	Commercial timber, 90% of land		
5	Agriculture, 90% of land		
6	Water diversion		
Watershed Contributions			
7	Full development, present fuel prices		
8	Full development, high fuel prices		

* Annual emdollar value of direct environmental contribution
\# Direct contribution multiplied by the ratio of emergy matching by the outside economy. (Investment ratio = 7 for lines 1-6; 1 for line 8)

Table 7
Umpqua Watershed Contributions to Different Scales

Note	Item	Watershed*	State#	Global**
1	Salmon sales			
2	Salmon tourism.			
3	Timber sales			
4	Local Forest use			
5	Water Diversion			
6	Hydroelectric Maximum			
7	Present watershed			
8	Matched economy			
9	Low Fuel economy			

* Emergy use within the area
\# Emergy contribution to Oregon
** All emergy contributions

Appendix A
Emergy of the Salmon Life Cycle

This appendix evaluates the emergy and transformities for stages in the life cycle of salmon, using the Umpqua River watershed in Oregon as the example. Salmon release fertilized eggs as they spawn upstream. Embryological development utilizing the yolk produces a larval stage. these become fingerling fish that begin to feed on freshwater insects and other invertebrates as they drift downstream. Young fish called smolts eventually reach the estuaries and move out to sea. After one or more years at sea the full sized salmon, laden with eggs and sperm return to the streams swimming up to the spawning grounds again. After spawning the fish die, their carcasses contributing to the biological fertility of the headwaters.

The cycle is shown in Figure A1a. An energy systems diagram in Figure A1b includes the sources of emergy that contribute to the cycle. These items are arranged from left to right according to the transformity of the stage with emergy increasing from eggs to adults.

In Table A1 the emergy increments for each segment of the cycle (Figure A1b) are added to that passing along with the previous stage in the circle to obtain the emergy of the next stage. Other columns calculate the transformities of the stages.

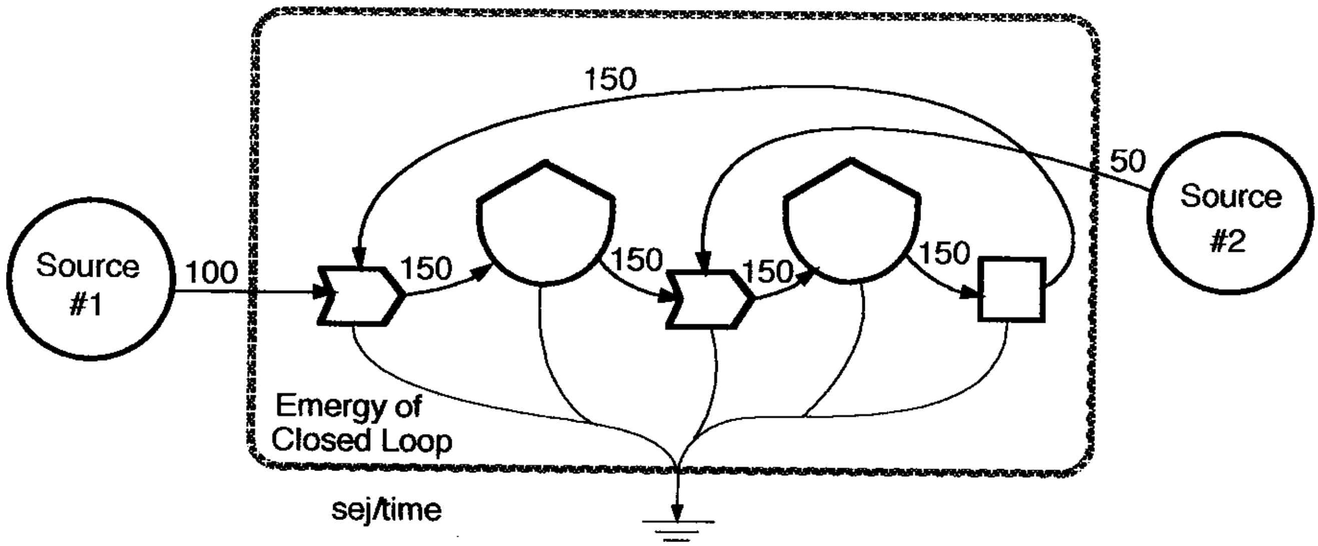
The main inflow to the life cycle on land is the emergy of the stream waters maintaining the spawining redds, and that of the food chain as the fry emerge to become smolts passing downstream to the sea. Then in the sea, emergy of the food chains leads to adult salmon returning upstream to spawn.

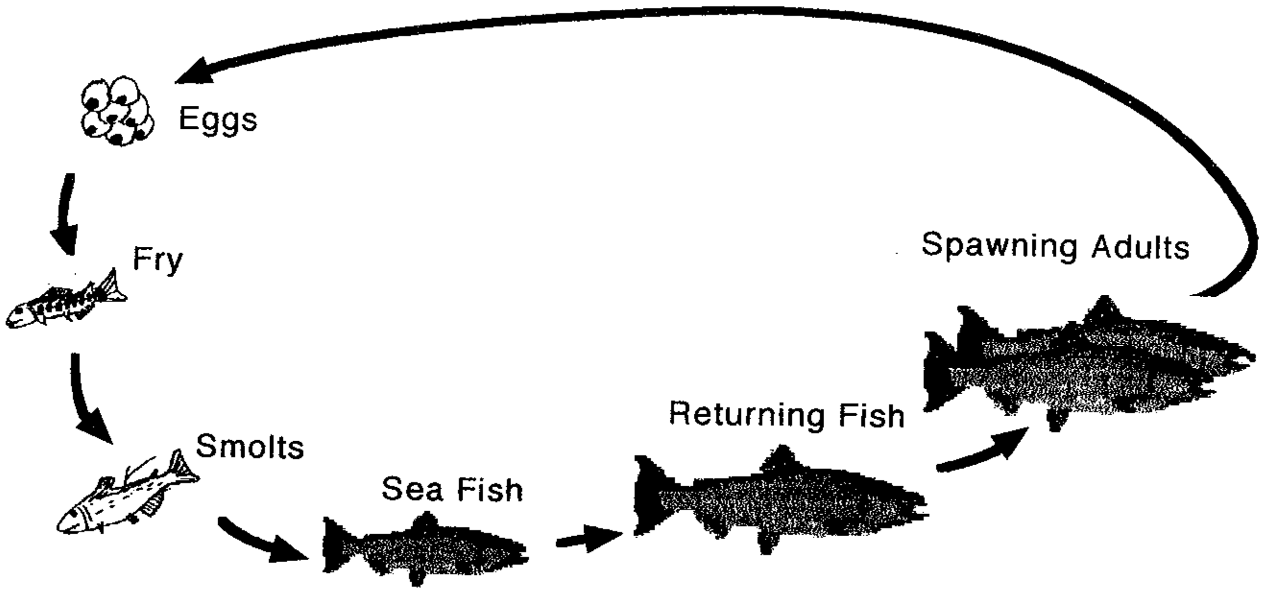
The precipitation over land is calculated with a transformity that includes the global contribution of solar energy. Therefore sun is already included in estimates of emergy in the stream water on land. The global estimate of emergy of the oceanic ecosystem was used to evaluate the contributions to the salmon during their life in the sea. This global estimate includes the solar energy, the tide, and the geological contributions to maintain the oceanic basins and processes. While in the sea the salmon share an upper carnivores position in the food chain energy hierarchy. Their emergy input is estimated from their food consumption and an estimate of the transformity of that food.

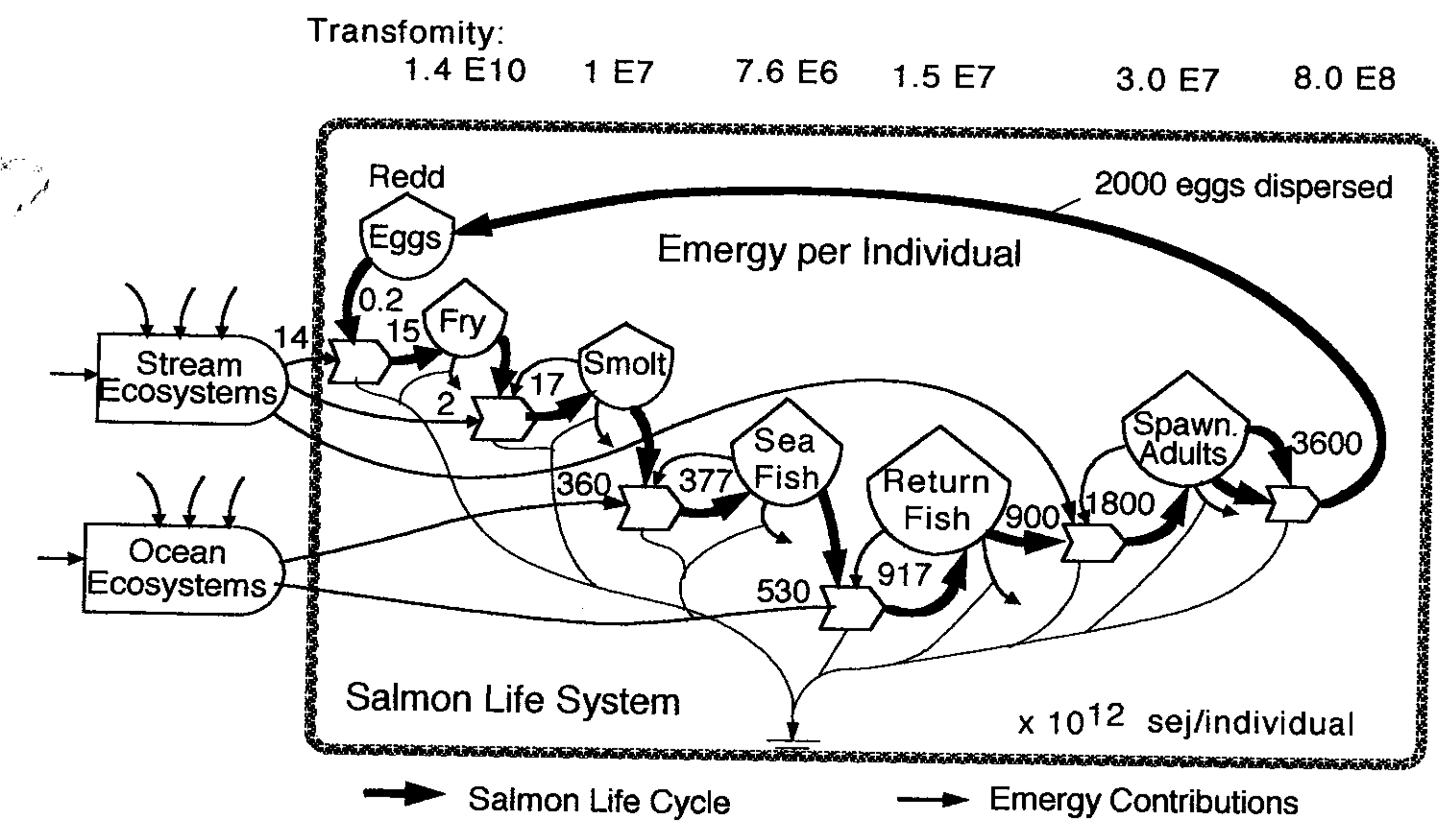
Evaluation with Closed Loop Principle

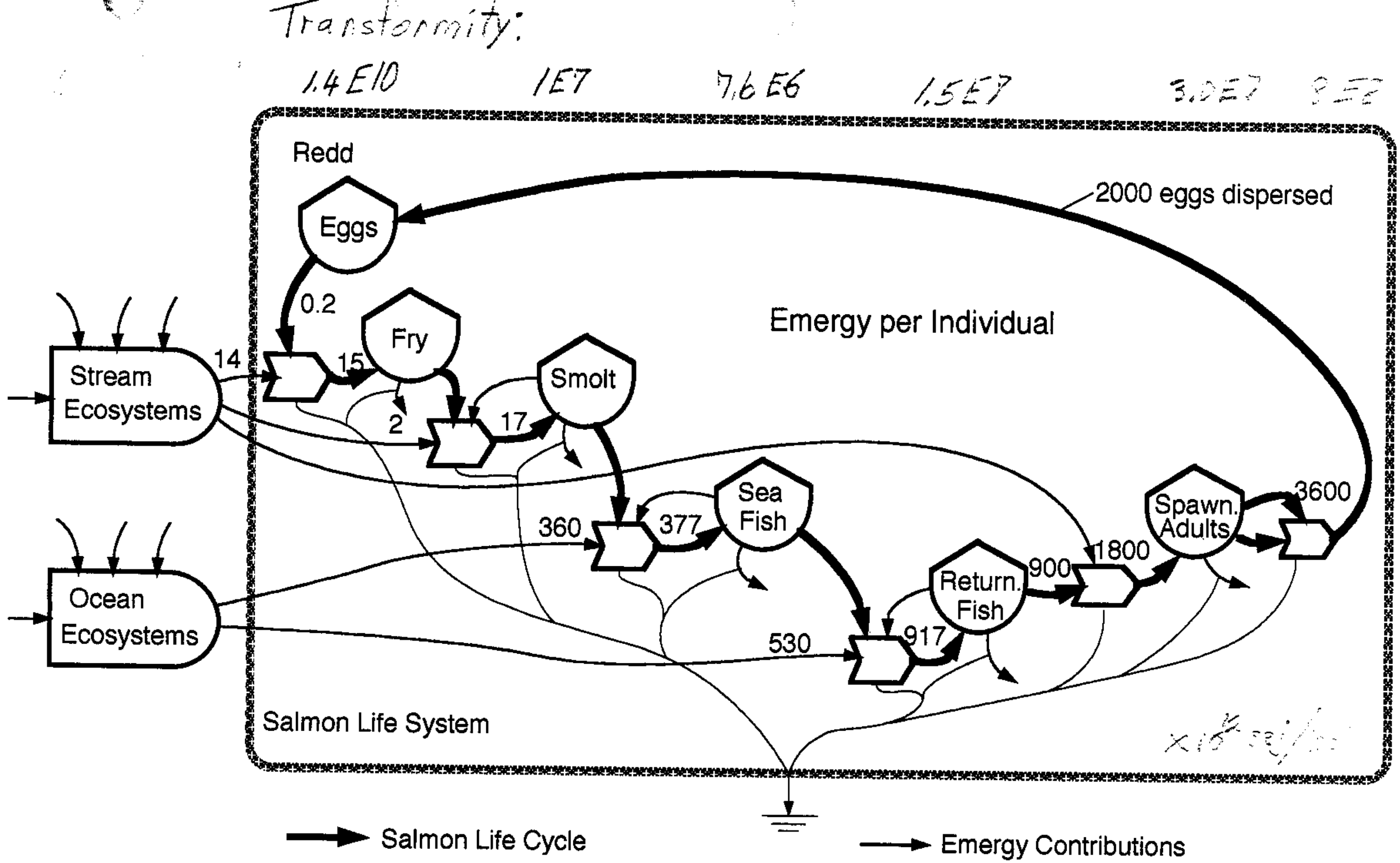
According to emergy concepts, emergy flowing in a closed loop is the sum of the emergy inflows to that loop. The principle is illustrated with Figure A2 with two inflows. Each emergy inflow passes around the loop until it disappears at the interaction with its own inflow. Thus no emergy inflow is double counted. Within the loop the emergy flow (empower) is the sum of the inflows, in this example, 150 solar emjoules per time.

The closed loop principle may be a simpler way to view the emergy support of biological life cycles. To apply the principle to the Salmon life cycle (Figure A1a), sum the independent input increments given in the footnotes Table A1 as drawn in Figure A1b. These include stream-stream bed inflows (redd, 1.4 E13 sej and food chain 1.7 E12 sej) and inflows from the sea (3.58 E14 sej and 5.3 E14 sej) for a total of 9.0 E14 sej/individual


150
50
Source #2
Source #1
100
150
150
150
150
Emergy of Closed Loop
sej/time


Eggs
Fry
Smolts
Sea Fish
Returning Fish
Spawning Adults


Transfomity:
1.4 E10
1 E7
7.6 E6
1.5 E7
3.0 E7
8.0 E8
Redd
Eggs
2000 eggs dispersed
Emergy per Individual
Stream Ecosystems
Ocean Ecosystems
Fry
Smolt
Sea Fish
Return Fish
Spawn. Adults
0.2
14
15
2
17
360
377
530
917
900
1800
3600
Salmon Life System
x 10^12 sej/individual
Salmon Life Cycle
Emergy Contributions


Transformity:
1.4E10
1E7
7.6E6
1.5E7
3.0E7
Redd
Eggs
0.2
Fry
15
2
Smolt
17
Stream Ecosystems
14
Ocean Ecosystems
360
Sea Fish
377
530
917
Return. Fish
900
1800
Spawn. Adults
3600
2000 eggs dispersed
Emergy per Individual
Salmon Life System
Salmon Life Cycle
Emergy Contributions
Fig A1

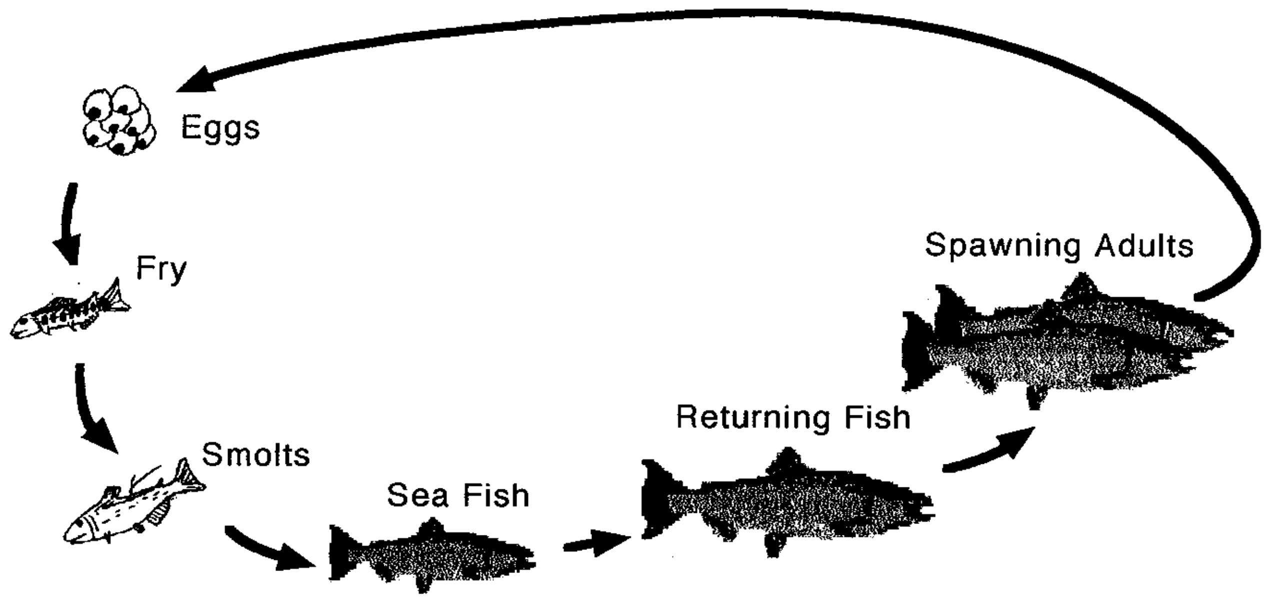


Fig. A1a

Table A2
Emergy Flow Distribution within the Life Cycle of a Salmon Population

Note	Stage	Individuals produced #/yr	Emergy Increment* sej/ind.	Emergy per ind sej/ind	Solar Transformity sej/J	Emergy of Population sej
1	Fry	4.0 E7	1.4 E13	1.52 E13	1.4 E10	6.1 E20
2	Smolts	4.0 E6	1.7 E12	1.7 E13	1.0 E7	6.8 E19
3	Sea Fish	2.0 E6	3.6 E14	3.8 E14	7.6 E6	7.6 E20
4	Returning adults	4.1 E5	5.3 E14	9.1 E14	1.46 E7	3.7 E20
5	Spawning adults	2.0 E5	--	1.8 E15	3.0 E7	3.6 E20
6	Eggs at release	2.0 E8	---	(1.8 E12)	8.2 E8	3.6 E20

Abbreviations: ind = individual organism
* Emergy inflow to that stage of the cycle: divided by the number of fish.

1 Emerging Fry; 2 months egg developing in gravels:= 20% of eggs: (0.2)(2 E8) = 4 E7 eggs remaining
Emergy of headwater streams from rain and geologic emergy divided by water runoff:
Runoff = Umpqua discharge = 350 m3/sec; (350 m3/sec)(3.15 E7 sec/yr) = 1.10 E10 m3/yr
(1.10 E10 m3/yr)/(1.3 E10 m3 rain) = 84.6 % runoff

Emergy of Umpqua watershed from Table 4, line 4
(78.9 E20 sej/yr Umpqua)/(1.10 E10 m3/yr runoff) = 7.7 E11 sej/m3 H2O

Emergy added per Redd from share of stream water times its transformity.
(1 m width)(0.1 m depth)(0.1 m/sec)(60 days)(8.64 E4 sec/day)(5.4 E11 sej/m3) = 2.8 E16 m3
(2.8 E16 m3)/(2000 eggs/redd) = 1.4 E13 sej/egg emerging

(1.4 E13 sej/fry)/(1000 j/ind) = 1.4 E10 sej/J

2 Smolts = 10% of eggs: (0.1)(4 E7) = 4 E6 individuals; 40 g each
Energy in individual: (40 g)(0.2 dry)(5 kcal/g)(4186 J/kcal) = 1.67 E5 J each

Emergy of the added growth: 10% conversion of food energy with transformity: 1 E6 sej/J
Energy input used: (1.67 E5 J/ind)(10)(1 E6 sej/J) = 1.7 E12 sej/ind
(1.7 E12 sej/ind)/(1.67 E5 J) = 1.0 E7 sej/J

3 Fish at sea = 1% of eggs: (0.01)(2 E8) = 2 E6 fish
Energy per fish: (12,000 g/fish)(0.20 dry)(5 kcal/g)(4186 J/kcal) = 5.0 E7 J/fish

Emergy of global ocean area: 15.83 E24 sej/yr from Folio #2, Table 1 divided by area of ocean:
(15.83 E24 sej/yr)/(3.61 E14 m2) = 4.38 E10 sej/m2/yr

Fish food in one square meter of ocean is 1% of the net primary. production.
(4 kcal/m2/day)(365 days)(4186 J/kcal)(0.01 efficiency) = 61116 J/m2/yr
Transformity: Emergy flow/area divided by the food energy flow.
(4.38 E10 sej/m2/yr)/(61116 j/m2/yr) = 7.16 E5 sej/J

Emergy per fish based on 10% efficiency and transformity of food:
(10)(5.0 E7 J/fish)(7.16 E5 sej/J) = 3.58 E14 sej/fish
(3.8 E14 sej/fish)/(5.0 E7 J/fish) = 7.6 E6 sej/J for sea fish

4 (For comparison Original Columbia basin: 17 million salmon/250,000 sqmi = (17 E6 fish)/(2.5 E5 sqmi)/(2.59 km2/sqmi) = 26.2 fish/km2)
For Umpqua watershed: (408,000 returning fish/yr)/(1.3 E4 Km2 Umpqua) = 31.4 Fish/km2
(4.1 E5 ind/yr)(15,000 g/ind)(0.20 dry)(5 kcal/g)(4186 J/kcal) = 2.57 E 13 j/yr or (6.4 E7 J/ fish)

Emergy of sea fish to generate returning fish: (3.7 E14 sej/ind)(2 E6 fish)/8.1 E5 fish = 9.1 E14 sej/fish
an increment of (9.1-3.8 = 5.3 E14 sej/fish); (9.1 E14 sej/fish)/(6.23 E7 J/fish) = 1.46 E7 sej/J

5 Spawning adults = 0.1% of eggs; (15,000 g)(0.20 dry)(5 kcal/g)(4186 J/kcal) = 6.3 E7 J stored
Emergy of spawning adults equal to emergy of returning adults divided by the number spawning:
(4.1 E5 returning)(9.1 E14 sej/ind)/(2 E5 spawning) = 1.86 E15 sej/ind, increment (18-9 = 9 E14 sej/ind)
(1.86 E15 sej/ind)/(6.23 E7 J/ind) = 3.0 E7 sej/J

6 Eggs from spawning adults: Half females; eggs half of body weight :
(2000 eggs/adult/yr)(1 E5 female spawning fish) = 2 E8 eggs
Egg volume: (0.1)(15,000 g/fish)(1 ml/g)/(2 eggs) = 10.75 ml/egg
Egg energy: (0.75ml/egg)(0.10 g dry/ml)(7 kcal/g)(4186 J/kcal) = 2197 J/egg

Emergy: (1.8 E15 sej/spawning adult)(2 adults)/(2000 eggs) = 1.8 E12 sej/egg before release.
(1.8 E12 sej/egg)/(2.2 E3 J/egg) = 8.2 E8 sej/J (a value of the isolated information of an egg)

Emergy flows into each egg from the spawning adults. Dispersal of eggs to environment disperses the adults emergy, reducing the transformity to lower values. In the closed life cycle loop new emergy from outside reconcentrates emergy again

Literature Cited
Bracket Letters are used in Table footnotes

Anderson, c.W., D.Q. Tanner and D.B. Lee Water quality data for the S. Umpqua River 1990-1992 U.S.G.S. Open File report 156 pp

Ballaire, W.C. and S. Fiekowsky 1953 Economic Value of Salmon and Steelhead trout in Oregon Rivers. School of Business, Univ of Oregon, Eugene, Or, 61 pp.

Beschta, R.L., S.J. O'Leary, R.E.Edwards, K.D.Knoop 1981 Sediment and organic matter transport in Oregon Coast Range Streams. Water Resources Research Institute pp. 75.

Curtis, D.A. 1975 Sediment yield of streams of the Umpqua River Basin Oregon. USGS Open file report AGI No 78-06673

Curtis, D.A. 1982 An evaluation of suspended sediment and turbidity in Cow Creek, Ore. Water Resources Investigations,WRI 83-364 USGS 26 pp

[K] Grant, G.E. ad A.L. Wolff 1991 Long term patterns of sediment transport after cutting forest in Western Casdades of Oregon.pp. 31-40 in Proceedings symposium, Vienna Va. 1991 ed by N.E. Peters, IAHS Publ #203

Hinkle, S.R. 1999 Inorganic chemistry of water and bed sediment in selected tributaries of the south Umpqua River, Oregon in 1998. wash. Research. Investigations Report # 99-4196

[A] Jackson, P.L & A.J. Kimerling, ed. 1993 Atlas of the Pacific Northwest, 1993 8th ed. Oregan State University Press, 152 pp.

[H] Keisling, P. Oregon Blue Book 1999, Secretary of State, Salem, Ore., 431 pp

[F] =Keller P., 1992 Emergy Evaluation of Oregon-1990 unpublished student report (Appendix 1),

[B] Loy, W.G., S.Allen, C.P. Patton, and R.D. Plank ed. 1976 Atlas of Oregon, Univ of Oregon Books, Eugene, Ore, 215 pp.

[D] Odum, H.T., F.C. Wang, J.F. Alezander, Jr, M. Gilliland, M. Miller, J. Sendzimier 1987 Energy Analysis of Environmental Value, Center for Wetlands, Univ. of Fl,91 pp.,1987

[G] = Odum, H.T. 1996 Environmental Accounting, Emergy and Decision Making, John Wiley, N.Y. 370 pp.

[I] Odum, H.T., M.T.Brown, and S. Brandt-Williams 2000 Introduction and Global Budget, Folio #1 of Hanbook of Emergy Evaluation, Center for Environmental Policy, University of Florida, Gainesville, 17 pp.

[E] = Odum, H.T. 2000 Emergy Evaluation of Earth Processes, Folio #2, Handbook of Emergy, Center for Environmental Policy, University of Florida, Gainesville, Fl., 28 pp.

Odum, H.T. 1967. Energetics of world food production. pp. 55-94 in Problems of World Food Supply, President's Science Advisory Committee Report, Vol. 3. White House, Washington, D.C.

Odum H.T. 1971. Environment Power and Society. John Wiley, N.Y., 331 pp.

Odum H.T. 1976. Energy quality and carrying capacity of the earth. Tropical Ecology, 16(1):1-8.

Ransickle, J. and R.L. Beschta
Water Resources research Institute ? 19(3):768-778.

Sollins, P., c.A. Glassman, and C.N. Dahia 1985 Composition and possible oigin of detrital matter in streams Ecology 66:297-299

Scienceman, D. 1987. Energy and Emergy. pp. 257-276 in Environmental Economics, ed. by G. Pillet and T. Murota. Roland Leimgruber, Geneva, Switzerland, 308 pp.

Schatz, J. 1975 Transition. A Report to the Oregon Energy Council, Office of energy research and planning, State of Oregon, 474 pp

[J] Swanson F.J., R.L. Fredriksen, F.M. Corison 1982 Material transfer in a western oregon forested wetland, pp233-266 in Analysis of Coniferous forest ecosystems in Western United States, ed by R.L.Edwards. US IBP Synthesis series #14 . Publisher: Hutchinson Ross, Stroudsburg, PA
[

C] U.S.Department of Commerce, 1999. Statistical Abstract of the United States, The National Data Book 119th edition, 1005 pp.,

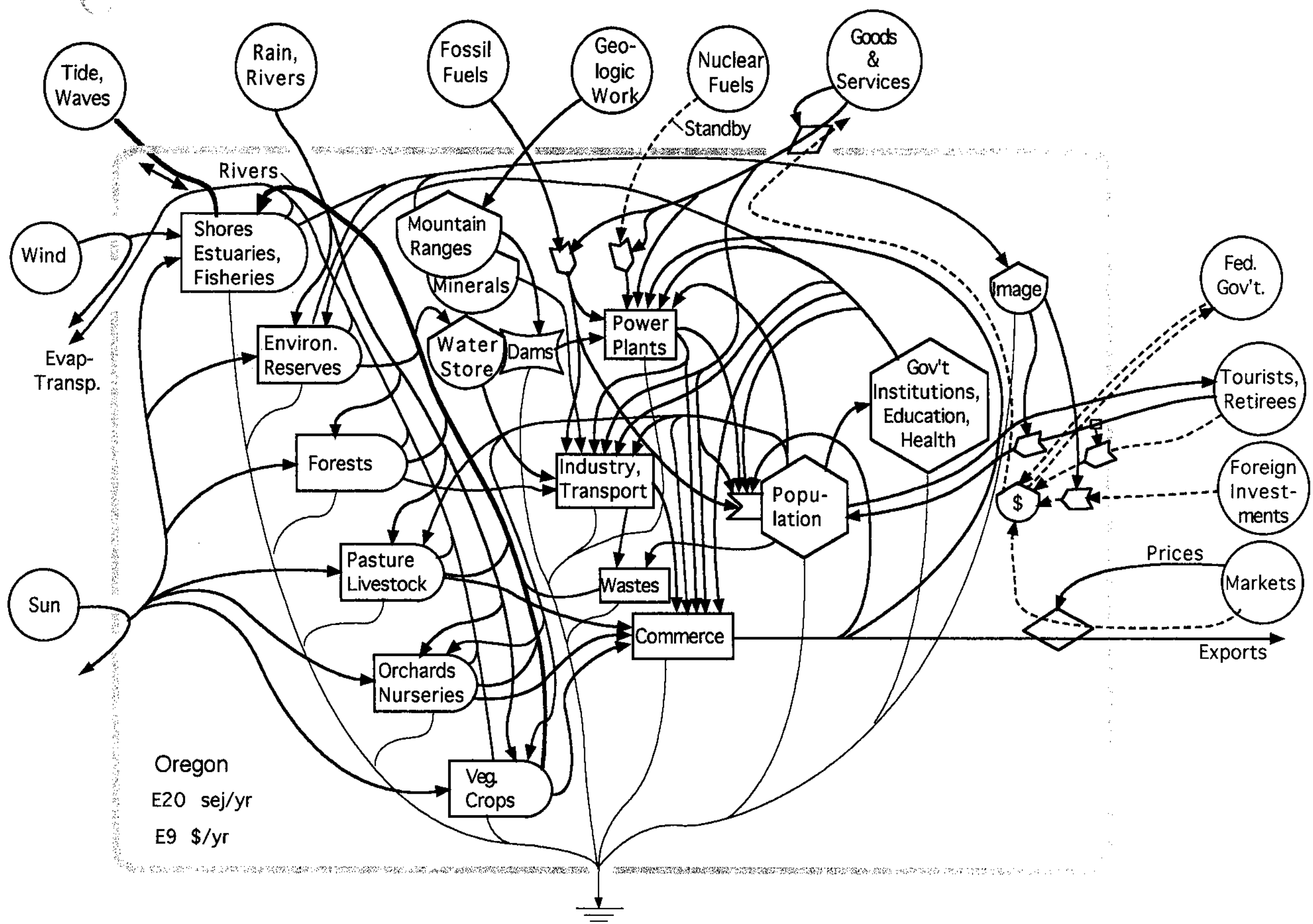
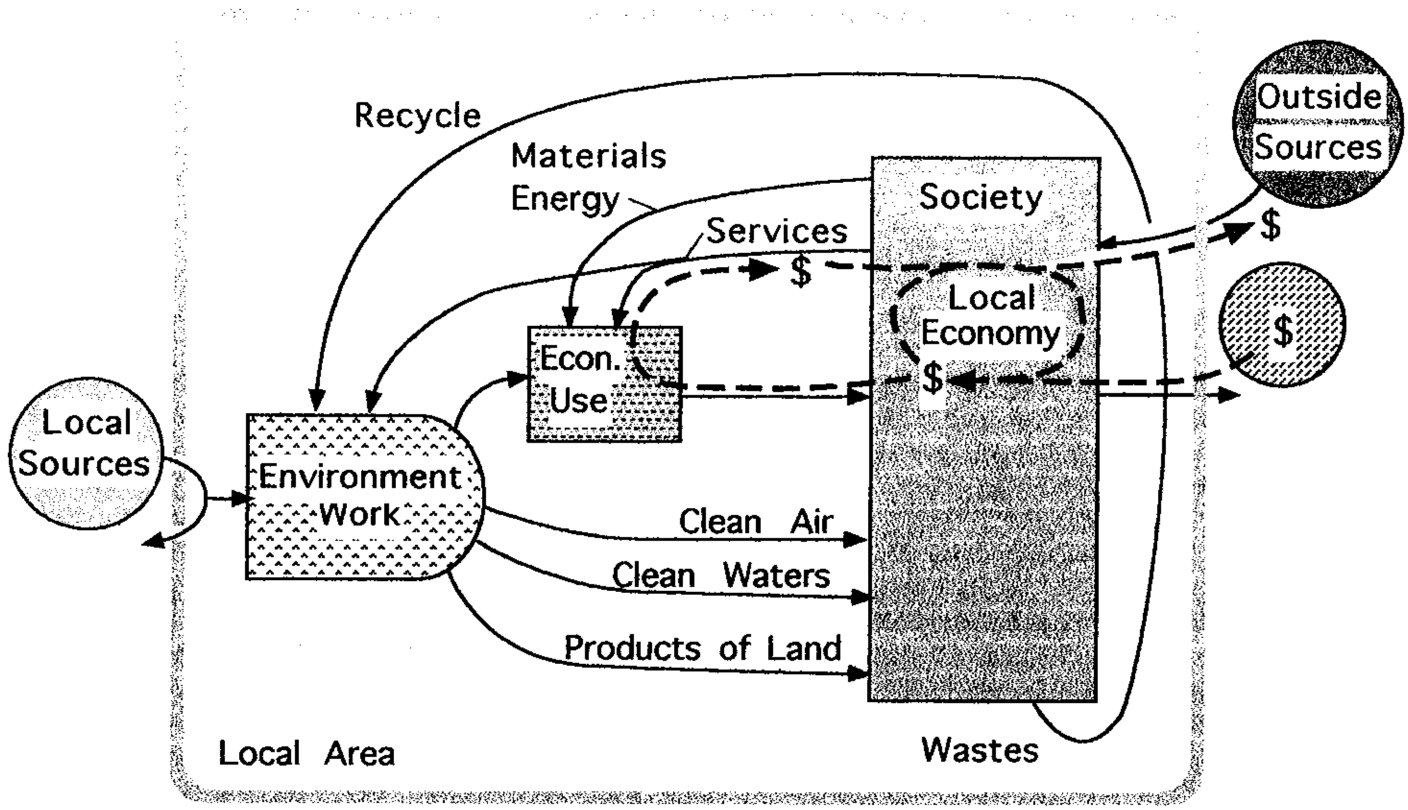

Tide, Waves
Rain, Rivers
Fossil Fuels
Geo-logic Work
Nuclear Fuels
Goods & Services
Standby
Rivers
Wind
Evap-Transp.
Shores Estuaries, Fisheries
Environ. Reserves
Mountain Ranges
Minerals
Water Store
Dams
Power Plants
Image
Fed. Gov't.
Tourists, Retirees
Gov't Institutions, Education, Health
Forests
Industry, Transport
Popu-lation
Foreign Invest-ments
$
Sun
Pasture Livestock
Wastes
Prices
Markets
Commerce
Exports
Orchards Nurseries
Oregon
E20 sej/yr
E9 $/yr
Veg. Crops

Fig B1

Emergy Indices:

Emergy sources:	External	48%
	Indigenous	52%
Emergy per person: Umpqua/USA		5
Emergy/money:	Umpqua/USA	3
Emdollar/dollar		4.4
Present salmon/Original salmon:		11 %
Salmon Role in Basin	Present salmon:	0.27 %
	Original salmon:	2.4 %
Salmon/Geopotential:	Present salmon:	0.65 %
	Original salmon:	5.7 %
Salmon/Hydroelectric:	Present salmon:	8.6 %
	Original salmon	75 %
Salmon/ Electric use:	Present salmon:	4.7%
	Original salmon:	41%
Water withdrawal:		3.7 %



(Pathways of Degraded Energy Dispersal Omitted)

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- Emergy in the Umpqua River Watershed
- Emergy Evaluation of Alternative Scenarios
- Emergy of Alternate Scenarios
- Effect of Global increase in Fuel Costs
- Differences due to Scale of View

Literature Cited

Figures

Figure 1 Umpqua River Watershed (Douglas County) with inset of Oregon

Figure 2. Systems Overview of the Umpqua River Watershed with estmates of annual emergy use.

Figure A1 Salmon Life Cycle: (a) pictures;

Figure A1 Salmon Life Cycle: (b) energy system diagram.

Figure A2 Evaluating empower in a closed loop

Figure B1 Emergy Inflow and the State System of Oregon
(to use if we update Keller's Oregon Analysis)

Tables

Table 1 Unit Emergy Values Used in the Evaluations
Table 2 Annual emergy inputs to the Umpqua Watershed in Oregon
Table 3 Emergy evaluation of products from the Umpqua Watershed
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Table 5 Evaluation indices for the Umpqua Watershed in Oregon
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Appendix B

EMERGY EVALUATION OF OREGON - 1990

Peter Keller
April 24, 1992

An emergy evaluation was conducted on the state of Oregon. Figure 1 shows a map of the state, and Figure 2 is an aggregated general systems energy diagram. The state is located on the Pacific northwestern coast of the U.S. and ranks 10th in area among the 50 states. Oregon's northern border with Washington is defined by the Columbia River, the third largest river in the U.S. To the south, Oregon borders California and Nevada. To the east, Oregon's border with Idaho is partially defined by the Snake River. The state's western border, 476 km, is the rugged coastline of the Pacific Ocean. Oregon is divided into distinct climatic regions by the Cascade Mountains, running north-south through the middle of the state. The Coast Range, with rainfall up to 208 cm per year, is well known for its highly productive Douglas fir and hemlock forests. Between these two mountain ranges lies the Willamette Valley, where one finds the four largest cities in the state and 2/3 of the state's population of 2,847,000.

Oregon's economy is based on natural resources, with the lumber industry and wood products industry leading the state, followed by agriculture. In recent years the economy has begun to diversify and now includes the high tech computer industry of the suburban Portland "silicon forest" as the fastest growing manufacturing sector. Being one of the most environmentally progressive states in the U.S., Oregon is trying to develop and diversify its economy without degrading the resource base on which it depends.

The emergy flows of indigenous renewable and nonrenewable sources as well as purchased imported emergy source of Oregon were calculated and are presented in Table 2. Also, refer to Figures 3 and 4 for summary diagrams of emergy flows for Oregon. Boundary exchanges with other states were calculated using a correlation of economic activity density with boundary exchange prepared by mark Brown (1980) and subtracting the international emergy exchange figures. International trade is important to Oregon, and emergy evaluation of trade reveals inequity in favor of overseas markets, specifically Japan. Although Oregon produces nearly half of its electric power use by hydroelectric, it is still heavily dependent on imported fossil fuels. Fuel imports were evaluated using the world emergy/$ ratio 3.8 E12 sej/$. The emergy currency exchange ratio for imported fuels benefits Oregon's wealth by approximately 10:1. The major goods and service imports to Oregon come from Japan, and include vehicles and parts, electrical equipment and machinery. These were evaluated using Japan's emergy/$ ratio of 1.0 E12 sej/$. Here Oregon and hence the U.S. has an emergy currency disadvantage of 4.8:1. Oregon's major exports are relatively untransformed natural resources such as forest products, often whole logs, and agricultural products. Again the major trading partner for Oregon exports is Japan, which benefits by an emergy currency exchange ratio of 2:1.

When comparing the indices calculated in Table 3 to those for the U.S. as a whole the following conclusions can be drawn. The fraction of emergy use that is locally renewable is three times as high, reflecting the rich renewable resource base. Emergy use per unit area (Empower density) of Oregon, 7.09 E11 sej/m^2, is slightly lower than the U.S., which shows the rural nature of the state. Emergy per person is nearly twice that for the U.S. The state's emergy/$ ratio is 2.6 times higher than that of the U.S.

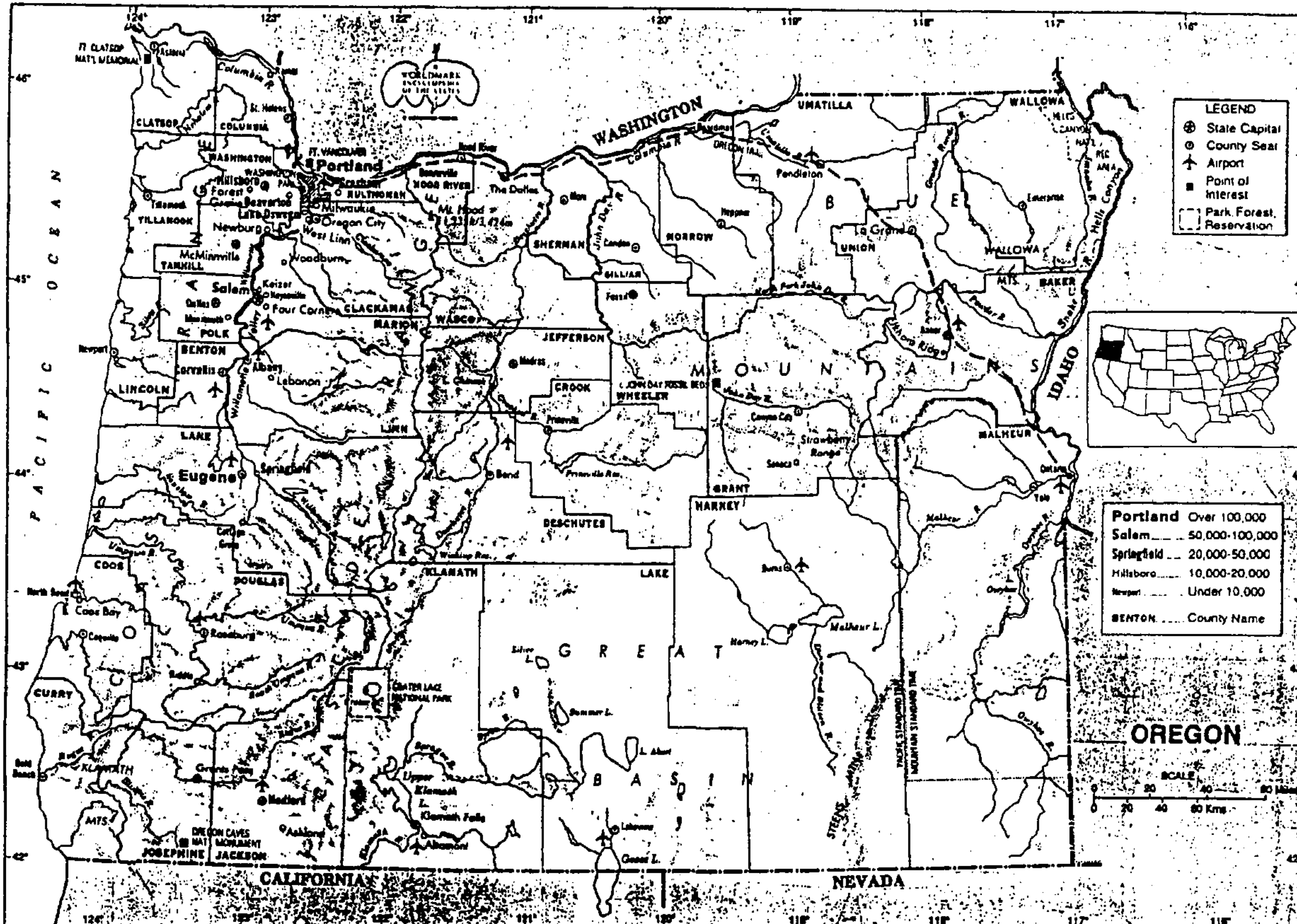

Figure 1. Map of Oregon. Location: 42⁰ to 46⁰15'N, 116⁰33' to 124⁰32'W. Boundaries: Washington line, 443 mi (713 km); Idaho line, 332 mi (534 km); Nevada line, 153 mi (246 km); California line, 220 mi (354 km); Pacific Ocean coastline, 296 mi (477 km).

Table 1. EMERGY Evaluation of Resource Basis for Oregon, Circa 1990.

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value E9 1992 US$)
RENEWABLE RESOURCES:					
1	Sunlight	1.21 E21 J	1	12.14	0.76
2	Rain, Chemical	8.39 E17 J	1.54 E4	129.36	8.09
3	Rain, Geopotential	6.33 E17 J	8.89 E3	56.30	3.52
4	Wind, Kinetic	1.72 E19 J	6.23 E2	107.16	6.70
5	Waves	3.75 E14 J	2.59 E4	0.10	0.01
6	Tide	1.52 E17 J	2.36 E4	35.70	2.23
7	River Inflows	5.58 E17 J	5.00 E4	279.00	17.44
8	Earth Cycle	5.02 E17 J	2.90 E4	145.58	9.10
INDIGENOUS RENEWABLE ENERGY:					
9	Hydroelectricity	1.77 E17 J	1.59 E5	281.62	17.60
10	Agriculture Prod.	1.44 E17 J	2.00 E5	288.62	18.04
11	Livestock Prod.	1.77 E16 J	2.00 E6	354.97	22.19
12	Fisheries	1.05 E15 J	2.00 E6	21.10	1.32
13	Fuelwood Prod.	1.13 E17 J	1.87 E4	21.13	1.32
14	Forest Extraction	1.25 E17 J	3.49 E4	43.63	2.73
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
15	Nuclear Elec.	1.48 E16 J	4.80 E4	7.08	0.44
16	Fuel Elec.	6.07 E16 J	5.30 E4	32.19	2.01
17	Minerals	3.00 E13 g	9.20 E8	276.00	17.25
18	Topsoil	1.06 E16 g	6.30 E4	6.71	0.42
19	Old Growth Forest Extraction	4.41 E16 J	3.49 E4	15.39	0.96
EXPORTS AND OUTSIDE SOURCES:					
20	Petroleum Prod.	3.41 E17 J	6.60 E4	225.06	14.07
21	Natural Gas	9.38 E16 J	4.80 E4	45.02	2.81
22	Vehicles & Parts	2.99 E9 $	1.00 E12	29.90	1.87
23	Elec. Equip.	6.21 E8 $	1.00 E12	6.21	0.39
24	Chemicals	5.09 E8 $	3.80 E12	19.34	1.21
25	Machinery	4.10 E8 $	3.80 E12	15.58	0.97
26	Tourism	2.30 E9 $	3.80 E12	87.40	5.46
27	Services	7.59 E9 $	3.80 E12	288.42	18.03

Table 1 (continued)

Note	Item	Raw Units	Trans-formity (sej/unit)	Solar Emergy (E20 sej)	Macroeconomic Value E9 1992 US$)
IMPORTS:					
28	Cash Crops	4.32 E16 J	2.00 E5	86.44	3.60
29	Forest Prod.	4.78 E16 J	3.49 E4	16.69	0.70
30	Technology & Mach.	3.22 E8 $	1.60 E12	5.15	0.21
31	Services	5.90 E9 $	1.60 E12	94.40	3.93

Footnotes to Table 1

1 SOLAR ENERGY:
Cont Shlf Area = 1.43 E10 m^2 at 200 m dpth
Land Area = 2.51 E11 m^2 (Worldmark, 1986)
Insolation = 1.35 E2 kcal/cm^2/yr (Odum, 1987)
Albedo = 0.19 (% given as decimal) (Odum, 1987)
Energy (J) = (area incl shelf)(avg insolation)(1 - albedo)
=(____m^2)(____Cal/cm^2/yr)(E4 cm^2/m^2)(1 - 0.19)(4186 J/kcal)
= 1.21 E21

2 Rain, CHEMICAL POTENTIAL ENERGY:
Land Area = 2.51 E11 m^2 (Worldmark, 1986)
Cont Shlf Area = 1.43 E10 m^2 at 200 M d. (Times Atlas of Oceans, 1983)
Rain (land) = 0.64 m/yr avg. (Worldmark, 1986)
Rain shelf) = 0.64 m/yr
Energy (land)(J) = (area)(evapotrans)(rainfall)(Gibbs no.)
=(____m^2)(____m)(1000 kg/m^3)(4.94 E3 J/kg)
= 7.94 E17
Energy (shlf)(J) = (area of shelf)(rainfall)(Gibbs no.)
= 4.52 E16
Total energy (J) = 8.39 E17

Footnotes for Table 1 (continued)

3 RAIN, GEOPOTENTIAL ENERGY:
Area = 2.51 E11 m^2
Rainfall = 0.64 m, as above
Avg elev = 1005.84 m (Odum, 1987)
Runoff rate = 0.40, (1.0 - ET)
Energy (J) = (area)(% runoff)(rainfall)(avg elevation)(gravity)
=(____m^2)(____m)(1000 kg/m^3)(____m)(9.8 m/s^2)
= 6.33 E17

4 WIND ENERGY:
Vertical diffusion coefficient = 5.2 $m^3/m^2/s$ winter, - .02 m^2/s summer
Vertical gradient = 3.4 E3 m/s/m winter, - 0.18 m/s/m summer
Height = 1000 m, density = 1.23 kg/m^3 (Medford, OR data in Odum, 1987)
(.5)(1000)(1.23)(5.2)(3.154 E7)(3.4 E-3)(2)(2.51 E11) = 1.72 E20
(.5)(1000)(1.23)(.02)(3.154 E7)(.18 E-3)(2)(2.51 E11) = 3.51 E16
Energy (J) = 1.72 E19 J/yr

5 WAVE ENERGY: Maui oil platform ave. wave energy used (Odum, 1992a)
(476 km)(25 E3 w/m)(1 J/s/w)(3.154 E7 s/yr)(0.5 absorbed)
Energy (J) = 3.75 E14 J/yr

6 TIDAL ENERGY:
Cont Shlf Area = 1.43 E10 m^2 (Times Atlas of Oceans, 1983)
Avg Tide Range = 1.70 m (Odum, 1987)
Density = 1.03 E3 kg/m^3 (Odum et al., 1983)
Tides/yr = 7.30 E2 (estm. of 2 tides/day in 365 days)
Energy (J) = shelf)(0.5)(tides/yr)(mean tidal range)^2 (density of seawater)(gravity)
=(____m^2)(0.5)(____/yr)(____m)^2(____kg/m^3)(9.8 m/s^2 = 1.52 E17

7 RIVER INFLOWS:
Flow = 7.08 E3 m^3/s Columbia River
Energy = (Flow)(Chemical Potential Energy)(0.5 Oregon/Wash. divide)
(7.08 E3 m^3/s)(0.5)(1 E6 g/m^3)(5 J/g)(3.154 E7 s/yr) = Energy (J)
= 5.58 E17

8 EARTH CYCLE:
Heat flux interpolated from U.S. data and % of land active vs. inactive
(2.0 E6 J/m^2/yr)(2.51 E11 m^2) = Enegy (J) = 5.02 E17

Footnotes for Table 1 (continued)

INDIGENOUS RENEWABLE ENERGY

9 HYDROELECTRICITY:
Kilowatt hrs/yr = 4.92 E10 Kwh/yr (Oregon Blue Book, 1986)
Energy (J) = (_____Kwh/yr)(_____3.6 E6 J/Kwh) = 1.77 E17

10 AGRICULTURAL PRODUCTION:
9.85 E6 MT (OR DOA, 1990)
Total: Field crops, seed crops, fruits and nuts, vegetables
Energy (J) = (3.74 E7 MT)(1 E6 g/MT)(3.5 Kcal/g)(4186 J/Cal) = 1.44 E17

11 LIVESTOCK PRODUCTION:
L'stock Prod = 1.06 E6 MT (OR DOA, 1990) Includes Poultry
Energy (J) = (1.06 E6 MT)(1 E6 g/MT)(4 Cal/g)(4186 J/Cal) = 1.77 E16

12 FISHERIES PRODUCTION:
Total catch: 6.3 E4 MT (OR DOA, 1990)
Total: Fish, shellfish
Energy (J) = (1.28 E6 MT)(1 E6 g/MT)(4 Cal/g)(4186 J/Cal) = 1.05 E15

13 FUELWOOD PRODUCTION: (Includes Spent Pulping Liquor)
Fuelwood Prof = 1.07 E14 BTU/yr (OR DOA, 1989)
Energy (J) = 1.07 E14 BTU)(1054.35 J/BTU) = 1.13 E17

14 FOREST EXTRACTION:
Harvest = 1.95 E7 m^3 = 8265 MMBF (Econ. Prof. Or., OEDD, 1991)
(0.7 sustained yield)
Energy (J) = 1.95 E7 m^3)(0.5 E6 g/m^3)(3.6 Cal/g)(4186 J/Cal) = 1.03 E17

NONRENEWABLE RESOURCE USE FROM WITHIN OREGON

15 NUCLEAR ELECTRICITY:
Consumption = 4.1 E9 Kwh/yr (Worldmark, 1986)
Energy (J) = (4.1 E9 Kwh/yr)(3.6 E6 J/Kwh) = 1.48 E16

16 FUEL ELECTRICITY:
Consumption = 5.76 E13 BTU/yr (Worldmark, 1986)
Energy (J) = (5.76 E9 BTU/yr)(1054.35 J/BTU) = 6.07 E16

Footnotes for Table 1 (continued)

17 MINERALS: (Sand, Gravel, Crushed Stone, Nickel, Gold)
Production = 3.0 E7 MT/yr (OR Dept. Geology, 1992)
(30 E6 MT)(1 E6 g/MT) = Energy (g) = 3.0 E13

18 TOPSOIL:
Soil loss = 1.57 E13 g/yr Calculated as area percentage of total U.S. soil loss (Odum, 1992)
Energy (J) = (6.76 E13 g/yr)(0.03 organic)(5.4 Kcal/g)(4186 J/Kcal) = (J) 1.06 E16

19 OLD GROWTH FOREST EXTRACTION - Includes non-sustained yield managed lands. Public lands managed for sustained yield, assume 50% of private timberland under non-sustained yield management.
(0.5)(0.4 harvest on private land) = 20% of total harvest + 10% of total harvest virgin timber (estimate) = 30% of total harvest = (J) 4.41 E16

IMPORTS OF OUTSIDE ENERGY SOURCES:

20 TOTAL PETROLEUM:
Imports = 3.23 E14 BTU/yr
Energy (J) = (323 E12 BTU)(1054.35 J/BTU) = 3.41 E17 (OR DOE, 1989)

21 NATURAL GAS:
Imports = 8.9 E13 BTU/yr (OR DOE, 1989)
Energy (J) = (8.9 E13 BTU)(1054.35 J/BTU) = 9.38 E16

22 VEHICLES AND PARTS:
Imports = 2.99 E9 $ (OEDD, 1991)
Emergy (sej) = 2.99 E9 $)(1.0 E12 sej/$ - Japan Ratio)

23 ELECTRICAL EQUIP. AND PARTS:
Imports = 6.21 E8 $
Emergy (sej) = (6.21 E8 $)(1.0 E12 sej/$ - Japan Ratio)

24 CHEMICAL MATERIAL:
Imports = 5.09 E8 $
EMERGY (sej) = (5.09 E8 $)(3.8 E12 sej/$ - World Ratio)

25 MACHINERY:
Imports = 4.1 E8 $
Emergy (sej) = (4.1 E8 $)(3.8 E12 sej/$ - World Ratio) = ?

Footnotes for Table 1 (continued)

26 TOURISM:
Dollar Value = 2.3 E9 $ US @ 1989 (OEDD, 1991)
Emergy (sej) = (2.98 E9 $ US)(1.6 E12 sej/$ - U.S. Ratio)

27 SERVICES:
Dollar Value = 5.96 E9 $ US (OEDD, 1991) + 1.63 E9 $ fuel
Emergy (sej) = (5.96 E9 $ US)(1 E12 sej/$) = 7.59 E9

EXPORTS OF ENERGY, MATERIALS AND SERVICES

28 CASH CROPS: (Agriculture)
Exports: 30% of Total Production Exported (OR DOA, 1990)
(0.03)(9.85 E6 2.95 E6 MT
(Energy (J) = 2.95 E6 MT)(1 E6 g/MT)(3.5 Cal/g)(4186 J/Cal) = 4.32 E16

29 FOREST PRODUCTS:
Exports = 5.71 E6 m^3 (OEDD, 1989)
Energy (J) = (6.64 m^3)(0.5 E6 g/m^3)(4 Cal/g)(4187 J/Cal) = 4.78 E16

30 TECHNOLOGY AND MACHINERY:
Exports: = 3.22 E8 $ (OEDD, 1990)
Emergy (sej) = (3.22 E8 $)(1.6 E12 sej/$)

Table 2. Summary of Flows in Oregon, circa 1990.

Variable	Item	Solar Emergy (E20 sej/yr)	Dollars
R	Renewable Sources (Rain, Tide, Earth Cycle, River Inflows)	589.65	
N	Nonrenewable Sources Flow Within Oregon	679.30	
No	Dispersed Rural Source	65.72	
N1	Concentrated Use	596.89	
N2	Exported Without Use	16.69	
F	Imported Fuels and Minerals	289.43	
G	Imported Goods	51.69	
I	Dollars Paid for Imports		7.59 E9
P21	Emergy Value of Goods and Service Imports	288.42	
E	Dollars Received for Exports		4.08 E10
P1E	Emergy Value of Goods and Service Exports	652.80	
B	Exported Products Transformed Within Oregon	5.15	
X	Gross State Product		4.50 E10
P2	World Emergy/$ Ratio, Used in Imports	3.80 E12	
	Japan Emergy/$ Ratio, Used in Goods Imported	1.00 E12	
P1	U.S. Emergy/$ Ratio	1.60 E12	

Table 3. Indices Using Emergy for Overview of Oregon, circa 1990

Item	Name of Index	Expression	Quantity
1	Renewable emergy flow	R	5.90 E22
2	Flow from indigenous nonrenewable reserves	N	6.79 E22
3	Flow of imported emergy	F+G+P21	6.30 E22
4	Total emergy inflows	R+N+F+G+P21	1.90 E23
5	Total emergy used, U	NO+N1+R+F+G+P21	1.88 E23
6	Total exported emergy	N2+B+P1E	6.75 E22
7	Fraction emergy use derived from home sources	(NO+N1+R)/U	0.67
8	Imports minus exports	(F+G+P21)-(N2+B+P1E)	-4.51 E21
9	Export to Imports	(N2+B+P1E)/(F+G+P21)	1.07
10	Fraction used, locally renewable	R/U	0.31
11	Fraction of use purchased	(F+G+P21)/U	0.33
12	Fraction imported service	P21/U	0.15
13	Fraction of use that is free	(R+NO)/U	0.35
14	Ratio of concentrated to rural	(F+G+P21+N1)/(R+NO)	1.87
15	Use per unit area	U/(area)	7.09 E11
16	Use per person	U/(population)	6.61 E16
17	Renewable carrying capacity at present living standard	(R/U)(population)	8.92 E5

Table 3 (continued)

Item	Name of Index	Expression	Quantity
18	Developed carrying capacity at same living standard	B(R/U)(population)	7.14 E6
19	Emergy/$ ratio	P1 = U/GSP	4.18 E12
20	Ratio of electricity to use	(el)/U	3.00 E-1
21	Fuel use per person	fuel/population	1.38 E15

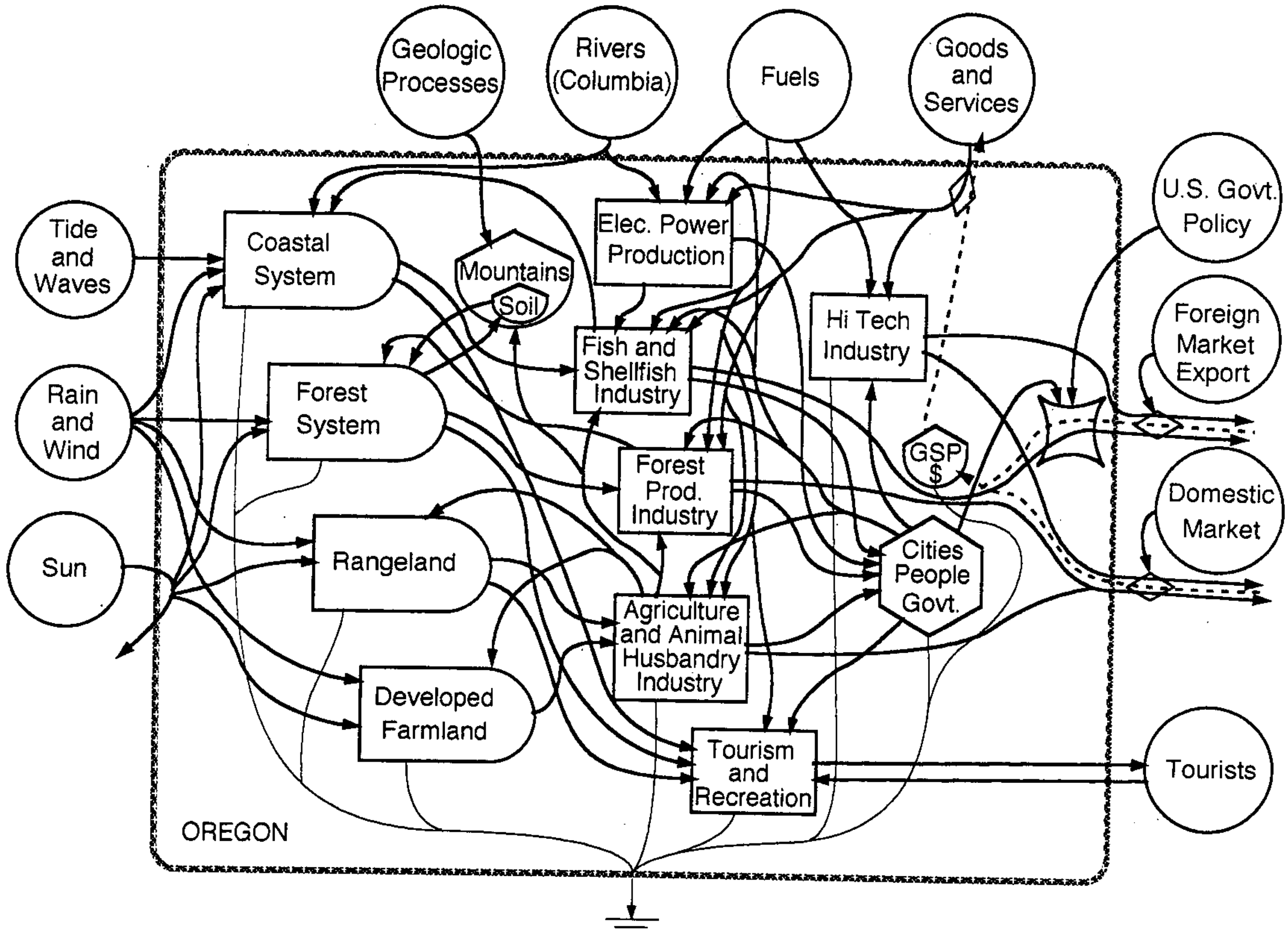

Figure 2. Aggregated general systems energy diagram of Oregon.

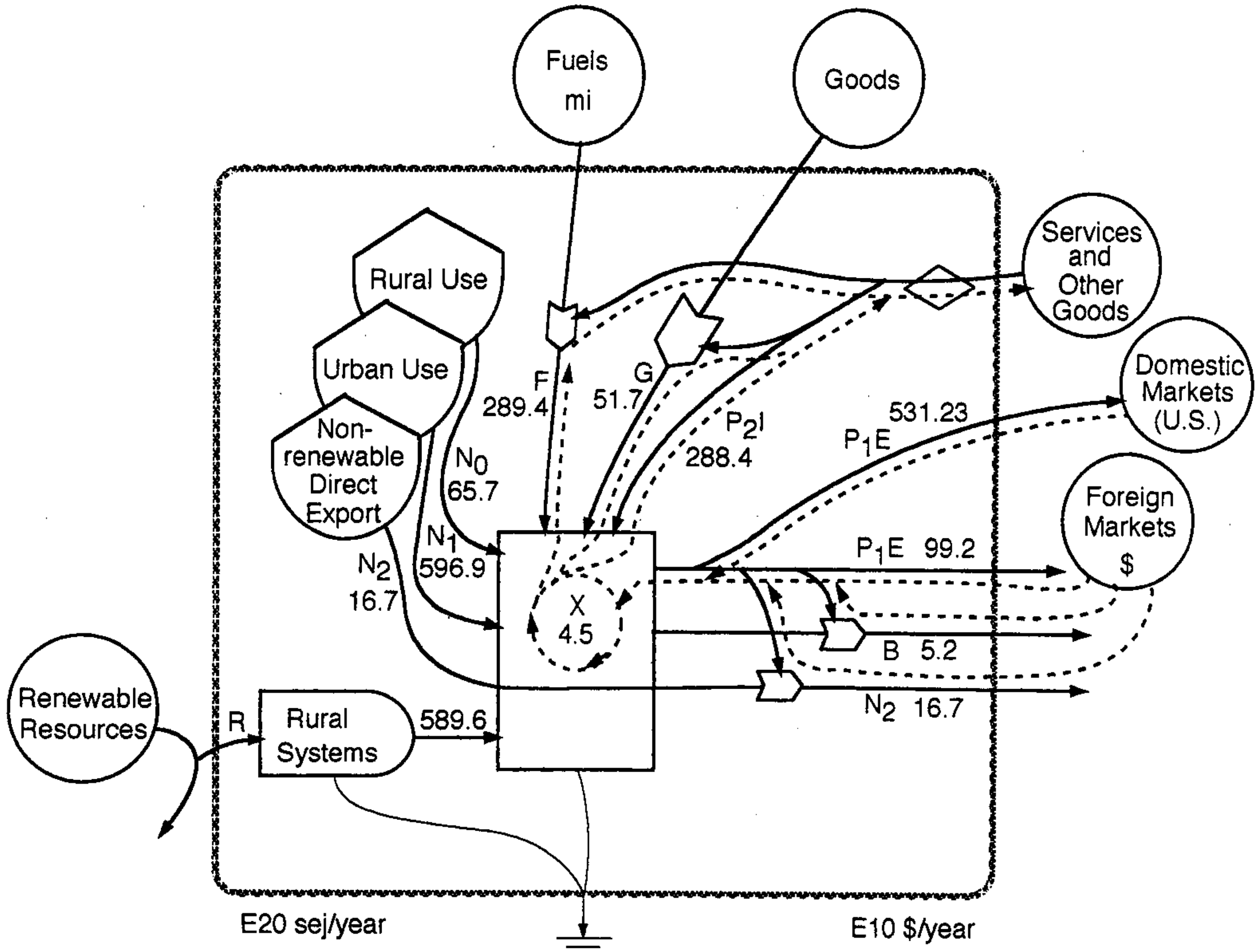

Figure 3. Summary diagram of emergy flows for Oregon.

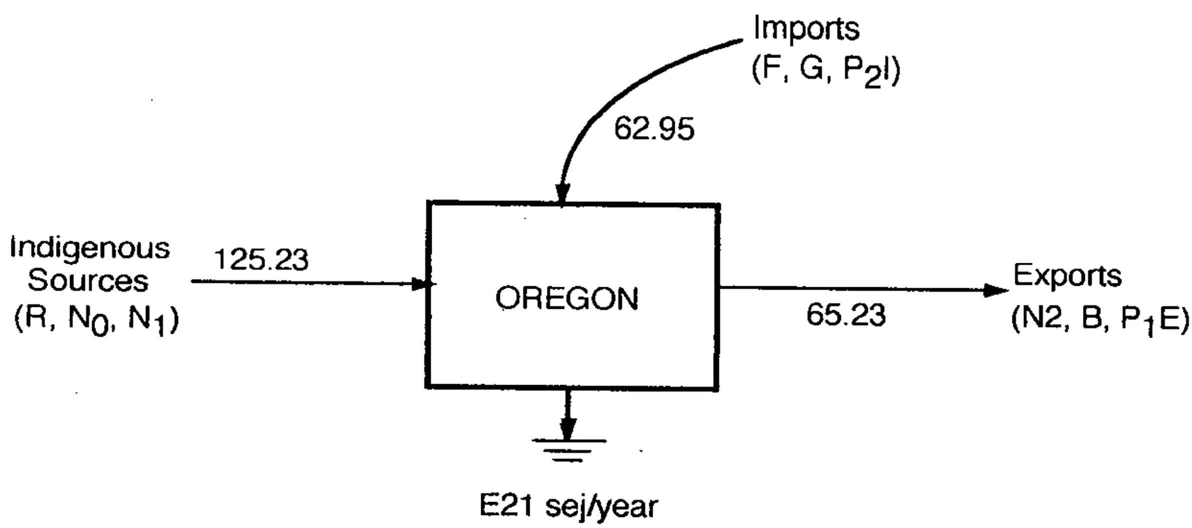

Figure 4. Summary diagram of indigenous resources, imports and exports for Oregon.

REFERENCES

1. Brown, M.T. 1992. Global Transformity Table

2. Brown, M.T. 1989. Emergy Evaluation of Mexico.

3. Economic Profile of Oregon. Oregon Economic Development Department (OEDD). 1991.

4. Oregon Blue Book. 1986.

5. Oregon Department of Agriculture (DOA). 1990. Statistics.

6. Oregon Department of Energy (DOE). 1989. Statistics.

7. Oregon Department of Geology. 1992. Production Statistics.

8. Odum, H.T. 1992. Emergy and Public Policy Part I. University of Florida, Gainesville, FL.

9. Odum, H.T. 1992. Emergy and Public Policy Part 2. University of Florida, Gainesville, FL.

10. Odum, H.T. and Jan E. Arding. 1991. Emergy Analysis of Shrimp Mariculture in Ecuador. University of Florida, Gainesville, FL.

11. Odum, H.T., et.al. 1987. Energy Analysis of Environmental Value. Center for Wetlands, University of Florida, Gainesville, FL.

12. Odum, H.T., et.al. 1986. Florida Systems and Environment. NSF Workshop, University of Florida, Gainesville, FL.

13. worldmark Encyclopedia of the U.S. Worldmark Press, Ltd. 1986.