EMERGY EVALUATION OF WATER

By

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I dedicate this work to my grandparents Joan and Abe Friedman, as well as to Jacinto, David, Alberto and Ciltalli; but most especially to my mother, Roberta D. Friedman, my first teacher.

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS iii

LIST OF TABLES viii

LIST OF FIGURES xii

ABSTRACT xv

INTRODUCTION 1

- Statement of the Problem 1
- Review of the Literature 2
  - Emergy Values of Water 2
    - Chemical potential energy of water. 2
    - Geopotential energy of water. 4
    - Nutrients and dissolved solids in water. 5
    - Waste assimilation capacity of water. 6
  - Economic Values of Water 7
    - Potable water supply. 7
    - Treated wastewater. 9
    - Agricultural water. 11
    - Waste assimilation values. 12
    - Water used for recreation and aesthetic purposes. 13
  - Summary of Water Values 13
- Plan of Study 16

METHODS 18

- Emergy Synthesis Methodology 18
  - Energy Systems Diagrams 18
  - Emergy Tables 21
  - Emergy Indices 22
    - Emergy investment ratio (EIR). 23
    - Emergy yield ratio (EYR). 24
    - Percent renewable emergy (%R). 24
    - Emergy benefit to the purchaser (EBP). 25
    - Em-dollars per volume (Em$/$m^3$). 25
    - Emergy-per-unit and transformity. 26

Emergy Evaluation of Global Water Storages and Flows... 26
Emergy Evaluation of Regional Waters Using Florida as a Case Study 27
    Surface Water 27
    Groundwater... 28
Emergy Evaluation of Potable Water Supply Alternatives... 31
    Surface (Lake) Water Source: West Palm Beach's Water Treatment Plant............. 34
    Surface Water Source: Hillsborough River Water Treatment Plant, Tampa. 34
    Groundwater Source: Murphree Water Treatment Plant, Gainesville. 35
    Water Conservation as a Source: Tampa Bay.. 39
    Brackish Water Source: City of Dunedin Reverse Osmosis Treatment Facility. 39
    Seawater Source: Reverse Osmosis Desalination, Tampa Bay................................ 40
    Surficial Groundwater Source: Transported Via Aqueduct, Florida Keys. 43
    Seawater Source: Reverse Osmosis Desalination, Stock Island 43
    Water Distribution System: Gainesville Regional Utility 47
Emergy Evaluation of Small Scale Water Purification Alternatives 47
    Groundwater Source: Home Filtration.. 48
    Groundwater Source: Boiling Water... 50
    Salty Water Source: Advanced Solar Distillation
        (Humidification-Dehumidification Cycle).. 50
    Salty Water Source: Traditional Solar Distillation. 53
    Tap Water Source: Purified Bottled Water. 53
Computer Simulation of Water Allocation 56
    Analysis and Diagramming.. 56
    Structure of the Model... 56
    Computer Simulation 59
    Sensitivity Analysis.. 59

RESULTS.. 61

Global Water Resources.. 61
Emergy Evaluation of Regional Water Flows and Storages.. 66
Potable Water Supply Alternatives Evaluated 78
    Surface (Lake) Water Source: West Palm Beach's Water Treatment Plant............. 78
    Surface Water Source: Hillsborough River Water Treatment Plant, Tampa. 81
    Groundwater Source: Murphree Water Treatment Plant, Gainesville. 81
    Water Conservation as a Source: Tampa Bay.. 82
    Brackish water source: City of Dunedin Reverse Osmosis Treatment Facility........ 89
    Seawater Source: Reverse Osmosis Desalination, Tampa Bay................................ 89
    Surficial Groundwater Source: Transported Via Aqueduct, Florida Keys. 90
    Seawater Source: Reverse Osmosis Desalination, Stock Island. 97
    Water Supply Distribution System: Gainesville Regional Utility. 97
    Summary of Potable Water Supply values... 102
Small Scale Water Purification Alternatives Evaluated.. 108
    Groundwater Source: Home Filtration... 108
    Groundwater Source: Boiling Water.. 111
    Salty Water Source: Advanced Solar Distillation
        (Humidification-Dehumidification Cycle)... 111

    Salty Water Source: Traditional Solar Distillation. 116
    Tap or Spring Water Source: Bottled Water. 116
    Summary of Small Scale Water Purification Values. 117
  Comparison of Potable Water Alternatives. 128
  Simulation of Water Allocation in Florida 130
    Output 130
    Sensitivity Analysis. 132

DISCUSSION 138

  Summary 138
  Principal Conclusions of this Study 139
  Discussion of Principal Conclusions 139
    Water Has Different Values. 139
      Factors affecting the value of water 141
      Comparison of potable water alternatives evaluated. 143
      Ranking of potable water systems. 148
      Large scale vs. small scale potable water systems. 149
      Potable water systems self organize to maximize empower by using high quality water sources. 150
    Much of the Emergy of Public Supply Water is Wasted. 150
      Enforce stronger water conservation measures. 153
      Emergy evaluations can complement economic analyses for determining the most appropriate water supply alternatives 153
    Regional Production is Maximized when Water Resources are Used in the Urban Economy. 155
  Environmental Impacts 157
  Suggestions for Further Research 158
    Evaluation of Other Potable Water Alternatives. 158
    Evaluation of Other Policies for the Appropriate Use of Public Supply 158
      Dual piping. 159
      Increase of water rates. 160

GLOSSARY 161

APPENDICES

A SYMBOLS OF ENERGY LANGUAGE USED TO REPRESENT SYSTEMS 164

B FOOTNOTES OF EMERGY TABLES 165

C ASSET CALCULATIONS 208

D TRANSFORMITIES 222

E COEFFICIENTS AND REFERENCES FOR THE WATER ALLOCATION MODEL 226

F ENVIRONMENTAL IMPACTS OF POTABLE WATER PRODUCTION............ 229

LIST OF REFERENCES 239

BIOGRAPHICAL SKETCH... 248

LIST OF TABLES

Table Page

1 Potable water supply component costs 8

2 Monthly water charges 9

3 Monthly wastewater disposal charges 10

4 Comparative values of water... 14

5 Tabular format of emergy evaluation tables used in this study............................ 22

6 Public supply alternatives evaluated with emergy synthesis. 32

7 Small scale water purification alternatives evaluated. 48

8 Distribution and emergy values of global water storages. 63

9 Distribution and emergy values of global water flows. 64

10 Emergy evaluation of Florida's intertidal water 67

11 Emergy evaluation of Florida's river and stream water....................................... 68

12 Emergy evaluation of Florida's lake water... 69

13 Emergy evaluation of Florida's wetland (freshwater marshes & swamps) water. 70

14 Summary of emergy evaluation of Florida's surface water resources.................. 71

15 Emergy evaluation of fresh groundwater from Florida's Surficial aquifer 72

16 Emergy evaluation of fresh groundwater from the Sand and Gravel aquifer system.. 73

17 Emergy evaluation of fresh groundwater from the Biscayne aquifer system 74

18 Emergy evaluation of fresh groundwater from the Intermediate aquifer 75

19 Emergy evaluation of fresh groundwater from the Floridan Aquifer system. 76

20 Summary of emergy evaluation of Florida's groundwater resources. 77

21 Emergy evaluation of the drinking water produced at the City of West Palm Beach Water Treatment Facility 80

22 Emergy indices and ratios for the drinking water produced at the City of West Palm Beach Water Treatment Facility. 80

23 Emergy evaluation of the drinking water produced at the Hillsborough River Water Treatment Plant 84

24 Emergy indices and ratios for the drinking water produced at the Hillsborough River Water Treatment Plant.. 84

25 Emergy evaluation of the drinking water produced at the Murphree Water Treatment Plant 86

26 Emergy indices and ratios for the drinking water produced at the Murphree Water Treatment Plant. 86

27 Emergy evaluation of Tampa Bay's water conservation/management plan.......... 88

28 Emergy indices and ratios for the drinking water saved by Tampa Bay's water conservation program. 88

29 Emergy evaluation of the drinking water produced at the City of Dunedin Reverse Osmosis Water Treatment Facility 92

30 Emergy indices and ratios for the drinking water produced at the City of Dunedin RO Water Treatment Facility. 92

31 Emergy evaluation of drinking water to be produced by RO desalination in Tampa Bay 94

32 Emergy indices and ratios for Tampa Bay's desalination plant. 94

33 Emergy evaluation of the drinking water produced and distributed through the aqueduct system of the Florida Keys Aqueduct Authority 96

34 Emergy indices and ratios for the drinking water produced and delivered by the Florida Keys Aqueduct Authority. 96

35 Emergy evaluation of the drinking water produced from a reverse osmosis water treatment plant in Stock Island 99

36 Emergy indices and ratios for the drinking water produced by Stock Island's RO facility. 99

37 Emergy evaluation of a 25 mgd drinking water distribution system in Gainesville 100

38 Summary of the emergy evaluations of public supply alternatives. 103

39 Emergy evaluation of the drinking water produced with a home filter 110

40 Emergy indices and ratios for the drinking water produced with a home filter. ... 110

41 Emergy evaluation of the boiling water to make it potable 113

42 Emergy indices and ratios for boiling water to make it potable. 113

43 Emergy evaluation of potable water produced by solar desalination with a 2.0 m^2 solar distiller using a humidification-dehumidification cycle 115

44 Emergy indices and ratios for the potable water produced with a solar distiller containing a humidification-dehumidification cycle. 115

45 Emergy evaluation of potable water produced by desalination using a 1.0 m^2 solar distiller 119

46 Emergy indices and ratios for the potable water produced by desalination using a 1.0 m^2 solar distiller. 119

47 Emergy evaluation of bottled water 122

48 Emergy indices and ratios of bottled water. 122

49 Summary of the emergy evaluation of small scale water purification alternatives. 123

50 Comparison of emergy values of potable water (home-consumed). 129

B-1 Notes for the emergy evaluation of the drinking water produced at the City of West Palm Beach Water Treatment Plant 166

B-2 Notes for the emergy evaluation of the drinking water produced at the Hillsborough River Water Treatment Plant 169

B-3 Notes for the emergy evaluation of the drinking water produced at the Murphree Water Treatment Plant. 172

B-4 Notes for the emergy evaluation of the drinking saved by Tampa Bay Water's Water Conservation Program 174

B-5 Notes for the emergy evaluation of the drinking water produced at the City of Dunedin Reverse Osmosis Water Treatment Facility 179

B-6 Notes for the emergy evaluation of the drinking water to be produced in Tampa Bay by desalinating water using reverse osmosis 182

B-7 Notes for the emergy evaluation of the drinking water produced and delivered by the Florida Keys Aqueduct Authority 185

B-8 Notes for the emergy evaluation of the drinking water produced at the Reverse Osmosis Desalination plant in Stock Island 188

B-9 Notes for the emergy evaluation of filtered water 191

B-10 Notes for the emergy evaluation of boiled water 193

B-11 Notes for the emergy evaluation of the potable water produced with a solar desalination with a humidification-dehumidification cycle 196

B-12 Notes for the emergy evaluation of the potable water produced by desalination using a 1.0 m^2 solar distiller.. 200

B-13 Notes for the emergy evaluation of the purified bottled water 204

C-1 West Palm Beach Water Treatment Plant assets... 209

C-2 Murphree Water Treatment Plant assets. 212

C-3 Florida Keys Aqueduct Authority assets.. 215

C-4 Gainesville Regional Utility water distribution system assets. 219

D-1 Transformities, emergy per mass and emergy per volume used in the study. 223

D-2 Summary of water transformities calculated in this study. 225

E-1 Flows and calibration values for the simulation of water allocation in Florida. . 227

F-1 Emergy evaluation of environmental impacts resulting from the production of potable water. 230

F-2 Emergy evaluation of environmental impacts resulting from the small scale production of potable water.. 236

LIST OF FIGURES

Figure Page

1 A generic systems diagram of the production of potable water for public supply... 20

2 Diagram illustrating the definition of the emergy indices used. The letters on the pathways refer to flows of emergy per unit time............................... 23

3 Sequence of aquifer systems in Florida 30

4 Approximate location of the public supply systems analyzed 33

5 Schematic of the production of drinking water at the City of West Palm Beach Water Treatment Plant. 36

6 Schematic of the production of drinking water at the Hillsborough River Water Treatment Plant 37

7 Schematic of the production of potable water at the Murphree Water Treatment Plant.. 38

8 Schematic of the production process of potable water at the City of Dunedin Reverse Osmosis Water Treatment Facility... 41

9 Schematic of the reverse osmosis desalination facility being built in Tampa Bay. . 42

10 Schematic of the production and transportation of potable water by the Florida Keys Aqueduct Authority... 45

11 Schematic of Stock Island's RO facility.. 46

12 Schematic of the production of purified water with a home filter. 49

13 Schematic diagram of boiling water.. 51

14 Schematic diagram of an advanced solar distillation process containing a humidification-dehumidification cycle. 52

15 Schematic of a traditional solar distiller.. 54

16 Schematic of the production of purified bottled water... 55

17 Model of water allocation for maximizing the total production of Florida. 60

18 The global hydrologic cycle 65

19 Energy systems diagram of the water production by the City of West Palm Beach. 79

20 Energy systems diagrams of the Hillsborough River Water Treatment Plant 83

21 Energy systems diagram of Tampa Bay's water conservation program.................. 85

22 Energy systems diagram for the Murphree Water Treatment Plant......................... 87

23 Energy systems diagram for the City of Dunedin Reverse Osmosis Water Treatment Facility. 91

24 Energy systems diagram of Tampa Bay's RO desalination plant 93

25 Energy systems diagram of the water production and transportation process by the Florida Keys Aqueduct Authority. 95

26 Energy systems diagram of Stock Island's reverse osmosis desalination plat. 98

27 Emergy Signature of the Public Water Supply Alternatives Evaluated.................. 104

28 Transformities for water source and finished (potable) water for the public water supply alternatives evaluated 105

29 Comparison of the public supply systems evaluated using several emergy indices and ratios. 106

30 Energy systems diagram of the production of purified water with a home filter..... 109

31 Energy systems diagram of boiling groundwater.. 112

32 Systems diagram of potable water produced by solar distillation with a humidification/dehumidification cycle. 114

33 Systems diagram of potable water produced by solar distillation.......................... 118

34 Systems diagram of the production of purified bottled water................................ 120

35 Systems diagram of the production of purified bottled water using spring water from the Floridan aquifer as a source. 121

36 Emergy signature of the small scale water purification alternatives evaluated. 124

37 Transformities for water source and finished (potable) water for the small scale water systems evaluated. 125

38 Comparison of the small scale water purification systems evaluated using several emergy indices and ratios.. 126

39 Graphs of simulation results of the model in Figure 17.. 133

40 Three-dimensional view of the model output 134

41 Results of sensitivity analysis based on total fuels, goods and services imported by the regional economy.. 136

42 Results of sensitivity analysis based on the distribution of total fuels, goods and services imported by the regional economy.. 137

43 Concentration and upgrading of water for human use. 140

44 Water value as a function of several key parameters. 141

45 Diagram of the level of water treatment as a function of annual benefits and costs of adding an additional step in the treatment process. 142

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EMERGY EVALUATION OF WATER

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To better understand the values of water within different contexts and spatial scales, the emergy inputs to water were evaluated and compared at four scales: 1) global, 2) regional (the state of Florida), 3) local (water supply utilities), and 4) small-scale (home water purification). Emergy (spelled with an "m") represents all the previous work of one kind required to generate a product or provide a service.

Since water can be found at all stages of the global hierarchy of biogeochemical processes, it has many emergy values and transformities. Transformities of water indicate the convergence of energy and materials that are required to produce the water. Global water storages were evaluated using the total emergy driving the geobiochemical processes of the biosphere and storage turnover times. Transformities for these water storages varied between 3.54 E3 sej/J (water vapor) and 1.05 E6 sej/J (glaciers).

Calculated transformities for global water flows ranged from 3.96 E3 sej/J (precipitation) to 9.55 E5 sej/J (ice melt).

Regional transformities of water resources reflected specific conditions of the landscape. The mean transformities for water in estuaries, rivers, lakes, wetlands and deep groundwater storages in Florida were calculated at 3.19 E4, 4.26E4, 5.64 E4, 7.09 E4 and 1.66 E5 sej/J, respectively.

Eight local water supply utilities in Florida were evaluated to determine the emergy cost of producing potable water. Potable water transformities ranged from 1.39 E5 (West Palm Beach plant) to 1.39 E6 (Stock Island reverse osmosis plant). Five home water purification processes were evaluated to compare the emergy costs of producing potable water just for drinking, yielding transformities between 5.19 E6 (filtered water) and 3.16 E7 sej/J (bottled water).

To test theories of the appropriate use of water to maximize economic vitality, a computer model of a generalized regional production function was simulated. Using Florida as a case study, maximum total production occurred when the economic/urban sector, the agricultural sector, and the environment received approximately 25, 30, and 45%, respectively, of the fresh water remaining after evapotranspiration.

Since the calculated transformities for potable water are equivalent in magnitude to gasoline and electricity, the use of potable water should correspond with its high value. Therefore, measures need to be taken at local and regional levels to use potable water more appropriately.

INTRODUCTION

Statement of the Problem

Water is essential for life. Water is a fundamental resource that is necessary to most processes of the biosphere. It is required as an input where its chemical and physical properties are used to dilute, cool, carry, react or physically drive processes. In addition, it is required as a sink for many processes, carrying away wastes and by-products that would other wise build up to lethal quantities in local environments. One of its values lies in this versatility. Water is valued for its chemical potential and for its physical potential energy. In essence, it is valued for its quality and for its quantity. Water has a cycle, driven by solar, tidal and geologic energies. It flows from one place to another and changes state from one time to another. In so doing it carries materials and energy. Another of its values lies in its ability to carry substances, and in the value of the substances it carries.

Increasingly, as quantity and quality of water resources decline, the following questions are posed by citizens and policy makers. What are the values of water? What are the best uses of present water resources? How can scarce water be allocated to best maximize its use and economic vitality? As adequate supplies of fresh water decrease due to the rapid growth of populations and the economies, there is a pressing need to answer these questions to decide what is the most appropriate use and allocation of water resources for the welfare of both humans and the environment. To answer these questions, the emergy contributions of water at different levels of the global and regional hydrological cycle were evaluated. Emergy (spelled with an "m") puts all products of nature, technology, and the economy on a common basis of the prior work required and embodied in the water. In addition, a simulation model of a generalized regional production function was used to explore theories of water allocation for maximizing empower.

Review of the Literature

Emergy Values of Water

Different aspects of water have been evaluated in previous emergy studies (Odum et al., 1987a; Odum et al., 1987b; Green, 1992; Brown and McClanahan, 1992; Doherty et al., 1993; Odum and Arding, 1991; Odum, 1996; Romitelli, 1997; Brandt-Williams, 1999; Howington, 1999). These aspects of water include 1) chemical potential energy, 2) geopotential energy, 3) nutrients, suspended solids and dissolved solids present in water, and 4) the capacity of water to assimilate wastes.

1) Chemical potential energy of water.

Odum et al. (1987b) calculated the emergy-based dollar (Em$) value of water resources used for irrigation in Texas by using the chemical potential energy of water. The calculated values for rain, river, and groundwater were 0.035, 0.091 and 0.25 Em$/m^3, respectively. In addition, Odum et al. (1987b) valued agricultural water and municipal drinking waters at 0.44 and 1.16 Em$/m^3, respectively. These values were 11 and 1.5 times greater than their corresponding market values at the time of calculation (Odum et al., 1987b). The chemical potential energy of water was used to measure the energy input of fresh water to fisheries by Odum et al. (1987b), Odum and Arding (1991), and Brown et al. (1991). Green (1992) calculated the emergy value of water and its economic contribution to the Bay of Banderas, between the states of Jalisco and Nayarit, in Mexico. The author calculated the emdollar values of several water types, including rainfall (0.027 Em\$/m^3), water used in fisheries (0.06 Em\$/m^3), river water (0.072 Em\$/m^3), irrigation water (0.11 Em\$/m^3), groundwater (0.27 Em\$/m^3), urban use water (0.64 Em\$/m^3), raw wastewater (1.55 Em\$/m^3), and treated wastewater (2.54 Em\$/m^3). Odum (1996) calculated the emdollar value of water stored in the Santa Fe Swamp in Florida at 6.0 million Em\$ or 0.1 Em\$/m^3. The average global value of river water was estimated at 0.12 Em\$/m^3 (Odum, 1996). In an evaluation of alternative ways of supplying freshwater to Windhoek, the capital of Namibia, the value of the water from the Kavango River that discharges to the Okavango Delta was estimated at 0.01 Em\$/m^3 (Buenfil, 2000). Using the chemical potential of rain relative to seawater, Odum (1996) calculated the "free" contribution of rain to the economy of the United States in 268.0 E9 Em\$ or 0.032 Em\$/m^3 for 1983. Odum (1996) estimated the average global values of oceanic precipitation and rain on land at 0.018 and 0.045 Em\$/m^3, respectively. In 1989 the chemical potential energy of rainfall in Ecuador was valued at 19.1 E9 U.S. Em\$ or 0.042 Em\$/m^3 (Odum and Arding, 1991). Brown and McClanahan (1992) estimated the chemical potential contribution of rain to the economy of Thailand in 1984 at 30.7 E9 U.S. Em\$ or 0.032 Em\$/m^3. In the same study, the authors valued the water used in the production of low-energy rice in Thailand at 760 E12 solar em-joules per year (sej/yr) per hectare of cultivation land, which was nearly 37% of the emergy yield of the rice produced. In a study of environmental alternatives in Martin County, Florida, Engel et al.

(1995) estimated the annual value of retaining local freshwater in the county in 0.15 Em\$/m^3. Furthermore, when this value was matched with the emergy investment ratio (EIR) of Martin County (1.4) and the EIR of Florida (7.0), the freshwater was worth 0.36 and 1.20 Em\$/m^3 per year, respectively (Engel et al., 1995). Tilley (1999) reported the chemical potential value of groundwater in North Carolina in 0.62 Em\$/m^3 for 1992. The average value of groundwater in the U.S. (1983) was estimated at 0.07 Em\$/m^3 (Odum, 1996). Brandt-Williams (1999) valued the water from two lakes in central Florida in 0.22 Em\$/m^3 (Newnan's Lake) and 0.063 Em\$/m^3 (Lake Weir).

2) Geopotential energy of water.

The value of the geopotential energy of water has also been examined in a number of emergy studies. Brown and McClanahan (1992) calculated the geopotential emergy of the Mekong River between Thailand and Laos (average flow of 17,000 m^3/sec) at 2.18 E9 sej/m^3 or 0.001 Em\$/m^3 for 1984. In an emergy evaluation of the United States, Odum (1996) estimated that the geopotential energy of rain falling in the U.S. was worth approximately 234.2 billion Em\$ or 0.028 Em\$/m^3 for 1983. The geopotential energy of rainfall in Ecuador was valued at 14.6 E9 U.S. Em\$ or 0.032 Em\$/m^3 for 1989 (Odum and Arding, 1991). Doherty et al. (1993) reported the geopotential value of rain in Papua New Guinea at 1.5 E9 U.S. Em\$ or 0.001 Em\$/m^3 for 1987. Tilley (1999) calculated the geopotential value of rain in North Carolina in 0.006 Em\$/m^3 for 1992. Romitelli (1997) used the geopotential energy of rivers in the Ribeira de Iguape River Basin, between Curitiba and Sao Paulo in Brazil, and the Coweeta Basin, between Tennessee and North Carolina in the U.S., to calculate the value of river water. Geopotential values increased as water flowed downstream to the lowest elevation of the basins. Geopotential river water values in the Ribeira watershed ranged from 1.9 E11 sej/m^3 (0.023 Em\$/m^3) for the Eta sub-basin to 2.2 E12 sej/m^3 (0.26 Em\$/m^3) for the Betari sub-basin. Values in the Coweeta River Basin averaged 2.86 E11 sej/m^3 or approximately 0.29 Em\$/m^3 (Romitelli, 1997).

3) Nutrients, suspended solids and dissolved solids present in water.

The value of water has also been calculated based on the nutrients or sediments present in water. In an evaluation of the Mississippi River Basin, Odum et al. (1987a) estimated the macroeconomic emergy value of the sediments carried by the Mississippi River at 1.05 billion Em\$/yr or 0.002 Em\$/m^3. In this study, the authors also estimated the contribution of river water for the formation of coastal wetlands by evaluating the suspended sediments and organic matter carried by the river. Odum and Arding (1991) calculated the value of the organic load present in Rio Chone, a coastal river in Ecuador, by using the chemical oxygen demand of the river water. With an average flow rate of 3,650 m^3/sec, the value of the organic load in the river was calculated at 8.63 E9 U.S. Em\$/yr or 0.075 Em\$/m^3. Howington (1999) calculated the emergy per volume of river water in the Catatumbo Drainage Basin between Colombia and Venezuela by using river sediment and nutrient concentrations. Using sediment concentrations, water in this basin was estimated at 1.4 E11 sej/m^3 (0.02 Em\$/m^3) for first order streams (Howington, 1999). The value of river water based on nutrient concentrations averaged 1.0 E9 sej/m^3 (0.0001 Em\$/m^3) and 5.0 E9 sej/m^3 (0.0007 Em\$/m^3) for the respective total phosphorous and total nitrogen present in the water (Howington, 1999). Brandt-Williams (1999) included the total phosphorous of watershed runoff to calculate the emergy of water in Newnan's Lake and Lake Weir in central Florida. Total phosphorous accounted for approximately 23% of the value of water in Newnan's Lake (3.44 E11 sej/m^3 or 0.22 Em$/$m^3$) and 4.4% of the value of water in Lake Weir (9.75 E10 sej/m^3 or 0.063 Em$/$m^3$).

4) Waste assimilation capacity of water.

Water values based on waste assimilation have also been estimated with emergy synthesis. Mitsch (1976) evaluated several disposal alternatives for secondarily treated wastewater effluent by comparing the changes in emergy flows caused by different disposal systems (a cypress dome, a lake system, and a tertiary treatment plant). The value of water for waste assimilation was measured by the amount of production the nutrient-rich effluent supported relative to the amount of outside emergy required for treating the wastewater. Nelson (1998) calculated the emergy value of highly treated wastewater effluent from the advanced wastewater treatment plant at the University of Florida in Gainesville. This treated effluent was valued in 2.32 E14 sej/m^3 or 170.1 Em$/$m^3$. Although high, this value is still less than what Nelson (1998) calculated for wastewater treated with a package sewage system in Yucatan, Mexico, which was reported at 3.38 E14 sej/ m^3 or 174.4 Em$/$m^3$. In both cases about 99% of this value of treated wastewater came from the raw sewage itself (Nelson, 1998). The value of raw sewage is very high since it was assumed to be equal to all the emergy needed to support an average person divided by the per-capita wastewater production in either Florida or Yucatan (Nelson, 1998).

Economic Values of Water

Economic values of water are normally synonymous to consumer surplus plus producer surplus (Howe, 1971; Gibbons, 1986; Achttienribbe, 1998; Sunding, 2000). Many economic studies have calculated the value of different types of water by using the marginal value of water based on existing or inferred market prices (Gibbons, 1986; Payton et al., 1990; Griffin, 1990; Kulshreshtha and Tewari, 1991) or the economic cost of production (Guttman and Clark, 1978; Clark et al., 1984; Proefke, 1984; South Florida Water Management District (SFWMD), 1992; Howe et al., 1994). These studies can be divided into evaluations of 1) potable water supply, 2) treated wastewater, 3) agricultural water, 4) water used for waste assimilation, and 5) water used for recreational and aesthetic purposes.

1) Potable water supply.

Total cost of potable water supply is basically a function of the water source quality, the type of treatment, and the flow rate of water treated. The lower the quality of the water source and the higher the level of treatment, the higher the costs of treatment. However, because of economies of scale, the larger the volume of water treated, the lower the cost per unit volume of water supply (Guttman and Clark, 1978; Fernald and Purdum, 1998). Table 1 shows some common potable water supply systems in Florida with their corresponding costs of treatment and delivery. Instead of developing new capital-intensive water treatment facilities, cities often explore expanding current facilities or opening new wells to increase production. For instance, marginal values for water supply augmentation for 221 communities in Texas were estimated to range from zero to 0.33 $\$/m^3$ (Griffin, 1990). Although groundwater and surface waters are traditionally used as sources of drinking water, scarcity and overpopulation in certain regions have promoted the use of other water source alternatives. For example, the city of San Diego is planning to construct a facility to process sewage to make it drinkable at an anticipated cost of approximately 0.53 $/m^3, which is less expensive than seawater desalination (Chapman, 2000).

Table 1. Potable water supply component costs (adapted from SFWMD, 1992).

Type of treatment (water source)	$/1000 gal capital cost for treatment	$/1000 gal O&M for treatment	$/1000 gal capital cost for water source	$/1000 gal O&M for water source	$/1000 gal 10-mi pipe	$/1000 gal Total system
Disinfection only (high quality groundwater)						
30 mgd	0.12	0.05	0.09	0.07	0.12	0.45
10 mgd	0.14	0.05	0.10	0.07	0.21	0.57
1 mgd	0.24	0.06	0.16	0.08	0.67	1.21
Wastewater reuse (effluent wastewater)						
30 mgd	0.25	0.17	0.00	0.00	0.12	0.54
10 mgd	0.43	0.21	0.00	0.00	0.21	0.85
1 mgd	0.91	0.57	0.00	0.00	0.67	2.15
Coagulation & Filtration (surface water)						
30 mgd	0.54	0.21	0.05	0.14	0.12	1.06
10 mgd	0.66	0.29	0.07	0.14	0.21	1.37
1 mgd	1.24	0.70	0.10	0.14	0.67	2.85
Lime softening (groundwater)						
30 mgd	0.41	0.35	0.09	0.02	0.12	0.99
10 mgd	0.57	0.42	0.10	0.02	0.21	1.32
1 mgd	1.26	0.85	0.16	0.02	0.67	2.96
Membrane softening (groundwater)						
30 mgd	0.59	0.52	0.09	0.02	0.12	1.34
10 mgd	0.95	0.60	0.10	0.02	0.21	1.88
1 mgd	2.25	1.01	0.16	0.03	0.67	4.12
Reverse Osmosis (groundwater)						
30 mgd	0.60	0.72	0.09	0.02	0.12	1.55
10 mgd	0.97	0.78	0.10	0.02	0.21	2.08
1 mgd	2.36	0.93	0.16	0.03	0.67	4.15

O&M = operation and maintenance
mgd = million gallons per day
mi = mile (1 mile = 1.6 km)

(Divide $/1000 gal by 3.785 to obtain $/m^3)

Table 2 shows average drinking water costs paid by different public supply user sectors in the United States and Florida. The apparent decrease in cost as more water is used (e.g., industrial vs. residential use) is not due to the actual price charged per volume of water, but due to the total cost of water supply service. All consumer classes pay relatively the same fixed charges for water service but residential users typically consume less water than other classes. Thus, when the water bill is averaged over total water use, the fixed charges spread over the volume used results in the apparent decrease in cost of higher users. The actual charge per unit volume may be constant or increasing as more water is used (Ayres Associates, 1997; Fernald and Purdum, 1998; Stone & Webster, 1999).

Table 2. Monthly water charges (adapted from Fernald and Purdum, 1998).

	Monthly water charges			
water consumption bill	Residential (7,000 gal)*	Commercial (22,000 gal)	Light industrial (374,000 gal)	Industrial (11.2 E6 gal)
avg. cost ($/1000 gal) in the U.S. (a)	1.76	1.48	1.25	1.10
avg. cost ($/1000 gal) in the U.S. (b)	2.21	1.96	1.71	1.54
avg. cost ($/1000 gal) in Florida (a)	1.28	1.06	1.00	1.01
avg. cost ($/1000 gal) in Florida (b)	2.36	2.05	2.05	2.06

(a) 1992 Ernst and Young National Water and Wastewater Rate Survey
(b) 1998 Raftelis Environmental Consulting Group National Water and Wastewater Survey
* 7,480 gal for (b)

(Divide $/1000 gal by 3.785 to obtain $/m^3)

2) Treated wastewater.

The same factors that affect the economic value of drinking water, like economies of scale, used capacity and level of treatment, also affect the cost of wastewater treatment and disposal. In addition, the cost of effluent disposal increases from low-cost disposal methods, such as percolation ponds and surface water discharge, to high-cost disposal methods such as reuse. Table 3 shows some wastewater economic values in the United States and Florida. These values are based on the average fees charged by utilities to different wastewater-producing classes. Higher wastewater producers, like industries, pay less per unit volume of wastewater produced since the fixed service fees are spread over the volume of wastewater produced.

Table 3. Monthly wastewater disposal charges (adapted from Fernald and Purdum, 1998).

	Monthly wastewater charges			
wastewater effluent bill	Residential (7,000 gal)*	Commercial (22,000 gal)	Light industrial (374,000 gal)	Industrial (11.2 E6 gal)
avg. cost ($/1000 gal) in the U.S. (a)	1.97	1.75	1.64	1.60
avg. cost ($/1000 gal) in the U.S. (b)	2.53	2.40	2.21	2.18
avg. cost ($/1000 gal) in Florida (a)	2.57	2.31	2.24	2.20
avg. cost ($/1000 gal) in Florida (b)	4.17	3.93	3.89	3.81

(a) 1992 Ernst and Young National Water and Wastewater Rate Survey
(b) 1998 Raftelis Environmental Consulting Group National Water and Wastewater Survey
* 7,480 gal for (b)

(Divide $/1000 gal by 3.785 to obtain $/m^3)

The values above represent the money households or business paid utilities to collect and treat their wastewater. Thus, these values include the administration services in addition to the cost of collection, treatment and disposal by the local utilities. However, other studies show that the value of just treating wastewater can be significantly lower. For instance, Payton et al. (1990) calculated the value of treated wastewater in 0.009 $/m^3. Raw wastewater also has an economic value. Gibbons (1986) estimated that the economic value of raw wastewater ranges from 0.0002 to 0.006 $/m^3.

3) Agricultural water.

The cost of irrigation water is a function of permitting, pumping depth, treatment, withdrawal impact avoidance, mitigation, transmission, distribution and disposal requirements (Fernald and Purdum, 1998). Generally, the further away the water has to be transmitted and distributed, the higher the cost of irrigation. Water requirements and irrigation costs are unique for different crops and vary according to site location, resulting in a wide range of irrigation demands. For example, to produce one kg of potatoes it is necessary to use 500 to 1,500 L of water and to yield one kg of rice the water requirements often range from 1,900 to 5,000 L (Gleick, 2000). High and low sides of these ranges depend on specific factors, such as climate, irrigation methods, types of seeds and the technology used. Thus, depending on the combination of all these factors, the economic value of agricultural water may vary substantially. Kulshreshtha and Tewari (1991) calculated the water value for irrigation in the south Saskatchewan irrigation district, Canada, to be approximately 0.077 $\$/m^3$. Using hedonic price analysis, Faux and Perry (1999) estimated that the value of irrigation water in Malheur County, Oregon, ranges from 0.008 $\$/m^3$ for the least productive lands to 0.037 $\$/m^3$ for the most productive lands. Gibbons (1986) estimated the range of irrigation water to vary from 0.01 to 0.093 $\$/m^3$. In this study Gibbons also estimated that the value of water used in fisheries ranged between 0.018 and 0.15 $\$/m^3$. Marginal pumping costs also vary depending on the agricultural region since different electric, fuel, wages, and services cost will affect the transmission and distribution of water. For example, mean marginal pumping costs for agricultural water in the U.S. were valued at 0.016, 0.013 and 0.019 $\$/m^3$ for the Northwest, Central plains, and Southwest, respectively (Moore et al., 1994).

4) Waste assimilation values.

Water also has a value associated with the dilution and assimilation of wastewater. Normally, marginal values can be estimated for treatment and dilution of a number of pollutants including biological oxygen demand (BOD), total dissolved solids (TDS), nitrogen, phosphorous, water-born pathogens and heavy metals. The value of water for waste assimilation is usually based on additional waste treatment costs forgone (Lynne, 1991). Thus, the cost of waste assimilation and dilution is a function of the treatment level required and is specific to each type of pollutant removed or diluted. Kneese (1964) was among the first to conduct benefit-cost analyses of water pollution control, thus indirectly comparing the value of water with and without pollution. Using construction and operational costs, Boyle (1981) determined the economic costs of wetland effluent application systems in Waldo, Florida. The author estimated the costs of these wetland application systems to be 0.11 $\$/m^3$ for wetland discharge, 0.28 $\$/m^3$ for advanced physical/chemical treatment and 0.17 $\$/m^3$ for spray irrigation systems. Boyle also estimated the costs of effluent disposal to a cypress dome and a cypress strand in Orlando, Florida. These values were estimated to be 0.19 and 0.06 $\$/m^3$, respectively (Boyle, 1981). Gibbons (1986) calculated the marginal values of wastewater treatment forgone by the initial assimilation capacity of rivers. This waste assimilation capacity ranged from 0.0004 $\$/m^3$ for the Pacific Northwest to 0.006 $\$/m^3$ in the upper Arkansas-White-Red river basin. In a study of the Colorado River Basin, Payton et al. (1990) used treatment costs forgone to calculate the value of water for dilution of TDS. The authors valued the Colorado River's capacity to dilute TDS in 0.008 $\$/m^3$.

5) Water used for recreation and aesthetic purposes.

Several methodologies have been used to estimate the value of water for recreation and aesthetic purposes (Howe, 1971; Gibbons, 1986; Johnson and Adams, 1988; Lant and Mullens, 1991). Recreational water values have been estimated using entrance fees, travel costs, contingent valuation (questionnaires and consumer surveys), hedonic pricing, or taking the water value as a portion of the total value of the recreational site. Gibbons (1986) estimated maximum marginal values of water for fishing (0.013 $\$/m^3$), shoreline recreation (0.008 $\$/m^3$), and rafting (0.005 $\$/m^3$) during low flows of the Colorado River. Gibbons (1986) also estimated values for fish hatchery water in California's Trinity River (0.019 $\$/m^3$) and the value for spawning water in California's Toulumne River (0.032 $\$/m^3$). In addition, Gibbons (1986) calculated the water value for recreational fish and wildlife in the Charles River, Massachusetts (0.021 $\$/m^3$), as well as the average wetland water value for fishing, waterfowl, hunting and recreation in Michigan coastal regions (0.48 $\$/m^3$). Johnson and Adams (1988) concluded that the marginal value of increasing summer water flows to enhance recreational steelhead fishing in the John Day River, Oregon, was worth approximately 0.002 $\$/m^3$.

Summary of Water Values

Table 4 summarizes the emergy and economic water values reported above. The table is divided into water types and water values are listed in ascending order. Overall, water values increase with increasing upgrading and concentration for human use (e.g., from rain to public supply). In addition, emergy values are generally higher than economic values for the same type of water.

Table 4. Comparative values of water. Legend: (a) geopotential energy of water, (b) chemical potential energy of fresh water relative to seawater, (c) phosphorous in river water, (d) nitrogen in river water, (e) sediments present in the water (f) sediments in first order streams, and (g) organic load.

Water type & location	Em$/m^3	$/m^3	source
Rain			
Papua New Guinea (a)	0.001		(Doherty et al., 1993)
North Carolina (a)	0.006		(Tilley, 1999)
Global average (oceanic rain) (b)	0.018		(Odum, 1996)
Bay of Banderas, Mexico (b)	0.027		(Green, 1992)
U.S. (a)	0.028		(Odum, 1996)
Thailand (b)	0.032		(Brown and McClanahan, 1992)
U.S. (b)	0.032		(Odum, 1996)
Ecuador (a)	0.032		(Odum and Arding, 1991)
Texas (b)	0.035		(Odum et al., 1978b)
Ecuador (b)	0.042		(Odum and Arding, 1991)
Global average (rain on land) (b)	0.045		(Odum, 1996)
River & River Basin Waters			
Catatumbo Basin, Colombia/Venezuela (c)	0.0001		(Howington, 1999)
Catatumbo Basin, Colombia/Venezuela (d)	0.0007		(Howington, 1999)
Mekong River, Thailand/Laos (a)	0.001		(Brown and McClanahan, 1992)
Mississippi River (e)	0.002		(Odum et al., 1987a)
Recreational steelhead fishing, John Day River, Oregon		0.002	(Johnson and Adams, 1988)
Water rafting, Colorado River, U.S.		0.005	(Gibbons, 1986)
Shore recreation, Colorado River, U.S.		0.008	(Gibbons, 1986)
Kavango River, Namibia/Angola (b)	0.010		(Buenfil, 2000)
Fishing, Colorado River, U.S.		0.013	(Gibbons, 1986)
Fish hatchery water, Trinity River, California		0.019	(Gibbons, 1986)
Catatumbo Basin, Colombia/Venezuela (f)	0.020		(Howington, 1999)
Recreational fishing, Charles River, Massachusetts		0.021	(Gibbons, 1986)
Eta River sub-basin, Brazil (a)	0.023		(Romitelli, 1997)
Spawning water for rec. fishing, Toulumne River, CA		0.030	(Gibbons, 1986)
Bay of Banderas, Mexico (b)	0. 072		(Green, 1992)
Rio Chone, Ecuador (g)	0.075		(Odum and Arding, 1991)
Texas (b)	0.091		(Odum et al., 1978b)
Global average (b)	0.12		(Odum, 1996)
Betari River sub-basin, Brazil (a)	0.26		(Romitelli, 1997)
Coweeta River basin, North Carolina (a)	0.29		(Romitelli, 1997)
Lake water			
Lake Weir, Florida (b)	0.063		(Brandt-Williams, 1999)
Martin County, Florida (b)	0.15		(Engel et al., 1995)
Newnan's Lake, Florida (b)	0.22		(Brandt-Williams, 1999)
Wetland water			
Santa Fe Swamp, Florida (b)	0.10		(Odum, 1996)
Value for fishing & recreation, Michigan		0.48	(Gibbons, 1986)
Groundwater			
U.S. (b)	0.07		(Odum, 1996)
Bay of Banderas, Mexico (b)	0.27		(Green, 1992)
Texas (b)	0.25		(Odum et al., 1978b)
North Carolina (b)	0.62		(Tilley, 1999)

Table 4--continued.

Water type & location	Em$/m^3	$/m^3	source
Agricultural/irrigation water			
Malheur County, Oregon		0.008	(Faux and Perry, 1999)
Central Plains, U.S.		0.013	(Moore et al., 1994)
Northwest U.S.		0.016	(Moore et al., 1994)
Southwest U.S.		0.019	(Moore et al., 1994)
Water for fisheries, Bay of Banderas, Mexico (b)	0.06		(Green, 1992)
South Saskatchewan irrigation district, Canada		0.077	Kulshreshtha (1991)
U.S.		0.01 to 0.093	(Gibbons, 1986)
Water for fisheries, U.S.		0.018 to 0.15	(Gibbons, 1986)
Bay of Banderas, Mexico (b)	0.11		(Green, 1992)
Texas (b)	0.44		(Odum et al., 1978b)
Raw wastewater			
Bay of Banderas, Mexico (b)	1.55		(Green, 1992)
Waste assimilation by river waters			
Pacific Northwest, U.S.		0.0004	(Gibbons, 1986)
Upper Arkansas-White-Red river basin, U.S.		0.006	(Gibbons, 1986)
Colorado River, U.S.		0.008	(Payton et al., 1990)
Treated wastewater			
Wetland application, Waldo, Florida		0.11	(Boyle, 1981)
30-mgd Wastewater reuse system, Florida		0.14	(SFWMD, 1992)
Spray irrigation systems, Waldo, Florida		0.17	(Boyle, 1976)
Advanced physical/chemical treatment, Florida		0.28	(Boyle, 1976)
1-mgd Wastewater reuse system, Florida		0.57	(SFWMD, 1992)
Industrial, U.S.		2.18	(Raftelis, 1998)
Light industrial, U.S.		2.21	(Raftelis, 1998)
Commercial, U.S.		2.40	(Raftelis, 1998)
Residential, U.S. .		2.53	(Raftelis, 1998)
Bay of Banderas, Mexico (b)	2.54		(Green, 1992)
Industrial, Florida		3.81	(Raftelis, 1998)
Light industrial, Florida		3.89	(Raftelis, 1998)
Commercial, Florida		3.93	(Raftelis, 1998)
Residential, Florida		4.17	(Raftelis, 1998)
University of Florida (b)	170.1		(Nelson, 1998)
Package sewage system, Yucatan, Mexico (b)	174.1		(Nelson, 1998)
Potable water supply			
Water supply augmentation, Texas		0 to 0.33	(Griffin, 1990)
30-mgd Disinfection (high quality groundwater), FL		0.12	(SFWMD, 1992)
30-mgd Lime softening treatment plant (gw), FL		0.26	(SFWMD, 1992)
30-mgd Coagulation/Filtration (surface water), FL		0.28	(SFWMD, 1992)
1-mgd Disinfection (high quality groundwater), FL		0.32	(SFWMD, 1992)
30-mgd Membrane softening treatment plant (gw), FL		0.35	(SFWMD, 1992)
Highly treated wastewater, San Diego, CA		0.53	(Chapman, 2000)
30-mgd RO treatment plant (groundwater), Florida		0.41	(SFWMD, 1992)
Bay of Banderas, Mexico (b)	0.64		(Green, 1992)
1-mgd Coagulation/Filtration (surface water), FL		0.75	(SFWMD, 1992)
1-mgd Lime softening treatment plant (gw), FL		0.78	(SFWMD, 1992)
1-mgd RO treatment plant (groundwater), Florida		1.10	(SFWMD, 1992)
1-mgd Membrane softening treatment plant (gw), FL		1.09	(SFWMD, 1992)
Texas (b)	1.16		(Odum et al., 1978b)

Plan of Study

To answer the questions raised in the statement of the problem (e.g., what are the values of water and what is the best allocation of water resources?), the emergy inputs to water were evaluated and compared at four scales: 1) global, 2) regional, 3) local (community-level), and 4) small-scale (household-level). In addition, the state of Florida was used as a case study for investigating the value and best allocation of water resources.

Transformities of global storages of water (e.g., oceans, groundwater, lakes, atmospheric water and biological water) were calculated using the global empower base, 9.44 E24 sej/yr (Odum, 1996), and storage replacement times. Transformities of global water flows (e.g., rain, runoff and infiltration) were calculated by dividing the global empower base by the chemical energy of the volumetric flow. Em-dollar per cubic meter (Em\$/m^3) values were calculated using the global emergy-per-dollar ratio, 2.0 E12 sej/\$ (Odum, 1996), the global empower (9.44 E24 sej/yr) and the flow rates (in m^3/yr) of each water resource.

The state of Florida was used as a case study to evaluate regional water storages in Florida, such as rain, surface water, and groundwater. Transformities of water reservoirs (wetlands, lakes and five aquifer systems) were calculated using storage turnover times and the emergy required to generate the water volume of each storage (i.e., the emergy of rain falling on the storage's drainage or recharge area). Emergy per cubic meter (sej/m^3) values were calculated by dividing the empower (sej/yr) of each water storage by its volumetric flow rate (m^3/yr). Em-dollar/m^3 values were calculated by dividing the sej/m^3 by the 2000 U.S. emergy-per-dollar ratio (9.1 E11 sej/\$).

Seven public water supply utilities in Florida, ranging from surface water treatment to seawater desalination with reverse osmosis, were evaluated with emergy synthesis to investigate the value of local potable water and compare treatment alternatives. In addition, a water conservation program in Tampa and a drinking water distribution system in Gainesville were evaluated. To evaluate small-scale drinking water production (i.e., water used just for drinking), five water purification schemes, ranging from filtering to boiling water, were analyzed. The emergy cost of each potable water system was calculated by adding the emergy of all the inputs needed to produce the finished water (e.g., raw water, materials, energy, technology and human services). Transformities and Em$/m^3 of each type of potable water were computed.

A water allocation model was simulated using Excel spreadsheets to explore the appropriate use of water to maximize total productivity. Using statewide data from Florida and two productive functions, the effect of varying water resource allocation among urban, agricultural and environmental sectors on total state production was explored.

METHODS

Emergy evaluations of global and regional hydrologic systems as well as potable water alternatives were conducted leading to suggestions concerning values, appropriate allocation, and potential metrics for public policy decision making regarding the best use of water resources. The general methodology employed was a "top-down" systems approach using both emergy synthesis and simulation modeling. First the general methodology of emergy synthesis is given, then specific methods are presented for each facet of the evaluation of water and, finally, methods used to develop and simulate the model of water allocation are provided. Odum (1996) provides further explanation of emergy concepts and evaluation methodology.

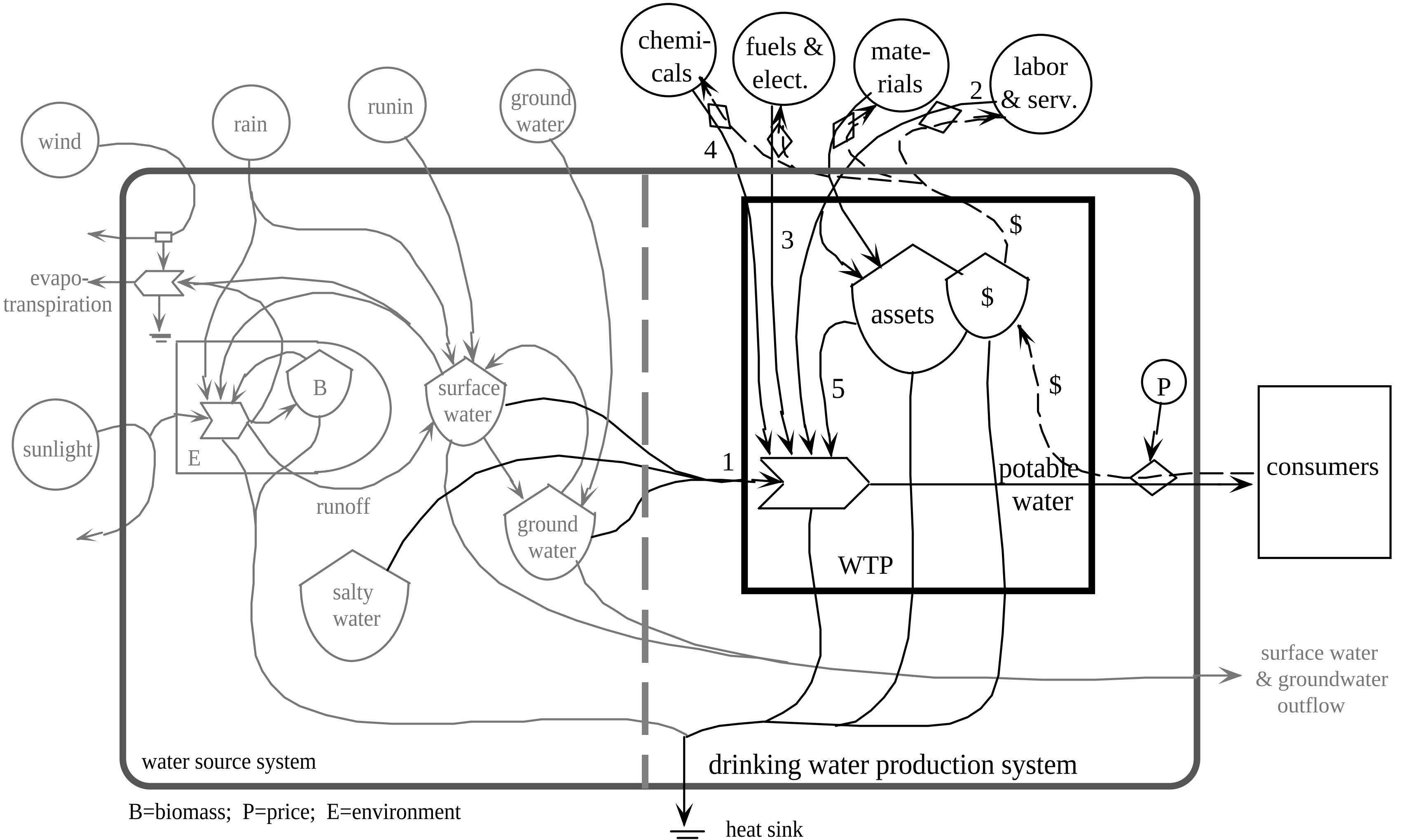
Emergy Synthesis Methodology

Energy Systems Diagrams

In order to identify the fundamental components and energy pathways required for water resources and the production of potable water, energy systems diagrams (Odum, 1994) were drawn for water resources and potable water alternative. Systems diagrams included the principal variables, sources, processes, components and energy flows of the water system studied. Flows crossing the system boundary (inputs) were evaluated. The procedure used for drawing systems diagrams was the following.

First, the boundary of the water system in question was defined and represented by drawing a rectangular box to separate the components and production processes within the system from the driving sources outside the system. The boundaries of potable water treatment facilities were defined as the physical property of the facility and were drawn inside a larger boundary representing the local environment. A generic systems diagram of a water treatment plant is given in Figure 1. The water treatment boundary is illustrated with the darkest rectangular box (right side). The inputs and outputs of this boundary (darkest box) were evaluated in the emergy tables. Second, the principal energy sources or forcing functions (e.g., materials, electricity, and services) were listed and drawn outside the system boundary. Third, the principal units and interactions necessary for the water production processes were drawn inside the diagram using the appropriate symbols (definitions of symbols are given in Appendix A). These symbols were arranged inside the diagram according to their place in the energy hierarchy (Odum, 1994). Fourth, lines representing water, energy and material flows were used to connect the symbols and processes inside the boundary. Finally, when appropriate, monetary flows--represented by dashed lines--were drawn to inventory the exchange of money for water (consumer side) and for human services and resources (production side).

The left side of Figure 1 was drawn to show where the water source comes from. The environmental system providing the water source was not included in the emergy evaluations of potable water alternatives. The purpose of showing this environmental side in the diagrams was to illustrate the larger support system, from nature, required for the production of drinking water.



B=biomass; P=price; E=environment

WTP=Water Treatment Plant

Figure 1. A generic systems diagram of the production of potable water for public supply.

Emergy Tables

The systems diagrams served as the blue print for developing the emergy evaluation tables. For potable water evaluations, each major input of material, energy, goods and services crossing the water treatment boundary (darkest box in the right side of the diagram) became a row in the emergy evaluation table. The input numbers used for the public supply evaluations were generally obtained from the water treatment facilities. The physical plant infrastructure of these facilities was evaluated and included as an annualized input to the process by dividing the value of the infrastructure by its average replacement time. Input quantities of materials and energy flows for the evaluation tables of global and regional water resources as well as the small-scale water purification systems were generally obtained from the literature.

As illustrated in Table 5, all emergy tables included the following seven columns: 1) *Note*, to document the source of data and calculations for each row in the table; 2) *Item*, to name or describe the item being evaluated; 3) *Unit*, to provide the unit of each item; 4) *Energy Data*, to show the value of the item with units given in column 3; 5) *Emergy-per-unit*, to be used as a "conversion factor" to yield values in solar emergy units; 6) *Solar Emergy*, to list the emergy value for a specific item, which was obtained by multiplying columns 4 and 5; and 7) *Emergy/*m^3, to show the emergy necessary to produce a cubic meter of water.

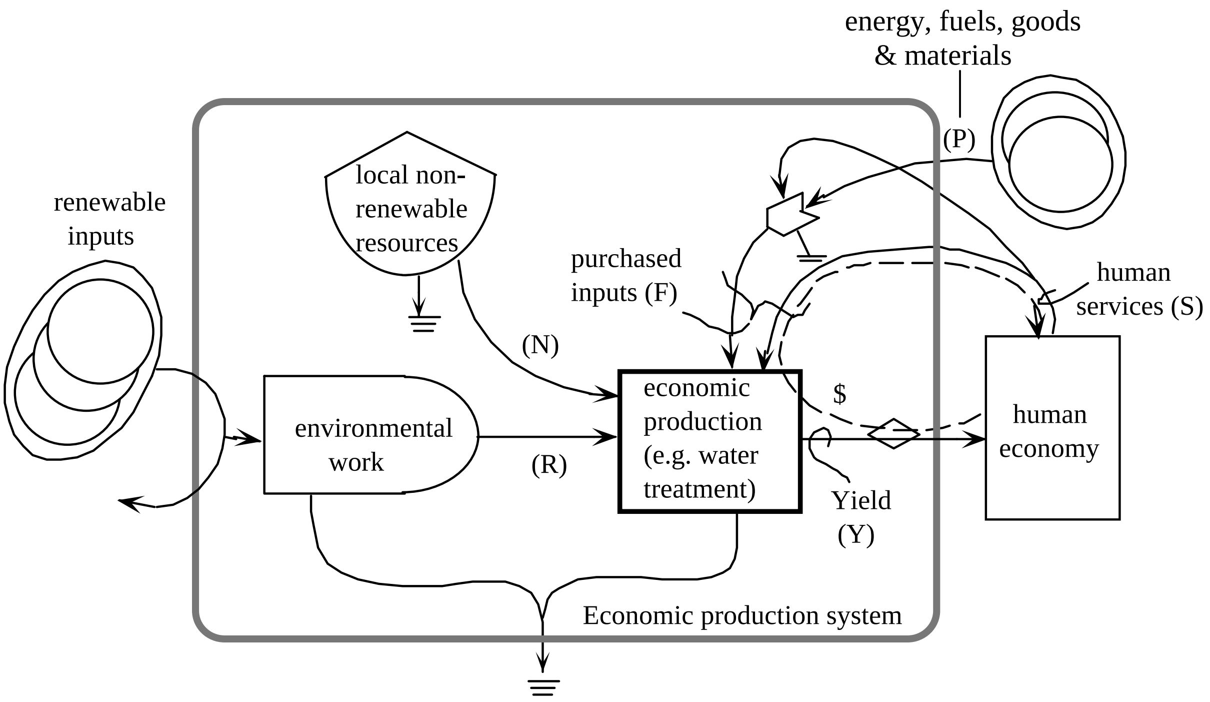
Inputs of the potable water systems were grouped into *Renewable Resources* (inputs obtained "free" from nature) and *Purchased & Operational Inputs* (those that were either purchased or processed by the human economy). The section *Emergy per unit of water* was provided to summarize the total emergy of water per unit of measurement (e.g., m^3, g, J). Transformities (sej/J) were provided with and without human services to facilitate future emergy studies.

Table 5. Tabular format of emergy evaluation tables used in this study.

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Water	J	A	B	A x B	(A x B) / m^3
PURCHASED & OPERATIONAL INPUTS						
2	Operating & Maintenance	$	C	D	C x D	(C x D) / m^3
3	Electricity	J	….			
...						
5	Plant Assets	kg	…	———	———	————
	Yield (Y) = Total emergy of drinking water:			sum 1	sum 2	sum 3
EMERGY PER UNIT OF POTABLE WATER						
6	Potable water produced	m^3	M	sum 1 / M		
7	Potable water produced	J	N	sum 1 / N		
8	Potable water produced	g	…			
9	Drinking water with-out services	J	P	(sum 1 – services) / P		

Emergy Indices

Several emergy indices and ratios were used to analyze and compare different water resources and technologies for producing potable water. Figure 2 illustrates the definition and way of calculating these emergy indices. The letters on the pathways refer to flows of emergy per unit time (usually one year). The meaning and application of the emergy indices are explained below.



Emergy Indices:
Purchased inputs (F) = P+S
Emergy Yield (Y) = R+N+F
Emergy Investment Ratio (EIR) = F/(R+N)
Emergy Yield Ratio (EYR) = Y/F
% Renewable = R/Y x 100
Emergy Benefit to the Purchaser (EBP) = (emergy of Y)/(emergy of $ paid for Y)
Em$/$m^3$ = (Y / m^3 of Y) / (sej/$)
Transformity of Y = (emergy of Y)/(energy of Y)

Figure 2. Diagram illustrating the definition of the emergy indices used. The letters on the pathways refer to flows of emergy per unit time (sej/yr).

1) Emergy investment ratio (EIR).

The EIR represents the purchased emergy feedback from the economy (F) divided by the free emergy inputs from the environment (R+N). This ratio measures the intensity of a production process. If the EIR of the proposed development is greater than the regional EIR, the project may be too emergy-intensive and negatively affect the environment. To be economical in the long-term, the process should have a ratio similar to the region's EIR. If the EIR of the production process is higher than that of the region, the opportunity costs will be higher and the process may not compete in the long run. On the other hand, EIRs that are lower than the regional average will have lower opportunity costs since much of the useful work is coming free from nature. However, operating below the regional EIR indicates that the environmental emergy is not being fully matched with economic emergy and the system may be operating below its development potential. Consequently, development processes tend to self-organize towards an optimum matching of the EIR in relation to the intensity of regional economic activity supported by the environment.

2) Emergy yield ratio (EYR).

The EYR of a process is the emergy of the output (Y) divided by the emergy of all inputs coming from the human economy (F). This ratio indicates if the process can be economically competitive and measures the net contribution of the product to the economy beyond its own generation. The higher the EYR, the greater the net benefit to society.

3) Percent renewable emergy (%R).

The percent renewable emergy is obtained by dividing the renewable emergy of a product (R) by the emergy yield of the product (Y) and multiplying this by 100. Renewable emergy includes sunlight, wind, rain, and most forms of water. The larger the %R, the more sustainable the production process is in the long run.

4) Emergy benefit to the purchaser (EBP).

The EBP represents the emergy in a product divided by the buying power of the money paid for such product (in terms of emergy). Since the environment is not paid with money for its services to the human economy, the emergy of environmental resources contributes more real wealth than the emergy embodied in the money paid for these resources. Thus, this ratio indicates how much more emergy is delivered in a product to the purchaser relative to the buying power of the payment. The higher the EBP the more the purchaser benefits; yet, at the expense of the environment.

5) Em-dollars per volume (Em\$/m^3).

Em-dollars (Em\$) are emergy-based monetary values of a good or service. Similarly to \$/m^3, Em\$/m^3 represent the cost of producing one cubic meter of water. The Em\$/m^3 for a specific year are calculated by dividing the emergy per volume (sej/m^3) of water by the emergy-per-dollar ratio (sej/\$) of the country were the water is produced. For global water resources, the sej/m^3 is divided by the global sej/\$ ratio. Emergy-per-dollar ratios used in this study were calculated by dividing the annual empower (sej/yr) of the U.S. economy by its gross national product (\$/yr) for the year of evaluation. Similarly, the global sej/\$ ratio was calculated by dividing the global empower base by the global gross economic product.

Odum (1996) gives U.S. sej/\$ ratios from 1947 to 1993. These values decline from 25.4 E12 sej/\$ in 1947 to 1.37 E12 sej/\$ in 1993 (Odum, 1996). Since the sej/\$ ratio decreased more rapidly during the 1983-1993 decade, a 2000 sej/\$ ratio was estimated from decreasing the sej/\$ ratio by 5.7% per year, which represents the average sej/\$ decrease between 1983 to 1993. The projected sej/\$ ratio for 2000 (i.e., 9.1 E11 sej/$) was used to calculate the Em$ values of the regional (Florida) water resources and all the potable water alternatives. Since the global sej/$ ratio remained fairly constant at 2.0 E12 sej/U.S.$ during the 1980's (Odum, 1996), this value was assumed to remain constant for 2000.

6) Emergy-per-unit and transformity.

The emergy-per-unit and transformity of a commodity indicates its place in the energy hierarchy and the efficiency of producing such commodity. Emergy-per-unit (e.g., sej/m^3, sej/g and sej/$) and transformities (sej/J) are calculated by dividing the emergy yield of a product (Y) by the corresponding unit of the product (e.g., m^3, g, $ or J). For any commodity or resource (e.g., potable water), the lower the emergy-per-unit or transformity, the greater the efficiency of the production process.

Emergy Evaluation of Global Water Storages and Flows

The emergy values of global water storages were calculated by assuming that these storages are co-products of the global empower base (9.44 E24 sej/yr). The global empower base (9.44 E24 sej/yr) represents the annual emergy flowing to Earth and was calculated by Odum (1996) by summing the annual emergy of the sun (3.93 E24 sej/yr), tide (1.44 E24 sej/yr), and deep heat (4.07 E24 sej/yr). Emergy per volume (sej/m^3) of global water storages were calculated by dividing the empower base by the annual average volumetric flow of each water storage. Volumetric flow rates were calculated by dividing the volume in each water storage by its replacement time. Similarly, global water flows were assumed to be co-products of the global empower base. Emergy per volume of global water flows were calculated also by dividing the empower base by the annual volumetric flow of each global water flux. Emergy per volume values were used to calculate emergy-per-mass (sej/g), transformities (sej/J), and Em-dollar (Em\$/m^3) values. For example, emergy per mass (sej/g) values were calculated by dividing the emergy per volume (sej/m^3) by the density of fresh water (1 E6 g/m^3).

Transformities for several types of global precipitation were calculated by dividing the global empower base by the volumetric flow rate of each type of precipitation. The volumetric flux of tropical rainfall was estimated by multiplying the average rainfall between latitudes 23.5° N and 23.5° S by the total surface area between the same latitudes. The volumetric flow rate of temperate rain was assumed to be the difference between the global precipitation and the estimated tropical precipitation. Tropical and temperate precipitation on land were estimated by using the corresponding land surface areas. For example, the land between latitudes 23.5° N and 23.5° S were used to calculate the tropical rain on land, whereas the land outside these latitudes was used to calculate the temperate rain flux on land.

Emergy Evaluation of Regional Waters Using Florida as a Case Study

The water resources of Florida (major storages and flows) were evaluated. Each category of water (estuaries, rivers, lakes, wetlands and groundwater) was evaluated as a storage. Detailed methods including calculations and assumptions are given for each in the following sections.

Surface Water

To calculate the emergy of surface waters, maps and statistical data (Fernald and Purdum, 1998) of the Florida watershed (which includes portions of Georgia and

Alabama) were used to proportion rainfall into river watersheds, lake watersheds, and wetland watersheds. The percent of total Florida watershed assigned to each type of surface water feature was estimated from the data on individual river, lake and wetland watersheds and visually from maps. Of the total area, approximately 55% was estimated to be river watershed, 15% was lake watershed, and 30% was wetland watershed.

The transformity of rain in Florida was assumed to be equivalent to the average global precipitation on land. The emergy of the total rainfall (sej/year) over the watershed for each surface water storage type multiplied by the turnover time of the storage (in years) resulted in the total emergy required for river, lake and wetland storages. The emergy of intertidal water (i.e., water in estuaries, salt marshes and mangrove ecosystems) was assumed to be equal to the emergy of river water. Tidal emergy was not added to the emergy of intertidal water since this is already included in the rain used to calculate the transformity of river water. Transformities for each surface water storage were then calculated by dividing the total emergy required by the chemical potential energy of each storage.

Groundwater

Emergy of groundwater storages was calculated for the main aquifers in Florida using rainfall and turnover times. The aquifers evaluated included the Surficial, Sand and Gravel, Biscayne, Intermediate, and Floridan. Emergy input to each aquifer was calculated as the emergy of rainfall on the recharge area.

Figure 3 shows the three principal groundwater storages making up the Florida aquifer system. The surficial aquifer overlays the intermediate and Floridan aquifers. The Biscayne aquifer because of its shallow depth and unconfined characteristics is considered surficial, as is the sand and gravel aquifer in the western portion of Florida's panhandle. The recharge areas of each aquifer were estimated from data and maps in Fernald and Purdum (1998) and Miller (1990). The annual emergy in rain falling on each recharge area was multiplied by the calculated turnover time of each aquifer to obtain total emergy required for the aquifer storage. Turnover times were calculated by dividing the total volume of each aquifer by its recharge rate (in volume/time). Transformities were then calculated by dividing the total emergy required by the energy of the storage.

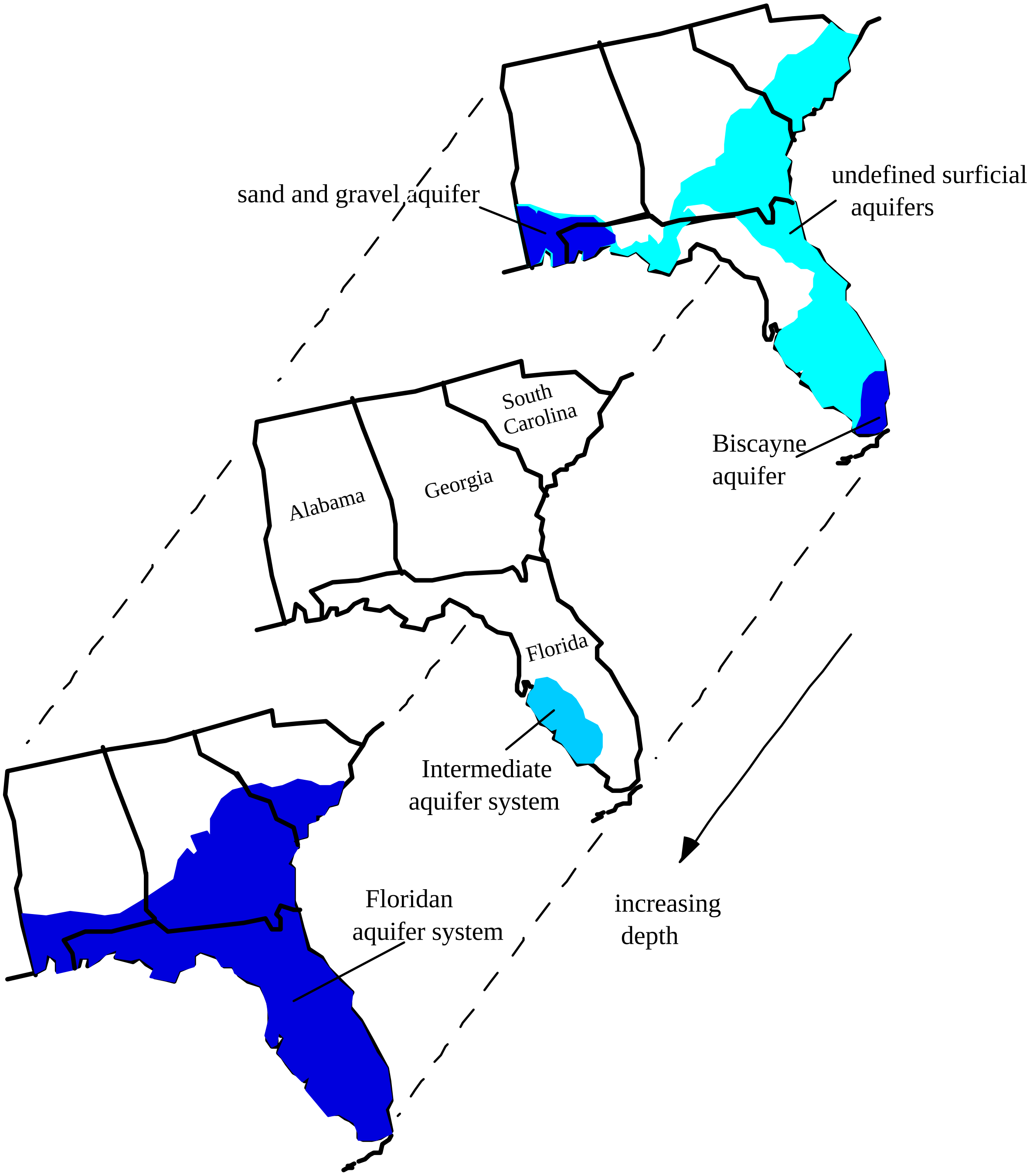


Figure 3. Sequence of aquifer systems in Florida (adapted from Miller, 1990).

Emergy Evaluation of Potable Water Supply Alternatives

A list of the public supply systems evaluated is given in Table 6. The approximate location of these public utilities is shown in Figure 4. For each public supply system the emergy value of finished water was calculated by adding the principal emergy inputs required to produce potable water. Using the systems diagram in Figure 1as a guide, the inputs included the following: 1) a water source (surface water, groundwater or salty water); 2) money paid to humans for their work and services (e.g., fees, wages, design and development costs, construction costs, operation and maintenance costs, chemical costs and power costs); 3) energy (e.g., fuels and electricity); 4) chemicals and supplies; and 5) assets and infrastructure materials (e.g., steel and concrete). Annual inputs were multiplied by their corresponding transformity (calculated separately) to convert them to emergy. Useful lifetimes of assets and treatment plants infrastructure were use as turnover times to annualize the emergy of plant assets. The assets of most public supply systems were assumed to have an average useful lifetime of 30 years.

The evaluations done for different plants had dollar costs for different years. The sej/$ ratio for the year in which the treatment system was evaluated was used to calculate the emergy input of human services and other economic costs for producing potable water. For example, if the year of evaluation was 1995, then a 1995 sej/$ ratio was used to evaluate annual flows of human services, or if the plant costs were in 1990 dollars then the ratio for 1990 was used. Emergy-dollar ratios for different years were obtained from Odum (1996). Since sej/$ ratios incorporate depreciation, monetary flows were not discounted with depreciation interest rates as commonly done in economic analyses. The process description and main characteristics of the public supply systems evaluated are presented below.

Table 6. Public supply alternatives evaluated with emergy synthesis.

plant name	type of treatment	location	water source	production
1) City of West Palm Beach Water Treatment Plant	Coagulation flocculation & settling	West Palm Beach	surface water (lake water)	28.0 mgd or 1.2 m^3/sec
2) Hillsborough River Water Treatment Plant	Coagulation flocculation & settling	Tampa	surface water (river water)	62.0 mgd or 2.7 m^3/sec
3) Murphree Water Treatment Plant	Lime softening	Gainesville	groundwater (Floridan aquifer)	21.0 mgd or 0.92 m^3/sec
4) Tampa Bay Water conservation program	Water conservation	Tampa Bay	potable water (saved)	25.0 mgd or 1.1 m^3/sec (saved)
5)City of Dunedin RO Facility	Reverse Osmosis	Dunedin	brackish groundwater	5.6 mgd or 0.25 m^3/sec
6) Tampa Bay Desalination Plant	Reverse Osmosis	Tampa	seawater	25.0 mgd or 1.1 m^3/sec
7) Florida Keys Aqueduct Authority	Lime softening	From Florida City to Key West	groundwater (Biscayne aquifer)	15.0 mgd or 0.66 m^3/sec
8) Seawater Desalination Facility	Reverse Osmosis	Stock Island (near Key West)	seawater	3.0 mgd or 0.13 m^3/sec

mgd = million gallons per day
RO = reverse osmosis

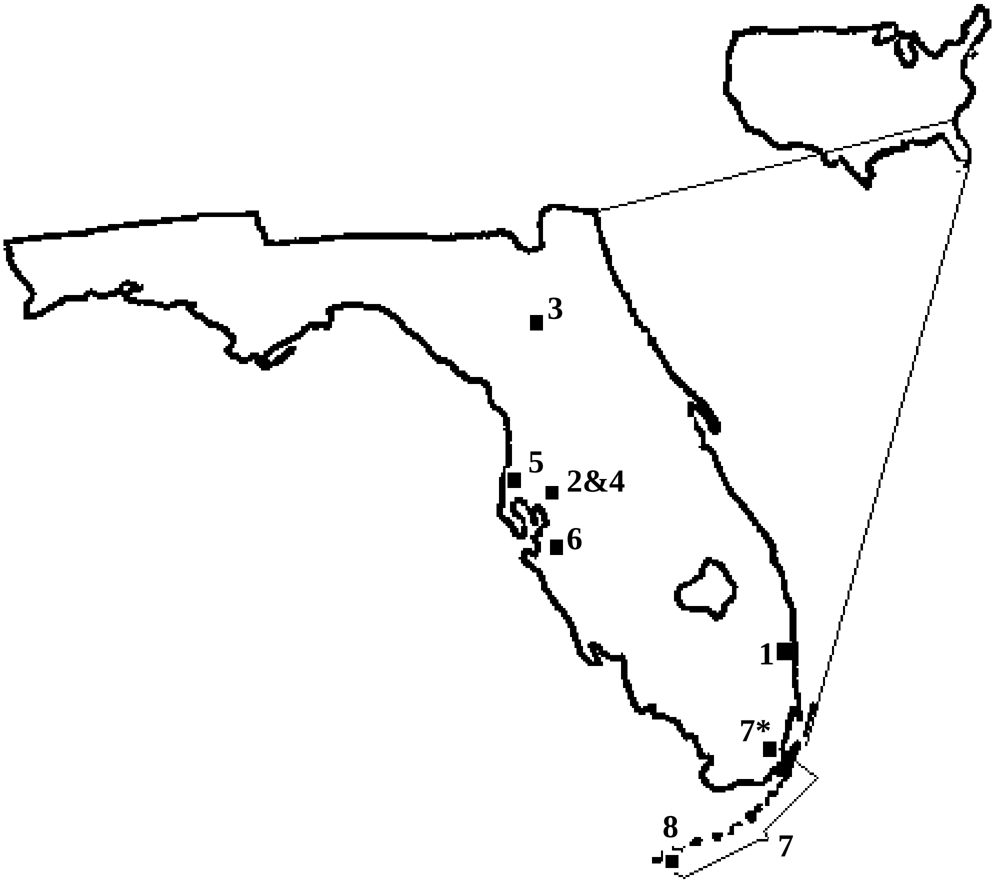


Figure 4. Approximate location of the public supply systems analyzed: 1) City of West Palm Beach Water Treatment Plant, 2) Hillsborough River Water Treatment Plant in Tampa; 3) Murphree Water Treatment Plant in Gainesville; 4) Tampa Bay Water's water conservation program; 5) City of Dunedin Reverse Osmosis Water Treatment Plant; 6) Tampa Bay desalination Plant; 7) Florida Keys Aqueduct Authority from Florida City (7*) to Key West; and 8) Stock Island desalination Plant next to Key West.

1) Surface (Lake) Water Source: West Palm Beach's Water Treatment Plant.

In 1999 (year of evaluation) the City of West Palm Beach Water Treatment Plant produced 28.0 mgd (1.23 m^3/sec) of drinking water from two lakes that get their water from a water catchment area south of Lake Okeechobee in south Florida. Figure 5 illustrates a schematic of the production of drinking water by this facility. The treatment process includes lime softening, flocculation, coagulation, clarification, filtration, fluorination, and disinfection by chloramination. The sludge from the settling basins and the backwash water from the filters is sent to a settling tank. The water from the top of this tank is recycled back to the treatment process. The settled sludge is air-dried on land next to the facility and then taken off-site for disposal. After treatment the finished water is stored and then sent to the distribution system.

2) Surface Water Source: Hillsborough River Water Treatment Plant, Tampa.

Figure 6 shows a schematic of the production of drinking water at the Hillsborough River Water Treatment Plant in Tampa, Florida. In 1996 this surface water treatment facility produced, on average, 62 mgd (2.72 m^3/sec) of potable water. The Hillsborough River has high concentrations of tannins and humic acids, which come from the slow decomposition of organic matter in the headwaters of the river (the Green Swamp) and along the river. In addition, the river has high concentrations of suspended and dissolved solids. Consequently, the treatment includes the removal of turbidity and dissolved solids by coagulation and settling, and the removal of suspended solids by filtration. Because of high concentrations of organic compounds in the river, post-disinfection is carried out with chloramines (chlorine and ammonia) to prevent the formation of trihalomethanes and other harmful disinfection by-products. After disinfection the finished water is stored in an underground clear well and then sent to the distribution system.

3) Groundwater Source: Murphree Water Treatment Plant, Gainesville.

Figure 7 shows a schematic of the Murphree Water Treatment Plant, which supplies most of Gainesville's drinking water. In 1994 the plant produced about 21 mgd or 0.92 m^3/sec. The schematic illustrates the principal unit operations and processes required for the production of this potable water. Since groundwater from the Floridan aquifer in this region is of very high quality, the treatment scheme consists primarily of calcium hardness removal and disinfection with chlorine. Calcium ions are removed by adding quicklime, which raises the pH and precipitates the calcium ions as calcium carbonate ($CaCO_3$). Just before entering the clarifiers, chlorine (Cl_2) is added to the water to oxidize hydrogen sulfide (H_2S). After settling the $CaCO_3$ in the plant's clarifiers, the water is filtered to remove additional particles and then disinfected with chlorine. The finished water is then stored and pumped to the distribution system.

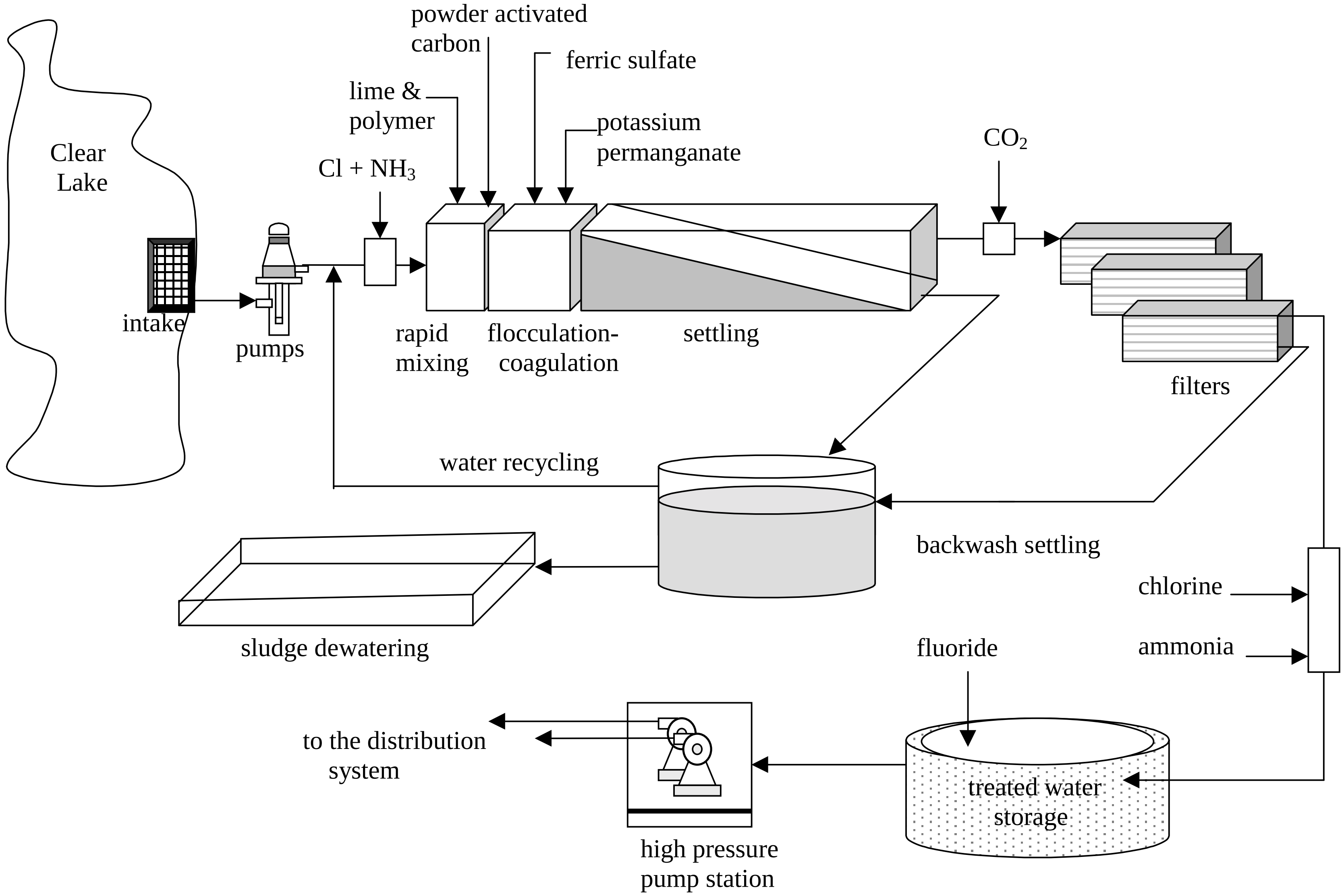


Figure 5. Schematic of the production of drinking water at the City of West Palm Beach Water Treatment Plant.

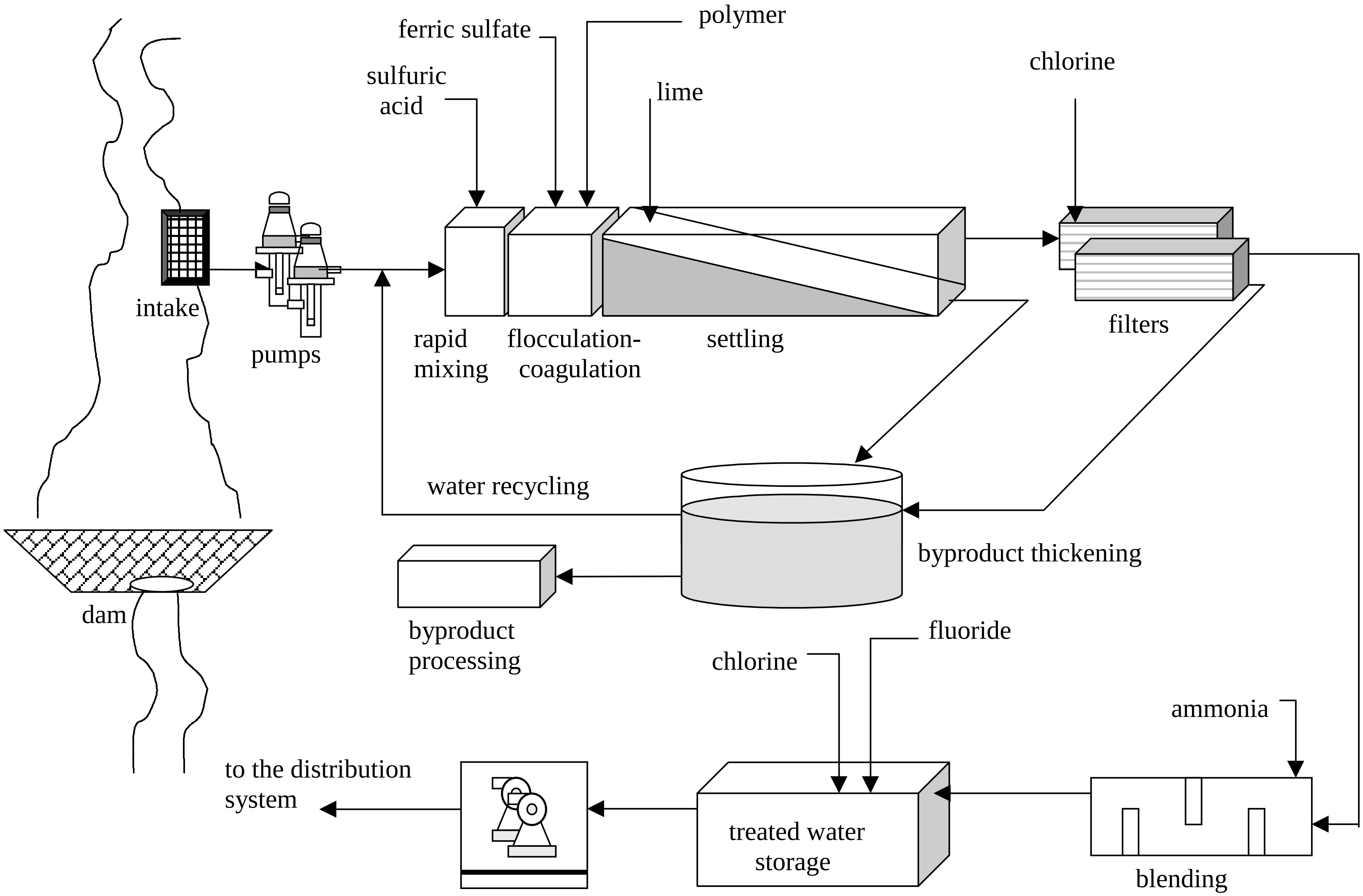


Figure 6. Schematic of the production of drinking water at the Hillsborough River Water Treatment Plant in Tampa, Florida.

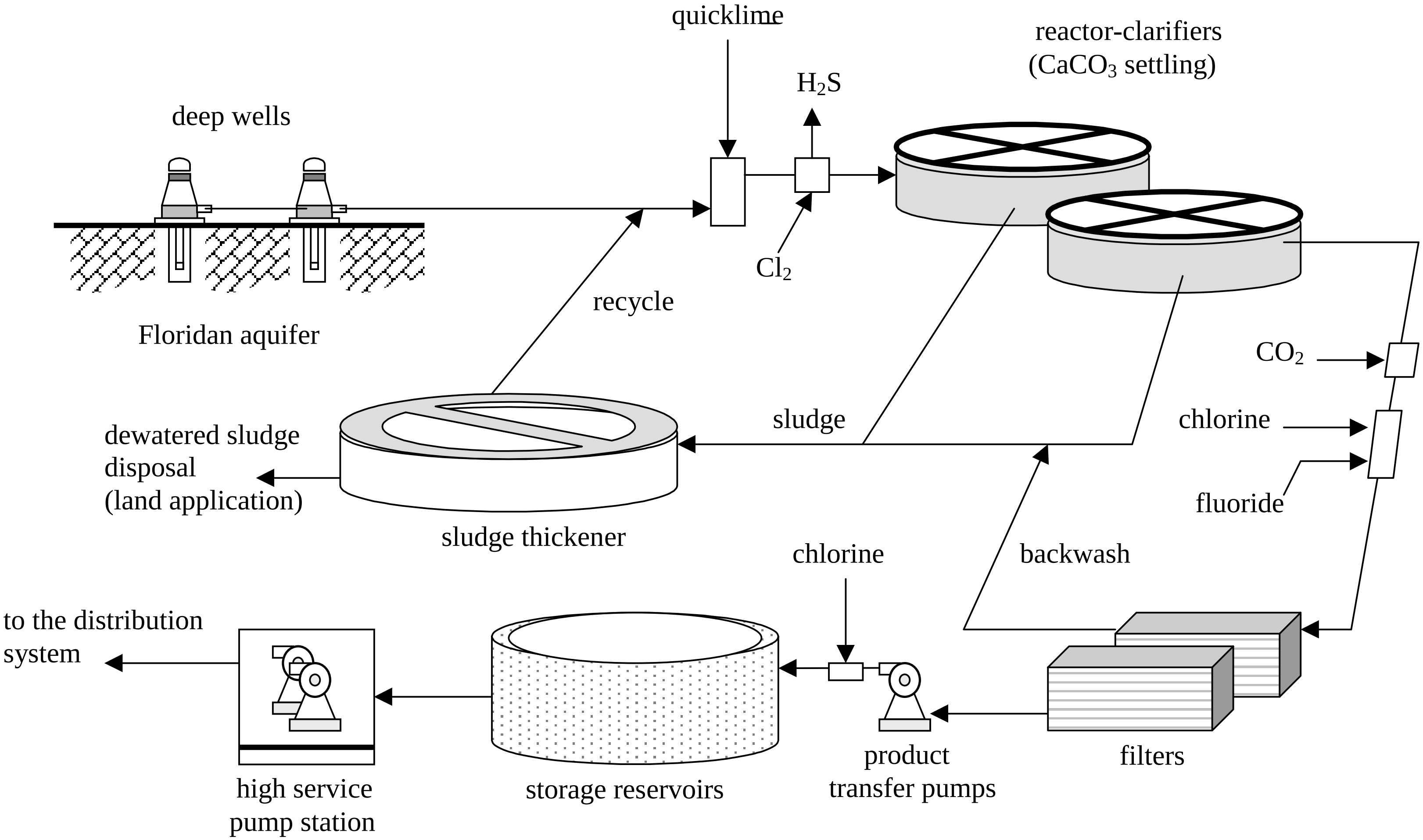


Figure 7. Schematic of the production of potable water at the Murphree Water Treatment Plant in Gainesville, Florida.

4) Water Conservation as a Source: Tampa Bay.

For comparative purposes, a water conservation program in Tampa was evaluated. A water management/conservation plan developed by Tampa Bay Water is expected to save approximately 24.4 mgd (1.07 m^3/sec) of potable water in the Bay area between 2000 and 2030. Tampa Bay Water (TBW) is in charge of supplying potable water to Pasco, Pinellas and Hillsborough County including the cities of Tampa, St. Petersburg and New Port Richey. Because of rapid population growth and limited fresh water resources in the region, TBW developed this demand management/conservation program by using best management practices and implementing several water conservation measures. These measures include the use of educational campaigns to increase the efficiency of water use and the implementation of economic incentives, such as rebates, to install water-saving devices (rain sensor shut-off units). The water conservation program also promotes replacing conventional fixtures with more efficient ones (low-volume toilets and low-flow showerheads), purchasing water-saving appliances (low-volume dishwashers), and reducing the use of potable water for irrigation (xeriscaping gardens and using reclaimed water).

5) Brackish Water Source: City of Dunedin Reverse Osmosis Treatment Facility.

In 1996 the City of Dunedin Reverse Osmosis (RO) Water Treatment Facility produced 5.6 mgd (0.25 m^3/sec) of drinking water from a blend of fresh [350 parts per million (ppm) of total dissolved solids (TDS)] and brackish (1,100 ppm of TDS) groundwater. The percentages of fresh and brackish groundwater used for the production of potable water in 1996 were 90% and 10%, respectively. A schematic of the treatment process is given in Figure 8. First, potassium permanganate is added to the raw water to oxidize iron and hydrogen sulfide (H_2S). After this, the water is pre-treated in a pressure filter (Greensand filter). Some of the exiting water goes through a 20 micron filter and the rest is fed with sulfuric acid and an antiscalant before entering a 5 micron filter. The water leaving the 5 micron filter goes through the RO membranes and is blended with the water exiting the 20 micron filter. The blended water is then degasified (to remove residual H_2S and CO_2), chlorinated, and fluorinated before pumped to the distribution system. The concentrate (reject brine) leaving the RO membranes, which represent about 17% of the water entering the membranes, is dosed with sodium hydroxide for pH control and then disposed to the city's sewer system.

6) Seawater Source: Reverse Osmosis Desalination, Tampa Bay.

A reverse osmosis desalination plant is under construction in Tampa Bay, Florida. When completed in 2003, the facility will produce 25 mgd (1.1 m^3/sec) from salty water discharged from the cooling system of an adjacent power plant. A schematic for Tampa Bay's RO desalination process is given in Figure 9. As depicted in the schematic, the water source will be taken from the discharge of Tampa Electric's Big Bend Power Station's cooling towers. The cooling water flows from Tampa Bay through an inlet canal and is discharged back to the bay. After intake from this canal, the water source will be screened and dosed with sulfuric acid and an antiscalant to prevent the precipitation of minerals on the surface of the filters and RO membranes. Next, the water will be filtered and then forced through the RO modules. The permeate (fresh water) will be sent to a drawback tank and then degasified to remove H_2S and CO_2. The pH will be neutralized and the water disinfected with chlorine before connected to the distribution system. Finally, the concentrate and backwashed water will be flushed to the Bay via the exiting side of the power plant's discharge canal.

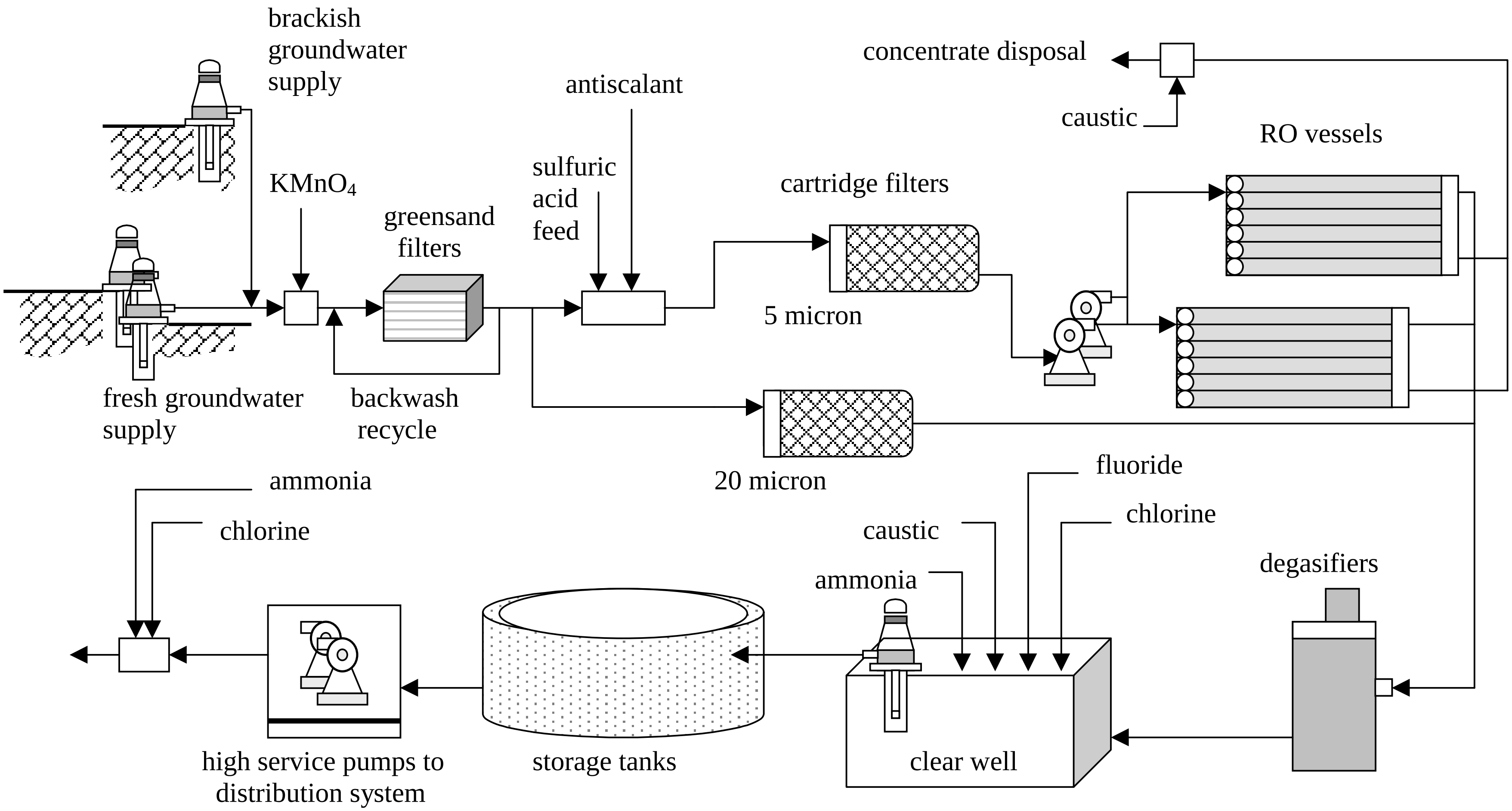


Figure 8. Schematic of the production process of potable water at the City of Dunedin Reverse Osmosis Water Treatment Facility.

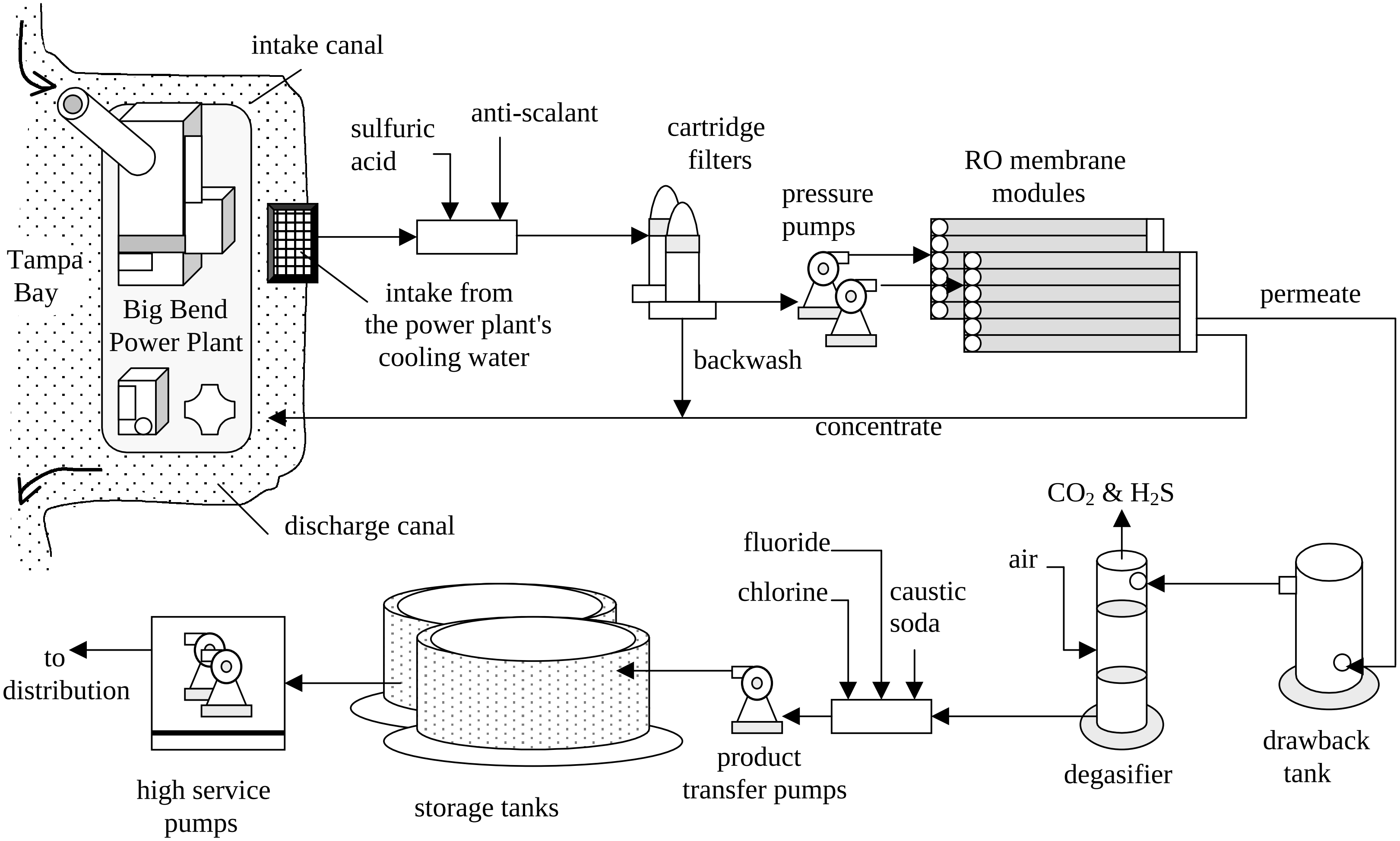


Figure 9. Schematic of the reverse osmosis desalination facility being built in Tampa Bay.

7) Surficial Groundwater Source: Transported Via Aqueduct, Florida Keys.

Figure 10 shows a schematic of the production and transportation of potable water by the Florida Keys Aqueduct Authority (FKAA). The aqueduct system delivered, on average, 15 mgd (0.66 m^3/sec) of potable water throughout the Florida Keys in 1996. Groundwater from the Biscayne aquifer is pumped near Florida City, southwest of Miami. Quicklime is added to the water to precipitate calcium and magnesium ions. Then the water is filtered to remove suspended solids and other contaminants. After disinfection with chlorine, the water is sent through a 210 km-long transmission pipeline ranging from 36 to 18 inches (92 to 46 cm) in diameter (Malgrat and Doughtry, 1996). This pipeline extends from Florida City to Key West along U.S. Highway 1. This section of the highway has 43 bridges (Malgrat and Doughtry, 1996), which "subsidize" the pipeline infrastructure. To provide the adequate pressure for the distribution system, the FKAA counts with 25 storage tanks (ranging from 1.9 E3 to 18.9 E3 m^3) and 42 pumps (ranging from 10.6 to 70.7 BTU/sec) (Malgrat and Doughtry, 1996).

8) Seawater Source: Reverse Osmosis Desalination, Stock Island (Adjacent to Key West).

A reverse osmosis desalination facility operated throughout the 1970's and early 1980's in Stock Island and supplied approximately 3.0 mgd (0.13 m^3/sec) of potable water to Key West. This facility was shut down after less expensive drinking water was available with the construction of the Florida Keys aqueduct. A schematic of the RO desalination process that operated in Stock Island, Florida, is given in Figure 11. Seawater was pumped from shallow wells on a small peninsula within the island and then filtered to remove larger particles and some corrosive elements. After this, high-pressure pumps were used to force the water through the RO membranes to separate the salts from the feed water. The concentrate was returned to the sea via an adjacent ship channel under permission of the Environmental Protection Agency and the Florida Department of Environmental Protection. The permeate (drinking water) was sent to a drawback tank which provided freshwater back to the RO membranes to prevent possible damage to the permeators in case of a power failure. After the drawback tank the fresh water was passed through a degasifier to strip off H_2S and CO_2. After the degasifier the fresh water entered a clear well where soda ash was added to raise the pH and then the water was sent to a ground storage tank where it was disinfected with chlorine. Finally, the finished water was pumped to Key West's distribution system.

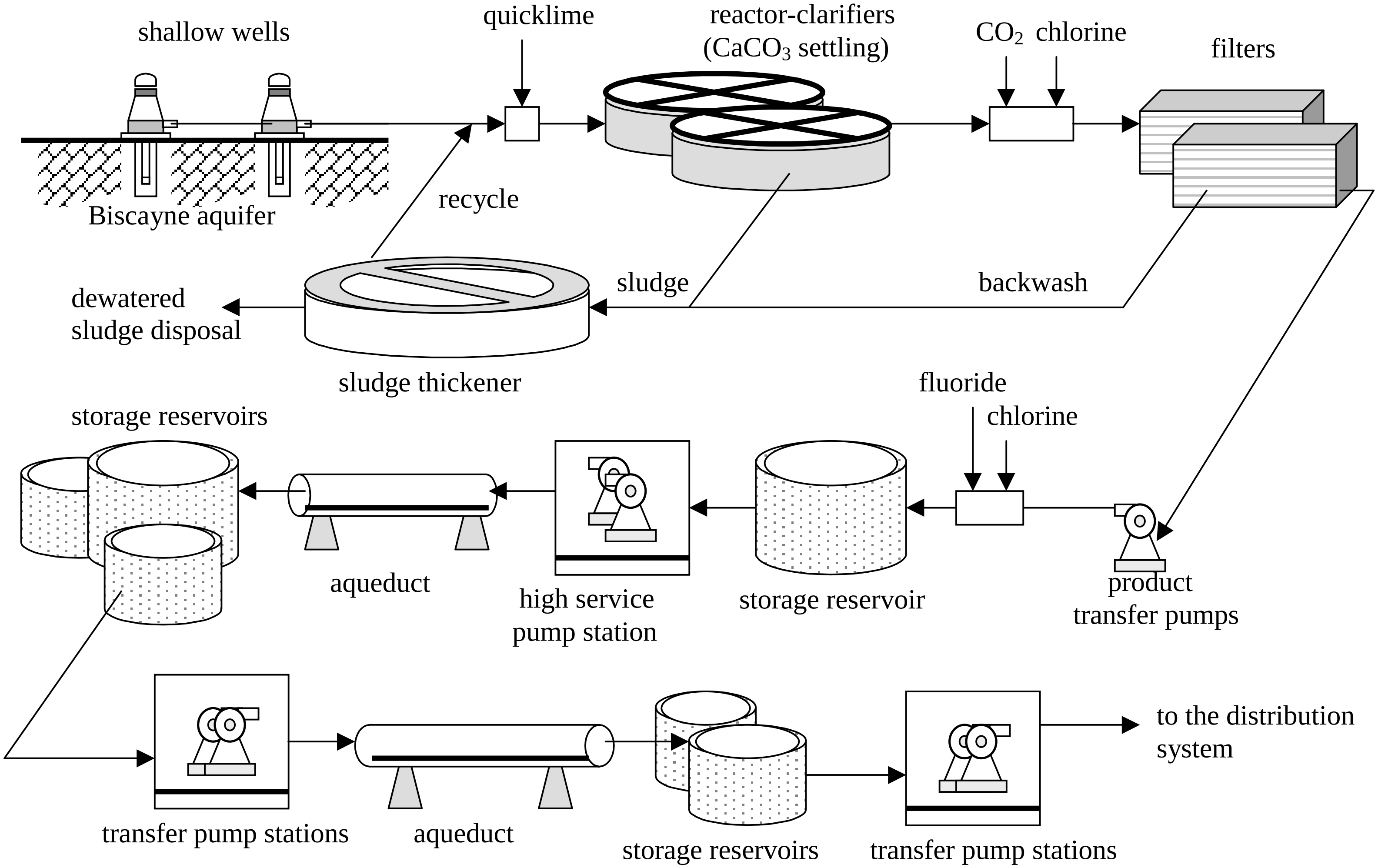


Figure 10. Schematic of the production and transportation of potable water by the Florida Keys Aqueduct Authority.

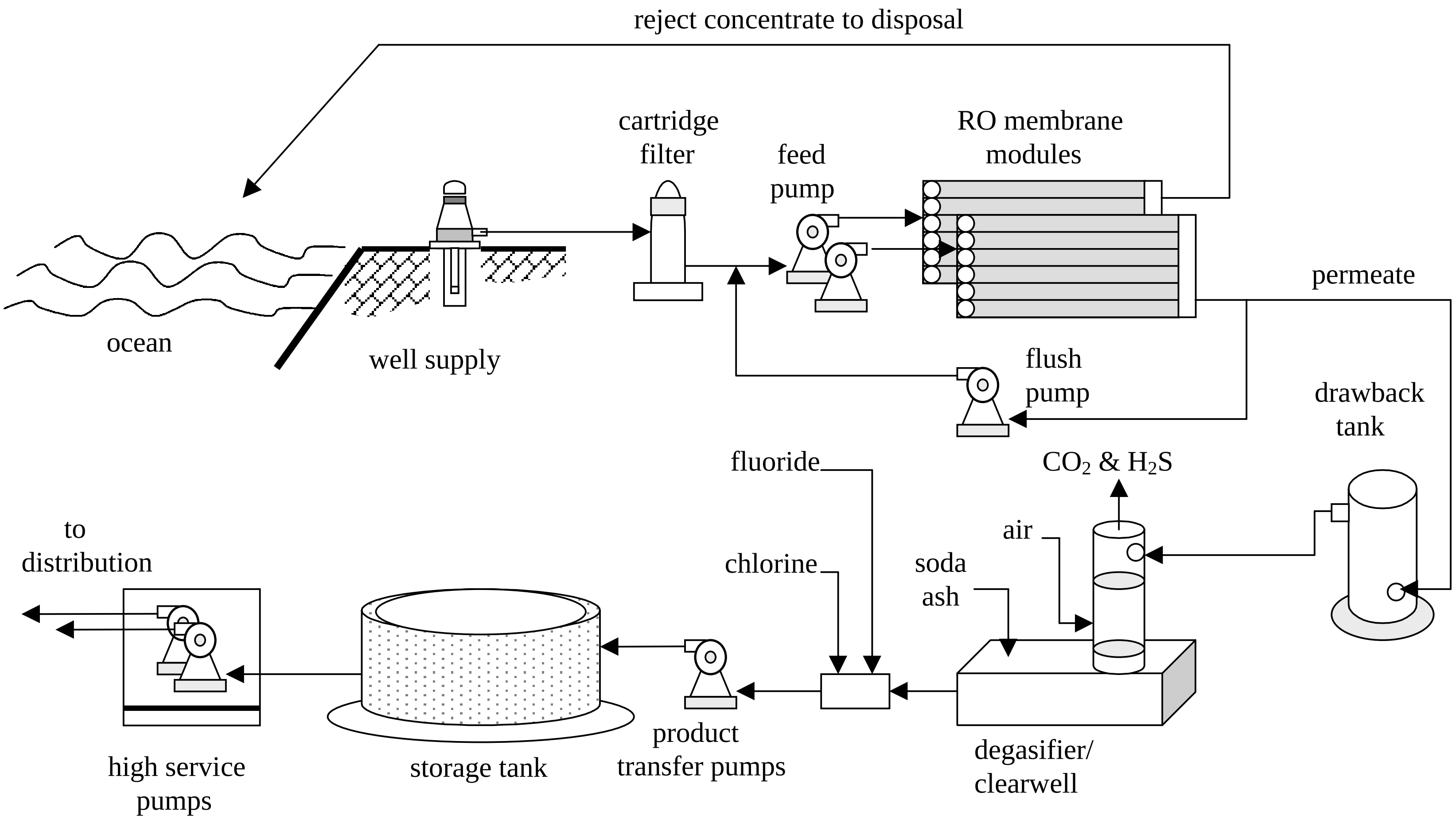


Figure 11. Schematic of Stock Island's RO facility that desalinated water for Key West, Florida, in the 1970's.

Water Distribution System: Gainesville Regional Utility.

Generally the distribution systems were not included in the evaluation of potable supply alternatives. So that the emergy required for the water yield was the sum of the inputs to the process, excluding distribution. The aqueduct in the Florida Keys however, was included in the evaluation for that water supply alternative, since the aqueduct is an integral part of the production process (the distribution system throughout the keys that distributes water to consumers was not included, however). A separate evaluation was conducted for a distribution system to give perspective to the additional costs of distribution so that comparisons with other consumer devices for potable water could be made.

The emergy required for distribution of potable water was evaluated using the system in Gainesville Florida. Inputs to the system included: pipe materials, electricity, goods, and services. The annualized emergy costs (sej/year) of the distribution system were divided by the annual flow rate (m^3/year) to obtain sej/m^3 of delivered water. For comparison with other consumer operated and small-scale potable water supply options, the emergy of distribution was added to emergy of production.

Emergy Evaluation of Small Scale Water Purification Alternatives

Several consumer oriented potable water alternatives were evaluated for comparison with the large scale public utilities. Table 7 lists the alternatives that were evaluated, and each alternative is described briefly below.

Table 7. Small scale water purification alternatives evaluated.

type of treatment	location	water source	production
1) Home filter	Florida	groundwater	10.0 gal/day or 37.9 L/day
2) Water boiling	Florida	groundwater	2.0 gal/day or 7.6 L/day
3) Solar distillation * with a humidification-dehumidification cycle	Florida	salty water	4.3 gal/day or 16.3 L/day
4) Solar distillation **	Florida	salty water	0.8 gal/day or 3.0 L/day
5) Bottled water: microfiltration/RO/ ozonation	Ocala, Florida	Ocala's tap water (from the Floridan aquifer)	13.5 E3 gal/day or 51.1 m^3/day

* production flows are per 2.0 m^2 of solar collector surface area.
** production flows are per 1.0 m^2 of effective evaporating surface area.

1) Groundwater Source: Home Filtration.

Figure 12 illustrates a schematic diagram of a home filter that produces 10 gal/day (37.9 L/day) of purified water. The schematic shows how either water coming from public supply or private wells are fed through the filter system, which is commonly placed under the kitchen sink. Only the second option (private well) was evaluated. The filter system consist of: 1) a reverse osmosis membrane for removing any water-born pathogens, 2) a micron filter for removing small solids, and 3) a carbon filter for absorbing unpleasant tastes and odors. After filtration the water is stored in a 2.5 gal (9.5 L) reservoir tank, which is connected to the kitchen faucet. A valve in the faucet is used to switch between filtered or regular water.

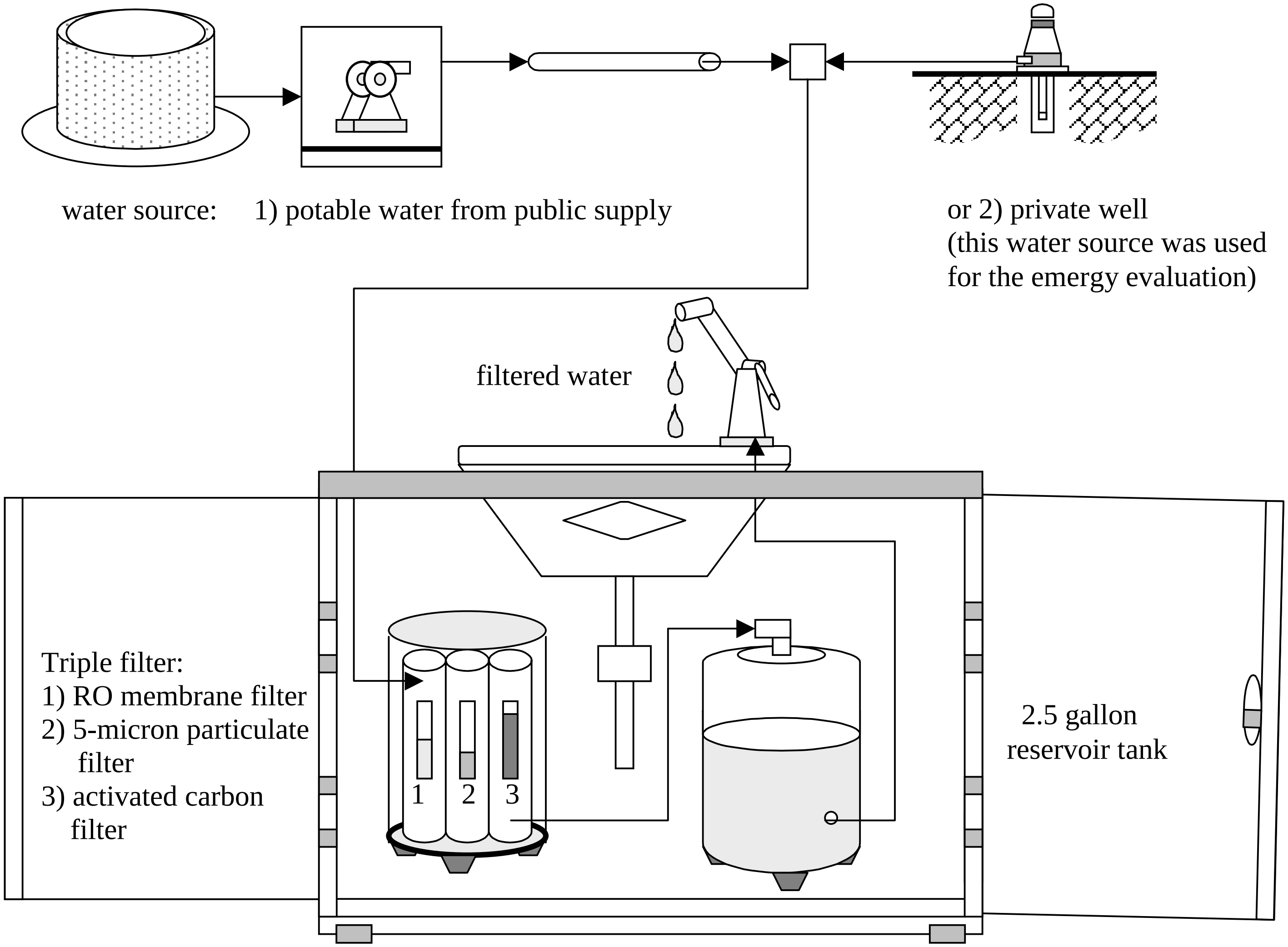


Figure 12. Schematic of the production of purified water with a home filter.

2) Groundwater Source: Boiling Water.

A schematic diagram of the process of boiling water in an average home in Florida is given in Figure 13. The daily volume of boiled water used for evaluation was 2.0 gal (7.6 L). First water from a kitchen sink is added to a pot. Then the pot is covered and placed on a range (stove), and the stove turned on. Finally, after ten minutes of vigorous boiling the range is tuned off and the water left to cool.

3) Salty Water Source: Advanced Solar Distillation (Humidification-Dehumidification Cycle).

The schematic of a solar distillation system that produces approximately 4.0 gal/day (15.0 L/day) of drinking water with a 2.0 m^2 solar collector is given in Figure 15. This distillation process integrates a humidification-dehumidification cycle to increase the water production capacity. The purpose of this cycle is to use the latent heat of condensation to preheat the seawater going into the solar collector. The preheated seawater passes through the solar collector where the water is further heated but not condensed. Then this water passes through a humidifier where some water evaporates and the rest leaves the system. Cool air blows through the humidifier and carries the water vapor to the condenser. The water vapor is then condensed as the hot moist air flows through the condenser. The fresh water is collected at the bottom of the condenser unit but the now cold dry air moves to the humidifier to close the cycle. Since this distiller works by condensing water vapor in the air moving through the system and not directly condensing seawater inside a distiller, large flows of seawater are required to operate this system.

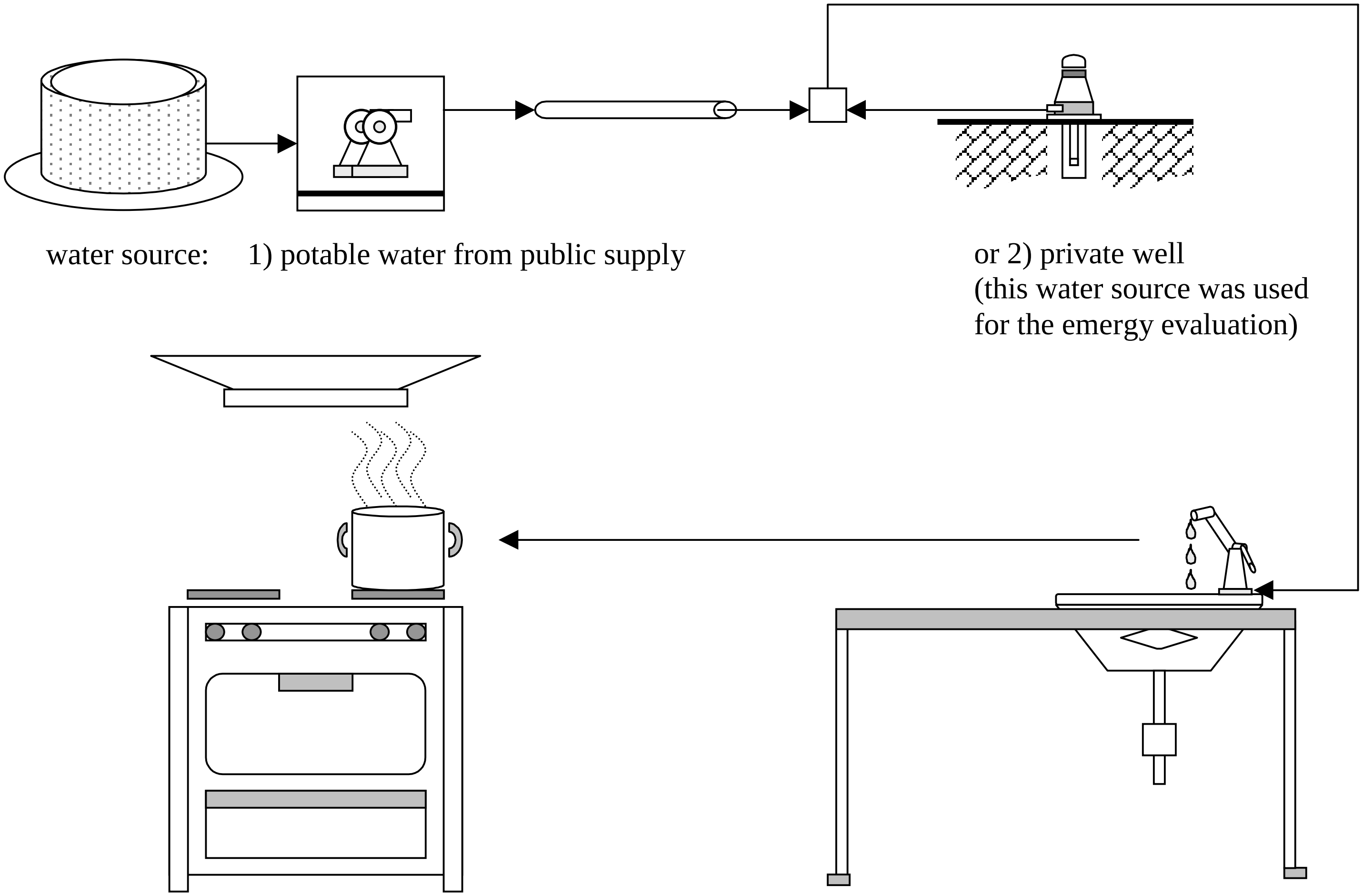
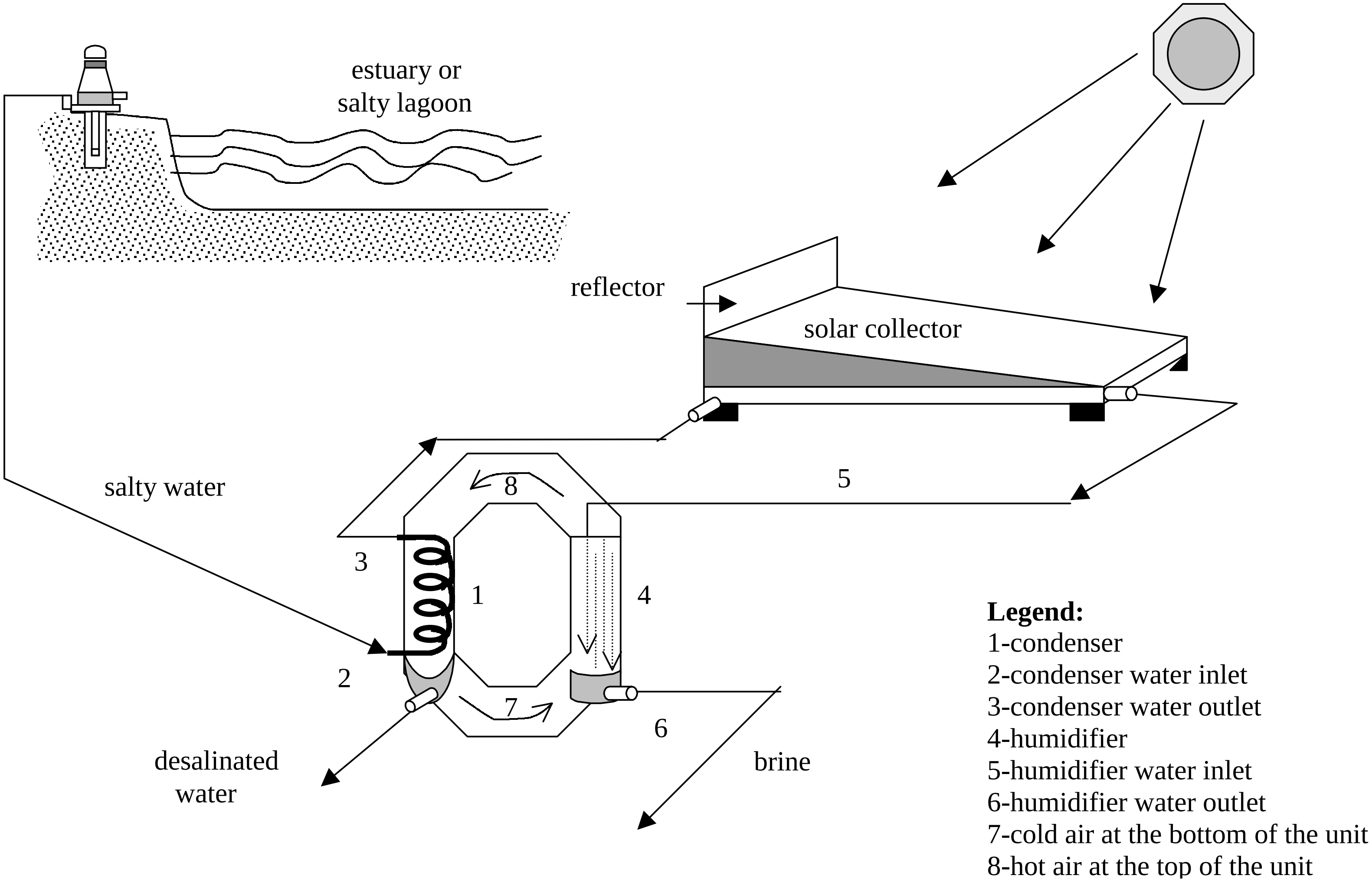


Figure 13. Schematic diagram of boiling water.



Legend:
1-condenser
2-condenser water inlet
3-condenser water outlet
4-humidifier
5-humidifier water inlet
6-humidifier water outlet
7-cold air at the bottom of the unit
8-hot air at the top of the unit

Figure 14. Schematic diagram of an advanced solar distillation process containing a humidification-dehumidification cycle.

4) Salty Water Source: Traditional Solar Distillation.

Figure 15 shows a schematic diagram of a common solar distillation unit that produces approximately 0.8 gal/day (3.0 L/day) of drinking water per m^2 of effective evaporating area. Salty water is hand-delivered to the distiller as required. Inside the distiller, the seawater slowly evaporates and condenses on the glass of the unit. The condensed (distilled) water is collected and the excess saltwater recycled or discarded. The main structure of the unit is made of fiberglass and covered with a one cm-thick glass. A jute cloth is used inside the distiller to act as a humidifier to increase the rate of evaporation. To maximize evaporation efficiency, the outer glass has to be cleaned once a week.

5) Tap Water Source: Purified Bottled Water.

In 1999 Culligan Co. in Ocala, Florida, sold roughly 2,700 five-gallon (18.9 L) bottles of purified water every day. A schematic of the bottling and delivery process is illustrated in Figure 16. The already potable water from the city of Ocala is softened and then passed through a carbon filter to remove any bad taste and odors (e.g., chlorine). After this, the water is fed through an RO filter and the brine is sent to the city's sewer system. The treated water is stored in a storage tank and then passed through another carbon filter. After this, the water is disinfected with ozone and radiated with ultraviolet light to kill any pathogens still remaining. Then, the water is re-filtered and re-ozonated before being bottled into sterilized 5-gallon plastic jugs. Finally, the water bottles are road-delivered to consumers.

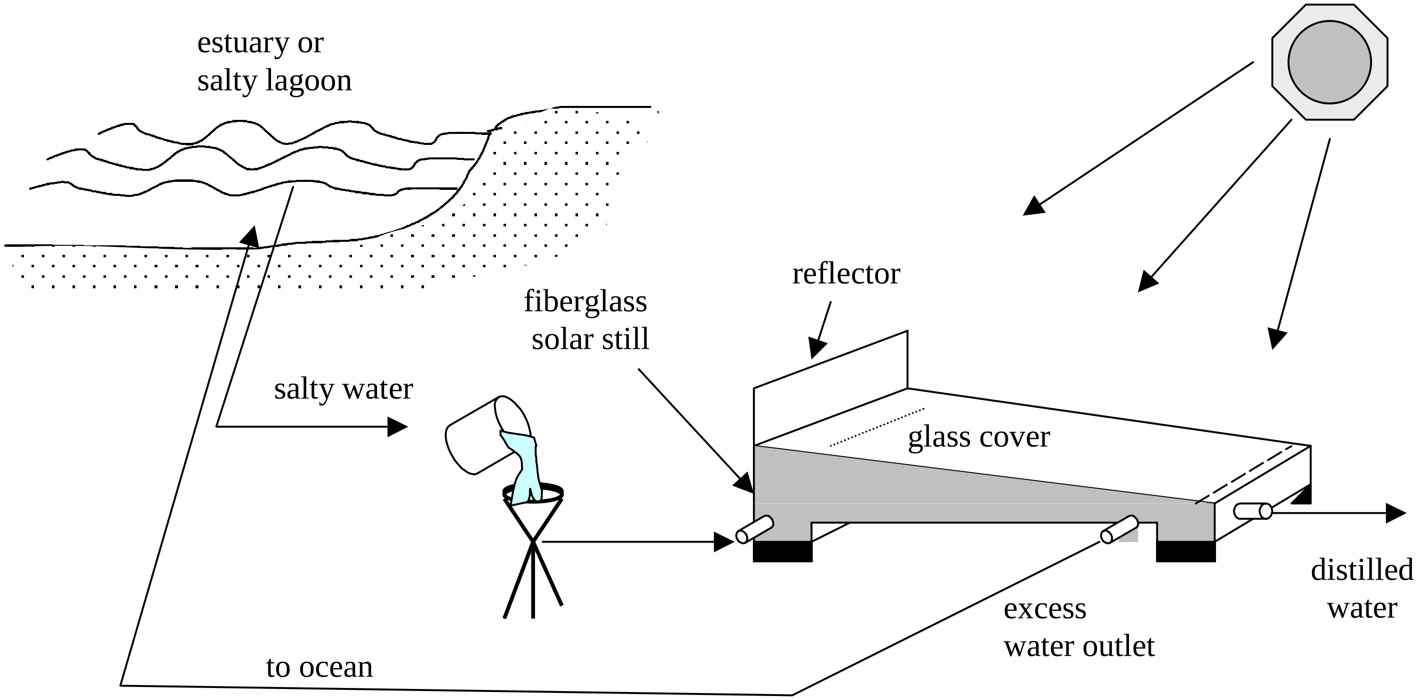


Figure 15. Schematic of a traditional solar distiller.

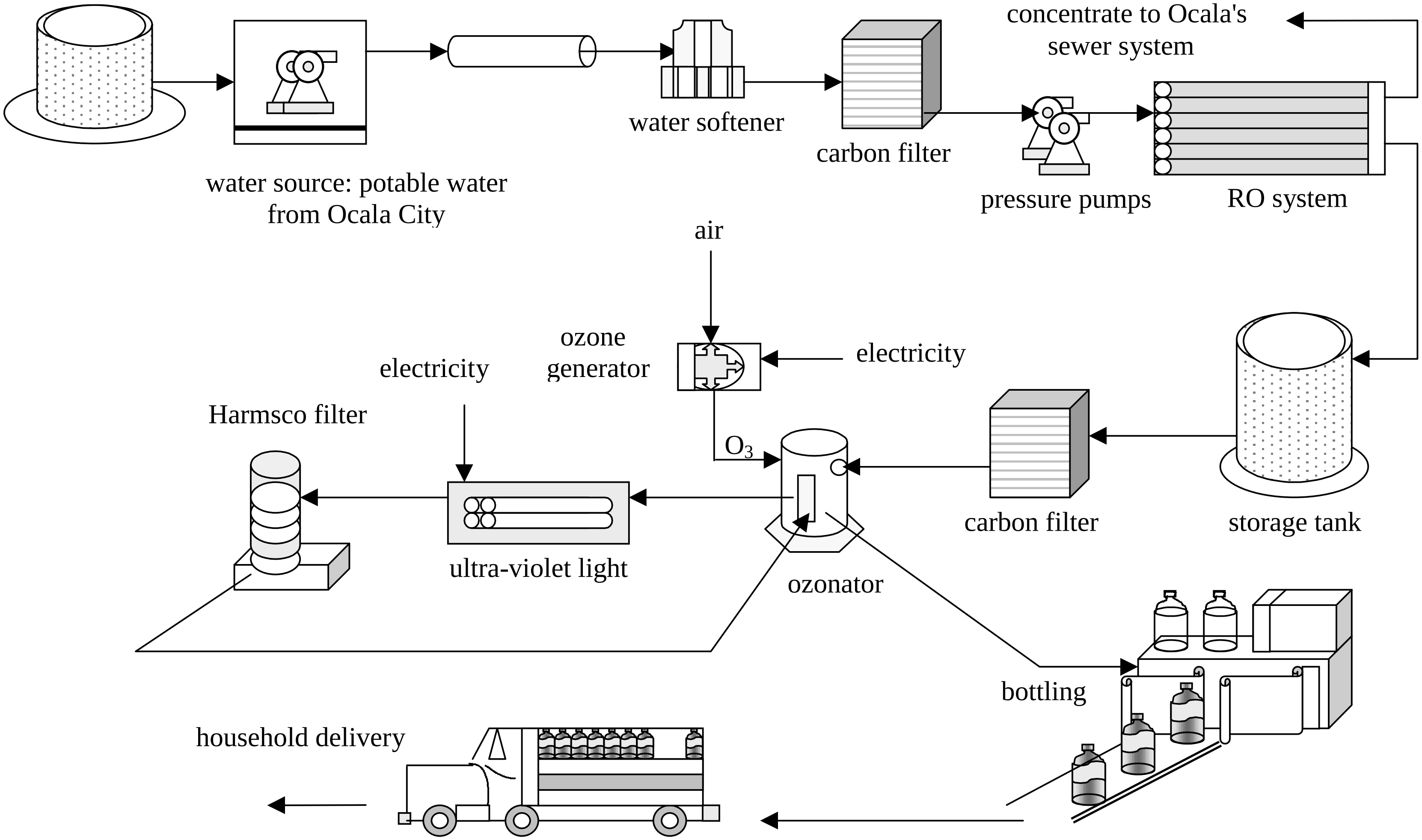


Figure 16. Schematic of the production of purified bottled water in Ocala, Florida.

Computer Simulation of Water Allocation

The main purpose of this model was to explore what allocation of water, among the natural, agricultural, and urban sectors, maximizes total regional production. The state of Florida was used as a case study (i.e., the region) for this water allocation simulation.

Analysis and Diagramming

Systems diagrams were drawn to understand the relation between Florida's water resources, the environment, agriculture, and the urban economy. After several revisions, one diagram was selected to define the simulation equations, which are implicit in systems language (Odum, 1994). The system diagram used for the simulation is given in Figure 17.

Structure of the Model

The model relates production in three sectors of the economy (urban, agricultural and environmental) to availability of purchased goods, fuels and services and the allocation of water. A systems diagram of the simulation model is given in Figure 17. Each sector has its own production function. In the urban sector, production is a function of imported fuels, goods and services to the urban economy ($FF*S_1$) and available water allocated to this sector (AW*Fu). Production in the agricultural sector is a function of sunlight (R), imported fuels goods and services for agriculture ($FF*S_2$) and available water for the agricultural sector (AW*FA). Environmental production is a function of sunlight (R) and available water to the environment (Fe). Here the fraction of regional available water (AW) is not multiplied by the fraction of water allocated to the environment (Fe) since AW is based on environmental production (Pe), which is a function of Fe. Purchased fuels goods and services (FF) result from the sale of exports from each of the sectors. Thus ultimately, the "health" of the regional economy is largely determined by its export base. The greater the exports, the greater the imports.

The model generates production curves for each sector, and for the regional economy. Each sector has a production function that generates an index of total product from that sector. The regional product is calculated in two ways: as a product function of the three sectors and as an empower function (addition of empowers from each of the sectors). Sector production functions used a simple product of each of the inputs as follows:

$$Pu = k_3*(FF*S_1)*(AW*Fu) \tag{1}$$
$$Pa = k_4*R*(FF*S_2)*(AW*Fa) \tag{2}$$
$$Pe = k_5*R*Fe \tag{3}$$

and:

$$R = J / [1 + (k_2*AW*Fa*FF*S_2 + k_1*Fe)] \tag{4}$$
$$FF = k_{10}*Pu + k_{11}*Pa + k_{12}*Pe \tag{5}$$
$$Fe + Fa + Fu = 1 \tag{6}$$
$$AW = k_6*Pe \tag{7}$$

where:

Pu = Total production from the urban sector.
Pa = Total production from the agricultural sector.
Pe = Total production from the environment.
R = Remainder of insolation (solar energy not directly converted by plants to a higher form of energy)
Fu = Fraction of total renewable freshwater used in the urban sector.
Fa = Fraction of total renewable fresh water used in the agricultural and forestry sectors.
Fe = Fraction of total renewable fresh water used in the environment (including estuaries and coastal ecosystems)
AW = Available water (renewable fresh surface and ground water)
FF = Total purchased goods, energy and services used in regional economy
S_1 = Fraction of purchased goods, energy and services from

the economy used in the urban sector.
S_2 = Fraction of purchased goods, energy and services from the economy used in the agricultural sector.
k_1-k_6, k_{10}-k_{12} = coefficients

The regional macro economic production function (an Index of Regional Production) was calculated as the product of the three sectors as follows:

$$TP = k_{14}*(Pe*Pa*Pu) \quad (8)$$

One can think of TP as regional gross economic product where the factors of production are the output from each of the sectors. Output from each sector is calibrated in physical units of material (g/yr) and the production indices include internal cycling. The available water (AW) factor relates the production in the urban and agricultural sectors to the amount of water captured and made available by the environment. As more water is used in the urban sector the environment is impacted, decreasing the overall availability of regional freshwater resources.

The second regional function is an index of regional Empower and is the sum of the emergy output from each sector as follows:

$$TMP = (Pe*te)+(Pa*ta)+(Pu*tu) \quad (9)$$

where:

te = transformity of environmental production (sej/J of biomass)
ta = transformity of agricultural production (sej/J of crops)
tu = transformity of urban production (sej/J)

This function is an index of total empower of the regional economy. Since emergies are additive, not multiplicative, the index is a summation of emergy outputs from each sector obtained by multiplying output of each sector by an average transformity for that sector.

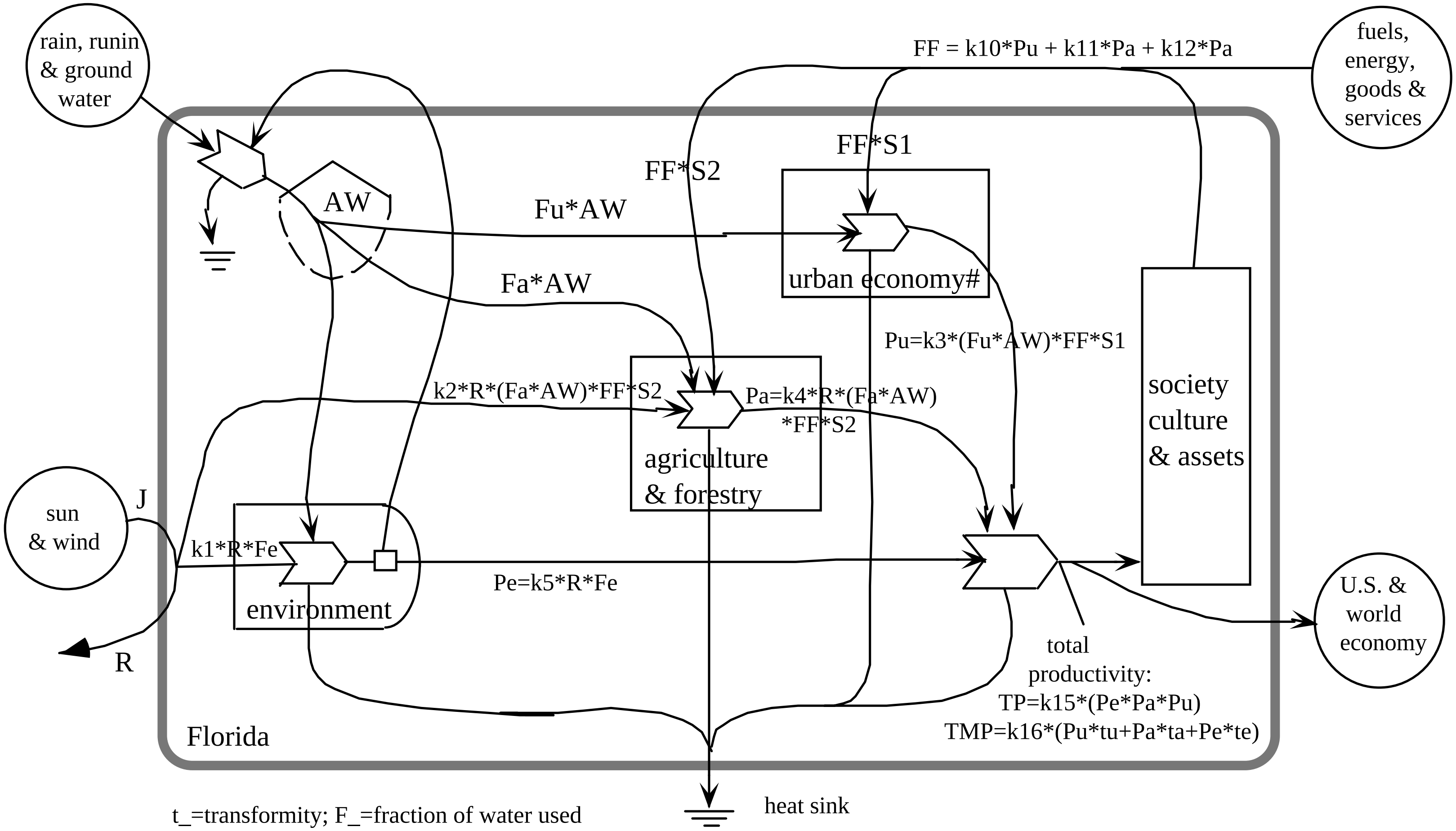
Simulation of the regional model was done to evaluate allocation of water between sectors of the economy. The hypothesis was that there should be some allocation scheme that maximizes total product as well as a scheme that maximizes empower. An open question was whether the same allocation scheme would maximize both total regional production and empower. The model was simulated in quasi-steady state where the allocation of water was varied between each of the sectors. The allocation of available water in the region was varied from 0% to 100% for each of the sectors and production under each scenario was calculated using the production functions. A table of coefficients, notes, and references for the models is included in Appendix E.

Computer Simulation

Excel spreadsheets were used to calibrate, program and simulate the model. A simulation graph plotted the changes in productivity (Pu, Pa, Pe, TP and TMP) as a function of the fraction of renewable water allocated to the urban sector (Fu).

Sensitivity Analysis

The effects of changing FF and its distribution between the urban and agricultural sectors on the model's output was explored as part of the sensitivity analysis. Changes in k_{10} where used to trigger changes in FF, whereas different combinations of S_1 and S_2 (always summing 1) were used to represent changes in the distribution of FF between these two sectors.



t_=transformity; F_=fraction of water used

AW = available water (renewable fresh surface water & ground water)

includes industry, manufacturing, construction, tourism, and other services.

Figure 17. Model of water allocation for maximizing the total production of Florida.

RESULTS

Emergy evaluations and simulation modeling of the values of water are given in the following sections. First the results of global and regional evaluations of the main flows and storages of water are provided, then the results of evaluations of 8 potable water supply alternatives and 5 small scale, consumer oriented systems, are presented. Finally, simulation results of the computer model developed to test theories of water allocation that maximize regional production are given.

Global Water Resources

Emergy evaluations of the main storages and flows of water in the biosphere are summarized in Tables 8 and 9, respectively. The storages of water in Table 8 are arranged by increasing transformity, which is the result of increasing turnover times. Atmospheric water vapor has the lowest transformity, while polar ice and glaciers, because of their long turnover times, have the highest transformity. Since seawater is considered the "ground state" it has no chemical potential energy and therefore its transformity is zero. The energy for fresh water is calculated as the chemical potential relative to seawater. An average transformity for all fresh water in the biosphere is given in the last row of the table as the weighted average of all transformities. The weighted average is relatively high as a result of the large portion of biosphere water that is in polar ice and glaciers. Transformities for these water storages varied between 3.54 E3 sej/J for water vapor in clouds and 1.05 E6 sej/J for polar ice and glaciers.

In Table 9, the flows of water in the biosphere are listed in ascending order of transformity. Several different types of rainfall were calculated. These data represent global averages. Rainfall in any particular location could have higher or lower transformities based on the conditions of a particular area. The transformity of global surface runoff (5.79 E4 sej/J) is about 3 times the transformity of average rainfall on land (1.82 E4 sej/J) while global recharge (2.27 E5 sej/J) is more than 12 times that of rainfall on land. As the flow rates decrease transformities increase. The transformity of tropical rain on land (3.19 E4 sej/J) is about 3.8 times greater than that of tropical rain on both land and water (8.43 E3 sej/J). Similarly, the transformity of temperate rain on land (2.43 E4 sej/J) is approximately 3.3 times greater than the transformity of temperate rain on both land and water (7.46 E3 sej/J).

Figure 18 summarizes the principal storages and flows of the global hydrologic cycle. This diagram includes storage turnover times, volumes and transformities (except oceans and salty lakes) as well as the rates and transformities of water flows.

Table 8. Distribution and emergy values of global water storages.

water stock	average (a) replacement time (yrs)	volume (a) (x1000 km^3)	% of water reserve		Emergy (b) per mass (sej/g)	Emergy (c) per volume (sej/m^3)	Transformity (d) (chem. potential) **(sej/J)**	Em-dollars (e) per volume (Em$/$m^3$)	Total Em$ (f) of water storage (trillion Em$)
			of total water	of fresh water					
World ocean *	3,278	1,370,000	97.3	-					
Saline lakes *	25	104	0.007	-					
water vapor in clouds	0.00015	0.08	0.00001	0.0002	1.75E+04	1.75E+10	3.54E+03	0.01	0.001
Atmospheric vapor	0.026	14	0.001	0.04	1.77E+04	1.77E+10	3.59E+03	0.01	0.12
Soil & subsoil water	0.77	67	0.005	0.18	1.08E+05	1.08E+11	2.19E+04	0.05	3.6
Freshwater lakes	3	125	0.009	0.33	2.27E+05	2.27E+11	4.59E+04	0.11	14.2
Biological water	0.05	2.1	0.0002	0.006	2.44E+05	2.44E+11	4.94E+04	0.12	0.26
Rivers and streams	0.04	1.2	0.0001	0.003	3.23E+05	3.23E+11	6.54E+04	0.16	0.19
Wetland water	1	11.5	0.001	0.03	8.21E+05	8.21E+11	1.66E+05	0.41	4.7
Fresh groundwater	994	8,350	0.59	22.2	1.12E+06	1.12E+12	2.27E+05	0.56	4,692
Polar ice and glaciers	16,000	29,000	2.06	77.2	5.21E+06	5.21E+12	1.05E+06	2.60	75,520
Total freshwater resources	12,571	37,571		100	3.16E+06	3.16E+12	6.39E+05	1.58	59,335

It was assumed that all global water storages are co-products of the global empower base (9.44 E24 sej/yr).

* emergy and transformity are 0.0 since salt water is considered the ground state.

(a) From Wetzel (1975; p. 1), **except:**

1) replacement times: oceans from Suomi (1992); biological water replacement times were assumed to be 20 days; wetland replacement time was assumed to be one year; the groundwater replacement time was calculated by dividing the groundwater reservoir (8.35 E6 km^3) by 8,400 km^3/yr, the annual renewable groundwater flow. This flow was estimated assuming that 8% of the global precipitation on land infiltrates the ground: 105,000 km^3/yr * 0.08 = 8,400 km^3/yr. The replacement time for total water reserves represents the weighted average of all storage replacement times. Similarly, the replacement time of total fresh water reserves represents the weighted average of all fresh water replacement times.

2) volumes: groundwater (up to a depth of 4,000 m) from van der Leeden (1975); wetland water from Gleick (1993); and biological water from Anthes (1997; p. 46).

(b) sej/g = (9.44 E24 sej/yr)(turn over time) / [(km^3)(1 E9 m^3/km^3)(1E6 g/m^3)]

(c) sej/m^3 = (sej/g)(1 E6 g/m^3)

(d) Water carries different available energies (e.g. Gibbs free energy of its chemical potential, geopotential, thermal gradient potential) from which transformities can be calculated (Odum, 1994). In this table, transformities were calculated using the chemical potential energy of fresh water (10 ppm) relative to seawater (35,000 ppm), with a Gibbs free energy of 4.94 J/g. Thus, sej/J = (sej/g) / (4.94 J/g). Since transformities were calculated using the chemical potential energy of freshwater relative to ocean water, the transformities of saline waters (e.g. ocean water) do not have chemical potential energy and, thus, their chemical potential energy-transformity is zero.

(e) Em$/$m^3$ = (sej/m^3) divided by 2.0 E12 sej/$, which is the world emergy per dollar ratio; sej/$ from Odum (1996; p. 201)

(f) Em$ = (9.44 E24 sej/yr)(replacement time in yrs)/(2.0 E12 sej/$)

Table 9. Distribution and emergy values of global water flows.

Note	water flow	annual (a) flow rate (E3 km^3/yr)	Emergy (b) per mass (sej/g)	Emergy (c) per volume (sej/m^3)	Transformity (d) (chem. potential) **(sej/J)**	Em-dollars (e) per volume (Em\$/m^3)
1	Evaporation	483	1.95E+04	1.95E+10	3.96E+03	0.01
2	from oceans	418	2.26E+04	2.26E+10	4.57E+03	0.01
3	from land areas*	65	1.45E+05	1.45E+11	2.94E+04	0.07
4	Precipitation	483	1.95E+04	1.95E+10	3.96E+03	0.01
5	to oceans	378	2.50E+04	2.50E+10	5.06E+03	0.01
6	Temperate rain	256	3.68E+04	3.68E+10	7.46E+03	0.02
7	Tropical rain	227	4.16E+04	4.16E+10	8.43E+03	0.02
8	to land **	105	8.99E+04	8.99E+10	1.82E+04	0.04
9	Temperate rain on land **	79	1.20E+05	1.20E+11	2.43E+04	0.06
10	Tropical rain on land	60	1.57E+05	1.57E+11	3.19E+04	0.08
11	Surface runoff to oceans	33.0	2.86E+05	2.86E+11	5.79E+04	0.14
12	Global groundwater recharge	8.4	1.12E+06	1.12E+12	2.27E+05	0.56
13	Ice melt	2.0	4.72E+06	4.72E+12	9.55E+05	2.36

It was assumed that all global water flows are co-products of the global empower base (9.44 E24 sej/yr).

* includes plant transpiration

** including frozen land

(a) Annual flow rates for notes 1, 2, 3, 4, 5, 8, 12 and 13 were obtained from Suomi (1992; p.20)

6) The volumetric flow rate of <u>temperate rain</u> was assumed to be the difference between global precipitation (483 E3 m^3/yr) and tropical rainfall (227 E3 km^3/yr), which estimation is described below.

7) The volumetric flux of <u>tropical rainfall</u> was estimated by using 1.26 m/yr of precipitation over the tropical surface are of the world (1.8 E8 km^2). The 1.26 m/yr was estimated from a global average rainfall map given in Hammond Atlas of the World (1999; p.31). The tropical surface are was calculated by multiplying the total surface area of the world (5.1 E8 km^2) by 0.354, which represents the ratio of tropical surface area (between latitudes 23.5° N and 23.5° S) to non-tropical area (23.5° N to 90° N plus 23.5° S to 90° S).

9) The flow rate of <u>temperate rain on land</u> was estimated by multiplying the avg. global temperate precipitation (0.78 m/yr) by the temperate (i.e. non-tropical) land area of the world (10.13 km^2). The global temperate precipitation was estimated by dividing the temperate rain (256 E3 km^3/yr) by the difference between the world's surface area (5.1 E8 km^2) and the tropical area (1.8 E8 km^2). The temperate land area (10.13 km^2) was estimated from subtracting the tropical land area (4.76 E7 km^2) from the total world land area (14.89 E7 km^2). Land areas were obtained from Hammond Atlas of the World (1999).

10) <u>Tropical rain on land</u> was estimated using 1.26 m/yr for tropical precipitation and the tropical land area of the world (4.76 E7 km^2). This area was estimated by summing the area of all countries within latitudes 23.5° N and 23.5° S using maps and country areas given in Hammond Atlas of the World (1999).

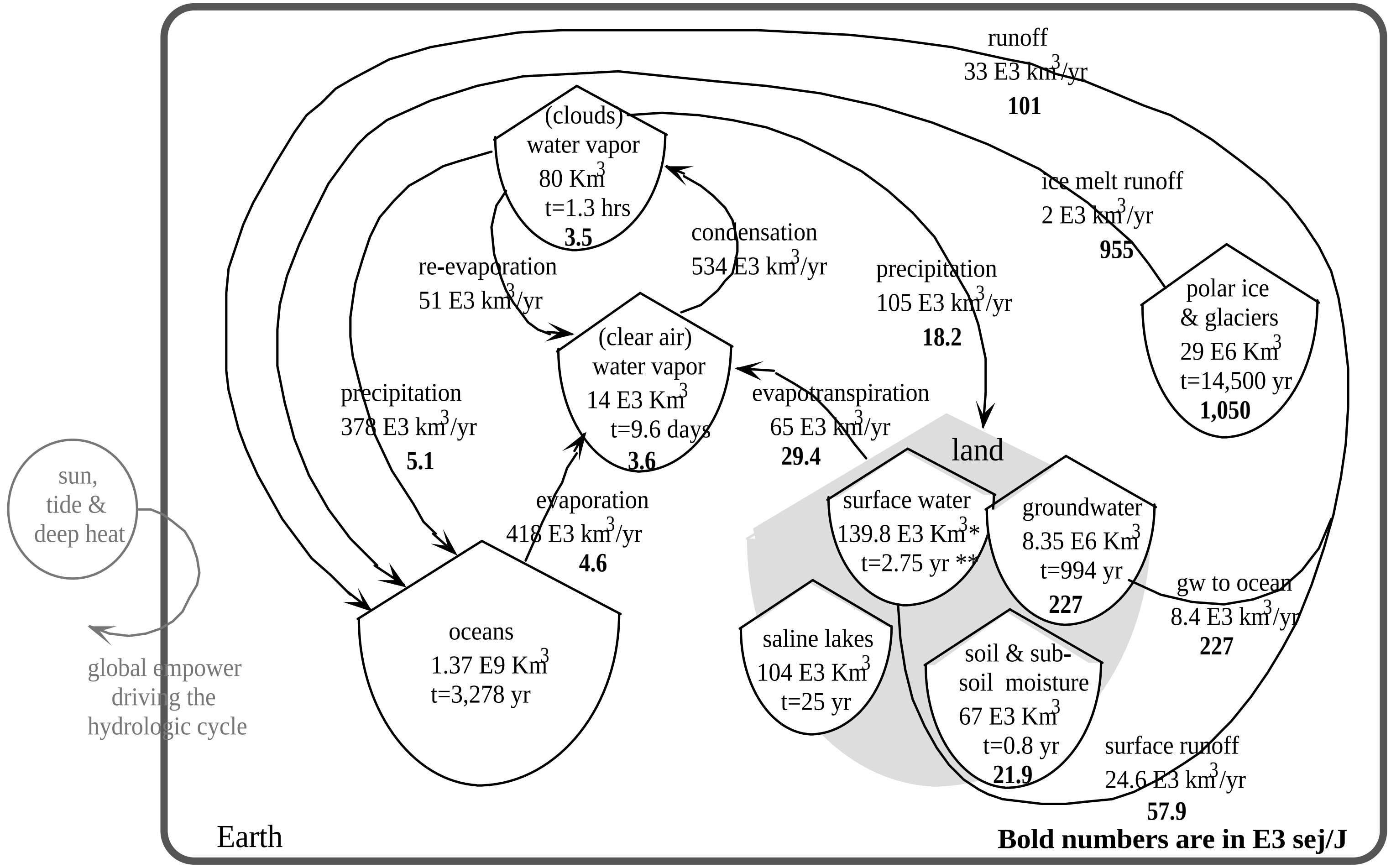
11) The <u>global groundwater recharge</u> was estimated by assuming that 8% of land precipitation infiltrates the ground and accumulates as groundwater.

(b) sej/g = (9.44 E24 sej/yr) / [(km^3/yr)(1 E9 m^3/km^3)(1E6 g/m^3)]

(c) sej/m^3 = (sej/g)(1 E6 g/m^3)

(d) transformities were calculated using the chemical potential energy of fresh water (10 ppm) relative to seawater (35,000 ppm), with a Gibbs free energy of 4.94 J/g: sej/J = (sej/g) / (4.94 J/g)

(e) Em\$/m^3 = (sej/m^3) divided by 2.0 E12 sej/\$, which is the world emergy per dollar ratio; sej/\$ from Odum (1996; p. 201)



* = sum of volumes & ** = prorated turnover time:
lake water (125 E3 km^3, t=3 yr, 45.9 E3 sej/J), river water (1.2 E3 km^3, t=0.04 yr, 65.4 E3 sej/J),
wetland water (11.5 E3 km^3, t=1 yr, 166.0 E3 sej/J), and biological water (2.1 E3 km^3, t=0.05 yr, 49.4 E4 sej/J).

Figure 18. The global hydrologic cycle. Reservoirs include volume (km^3), average replacement time (t) and transformities (bold numbers). Global water flows are given in km^3/yr and bold numbers represent water transformities in E3 sej/J.

Emergy Evaluation of Regional Water Flows and Storages

The emergy evaluation of intertidal water (estuaries) and river water in Florida are given in Tables 10 and 11, respectively. The most important numbers in these and the rest of the emergy tables consist of the water transformity and total sej/m^3 values. The sej/yr values shown in Table 11 represent the emergy of all the river water flowing through Florida every year. The sej/m^3 values indicate the average emergy per volume of river water in Florida. The emergy of river water was used as the input to intertidal water. Tables 12 and 13 show the results from the emergy evaluations for lake-pond and wetland waters, respectively. Table 14 summarizes the results from the emergy evaluations of Florida's surface water resources.

Florida groundwater resources are typically divided into three aquifer systems: 1) the surficial, including the Sand and Gravel and the Biscayne aquifers; 2) the Intermediate; and 3) the deep (i.e., the Floridan) aquifer. Results of the emergy evaluation of surficial groundwater are given in Table 15. Table 16 and 17 show the results of the emergy evaluation of groundwater from Sand and Gravel and the Biscayne aquifers in northwestern and southeastern Florida, respectively. Both of these aquifers are also surficial systems but were evaluated separately because of their importance as regional water sources. The evaluation in Table 15 does not include the water from these two aquifers. Tables 18 and 19 show the results from the emergy evaluations of groundwater from the Intermediate and the Floridan aquifer systems, respectively. Table 20 summarizes the results of the emergy evaluations of Florida's groundwater resources.

Table 10. Emergy evaluation of Florida's intertidal water (water from estuaries, salt marshes and mangrove ecosystems).

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Emergy of all FL rivers	sej	1.69E+22	-	16,910	4.50
EMERGY PER UNIT OF INTERTIDAL WATER IN FLORIDA						
2	Intertidal water	g	3.83E+17	44,159	16,910	4.50
3	Intertidal water	m^3	3.75E+11	4.50E+10	16,910	4.50
4	Chem. energy of intertidal water	J	5.30E+17	**31,917**	16,910	4.50

Notes

1	Since tidal emergy is already included in the rain used to calculate the transformity of river water, no tidal emergy is added to the emergy of intertidal water.			
	Emergy of Florida's river water (based on rain fallen on total river/stream drainage area), sej			
	Emergy of major FL rivers:	sej/yr	1.69E+22	(Table 11)
2	Area of intertidal waters (Gulf coast)	km^2	12,000	(Livingston, 1990; p. 550)
	Area of intertidal waters (East coast)	km^2	2,400	20% of Gulf area (est. from Livingston, 1990)
	Total area of intertidal waters:	km^2	14,400	(Gulf coast area + East coast area)
	Avg. depth of intertidal waters	m	1.5	assumed
	Average vol. of FL intertidal waters:	m^3	2.16E+10	$(km^2)(1000\ m/km)^2(m)$
	Turnover time of estuarine water:	yr	0.06	3 weeks, assumed
	Annual volume of intertidal water:	m^3/yr	3.75E+11	$(m^3)/(yr)$
	Annual mass of intertidal water:	g/yr	3.83E+17	$(m^3/yr)(1.02\ E6\ g/m^3)$
	Emergy of intertidal water:	sej/yr	1.69E+22	from note 1
	Emergy/mass of intertidal water:	sej/g	4.42E+04	(sej/yr) / (g/yr)
3	Annual volume of intertidal water:	m^3/yr	3.75E+11	$(g/yr)/(1.02\ E6\ g/m^3)$
	Emergy of intertidal water:	sej/yr	1.69E+22	from note 1
	Emergy/volume of intertidal water:	sej/m^3	4.50E+10	$(sej/yr) / (m^3/yr)$
4	Avg. TDS of FL estuarine water:	ppm	25,000	assumed
	Avg. Gibbs free energy water:	J/g	1.38	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. energy of intertidal water:	J/yr	5.30E+17	(g/yr)(J/g)
	Emergy of intertidal water:	sej/yr	1.69E+22	from note 1
	Transformity of FL intertidal water:	sej/J	31,917	(sej/yr) / (J/yr)

Table 11. Emergy evaluation of Florida's river and stream water.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Rainfall on river watershed:	J	9.29E+17	18,200	16,910	20.31
EMERGY PER UNIT OF RIVER WATER IN FLORIDA						
2	River water:	g	8.33E+16	203,113	16,910	20.31
3	River water:	m^3	8.33E+10	2.03E+11	16,910	20.31
4	Chemical pot. energy of river water:	J	3.97E+17	**42,586**	16,910	20.31

Notes

1	Florida's drainage area:	mi^2	98,000	measured from Fernald and Purdum (1998; p.66) includes all of FL and parts of GA and AL
	Effective drainage river drainage A:	mi^2	53,900	est. from maps in Fernald and Purdum (1998; p. 67)
	Annual rainfall on drainage area:	in/yr	53	(Fernald and Purdum, 1998)
	Rainfall on effective drainage area:	gal/yr	4.97E+13	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254 m/in)(264.2gal/m^3)
	Chem. potential energy of rainfall:	J/yr	9.29E+17	(gal/yr)(1E6 g/m^3)(4.94 J/g)/(264.2 gal/m^3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Avg. flow of major rivers in FL:	m^3/sec	2,640	(Nordlie, 1990; p.398)
	Avg. flow of major rivers in FL:	m^3/yr	8.33E+10	(m^3/sec)(3,600 sec/hr)(24 hr/day)(365 day/yr)
	Annual mass of river water:	g/yr	8.3E+16	(m^3/yr)(1 E6 g/m^3)
	Emergy per mass of river water:	sej/g	2.0E+05	(sej/yr from line 1) / (g/yr)
3	Avg. annual flow of river water:	m^3/yr	8.33E+10	(g/yr)/(1 E6 g/m^3)
	Emergy/volume of river water:	sej/m^3	2.03E+11	(sej/yr from line 1) / (m^3/yr)
4	Prorated hardness of major FL rivers:	ppm	62	(Nordlie, 1990; p.399)
	Avg. dissolved solids (TDS) of FL rivers:	ppm	89	(assuming hardness = 70% of TDS)
	Avg. Gibbs free energy of FL's rivers:	J/g	4.77	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. Potential energy of FL river water:	J/yr	3.97E+17	(g/yr)(J/g)
	Transformity (chem. pot.) of river water:	sej/J	42,586	(sej/yr from line 1) / (J/yr)

Table 12. Emergy evaluation of Florida's lake water.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Rainfall on lake's drainage area:	J	2.53E+17	18,200	4,612	26.87
EMERGY PER UNIT OF LAKE WATER IN FLORIDA						
2	Lake water	g	1.72E+16	268,653	4,612	26.87
3	Lake water	m^3	1.72E+10	2.69E+11	4,612	26.87
4	Chemical energy of lake water	J	8.17E+16	**56,427**	4,612	26.87

Notes

1	Florida's drainage area:	mi^2	98,000	measured from Fernald and Purdum (1998; p.66) includes all of FL and parts of GA and AL
	Lake's drainage area:	mi^2	14,700	estimated from Fernald and Purdum (1998; p. 67)
	Annual rainfall on lake drainage area:	in/yr	53	(Fernald and Purdum, 1998)
	Annual rainfall on lake drainage area:	gal/yr	1.36E+13	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254 m/in)(264.2 gal/m^3)
	Chem. potential energy of rainfall:	J/yr	2.53E+17	(gal/yr)(1E6 g/m^3)(4.94 J/g)/(264.2 gal/m^3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Tot. area of lakes > 0.4 ha in Florida:	km^2	9,270	(Brenner et al., 1990; p. 364)
	Avg. depth of Florida lakes	m	5.0	estimated from (Brenner et al., 1990; p. 365)
	Average volume of Florida lakes:	m^3	4.64E+10	(km^2)(1000 m/km)^2(m)
	Mean residence time of Florida lakes:	yr	2.7	(Brenner et al., 1990; p. 372)
	Annual volume of lake water:	m^3/yr	1.72E+10	(m^3)/(yr)
	Annual mass of lake water:	g/yr	1.72E+16	(m^3/yr)(1 E6 g/m^3)
	Emergy per mass of lake water:	sej/g	2.7E+05	(sej/yr from line 1) / (g/yr)
3	Annual volume of lake water:	m^3/yr	1.72E+10	(g/yr)/(1 E6 g/m^3)
	Emergy per volume of lake water:	sej/m^3	2.69E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg. dissolved solids (TDS) of FL lakes:	ppm	151	(Brenner et al., 1990; p. 378)
	Avg. Gibbs free energy of FL's lake water:	J/g	4.76	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. Potential energy of FL lake water:	J/yr	8.17E+16	(g/yr)(J/g)
	Transformity (chem. pot.) of lake water:	sej/J	56,427	(sej/yr from line 1) / (J/yr)

Table 13. Emergy evaluation of Florida's wetland (freshwater marshes & swamps) water.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Rainfall on wetland drainage area:	J	5.07E+17	18,200	9,224	33.76
EMERGY PER UNIT OF WETLAND WATER IN FLORIDA						
2	Wetland water:	g	2.73E+16	337,584	9,224	33.76
3	Wetland water:	m^3	2.73E+10	3.38E+11	9,224	33.76
4	Chemical pot. energy of wetland water:	J	1.30E+17	**70,905**	9,224	33.76

Notes

1	Florida's drainage area:	mi^2	98,000	measured from Fernald and Purdum (1998; p.66) includes all of FL and parts of GA and AL
	Wetland drainage area:	mi^2	29,400	estimated from Fernald and Purdum (1998; p. 67)
	Rainfall on wetland drainage area:	in/yr	53	(Fernald and Purdum, 1998)
	Rainfall on wetland drainage area:	gal/yr	2.71E+13	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254 m/in)(264.2gal/m^3)
	Chem. potential energy of rainfall:	J/yr	5.07E+17	(gal/yr)(1E6 g/m3)(4.94 J/g)/(264.2 gal/m3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Surface A of freshwater wetlands in FL:	mi^2	10,541	(Fernald and Purdum, 1998; p. 3)
	Avg. depth of Florida wetlands:	m	0.5	assumed
	Average volume of Florida wetlands:	m^3	1.37E+10	(mi^2)(1,610 m/mi)^2(m)
	Mean residence time of Florida wetlands:	yr	0.5	assumed
	Annual value of wetland water:	m^3/yr	2.73E+10	(m^3)/(yr)
	Annual mass of wetland water:	g/yr	2.73E+16	(m^3/yr)(1 E6 g/m^3)
	Emergy per mass of wetland water:	sej/g	3.4E+05	(sej/yr from line 1) / (g/yr)
3	Annual value of wetland water:	m^3/yr	2.73E+10	(g/yr)/(1 E6 g/m^3)
	Emergy/volume of wetland water:	sej/m^3	3.38E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg.diss. solids (TDS) of FL wetlands:	ppm	151	assuming the same as lakes (Brenner et al., 1990; p. 378)
	Avg. Gibbs free energy of wetland water:	J/g	4.76	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. potential energy of wetland water:	J/yr	1.30E+17	(g/yr)(J/g)
	sej/J (chem. pot.) of wetland water:	sej/J	70,905	(sej/yr from line 1) / (J/yr)

Table 14. Summary of emergy evaluation of Florida's surface water resources.

	Fresh surface water values					
Surface water type	volume (a) (E9 m^3)	(b) **sej/J**	(c) sej/g	sej/m^3 (d) (xE10)	Em$/yr (e) (xE9)	Em$/$m^3$ (f) year 2000
Intertidal *	21.6	31,917	44,159	4.50	18.58	0.05
River	8.3	42,586	203,113	20.31	18.58	0.22
Lake	46.4	56,427	268,653	26.87	5.07	0.30
Wetland	13.7	70,905	337,584	33.76	10.14	0.37
Total:	76.3				42.23	
Fresh surface water average #:		57,630	219,136	21.93		0.24

* Includes waters on shallow bays, estuaries, salt marshes, mangroves and salty lagoons.

Average values were weighted to represent the proportion of the volume for each surface water type. To avoid double counting, the prorated average does not include the transformity of intertidal water since this is based on the emergy of river water.

(a) volume from tables 10, 11, 12 and 13.

(b) sej/J from tables 10, 11, 12 and 13.

(c) sej/g = (sej/J)(4.94 J/g)

(d) $sej/m^3 = (sej/g)(1\ E6\ g/m^3)$

(e) Em$/yr (year 2000) = $(m^3/yr)(sej/m^3)/(9.1\ E11\ sej/\$)$

(f) Em$/$m^3$ (year 2000) = $(sej/m^3)/(9.1\ E11\ sej/\$)$

Table 15. Emergy evaluation of fresh groundwater from Florida's Surficial aquifer system.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (xE10)
RENEWABLE RESOURCES						
1	Rainfall on rechargeable aquifer area:	J	8.20E+17	18,200	14,917	20.97
EMERGY/UNIT OF FRESH GROUNDWATER FROM THE SURFICIAL AQUIFER						
2	Surficial groundwater:	g	7.11E+16	209,732	14,917	20.97
3	Surficial groundwater:	m^3	7.11E+10	2.10E+11	14,917	20.97
4	Surficial groundwater:	J	3.37E+17	**44,300**	14,917	20.97

Notes

1	Recharge A of the Surficial aquifer:	mi^2	45,000	assumed to be 75% of aquifer surface area
	Annual rainfall on rechargeable area:	in/yr	56	(Fernald and Purdum, 1998; p.17)
	Annual flux of rainfall on recharge A:	gal/yr	4.38E+13	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254m/in)(264.2gal/m^3)
	Chem. potential energy of rainfall:	J/yr	8.20E+17	(gal/yr)(1E6 g/m^3)(4.94 J/g)/(264.2 gal/m^3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Surface A overlaying the aquifer:	mi^2	60,000	(Measured from Miller, 1990; p6)
	Porosity fraction of aquifer:		0.11	(0.65)(Avg. sand and limestone porosity) (Odum, 1996)
	Avg. aquifer thickness:	ft	70	Inferred from Miller (1990; p.6)
	Land volume of aquifer:	m^3	5.02E+12	(mi^2)(ft)(5,280 ft/mi)^2(0.305 m/ft)^3
	Volume of water in the aquifer:	m^3	5.71E+11	(land volume)(porosity)
	Average recharge rate:	ft/yr	2.0	Estimated from Fernald and Purdum (1998)
	Recharge area:	mi^2	45,000	Estimated from Fernald and Purdum (1998)
	Turn-over time:	yrs	8.0	(m^3) / [(ft/yr)(mi^2)(1 m / 3.28 ft)(1,610 m/mi)^2]
	Annual mass of groundwater:	g/yr	7.1E+16	(m^3)(1 E6 g/m^3) / (yrs)
	Emergy per mass of groundwater:	sej/g	2.1E+05	(sej/yr from line 1) / (g/yr)
3	Total m^3/yr of groundwater:	m^3/yr	7.11E+10	(g/yr)/(1 E6 g/m^3)
	Emergy/volume of groundwater:	sej/m^3	2.10E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg. total dissolved solids (TDS):	ppm	350	(Fernald and Purdum, 1998; p. 54)
	Gibbs free energy of Biscayne gw:	J/g	4.73	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. potential energy of gw:	J/yr	3.37E+17	(m^3)(J/g)(1E6 g/m^3)/(yrs)
	Transformity of surficial groundwater:	sej/J	44,300	(sej/yr from line 1) / (J/yr)

Table 16. Emergy evaluation of fresh groundwater from the Sand and Gravel aquifer system in NW Florida.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (xE10)
RENEWABLE RESOURCES						
1	Rainfall on rechargeable aquifer area:	J	8.66E+16	18,200	1,576	22.47
EMERGY/UNIT of FRESH GROUNDWATER from the SAND & GRAVEL AQUIFER						
2	Sand & Gravel groundwater:	g	7.01E+15	224,712	1,576	22.47
3	Sand & Gravel groundwater:	m^3	7.01E+09	2.25E+11	1,576	22.47
4	Sand & Gravel groundwater:	J	3.35E+16	**47,103**	1,576	22.47

Notes

1	Recharge A of the Sand & G. aquifer:	mi^2	4,225	assumed to be 65% of aquifer surface area
	Annual rainfall on rechargeable area:	in/yr	63	(Fernald and Purdum, 1998; p.17)
	Annual flux of rainfall on recharge A:	gal/yr	4.63E+12	$(mi^2)(1{,}610\ m/mi)^2(in/yr)(0.0254\ m/in)(264.2gal/m^3)$
	Chem. potential energy of rainfall:	J/yr	8.66E+16	$(gal/yr)(1E6\ g/m^3)(4.94\ J/g)/(264.2\ gal/m^3)$
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Porosity fraction of Sand & G. aquifer:		0.13	(0.65)(Avg. sand porosity) (Odum, 1996)
	Land volume of aquifer:	m^3	2.50E+12	calculated from Miller (1990; p7)
	Volume of water in the aquifer:	m^3	3.26E+11	(land volume)(porosity)
	Average recharge rate:	ft/yr	2.1	Estimated from Fernald and Purdum (1998)
	Recharge area:	mi^2	4,225	assumed to be 65% of aquifer surface area
	Turn-over time:	yrs	46.4	$(m^3)/[(ft/yr)(mi^2)(1\ m/3.28\ ft)(1{,}610\ m/mi)^2]$
	Annual mass of Sand & Gravel gw:	g/yr	7.0E+15	$(m^3)(1\ E6\ g/m^3)$ / (yrs)
	Emergy/mass of Sand & Gravel gw:	sej/g	2.2E+05	(sej/yr from line 1) / (g/yr)
3	Total m^3/yr of Sand & Gravel gw:	m^3/yr	7.0E+09	$(g/yr)/(1\ E6\ g/m^3)$
	Emergy/volume of Sand & Gravel gw:	sej/m	2.2E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg. total dissolved solids (TDS):	ppm	80	(Fernald and Purdum, 1998; p. 54)
	Gibbs free energy of Sand & Gravel gw:	J/g	4.77	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. Potential energy of S&G gw:	J/yr	3.35E+16	$(m^3)(J/g)(1E6\ g/m^3)/(yrs)$
	Transformity of Sand & Gravel gw:	sej/J	47,103	(sej/yr from line 1) / (J/yr)

Table 17. Emergy evaluation of fresh groundwater from the Biscayne aquifer system in South Florida.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (xE10)
RENEWABLE RESOURCES						
1	Rainfall on rechargeable aquifer area:	J	3.71E+16	18,200	675	28.46
EMERGY/UNIT OF FRESH GROUNDWATER FROM THE BISCAYNE AQUIFER						
2	Groundwater from the Biscayne:	g	2.37E+15	284,636	675	28.46
3	Groundwater from the Biscayne:	m^3	2.37E+09	2.85E+11	675	28.46
4	Groundwater from the Biscayne:	J	1.12E+16	**60,206**	675	28.46

Notes

1	Recharge area of the Biscayne aquifer:	mi^2	2,000	(Fernald and Purdum, 1984; p.37-38)
	Annual rainfall on rechargeable area:	in/yr	57	(Fernald and Purdum, 1998; p.17)
	Annual flux of rainfall on recharge A:	gal/yr	1.98E+12	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254 m/in)(264.2gal/m^3)
	Chem. potential energy of rainfall:	J/yr	3.71E+16	(gal/yr)(1E6 g/m^3)(4.94 J/g)/(264.2 gal/m^3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Surface A overlaying the Biscayne aquifer:	mi^2	3,200	(Fernald and Purdum, 1984; pp. 37-38)
	Porosity fraction of aquifer:		0.1	Estimated based on avg. limestone porosity
	Aquifer thickness:	ft	175	wedge shaped -(Fernald and Purdum, 1984; p. 37)
	Volume of the Biscayne groundwater:	m^3	2.21E+10	[(mi^2)(1,610 m/mi)^2][(ft / 2)(1 m/3.28 ft)](porosity)
	Average recharge rate:	ft/yr	1.5	(Fernald and Purdum, 1984; p. 37)
	Recharge area:	mi^2	2,000	(Fernald and Purdum, 1984; p. 38)
	Turn-over time:	yrs	9.3	(m^3) / [(ft/yr)(mi^2)(1 m/3.28 ft)(1,610 m/mi)^2]
	Annual mass of fresh Biscayne gw:	g/yr	2.4E+15	(m^3)(1 E6 g/m^3) / (yrs)
	Emergy per mass of Biscayne gw:	sej/g	2.8E+05	(sej/yr from line 1) / (g/yr)
3	Total volume/yr of Biscayne gw:	m^3/yr	2.4E+09	(g/yr)/(1 E6 g/m^3)
	Emergy per volume of Biscayne gw:	sej/m^3	2.8E+11	(sej/yr from line 1) / (gal/yr)
4	Avg. total dissolved solids (TDS):	ppm	400	(Fernald and Purdum, 1998; p. 54)
	Gibbs free energy of Biscayne gw:	J/g	4.73	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. Potential energy of Biscayne gw:	J/yr	1.12E+16	(m^3)(J/g)(1E6 g/m^3)/(yrs)
	Transformity of Biscayne groundwater:	sej/J	60,206	(sej/yr from line 1) / (J/yr)

Table 18. Emergy evaluation of fresh groundwater from the Intermediate aquifer in western Florida.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (xE10)
RENEWABLE RESOURCES						
1	Rainfall on rechargeable aquifer area:	J	7.32E+16	18,200	1,332	53.50
EMERGY/UNIT of FRESH GROUNDWATER from the INTERMEDIATE AQUIFER						
2	Groundwater from the Intermediate:	g	2.49E+15	535,030	1,332	53.50
3	Groundwater from the Intermediate:	m^3	2.49E+09	5.35E+11	1,332	53.50
4	Groundwater from the Intermediate:	J	1.18E+16	**113,170**	1,332	53.50

Notes

1	Recharge A of the aquifer:	mi^2	4,500	assumed to be 50% of aquifer surface area
	Annual rainfall on rechargeable area:	in/yr	50	(Fernald and Purdum, 1998; p.17)
	Annual flux of rainfall on recharge A:	gal/yr	3.91E+12	(mi^2)(1,610 m/mi)^2(in/yr)(0.0254 m/in)(264.2gal/m^3)
	Chem. potential energy of rainfall:	J/yr	7.32E+16	(gal/yr)(1E6 g/m^3)(4.94 J/g)/(264.2 gal/m^3)
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Surface A overlaying the aquifer:	mi^2	9,000	(Measured from Miller, 1990; p11)
	Porosity fraction of aquifer:		0.065	(0.65)(Avg. limestone porosity) (Odum, 1996)
	Land volume of aquifer:	m^3	2.85E+12	(Calculated from Miller, 1990; p11)
	Volume of water in the aquifer:	m^3	1.85E+11	(land volume)(porosity)
	Average recharge rate:	ft/yr	0.7	Estimated from Fernald and Purdum (1998)
	Recharge area:	mi^2	4,500	Estimated from Fernald and Purdum (1998)
	Turn-over time:	yrs	74.3	(m^3) / [(ft/yr)(mi^2)(1 m/3.28 ft)(1,610 m/mi)^2]
	Annual mass of groundwater:	g/yr	2.5E+15	(m^3)(1 E6 g/m^3) / (yrs)
	Emergy per mass of groundwater:	sej/g	5.4E+05	(sej/yr from line 1) / (g/yr)
3	Total m^3/yr of groundwater:	m^3/yr	2.49E+09	(g/yr)/(1 E6 g/m^3)
	Emergy per volume of groundwater:	sej/m^3	5.35E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg. total dissolved solids (TDS):	ppm	400	(Fernald and Purdum, 1998; p. 54)
	Gibbs free energy of intermediate gw:	J/g	4.73	[(8.33 J/mol/ K)(290 K)/(18 g/mol)] * ln [(1E6 - TDS in ppm)/(965,000)]
	Chem. potential energy of groundwater:	J/yr	1.18E+16	(m^3)(J/g)(1E6 g/m^3)/(yrs)
	Transformity of groundwater:	sej/J	113,170	(sej/yr from line 1) / (J/yr)

Table 19. Emergy evaluation of fresh groundwater from the Floridan aquifer system.

Note	Item	Unit	Energy Data Unit/yr	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Rainfall on rechargeable aquifer area:	J	7.6E+17	18,200	13,923	77.46
EMERGY/UNIT OF FRESH GROUNDWATER FROM THE FLORIDAN AQUIFER						
2	Fresh Floridan groundwater	g	1.80E+16	774,594	13,923	77.46
3	Fresh Floridan groundwater	m^3	1.80E+10	7.75E+11	13,923	77.46
4	Fresh Floridan groundwater	J	8.39E+16	**166,010**	13,923	77.46

Notes

1	Recharge area of the Floridan aquifer:	mi^2	42,000	(Estimated from Fernald and Purdum, 1998; p.53).
	Avg. annual rainfall on rechargeable A:	in/yr	56	(Fernald and Purdum, 1998; p. 17).
	Annual flux of rainfall on recharge A:	gal/yr	4.09E+13	$(mi^2)(1{,}610\ m/mi)^2(in/yr)(0.0254\ m/in)(264.2\ gal/m^3)$
	Chem. potential energy of rainfall:	J/yr	7.65E+17	$(gal/yr)(1E6\ g/m^3)(4.94\ J/g)/(264.2\ gal/m^3)$
	Transformity:	sej/J	18,200	chemical energy, rain on land (Table 9)
2	Volume of fresh groundwater in FL:	gal	1.0E+15	(Fernald and Purdum, 1998; p. 38)
	% of this gw that is in the Floirdan:	%	75	estimated from Miller (1990)
	Vol. of fresh gw in the Florida aquifer:	gal	7.5E+14	(gal)(% / 100)
	Avg. recharge rate of aquifer in rech. A:	in/yr	6.50	(calc. from data in Fernald and Purdum, 1998, p53)
	Replacement time of Floridan fresh gw:	yrs	158	$gal/[(mi^2)(1{,}610\ m/mi)^2(in/yr)(0.0254m/in)(264.2gal/m^3)]$
	Annual mass of fresh Floridan gw:	g/yr	1.8E+16	(gal)(1000 g/L)(3.785 L/gal) / (yrs)
	Emergy per mass of fresh Floridan gw:	sej/g	7.7E+05	(sej/yr from line 1) / (g/yr)
3	Total m^3/yr of fresh Floridan gw:	m^3/yr	1.8E+10	$(g/yr)/(1\ E6\ g/m^3)$
	Emergy per volume of fresh Floridan gw:	sej/m^3	7.7E+11	(sej/yr from line 1) / (m^3/yr)
4	Avg. dissolved solids in upper Floridan:	ppm	250	(Fernald and Purdum, 1998, p. 54)
	Gibbs free energy of upper Floridan gw:	J/g	4.67	[(8.33 J/mole/K)(285 K)/(18 g/mole)] * [ln (1000,000 - ppm / 965,000)]
	Chem. Pot energy of fresh Floridan gw:	J/yr	8.4E+16	(g/yr)(J/g)
	Transformity of fresh Floridan gw:	sej/J	166,010	(sej/yr from line 1) / (gal/yr)

Table 20. Summary of emergy evaluation of Florida's groundwater resources.

Aquifer	Fresh groundwater values volume (a) (E9 m^3)	avg. withdrawal (m^3/sec) (b)	% of total withdrawal	(c) **sej/J**	(d) sej/g	sej/m^3 (e) (xE10)	Em$/yr (xE9) (f)	Em$ (g) per m^3
Surficial	571	28.5	18.0	44,300	209,732	20.97	16.39	0.23
Sand & gravel	326	5.5	3.5	47,103	224,712	22.47	1.73	0.25
Biscayne	22	39.4	24.9	60,206	284,636	28.46	0.74	0.31
Intermediate	185	11.0	6.9	113,170	535,030	53.50	1.46	0.59
Floridan	2,839	107.8	68.1	166,010	774,594	77.46	15.30	0.85
Total:	3,046	158.2	100.0				17.50	
Weighted average *:				145,580	681,398	68.14		0.75

* Average values were weighted to represent the proportion of groundwater withdrawn from each aquifer
e.g. 145,580 was obtained by the sum of each (% of total withdrawal)*(sej/J)

(a) volume from Tables 15, 16, 17, 18, and 19.
(b) Total fresh water withdrawals in 1995 (Marella, 1999)
(c) sej/J from Tables 15, 16, 17, 18 and 19.
(d) sej/g = (sej/J)(4.94 J/g)
(e) sej/m^3 = (sej/g)(1 E6 g/m^3)
(f) Em$/yr (year 2000) = ($m^3$/yr)(sej/$m^3$)/(9.1 E11 sej/$)
(g) Em$/$m^3$ (year 2000) = (sej/m^3)/(9.1 E11 sej/$)

The last 3 columns represent the emergy values of the fresh groundwater in the aquifers, and not for the water withdrawn.

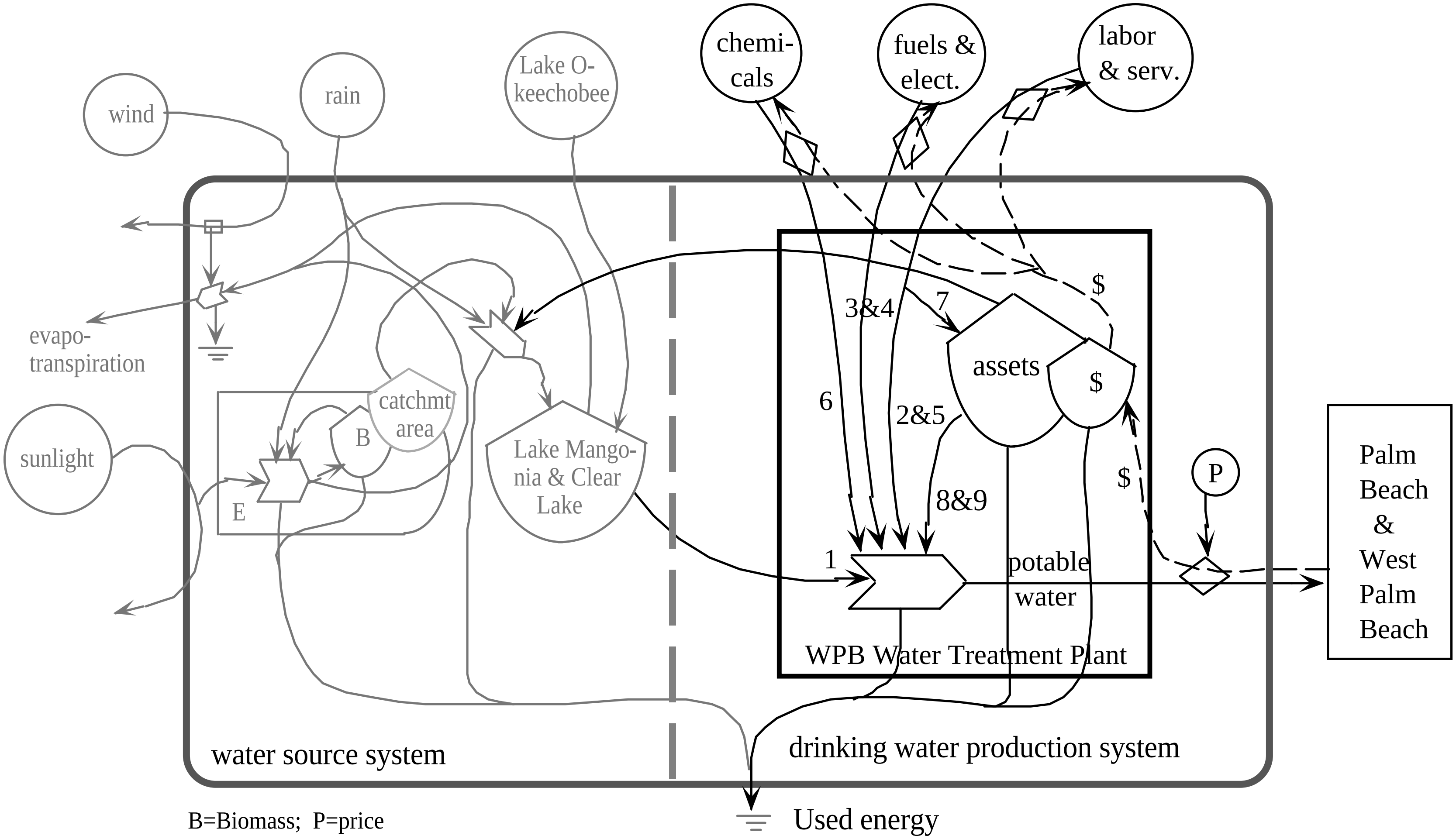
Potable Water Supply Alternatives Evaluated

A brief description of the water supply alternatives and the results for each evaluation is presented below. All the notes that document the emergy tables below are given in Appendix B.

1) Surface (Lake) Water Source: West Palm Beach's Water Treatment Plant.

Figure 19 illustrates a systems diagram for the production of drinking water by the City of West Palm Beach Water Treatment Plant. The plant's water source comes from two lakes (Lake Mangonia and Clear Lake) that get their water from a water catchment area south of Lake Okeechobee in south Florida. This diagram illustrates the principal inputs required for the production of drinking water in West Palm Beach. The numbers on the diagram correspond to the input rows in the emergy evaluation table of potable water produced by the facility.

The emergy evaluation of this drinking water is given in Table 21. Of special importance in this table are the transformity (1.39 E5 sej/J), the emergy yield (2.66 E19 sej/yr) and the total emergy per volume (0.69 E12 sej/m^3). Lake water represented the greatest emergy input for producing this drinking water followed by the emergy of chemicals used in the treatment process. Several emergy indices and ratios for the drinking water produced at the West Palm Beach plant are given in Table 22.



B=Biomass; P=price
WPB = West Palm Beach
E=watershed environment

Figure 19. Energy systems diagram of the water production by the City of West Palm Beach.

Table 21. Emergy evaluation of the drinking water produced at the City of West Palm Beach Water Treatment Facility, Florida (28 mgd or 1.23 m^3/sec).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Surface water	J	1.94E+14	5.64E+04	10.96	28.25
PURCHASED & OPERATIONAL INPUTS						
2	Operating & Maintenance	$	2.42E+06	9.60E+11	2.32	5.98
3	Electricity	J	3.00E+13	1.60E+05	4.79	12.35
4	Fuels	J	5.32E+12	6.60E+04	0.35	0.90
5	Chemicals ($)	$	1.30E+06	9.60E+11	1.25	3.22
6	Chemicals (kg)	kg	5.09E+06	1.00E+12	5.09	13.12
7	Plant construction & upgrading	$	8.13E+05	9.60E+11	0.78	2.01
8	Plant Assets (concrete)	kg	7.82E+05	1.23E+12	0.96	2.48
9	Plant Assets (steel & iron)	kg	4.62E+04	1.80E+12	0.08	0.21
Yield (Y) = Total emergy of drinking water (not including distribution):					**26.59**	**68.52**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
10	Drinking water produced	m^3	3.88E+07	6.85E+11	26.59	68.52
11	Drinking water produced	$	1.13E+07	2.36E+12	26.59	68.52
12	Drinking water produced	J	1.92E+14	**1.39E+05**	26.59	68.52
13	Drinking water produced	g	3.88E+13	6.85E+05	26.59	68.52
14	Drinking water with-out services	J	1.92E+14	1.27E+05	24.27	62.54

Table 22. Emergy indices and ratios for the drinking water produced at the City of West Palm Beach Water Treatment Facility.

Note	Name of Index	Short expression	Quantity
15	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	1.43
16	Emergy Yield Ratio (EYR)	Y/(P + S)	1.70
17	% Renewable emergy	100 x (R/Y)	41.2
18	Emergy Benefit to the Purchaser (EBP) in 1999	Em$/$	2.46
19	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	0.75
20	Transformity of potable water	sej/J	1.39E+05
21	Emergy per m^3 of potable water	sej/m^3	6.85E+11

Footnotes to tables 21 and 22 in Appendix B.

2) Surface Water Source: Hillsborough River Water Treatment Plant, Tampa.

Figure 20 shows the systems diagrams of the Hillsborough River Water Treatment Plant, the principal drinking water source for the city of Tampa, Florida. The diagram illustrates the main environmental and economic components required to produce drinking water by this facility.

Table 23 shows the results of the emergy evaluation for the production of drinking water at the Hillsborough River plant. The numbers of the items listed in the table correspond to the numbers shown in Figure 20. The calculated transformity, emergy yield and emergy per volume of this drinking water were 1.87 E5 sej/J, 7.86 E19 sej/yr and 0.92 E12 sej/m^3, respectively. The emergy of the chemicals used in the treatment process had the highest emergy contribution for the production of drinking water followed by the emergy of river water. Several emergy indices and ratios for the drinking water produced by this water treatment plant are given in Table 24.

3) Groundwater Source: Murphree Water Treatment Plant, Gainesville.

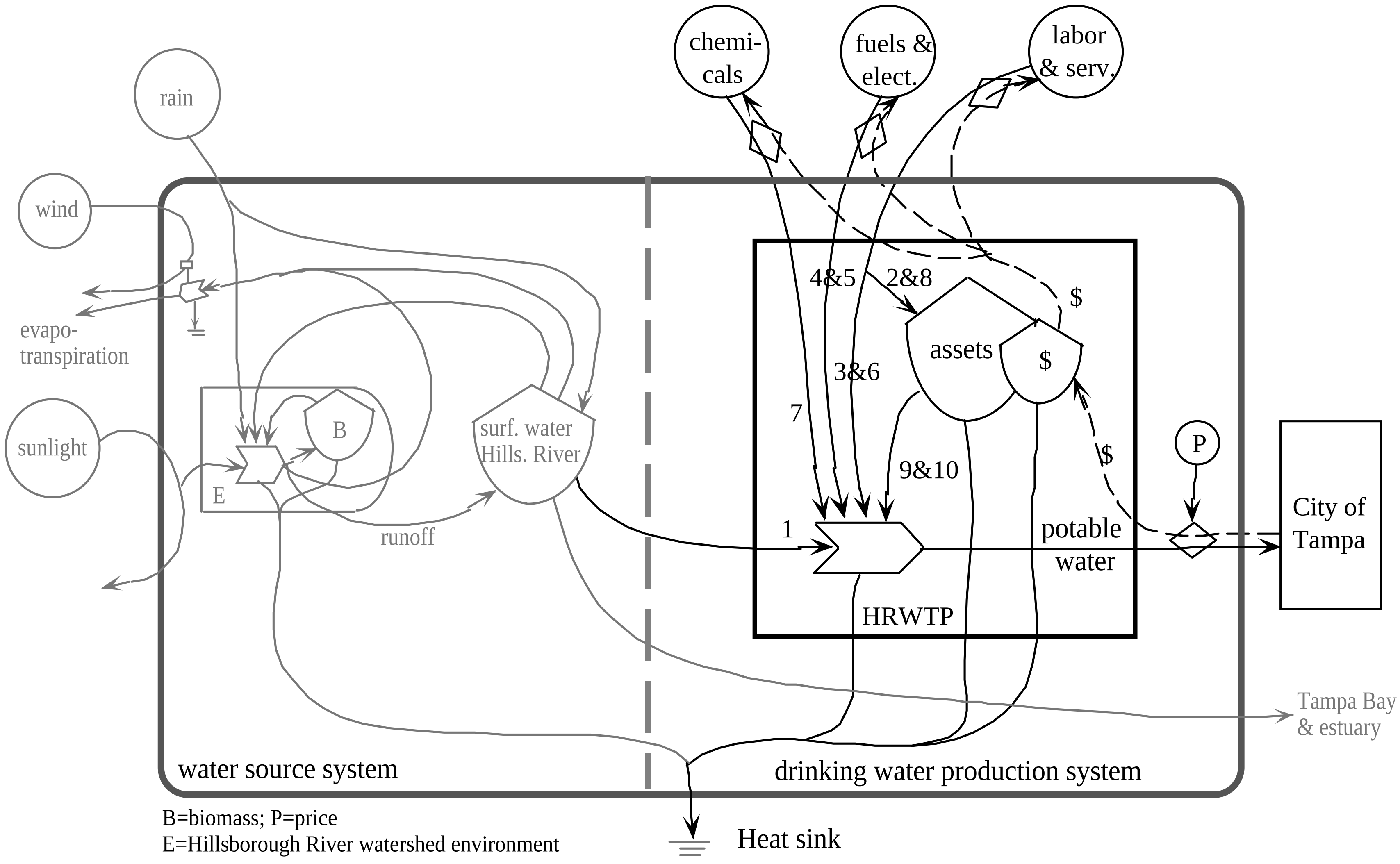
A systems diagram of the Murphree groundwater treatment plant that supplies most of Gainesville's drinking water is given in Figure 21. The diagram illustrates the flows of groundwater, chemicals, energy, materials and services necessary to produce drinking water in Gainesville.

Table 25 shows the results of the emergy evaluation of the water produced by the facility. The calculated transformity, emergy yield, and total emergy per volume were 2.95 E5 sej/J, 4.22 E19 sej/yr and 1.46 E12 sej/m^3, respectively. The emergy of groundwater had the highest contribution to the total emergetic value of this drinking water followed by electricity. Several emergy indices and ratios for the drinking water produced at the Murphree plant are given in Table 26.

4) Water Conservation as a Source: Tampa Bay.

A systems diagram of the water conservation program developed by Tampa Bay Water (TBW) is given in Figure 22. The potable water (A) entering the left side of the interaction symbol is divided by the energy flows entering the top of the symbol (B). The water demand or output of the water conservation program (C) is proportional to (A/B). Thus, the water demand (C) equals k(A/B), where k represents a transformation coefficient. Therefore, as more energy, goods, and services (e.g., B) are assigned to the water conservation program, the lower the demand for potable water (C).

Table 27 shows the emergy evaluation for TBW's water demand management/conservation program. The transformity, emergy yield and emergy per volume of water saved with the conservation program were 3.06 E5 sej/J, 5.09 E19 sej/yr and 1.51 E12 sej/m^3, respectively. The actual potable water saved represented the greatest emergy input of the conservation program. The second most important emergy input were water-efficient appliances installed in place of conventional appliances. Emergy indices for the water saved by this water conservation program are given in Table 28.



B=biomass; P=price

E=Hillsborough River watershed environment

HRWTP=Hillsborough River Water Treatment Plant

Figure 20. Energy systems diagrams of the Hillsborough River Water Treatment Plant, Tampa, Florida.

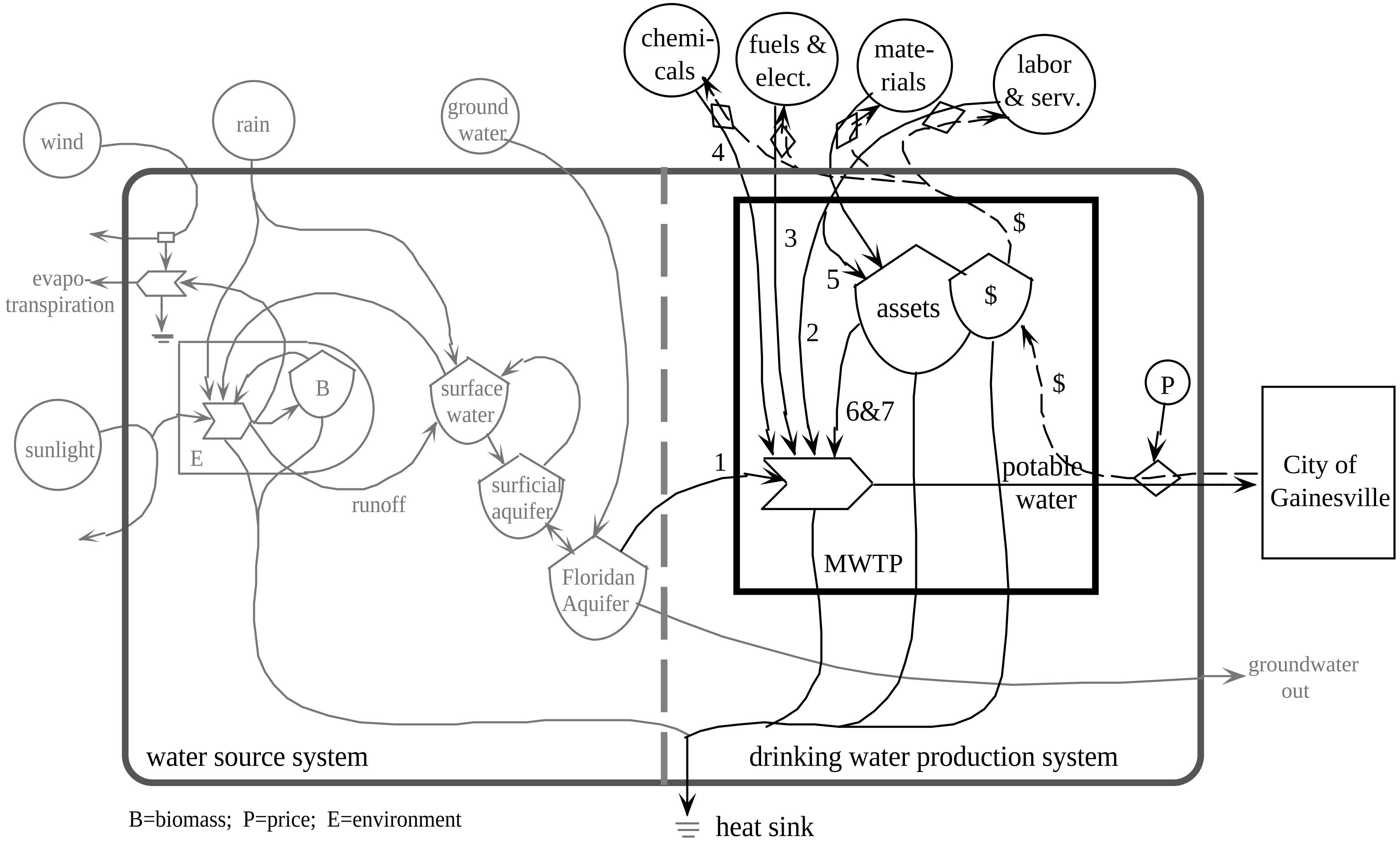
Table 23. Emergy evaluation of the drinking water produced at the Hillsborough River Water Treatment Plant, Tampa, Florida (62 mgd or 2.72 m^3/sec).

Note	Item	Unit	Energy Data (unit/yr)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Surface (river) water used	J	4.5E+14	4.26E+04	19.2	22.51
PURCHASED & OPERATIONAL INPUTS						
2	Operation & maintenance	$	3.9E+06	1.15E+12	4.5	5.29
3	Labor and services	$	3.7E+06	1.15E+12	4.2	4.97
4	Electricity	J	8.7E+13	1.60E+05	13.9	16.28
5	Fuels (oil)	J	6.2E+12	6.60E+04	0.4	0.48
6	Chemicals ($)	$	4.0E+06	1.15E+12	4.6	5.38
7	Chemicals (kg)	kg	2.8E+07	1.00E+12	28.0	32.90
8	Depreciation & purchased assets	$	9.9E+05	1.15E+12	1.1	1.34
9	Plant Assets (concrete)	kg	2.0E+06	1.23E+12	2.4	2.84
10	Plant Assets (steel & iron)	kg	1.5E+05	1.80E+12	0.3	0.32
Yield (Y) = Total emergy of drinking water (not including distribution):					**78.6**	**92.29**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
11	Potable water produced	m^3	8.5E+07	9.2E+11	78.6	92.29
12	Potable water produced	$	2.7E+07	2.9E+12	78.6	92.29
13	Potable water produced	J	4.2E+14	**1.87E+05**	78.6	92.29
14	Potable water produced	g	8.5E+13	9.2E+05	78.6	92.29
15	Drinking water with-out services	J	4.2E+14	1.7E+05	69.8	82.03

Table 24. Emergy indices and ratios for the drinking water produced at the Hillsborough River Water Treatment Plant in Tampa.

Note	Name of Index	Short expression	Quantity
16	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	3.10
17	Emergy Yield Ratio (EYR)	Y/(P + S)	1.32
18	% Renewable emergy	100 x (R/Y)	24.39
19	Ratio of Emergy Benefit to the Purchaser (EBP) in 1996	Em$/$	2.53
20	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	1.01
21	Transformity of potable water	sej/J	1.87E+05
22	Emergy per m^3 of potable water	sej/m^3	9.23E+11

Footnotes to tables 23 and 24 in Appendix B.



B=biomass; P=price; E=environment
MWTP=Murphree Water Treatment Plant

Figure 21. Energy systems diagram for the Murphree Water Treatment Plant in Gainesville, Florida.

Table 25. Emergy evaluation of the drinking water produced at the Murphree Water Treatment Plant in Gainesville, Florida (21 mgd or 0.92 m^3/sec).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Ground Water	J	1.42E+14	1.66E+05	23.65	81.80
PURCHASED & OPERATIONAL INPUTS						
2	Operating & Maintenance	$	2.32E+06	1.29E+12	2.99	10.35
3	Electricity	J	5.31E+13	1.60E+05	8.50	29.39
4	Chemicals (kg)	kg	5.59E+06	1.00E+12	5.59	19.33
5	Plant Construction & Upgrading	$	4.37E+05	1.29E+12	0.56	1.95
6	Plant Assets (concrete)	kg	6.65E+05	1.23E+12	0.82	2.83
7	Plant Assets (steel & iron)	kg	5.10E+04	1.80E+12	0.09	0.32
Yield (Y) = Total emergy of drinking water (not including distribution):					**42.20**	**145.96**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
8	Potable water produced	m^3	2.89E+07	1.46E+12	42.20	145.96
9	Potable water produced	$	7.49E+06	5.64E+12	42.20	145.96
10	Potable water produced	J	1.43E+14	**2.95E+05**	42.20	145.96
11	Potable water produced	g	2.89E+13	1.46E+06	42.20	145.96
12	Drinking water with-out services	J	1.43E+14	2.75E+05	39.21	135.61

Table 26. Emergy indices and ratios for the drinking water produced at the Murphree Water Treatment Plant.

Note	Name of Index	Short expression	Quantity
13	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	0.78
14	Emergy Yield Ratio (EYR)	Y/(P + S)	2.27
15	% Renewable emergy	100 x (R/Y)	56.0
16	Emergy Benefit to the Purchaser (EBP) in 1994	Em$/$	4.37
17	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	1.60
18	Transformity of potable water	sej/J	2.95E+05
19	Emergy per m^3 of potable water	sej/m^3	1.46E+12

Footnotes to tables 25 and 26 in Appendix B.

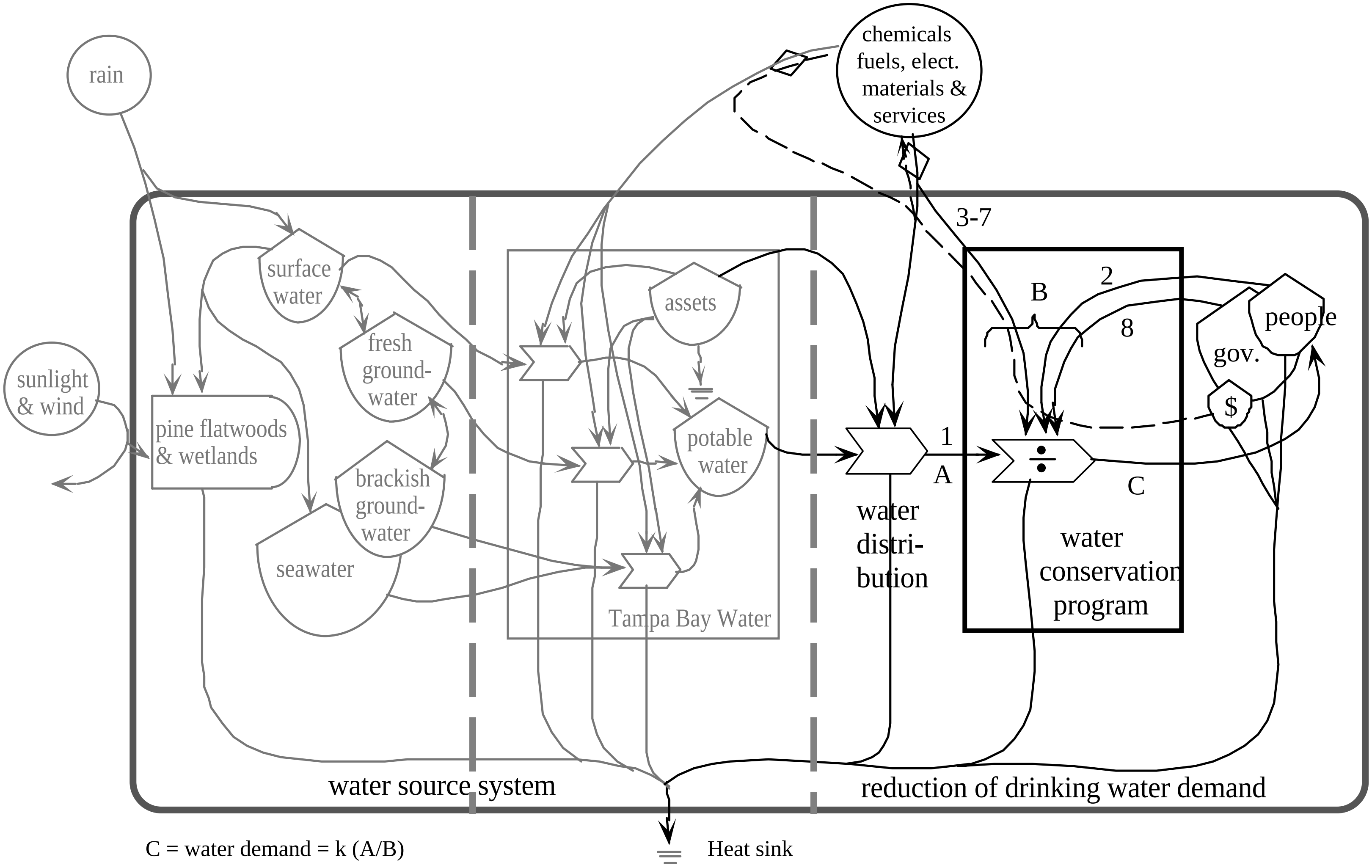


Figure 22. Energy systems diagram of Tampa Bay's water conservation program.

Table 27. Emergy evaluation of Tampa Bay's water conservation/management plan (approximately 24.4 mgd or 1.07 m^3/sec of water "saved").

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
WATER RESOURCES						
1	Potable water saved	J	1.66E+14	1.87E+05	31.08	92.30
MARKETING, PLAN IMPLEMENTATION & SERVICES						
2	Total services to "save" 25 mgd	$	3.66E+06	1.15E+12	4.21	12.51
3	Low-volume toilets replaced	kg	1.01E+06	1.85E+12	1.86	5.53
4	Low-volume & water-less urinals	kg	3,056	1.85E+12	0.006	0.02
5	Low-flow showerheads & faucets	kg	8,038	3.80E+11	0.003	0.009
6	Water-saving appliances replaced	kg	1,873,622	6.70E+12	12.55	37.28
7	Water-saving systems installed	kg	103,319	7.60E+11	0.08	0.23
8	Mass media & propaganda receptic	J/yr	1.56E+11	6.76E+06	1.05	3.13
Yield (Y) = Total emergy of drinking water saved through water conservation					**50.85**	**151.01**
EMERGY PER UNIT OF POTABLE WATER SAVED						
9	Potable water saved	m^3	3.37E+07	1.51E+12	50.85	151.01
10	Potable water saved	$	3.66E+06	1.39E+13	50.85	151.01
11	Potable water saved	J	1.66E+14	**3.06E+05**	50.85	151.01
12	Potable water saved	g	3.37E+13	1.51E+06	50.85	151.01
13	Potable water saved w/out services	J	1.66E+14	2.74E+05	45.58	135.37

Table 28. Emergy indices and ratios for the drinking water saved by Tampa Bay's water conservation program.

Note	Name of Index	Short expression	Quantity
14	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	2.61
15	Emergy Yield Ratio (EYR)	Y/(P + S)	2.57
16	% Renewable emergy	100 x (R/Y)	14.9
17	Ratio of emergy benefit to the purchaser (EBP) in 1996	Em$/$	12.07
18	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	1.66
19	Transformity of potable water	sej/J	3.06E+05
20	Emergy per m^3 of potable water	sej/m^3	1.51E+12

Footnotes to tables 27 and 28 in Appendix B.

5) Brackish water source: City of Dunedin Reverse Osmosis Treatment Facility.

A systems diagram of the production of drinking water by the City of Dunedin Reverse Osmosis Water Treatment Facility is given in Figure 23. The water source consists of a blend of fresh (90%) and brackish (10%) groundwater from the Florida aquifer system.

The results of the emergy evaluation for the production of drinking water by this treatment facility are given in Table 29. The calculated transformity, emergy yield and emergy per volume of the finished water were 3.80 E5 sej/J, 1.22 E19 sej/yr and 1.88 E12 sej/m^3, respectively. The highest emergy input consisted of fresh groundwater followed by electricity. Table 30 shows some emergy indices and ratios for the drinking water produced by this RO facility.

6) Seawater Source: Reverse Osmosis Desalination, Tampa Bay.

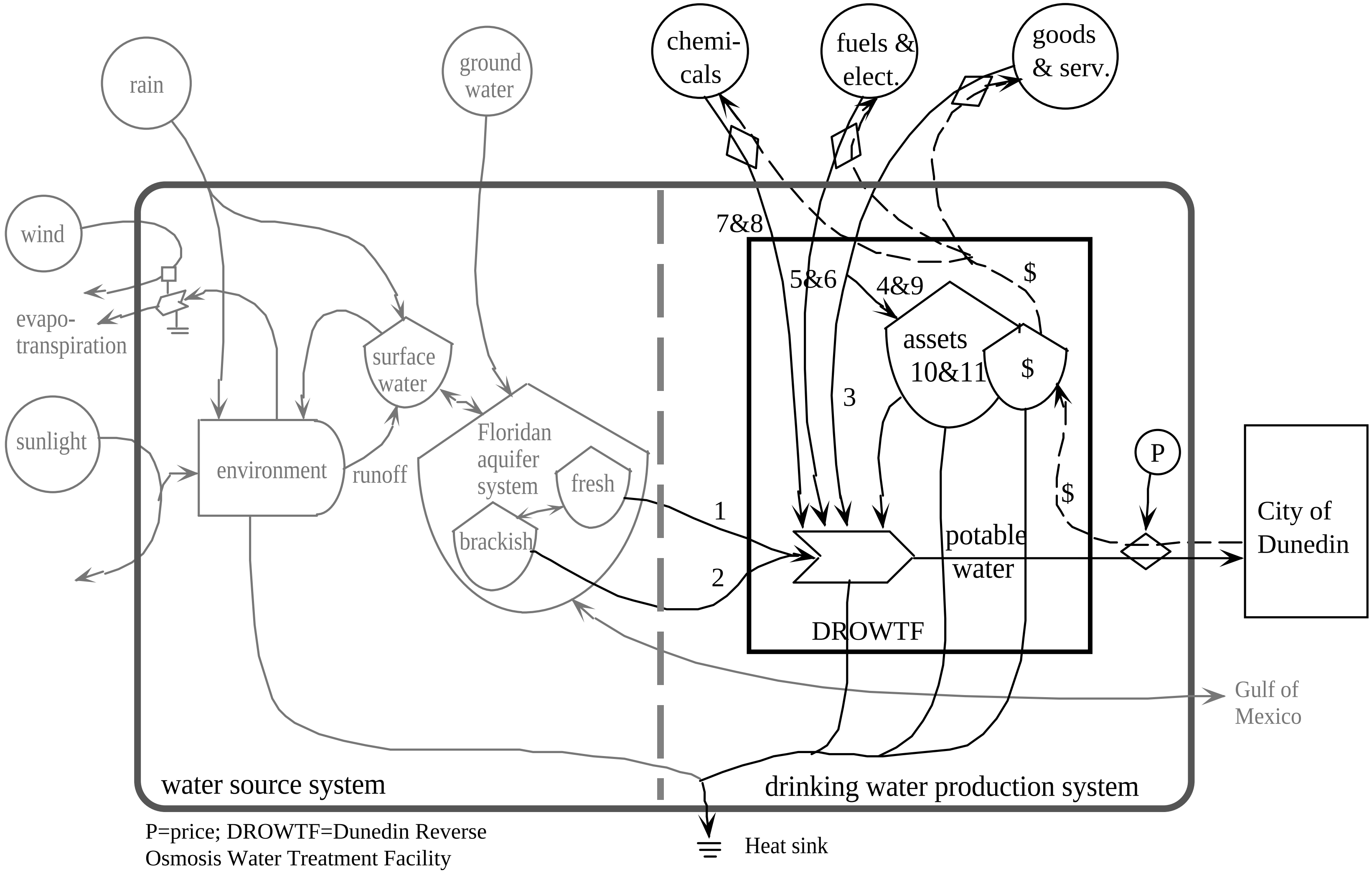
Figure 24 shows a systems diagram of Tampa Bay's proposed RO desalination facility. This facility is under construction and is expected to start operating in 2003. The high salinity of the brine released is likely to stress the local benthic community and other important organisms. This environmental stress is represented in the diagram as the interaction of the brine with the productivity of the environment. As more seawater is desalinated resulting in more brine added to the ocean, the biological productivity decreases.

The results from the emergy evaluation of drinking water to be produced by this RO facility are given in Tables 31. The calculated transformity, emergy yield and emergy per volume of the finished water were 4.57 E5 sej/J, 7.80 E19 sej/yr and 2.26 E12 sej/m^3, respectively. Because of the high energy required to operate the RO system, electricity had the highest emergy input for the production of potable water. The second most important input consisted of human services (to design and construct the water treatment facility). Several emergy indices and ratios for the production of drinking water are provided in Table 32.

7) Surficial Groundwater Source: Transported Via Aqueduct, Florida Keys.

Figure 25 illustrates the energy systems diagram of the potable water produced and transported by the Florida Keys Aqueduct Authority (FKAA). The water source used by the FKAA comes from surficial groundwater pumped from the Biscayne aquifer system. The diagram shows the assets of the water treatment plant (in Florida City) separate from the assets of the 210 km long aqueduct that delivers water throughout the Florida keys.

Table 33 shows the results from the emergy evaluation of the treatment and transportation of potable water along the aqueduct system. The calculated transformity, emergy yield and emergy per volume of this public supply system were 5.45 E5 sej/J, 4.47 E19 sej/yr and 2.69 E12 sej/m^3, respectively. The emergy of operation and maintenance, which includes salaries and administration fees, represented the largest emergy input for the potable water produced and transported by the aqueduct authority. The second most important input was electricity. Emergy indices of the potable water transported through the aqueduct system are given in Table 34.



P=price; DROWTF=Dunedin Reverse
Osmosis Water Treatment Facility

Figure 23. Energy systems diagram for the City of Dunedin Reverse Osmosis Water Treatment Facility.

Table 29. Emergy evaluation of the drinking water produced at the City of Dunedin Reverse Osmosis Water Treatment Facility (5.6 mgd or 0.25 m^3/sec).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Ground Water (fresh)	J	3.40E+13	1.66E+05	5.64	86.44
2	Ground Water (brackish)	J	2.32E+12	3.19E+04	0.07	1.14
PURCHASED & OPERATIONAL INPUTS						
3	Operation (wages & benefits)	$	4.18E+05	1.15E+12	0.48	7.37
4	Repair & Maintenance	$	5.18E+05	1.15E+12	0.60	9.13
5	Electricity ($)	$	3.68E+05	1.15E+12	0.42	6.48
6	Electricity	J	2.21E+13	1.60E+05	3.53	54.10
7	Fuels (diesel)	J	3.69E+11	6.60E+04	0.02	0.37
8	Chemicals ($)	$	2.84E+05	1.15E+12	0.33	5.01
9	Chemicals (kg)	kg	2.22E+05	1.00E+12	0.22	3.41
10	Plant Construction & Upgrading	$	4.36E+05	1.55E+12	0.68	10.35
11	Plant Assets (concrete)	kg	1.77E+05	1.23E+12	0.22	3.34
12	Plant Assets (steel & iron)	kg	1.36E+04	1.80E+12	0.02	0.38
Yield (Y) = Total emergy of drinking water (not including distribution):					**12.23**	**187.52**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
13	Potable water produced	m^3	6.52E+06	1.88E+12	12.23	187.52
14	Potable water produced	$	3.17E+06	3.86E+12	12.23	187.52
15	Potable water produced	J	3.22E+13	**3.80E+05**	12.23	187.52
16	Potable water produced	g	6.52E+12	1.88E+06	12.23	187.52
17	Potable water with-out services	J	3.22E+13	3.46E+05	11.16	171.02

Table 30. Emergy indices and ratios for the drinking water produced at the City of Dunedin RO Water Treatment Facility.

Note	Name of Index	Short expression	Quantity
18	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	1.14
19	Emergy Yield Ratio (EYR)	Y/(P + S)	1.88
20	% Renewable emergy	100 x (R/Y)	46.7
21	Ratio of Emergy Benefit to the Purchaser (EBP) in 1996	Em$/$	3.35
22	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	2.06
23	Transformity of potable water	sej/J	3.80E+05
24	Emergy per m^3 of potable water	sej/m^3	1.88E+12

Footnotes to tables 29 and 30 in Appendix B.

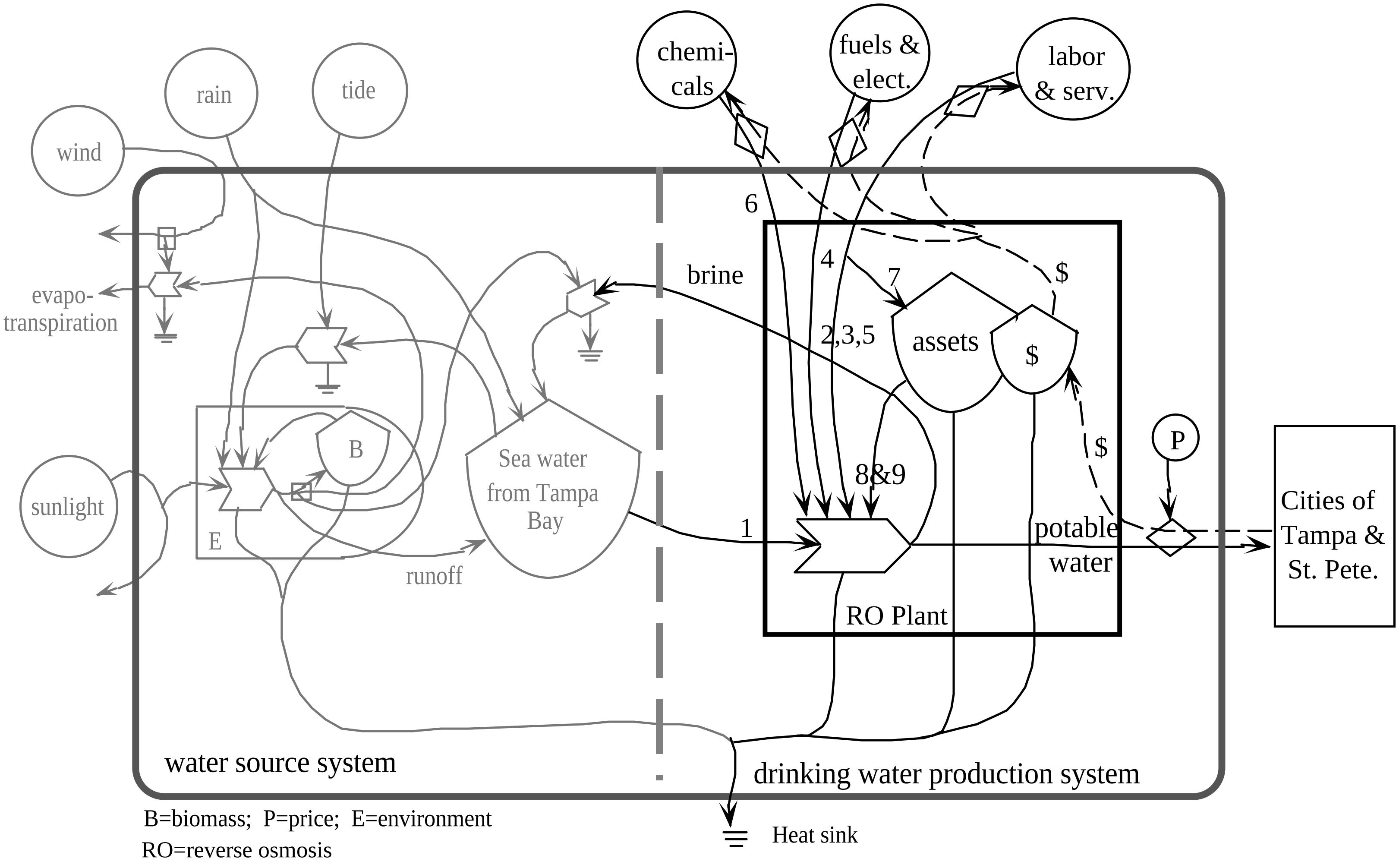


Figure 24. Energy systems diagram of Tampa Bay's RO desalination plant, which is expected to start operating in early 2003.

Table 31. Emergy evaluation of drinking water to be produced by RO desalination in Tampa Bay. This plant is expected to produce 25 mgd (1.1 m^3/sec) by 2003.

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Salty water from the Bay	J	7.32E+13	3.19E+04	2.33	6.76
PURCHASED & OPERATIONAL INPUTS						
2	Operation & maintenance	$	2.31E+06	8.10E+11	1.87	5.43
3	Electricity ($)	$	4.47E+06	8.10E+11	3.62	10.49
4	Electricity	J	3.81E+14	1.60E+05	60.97	176.53
5	Chemicals ($)	$	6.79E+05	8.10E+11	0.55	1.59
6	Chemicals (kg)	kg	7.25E+05	1.00E+12	0.72	2.10
7	Total Assets	$	8.16E+06	8.10E+11	6.61	19.14
8	Concrete	kg	9.23E+05	1.23E+12	1.14	3.29
9	Steel & iron	kg	7.08E+04	1.80E+12	0.13	0.37
Yield (Y) = Total emergy of drinking water (not including distribution):					**77.95**	**225.69**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
10	Drinking water produced	m^3	3.45E+07	2.26E+12	77.95	225.69
11	Drinking water produced	2002 $	1.96E+07	3.97E+12	77.95	225.69
12	Drinking water produced	J	1.71E+14	**4.57E+05**	77.95	225.69
13	Drinking water produced	g	3.45E+13	2.26E+06	77.95	225.69
14	Drinking water with-out services	J	1.71E+14	3.83E+05	65.29	189.04

Table 32. Emergy indices and ratios for Tampa Bay's desalination plant.

Note	Name of Index	Short expression	Quantity
15	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	32.39
16	Emergy Yield Ratio (EYR)	Y/(P + S)	1.03
17	% Renewable emergy	100 x (R/Y)	3.0
18	Ratio of Emergy Benefit to the Purchaser (EBP) in 2002	Em$/$	4.91
19	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	2.48
20	Transformity of potable water	sej/J	4.57E+05
21	Emergy per m^3 of potable water	sej/m^3	2.26E+12

Footnotes to tables 31 and 32 in Appendix B.

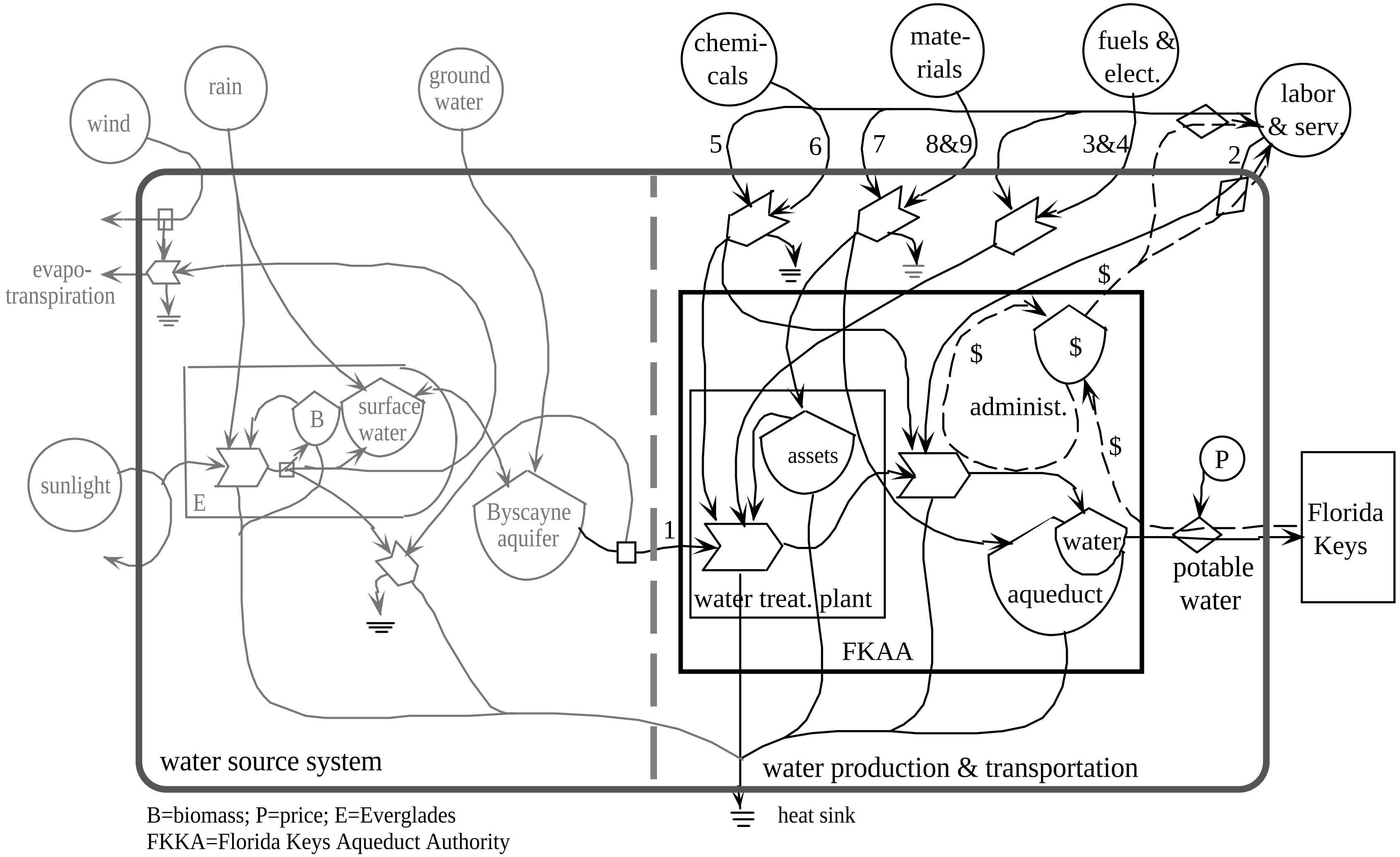


Figure 25. Energy systems diagram of the water production and transportation process by the Florida Keys Aqueduct Authority.

Table 33. Emergy evaluation of the drinking water produced and distributed through the aqueduct system of the Florida Keys Aqueduct Authority (15 mgd or 0.66 m^3/sec).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES						
1	Groundwater	J	9.60E+13	6.02E+04	5.78	34.78
PURCHASED & OPERATIONAL INPUTS						
2	Operation & maintenance	$	1.55E+07	1.15E+12	17.77	107.00
3	Electricity	J	5.29E+13	1.60E+05	8.46	50.93
4	Fuels	J	2.13E+13	6.60E+04	1.41	8.47
5	Chemicals ($)	$	4.39E+05	1.15E+12	0.51	3.04
6	Chemicals (kg)	kg	3.19E+06	1.00E+12	3.19	19.23
7	Total assets	$	5.01E+06	1.15E+12	5.76	34.66
8	Concrete	kg	6.15E+05	1.23E+12	0.76	4.56
9	Steel & ductile iron	kg	5.94E+05	1.80E+12	1.07	6.43
Yield (Y) = Total emergy of drinking water (including main distribution):					**44.70**	**269.10**
EMERGY PER UNIT OF POTABLE WATER (including main distribution):						
10	Drinking water produced	m^3	1.66E+07	2.69E+12	44.70	269.10
11	Drinking water produced	$	2.27E+07	1.97E+12	44.70	269.10
12	Drinking water produced	J	8.21E+13	**5.45E+05**	44.70	269.10
13	Drinking water produced	g	1.66E+13	2.69E+06	44.70	269.10
14	Drinking water with-out services	J	8.21E+13	3.28E+05	26.93	162.10

Table 34. Emergy indices and ratios for the drinking water produced and delivered by the Florida Keys Aqueduct Authority.

Note	Name of Index	Short expression	Quantity
15	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	6.74
16	Emergy Yield Ratio (EYR)	Y/(P + S)	1.15
17	% Renewable emergy	100 x (R/Y)	12.9
18	Ratio of Emergy Benefit to the Purchaser in 1996	Em$/$	1.71
19	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	2.96
20	Transformity of potable water	sej/J	5.45E+05
21	Emergy per m^3 of potable water	sej/m^3	2.69E+12

Footnotes to tables 33 and 34 in Appendix B.

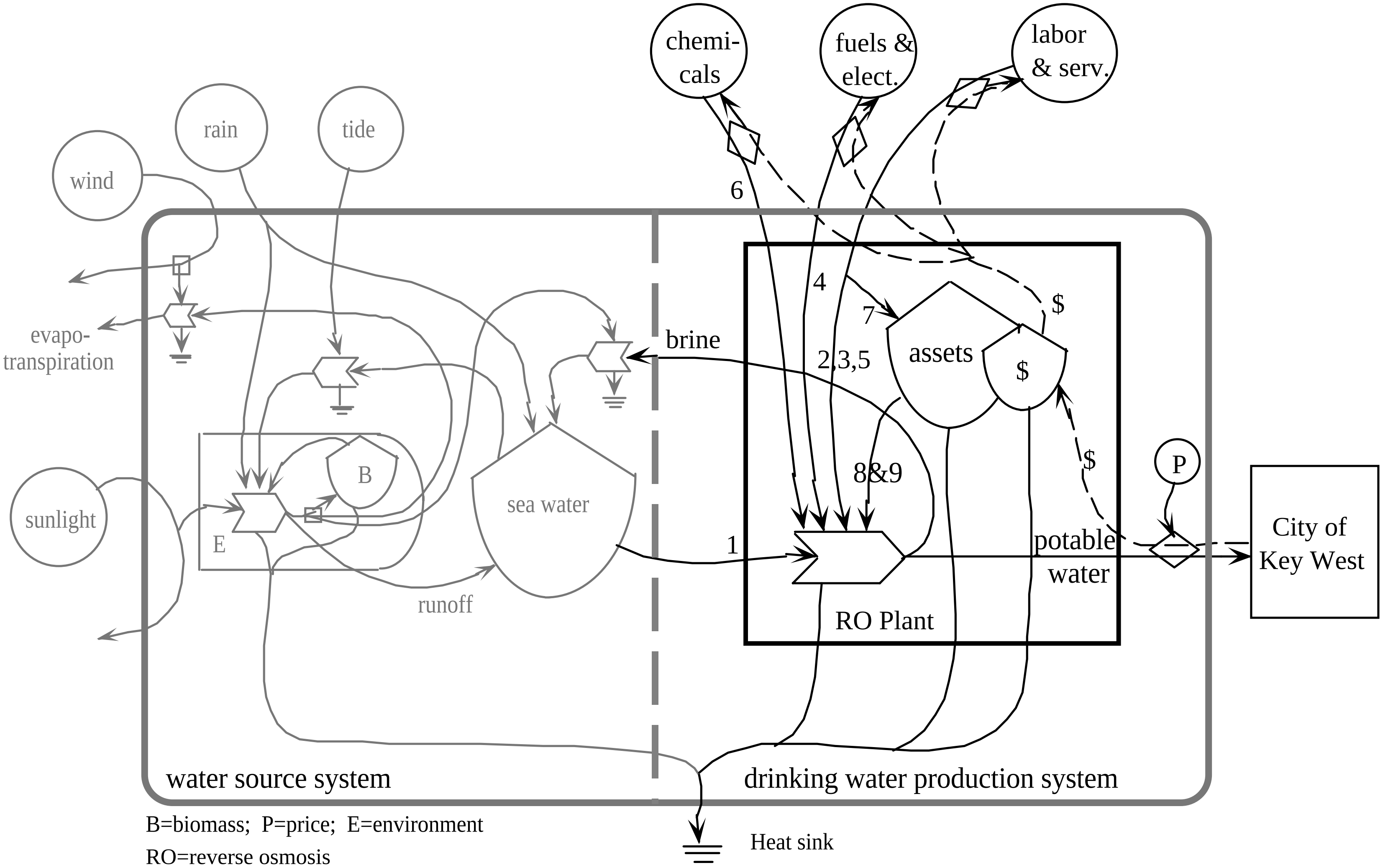
8) Seawater Source: Reverse Osmosis Desalination, Stock Island.

Figure 26 illustrates a systems diagram of Stock Island's RO desalination system that supplied potable water to Key West throughout the 1970's but was closed in the early 1980's. Similarly to Figure 24, Figure 26 shows the negative effect of the brine on the coastal ecosystem. Figure 26 also illustrates the energy, materials and services that were required to operate this desalination plant.

Table 35 shows the emergy evaluation for the production of drinking water from seawater in Stock Island in 1980. The calculated transformity, emergy yield and emergy per volume of desalinated water were 1.39 E6 sej/J, 2.81 E19 sej/yr and 6.79 E12 sej/m^3, respectively. Electricity had the highest emergy input for the production of this potable water followed by the emergy of human services associated with the money paid for electricity. Several emergy indices and ratios of the desalinated water are given in Table 36.

Water Supply Distribution System: Gainesville Regional Utility (GRU).

The emergy evaluation of GRU's water distribution network is provided in Table 37. This table includes several emergy-per-unit values that show the emergy cost of delivering drinking water. The emergy per volume and transformity of water delivered were calculated at 3.0 E11 sej/m^3 and 6.08 E4 sej/J, respectively. The emergy of delivered water per linear meter of pipe was calculated at 2.07 E14 sej/m.



B=biomass; P=price; E=environment

RO=reverse osmosis

Figure 26. Energy systems diagram of Stock Island's reverse osmosis desalination plat.

Table 35. Emergy evaluation of the drinking water produced from a reverse osmosis water treatment plant in Stock Island, Florida, before stopping its operation in the early 1980's (3.0 mgd or 0.13 m^3/sec).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
RENEWABLE RESOURCES (R)						
1	Sea water	J	3.95E+12	3.19E+04	0.13	3.04
PURCHASED & OPERATIONAL INPUTS						
2	Operating & maintenance	1980$	4.60E+05	3.20E+12	1.47	35.51
3	Money paid for electricity	1980$	2.22E+06	3.20E+12	7.11	171.62
4	Electricity	J	9.97E+13	1.60E+05	15.96	385.01
5	Supplies and chemicals	1980$	1.42E+05	3.20E+12	0.46	10.99
6	Chemicals (kg)	kg	8.70E+04	1.00E+12	0.09	2.10
7	Plant construction upgrading	1980$	8.68E+05	3.20E+12	2.78	67.00
8	Plant assets (concrete)	kg	1.11E+05	1.23E+12	0.14	3.29
9	Plant assets (steel & iron)	kg	8.50E+03	1.80E+12	0.02	0.37
Yield (Y) = Total emergy of drinking water (not including distribution):					**28.14**	**678.93**
EMERGY PER UNIT OF POTABLE WATER (not including distribution):						
10	Drinking water produced	m^3	4.14E+06	6.79E+12	28.14	678.93
11	Drinking water produced	1980 $	1.15E+07	2.45E+12	28.14	678.93
12	Drinking water produced	J	2.02E+13	**1.39E+06**	28.14	678.93
13	Drinking water produced	g	4.14E+12	6.79E+06	28.14	678.93
14	Drinking water with-out services	J	2.02E+13	1.32E+06	26.67	643.42

Table 36. Emergy indices and ratios for the drinking water produced by Stock Island's RO facility.

Note	Name of Index	Short expression	Quantity
15	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	222.39
16	Emergy Yield Ratio (EYR)	Y/(P + S)	1.004
17	% Renewable emergy	100 x (R/Y)	0.4
18	Ratio of Emergy Benefit to the Purchaser (EBP) in 1980	Em$/$	1.11
19	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	7.46
20	Transformity of potable water	sej/J	1.39E+06
21	Emergy per m^3 of potable water	sej/m^3	6.79E+12

Footnotes to tables 35 and 36 in Appendix B.

Table 37. Emergy evaluation of a 25 mgd (1.1 m^3/sec) drinking water distribution system in Gainesville, Florida, which provides service to approximately 53,000 customers (130,000 people) over 302 km^2.

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)
PURCHASED & OPERATIONAL INPUTS						
1	Design and construction	$	2.10E+06	9.10E+11	1.91	5.51
2	Operation & maintenance	$	4.14E+06	9.10E+11	3.77	10.87
3	Electricity	J	2.15E+13	1.60E+05	3.44	9.91
4	Concrete	kg	5.20E+04	1.23E+12	0.06	0.18
5	Steel & ductile iron	kg	6.70E+05	1.80E+12	1.21	3.48
6	PVC	kg	4.04E+04	7.60E+11	0.03	0.09
	Yield (Y) = Emergy of potable water delivered through the distribution systen				**10.42**	**30.03**
EMERGY PER UNIT OF WATER DISTRIBUTION						
7	Distribution system (water delivered)	m^3	3.47E+07	**3.00E+11**	10.42	30.03
8	Distribution system (water delivered)	J	1.71E+14	6.08E+04	10.42	30.03
9	Distribution system (water delivered)#	J	1.71E+14	2.76E+04	4.74	13.66
10	Distribution system (linear meter)	m	5.03E+04	2.07E+14	10.42	30.03
11	Distribution system (linear meter)#	m	5.03E+04	9.43E+13	4.74	13.66

without services

Notes

-	**Drinking water delivered, m^3/sec**			
	Drinking water delivered in 2000:	m^3/sec	1.10	(Richardson, 2001)
	Annual flow of delivered water in 2000:	m^3/yr	3.47E+07	(m^3/sec)(3,600 sec/hr)(8,760 hr/yr)
1	**Design and Construction costs, $**			
	2000 economic value of total infrastructure:	$	6.30E+07	(Richardson, 2001)
	Avg. life span of infrastructure:	yrs	30	assumed
	Annualized value of infrastructure:	$/yr	2.10E+06	($)/(yrs)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
2	**Operation & maintenance (including electricity), $**			
	Total $ spent for O & M in 2000:	$/yr	4.14E+06	(Richardson, 2001)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
3	**Electricity required for moving the water, J**			
	Total kWh used:	kWh	5.97E+06	(Richardson, 2001)
	Total annual energy used:	J/yr	2.15E+13	(kWh)(3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
4	**Total concrete used (with out services), kg**			
	Total concrete in distribution system:	kg	1.56E+06	(from C-2 in Table C-4)
	Avg. life span of aqueduct infrastructure:	yrs	30	assumed
	Prorated concrete assets:	kg/yr	5.20E+04	(Total assets in kg)/(yrs)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)

Table 37--continued.

5	**Total steel and iron used, kg**			
	Total steel & iron assets:	kg	2.01E+07	(from C-1 in Table C-4)
	Useful life of aqueduct assets:	yrs	30	assumed
	Prorated steel & iron assets:	kg/yr	6.70E+05	(Total assets in kg)/(yrs)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
6	**Total PVC, kg**			
	Total steel & iron assets:	kg	1.21E+06	(from C-3 in Table C-4)
	Useful life of aqueduct assets:	yrs	30	assumed
	Prorated steel & iron assets:	kg/yr	4.04E+04	(Total assets in kg)/(yrs)
	Emergy per unit of PVC:	sej/kg	7.60E+11	Assuming twice the transformity of plastic, from Brown et al. (1992)
7	**Distribution of potable water, m^3**			
	Drinking water delivered:	m^3/sec	1.10	(Richardson, 2001)
	Annual flow of delivered water:	m^3/yr	3.47E+07	(m^3/sec)(3,600 sec/hr)(8,760 hr/yr)
	Tot. emergy of water distribution (Y):	sej/yr	1.04E+19	(sum of items 1 to 5)
	Emergy/m^3 of water distribution:	sej/m^3	3.00E+11	(sej/yr) / (m^3/yr)
8	**Distribution of potable water, J**			
	Drinking water delivered:	m^3/yr	3.47E+07	(Richardson, 2001)
	Annual flow of delivered water:	J/yr	1.71E+14	(m^3/yr)(4.94 J/g)(1E6 g/m3)
	Tot. emergy of water distribution (Y):	sej/yr	1.04E+19	(sum of items 1 to 9)
	Transformity of water distribution:	sej/J	**6.08E+04**	(sej/yr) / (J/yr)
9	**Distribution of potable water, without services, J**			
	Emergy of distribution w/out services:	sej/yr	4.74E+18	(total emergy - services) = Y - (items 1 & 2)
	Annual flow of delivered water:	J/yr	1.71E+14	(same as note 9)
	Transformity with out services:	sej/J	2.76E+04	(sej/yr) / (J/yr)
10	**Distribution of potable water, linear m of distribution system**			
	Drinking water delivered:	m^3/yr	4.74E+18	(Richardson, 2001)
	Total length of distribution system:	m	1.51E+06	(Richardson, 2001)
	Useful life of aqueduct assets:	yrs	30	assumed
	Annualized length of distribution system	m/yr	5.03E+04	(m)/(yrs)
	Tot. emergy of water distribution (Y):	sej/yr	1.04E+19	(sum of items 1 to 9)
	sej/km of pipes of distribution system:	sej/m	2.07E+14	(sej/yr) / (m/yr)
11	**Distribution of potable water, linear m of distribution system (without services)**			
	Annualized length of distribution system	m/yr	5.03E+04	(same as note 11)
	Emergy of distribution w/out services:	sej/yr	4.74E+18	(same as note 10)
	sej/km of pipes of distribution system:	sej/m	9.43E+13	(sej/yr) / (m/yr)

Summary of Potable Water Supply values.

Table 38 summarizes the results of the emergy evaluations of public water supply alternatives. Figure 27 compares the emergy signatures of these public supply systems. These signatures include the principal types of emergy inputs required for each potable water production process. Figure 28 shows the transformities for the raw (source) water and finished (potable) water of the alternatives evaluated. The difference between the two columns represents the "emergy added" to the water source. However, from a general perspective, the smaller the difference between these two transformities, the higher the net contribution of the potable water to the economy. To compare the results of the public supply alternatives, Figure 29 shows the graphs of several emergy indices and ratios.

Table 38. Summary of the emergy evaluations of public supply alternatives.

Description	Public potable water supply systems							
Location	**WPB**	**Tampa**	**Gainesville**	**Tampa Bay**	**Dunedin**	**Tampa Bay**	**FL Keys**	**Stock Island**
Type of water treatment	surface	surface	groundwater	*potable water*	groundwater	RO (new tech)	gw/aqueduct	RO (old tech)
Water source	lakes	Hills. River	Floridan aquifer	*conservation*	brackish gw	seawater	Biscayne aquifer	seawater
Avg. flowrate produced:	1.23 m^3/sec	2.72 m^3/sec	0.96 m^3/sec	1.10 m^3/sec	0.25 m^3/sec	1.10 m^3/sec	0.66 m^3/sec	0.13 m^3/sec
Emergy Values (2000 Em$/m^3)								
Water used	0.31	0.25	0.90	1.01	0.96	0.07	0.38	0.03
Human services #	0.12	0.19	0.14	0.17	0.42	0.40	1.59	3.13
Fuels & electricity	0.15	0.18	0.32	-	0.60	1.94	0.65	4.23
Chemicals & supplies	0.14	0.36	0.21	-	0.04	0.02	0.21	0.02
Plant assets	0.03	0.03	0.03	0.47	0.04	0.04	0.12	0.04
Total emergy of water	0.75	1.01	1.60	1.66	2.06	2.48	2.96	7.46
Emergy Indices & Ratios								
Emergy Investment Ratio	1.43	3.10	0.78	2.61	1.14	32.39	6.74	222.39
Emergy Yield Ratio	1.70	1.32	2.27	2.57	1.88	1.03	1.15	1.004
% Renewable emergy	41.23	24.4	56.0	14.9	46.7	3.0	12.9	0.4
Emergy Benefit to Purchaser	2.46	2.53	4.37	12.07	3.35	4.91	1.71	1.11
Emergy per volume (sej/m^3)	6.85E+11	9.23E+11	1.46E+12	1.51E+12	1.88E+12	2.26E+12	2.69E+12	6.79E+12
Transformity of potable water	1.39E+05	1.87E+05	2.95E+05	3.06E+05	3.80E+05	4.57E+05	5.45E+05	1.39E+06
Transformity of water source	5.64E+04	4.26E+04	1.66E+05	1.87E+05	1.53E+05	3.19E+04	6.02E+04	3.19E+04

# values for human services represent the sum of all dollar flows
gw = groundwater; WPB = West Palm Beach

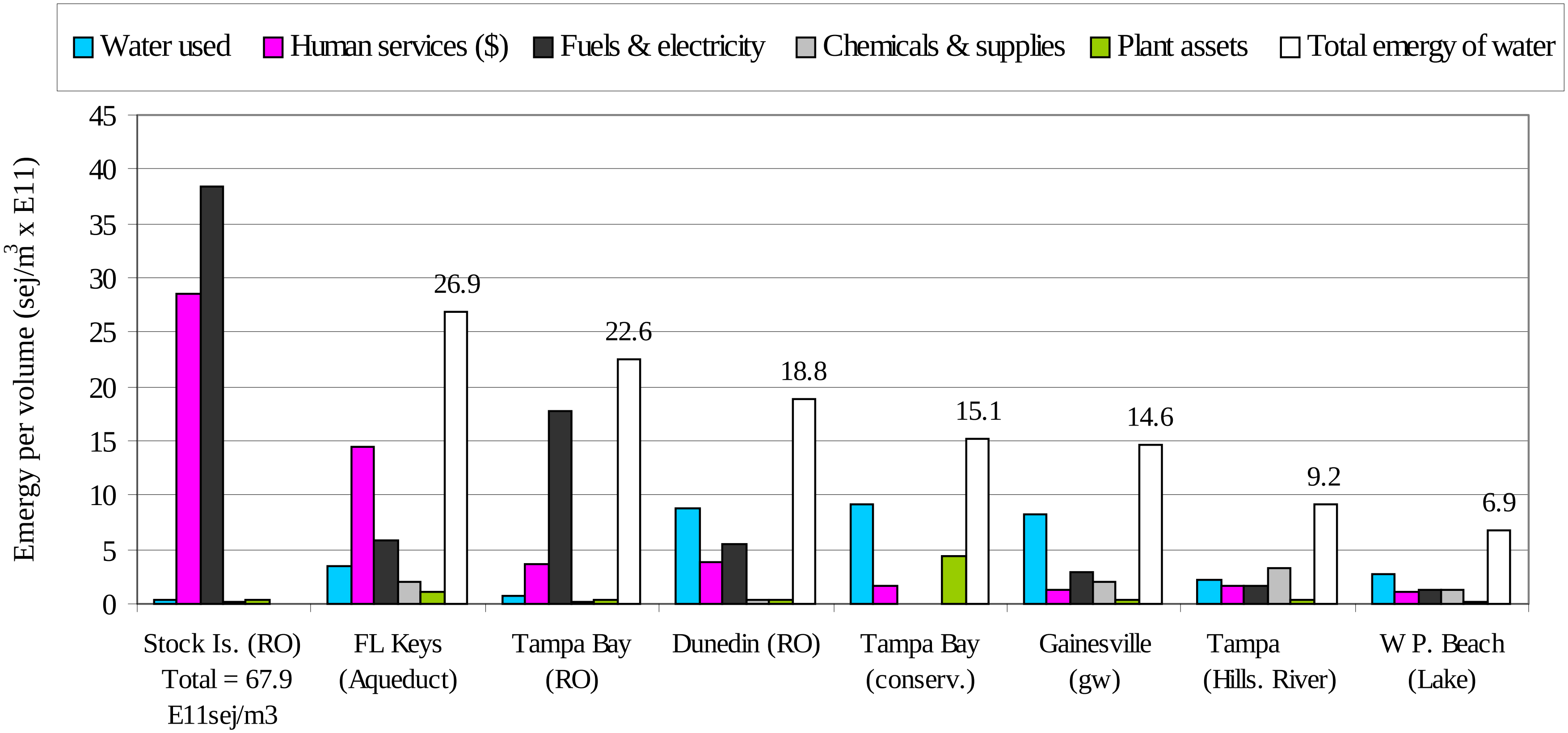


Figure 27. Emergy Signature of the Public Water Supply Alternatives Evaluated (the bar for total emergy of Stock Island RO water is not included but equals 67.9 E11 sej/m^3; the emergy of water distribution is not included, except for the FL Keys aqueduct).

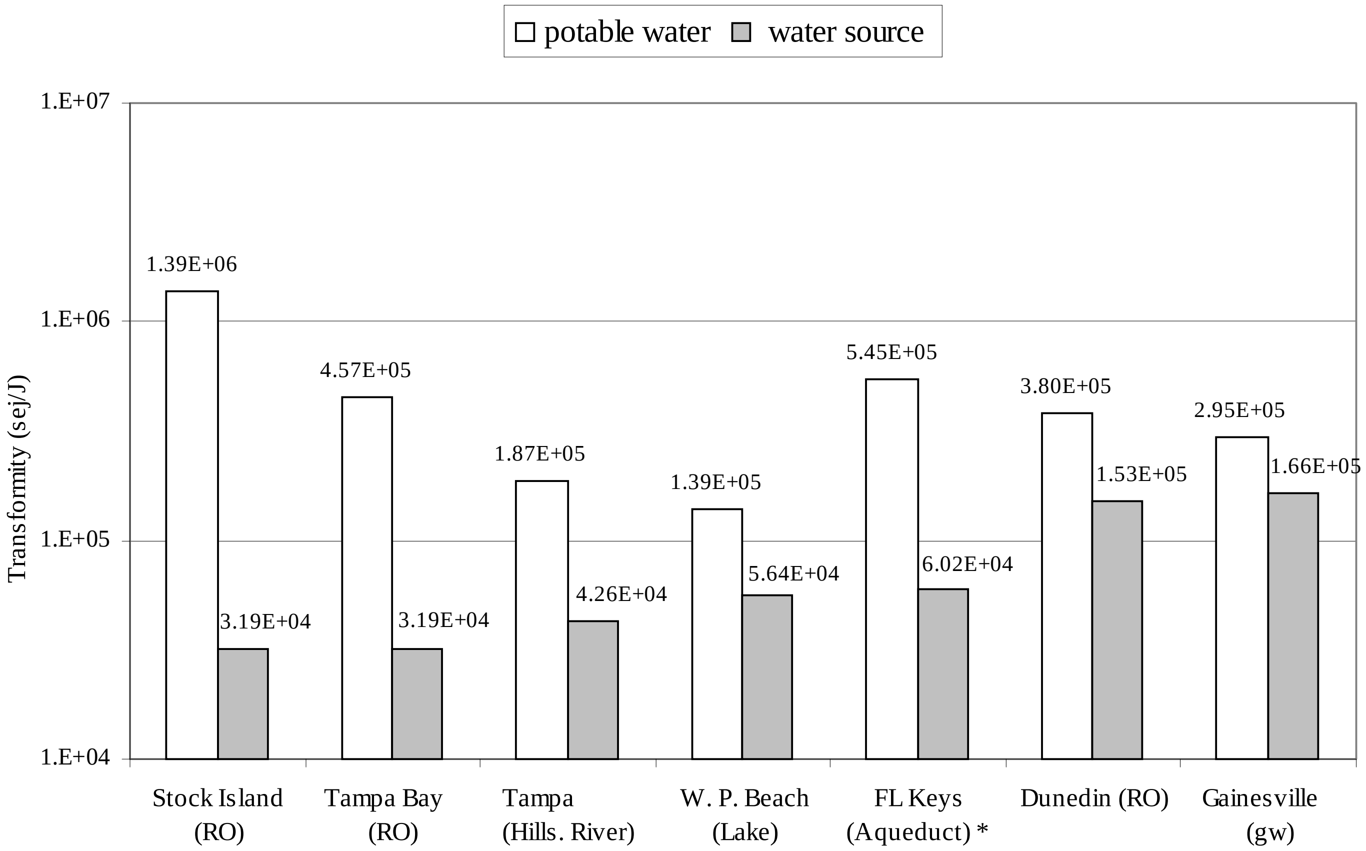
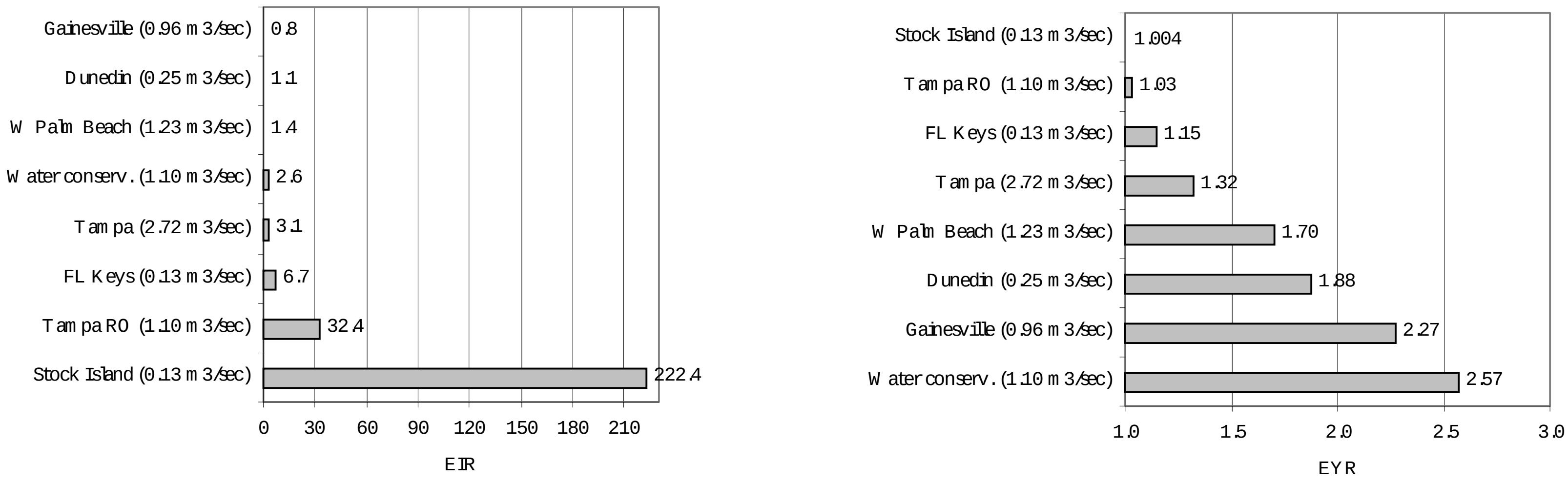
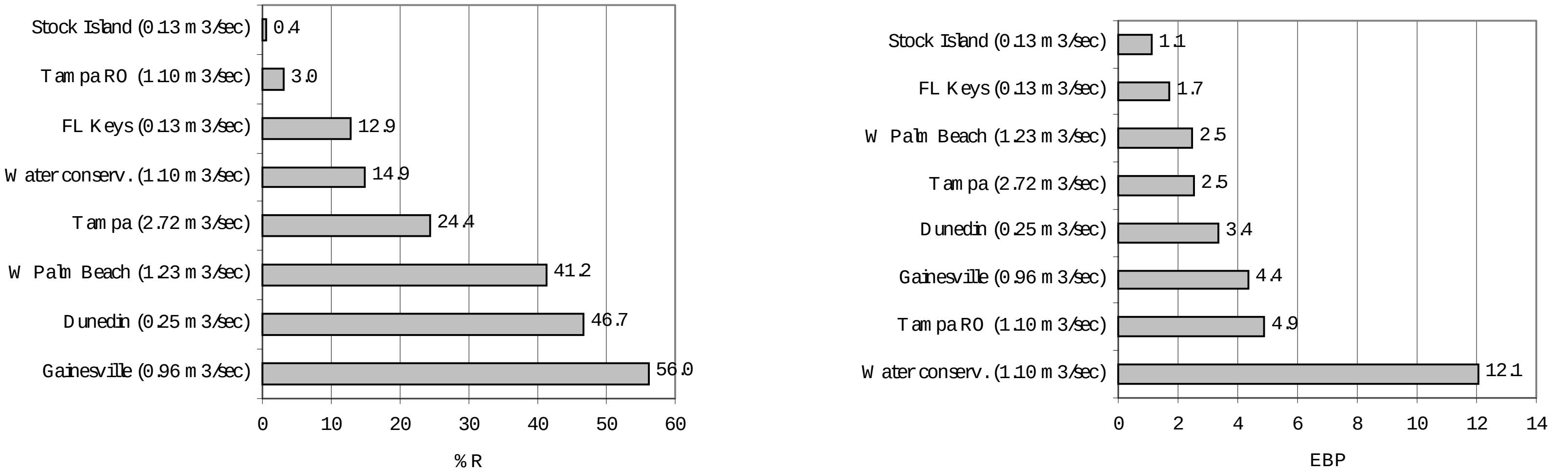


Figure 28. Transformities for water source and finished (potable) water for the public water supply alternatives evaluated. * This finished water transformity is the only one that includes part of the distribution system (i.e., the aqueduct).



(a) Emergy Investment Ratio, EIR = (P+S)/(N+R)

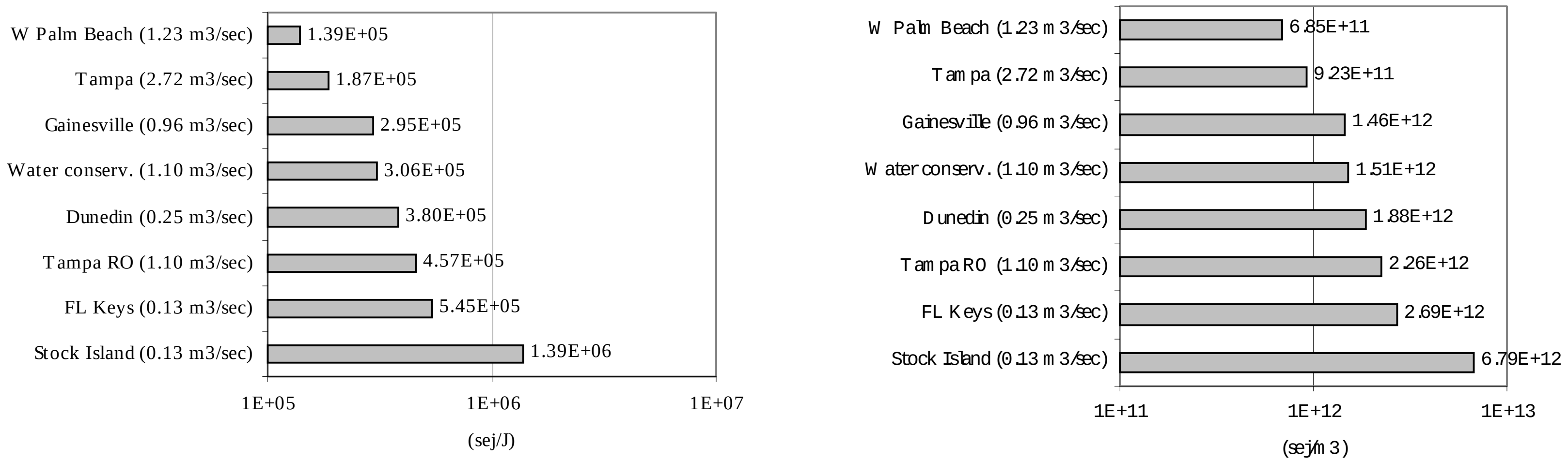
(b) Emergy Yield Ratio, EYR = Y/(P+S)



(c) Percent Renewable Emergy, % R = (R/Y)*100

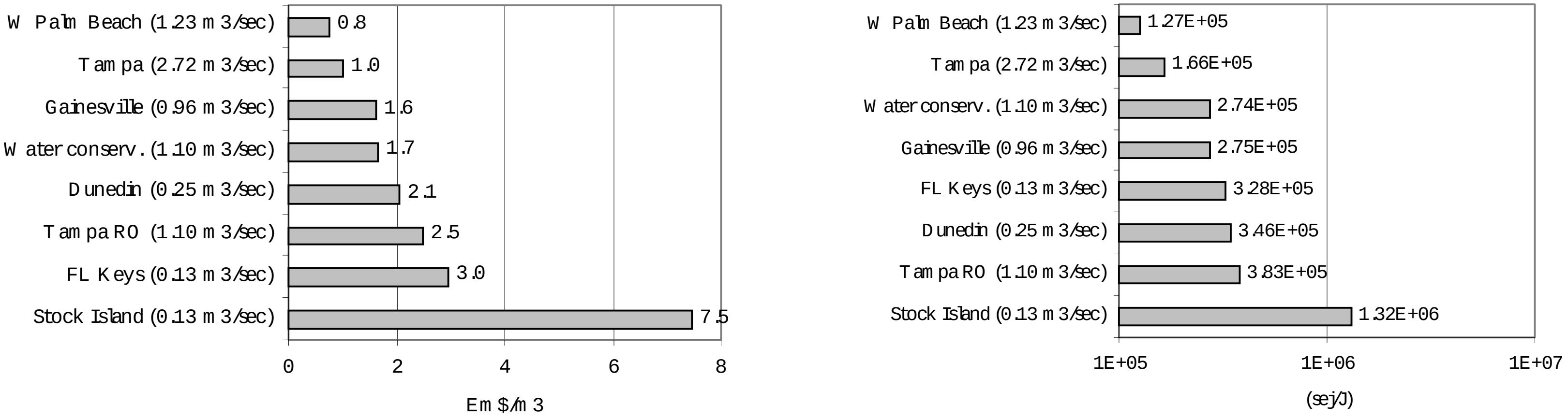
(d) Emergy Benefit to the Purchaser (EBP)

Figure 29. Comparison of the public supply systems evaluated using several emergy indices and ratios.



(e) Transformity of potable water (sej/J)

(f) Emergy per volume of potable water (sej/m3)



(g) Emdollars per volume of potable water

(h) Transformity of potable water without services (sej/J)

Figure 29--continued.

Small Scale Water Purification Alternatives Evaluated

A brief description and evaluation of four home water purification schemes and a bottling water system are presented below. The four water purification systems produce water on-site, hence no delivery is required. The emergy values of the bottled water included the emergy of household delivery. Thus, these individual-scale potable water systems can be directly compared. All the notes that document the emergy tables below are given in Appendix B.

1) Groundwater Source: Home Filtration.

A systems diagram of a home water filter used to purify water is given in Figure 30. As illustrated in the diagram, the more water is produced the more filters are used.

The emergy evaluation of this filtered water is presented in Table 39. The transformity, emergy yield and emergy per volume of filtered water were calculated to be 5.19 E6 sej/J, 3.54 E14 sej/yr and 25.6 E12 sej/m^3, respectively. The emergy of human services embodied in the money spent for replacing the filters represented the highest emergy input for producing this type of potable water followed by the emergy of the filter materials. Table 40 displays the emergy indices and ratios for the production of drinking water with this filter.

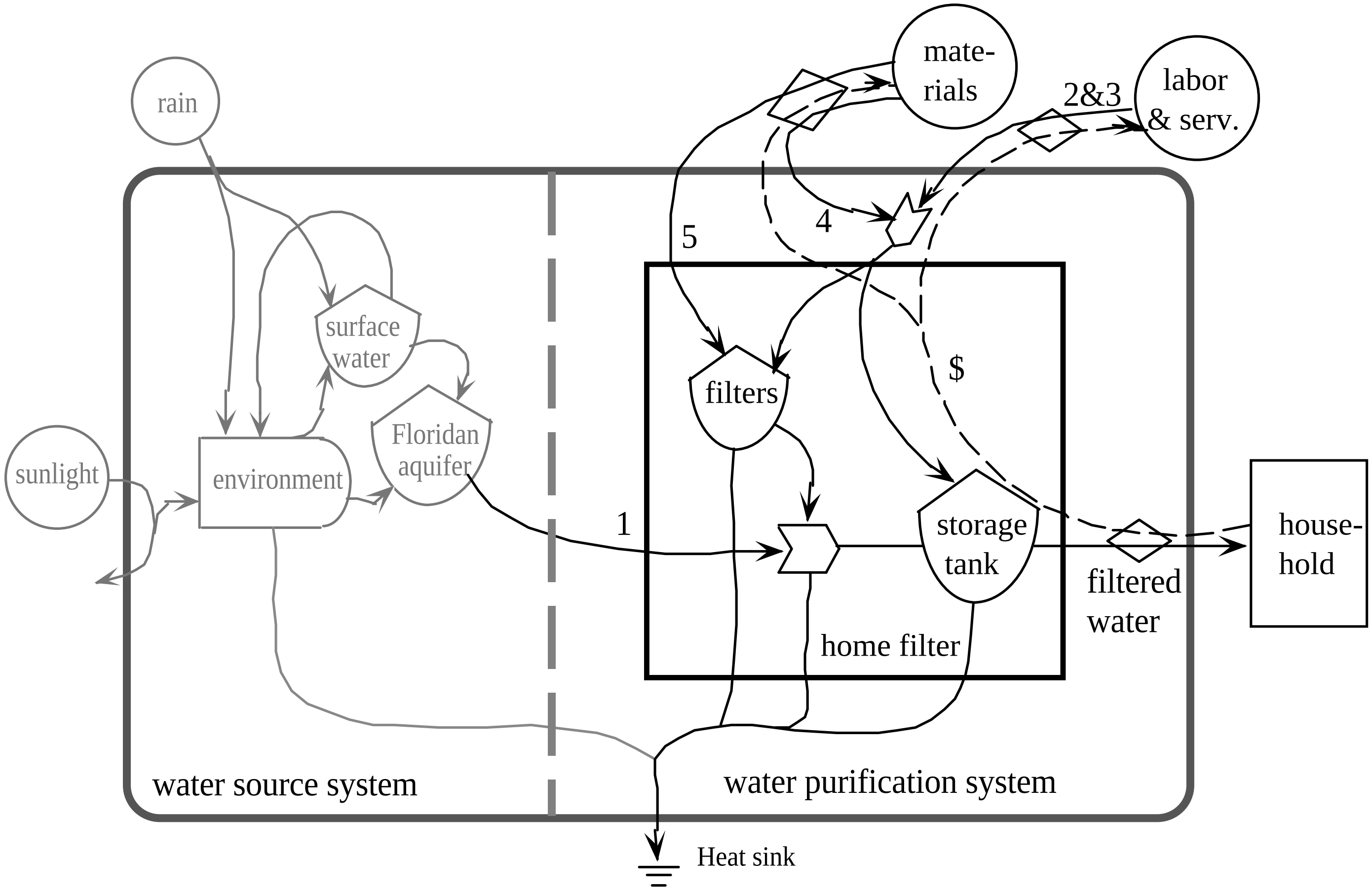


Figure 30. Energy systems diagram of the production of purified water with a home filter.

Table 39. Emergy evaluation of the drinking water produced with a home filter (10 gallons/day or 37.9 L/day).

Note	Item	Unit	Energy Data (unit/yr)	Emergy per unit (sej/unit)	Solar Emergy (E13 sej/yr)	Emergy (sej) per m^3 (E12)
RENEWABLE RESOURCES						
1	Ground Water	J	6.77E+07	1.46E+05	0.99	0.7
PURCHASED & OPERATIONAL INPUTS						
2	Filter replacement & maintenance	$	1.62E+02	9.60E+11	15.58	11.3
3	Purchase & installation	$	8.49E+01	9.60E+11	8.15	5.9
4	Materials (filter structure & tank)	g	5.00E+02	1.80E+09	0.09	0.1
5	Materials (filters replaced)	g	1.47E+03	7.20E+10	10.58	7.7
	Yield (Y) = Total emergy of drinking water produced:				**35.39**	**25.6**
EMERGY PER UNIT OF POTABLE WATER (inside households)						
6	Potable water	m^3	1.38E+01	2.56E+13	35.39	25.6
7	Potable water	$	2.47E+02	1.43E+12	35.39	25.6
8	Potable water	J	6.82E+07	**5.19E+06**	35.39	25.6
9	Potable water	g	1.38E+07	2.56E+07	35.39	25.6
10	Drinking water with-out services	J	6.82E+07	1.71E+06	11.66	8.4

Table 40. Emergy indices and ratios for the drinking water produced with a home filter.

Note	Name of Index	Short expression	Quantity
11	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	34.91
12	Emergy Yield Ratio (EYR)	Y/(P + S)	1.03
13	% Renewable emergy	100 x (R/Y)	2.8
14	Ratio of Emergy Benefit to the Purchaser (EBP) in 1999	Em$/$	1.57
15	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	28.15
16	Transformity of potable water	sej/J	5.19E+06
17	Emergy per m^3 of potable water	sej/m^3	2.56E+13

Footnotes to tables 39 and 40 in Appendix B.

2) Groundwater Source: Boiling Water.

A systems diagram of the process of boiling water in an average home in Florida is given in Figure 31. Self-supplied groundwater is boiled on an electric range (stove) and after cooling the water is used just for drinking.

Table 41 shows the emergy evaluation of producing 2 gal/day (7.6 L/day) from boiling water on an electric range. The transformity, emergy yield and emergy per volume of boiled water were calculated to be 1.98 E7 sej/J, 2.70 E14 sej/yr and 97.6 E12 sej/m^3, respectively. Electricity accounted for the largest emergy input of boiled water followed by the human work required for conduct the boiling process. The emergy indices and ratios of this water purification method are given in Table 42.

3) Salty Water Source: Advanced Solar Distillation (Humidification-Dehumidification Cycle).

A systems diagram of an advanced solar distillation process that integrates a humidification-dehumidification cycle to increase the water production capacity is given in Figure 32. The purpose of the humidification-dehumidification cycle is to use the latent heat of condensation to preheat the salty water going into the solar collector.

The emergy evaluation of this advanced distillation system is given in Table 43. Values in this table are for a 2.0 m^2 solar collector unit producing 4.0 gal/day (15.0 L/day) of drinking water. The calculated transformity, emergy yield and emergy per volume of the distilled water were 2.05 E7 sej/J, 5.55 E14 sej/yr and 101.4 E12 sej/m^3, respectively. The electric power used to pump salty water to the solar still had the highest emergy input followed by the costs to build and operate the unit. The emergy indices of the distilled water are presented in Table 44.

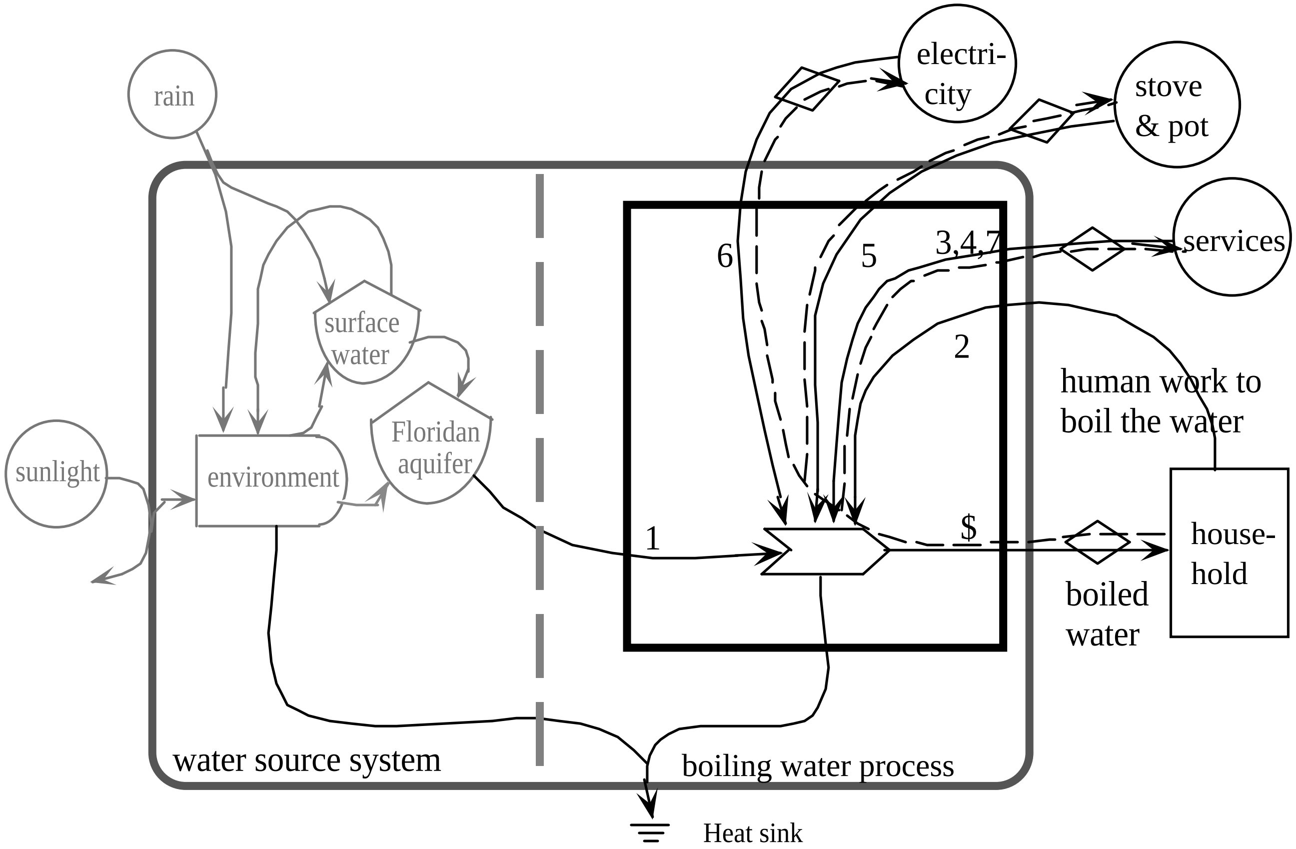


Figure 31. Energy systems diagram of boiling groundwater in Florida.

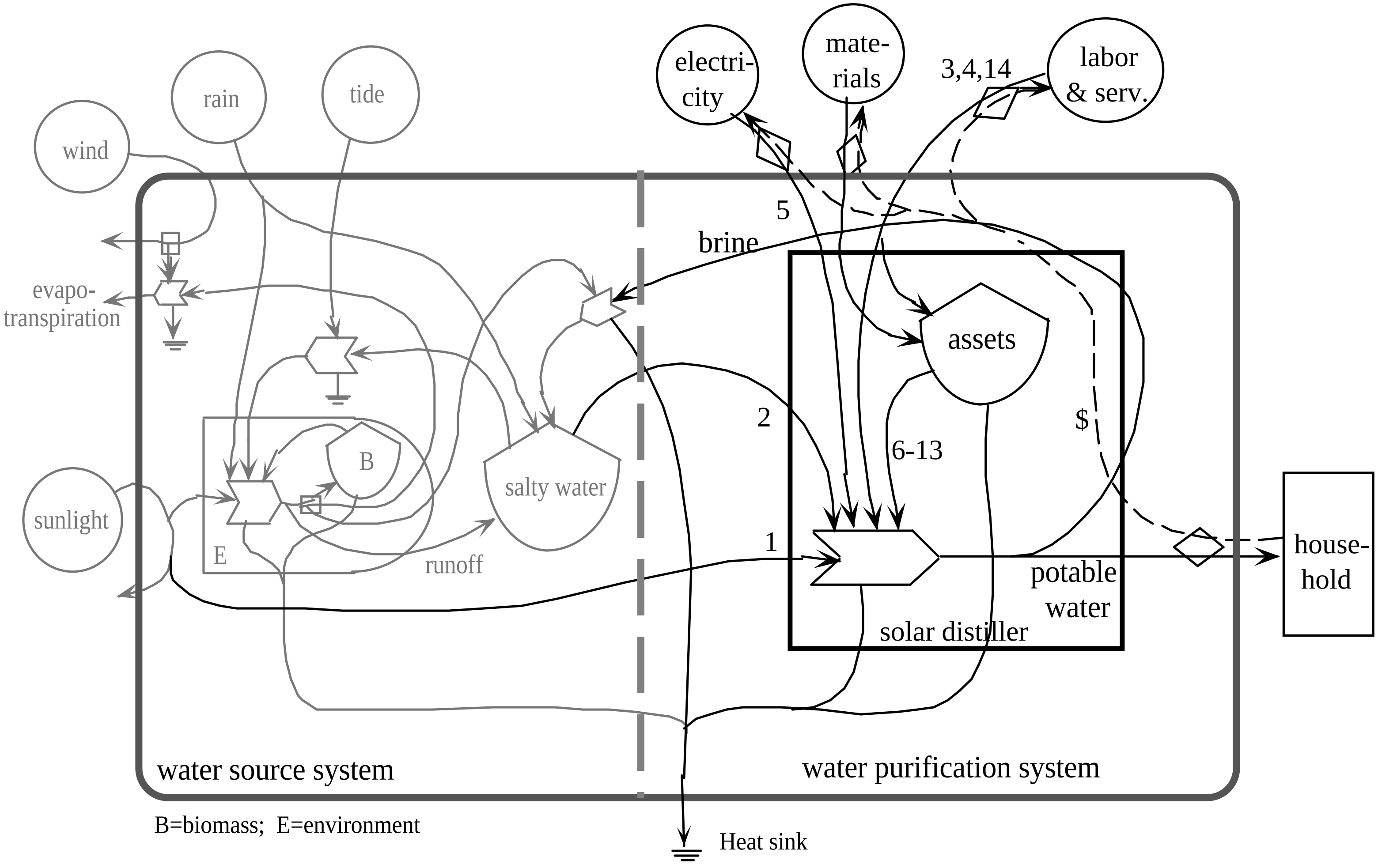
Table 41. Emergy evaluation of the boiling water to make it potable (2.0 gal/day or 7.6 L/day).

Note	Item	Unit	Energy Data (unit/yr)	Emergy per unit (sej/unit)	Solar Emergy (E13 sej/yr)	Emergy (sej) per m^3 (E12)
RENEWABLE RESOURCES						
1	Ground Water	J	1.49E+07	1.46E+05	0.22	0.78
PURCHASED & OPERATIONAL INPUTS						
2	Work required to boil water	J	6.37E+06	6.76E+06	4.31	15.58
3	Proportion of stove use for boiling	$	6.9	9.10E+11	0.62	2.26
4	Proportion of pot use for boiling	$	4.4	9.10E+11	0.40	1.44
5	Total materials required	kg	5.57	1.80E+12	1.00	3.63
6	Electricity required to boil water	J	1.13E+09	1.60E+05	18.13	65.63
7	Cost of electric power used for boiling	$	25.2	9.10E+11	2.29	8.29
	Yield (Y) = Total emergy to boiled water:				**26.97**	**97.62**
EMERGY PER UNIT OF POTABLE WATER (inside households)						
8	Potable water	m^3	2.76E+00	9.76E+13	26.97	97.62
9	Potable water	J	1.36E+07	**1.98E+07**	26.97	97.62
10	Potable water	g	2.76E+06	9.76E+07	26.97	97.62
11	Drinking water with-out services	J	1.36E+07	1.42E+07	19.35	70.04

Table 42. Emergy indices and ratios for boiling water to make it potable.

Note	Name of Index	Short expression	Quantity
12	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	123.39
13	Emergy Yield Ratio (EYR)	Y/(P + S)	1.008
14	% Renewable emergy	100 x (R/Y)	0.8
15	Emergy Benefit to the Purchaser (EBP) in 2000	Em$/$	8.14
16	2000 Em-dollar value of potable water per m^3	Em$/$m^3$	107.27
17	Transformity of potable water	sej/J	1.98E+07
18	Emergy per m^3 of potable water	sej/m^3	9.76E+13

Footnotes to tables 41 and 42 in Appendix B.



B=biomass; E=environment

Figure 32. Systems diagram of potable water produced by solar distillation with a humidification/dehumidification cycle.

Table 43. Emergy evaluation of potable water produced by solar desalination with a 2.0 m^2 solar distiller using a humidification-dehumidification cycle in central Florida (4.0 gal/day or 15.0 L/day).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E12 sej/yr)	Emergy (sej) per m^3 (E12)
RENEWABLE RESOURCES						
1	Sunlight	J	1.08E+10	1.0	0.01	0.002
2	Salty water	J	1.68E+08	3.19E+04	5.36	0.98
PURCHASED & OPERATIONAL INPUTS						
3	Construction & operation costs	$	1.83E+02	9.10E+11	166.08	30.34
4	Work reqd. to clean the glass cover	J	5.46E+06	6.76E+06	36.90	6.74
5	Electricity required to pump water	J	8.21E+08	1.60E+05	131.40	24.01
6	Wood used in the evaporator	J	2.39E+07	3.50E+04	0.84	0.15
7	Steel plates used for hum-dehum unit	g	2.75E+04	1.78E+09	48.93	8.94
8	Pump materials	g	6.00E+02	6.70E+09	4.02	0.73
9	PVC pipes for pumping salty water	g	1.35E+04	7.60E+08	10.26	1.87
10	Copper tube (condenser)	g	1.01E+03	6.80E+10	68.62	12.54
11	Solar collector (steel)	g	3.53E+04	1.78E+09	62.78	11.47
12	Solar collector (glass)	g	4.40E+03	8.40E+08	3.70	0.68
13	Concrete & cement	g	4.00E+03	1.23E+09	4.92	0.90
14	Land lease	$	1.20E+01	9.10E+11	10.92	2.00
	Yield (Y) = Total emergy of drinking water (produced on site):				**554.73**	**101.35**
EMERGY PER UNIT OF DISTILLED WATER (HUM/DEHUM CYCLE)						
15	Potable water	m^3	5.47	1.01E+14	554.73	101.35
16	Potable water	J	2.70E+07	**2.05E+07**	554.73	101.35
17	Potable water	g	5.47E+06	1.01E+08	554.73	101.35
18	Potable water with-out services	J	2.70E+07	1.26E+07	340.83	62.27

Table 44. Emergy indices and ratios for the potable water produced with a solar distiller containing a humidification-dehumidification cycle.

Note	Name of Index	Expression	Quantity
19	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	88.37
20	Emergy Yield Ratio (EYR)	Y/(P + S)	1.011
21	% Renewable emergy	100 x (R/Y)	1.1
22	Emergy Benefit to the Purchaser (EBP) in 2000	Em$/$	3.1
23	Em-dollar value of potable water/m^3	Em$/$m^3$	111.4
24	Transformity of potable water	sej/J	2.05E+07
25	Emergy per m^3 of potable water	sej/m^3	1.01E+14

Footnotes to tables 43 and 44 in Appendix B.

4) Salty Water Source: Traditional Solar Distillation.

Figure 33 shows the systems diagram of a typical solar distiller. The base of the distiller is made of fiberglass. No electricity or fuels are used to operate this low energy-insensitive solar still since salty water is had-carried to the still.

The emergy evaluation, per m^2 of effective evaporating area, of this fiberglass solar distillation unit is given in Table 45. The calculated transformity, emergy yield and emergy per volume of this distilled water were 2.31 E7 sej/J, 1.21 E14 sej/yr and 113.9 E12 sej/m^3, respectively. Construction and operational costs had the greatest emergy contribution for producing this potable water followed by black polythene used as a heat absorbent between the jute cloth. The emergy indices of the potable water produced are provided in Table 46.

5) Tap or Spring Water Source: Bottled Water.

A systems diagram of the production of purified bottled water by Culligan Co. in Ocala, Florida, is given in Figure 34. The diagram shows how drinking water from the City of Ocala is used as the water source and then is further purified, bottled, and truck-delivered to consumers. Figure 35 shows a system diagram in which instead of using drinking water as the source for bottled water (e.g., Figure 34), groundwater flowing naturally through springs in Ocala is used to produced bottled water. The main difference between the bottled water produced in Figure 34 and Figure 35 consists of the transformity of the water source (e.g., drinking water vs. spring water).

The emergy evaluation for this bottling water system is given in Table 47. The table compares the emergy value of the bottled water produced with tap water (Figure 34) to the bottled water produced with spring water (Figure 35). The calculated transformities of the actual bottling process using tap water as the water source and the alternative scenario in which spring water is used as the water source were 3.16 E7 sej/J and 2.90 E7 sej/J, respectively. The emergy per volume of the actual bottling process and the alternative scenario in which spring water is used as the water source were 155.9 E12 sej/m^3 and 143.1 E12 sej/m^3, respectively. For both the actual bottling process and the alternative scenario, the emergy of the diesel used by the delivery trucks represented the highest emergy of bottled water followed by operation and maintenance costs. The emergy indices for both of these bottle water scenarios are given in Table 48.

Summary of Small Scale Water Purification Values.

Table 49 summarizes the results of the emergy evaluations of small scale water purification systems. Emergy signatures of these potable water alternatives are given in Figure 36. Figure 37 contrasts the transformities of the water source and the finished water produced by each alternative. Figure 38 compares several emergy indices and ratios of these small scale water purification systems. Only the tap water scenario for producing bottled water (e.g., Figure 34) was used in these summary table and figures.

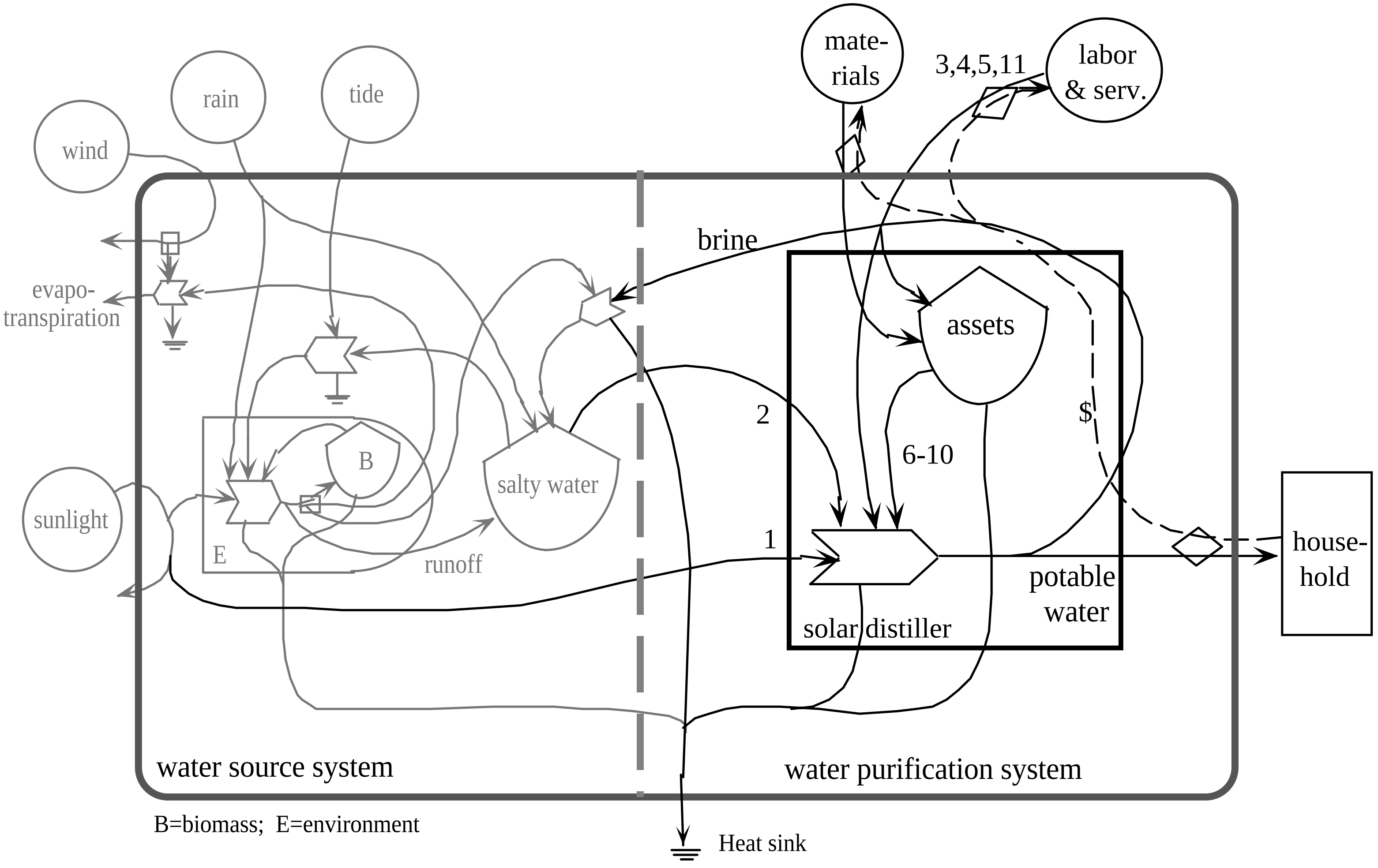


Figure 33. Systems diagram of potable water produced by solar distillation.

Table 45. Emergy evaluation of potable water produced by desalination using a 1.0 m^2 solar distiller in central Florida (0.8 gal/day or 2.9 L/day).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E12 sej/yr)	Emergy (sej) per m^3 (E12)
RENEWABLE RESOURCES						
1	Sunlight	J	5.40E+09	1.00E+00	0.01	0.005
2	Salty water	J	2.99E+06	3.19E+04	0.10	0.09
PURCHASED & OPERATIONAL INPUTS						
3	Construction & operation costs	$	17.6	9.10E+11	16.05	15.17
4	Work to carry seawater to distiller	J	6.82E+06	6.76E+06	46.13	43.59
5	Work reqd. to clean the glass cover	J	3.18E+06	6.76E+06	21.53	20.34
6	Fiber reinforced plastic	g	6,270	7.60E+08	4.77	4.50
7	Black polythene	g	3,604	4.30E+09	15.50	14.64
8	Jute cloth	J	1.92E+06	2.85E+06	5.48	5.18
9	Solar collector (glass)	g	4.40E+03	8.40E+08	3.70	3.49
10	Concrete & cement	g	1.50E+03	1.23E+09	1.85	1.74
11	Land lease	$	6.0	9.10E+11	5.46	5.16
	Yield (Y) = Total emergy of drinking water (produced on site):				**120.56**	**113.93**
EMERGY PER UNIT OF DISTILLED WATER						
12	Potable water	m^3	1.06	1.14E+14	120.56	113.93
13	Potable water	J	5.23E+06	**2.31E+07**	120.56	113.93
14	Potable water	g	1.06E+06	1.14E+08	120.56	113.93
15	Potable water with-out services	J	5.23E+06	7.05E+06	36.85	34.82

Table 46. Emergy indices and ratios for the potable water produced by desalination using a 1.0 m^2 solar distiller.

Note	Name of Index	Expression	Quantity
16	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	1195.6
17	Emergy Yield Ratio (EYR)	Y/(P + S)	1.001
18	% Renewable Emergy	(P+N)/(R)	0.1
19	Emergy Benefit to the Purchaser (EBP) in 2000	Em$/$	5.6
20	Em-dollar value of potable water/m^3	Em$/$m^3$	125.19
21	Transformity of potable water	sej/J	2.31E+07
22	Emergy per m^3 of potable water	sej/m^3	1.14E+14

Footnotes to tables 45 and 46 in Appendix B.

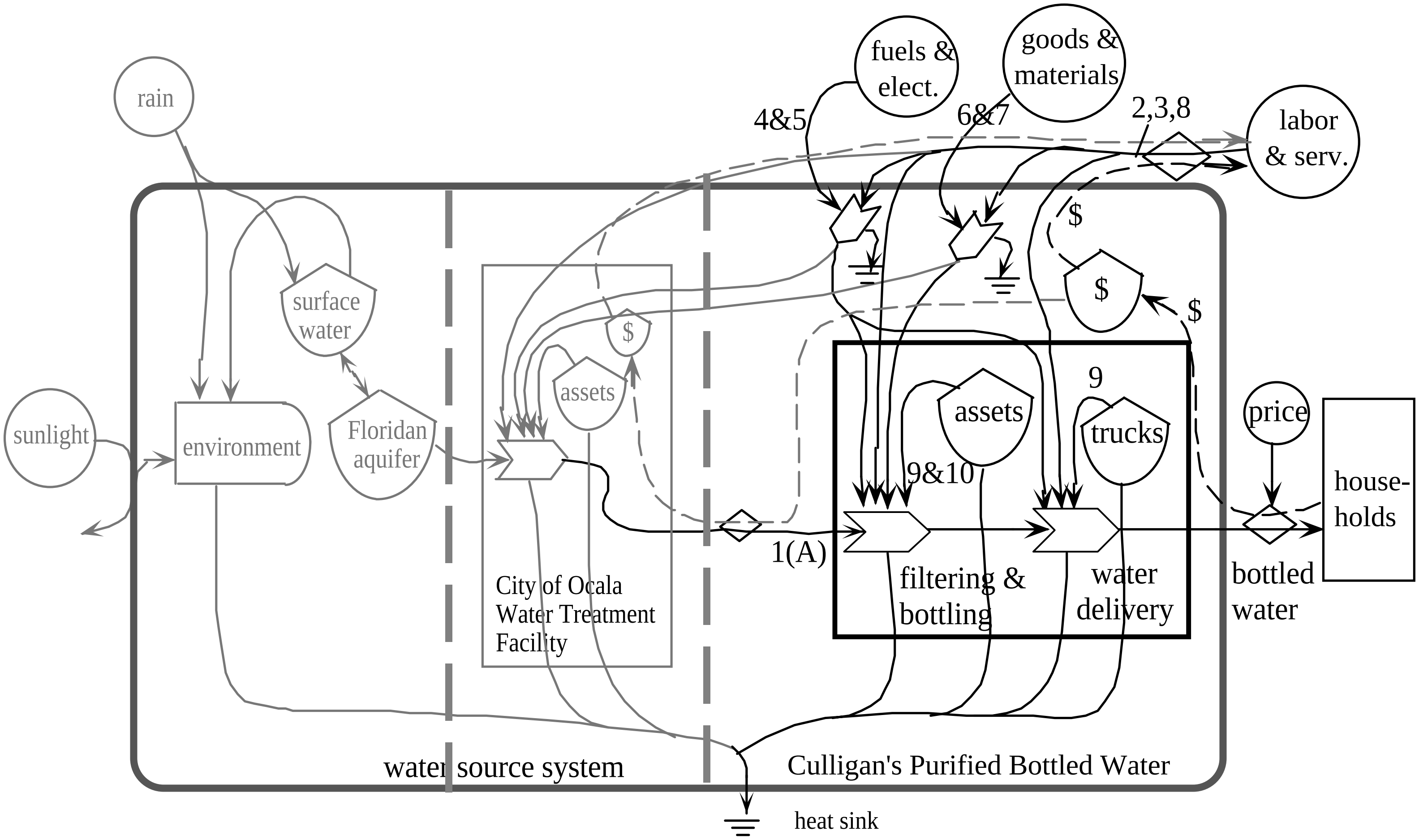


Figure 34. Systems diagram of the production of purified bottled water by Culligan, Co. in Ocala, Florida.

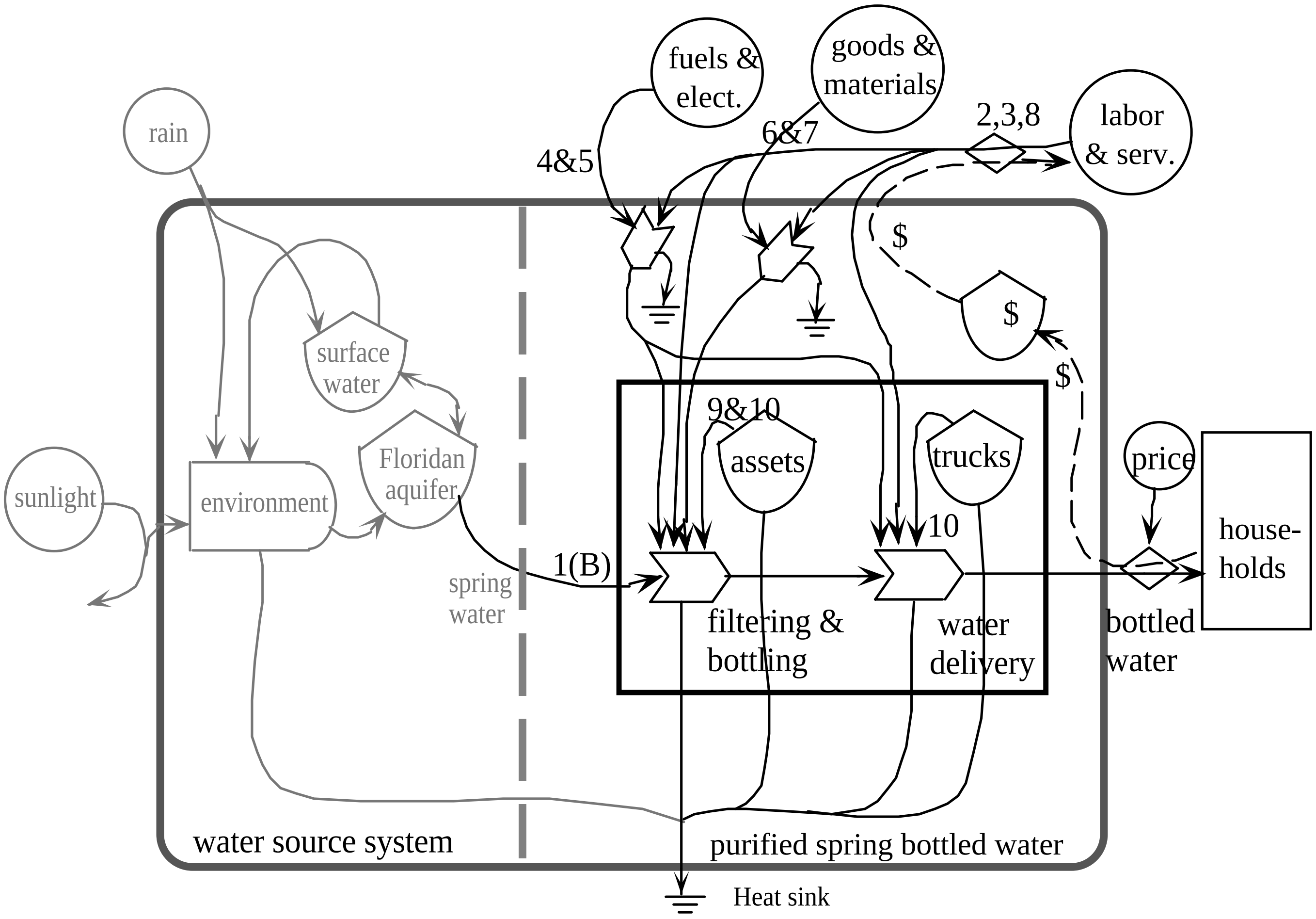


Figure 35. Systems diagram of the production of purified bottled water using spring water from the Floridan aquifer as a source.

Table 47. Emergy evaluation of bottled water produced in Ocala, Florida (13,500 gal/day or 51.1 m^3/day).

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E12)
RENEWABLE RESOURCES						
1(A)	Tap water	J	1.84E+12	2.95E+05	0.54	29.20
1(B)	Spring water	J	1.84E+12	1.66E+05	0.31	16.40
PURCHASED & OPERATIONAL INPUTS						
2	Operation & maintenance	$	8.66E+05	9.60E+11	0.83	44.55
3	Marketing & advertisement	$	1.80E+05	9.60E+11	0.17	9.27
4	Electricity	J	6.89E+11	1.60E+05	0.11	5.91
5	Diesel used by delivery trucks	J	1.59E+13	6.60E+04	1.05	56.37
6	Filter replacement & detergents	$	3.30E+04	9.60E+11	0.03	1.70
7	Plastic bottles	kg	7.35E+03	3.80E+11	0.003	0.15
8	Total Assets	$	9.00E+04	9.60E+11	0.09	4.63
9	Concrete	kg	2.40E+04	1.23E+12	0.03	1.58
10	Steel & iron	kg	2.65E+04	1.80E+12	0.05	2.56
	Y(A) = Total emergy of bottled water (delivered to customers):				**2.91**	**155.92**
	Y(B) = Total emergy of bottled water (delivered to customers):				2.67	143.13
EMERGY PER UNIT FOR BOTTLED WATER (delivered to customers)						
			Tap water source (A)			sej/unit for (B)
11(A,B)	Bottled water produced	m^3	1.87E+04	1.56E+14		1.43E+14
12(A,B)	Bottled water produced	1999 $	4.68E+06	6.21E+11		5.70E+11
13(A,B)	Bottled water produced	J	9.21E+10	**3.16E+07**		**2.90E+07**
14(A,B)	Bottled water produced	g	1.87E+10	1.56E+08		1.43E+08
15(A,B)	Bottled water w/out services	J	9.21E+10	1.94E+07		1.68E+07

A = tap (drinking) water source

B = spring water source

Table 48. Emergy indices and ratios of bottled water.

Note	Name of Index	Short expression	Values for (A)	Values for (B)
16(A,B)	Emergy Investment Ratio (EIR)	(P + S)/(N + R)	7.75	7.73
17(A,B)	Emergy Yield Ratio (EYR)	Y/(P + S)	1.23	1.13
18(A,B)	% Renewable emergy	100 x (R/Y)	10.5	11.5
19(A,B)	Emergy Benefit to the Purchaser, 1999	Em$/$	0.65	0.59
20(A,B)	2000 Em-dollar per m^3	Em$/m^3	171.34	157.28
21(A,B)	Transformity of potable water	sej/J	3.16E+07	2.90E+07
22(A,B)	Emergy per m^3 of potable water	sej/m^3	1.56E+14	1.43E+14

Footnotes to tables 47 and 48 in Appendix B.

Table 49. Summary of the emergy evaluation of small scale water purification alternatives.

Description	Household-level potable water systems				
Type of water treatment	home filter	boiled water	solar distiller (H/D)	solar distiller	bottled water
Water source	Floridan aquifer	Floridan aquifer	salty water	salty water	tap water
Avg. flowrate produced	37.9 L/day	7.6 L/day	15.0 L/day	3.0 L/day	51,100 L/day
Emergy Values (2000 Em$/m^3)					
Water used	0.8	0.9	1.1	0.10	32.1
Human services #	18.9	30.3	42.9	92.6	66.1
Fuels & electricity	0.0	72.1	26.4	0.0	68.4
Plant assets	8.5	4.0	41.0	32.5	4.7
Total emergy of water	28.2	107.3	111.4	125.2	171.3
Emergy Indices & Ratios					
Emergy Investment Ratio	34.9	123.4	88.4	1,195.6	7.7
Emergy Yield Ratio	1.03	1.008	1.01	1.001	1.23
% Renewable emergy	2.8	0.8	1.1	0.08	10.49
Emergy Benefit to Purchaser	1.6	8.1	3.1	5.60	0.65
Emergy per volume (sej/m^3)	2.56E+13	9.76E+13	1.01E+14	1.14E+14	1.56E+14
Transformity of potable water	5.19E+06	1.98E+07	2.05E+07	2.31E+07	3.16E+07
Transformity of water source	1.46E+05	1.46E+05	3.19E+04	3.19E+04	2.95E+05

H/D = humidification / dehumidification cycle

values for human services represent the sum of all dollar flows

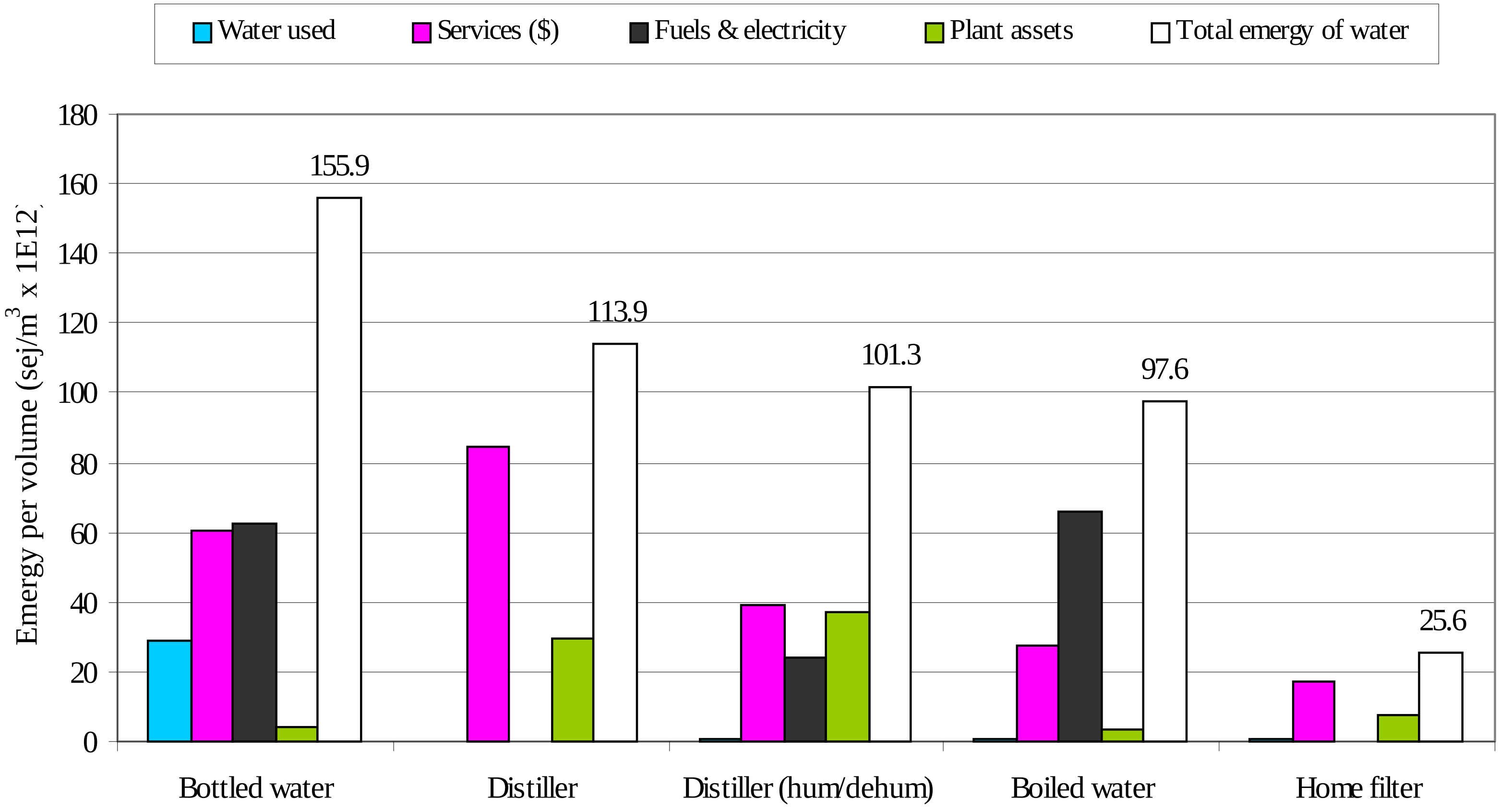


Figure 36. Emergy signature of the small scale water purification alternatives evaluated.

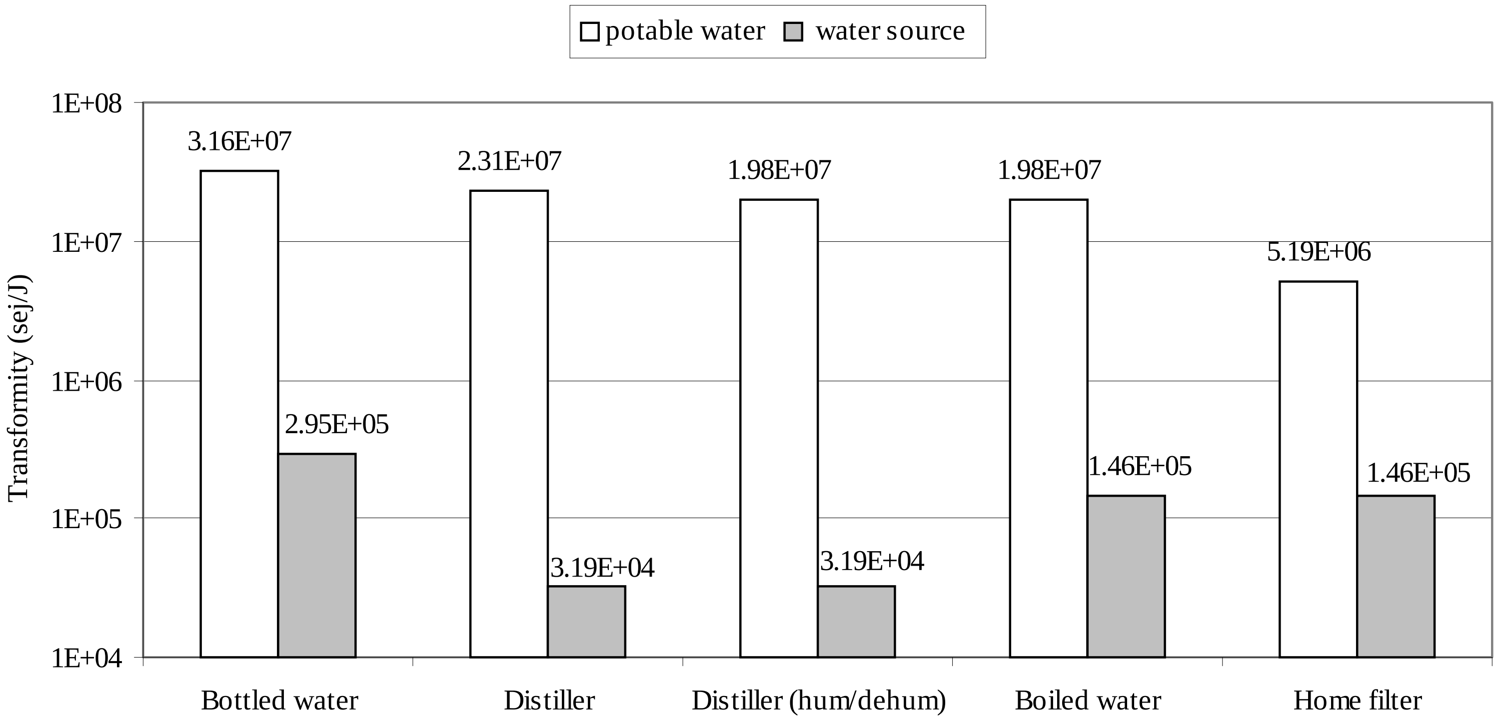
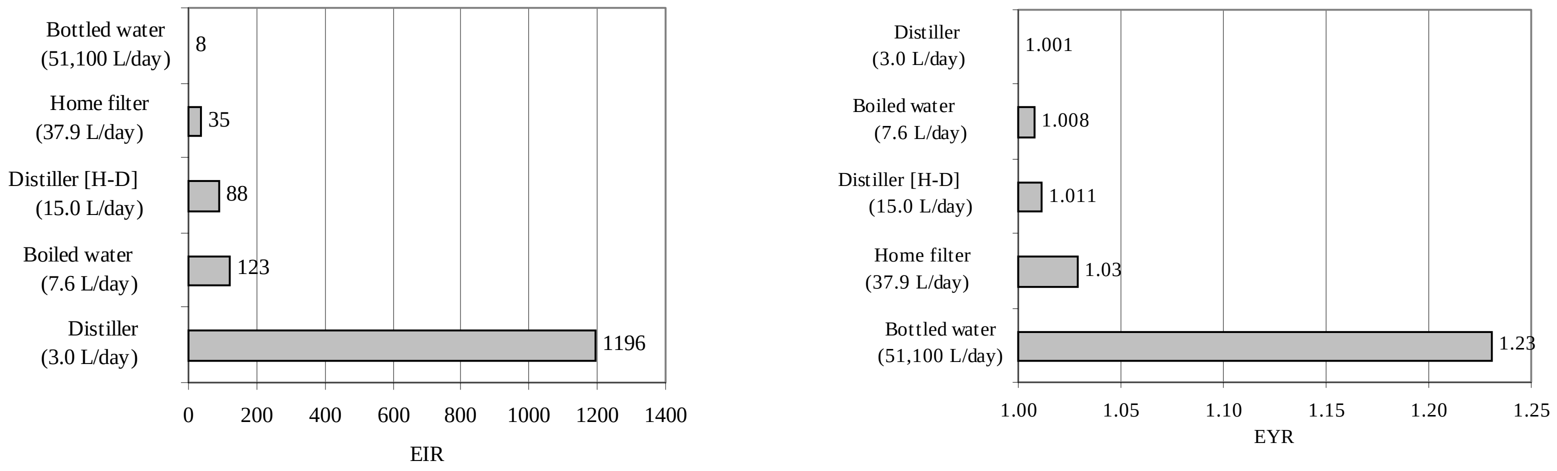
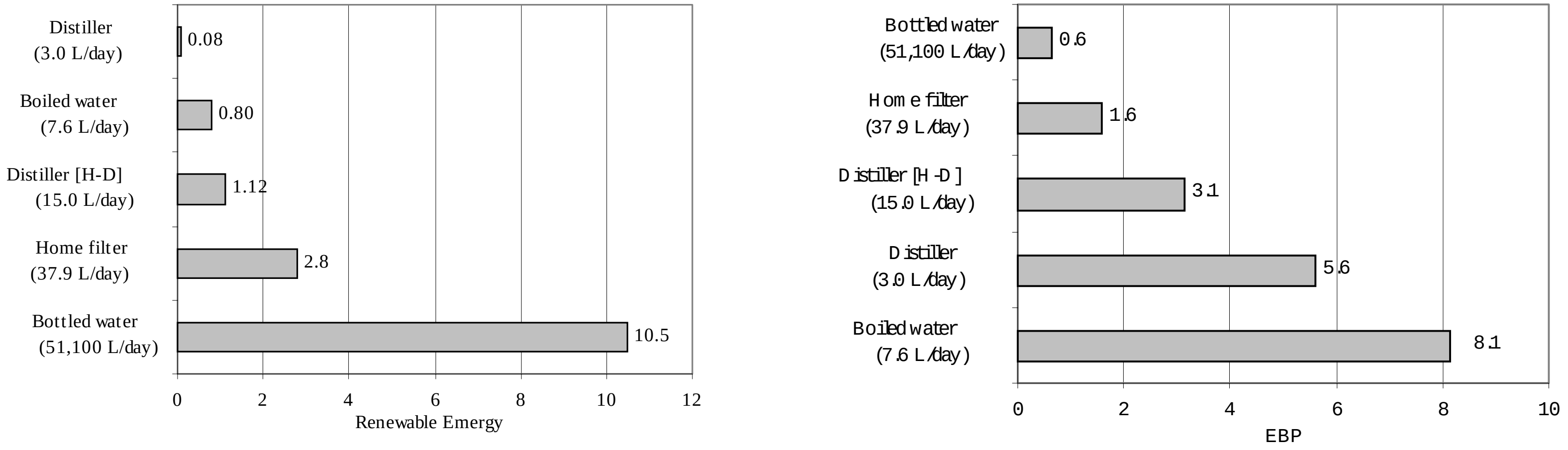


Figure 37. Transformities for water source and finished (potable) water for the small scale water systems evaluated.



(a) Emergy Investment Ratio, EIR = (P+S)/(N+R)

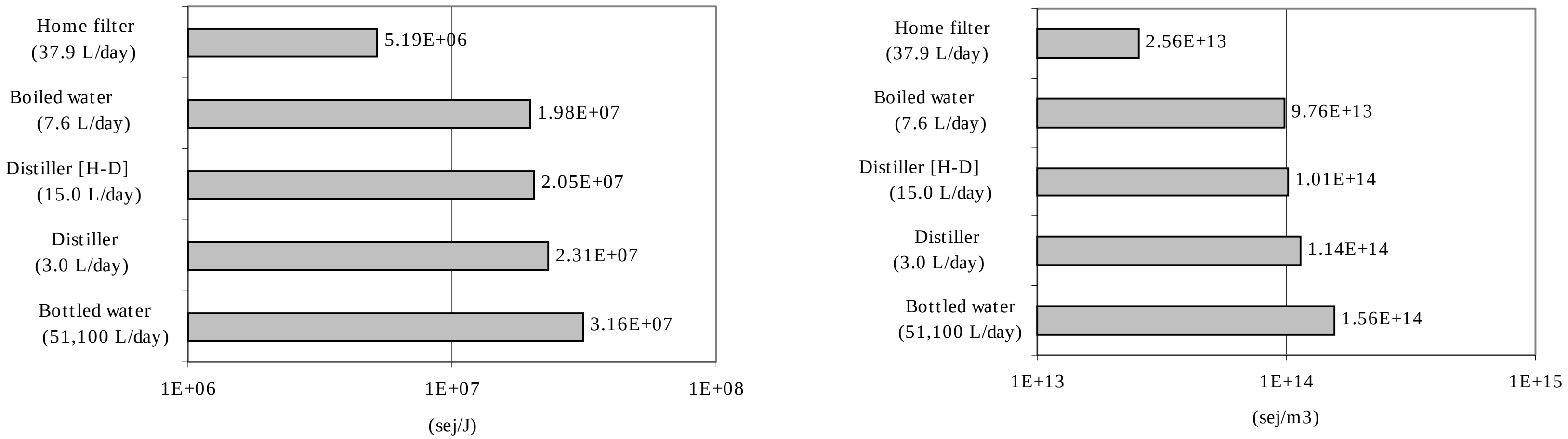
(b) Emergy Yield Ratio, EYR = Y/(P+S)



(c) Percent Renewable Emergy, (R/Y)*100

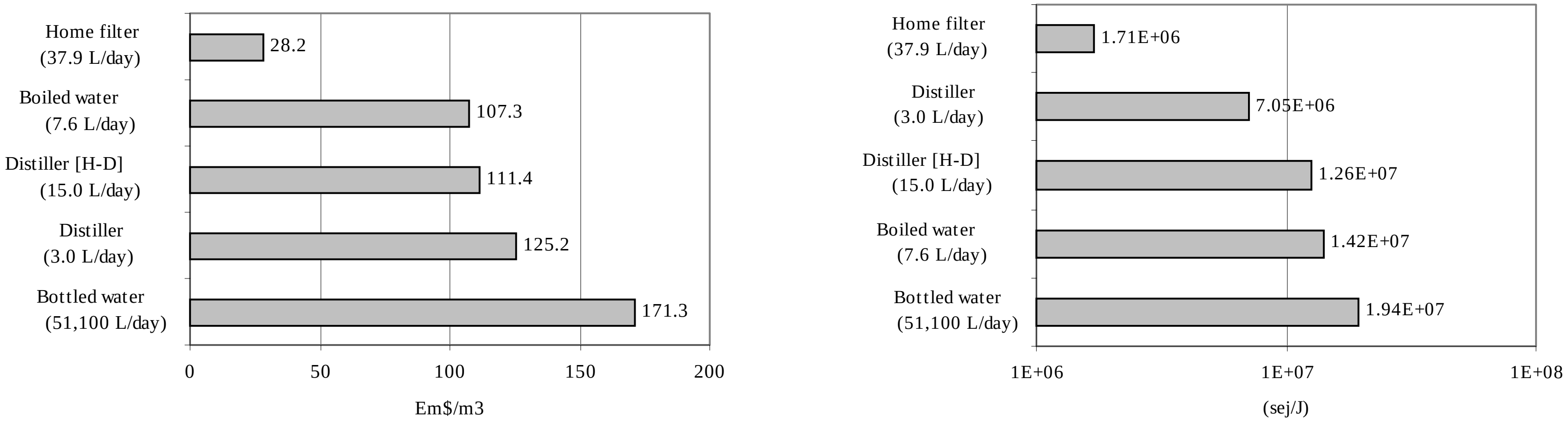
(d) Emergy Benefit to the Purchaser (EBP).

Figure 38. Comparison of the small scale water purification systems evaluated using several emergy indices and ratios.



(e) Transformity of potable water (sej/J)

(f) Emergy per volume of potable water (sej/m3)



(g) Emdollars per volume of potable water

(h) Transformity of potable water without services (sej/J)

Figure 38--continued.

Comparison of Potable Water Alternatives.

Table 50 compares all the potable water systems evaluated. The emergy of water distribution, which was calculated from the evaluation of Gainesville's Regional utility water distribution system (Table 37), was added to the public supply values. Thus, the numbers given in this table represent home-consumed potable water. The last column in Table 50 shows the Em$ values of public supply alternatives per cubic meter of water consumed just for drinking and cooking. This column is probably more appropriate for comparison with the Em$/$m^3$ values of the small scale production systems.

Table 50. Comparison of emergy values of potable water (home-consumed).

Potable water alternative	Location	Water production	sej/m^3 (a) (x1E12)	Em$/m^3 (b) (year 2000)	Em$/m^3 (c) (year 2000)
Public supply *		(m^3/sec)			
1) Surface water (lake) source	West Palm Beach	1.23	0.99	1.08	47.1
2) Surface water (river) source	Tampa	2.72	1.22	1.34	58.4
3) Groundwater (Floridan aquifer) source	Gainesville	0.96	1.76	1.93	84.1
4) Water conservation program	Tampa	1.10	1.81	1.99	86.5
5) Brackish groundwater source (RO)	Dunedin	0.25	2.18	2.39	103.9
6) Salty water source (new RO technology)	Tampa	1.10	2.56	2.81	122.2
7) Groundwater (Biscayne aquifer) source	FKAA	0.66	2.99	3.29	142.9
8) Seawater source (old RO technology)	Stock Island	0.13	7.09	7.79	338.7
Small-scale		(L/day)			
1) Groundwater source, home filter	Central Florida	38.0	25.6	28.2	
2) Groundwater source, boiling	Central Florida	7.6	97.6	107.3	
3) Salty water source, solar distiller (hum/dehum)	Central Florida	15.0	101.3	111.4	
4) Salty water source, solar distiller	Central Florida	3.0	113.9	125.2	
5) Tap (drinking) water source, bottled water	Ocala, Florida	51,000	155.9	171.3	

* including distribution of drinking water from Table 37.

(a) sej/m^3 values were obtained from the corresponding emergy evaluation table.
(b) Em$/m^3 were calculated by dividing the sej/m^3 value by 9.1 E11 sej/$, which represents the U.S. emergy-per-dollar ratio in 2000.
(c) This column shows the value of potable water when the total emergy of public supply is used just for drinking and cooking. Em$/m^3 values were calculated by dividing the Em$/m^3 in column 5 by 0.023 to represent that only about 2.3% (15 L/capita/day) of the public supply water delivered to households (645 L/capita/day) is required for drinking and food preparation (Gleick, 2000).

FKAA = Florida Keys Aqueduct Authority
RO = reverse osmosis

Simulation of Water Allocation in Florida

Output.

The systems diagram used to define the simulation equations is shown in Figure 17. Definitions, equations and calibration values used for the simulation are given in Appendix E. A sample graph of the simulation results for the model using the “simple sector production functions” (Equations 1,2, and 3) is given in Figure 39. This simulation graph results from varying the allocation of water to the urban sector from 0% to 100% and allocating 80% and 20% of the remaining water to the environment and agriculture, respectively. Thus if the allocation to the urban sector is 50%, then, of the remaining fifty percent, 40% is allocated to the environment and 10% percent to agriculture.

In the top graph in Figure 39 the index of production for each sector is shown on the Y-axis and the percent of water that is allocated to the urban sector is on the X-axis. The environmental production index is greater than both the urban and agricultural indices. This is because the production values used to calibrate the model were based on g/year of net production and the environmental production was estimated to be more than 20 times greater than total agricultural production and 12 times greater than total urban production (see Table E-1). Production in the urban sector is maximized when about 45% of available water is allocated to the urban sector. Agricultural and environmental maximum production occur when most of the available water is not allocated to the urban sector.

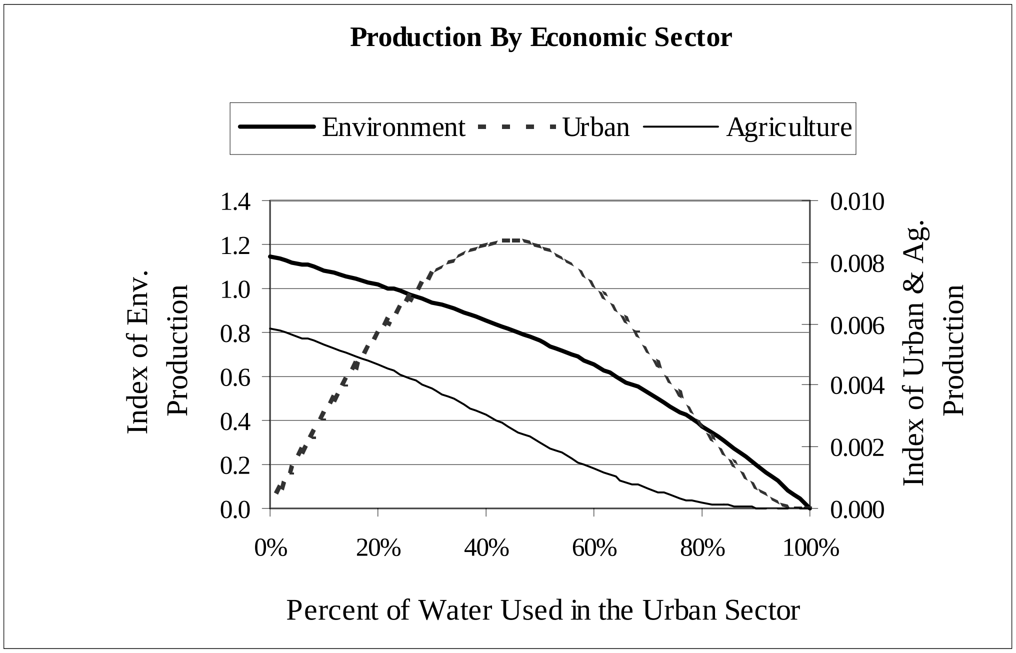
The bottom graph in Figure 39 shows two regional production indices. The first (TP) is a regional index that closely resembles an index of gross economic product. The second (TMP) is a graph of empower. The gross economic product index (TP) is maximum when about 25% of water is allocated to the urban sector, while empower is maximized when about 45% of water is allocated to the urban sector. Both these graphs were generated assuming a 80% – 20% split of the remaining water between environmental and agricultural uses.

Figure 40 shows three-dimensional graphs that result from numerous simulation runs where both the percent water used in the urban sector and the percent of remaining water used in agriculture are varied. Water not used in urban or agricultural sectors contributes to environmental productivity. Figure 40-a shows the effect of varying water allocation on the regional production index and Figure 40-b shows the effect on the regional empower index. In general, the maximum regional productivity results when about 25% and 30% of water are allocated to urban and agricultural uses, respectively. The remaining water (45%) is allocated to the environmental system. The regional empower index is maximized when approximately 45% of the water is allocated to the urban sector and zero percent to the agricultural sector. The reason why even when the agricultural sector receives no water (thus P=0) TPM is maximum is because this production index is based on adding the emergy output of the three production sectors. Based on the setup of the equations and since the net environmental production is much larger than agricultural production, environmental production "out competes" agricultural production even though this sector has a higher transformity. In addition, since products from the urban sector have transformities that are roughly 1000 and 10 times greater than the products from the environment and agriculture, respectively, TMP is maximized at the highest urban production.

Sensitivity Analysis.

The model is sensitive to two main sets of coefficients: 1) coefficients that affect the input of purchased fuels and goods (k_{10}, k_{11}, and k_{12}) and the fractions that affect the proportion of imported fuels and goods that are consumed in the urban and agricultural sectors (S_1 and S_2). Figure 41 illustrates the effect of decreasing FF (by decreasing k_{10}, the dominant FF coefficient) on the magnitude of the total production indices. For both regional production indices, maximum production decreases with decreasing FF inputs. Also for both indices, as the maximum production decreases, the point of maximization slightly shifts towards a lower percentage of water allocated to the urban sector.

The effects of shifting the proportion of imported goods and fuels from the urban sector to agriculture (by adjusting coefficients S_1 and S_2) is illustrated Figure 42. For initial model runs, 70% of imported fuels and goods were consumed in the urban sector and 30% were consumed in agriculture. When these coefficients were changed to decrease or increase the portion of imported fuels and goods going to the urban sector, the magnitude of the total production indices changed. The regional empower index (TMP) increases as more fuels and goods are used in the urban economy rather than in the agricultural sector. The regional production index (TP), however, increases with increasing fuels and goods up to a specific point, when the distribution of these fuels and goods is approximately 50% to urban and 50% to agriculture. After this point, allocating more fuels and goods to the urban economy decreases the maximum production index. This oscillation of TP to reach a maximum point based on the allocation of fuels and goods comes from the multiplicative nature of the TP index.



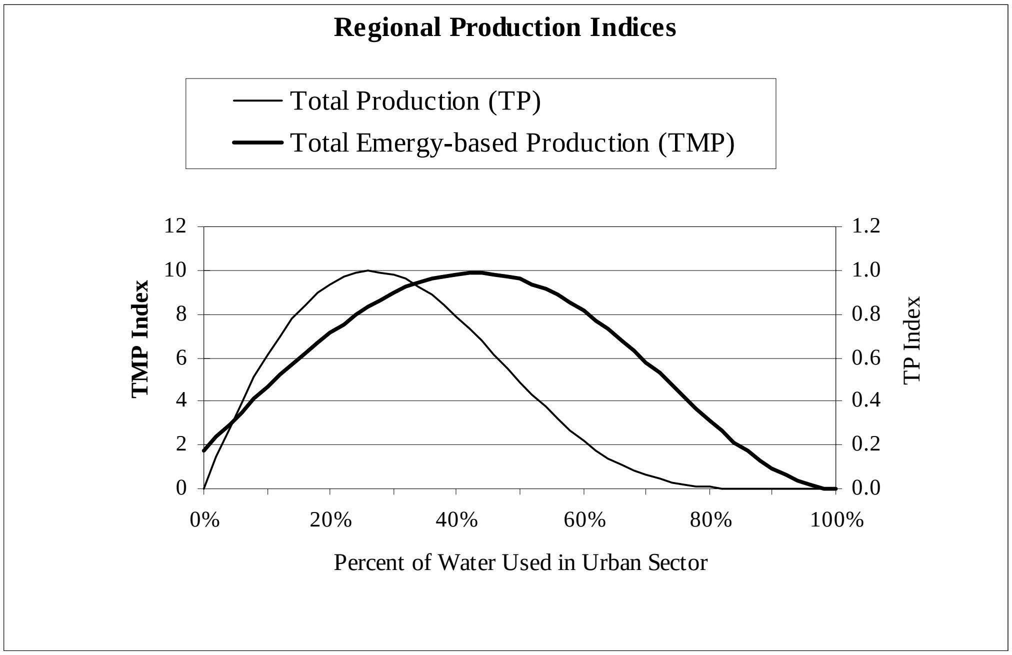


Figure 39. Graphs of simulation results of the model in Figure 17. Total imported energy (FF) is allocated between urban and agricultural sectors with a 70% / 30% split. Agriculture and the environment are allocated 20 and 80%, respectively, of the water not used in the urban sector. Top graphs show the effect of changing the water use by the urban sector from 0% to 100% of available water on the three sectors of the economy. The bottom graph shows the effect of changing urban water consumption on regional production indices.

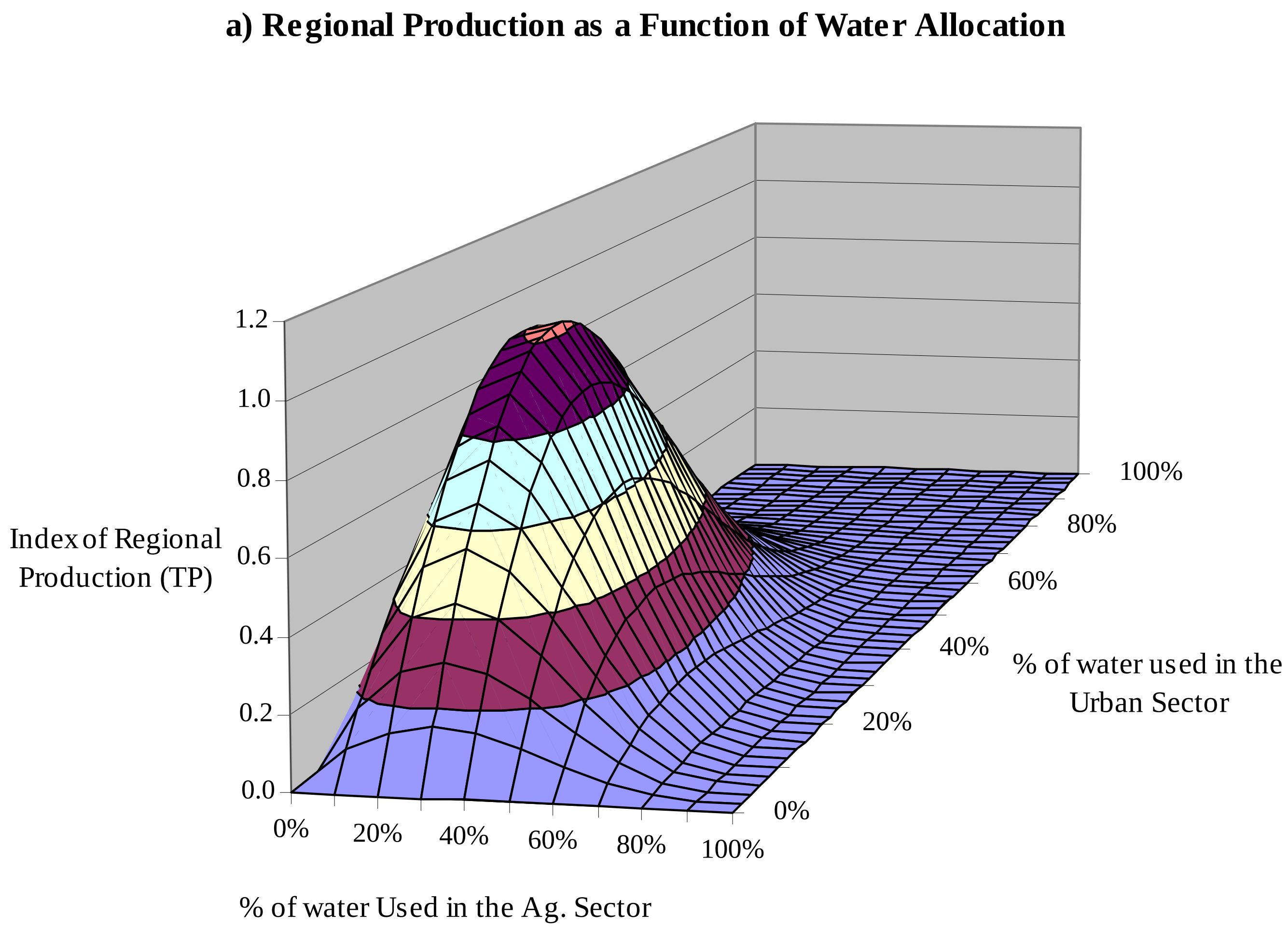
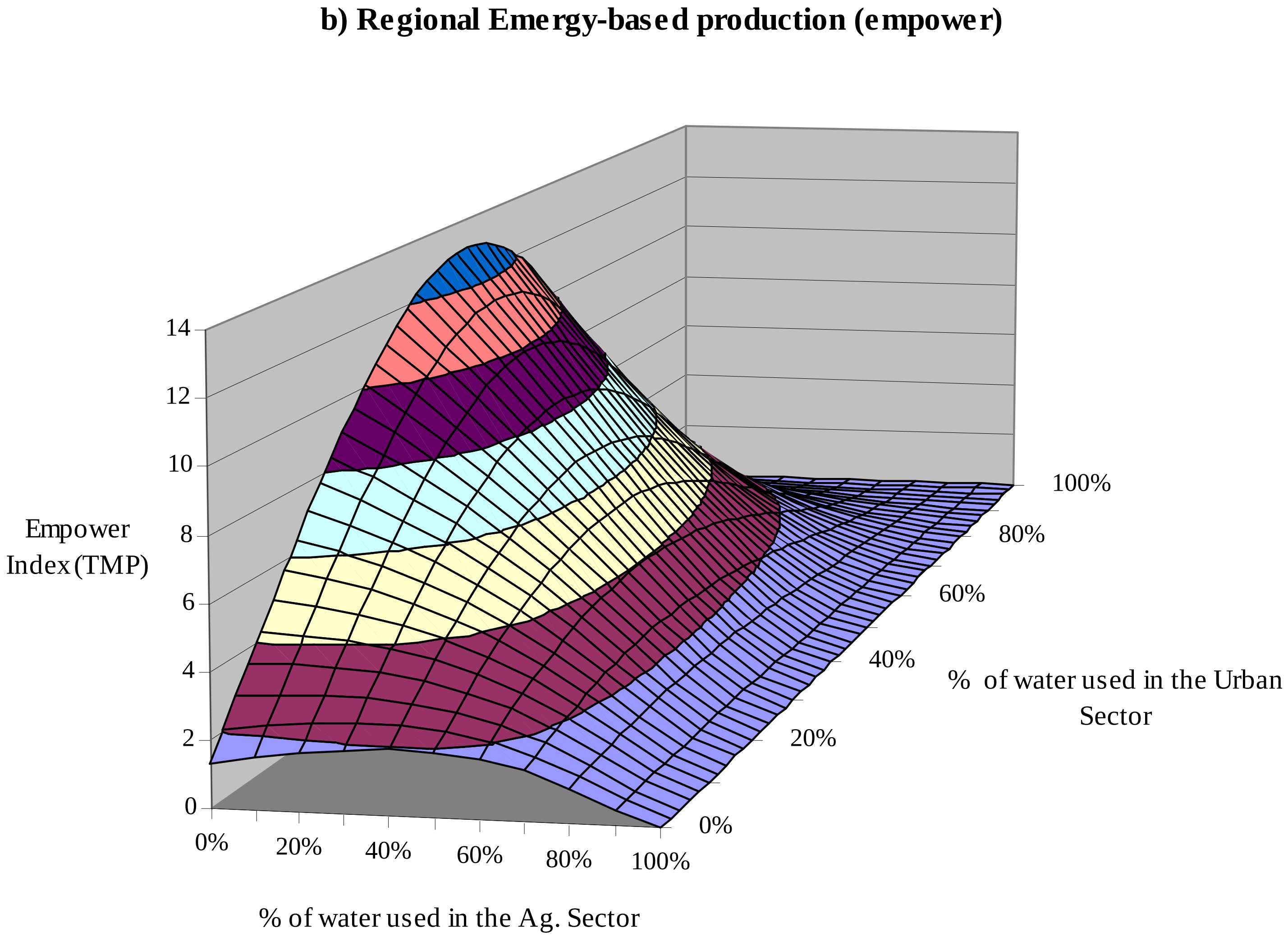
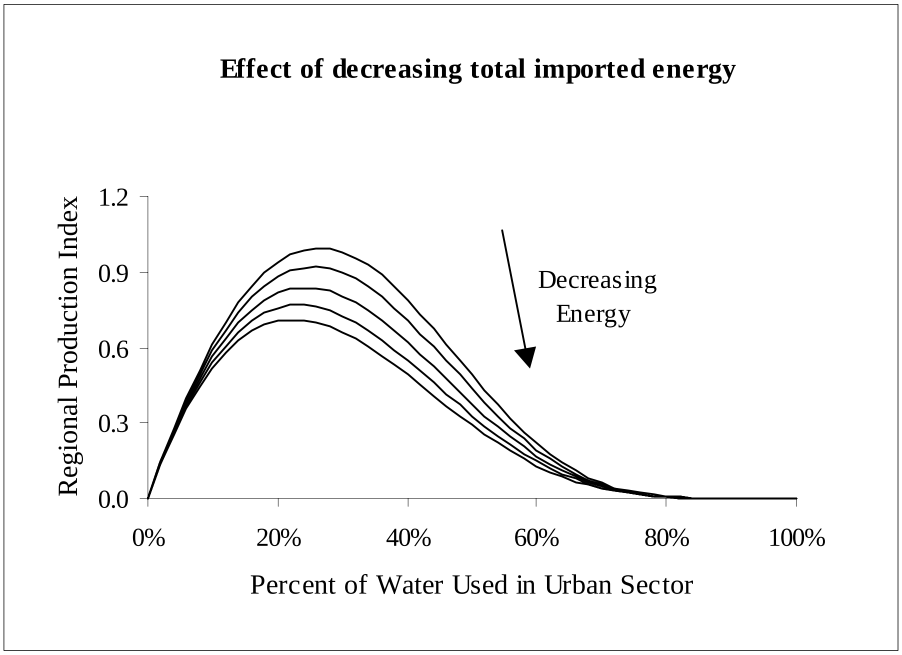


Figure 40. Three-dimensional view of the model output. Graph (a) shows effect of varying both urban and agricultural water use on the regional production index. Graph (b) illustrates the effect on regional empower.



b) Regional Emergy-based production (empower)

Figure 40--continued.



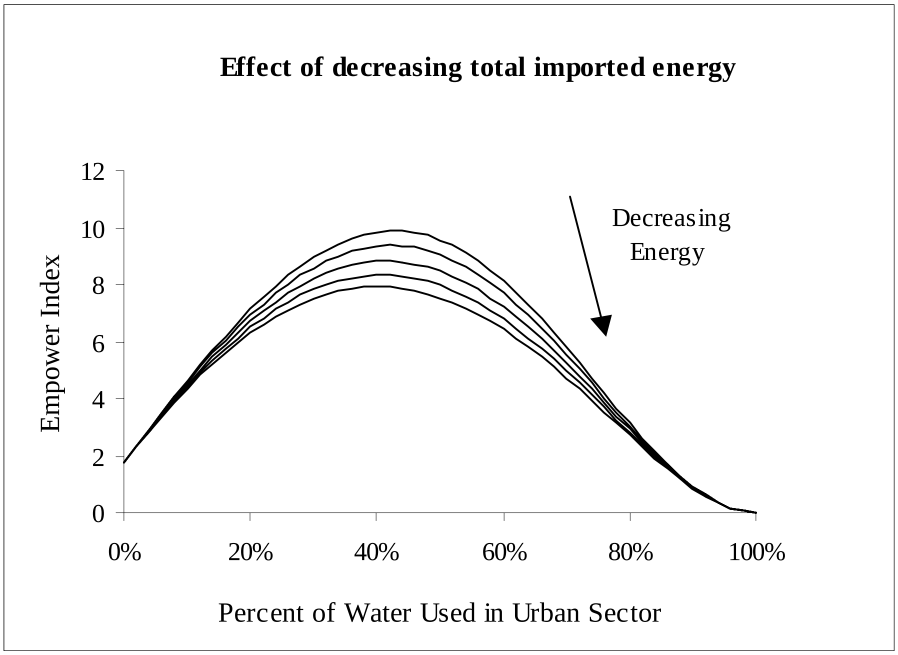
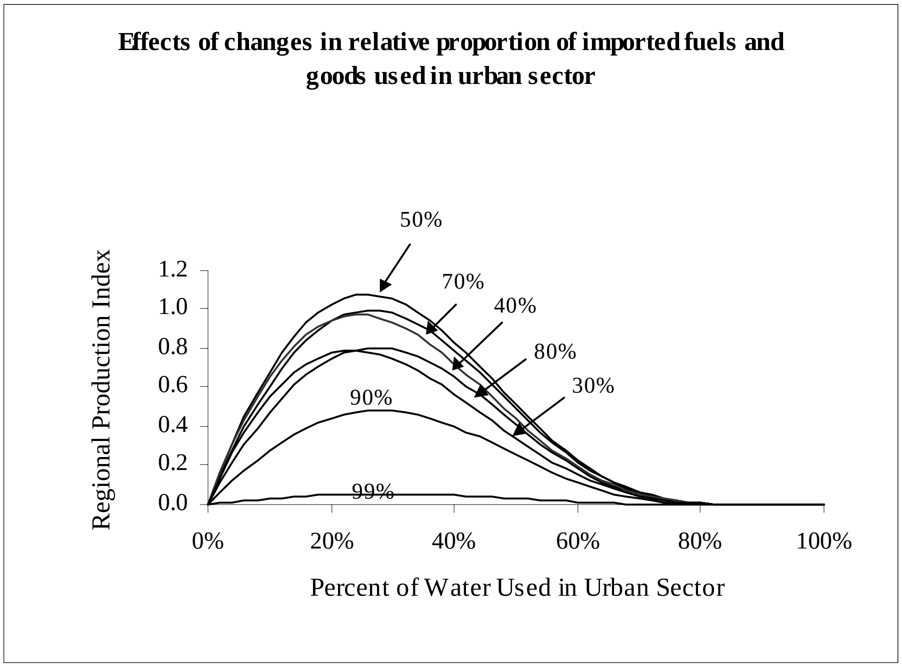


Figure 41. Results of sensitivity analysis based on total fuels, goods and services imported by the regional economy. The amount of imported energy (FF) to the region is decreased (allocation between Urban and Agriculture remains constant at 70 and 30%, respectively). Top graphs show the effect of this change of imported energy on the relative magnitude of regional production index. The bottom graph shows the effect on regional empower.



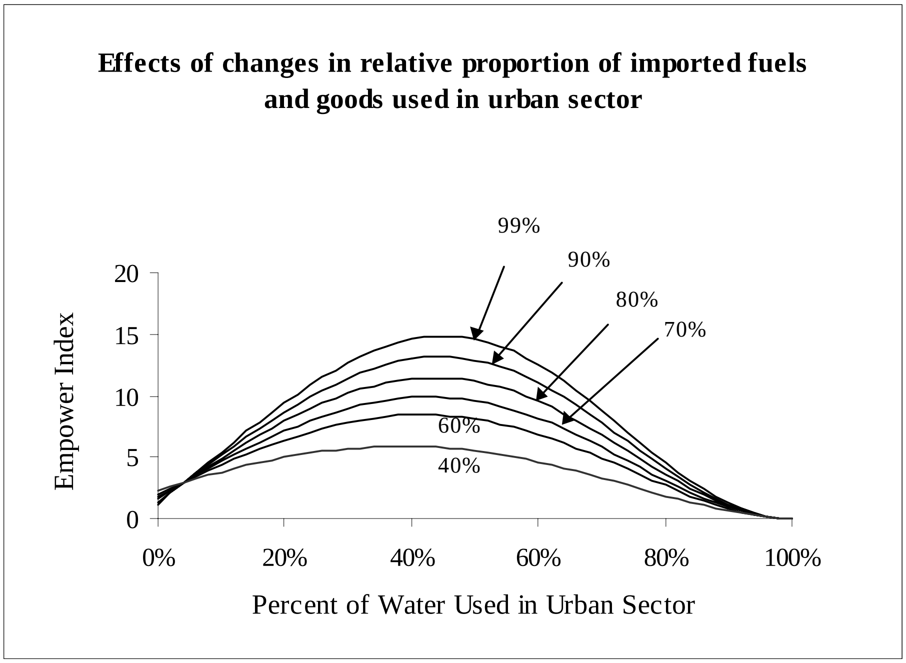


Figure 42. Results of sensitivity analysis based on the distribution of total fuels, goods and services imported by the regional economy. The proportion of imported energy (FF) allocated to the urban sector is increased from 40% to 99%. Top graphs show the effect of this change of energy allocation on the point of maximum regional production index. The bottom graph shows the effect on regional empower.

DISCUSSION

Summary

As global populations increase in both numbers and load on their environmental support system, the demands for water have also increased. In many areas of the globe there are insufficient water resources to meet quantitative demands. In others regions, the quality of water is being degraded so that it no longer meets qualitative demands. Shortages of potable water are limiting economic development and the quality of life. Access to water resources depends on the energetic processes of the hydrologic cycle and the human technological systems. In this dissertation, emergy was used to evaluate water resources of global and regional (Florida) scale. Furthermore, emergy synthesis was used to evaluate potable water produced at a local scale (public supply) and small scale (home purification). Emergy puts all products of nature, technology, and the economy on a common basis of the prior work (of one kind) required and embodied in the water. In addition, a computer simulation model was generated to investigate the best allocation of water resources in Florida for maximizing economic and environmental welfare.

Overall, water resources and drinking water are undervalued by society. This leads to wasteful consumption of water resources as well as the materials and fossil fuels required to produce potable water. As part of the conclusions, it was recommended to promote water conservation and to conduct emergy evaluations to complement benefit-cost analyses for selecting future public supply developments.

Principal Conclusions of this Study

1) Water has different values, which increase with convergence, quality, turnover times, scarcity and demand.
2) Much of the emergy of public supply water is wasted.
3) Regional production is maximized when water resources are used in the urban economy.

Discussion of Principal Conclusions

1) Water Has Different Values.

This study illustrates that different types of water have very distinct values. The emergy value of water is dependent on its place in the hierarchy of the water cycle. In the global water cycle, seawater has the lowest emergy value since it is regarded at the geopotential and chemical potential base of the cycle. Evaporated seawater converges into clouds, which precipitate to the ocean or continents. Continental rain converges into rivers, wetlands, lakes, estuaries, or groundwater storages. As fresh water converges and is accumulated in natural reservoirs, its emergy value increases. As water is processed through treatment plants for public use, its emergy value increases. Transformities and Em\$/m^3 were used to quantify these values. Water values calculated in this study ranged from zero Em\$/m^3 for ocean water (by definition for being the ground state) to 171.3 Em\$/m^3 for bottled water. Figure 43 illustrates the transformation stages in water processing for human use. This figure also summarizes water values from the literature review as well as the transformities and Em\$/m^3 values calculated in this study.

units	rain	river water	lake water	groundwater	agricultural water	treated wastewater	public supply	home treatment
From the literature								
$\$/\mathrm{m}^3$:		0.002 - 0.03			0.008 - 0.093	0.11 - 4.17	0.12 - 1.09	
Em$\$/\mathrm{m}^3$:	0.001 - 0.045	0.0001 - 0.29	0.063 - 0.22	0.07 - 0.62	0.06 - 0.44	2.54 - 174.1	0.64 - 1.16	
From this study								
Em$\$/\mathrm{m}^3$:	0.01 - 0.08	0.16 - 0.22	0.11 - 0.30	0.23 - 0.85			0.75 - 7.46	28.2 - 171.3
sej/J:	3.96E3 - 3.19E4	4.26E4 - 6.54E4	4.59E4 - 5.64E4	4.43E4 - 2.27E5			1.39E5 - 1.39E6	5.19E6 - 3.16E7

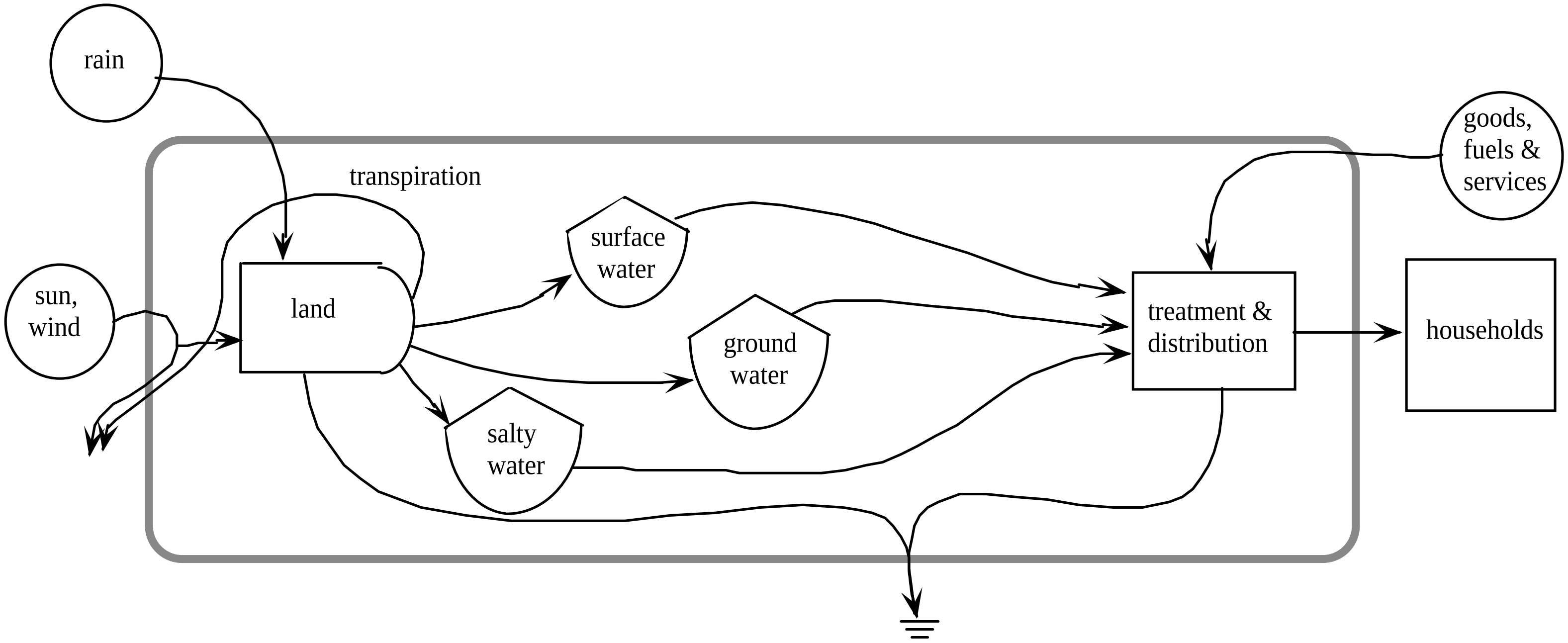


Figure 43. Concentration and upgrading of water for human use.

Factors affecting the value of water

The value of water resources is a function of several factors, such as quality, scarcity, demand, turnover times, dissolved solids concentration, aesthetic and recreational importance, and waste assimilation capacity. Generally, these factors affect the value of water as illustrated in Figure 44. With the exception of dissolved solids concentration, the higher the values of these factors, the greater the transformity and, thus, the value of water. Religious and cultural traditions can also affect the value of water resources. For example, despite its poor quality, water from the Ganges River in Benares, India, is extremely valuable for followers of Hinduism.

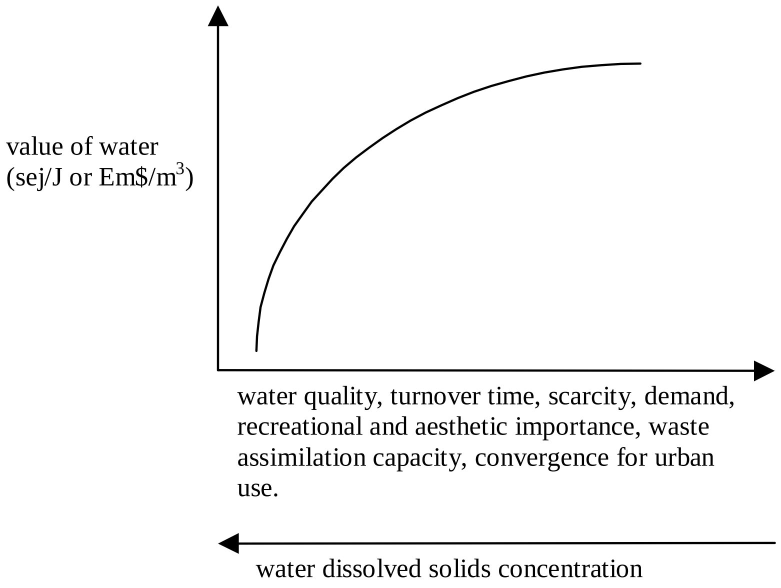


Figure 44. Water value as a function of several key parameters.

Factors that affect the value of potable water include 1) the degree of treatment, 2) demand and supply, and 3) the water source. The higher the level of treatment, the higher the value of potable water. However, as illustrated in Figure 45, there is an appropriate level of treatment that maximizes the net benefit of additional treatment. Benefits and costs in this figure apply for both emergy and economic analyses. The higher the demand and lower the supply of potable water, the higher its marginal and emergy values. The higher the quality of the water source (e.g., fresh groundwater), the higher the value of the finished water.

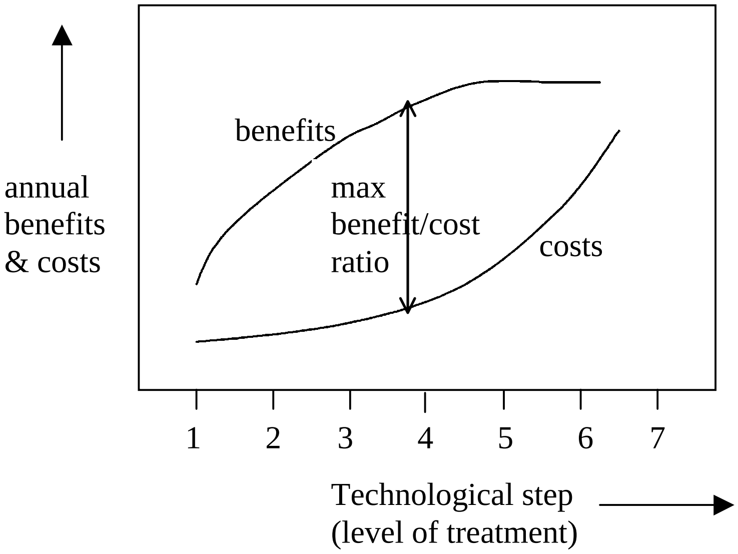


Figure 45. Diagram of the level of water treatment as a function of annual benefits and costs of adding an additional step in the treatment process.

Transformities are good indicators of quality. High-quality freshwater resources have greater transformities than lower quality freshwater resources. For example, the calculated transformity of deep groundwater from the Floridan aquifer system (1.66 E5 sej/J) is roughly 5, 4 and 3 times greater than the calculated transformities of Florida's intertidal, river, and lake waters, respectively. Since high quality water resources require less emergy for treatment, transformities can be used as indicators for selecting potable water sources. For example, from the four water sources mentioned above, groundwater would be the first choice for producing potable water, followed by lake, river, and intertidal waters. Transformities are also a good measure of production efficiency. Since potable water produced from different sources and methods have relatively the same quality (i.e., water that is suitable for drinking by common people), the process yielding the finished water with the lowest transformity represents the most emergy-efficient method of producing potable water.

The way in which potable water is used may not directly affect the emergy cost of producing potable water but can affect public perception of water. The public perception or image of water affects how much people are willing to pay for water and, thus, the demand and supply of water. For example, although bottled water and tap water from public supply have very similar quality (both are drinkable), bottled water is generally regarded as more valuable in people's mind (because of marketing and advertising). Therefore, consumers are willing to pay up to three thousand times more for bottled water than drinkable tap water (based on 2001 prices for Gainesville's public supply water relative to imported bottled water).

Comparison of potable water alternatives evaluated.

1) Emergy investment ratio (EIR). The higher the EIR, the more resources have to be used from the economy for the treatment process. Thus, the lower the EIR of drinking water, the greater the benefit to the economy. From the public supply systems evaluated, the water produced in Gainesville (0.8) and Stock Island (222.4) had the lowest and highest EIR, respectively. From the small scale water purification alternatives

evaluated, bottled water (7.7) and solar distillation (1,196) had the lowest and highest EIR, respectively.

The EIR of Florida is approximately 7.0 (Odum et al., 1998). Base on maximum empower theory (Odum, 1994; Odum, 1996), the appropriate intensity of development occurs when the EIR of a process matches the EIR of the regional economy (e.g., Florida). Processes with much higher EIR than the regional EIR (e.g., desalination by either solar distillation or reverse osmosis) may not compete (emergetically and economically) in the long run. This is one of the reasons why in the early 1980's the Florida Keys aqueduct system (EIR = 6.7) replaced the Stock Island desalination plant (EIR = 222.4) for supplying drinking water to the lower Florida Keys.

2) Emergy yield ratio (EYR). The higher the EYR, the more a resource or commodity stimulates the economy. The water conservation program in Tampa Bay had the highest EYR (2.6), followed by the potable water produced from deep groundwater in Gainesville (2.3). The desalinated water from Stock Island had the lowest EYR (1.004). For the small scale potable water alternatives, bottled water (1.23) and solar distillation (1.001) had the highest and lowest EYR, respectively.

Emergy yield ratios close to one imply that no net emergy is contributed to society by the production of potable water. Therefore, desalination is consuming as much emergy (mostly in the form of electricity for RO treatment facilities and human services for solar distillation units) as the emergy yielded in potable water. On the other hand, processes producing potable water with high emergy yield ratios, such as Tampa's water conservation program and Gainesville's treatment plant, contribute net emergy to society and, thus, promote development and high standards of living.

<u>3) Percent renewable emergy (%R).</u> The higher the %R, the more sustainable the production process is in the long run. From the public supply alternatives evaluated, the potable water produced from groundwater in Gainesville (56.0) and from seawater in Stock Island (0.4) had the highest and lowest %R measures, respectively. From the small scale water alternatives evaluated, bottled water (10.5) and solar distillation (0.08) had the highest and lowest %R values. The reason why bottled water has a relatively high %R value is because of the low recovery rate of the bottling company's RO units (5%). Such low recovery rate wastes 95% of the water input to the purification process; yet, since this flow is renewable, it increases the %R of bottled water. The low recovery rate is a trade-off between energy costs and efficiency. If the recovery rate was 60% instead of 5%, less water would be wasted but the %R of bottled water would be just 1.1.

Processes with high %R indices are typically less dependent on fossil fuels and, thus, are common for regions with low EIRs (e.g., most developing nations). If fossil fuels become scarce, developed countries, which typically have relatively high EIRs, may depend more on water production alternatives with high %R (e.g., surface and ground water treatment) and less on alternatives with low %R (e.g., desalination).

<u>4) Emergy benefit to the purchaser (EBP).</u> Since money is only paid to people for their work and never to the environment for its contribution (Odum, 1996), humans receive more emergy than the emergy embodied in money used to purchase goods and services. This additional emergy received per monetary payment is measured with the EBP. The greater the EBP, the more "free" wealth consumers receive in return for their purchase, promoting high standards of living. The potable water saved through the water conservation program in Tampa had the highest EBP (12.1), whereas desalinated water

from the Stock Island facility had the lowest EBP (1.1). From the small scale water alternatives evaluated, boiled water (8.1) and bottled water (0.7) had the highest and lowest EBP values, respectively.

The EBP can be used to inform consumers of the bargain they get from conserving water or purchasing potable water from public supply compared to buying bottled water. Using the EBP to show that society receives much "free" wealth from nature can help educate consumers of the importance of conserving and protecting the environment to secure a high quality of life for present and future generations.

5) Em-dollars per volume (Em$/m^3). The lower the Em$/m^3, the lower the emergy cost of producing potable water. The alternatives with the lower Em$/m^3 produce potable water more efficiently. From the public supply alternatives evaluated, the drinking water produced by the West Palm Beach surface water treatment plant had the lowest Em$/m^3 (0.8), whereas the water produced by the Stock Island RO facility had the highest Em$/m^3 (7.5). Assuming that the cost of water distribution is proportional to that in Gainesville, an additional 0.33 Em$/m^3 for water distribution should be added to the cost of potable water production to determine the total emergy cost of delivered potable water (see Table 37). From the small scale potable water alternatives evaluated, filtration had the lowest Em$/m^3 (28.2) and solar distillation the highest Em$/m^3 (171.3).

As illustrated in Figure 43, emergy values (Em$/m^3) are generally greater than actual monetary expenditures ($/m^3). This is because in addition to human work, emergy values include the work and services of nature, which do not have a direct market price. Although Em-dollar values are not intended to replace economic values, they can help quantify the contribution of nature for the production of potable water. This can provide an economic and political leverage for protecting watersheds and recharge areas that maintain the quality and quantity of important potable water sources.

6) Transformity. As described above, transformities are a measure of the efficiency of a production process since they rank products and commodities in the hierarchy of energy transformations. Similarly to Em$/m^3, the lower the transformity, the more efficient the production process. From the public supply systems evaluated, the water produced by the City of West Palm Beach had the lowest transformity (1.39 E5 sej/J), whereas the water produced by the Stock Island RO facility had the highest transformity (1.39 E6 sej/J). Therefore, the West Palm Beach plant was the public supply system that produced potable water most efficiently and the Stock Island facility was the public supply system that produced potable water least efficiently. For the small scale water purification alternatives evaluated, home filtration (5.19 E6 sej/J) and bottled water (3.16 E7 sej/J) were the most efficient and least efficient methods of producing potable water.

Transformities can also be used to compare the position of different commodities in the energy transformation hierarchy. The calculated transformities for potable water are actually higher than the transformities of many essential fuels. For example, the transformities calculated by Odum (1996) for natural gas (4.8 E4 sej/J), crude oil (5.4 E4 sej/J) and diesel (6.6 E4 sej/J) are lower than the transformity of West Palm Beach's potable water, which had the lowest transformity (1.39 E5 sej/J) from all the potable water systems studied. This means that potable water is as valuable as the main fuels powering our present economy. Therefore, the relatively high transformities of potable water indicate the importance of this valuable commodity.

Ranking of potable water systems.

Based on emergy yield ratios, emergy investment ratios and the percent renewable indices, the general ranking of the potable water alternatives evaluated was (averaging the ranking of these three indices):

1) fresh groundwater treatment
2) brackish groundwater treatment
3) water conservation
4) surface water treatment (lake source)
5) surface water treatment (river source)
6) fresh groundwater treatment plus aqueduct
7) RO desalination (new technology)
8) RO desalination (old technology)
9) bottled water
10) home filtration
11) advanced solar distillation
12) boiling water
13) traditional solar distillation

Based on transformities and emergy costs (Em\$/m^3), the general ranking of the potable water alternatives evaluated was:

1) surface water treatment (lake source)
2) surface water treatment (river source)
3) fresh groundwater treatment
4) water conservation
5) brackish groundwater treatment
6) RO desalination (new technology)
7) fresh groundwater treatment plus aqueduct
8) RO desalination (old technology)
9) home filtration
10) boiling water
11) advanced solar distillation
12) traditional solar distillation
13) bottled water

These two lists rank potable water production alternatives from different perspectives. If the major concern is the appropriate use of resources and long term viability for producing potable water, the first list is the appropriate one. However, if the emphasis is on efficiency and the least emergy cost of water production, the second list is the most adequate. The ultimate list of potable water alternatives depends on local conditions (i.e., surface or ground water availability) and the stage of social development, which is related to the rate of energy use per capita.

The brackish groundwater alternative evaluated (Dunedin's RO facility) uses 90% fresh groundwater and only 10% brackish groundwater. Therefore, the position of this type of water in the rankings above is misleading. It is expected that if 100% of the water source was brackish, the ranking of such alternative would be just slightly better than RO desalination.

Large scale vs. small scale potable water systems.

Economies of scale play an important role for determining the economic cost and emergy required for producing potable water. Large water treatment plants produce drinking water at a lower emergy and economic cost per unit volume than small water treatment plants (see Table 1). Similarly, small scale purification systems require more emergy to produce one cubic meter of potable water than public supply systems (see Table 50). For example, from the alternatives evaluated, the Em$/m^3 of the least emergy-expensive small scale production system (home filtration) required almost three times more emergy per m^3 than the most emergy-expensive public supply system (Stock Island).

Poor nations often can not afford to build large scale public supply systems. People in these countries are forced to spend more resources and emergy to produce one cubic meter of potable water by building many small scale treatment systems. This decentralized system of potable water production has the advantage of dispersing sludge and other water treatment byproducts over large areas, minimizing site-specific impacts. Nevertheless, because they are more dispersed, appropriate management of these non point source wastes and byproduct is not easily enforced, which could result in more environmental impacts than centralized plants. Therefore, in urban areas, centralized public supply systems are more effective than decentralized (small scale) water treatment units.

Potable water systems self organize to maximize empower by using high quality water sources.

Since groundwater has the highest quality, its treatment requires the least amount of emergy. This is illustrated in Figure 28 by the difference between the transformities of the water source and the finished water (Gainesville's groundwater treatment plant had the smallest difference between these two transformities). Because of the high quality of the water source, Gainesville's drinking water also had the highest emergy yield ratio. More than 90% of all public supply water in Florida comes from groundwater treatment plants (Marella, 1999). Thus, Florida's potable water institution has self organized to use water resources with the highest emergy yield, thus maximizing the empower of society and its economy. This exemplifies how systems self organize to maximize empower. Similar to extracting wood from mature forests in early forestry practices or using nutrient-rich soils before using nutrient-deficient soils for agriculture, society self organizes to tap high-yielding groundwater resources.

2) Much of the Emergy of Public Supply Water is Wasted.

The average use of public supply water in Florida, which includes commercial, industrial and public areas, is approximately 640 L/capita/day (Marella, 1999). Domestic consumption of public supply accounts for about 60% of this flow (Marella, 1999). The distribution of household water use in Tampa is given in Figure 46. Approximately 46% of this potable water is used outdoors (mostly for lawn irrigation) and 14% is used for toilet flushing. Thus, roughly 60% of the drinking water used by the average home in Tampa do not has to be of drinking quality. In fact, only about 15 L/capita/day are required for drinking and cooking (Gleick, 2000). Although this is less than 4% of the potable water consumed by the average household in Tampa, the volume of water drank is actually less since many households purchase bottled water and do not drink tap water. Nevertheless, for health concerns all the white area of the chart (roughly 40%) should be of potable quality. Most water leaks occur in toilets and outdoor piping (Mayer and DeOreo, 1999), which would reduce the required potable volume by 9%. Consequently, approximately 70% of potable water in Tampa is used for reasons that do not require treatment. In other words, nearly 70% of the emergy added to the raw water to produce potable water for public supply is wasted. This means that 0.7 Em$ of every Em$ required to treat and deliver potable water literally goes down the drain. This emergy (in the form of chemicals, materials, electricity, fuels and services) is being drained from society and the environment. To use all these resources more effectively, raw water or treated wastewater could be used instead of drinking water for flushing and irrigation.

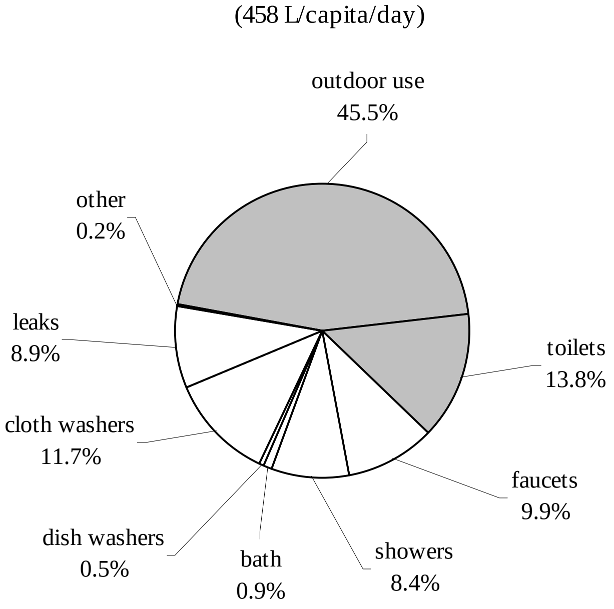


Figure 46. Potable water use for an average household in Tampa, Florida (Mayer and DeOreo, 1999).

When the entire emergy of producing potable water for public supply is used just to consume 15 L/capita/day for drinking and cooking, the Em\$/m^3 of public supply systems fall within the range of small scale potable water production (Table 53). However, the large flows of potable water produced for public supply subsidize high living standards. Being able to have running drinking water inside most buildings is a luxury that is often taken for granted, leading to wasteful uses of drinking water. Policies to enforce the appropriate use of potable water can be implemented, yet these could have some negative effects on accustomed standards of living.

Two policies for minimizing the inappropriate use of potable water from public supply are presented next.

Enforce stronger water conservation measures.

Water conservation was shown to be very a good "public supply" alternative. The emergy cost of conserving potable water in Tampa Bay was higher than the cost for producing potable water from surface water sources and approximately the same for producing drinking water from high quality groundwater (Table 38). However, the EYR and EBP for water conservation were the highest of all the potable water systems studied. This means that water conservation may stimulated the economy more than any other public supply option. Thus, it is recommended that water conservation programs are developed at local, regional and national levels.

Recent federal regulations requiring water conservation plumbing fixtures are helping reduce demand. For example, the U.S. Energy Policy Act of 1992 (EPACT) mandated the installation of 1.6 gal per flush (gpf) toilets instead of traditional 4-5 gpf toilets for most new developments. This measure is important for reducing the potable water used for flushing, which consumes roughly 27% of indoor water in the U.S. (Mayer and DeOreo, 1999). However, local governments should become more active to implement their own water management programs to address their specific needs.

Emergy evaluations can complement economic analyses for determining the most appropriate water supply alternatives.

To minimize the possibility of developing alternatives that may not compete economically in the long run (e.g., by having very low emergy yield ratios, high transformities, high emergy yield ratios and low percent renewable indices), emergy synthesis should be used to evaluate the feasibility of all new public supply developments. By adding monetary and non-monetary inputs required in any production process and comparing them on the same basis, emergy synthesis is an effective tool for selecting alternatives. Emergy evaluations, which are inexpensive and relatively fast to conduct, could save millions of dollars and prevent detrimental environmental effects by complementing benefit-cost analyses for decision making.

The Tampa Bay seawater desalination plant can be used to illustrate the advantage of using emergy for evaluating development alternatives. The emergy investment ratio of the water to be produced from this facility is 32.4. This is approximately 4.5 times greater than the average EIR of Florida (Odum et al., 1998) and more than 20 times greater than the EIR of the potable water produced from surface water by the Hillsborough River Water Treatment Plant (also in Tampa). This indicates that, in the long run, the RO treatment process may be too intensive to compete at both local and state levels. Furthermore, the low EYR (1.03) and low %R index (3.0) suggest that this facility could face the same fate as the one shut down about 20 years ago in Stock Island. Most likely the Tampa desalination plant will produce drinking water at a significantly higher cost than expected since the cost of electrical power is increasing. Although other potable water treatment plants also use electricity, desalination with reverse osmosis requires much more electric power to run the RO modules. For example, to produce one cubic meter of potable water, the RO facility is expected to consume about 11 times more electricity than the Hillsborough River Water Treatment Plant. The economic feasibility studies for developing this RO facility did not take into consideration that, in addition to inflation, energy costs will rise in the event of energy scarcity (unless the government heavily subsidize energy production). As oil and natural gas become scarce within the next 25 years (International Energy Agency, 1998; Campbell and Laherrere, 1998), electrical energy will be in great demand, thus more expensive. Furthermore, since oil is used directly or indirectly to run the global economy, as oil becomes scarce and the energy costs of oil increases, so does the energy costs of other forms of energy. For instance, oil provides close to 50% of the fuel used for the extraction of coal (Costanza et al., 1996). Despite that the Big Bend Power Station, which will power Tampa's desalination plant, generates electricity from coal, it will also cost more to produce one kW of power if oil and natural gas are scarce. Thus, as energy becomes more expensive, Tampa Bay citizens may decide to use electricity more appropriately, such as powering essential appliances and computers, rather than producing highly energy-intensive drinking water.

3) Regional Production is Maximized when Water Resources are Used in the Urban Economy.

As urban and agricultural demand for fresh water increases because of rapid population and economic growth, more water has to be extracted from the environment, thus threatening the health of ecosystems. These threats include changing hydroperiods, which induce replacement of native species with non-native ones, oxidizing organic matter of dryer wetland areas, and stressing flora and fauna. Overall these problems decrease biodiversity and ecosystem resilience and often lower the net productivity of the environment. Therefore, it is important to determine what is the most appropriate use of regional water resources so that society can progress without deteriorating its life support system (i.e., the environment).

The model simulated in this study investigated what patterns of water allocation among the urban, agricultural and environmental sectors maximize the total productivity of a region. Data from the state of Florida was used to calibrate the model. Although the model was an aggregated production function, it provided interesting water allocation results and insight for exploring different production functions.

Two regional indices were simulated: a production index (TP) and an emergy-based production index (TMP). It was assumed that optimum allocation of water resources was achieved when total regional production was maximized (when the TP and TMP curves were at a maximum). The allocation pattern to maximize production was different for each index. The TP index reached a maximum with less water allocated to the urban sector compared to the TPM index (Figures 39 and 40). This is based on the characteristics of each of the production functions used to generate the indices. The TP index is a multiplicative index where production in each sector is given equal weight. The TMP index, on the other hand, is an additive index that uses transformities to weight the importance of each production sector. Transformities for urban production are roughly one and three orders of magnitude greater than agricultural and environmental production, respectively. Thus, although the environment produces much more materials than the economic sector their emergy value is lower, and total production is maximized when more water is allocated to the urban economy to produce high transformity products.

Maximizing total production by using more water in the urban sector, however, will deteriorate the environment. For example, in the top chart in Figure 39, when the urban production reaches its maximum (at roughly 45% of water allocation to this sector) the environmental production is approximately 30% lower than its "pristine" value when no water was extracted for urban use. For obvious ecological, recreational, and aesthetic reasons, it is not desirable to use the model's high allocations of water to drive economic development for maximizing total production. Furthermore, because of diminishing marginal returns, the best allocation of water is not where these production indices reach their maximum, but at roughly 5% less than the percentage of water use in the urban sector at which total production reaches its maximum.

Overall, the simulation results indicate that total regional production was maximized when a substantial portion of water resources was used to drive urban economic production. The environment is affected as more water is diverted to run power plants, drive industrial processes to produce valuable commodities, and subsidize high standards of living of urban societies. However, as exemplified throughout the world, the short-term benefits of supplying water for urban use seems to outweigh the long-term costs associated with environmental degradation. Similarly, the return of investing one cubic meter of water in the urban sector is many times greater than using the same volume in agriculture.

Environmental Impacts

Each potable water production alternative has associated environmental impacts. These impacts are difficult to quantify because very little data has been recorded by the utilities or local governments regarding this subject. There are many general environmental issues that are directly (i.e., production of potable water) and indirectly (i.e., production of inputs necessary for the production of potable water) associated with water treatment. These environmental issues include 1) exhaustion of abiotic materials, 2) exhaustion of fuels, 3) energy consumption, 4) hazardous waste production, 5) non-hazardous waste production, 6) release of greenhouse gases, 7) ozone depletion, 8) smog formation, 9) acidification, 10) eutrophication, 11) aquatic toxicity, 12) human toxicity,

13) alteration of biological habitat, 14) decrease in ecosystem productivity from hydrological changes, and 15) decrease in net productivity due to ecosystem stress from land, air or water contamination.

Evaluating all of these potential environmental effects would be very difficult and probably irrelevant since only a few are predominant for each potable water alternative. However, the two or three impacts that were considered the most significant for each potable water production alternative were evaluated. Tables F-1 and F-2 show the emergy evaluation of these impacts and the table footnotes provide the data, assumptions and criteria used to calculate these values. Overall, it appears that small scale water production has a grater effect on the environment, per unit volume, than large scale public supply systems.

Suggestions for Further Research

Evaluation of Other Potable Water Alternatives.

Other drinking water alternatives that should be evaluated for comparison with the ones studied in this dissertation include:

1) Rain collection and treatment.
2) Urban runoff collection and treatment.
3) Purification of treated wastewater.
4) Aquifer storage recovery (storing excess surface water during the wet season underground for later use during the dry season).

Evaluation of Policies for the Appropriate Use of Public Supply

The options discussed below were not evaluated in this study. However, they appear to move in the right direction to maximize the welfare of society and nature by using potable water resources more effectively. Thus, it is recommended to evaluate these options with emergy synthesis to investigate if they should become part of established water policies. Nevertheless to verify if these policies are appropriate, in addition to emergy and economic evaluations, it is necessary to look at them in regards to public health, public acceptance and environmental impacts.

Dual piping.

To maximize the use of the emergy embodied in potable water, it may be appropriate to enforce new developments to have two types of water pipes: 1) *pipe one* for drinking water, and 2) *pipe two* for clean water. Drinking water would be the same as currently supplied by public utilities. Clean water would be simply screened and chlorinated raw water (i.e., surface or ground water). *Pipe one* would be used to deliver drinking water to bathrooms and kitchen sinks, bathtubs, showers, cloth washers, dishwashers, heat pumps and swimming pools. *Pipe two* would be used to deliver clean water to lawn irrigation systems and toilets. A small dose of chlorine could be added to the raw water (on-line) to minimize public health risks and reduce biological growth in toilets.

In low-density housing areas, gray waters (i.e., effluent of the water delivered by *pipe one*) could be treated in constructed wetlands or other low energy-intensive treatment systems. Treated effluent from these systems can be recycled to supply clean water to *pipe two*. Filtered stormwater and rainwater, locally collected from roofs, could also be used as a source of clean water, reducing the environmental effect of extracting surface and ground water. Wastewater from toilet flushing could be either treated in traditional wastewater treatment plants or in septic tanks. Therefore, as a whole, the volume of wastewater would be just a fraction of present flows, saving energy and taxpayer's money for wastewater treatment.

Increase of water rates.

Increasing water rates is a simple, yet a controversial approach to encourage water conservation. Since water demand is often price-inelastic (Mayer and DeOreo, 1999), increasing water rates as a conservation measure may not cause a major decline in water use in the short term. Nevertheless, it is worthwhile to investigate this alternative since it could help consumers understand that potable water is a valuable resource. Low water prices, often kept low because of government subsidies, mislead consumers to believe that drinking water is not valuable, thus discouraging conservation. Higher prices might change public perception and the social controversy of increasing water rates might start public discussions on the subject. Media coverage of such debates may further educate consumers about the benefits of conservation. If these discussions favor increasing water rates, the additional money obtained could be used to mitigate environmental impacts related to drinking water production and wastewater treatment/disposal. Additional money earned from water sales can also be used to fund water-related research to better understand how to manage water resources for the long term benefit of humans and the environment.

GLOSSARY

(Adapted from Odum, 1996)

Available energy: energy with the potential to do work.

Donor value: a theory of value in which the value of a product is determined by what is required to produce the commodity rather than willingness to pay for it.

Em-dollar (Em$): the emergy-based monetary value of a product, resource, or service, which is obtained by dividing the emergy of something by the emergy/money ratio for a particular currency of a particular year.

Emergy: (spelled with an "m"): all the available energy required to make a product and expressed in units of one type of energy (e.g., solar em-joules or sej).

Emergy Benefit to the Purchaser (EBP): the emergy of a product divided by the buying power of the money (in terms of emergy) paid for this product.

Emergy Benefit to Society index (EBS): the difference between the Em$ value of a commodity and its monetary cost.

Emergy Investment Ratio (EIR): the purchased emergy feedback from the economy (F) divided by the free emergy inputs from the environment (R+N).

Emergy Yield Ratio (EYR): the emergy of the output (Y) divided by the emergy of all inputs coming from the human economy (F).

Em-joule: the unit of emergy, which has the dimensions of the energy previously used.

Emergy Yield (Y): the sum of all emergy inputs to produce a product or generate a service.

Energy: a property that can be turned into heat and measured in heat units (e.g., kcal, Joules).

Energy hierarchy: the convergence and transformation of energy of many small units into smaller amounts of higher-level types of energy with greater ability to interact with and control smaller units.

Energy systems language: a general systems language for representing units and connections for processing the materials, energy, and information of any system. Diagrammatic representations in energy systems language have precise mathematical and energetic meanings.

Gross National Product (GDP): the total market value of the final goods and services produced in an economy in one year.

Osmosis: the transport of water from one side of lesser TDS concentration to a side of higher TDS concentration through a semipermeable membrane.

Reverse osmosis (RO): the opposite of osmosis, is carried out by applying a pressure to a concentrated solution (e.g., seawater) forcing it through a semipermeable membrane to the dilute side (e.g., freshwater).

Maximum power principle: an explanation for the designs observed in self-organizing systems (i.e., energy transformations, hierarchical patterns, feedback controls, amplifier actions, etc.). Designs prevail because they draw in more available energy and use it with more efficiency than alternatives. Thus, all systems (social and biological) self-organize to maximize empower.

Self-organization: the process by which systems use energy to develop structure and organization.

Maximizing emergy: the process by which the maximum power principle operates within a system to select from among the available components and interactions the combination that results in production of the most emergy.

Purchased Emergy Inputs (F): the sum of human services (S) and the goods, fuels and energy (P) required in a production process.

Renewable Emergy (R): the "free" renewable emergy required in a production process (e.g., rain and sun for agriculture).

Second law of thermodynamics: the principle that energy concentrations disperse spontaneously and that any energy transformation has some of its available energy dispersed in the process.

Solar transformity: solar emergy per unit of energy, expressed in solar em-joules per joule (sej/J).

Sustainable use: the resource use that can be continued by society in the long run because the use level and system design allow resources to be renewed by natural or human-aided processes.

Systems ecology: the field that came from the union of systems theory and ecology and provides views of many scales for emergy synthesis.

TDS: Total dissolved solids, which units are commonly expressed in mg/L or parts per million (ppm).

Transformity: the emergy of one type required to make a unit of energy of another type.

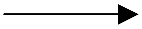
Turnover time or **replacement time**: the time for a flow to replace a stored quantity (e.g., a flow of 10 L per day will replace a 1000 L storage of water in 100 days).

Wealth: usable products and services however produced.

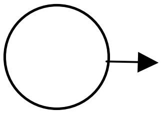
APPENDIX A

SYMBOLS OF ENERGY LANGUAGE USED TO REPRESENT SYSTEMS

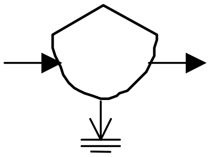
(Adapted from Odum, 1996)



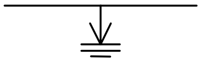
Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.



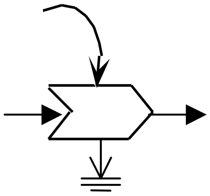
Source. Outside source of energy delivering forces according to a program controlled from outside; a forcing function.



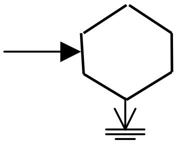
Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.



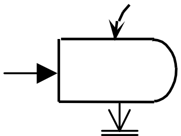
Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



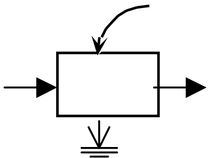
Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



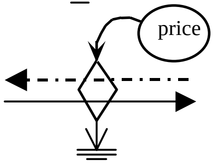
Consumer. Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.



Producer. Unit that collects and transforms low-quality energy under control interactions of high quality flows.



Box. Miscellaneous symbol to use for whatever unit or function is labeled.



Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

APPENDIX B

FOOTNOTES OF EMERGY TABLES

This appendix contains the footnotes documenting the calculations and references of the emergy evaluations of all the potable water systems evaluated.

Table B-1. Notes for the emergy evaluation of the drinking water produced at the City of West Palm Beach Water Treatment Plant (footnotes for Tables 21 and 22). Blakeney, 2000, for personal communication with K. Blakeney, department of engineering director, City of West Palm Beach Water Treatment Plant; July 7, 2000; West Palm Beach.

Notes				
1	**Lake water, J**			
	water pumped per year:	gals/yr	1.04E+10	(Blakeney, 2000)
	Annual chemical energy or water used:	J/yr	1.94E+14	(gals/yr)(1 m^3/264.17 gals)(4.94 J/g)(1 E6 g/m^3)
	Transformity of lake water:	sej/J	56,427	(Table 12)
2	**Operating and Maintenance, $**			
	a) Operat. $ in 99 (w/out chem & elect):	$/yr	439,409	(Blakeney, 2000)
	b) Maintenance cost in 1999:	$/yr	1,293,385	(Blakeney, 2000)
	c) Electric cost in 1999:	$/yr	665,760	(Blakeney, 2000)
	d) Fuels cost in 1999:	$/yr	18,360	(Blakeney, 2000)
	Tot. Operating and maintenance in 1999:	$/yr	2,416,914	(a+b+c+d)
	Emergy/dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
3	**Electricity, J**			
	Total kWh used in 1999:	kWh	8.32E+06	(Blakeney, 2000)
	Annual electric energy used:	J/yr	3.00E+13	(kWh)(3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
4	**Fuels , J**			
	Total diesel used:	gal	36,000	(Blakeney, 2000)
	Total annual energy used:	J/yr	5.32E+12	(gal/yr)(14.8E7 J/gal diesel) (Milliman and Sipe, 1981)
	Transformity:	sej/J	6.60E+04	(Odum, 1996; p.308)
5	**Chemicals, $**			
	Tot. cost of chemical usage in the plant:	$/yr	1,300,000	(Blakeney, 2000)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
6	**Chemicals, kg**			
	a) Total lime (CaO) used in 1999:	kg/yr	3.98E+06	(Blakeney, 2000)
	b) Total chlorine used in 1999:	kg/yr	2.94E+05	(Blakeney, 2000)
	c) Total ammonia used in 1999:	kg/yr	9.81E+04	(Blakeney, 2000)
	d) Tot. activated carbon used in 1999:	kg/yr	4.41E+05	(Blakeney, 2000)
	e) Total polymer used in 1999:	kg/yr	9.81E+04	(Blakeney, 2000)
	f) Total ferric sulfate used in 1999:	kg/yr	1.82E+05	(Blakeney, 2000)
	Tot. weight of chemicals used in 1999:	kg/yr	5.09E+06	(a+b+c+d+e+f)
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)
7	**Plant Construction and Upgrading, $**			
	Total construction & upgrading cost:	$	6.5.E+07	since 1955 (Estimated by Blakeney, 2000)
	Prorated plant life:	years	80	[estimated: 2000 - 1955 + 35]
	Total Assets of plant:	$/yr	812,500	($/yr)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)

Table B-1--continued.

8	**Plant Assets (concrete, with out services), kg**			
	Total mass of concrete:	kg	2.74E+07	(from A-4 in Table C-1)
	Average useful life of plant:	yr	35	assumed
	Total concrete:	kg/yr	782,090	(kg)/(useful plant life)
	Emergy per weight:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
9	**Plant Assets (steel & iron), kg**			
	Total mass of steel & iron:	kg	1.62E+06	(from B-1 in Table C-1)
	Average useful life of plant:	yr	35	assumed
	Total steel & iron:	kg/yr	46,158	(kg)/(useful plant life)
	Emergy per weight:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
10	**Drinking Water Produced, m^3**			
	Tot. drinking water produced in 1999:	m^3/yr	3.88E+07	(Blakeney, 2000)
	Total emergy of drinking water (Y):	sej/yr	2.66E+19	(sum of items 1 to 9)
	Emergy per volume of drinking water:	sej/m^3	6.85E+11	(sej/yr) / (m^3/yr)
11	**Drinking Water Produced, $**			
	Retail consumer price per 1000 gals:	1999$	1.1	(Blakeney, 2000)
	Total drinking water produced:	gals/yr	1.03E+10	(drinking water produced in m^3/yr)(264.2 gal/m^3)
	Total $ gained from water sold to public:	$/yr	1.13E+07	(price per 1000 gal)(gal/yr)/1000
	Total emergy of drinking water (Y):	sej/yr	2.66E+19	(sum of items 1 to 9)
	Emergy per 1999$ of drinking water:	sej/$	2.36E+12	(sej/yr) / ($/yr)
12	**Drinking Water Produced, J**			
	Total drinking water produced:	m^3/yr	3.88E+07	(Blakeney, 2000)
	Total energy of water:	J/yr	1.92E+14	(m^3/yr)(4.94 J/g)(1E6 g/m3)
	Total emergy of drinking water (Y):	sej/yr	2.66E+19	(sum of items 1 to 9)
	Transformity of drinking water:	sej/J	1.39E+05	(sej/yr) / (J/yr)
13	**Drinking Water Produced, g**			
	Total mass of water:	g/yr	3.88E+13	(m^3/yr)(1 E6 g/ m3)
	Total emergy of drinking water (Y):	sej/yr	2.66E+19	(sum of items 1 to 9)
	Emergy per weight of drinking water:	sej/g	6.85E+05	(sej/yr) / (g/yr)
14	**Drinking water with-out services, J**			
	Emergy of potable water:	sej/yr	2.22E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	1.92E+14	(same as note 12)
	Transformity with out services:	sej/J	1.16E+05	(sej/yr) / (J/yr)
15	**Emergy Investment Ratio (EIR)**			
	P = Items 3+4+6+8+9	sej/yr	1.13E+19	(P = Fuels, goods, materials & resources)
	S= Item 2+5+7	sej/yr	4.35E+18	(S = services -money flows-)
	N = negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	1.09642E+19	(R = renewable resources)
	Emergy Investment Ratio (EIR):		1.43	(P+S) / (N+R)
16	**Emergy Yield Ratio (EYR)**			
	Y = items 1 to 9	sej/yr	2.66E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.7	(Y) / (P+S)

Table B-1--continued.

17	**Percent Renewable Emergy**			
	% Renewable emergy:		41.2	100 x (R/Y)
18	**Ratio of Emergy benefit to the purchaser (in 1999)**			
	Em$ value of water:	Em$/yr	2.8E+07	(Y)/(sej/1999$)
	Total water produce in 1999:	gal/yr	1.03E+10	(Blakeney, 2000)
	Em$ value of water per 1000 gals:	Em$	2.70	(Em$/yr)/(gals/yr)*1000
	Market price of water per 1000 gals:	$/1000gal	1.10	(Blakeney, 2000)
	Emergy Benefit to the Purchaser (EBP):		2.46	(Em$) / ($)
19	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/$m^3$:		0.75	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
20	**Transformity of potable water, sej/J**		1.39E+05	(see note 12)
21	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		6.85E+11	(Y)/(m^3 produced/yr)

Table B-2. Notes for the emergy evaluation of the drinking water produced at the Hillsborough River Water Treatment Plant in Tampa (footnotes for Tables 23 and 24).

Notes				
1	**Surface water, J**			
	Total dissolved solids of River:	ppt	500	(HRWTP, 1997)
	Gibbs Free Energy (G):	J/g	4.88	[(8.33 J/mol/C)(299 K)/(18 g/mole)]*ln(999,500/965,000)
	water pumped per year:	gals/yr	2.44E+10	(HRWTP, 1996)
	Annual energy:	J/yr	4.50E+14	(gals/yr)(1 m^3/264.17 gals)(J/g)(1 E6 g/m^3)
	Transformity (river water):	sej/J	4.26E+04	(Table 11)
2	**Operation and Maintenance costs in 1996, $**			
	a) Cost of goods & contracted work:	$/yr	2,446,469	(HRWTP, 1997)
	b) $ paid for fuels & electricity:	$/yr	1,467,179	(HRWTP, 1997)
	Money spent for O & M:	$/yr	3,913,648	(a+b)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
3	**Money paid for labor and services in 1996, $**			
	Total $ spent for salaries & wages:	$/yr	3,678,193	(HRWTP, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
4	**Electricity, J**			
	Total electricity in to plant:	kWh	2.41E+07	(HRWTP, 1997)
	Total annual energy used:	J/yr	8.66E+13	(kWh/yr) (3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
5	**Fuels (oil), J**			
	Total oil used:	gal	41,770	(HRWTP, 1997)
	Total annual energy used:	J/yr	6.17E+12	(gal/yr)(14.77E7 J/gal of diesel) (Milliman and Sipe, 1981)
	Transformity:	sej/J	6.60E+04	(Odum, 1996; p.308)
6	**Chemicals, $**			
	Total $ spent for chemicals in 1996:	$/yr	3,978,670	(HRWTP, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
7	**Chemicals used in 1996, kg**			
	Ferric sulfate:	kg/yr	16,672,620	(HRWTP, 1997)
	Caustic soda:	kg/yr	2,542,550	(HRWTP, 1997)
	Sulfuric acid:	kg/yr	4,133,940	(HRWTP, 1997)
	Quicklime:	kg/yr	3,383,510	(HRWTP, 1997)
	Chlorine:	kg/yr	825,130	(HRWTP, 1997)
	Ammonia:	kg/yr	118,230	(HRWTP, 1997)
	Activated carbon:	kg/yr	100,340	(HRWTP, 1997)
	Potassium perganmanate:	kg/yr	68,850	(HRWTP, 1997)
	Fluoride:	kg/yr	65,330	(HRWTP, 1997)
	Polymer:	kg/yr	59,640	(HRWTP, 1997)
	Copper sulfate:	kg/yr	31,860	(HRWTP, 1997)
	Total weight of all chemicals used:	kg/yr	28,002,000	sum
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)

Table B-2--continued.

8	**Annual (depreciated) value of plant assets, $**			
	Plant depreciation & purchased assets:	$/yr	993,989	(HRWTP, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
9	**Plant Assets (concrete with out services), kg**			
	Total mass of concrete:	kg	6.87E+07	prorated from A-4 in Table C-2: (kg in A-4) * (62 mgd/21 mgd)
	Average useful life of plant:	yr	35	assumed
	Total concrete:	kg/yr	1,961,972	(kg)/(useful plant life)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
10	**Plant Assets (steel & iron), kg**			
	Total mass of steel & iron:	kg	5.27E+06	prorated from B-3 in Table C-2: (kg in B-3) * (62 mgd/21 mgd)
	Average useful life of plant:	yr	35	assumed
	Total steel & iron:	kg/yr	1.51E+05	(kg)/(useful plant life)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
11	**Drinking Water Produced, m^3**			
	Total emergy of drinking water (Y):	sej/yr	7.85544E+19	(sum of items 1 to 10)
	Water to the distribution system:	m^3/yr	8.51E+07	(HRWTP, 1997)
	Emergy per volume of drinking water:	sej/m^3	9.2E+11	(sej/yr) / (m^3/yr)
12	**Drinking water produced, $**			
	Total emergy of drinking water (Y):	sej/yr	7.85544E+19	(sum of items 1 to 10)
	Water to the distribution system:	gal/yr	2.25E+10	(HRWTP, 1997)
	Market price of the water per 1000 gals:	1996$	1.2	(HRWTP, 1997)
	$ paid for the water:	$/yr	2.70E+07	($/1000 gals)(gals)/1000
	Emergy per 1996$ of drinking water:	sej/$	2.9E+12	(sej/yr) / ($/yr)
13	**Drinking water produced, J**			
	Water to the distribution system:	m^3/yr	8.51E+07	(HRWTP, 1997)
	Total energy of water:	J/yr	4.20E+14	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	7.86E+19	(sum of items 1 to 10)
	Transformity of drinking water:	sej/J	1.87E+05	(sej/yr) / (J/yr)
14	**Drinking water produced, g**			
	Total mass of water:	g/yr	8.51E+13	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of drinking water (Y):	sej/yr	7.86E+19	(sum of items 1 to 10)
	Emergy per weight of drinking water:	sej/g	9.23E+05	(sej/yr) / (g/yr)
15	**Drinking water with-out services, J**			
	Emergy of potable water:	sej/yr	6.98E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	4.20E+14	(same as note 13)
	Transformity with out services:	sej/J	1.66E+05	(sej/yr) / (J/yr)

Table B-2--continued.

16	**Emergy Investment Ratio (EIR)**			
	P = Items 4+5+7+9+10	sej/yr	4.49E+19	(P = Electricity, Fuels, goods & materials)
	S= Items 2+3+6+8	sej/yr	1.44E+19	(S = services -all money flows-)
	N= negligible	sej/yr	0.00E+00	(N = local non-renewable resources)
	R = Item 1	sej/yr	1.92E+19	(R = renewable resources)
	Emergy Investment Ratio (EIR):		3.10	(P+S) / (N+R)
17	**Emergy Yield Ratio (EYR)**			
	Y = sum of items 1 to 10	sej/yr	7.86E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.32	(Y) / (P+S)
18	**Percent Renewable Emergy**			
	% Renewable Emergy:		24.39	100 x (R/Y)
19	**Ratio of Emergy Benefit to the Purchaser (EBP) in 1996**			
	Em$ value of water:	Em$/yr	6.8E+07	(Y)/(sej/1996$ ratio)
	Em$ value of water per 1000 gals:	Em$	3.04	(Em$/yr)/(gals/yr)*1000
	Market price of water per 1000 gals:	1996$	1.2	(HRWTP, 1996)
	Emergy Benefit to the Purchaser (EBP):		2.53	(Em$) / ($)
20	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		1.01	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
21	**Transformity of potable water, sej/J**		1.87E+05	(see note 13)
22	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		9.23E+11	(Y)/(m^3 produced/yr)

Table B-3. Notes for the emergy evaluation of the drinking water produced at the Murphree Water Treatment Plant in Gainesville, Florida (footnotes for Tables 25 and 26). Richardson, 1996, for personal communication with D. Richardson, water & wastewater administrator and engineer, Gainesville Regional Utility; October 4, 1996; Gainesville.

Notes				
1	**Groundwater, J**			
	Water pumped per year:	gals/yr	7.68E+09	(Murphree Water Treatment Plant, 1994)
	Annual chemical energy of water:	J/yr	1.42E+14	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
	Transformity:	sej/J	1.66E+05	(from Table 19)
2	**Operation and maintenance costs in 1994, $**			
	a) $ paid for labor & services in 1994:	$/yr	800,000	(Murphree Water Treatment Plant, 1994)
	b) $ paid for electricity in 1994:	$/yr	818,871	(Murphree Water Treatment Plant, 1994)
	c) $ paid for chemical in 1994:	$/yr	700,961	(Murphree Water Treatment Plant, 1994)
	Total money spent for O & M in 1994:	$/yr	2,319,832	(a+b+c)
	Emergy per dollar ratio in 1994:	sej/$	1.29E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
3	**Electricity, J**			
	Total kWh used:	kWh	1.48E+07	(Murphree Water Treatment Plant, 1994)
	Total annual energy used:	J/yr	5.31E+13	(kWh)(3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
4	**Chemicals, kg**			
	a) Total lime used in 1994:	kg/yr	4,308,351	(Murphree Water Treatment Plant, 1994)
	b) Total chlorine used in 1994:	kg/yr	517,286	(Murphree Water Treatment Plant, 1994)
	c) Total fluosilicic acid used in 1994:	kg/yr	68,705	(Murphree Water Treatment Plant, 1994)
	d) Total liquid CO_2 used in 1994:	kg/yr	693,733	(Murphree Water Treatment Plant, 1994)
	Total weight of chemicals used in 1994:	kg/yr	5,588,075	(a+b+c+d)
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)
5	**Plant Construction and Upgrading, $**			
	Total 1994 depreciated costs for the construction and upgrading of water Treatment Plant:	$	15,297,840	(Richardson, 1996)
	plant life:	yrs	35	assumed
	Total Assets of plant:	$/yr	437081	($/useful plant life)
	Emergy per dollar ratio in 1994:	sej/$	1.29E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
6	**Plant Assets (concrete, with out services), kg**			
	Total mass of concrete:	kg	2.33E+07	(from A-4 in Table C-2)
	Average useful life of plant:	yr	35	Assumed
	Total concrete:	kg/yr	664539	(kg)/(useful plant life)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
7	**Plant Assets (steel & iron), kg**			
	Total mass of steel & iron:	kg	1.79E+06	(from B-3 in Table C-2)
	Average useful life of plant:	yr	35	assumed
	Total steel & iron:	kg/yr	51009	(kg)/(useful plant life)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
8	**Drinking Water Produced, m^3**			
	Total drinking water produced:	m^3/yr	2.89E+07	(Murphree Water Treatment Plant, 1994)
	Total emergy of drinking water (Y):	sej/yr	4.22E+19	(sum of items 1 to 7)
	Emergy per volume of drinking water:	sej/m^3	1.46E+12	(sej/yr) / (m^3/yr)

Table B-3--continued.

9	**Drinking Water Produced, $**			
	Economic value of water ($/1000 gal):	1994$	0.98	(Murphree Water Treatment Plant, 1994)
	Total drinking water produced:	gals/yr	7.64E+09	(drinking water produced in m^3/yr)(264.2 gal/m^3)
	Total $ of water to distribution system:	$/yr	7.49E+06	($/1000 gal)(gal)/1000
	Total emergy of drinking water (Y):	sej/yr	4.22E+19	(sum of items 1 to 7)
	Emergy per 1994$ of drinking water:	sej/$	5.64E+12	(sej/yr) / ($/yr)
10	**Drinking Water Produced, J**			
	Total drinking water produced:	m^3/yr	2.89E+07	(drinking water produced from note 9)
	Total energy of water:	J/yr	1.43E+14	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	4.22E+19	(sum of items 1 to 7)
	Transformity of drinking water:	sej/J	2.95E+05	(sej/yr) / (J/yr)
11	**Drinking Water Produced, g**			
	Total mass of water:	g/yr	2.89E+13	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of drinking water (Y):	sej/yr	4.22E+19	(sum of items 1 to 7)
	Emergy per weight of drinking water:	sej/g	1.46E+06	(sej/yr) / (g/yr)
12	**Drinking water with-out services, J**			
	Emergy of potable water:	sej/yr	3.86E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	1.43E+14	(same as note 10)
	Transformity with out services:	sej/J	2.71E+05	(sej/yr) / (J/yr)
13	**Emergy Investment Ratio (EIR)**			
	P = Items 3+4+6+7	sej/yr	1.50E+19	(P = Electricity, Fuels, goods & materials)
	S= Item 2+5	sej/yr	3.56E+18	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	2.36506E+19	(R = renewable resources)
	Emergy Investment Ratio (EIR):		0.78	(P+S) / (N+R)
14	**Emergy Yield Ratio (EYR)**			
	Y = items 1 to 7	sej/yr	4.22E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		2.3	(Y) / (P+S)
15	**Percent Renewable Emergy**			
	% Renewable Emergy:		56.0	100 x (R/Y)
16	**Ratio of Emergy benefit to the purchaser (in 1994)**			
	Annual Em$ value of water:	Em$/yr	3.3E+07	(Y)/(sej/1994$ ratio)
	Em $ value of water per 1000 gals:	Em$	4.28	(Em$/yr)/(gals/yr)*1000
	Market price of water per 1000 gals:	$	0.98	(Murphree Water Treatment Plant, 1994)
	Emergy Benefit to the Purchaser (EBP):		4.37	(Em$) / ($)
17	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/$m^3$:	Em$/$m^3$	1.60	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
18	**Transformity of potable water, sej/J**		2.95E+05	(see note 10)
19	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.46E+12	(Y)/(m^3 produced/yr)

Table B-4. Notes for the emergy evaluation of the drinking saved by Tampa Bay Water's Water Conservation Program (footnotes for Tables 27 and 28).

Notes

1 **Potable water saved, J**

Potable water saved per year:	gals/yr	8.90E+09	(Ayres Associates, 1997) p. 8 executive summary
Annual energy:	J/yr	1.66E+14	(gals/yr)(1 m^3/264.17 gals)(4.94 J/g)(1 E6 g/m^3)
Transformity:	sej/J	1.87E+05	(assumed the same as potable water from Table 23)

2 **Total money to be spent for the water management/conservation program by TBW, the local water utilities and water consumers, $**

$ to be spent by TBW & utilities:	$	7.85E+07	(Ayres Associates, 1997; p. 8 ineffective summary)
$ to be spent by consumers:	$	3.14E+07	assuming consumers will spend 40% of TBW & utilities water conservation expenses
Total money to be spent:	$	1.10E+08	sum
Annualized water conservation cost:	$/yr	3.66E+06	($) / (30 years of conservation program)
Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (95; p.314) using a 5.7% decrease/yr)

Only materials needed to replaced existing water-using units and appliances are included below. Implementation of water-saving units or measures in new construction or new consumers were not included in the evaluation. Since the conservation program is supposed to be implemented for 30 years, annualized material flows were calculated by dividing the total mass of materials by the implementation time (i.e. 30 years).

3 **Low-volume toilets (1.6 gal/flush) to replace conventional toilets (3.5 - 5.5 gal/flush), kg**

1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
Persons per household in Florida	cap/house	2.46	(U.S. Census Bureau, 1999)
Households affected by the program:	houses	726,220	(people)/(people/house)
Avg. no. of bathrooms/household:	bath/house	1.64	estimated from U.S. Census Bureau (1999; p. 730)
No. of bathrooms affected by progr.:	bathroom	1,191,000	(no, of bathrooms/household)(no. of households)
% of all toilets to be replaced:	%	75	assuming 75% of full potential (all households) replacement
Low-vol. toilets replaced < 1996:	units	37,862	(Ayres Associates, 1997; Chapter 3, p. 4)
Low-vol. toilets to be installed:	units	864,854	assume [(1 low-vol. toilet / bathroom) - (toilets in place)]*0.75
Mass of each low-vol. toilet:	kg/unit	35.0	(Terrylove.com, 2001)
Total mass of low-vol. toilets:	kg	30,269,873	(no.)(kg/unit)
Time to implement cons. program:	yr	30	(Ayres Associates, 1997)
Annualized mass of all toilets:	kg/yr	1,008,996	(kg) / (yr)
Emergy per mass of toilets:	sej/kg	1.85E+12	assuming that the sej/kg of vitreous china equals 1.5 * sej/kg of concrete (Buranakarn, 1998; p. 175)

4 **Low-volume urinals (1.0 gal/flush) and water-less urinals to replace conventional urinals (1.5 - 2.5 gal/flush), kg**

1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
<u>a) low-volume urinals:</u>			
% of all urinals to be replaced:	%	60	assumed
Low-vol. urinals to be installed:	units	5,360	assume (1 low-vol. urinal / 200 people)*0.6
Mass of each low-vol. urinal:	kg/unit	16.5	(Eljir.com, 2001)
Total mass of low-vol. urinals:	kg	88,432	(no.)(kg/unit)
<u>b) water-less urinals:</u>			
% of all urinals to be replaced:	%	20	assumed
water-less urinals in place < 1996:	units	6	(Ayres Associates, 1997; Chapter 3, p. 4)
Water-less urinals to be installed:	units	356	assume [(1 water-less urinal/1000 people) - (urinals in place)]*0.2

Table B-4--continued.

	Mass of each water-less urinal:	kg/unit	9.1	(Waterless.com, 2001)
	Total mass of water-less urinals:	kg	3,241	(no.)(kg/unit)
	Total:			
	Total mass of all urinals:	kg	91,672	(a) + (b)
	Time to implement cons. program:	yr	30	(Ayres Associates, 1997)
	Annualized mass of all urinals:	kg/yr	3,056	(kg) / (yr)
	Emergy per mass of urinals:	sej/kg	1.85E+12	assuming that the sej/kg of vitreous china equals 1.5 * sej/kg of concrete (Buranakarn, 1998; p. 175)
5	**Low-flow showerheads (2.5 gal/min) & faucet aerators (2.5 gal/min) to replace existing high-volume showerheads and aerators, kg**			
	1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
	Persons per household in Florida	cap/house	2.46	(U.S. Census Bureau, 1999)
	Households affected by the program:	houses	726,220	(people)/(people/house)
	a) low-flow showerheads:			
	No. of bathrooms affected by progr.:	bathroom	1,191,000	(from note 3)
	% of all s. heads to be replaced:	%	90	assuming 90% of full potential (all households) replacement
	Low-flow s. heads replaced <1996:	units	6,652	(Ayres Associates, 1997; Chapter 3, p. 4)
	Low-flow s. heads to be installed:	units	1,065,913	assuming [(1 low-flow s. head/bathroom) - (s. heads in place)]*0.90
	Mass of each low-vol. s. head:	kg/unit	0.15	assumed
	Total mass of low-vol. s. heads:	kg	159,887	(no.)(kg/unit)
	b) low-flow faucet aerators:			
	% of all faucets to be replaced:	%	90	assuming 90% of full potential (all households) replacement
	Low-flow faucets replaced <1996:	units	9,652	(Ayres Associates, 1997; Chapter 3, p. 4)
	Low-flow faucets to be installed:	units	1,625,307	assuming [(2.5 low-flow faucet / household) - (faucets in place)]*0.9
	Mass of each low-vol. faucet:	kg/unit	0.05	assumed
	Total mass of low-vol. faucets:	kg	81,265	(no.)(kg/unit)
	Total:			
	Total mass of s. heads & faucets:	kg	241,152	(a) + (b)
	Time to implement cons. program:	yr	30	(Ayres Associates, 1997)
	Annualized mass of all units:	kg/yr	8,038	(kg) / (yr)
	Emergy per mass:	sej/kg	3.8E+11	assuming the same as plastic (Brown et al., 1992)
6	**Water-saving appliances, kg**			
	1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
	Persons per household in Florida	cap/house	2.46	(U.S. Census Bureau, 1999)
	Households affected by the program:	houses	726,220	(people)/(people/house)
	a) Point of use water heaters:			
	Households with water heaters:	%	91.2	(U.S. Census Bureau, 1999; p. 735)
	% of all heaters to be replaced:	%	50	assuming 50% of full potential (91.2% of households) replacement
	Heaters to be installed:	units	40,732	assume (1 point of use heater / 20 people)*0.5*0.912
	Mass of each point of use heater:	kg/unit	43	(State Select.com, 2001)
	Total mass of heaters:	kg	1,751,485	(no.)(kg/unit)
	b) Water-efficient clothe washers (15 - 20 gal/load) to replace conventional clothe washers (30 - 45 gal/load):			
	Households with cloth washers:	%	77.4	(U.S. Census Bureau, 1999; p. 735)
	% of all c. washers to be replaced:	%	80	assuming 80% of full potential (77.4% of households) replacement
	Clothe washers to be installed:	units	449,675	(1 cloth washer / household)*0.8*0.774
	Avg. mass of each cloth washer:	kg/unit	77	(Sears.com, 2001)
	Total mass of cloth washers:	kg	3.46E+07	(no.)(kg/unit)

Table B-4--continued.

	c) Water-efficient dishwashers (6.5 - 7.5 gal/load) to replace conventional dishwashers (10 - 14 gal/load):			
	Households with dishwashers:	%	50.2	(U.S. Census Bureau, 1999; p. 735)
	% of all d. washers to be replaced:	%	80	assuming 80% of full potential (50.2% of households) replacement
	Dish washers to be installed:	units	291,650	assuming (1 dishwasher / household)*0.8*0.502
	Avg. mass of each dishwasher:	kg/unit	68	(Sears.com, 2001)
	Total mass of dish washers:	kg	1.98E+07	(no.)(kg/unit)
	Total:			
	Total mass of water-saving units:	kg	5.62E+07	(a) + (b) + (c)
	Time to implement cons. program:	yr	30	(Ayres Associates, 1997)
	Annualized mass of all appliances:	kg/yr	1,873,622	(kg) / (yr)
	Emergy per mass:	sej/kg	6.7E+12	assuming the same as machinery (Brown et al., 1992)
7	**Other water-saving changes proposed by the water conservation program, kg**			
	1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
	a) Process reuse of non-residential process waters:			
	% of reuse systems to be installed:	%	25	assuming that only 25% of full potential will be implemented
	Reuse processes to be installed:	units	89	assume (1 reuse process / 5,000 people)*0.25
	Mass of each reuse process:	kg/unit	500	assumed
	Total mass of heaters:	kg	44,663	(no.)(kg/unit)
	b) Alternative on-site reuse systems of non-potable waters (e.g. gray waters)			
	% of reuse systems to be installed:	%	30	assuming that only 30% of full potential will be implemented
	Reuse systems to be installed:	units	536	assuming (1 system / 1,000 people)*0.3
	Mass of each reuse system:	kg/unit	300	assumed
	Total mass of cloth washers:	kg	1.61E+05	(no.)(kg/unit)
	c) Water-efficient irrigation systems to replace conventional systems (saving 10% - 20% of outdoor water use):			
	% of full potential implementation:	%	40	assuming that only 40% of full potential will be implemented
	Irrigation systems to be installed:	units	23,820	assuming (1 system / 30 people)*0.4
	Avg. mass per irrigation system:	kg/unit	120	assumed
	Total mass of irrigation system:	kg	2.86E+06	(no.)(kg/unit)
	d) Re-circulating cooling systems (saving 15% - 35% of commercial/industrial & public facilities):			
	% of system to be installed:	%	30	assuming that only 30% of full potential will be implemented
	Irrigation systems to be installed:	units	179	assuming (1 system / 3,000 people)*0.3
	Avg. mass per cooling system:	kg/unit	200	assumed
	Total mass of cooling system:	kg	3.57E+04	(no.)(kg/unit)
	Total:			
	Total mass of water-saving systems:	kg	3.10E+06	(a) + (b) + (c) + (d)
	Time to implement cons. program:	yr	30	(Ayres Associates, 1997)
	Annualized mass of all systems:	kg/yr	103,319	(kg) / (yr)
	Emergy per mass:	sej/kg	7.60E+11	assuming the same as PVC
				using a PVC sej/kg = to 2 x sej/kg of plastic (Brown et al., 1992)
8	**Mass media reception by the Bay area population, J**			
	Avg. per capita time receiving water conservation info in the Bay area:	min/yr	10	assuming that on average each person spends 10 minutes per year watching, reading, or hearing conservation propaganda
	Fraction of total time in one year:	fraction	1.9E-05	(10 min/yr)/(52.56E4 min/yr)
	Avg. metabolic energy / person	J/day/cap	1.3E+07	(3,000 kcal)(4186 J/kcal)
	Fraction of energy spent hearing about the water conservation program:	J/day/cap	2.4E+02	assuming split of 3,000 kcal/day/person: (fraction of time spent hearing about conservation)(J/day/cap)
	1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
	Total energy spent learning conserv,:	J/day	4.27E+08	(J/day/cap)(population)

Table B-4--continued.

	Total energy spent learning conserv.:	J/yr	1.56E+11	(J/day)(365 days/yr)
	Transformity (metabolic energy):	sej/J	6.76E+06	for average Floridian
	Emergy per person per year in FL:	sej/cap/yr	3.1E+16	(Odum et al., 1998)
	Avg. metabolic energy per cap:	J/cap/yr	4.58E+09	(3,000 kcal/day)(365 day/yr)(4,186 J/kcal)
	Transformity (metabolic energy):	sej/J	6.76E+06	(sej/cap/yr)/(J/cap/yr)
9	**Drinking water saved, m^3**			
	Water saved per year:	m^3/yr	3.37E+07	(Ayres Associates, 1997) p. 8 executive summary
	Total emergy of water saved (Y):	sej/yr	5.09E+19	(sum of items 1 to 8)
	Emergy per volume:	sej/m^3	1.51E+12	(sej/yr) / (m^3/yr)
10	**Drinking water saved, $**			
	Average annual (1996) cost:	$/yr	3.66E+06	(annual $ / 30 years)
	Total emergy of water saved (Y):	sej/yr	5.09E+19	(sum of items 1 to 8)
	Emergy per 1996$ of water saved:	sej/$	1.39E+13	(sej/yr) / ($/yr)
11	**Drinking water saved, J**			
	Water saved per year:	m^3/yr	3.37E+07	(Ayres Associates, 1997) p. 8 executive summary
	Annual energy of water saved:	J/yr	1.66E+14	(m^3/yr)(4.94 J/g)(1 E6 g/m^3)
	Total emergy of water saved (Y):	sej/yr	5.09E+19	(sum of items 1 to 8)
	Transformity of drinking water saved:	sej/J	3.06E+05	(sej/yr) / (J/yr)
12	**Drinking water saved, g**			
	Water saved per year:	m^3/yr	3.37E+07	(Ayres Associates, 1997) p. 8 executive summary
	Total weight of water:	g/yr	3.37E+13	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of water saved (Y):	sej/yr	5.09E+19	(sum of items 1 to 8)
	Emergy per weight of water saved:	sej/g	1.51E+06	(sej/yr) / (g/yr)
13	**Drinking water saved (with-out services), J**			
	Emergy of water saved w/out services	sej/yr	4.56E+19	(total emergy) - (human services) = Y - S
	Energy of water saved:	J/yr	1.66E+14	(same as note 11 above)
	Transformity with-out services:	sej/J	2.74E+05	(sej/yr) / (J/yr)
14	**Emergy Investment Ratio (EIR)**			
	P=itms 3 to 7	sej/yr	1.45E+19	(P = Electricity, Fuels, goods & materials)
	S= Items 2 and 8	sej/yr	5.26792E+18	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R =(Item 1)(%R/100 in Table 24)	sej/yr	7.58055E+18	(R = renewable resources)
	the renewable fraction of potable water (i.e. from the HRWTP) was multiplied by the emergy flow in line 1.			
	Emergy Investment Ratio (EIR):		2.61	(P+S) / (N+R)
15	**Emergy Yield Ratio (EYR)**			
	Y = sum of items 1 to 8	sej/yr	5.09E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		2.6	(Y) / (P+S)
16	**Percent Renewable Emergy**			
	% Renewable emergy:		14.9	100 x (R/Y)

Table B-4--continued.

17	**Ratio of Emergy benefit to the purchaser (in 1996)**			
	Em$ value of water:	Em$/yr	4.42E+07	(Y)/(sej/1996$ ratio)
	Annual cost of potable water:	$/yr	3.66E+06	(Ayres Associates, 1997; with a time of 30 yrs.
	Emergy Benefit to the Purchaser (EBP):		12.07	(Em$) / ($)
18	**2000 Em-dollar value of potable water saved per m^3**			
	2000 Em$/m^3:		1.66	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
19	**Transformity of potable water saved, sej/J**			
	Transformity of drinking water saved:	sej/J	3.06E+05	(see note 11)
20	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.51E+12	(Y)/(m^3 produced/yr)

Table B-5. Notes for the emergy evaluation of the drinking water produced at the City of Dunedin Reverse Osmosis Water Treatment Facility (footnotes for Tables 29 and 30). Stevens, 1998, for personal communication with L. Stevens, water production forewoman, City of Dunedin RO Water Treatment Facility; November 7, 197; Dunedin.

Notes				
1	**Groundwater (fresh), J**			
	Total fresh gw from wells:	gal/yr	1.90E+09	(City of Dunedin, 1997)
	Annual energy:	g/yr	7.17E+12	(gals/yr)(1 m^3/264.17 gals)(1E6 g/m^3)
	Avg. TDS of brackish gw used:	ppm	350	(City of Dunedin, 1997)
	Avg. Gibbs Free Energy of water:	J/g	4.73	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
	Energy of salty water used:	J/yr	3.40E+13	(g/yr)(J/g)
	Transformity:	sej/J	1.66E+05	(Table 19)
2	**Groundwater (brackish) in to treatment plant, J**			
	Total fresh gw from wells:	gal/yr	1.32E+08	(City of Dunedin, 1997)
	Annual mass of brackish water:	g/yr	5.01E+11	(gals/yr)(1 m^3/264.17 gals)(1E6 g/m^3)
	Avg. TDS of brackish gw used:	ppm	1,100	(City of Dunedin, 1997)
	Avg. Gibbs Free Energy of water:	J/g	4.63	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
	Energy of salty water used:	J/yr	2.32E+12	(g/yr)(J/g)
	Transformity:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)
3	**Personnel (wages, benefits, etc.), $**			
	Total wages & benefits:	$/yr	417,898	(City of Dunedin, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
4	**Repair and Maintenance costs in 1996, $**			
	Total $ spent for repair & maint:	$/yr	518,147	(City of Dunedin, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
5	**Money paid for electricity in 1996, $**			
	Money paid for electricity:	$/yr	367,672	(City of Dunedin, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
6	**Electricity, J**			
	Total $ paid for electricity:	$/yr	367,672	(City of Dunedin, 1997)
	1996-97 price paid for electricity:	$/kWh	0.06	(City of Dunedin, 1997)
	Total annual energy used:	J/yr	2.21E+13	($/yr)(3.6 E6 J/kWh)/($/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
7	**Fuels, J**			
	Avg. diesel used:	gal/yr	2,500	(City of Dunedin, 1997)
	Average diesel use:	J/yr	3.7E+11	(gal/yr)(14.77E7 J/gal of diesel) (Milliman and Sipe, 1981)
	Transformity:	sej/J	6.60E+04	(Odum, 1996; p.308)
8	**Chemicals, $**			
	Total $ of chemicals used:	$/yr	284,199	(City of Dunedin, 1997)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)

Table B-5--continued.

9	**Chemicals, kg**			
	a) Total chlorine used in 1996:	kg/yr	30,280	(City of Dunedin, 1997)
	b) Tot. potassium perganmanate used:	kg/yr	31,085	(City of Dunedin, 1997)
	c) Tot. sulfuric acid used in 1996:	kg/yr	102,748	(City of Dunedin, 1997)
	d) Total polymer used in 1996:	kg/yr	1,684	(City of Dunedin, 1997)
	e) Total fluoride used in 1996:	kg/yr	16,725	(City of Dunedin, 1997)
	f) Total sodium hydroxide used:	kg/yr	39,895	(City of Dunedin, 1997)
	Tot. weight of chemicals used in 1994:	kg/yr	222,418	(a+b+c+d+e+f)
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)
10	**Plant Construction and Infrastructure, $**			
	a) Cost for design & construction (1991):		1.10E+07	(Stevens, 1997)
	b) Costs for storage tanks, wells, etc.:		2.50E+06	(Stevens, 1997)
	c) membrane replacement:		1.75E+06	($0.5 E6 every 10 yrs for a plant life of 35 yrs)
	Total construction costs:	$	1.53E+07	(a+b+c)
	Average life of plant:	yrs	35	assumed
	Tot. $ for design and construction:	$/yr	4.36E+05	(total $) / life of plant
	Emergy per dollar ratio in 1991:	sej/$	1.55E+12	(Odum, 1996; p.314)
11	**Plant Assets (concrete with out services), kg**			
	Total mass of concrete:	kg	6.20E+06	prorated from A-4 in Table C-2: (kg in A-4) * (5.6 mgd/21 mgd)
	Average useful life of plant:	yr	35	assumed
	Total concrete:	kg/yr	177210	(kg)/(useful plant life)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
12	**Plant Assets (steel & iron), kg**			
	Total mass of steel & iron:	kg	4.76E+05	prorated from B-3 in Table C-2: (kg in B-3) * (5.6 mgd/21 mgd)
	Average useful life of plant:	yr	35	assumed
	Total steel & iron:	kg/yr	13602	(kg)/(useful plant life)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
13	**Drinking Water Produced, m^3**			
	water pumped per year:	gals/yr	2.03E+09	(City of Dunedin, 1997)
	% recovery from inflow:	%	85	(Stevens, 1997)
	Total drinking water produced:	m^3/yr	6.52E+06	(gals/yr)(0.003785 m^3/gal)(%recovery / 100)
	Total emergy of drinking water (Y):	sej/yr	1.22E+19	(sum of items 1 to 12)
	Emergy per volume of drinking water:	sej/m^3	1.88E+12	(sej/yr) / (m^3/yr)
14	**Drinking Water produced, $**			
	Total emergy of drinking water (Y):	sej/yr	1.223E+19	(sum of items 1 to 12)
	Water to the distribution system:	gal/yr	1.72E+09	(drinking water produced in m^3/yr)(264.2 gal/m^3)
	Market price of water/1000 gals:	1996$	1.84	(Stevens, 1997)
	Money paid for the water:	$/yr	3.17E+06	($/1000 gals)(gals)/1000
	Emergy/1996$ of drinking water:	sej/$	3.9E+12	(sej/yr) / ($/yr)

Table B-5--continued.

15	**Drinking Water produced, J**			
	Total drinking water produced:	m^3/yr	6.52E+06	(drinking water produced from note 13)
	Total energy of water:	J/yr	3.22E+13	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	1.22E+19	(sum of items 1 to 12)
	Transformity of drinking water:	sej/J	3.80E+05	(sej/yr) / (J/yr)
16	**Drinking Water, g**			
	Total weight of water:	g/yr	6.52E+12	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of drinking water (Y):	sej/yr	1.22E+19	(sum of items 1 to 12)
	Emergy/weight of drinking water:	sej/g	1.88E+06	(sej/yr) / (g/yr)
17	**Drinking water with-out services, J**			
	Emergy of potable water w/out s:	sej/yr	9.73E+18	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	3.22E+13	(same as note 15)
	Transformity with out services:	sej/J	3.02E+05	(sej/yr) / (J/yr)
18	**Emergy Investment Ratio (EIR)**			
	P = Items 6+7+9+11+12	sej/yr	4.02E+18	(P = Electricity, Fuels, goods & materials)
	S= Item 3+4+5+8+10	sej/yr	2.50E+18	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1+2	sej/yr	5.71E+18	(R = renewable resources)
	Emergy Investment Ratio (EIR):		1.14	(P+S) / (N+R)
19	**Emergy Yield Ratio (EYR)**			
	Y = items 1 to 12	sej/yr	1.223E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.9	(Y) / (P+S)
20	**Percent Renewable Emergy**			
	% Renewable emergy:		46.7	100 x (R/Y)
21	**Ratio of Emergy Benefit to the Purchaser (in 1996)**			
	Em$ value of water:	Em$/yr	1.1E+07	(Y)/(sej/1996$ ratio)
	Em $ value of water/1000 gals:	Em$	6.17	(Em$/yr)/(gals/yr)*1000
	Market price of water/1000 gals:	$	1.84	(Stevens, 1997)
	Emergy Benefit to the Purchaser (EBP):		3.35	(Em$) / ($)
22	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/$m^3$:		2.06	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
23	**Transformity of potable water, sej/J**		3.80E+05	(see note 15)
24	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.88E+12	(Y)/(m^3 produced/yr)

Table B-6. Notes for the emergy evaluation of the drinking water to be produced in Tampa Bay by desalinating water using reverse osmosis (footnotes for Tables 31 and 32).

Notes				
1	**Salty water used to produce drinking water, J**			
	Drinking water to be produced:	gal/day	2.5E+07	(Stone & Webster, 1999)
	recovery rate to produce 25 mgd:	%	60	(Stone & Webster, 1999)
	Salty water used:	gal/day	4.17E+07	(gal/day)/(%recovery)*100
	Salty water used:	g/yr	5.9E+13	(gal/day)(365 day/yr)(3.785 L/gal)(1020 g/L)
	Avg. TDS of salty water used:	ppm	26,000	(Stone & Webster, 1999)
	Avg. Gibbs Free Energy of water:	J/g	1.25	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
	Energy of salty water used:	J/yr	7.32E+13	(g/yr)(J/g)
	Transformity of Bay water:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)
2	**Operation & Maintenance, $**			
	Tot. $ for operation & maintenance:	2002$/yr	2,314,138	(Stone & Webster, 1999)
	Emergy per dollar ratio in 2002:	sej/$	8.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
3	**Money to be spent for electricity, $**			
	Money to be spent for electricity:	2002$/yr	4,472,877	(Stone & Webster, 1999)
	Emergy per dollar ratio in 2002:	sej/$	8.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
4	**Electricity, J**			
	a) Energy for water / 1000 gal:	kWh	11.60	(Stone & Webster, 1999)
	Total drinking water produced:	mgd	25.0	(Stone & Webster, 1999)
	Total drinking water produced:	gal/yr	9.13E+09	(mgd)(365 d/yr)(1E6)
	Electric energy to be used:	J/yr	3.8E+14	(total KWh/1000 gal)(gal/yr)(3.6 E6 J/kWh)/1000
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
5	**Chemicals, $**			
	Total annual $ paid for chemicals:	2002$/yr	679,173	(Stone & Webster, 1999)
	Emergy per dollar ratio in 2002:	sej/$	8.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
6	**Chemicals, kg**			
	a) Tot. chlorine to be used per year:	kg/yr	104,025	Assuming a dose of 3.0 mg/l
	b) Tot. ammonia to be used per yr:	kg/yr	34,675	Assuming 1/3 of chlorine dose
	c) Tot. sulfuric acid to be used / yr:	kg/yr	294,738	Assuming a dose of 8.5 mg/l
	d) Total sodium hydroxide:	kg/yr	208,050	Assuming a dose of 6.0 mg/l
	e) Tot fluoride to be used per yr:	kg/yr	83,220	Assuming a dose of 2.4 mg/l
	Total weight of chemicals:	kg/yr	724,708	(a+b+c+d)
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)
7	**Assets (cost of total infrastructure to be constructed), $**			
	Tot. annual fixed charges for develop:	2002$/yr	8,162,150	(Stone & Webster, 1999)
	Emergy per dollar ratio in 2002:	sej/$	8.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)

Table B-6--continued.

8	**Total concrete (with out services), kg**			
	Total concrete assets:	kg	2.77E+07	prorated from A-4 in Table C-2: (kg in A-4) * (25 mgd / 21 mgd)
	Avg. useful life of assets:	yrs	30	(Stone & Webster, 1999)
	Prorated concrete assets:	kg/yr	9.23E+05	(Total assets in kg)/(yrs)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
9	**Total steel and iron, kg**			
	Total steel & iron assets:	kg	2.1E+06	(prorated from B-3 in Table C-2) (kg in B-3) * (25 mgd / 21 mgd)
	Avg. useful life of assets:	yrs	30	(Stone & Webster, 1999)
	Prorated steel & iron assets:	kg/yr	7.08E+04	(Total assets in kg)/(yrs)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
10	**Drinking Water Produced, m^3**			
	Total drinking water produced:	mgd	25.0	(Stone & Webster, 1999)
	Total drinking water produced:	m^3/yr	3.45E+07	(mgd)(365 d/yr)(1E6)(0.003785 m^3/gal)
	Total emergy of water produced (Y):	sej/yr	7.80E+19	(sum of items 1 to 9)
	Emergy per volume of drinking water:	sej/m^3	2.26E+12	(sej/yr) / (m^3/yr)
11	**Drinking water produced, $**			
	Total emergy of water produced (Y):	sej/yr	7.80E+19	(sum of items 1 to 9)
	Total drinking water produced:	gal/yr	9.13E+09	(Stone & Webster, 1999)
	Market price of the water / 1000 gals:	2002$	2.15	(Stone & Webster, 1999)
	$ paid for the water:	$/yr	1.96E+07	($ / 1000 gals)(gals)/1000
	Transformity of drinking water:	sej/$	4.0E+12	(sej/yr) / ($/yr)
12	**Drinking water produced, J**			
	Total drinking water produced:	m^3/yr	3.45E+07	(Stone & Webster, 1999)
	Total energy of water:	J/yr	1.71E+14	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of water produced (Y):	sej/yr	7.80E+19	(sum of items 1 to 9)
	Emergy per 2002$ of drinking water:	sej/J	4.57E+05	(sej/yr) / (J/yr)
13	**Drinking water produced, g**			
	Total drinking water produced:	m^3/yr	3.45E+07	(Stone & Webster, 1999)
	Total weight of water:	g/yr	3.45E+13	(m^3/yr)(1 E6 g/m^3)
	Total emergy of water produced (Y):	sej/yr	7.80E+19	(sum of items 1 to 9)
	Emergy/mass of drinking water:	sej/g	2.26E+06	(sej/yr) / (g/yr)
14	**Drinking water produced with-out services, J**			
	Emergy of potable water:	sej/yr	6.53E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	1.71E+14	(same as note 12)
	Transformity with out services:	sej/J	3.83E+05	(sej/yr) / (J/yr)
15	**Emergy Investment Ratio (EIR)**			
	P = Items 4+6+8+9	sej/yr	6.30E+19	(P = Electricity, Fuels, goods & materials)
	S= Items 2+3+5+7	sej/yr	1.27E+19	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	2.33E+18	(R = renewable resources)
	Emergy Investment Ratio (EIR):		32.39	(P+S) / (N+R)

Table B-6--continued.

16	**Emergy Yield Ratio (EYR)**			
	Y = sum of items 1 to 9	sej/yr	7.80E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.03	(Y) / (P+S)
17	**Percent Renewable Emergy**			
	% Renewable emergy:		3.0	100 x (R/Y)
18	**Ratio of Emergy benefit to the purchaser (for 2002 dollars)**			
	Em$ value of water:	Em$/yr	9.62E+07	(Y)/(sej/2002$ ratio)
	Em$ value of water per 1000 gals:	Em$	10.55	(Em$/yr)/(gals/yr)*1000
	Market price of water per 1000 galls:	$	2.15	(Stone & Webster, 1999)
	Emergy Benefit to the Purchaser (EBP):		4.91	(Em$) / ($)
19	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		2.48	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
20	**Transformity of potable water, sej/J**		3.83E+05	(see note 12)
21	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		2.26E+12	(Y)/(m^3 produced/yr)

Table B-7. Notes for the emergy evaluation of the drinking water produced and delivered by the Florida Keys Aqueduct Authority (footnotes for Tables 33 and 34).

Notes				
1	**Groundwater pumped from the Biscayne aquifer system, J**			
	Total gw pumped for treatment:	gal/yr	5.17E+09	(Malgrat & Doughtry, 1996)
	Annual energy:	J/yr	9.60E+13	(gals/year)(1 m^3/264.17 gals)(4.9 J/g)(1E6 g/m^3)
	Transformity:	sej/J	60,206	groundwater from the Biscayne aquifer, (Table 17)
2	**Operation & maintenance, $**			
	a) Salaries:	$/yr	8.315E+06	(Malgrat & Doughtry, 1996)
	b) Employee pension & benefits:	$/yr	3.033E+06	(Malgrat & Doughtry, 1996)
	c) Contracted services:	$/yr	2.360E+06	(Malgrat & Doughtry, 1996)
	d) Fuels:	$/yr	1.421E+05	(Malgrat & Doughtry, 1996)
	e) Materials & supplies:	$/yr	4.300E+05	(Malgrat & Doughtry, 1996)
	f) Electricity:	$/yr	1.175E+06	(Malgrat & Doughtry, 1996)
	Total $ for operation & maintenance:	$/yr	1.546E+07	(a+b+c+d+e+f)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
3	**Electricity, J**			
	Total purchased power:	$/yr	1.175E+06	(Malgrat & Doughtry, 1996)
	$ per kWh of electric power:	$/kWh	0.08	(assumed)
	Total annual energy used:	J/yr	5.3E+13	[($)/($/kWh)](3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
4	**Fuels, J**			
	$ paid for total fuel used:	$/yr	142,100	(Malgrat & Doughtry, 1996)
	Annual energy of fuels used:	J/yr	2.13.E+13	(1.5E8 J/gal)($/yr)/(1996$1.0/gal of diesel)
	Transformity:	sej/J	6.60E+04	(Odum, 1996; p.308)
5	**Chemicals, $**			
	Total cost for chemical used:	$/yr	439,300	(Malgrat & Doughtry, 1996)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)
6	**Chemicals, kg**			
	a) Total lime used in 1996:	kg/yr	2,418,119	assumed dose: 145.0 mg/l
	b) Total chlorine used in 1996:	kg/yr	333,534	assumed dose: 20.0 mg/l
	c) Total fluoride used in 1996:	kg/yr	41,692	assumed dose: 2.5 mg/l
	d) Total liquid CO_2 used in 1996:	kg/yr	400,240	assumed dose: 24.0 mg/l
	Total weight of chemicals used in 1996:	kg/yr	3,193,584	(a+b+c+d)
	Emergy per weight:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)
7	**Total assets (pipeline & storage capacity), $**			
	Total $ of assets:	$	1.50E+08	(Malgrat & Doughtry, 1996)
	Useful life of aqueduct assets:	yrs	30	assumed
	Prorated assets:	$/yr	5.01E+06	(Total assets)/(yrs)
	Emergy per dollar ratio in 1996:	sej/$	1.15E+12	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using a 5.7% decrease/yr)

Table B-7--continued.

8	**Total concrete (with out services), kg**			
	Total concrete assets:	kg	1.85E+07	(from A-3 in Table C-3)
	Avg. life span of aqueduct infrastructure	yrs	30	assumed
	Prorated concrete assets:	kg/yr	6.15E+05	(Total assets in kg)/(yrs)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
9	**Total steel and iron, kg**			
	Total steel & iron assets:	kg	1.78E+07	(from B-4 in Table C-3)
	Useful life of aqueduct assets:	yrs	30	assumed
	Prorated steel & iron assets:	kg/yr	5.94E+05	(Total assets in kg)/(yrs)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
10	**Drinking water produced and transported, m^3**			
	Total drinking water produced:	m^3/yr	1.66E+07	(Malgrat & Doughtry, 1996)
	Tot. emergy of transported water (Y):	sej/yr	4.47E+19	(sum of items 1 to 9)
	Emergy per volume of drinking water:	sej/m^3	2.69E+12	(sej/yr) / (m^3/yr)
11	**Drinking water produced and transported, $**			
	Tot. emergy of transported water (Y):	sej/yr	4.47E+19	(sum of items 1 to 9)
	Total drinking water produced:	gal/yr	4.39E+09	(m^3/yr)(264.2 gal/m^3)
	Market price of the water/1000 gals:	1996$	5.18	(Malgrat & Doughtry, 1996)
	Money paid for the water:	$/yr	2.27E+07	($ / 1000 gals)(gals)/1000
	Emergy per 1996$ of drinking water:	sej/$	2.0E+12	(sej/yr) / ($/yr)
12	**Drinking water produced and transported, J**			
	Total drinking water produced:	m^3/yr	1.66E+07	(Malgrat & Doughtry, 1996)
	Total energy of water:	J/yr	8.21E+13	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Tot. emergy of transported water (Y):	sej/yr	4.47E+19	(sum of items 1 to 9)
	Transformity of drinking water:	sej/J	5.45E+05	(sej/yr) / (J/yr)
13	**Drinking water produced and transported, g**			
	Total drinking water produced:	m^3/yr	1.66E+07	(Malgrat & Doughtry, 1996)
	Total weight of water:	g/yr	1.66E+13	(m^3/yr)(1 E6 g/ m^3)
	Tot. emergy of transported water (Y):	sej/yr	4.47E+19	(sum of items 1 to 9)
	Transformity of drinking water:	sej/g	2.69E+06	(sej/yr) / (g/yr)
14	**Drinking water produced and transported with-out services, J**			
	Emergy of potable water:	sej/yr	2.07E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	8.21E+13	(same as note 12)
	Transformity with out services:	sej/J	2.52E+05	(sej/yr) / (J/yr)
15	**Emergy Investment Ratio (EIR)**			
	P = Items 3+4+6+8+9	sej/yr	1.49E+19	(P = Electricity, Fuels, goods & materials)
	S= Items 2+5+7	sej/yr	2.40E+19	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	5.78E+18	(R = renewable resources)
	Emergy Investment Ratio (EIR):		6.74	(P+S) / (N+R)

Table B-7--continued.

16	**Emergy Yield Ratio (EYR)**			
	Y = items 1 to 9	sej/yr	4.47E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.1	(Y) / (P+S)
17	**Percent Renewable Emergy**			
	% Renewable emergy:		12.9	100 x (R/Y)
18	**Ratio of Emergy benefit to the purchaser (in 1996)**			
	Em$ value of water:	Em$/yr	3.9E+07	(Y)/(sej/1996$ ratio)
	Em$ value of water per 1000 gals:	Em$	8.86	(Em$/yr)/(gals/yr)*1000
	Market price of water/1000 gals:	$	5.18	(Malgrat & Doughtry, 1996)
	Emergy Benefit to the Purchaser (EBP):		1.71	(Em$) / ($)
19	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		2.96	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
20	**Transformity of potable water, sej/J**		5.45E+05	(see note 12)
21	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		2.69E+12	(Y)/(m^3 produced/yr)

Table B-8. Notes for the emergy evaluation of the drinking water produced at the Reverse Osmosis Desalination plant in Stock Island, Florida (footnotes for Tables 35 and 36).

Notes				
1	**Seawater used to produce drinking water, J**			
	Total drinking water produced:	gal/day	3.0E+06	(Water Services, 1981)
	recovery rate to produce 3.0 mgd:	%	30	(Water Services, 1981)
	Seawater used:	gal/day	1.0E+07	(gal/day)/(%recovery)*100
	Seawater used:	g/yr	1.4E+13	(gal/day)(365 day/yr)(3.785 L/gal)(1026 g/L)
	avg. TDS of salty water used:	ppm	37,000	(Water Services, 1981)
	Avg. Gibbs Free Energy of water:	J/g	0.28	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
	Energy of salty water used:	J/yr	3.95E+12	(g/yr)(J/g)
	Transformity of Bay water:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)
2	**Operating and Maintenance, $**			
	Cost for O&M per 1000 gals:	$	0.39	(Water Services, 1981)
	Total potable water produced:	gal/day	3.0E+06	(Water Services, 1981)
	a) Total $ for oper & maintenance:	$/yr	4.E+05	($/1000 gallons)(gal/day)(365 d/yr)/1000
	Cost for services/1000 gals:	$	0.03	(Water Services, 1981)
	b) Purchased services:	$/yr	3.29E+04	($/1000 gal)(gal/day)(365 d/yr)/1000
	Total $ for oper & maintenance:	$/yr	4.60E+05	(a+b)
	Emergy per dollar ratio in 1980:	sej/$	3.20E+12	(Odum, 95; p.314)
3	**Money paid for Electricity, $**			
	Cost for O&M per 1000 gals:	$	2.03	(Water Services, 1981)
	Total potable water produced:	gal/day	3.0E+06	(Water Services, 1981)
	Total $ paid for electricity:	$/yr	2.22E+06	($/1000 gallons)(gal/day)(365 d/yr)/1000
	Emergy per dollar ratio in 1980:	sej/$	3.20E+12	(Odum, 95; p.314)
4	**Electricity, J**			
	Power used per 1000 gal:	kWh	25.3	(Water Services, 1981)
	Total potable water produced:	gal/day	3.0E+06	(Water Services, 1981)
	Total annual energy used:	J/yr	9.97E+13	(kWh/1000 gal)(1000 J/sec/kW)(gal/d) *(365d/yr)(3600 sec/hr)/1000
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
5	**Supplies and Chemicals, $**			
	Cost per 1000 gal:	$	0.08	(Water Services, 1981)
	a) cost for chemical & lab supplies:	$/yr	8.76E+04	($/1000 gal)(gal/day)(365 day/yr)/1000
	Cost for chlorination / 1000 gals:	$	0.05	estimated from Water Services (1981)
	b) cost for chlorination:	$/yr	5.48E+04	($/1000 gal)(gal/day)(365 day/yr)/1000
	Total cost for chemicals:	$/yr	1.42E+05	(a+b)
	Emergy per dollar ratio in 1980:	sej/$	3.20E+12	(Odum, 95; p.314)
6	**Chemicals, kg**			
	a) Total chlorine used in 1980:	kg/yr	12,483	Assuming a dose of 3.0 mg/l
	b) Total ammonia used in 1980:	kg/yr	4,161	Assuming 1/3 of chlorine dose
	c) Total sulfuric acid used in 1980:	kg/yr	35,368	Assuming a dose of 8.5 mg/l
	d) Total sodium hydroxide used:	kg/yr	24,966	Assuming a dose of 6.0 mg/l
	e) fluoride used in 1980:	kg/yr	9,986	Assuming a dose of 2.4 mg/l
	Total weight of chemicals:	kg/yr	86,965	(a+b+c+d)
	Emergy per mass:	sej/kg	1.00E+12	assumed the same as limestone or coal (Odum, 1996; p. 310)

Table B-8--continued.

7	**Plant Construction and Upgrading, $**			
	Total capital costs per gal/day:	$	3.75	(Water Services, 1981)
	Avg. plant life:	yrs	30	assumed
	a) Total capital costs:	$/yr	3.75E+05	[$ per (gal/day)] * [(gal/d)/plant life]
	Membrane replace $ per 1000 gals:	$	0.45	(Water Services, 1981)
	b) Membrane replace cost:	$/yr	4.93E+05	($0.45/1000 gal)(gal/day)(365d/yr)/1000
	Total construction & upgrading:	$/yr	8.68E+05	(a+b)
	Emergy per dollar ratio in 1980:	sej/$	3.20E+12	(Odum, 95; p.314)
8	**Plant Assets (concrete with out services), kg**			
	Total mass of concrete:	kg	3.32E+06	prorated from A-4 in Table C-2: (kg in A-4) * (3 mgd / 21 mgd)
	Average useful life of plant:	yr	30	assumed
	Total concrete:	kg/yr	110756	(kg)/(useful plant life)
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
9	**Plant Assets (steel & iron), kg**			
	Total mass of steel & iron:	kg	2.55E+05	(prorated from B-3 in Table C-2) (kg in B-3) * (3 mgd / 21 mgd)
	Average useful life of plant:	yr	30	assumed
	Total steel & iron:	kg/yr	8501	(kg)/(useful plant life)
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
10	**Drinking Water Produced, m^3**			
	Total drinking water produced:	gal/d	3.0E+06	(Water Services, 1981)
	Total drinking water produced:	m^3/yr	4.1E+06	(gal/day)(0.003785 m^3/gal)(365 d/yr)
	Total emergy of drinking water (Y):	sej/yr	2.81E+19	(sum of items 1 to 9)
	Emergy per volume of drinking water:	sej/m^3	6.79E+12	(sej/yr) / (m^3/yr)
11	**Drinking water produced, $**			
	Economic value of water ($/1000 gal):	1980$	10.5	(Water Services, 1981)
	Total drinking water produced:	gals/yr	1.09E+09	(m^3/yr)(264.2 gal/m^3)
	Total $ obtained for the water sold:	$/yr	1.15E+07	(gal/yr)($/1000 gal)/1000
	Total emergy of drinking water (Y):	sej/yr	2.81E+19	(sum of items 1 to 9)
	Emergy per 1980$ of drinking water:	sej/$	2.45E+12	(sej/yr) / ($/yr)
12	**Drinking water produced, J**			
	Total drinking water produced:	m^3/yr	4.14E+06	(see note 10)
	Total energy of water:	J/yr	2.02E+13	(gal/yr)(4.88 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	2.81E+19	(sum of items 1 to 9)
	Transformity of drinking water:	sej/J	1.39E+06	(sej/yr) / (J/yr)
13	**Drinking water produced, g**			
	Total drinking water produced:	m^3/yr	4.14E+06	(see note 10)
	Total weight of water:	g/yr	4.14E+12	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of drinking water (Y):	sej/yr	2.81E+19	(sum of items 1 to 9)
	Emergy per weight of drinking water:	sej/g	6.79E+06	(sej/yr) / (g/yr)

Table B-8--continued.

14	**Drinking water with-out services, J**			
	Emergy of drinking water w/out serv:	sej/yr	1.63E+19	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	2.02E+13	(same as note 12)
	Transformity with-out services:	sej/J	8.07E+05	(sej/yr) / (J/yr)
15	**Emergy Investment Ratio (EIR)**			
	P = Items 4+6+8+9		1.6196E+19	(P = Electricity, Fuels, goods & materials)
	S= Items 2+3+5+7		1.1817E+19	(S = services -all money flows-)
	N= negligible		0	(N = local non-renewable resources)
	R = Item 1		1.2596E+17	(R = renewable resources)
	Emergy Investment Ratio (EIR):		222.39	(P+S) / (N+R)
16	**Emergy Yield Ratio (EYR)**			
	Y = items 1 to 9	sej/yr	2.8139E+19	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.0	(Y) / (P+S)
17	**Percent Renewable Emergy**			
	% Renewable emergy:		0.4	100 x (R/Y)
18	**Ratio of Emergy benefit to the purchaser (EBP) in 1980**			
	Em$ value of water in 1980:	Em$/yr	8.8E+06	(Y)/(sej/1980$ ratio)
	1980 Em$ of water per 1000 gals:	Em$	8.03	1000*(Em$/yr)/(gals/yr)
	Market price of water per 1000 gals:	1980$	7.22	(Water Services, 1981)
	Emergy Benefit to the Purchaser (EBP):		1.11	(80Em$) / (Market 1980$ price of water)
19	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		7.5	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
20	**Transformity of potable water, sej/J**		1.39E+06	(see note 12)
21	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		6.79E+12	(Y)/(m^3 produced/yr)

Table B-9. Notes for the emergy evaluation of the drinking water produced with a home filter (footnotes for Tables 39 and 40).

Notes				
1	**Groundwater, J**			
	potable water produced per year:	gals/yr	3,650	[using an avg. production = 10 gal/day (gpd); max capacity = 12 gdp]
	Annual chemical energy of water used:	J/yr	6.77E+07	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
	Transformity (avg. groundwater in FL):	sej/J	1.46E+05	assumed = avg. groundwater in FL (Table 20)
2	**Filter replacement & maintenance, $**			
	Annual filter replacement costs:	$/yr	162.3	(Culligan, 2000)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
3	**Purchase & installation, $**			
	1999 retail purchase & installation:	$	849	(Culligan, 2000)
	Average replacement time:	yr	10	assumed
	Annual cost:	$/yr	84.9	($) / (yr)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
4	**Materials (filter casing & storage tank), g**			
	Total weight of unit:	g	5,000	[estimated from Culligan, 2000)
	Average replacement time:	yr	10	assumed
	Annualized material weight:	g/yr	500	($) / (yr)
	Emergy per weight:	sej/g	1.80E+09	(Assume the same as steel; Odum, 1996; p.192).
5	**Materials (filter replacements), g**			
	The piping and pumping required to get the water to the kitchen sink is not included since this represents only a small fraction of total pipe/pump use.			
	a) RO & 5- micron filters replaced:	units/yr	2.25	3 filters per 16 months (Culligan, 2000)
	b) Activated carbon filter replaced:	units/yr	0.2	replaced every 5 years (Culligan, 2000)
	Sum of filters replaced/yr:	units/yr	2.45	(a+b)
	Avg. weight per filter:	g/unit	600	Estimated
	Total weight of all replaced filters/yr:	g/yr	1,470	(total units/yr)(g/unit)
	Emergy per weight:	sej/g	7.20E+10	(Assume the same as silk; Odum, 1996; p.311).
6	**Drinking Water Produced, m^3**			
	Total drinking water produced:	m^3/yr	13.82	(Culligan, 2000)
	Total emergy of drinking water (Y):	sej/yr	3.54E+14	(items 1+2+3+4+5)
	Emergy per volume of drinking water:	sej/m^3	2.56E+13	(sej/yr) / (m^3/yr)
7	**Drinking Water Produced, $**			
	Total annual cost to produce water:	$/yr	247.3	($162.4/yr filter + $84.9/yr capital cost)
	Total emergy of drinking water (Y):	sej/yr	3.54E+14	(items 1+2+3+4+5)
	Emergy per 1999$ of drinking water:	sej/$	1.43E+12	(sej/yr) / ($/yr)
8	**Drinking Water Produced, J**			
	Total drinking water produced:	m^3/yr	13.82	(Culligan, 2000)
	Total energy of water:	J/yr	6.82E+07	(m^{3yr})(4.94 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	3.54E+14	(items 1+2+3+4+5)
	Transformity of drinking water:	sej/J	5.19E+06	(sej/yr) / (J/yr)

Table B-9--continued

9	**Drinking Water Produced, g**			
	Total mass of water;	g/yr	1.38E+07	(m^3/yr)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	3.54E+14	(items 1+2+3+4+5)
	Emergy per weight of drinking water:	sej/g	2.56E+07	(sej/yr) / (g/yr)
10	**Drinking water with-out services, J**			
	Emergy of potable water:	sej/yr	1.17E+14	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	6.82E+07	(same as note 8)
	Transformity with out services:	sej/J	1.71E+06	(sej/yr) / (J/yr)
11	**Emergy Investment Ratio (EIR)**			
	P = Items 4+5	sej/yr	1.07E+14	(P = Fuels, goods, materials & resources)
	S= Item 2+3	sej/yr	2.37E+14	(S = services -money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	9.85618E+12	(R = renewable resources)
	Emergy Investment Ratio (EIR):		34.91	(P+S) / (N+R)
12	**Emergy Yield Ratio (EYR)**			
	Y = items 1+2+3+4+5	sej/yr	3.54E+14	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.0	(Y)/(P+S)
13	**Percent Renewable Emergy**			
	% Renewable emergy:		2.8	100 x (R/Y)
14	**Ratio of Emergy benefit to the purchaser (in 1999)**			
	Em$ value of water:	Em$/yr	388.9	(Y)/(sej/$ ratio)
	Annual cost of potable water:	$/yr	247.3	($162.4 filters/yr + $849 capital cost/ 10 yr)
	Emergy Benefit to the Purchaser (EBP):		1.57	(Em$) / ($)
15	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		28.15	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
16	**Transformity of potable water, sej/J**		5.19E+06	(see note 8)
17	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		2.56E+13	(Y)/(m^3 produced/yr)

Table B-10. Notes for the emergy evaluation of boiled water (footnotes for Tables 41 and 42).

Notes				
1	**Groundwater, J**			
	potable water produced per year:	gals/yr	803	(2.2 gal/day)(365 day/yr)
	Annual chemical energy of water used:	J/yr	1.49E+07	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
	Transformity (avg. groundwater in FL):	sej/J	1.46E+05	assumed = avg. groundwater in FL (Table 20)
2	**Work required to boil water, J**			
	Daily human kcal reqd. for boiling water:	kcal/day	4	assuming it takes one person 2 minutes @ 3000 kcal/day
		to boil 2 gal/day: (1 person)(3,000 kcal/day/person)(2 min)(day/1,440 min)		
	Annual human J reqd. for boiling water:	J/year	6.37E+06	(kcal/day)(4,186 J/kcal)(365 day/yr)
	Transformity (metabolic energy):	sej/J	6.76E+06	for an avg. worker in FL
	Emergy per person per year in FL:	sej/cap/yr	3.1E+16	(Odum et al., 1998)
	Avg. metabolic energy per cap:	J/cap/yr	4.58E+09	(3,000 kcal/day)(365 day/yr)(4,186 J/kcal)
	Transformity (metabolic energy):	sej/J	6.76E+06	(sej/cap/yr)/(J/cap/yr)
3	**Proportion of electric ranger (stove) use for boiling water, $**			
	Avg. purchase price of an electric stove:	$	840	(Sears.com, 2001)
	Installation & delivery costs:	$	190	(Sears.com, 2001)
	Total costs for new electric stove	$	1,030	(840+190)
	Stove use just for boiling water:	$	82.4	($1,030)(0.08)
			assuming 8% of the time stove is used just of boiling water	
	Average replacement time:	yr	12	Assumed
	Annual cost:	$/yr	6.87	($) / (yr)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
4	**Proportion of pot use for boiling, $**			
	Purchase price of boiling pot in 2000	$	25	(Sears, 2001) for 2.5 gal stainless steel pot with cover.
	Stove use just for boiling water:	$	17.5	($)(0.7)
			assuming 70% of the time stove is used just of boiling water	
	Average replacement time:	yr	4	Assumed
	Annual cost:	$/yr	4.38	($) / (yr)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
5	**Total materials required, g**			
	The piping and pumping required to get the water to the kitchen sink is not included since this represents only a small fraction of total pipe/pump use.			
	Weight of stove	kg	65.5	(Sears.com, 2001)
	Average replacement time of stove:	yr	12	Assumed
	(a) Annual weight of stove:	kg/yr	5.5	(kg)/(yr)
	Weight of boiling pot	kg	0.45	(Sears.com, 2001)
	Average replacement time of pot:	yr	4	Assumed
	(a) Annual weight of stove:	kg/yr	0.11	(kg)/(yr)
	Total weight of all replaced filters/yr:	kg/yr	5.57	(a)+(b)
	Emergy per mass of steel:	sej/kg	1.80E+12	(assuming all mass is steel; Odum, 1996; p. 192)

Table B-10--continued.

6	**Electricity required to boil 2 gal of water in the electric ranger (stove), J**			
	Avg. power reqd. for one element (coil):	kW	1.5	(Sears.com, 2001)
	Avg. heating time before boiling:	min/day	24.5	(see boiling procedure in note 19)
	Boiling time reqd. to kill all pathogens:	min/day	10	(US EPA, 2001)
	Total time of required to burn the gas:	min/day	34.5	sum of min/day
	Energy reqd. to boil 2.2 gal/day:	J/yr	1.13E+09	(kW)(1000 J/sec/kW)(60 sec/min)(min/day)(356 day/yr)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
7	**Money paid for the electric power used for boiling water, $**			
	Avg. cost per kW in 2000:	$/kW-hr	0.08	assumed
	Total electric power used per year:	kW-hr/yr	314.8	(1.8 kW)(23.5 min/day)(hr/60 min)(365 days/yr)
	Gas used per minute in avg. stove:	$/yr	25.2	($/kW-hr)(kW-hr/yr)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
8	**Drinking Water Produced, m^3**			
	It is assumed that 2.2 gal are required to produce 2.0 gal of boiled water (0.2 gal are evaporated).			
	Total drinking water produced:	m^3/yr	2.76	(2.0 gal/day)(0.003785 m^3/gal)(365 days/yr)
	Total emergy of drinking water (Y):	sej/yr	2.70E+14	(items 1+2+3+4+5+6+7)
	Emergy per volume of drinking water:	sej/m^3	9.76E+13	(sej/yr) / (m^3/yr)
9	**Drinking Water Produced, J**			
	Total drinking water produced:	m^3/yr	2.76	(2.0 gal/day)(0.003785 m^3/gal)(365 days/yr)
	Total energy of water:	J/yr	1.36E+07	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	2.70E+14	(items 1+2+3+4+5+6+7)
	Transformity of drinking water:	sej/J	1.98E+07	(sej/yr) / (J/yr)
10	**Drinking Water Produced, g**			
	Total mass of water;	g/yr	2.76E+06	(m^3/yr)(1E6 g/m^3)
	Total emergy of drinking water (Y):	sej/yr	2.70E+14	(items 1+2+3+4+5+6+7)
	Emergy per weight of drinking water:	sej/g	9.76E+07	(sej/yr) / (g/yr)
11	**Drinking water with-out services, J**			
	Emergy of potable water:	sej/yr	1.94E+14	(total emergy - services) = Y-S
	Energy of potable water:	J/yr	1.36E+07	(same as note 9)
	Transformity with out services:	sej/J	1.42E+07	(sej/yr) / (J/yr)
12	**Emergy Investment Ratio (EIR)**			
	P = Items 5+6	sej/yr	1.91E+14	(P = Fuels, goods, materials & resources)
	S= Item 2+3+4+7	sej/yr	7.62E+13	(S = human services)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1	sej/yr	2.168E+12	(R = renewable resources)
	Emergy Investment Ratio (EIR):		123.4	(P+S) / (N+R)
13	**Emergy Yield Ratio (EYR)**			
	Y = items 1+2+3+4+5+6+7	sej/yr	2.70E+14	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.01	(Y)/(P+S)
14	**Percent Renewable Emergy**			
	% Renewable emergy:		0.8	100 x (R/Y)

Table B-10--continued.

15	**Ratio of Emergy benefit to the purchaser (in 2000)**			
	Em$ value of water:	Em$/yr	296.4	(Y)/(sej/$ ratio)
	Annual cost boiling 2 gal/day:	$/yr	36.4	(money flow of items 3+4+7)
	Emergy Benefit to the Purchaser (EBP):		8.14	(Em$) / ($)
16	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/m^3:		107.27	(Y)/[(sej/2000$ ratio)(potable m^3/yr)]
17	**Transformity of potable water, sej/J**		1.98E+07	(see note 9)
18	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		9.76E+13	(Y)/(m^3 produced/yr)

19 Boiling procedure: a 2.5 gal (0.35 kg) stainless steel pot (with cover) was used to boil 2.2 gal of water in an electric ranger (stove). A 10 cm (in diameter) ranger element was used at "Hi" heat to boil the water. Times were measured with a chronometer for: 1) the time to pore the water from the sink to the pot, put it on the stove (with cover) and then remove it from the stove (stopping the chronometer between each step); and 2) the time for the water to boil once placed on the stove. "Boiling" was defined as the presence of boiling bubbles greater than approx. 5 cm in diameter. This procedure was conducted three times, yielding an average time to reach boiling of 24.5 min.

Table B-11. Notes for the emergy evaluation of the potable water produced with a solar desalination with a humidification-dehumidification cycle (footnotes for Tables 43 & 44).

Notes				
1	**Solar radiation, J**			
	Avg. surface solar radiation in FL:	kcal/m^2/yr	1.29E+06	(Odum, et al., 1998; p. 396)
	Avg. surface solar radiation in FL:	J/m^2/yr	5.40E+09	(kcal/m^2/yr)(4186 J/kcal)
	Surface area of solar collector:	m^2	2.0	(Al-Hallaj et al, 1998)
	Avg. solar radiation per year:	J/yr	1.08E+10	(J/m^2/yr)(m^2)
	Transformity:	sej/J	1.0	(by definition)
2	**Salty water, J**			
	Fresh water produced per day in FL:	L/m^2-day	7.5	Assuming 95% of production rate in Jordan from Al-Hallaj et al. (1998)
	Fresh water produced per year:	L/yr	5,475	(L/m^2-day)(365days/yr)(2 m^2 of solar collector)
	Salty water conversion to fresh water:	%	4.6	(Nawayseh et al., 1997; p. 283)
	Salty water used per year:	L/yr	119,022	(fresh water L/yr)/(% seawater conversion/100)
	Mass of salty water used per year:	g/yr	1.2E+08	(L/yr)(1,020 g/L)
	avg TDS of salty water used:	ppm	25,000	assumed for avg. estuary
	Avg. Gibbs Free Energy of water:	J/g	1.38	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
	Energy of salty water used:	J/yr	1.68E+08	(g/yr)(J/g)
	Transformity:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)
3	**Construction & operation costs, $**			
	Cost of water production(w/out pump):	$/L	0.033	assumed to be twice as expensive as the distiller in Table 45 (0.017 $/L, from Tiwari and Rao, 1985; p. 1356)
	Fresh water produced per day in FL:	L/m^2-day	7.5	Assuming 95% of production rate in Jordan from Al-Hallaj et al. (1998)
	Total potable water produced:	L/yr	5,475	(L/m^2-day)(2.0 m^2)(365 day/yr)
	a) Annual cost of water production:	$/yr	183	($/L)(L/yr)
	Water pump cost	$	260	(Alita, 2001)
	Avg. pump replacement time:	yr	6	(Alita, 2001)
	b) Annualized pump cost:	$/yr	43	($) / (yr)
	Total cost of water production:	$/yr	226	(a) + (b)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
4	**Work required to clean glass cover, J**			
	To maximize distillation efficiency, it is recommended to clean the glass cover of the solar collector at least once per week. This work is considered an emergy split of the daily metabolic emergy of an individual.			
	Time to clean the glass cover:	min/week	12	assumed for cleaning 2.0 m^2 of glass
	Calories required to clean the cover:	kcal/day	3.6	(3,000 kcal/day)(min/week)/(10,108 min/week)
	Work required to clean the glass cover:	J/yr	5.5E+06	(kcal/day)(4,186 J/kcal)(362 days/year)
	Transformity (metabolic energy):	sej/J	6.76E+06	for an avg. worker in FL
	Emergy per person per year in FL:	sej/cap/yr	3.1E+16	(Odum et al., 1998)
	Avg. metabolic energy per cap:	J/cap/yr	4.58E+09	(3,000 kcal/day)(365 day/yr)(4,186 J/kcal)
	Transformity (metabolic energy):	sej/J	6.76E+06	(sej/cap/yr)/(J/cap/yr)
5	**Electricity, J**			
	Power for a 1/6 HP submersible pump:	W	125	pump power to feed seawater to distiller (Alita.com, 2001
	Power required to pump salty water:	J/yr	8.21E+08	(W)(J/sec / W)(3,600 sec/hr)(5 hr/day)(365 day/yr) Assuming the pump operates for 5 hours per day
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)

Table B-11--continued.

6	**Wood (Evaporator), J**			
	Total weight of solar desalination unit:	g	3.0E+05	(Al-Hallaj et al., 1998; p.280)
	Weight of wood:	g	1.5E+04	(assuming 5% of total weight)
	Energy of wood:	J/yr	2.4E+07	(g)(3.8 kcal/g)(4186 J/kcal)/(10 yrs)
	Transformity:	sej/J	3.50E+04	(Odum and Arding, 1991; p 26)
7	**Steel plates, g**			
	Total weight of solar desalination unit:	g	3.0E+05	(Al-Hallaj et al., 1998)
	weight of steel:	g	2.75E+05	(total weight - weight of wood and copper)
	weight of steel used:	g/yr	27,491	(g)/(10 yrs)
	Emergy per mass:	sej/g	1.78E+09	(Odum, 1996; p. 186)
8	**Pump materials, g**			
	Avg weight of pump:	g	3,600	(Alita.com, 2001) mostly stainless steel
	Avg. pump replacement time:	yr	6	(Alita.com, 2001)
	Annualized mass of pump:	g/yr	600	(g) / (yr)
	Emergy per mass:	sej/kg	6.7E+09	assuming = to machinery (Brown et al., 1992)
9	**Pipes to pump salty water to the distiller, g**			
	Length of pipes:	m	300	assumed
	weight of 1 inch PVC pipes/unit length:	g/m	450	measured
	Total weight of 1 inch PVC pipe:	g	135,000	(m)*(g/m)
	Avg. pipe replacement time:	yr	10	assumed
	Total annualized mass of PVC pipe:	g/yr	13,500	(g) / (yr)
	Emergy per unit:	sej/g	7.60E+08	Assuming twice the transformity of plastic, from Brown et al. (1992)
10	**Copper condenser, g**			
	Total volume of copper used:	cm^3	1,130	(calculated from Al-Hallaj et al, 1998)
	total weight of copper used:	g/yr	1,009	$(cm^3)(8.93\ g/cm^3)/(10\ yrs)$
	Emergy per mass:	sej/g	6.80E+10	(Brown et al., 1992)
11	**Solar collector (steel), g**			
	a) volume of steel plates in collector:	cm^3	40,000	(200cm x 100cm x 2cm) x 2 (Al-Hallaj et al., 1998)
	b) volume of steel pipe:	cm^3	4,869	50 m of 3 cm (diam) steel pipe (Al-Hallaj et al., 1998) assuming pipe thickness = 0.2 cm
	total steel used for collector:	cm^3	44,869	(a) + (b)
	density of steel:	g/cm^3	7.9	(Beer and Johnston, 1992; p. 701)
	weight of steel used:	g	352,674	$(cm^3)(g/cm^3)$
	weight of steel used:	g/yr	35,267	(g)/(10 yrs)
	Emergy per mass:	sej/g	1.78E+09	(Odum, 1996; p. 186)
12	**Solar collector (glass), g**			
	weight of glass used:	g	44,000	(200cm x 100cm x 1cm @ 2.2 g/cm^3)
	weight of glass used:	g/yr	4,400	(g)/(10 yrs)
	Emergy per mass:	sej/g	8.40E+08	(Odum et al., 1987b)
13	**Concrete & cement, g**			
	weight of concrete used:	g	40,000	assumed
	weight of concrete used per year:	g/yr	4,000	(kg)/(10 yrs)
	Emergy per mass:	sej/g	1.23E+09	(Buranakarn, 1998; page 175)

Table B-11--continued.

14	**Land lease, $**			
	Land required:	m^2	6.0	assuming 3 time the distiller area
	Land lease:	$\$/m^2$-yr	2.0	Assuming avg. land rents for $2000/1000 m^2 per yr.
	Land lease:	$/yr	12.0	(m^2)($\$/m^2$/yr)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
15	**Drinking Water Produced, m^3**			
	Total potable water produced:	m^3/yr	5.47	(L/m^2-day)(2.0 m^2)(365 day/yr)(1 m^3/1000 L) (for 8 L/m^2-day from Al-Hallaj et al., 1998)
	Total emergy yield:	sej/yr	5.55E+14	(sum of items 1 to 14)
	Emergy per volume of drinking water:	sej/m^3	1.01E+14	(total emergy yield/yr) / (m^3/yr)
16	**Potable Water Produced, J**			
	Total drinking water produced:	m^3/yr	5.47	(from Note 15 above)
	Total energy of water:	J/yr	2.70E+07	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy yield:	sej/yr	5.55E+14	(sum of items 1 to 14)
	Transformity of potable water:	sej/J	2.05E+07	(total emergy yield/yr) / (total J water/yr)
17	**Potable water produced, g**			
	Total drinking water produced:	m^3/yr	5.47	(from Note 15 above)
	Total weight of water:	g/yr	5.47E+06	(m^3/yr)(1 E6 g/m^3)
	Total emergy of water produced (Y):	sej/yr	5.55E+14	(sum of items 1 to 14)
	Emergy per mass of potable water:	sej/g	1.01E+08	(sej/yr) / (g/yr)
18	**Potable water produced with-out services, J**			
	Emergy of potable water w/out servs.:	sej/yr	3.41E+14	(total emergy) - (human services) = Y - S
	Energy of potable water:	J/yr	2.70E+07	(same as note 16 above)
	Transformity with-out services:	sej/J	1.26E+07	(sej/yr) / (J/yr)
19	**Emergy Investment Ratio (EIR)**			
	P = Items 5 + 7 to 13		3.35E+14	(P = goods & materials)
	S= Items 3+4+14		2.14E+14	(S = human work & services)
	N = negligible		0	(N = local non-renewable resources)
	R = Items 1+2+6		6.21E+12	(R = renewable resources)
	Emergy Investment Ratio (EIR):		88.4	(P+S) / (N+R)
20	**Emergy Yield Ratio (EYR)**			
	Y = items 1 trough 14	sej/yr	5.55E+14	
	Emergy Yield Ratio (EYR):		1.011	(Y) / (P+S)
21	**Percent Renewable Emergy**			
	% Renewable emergy:		1.12	100 x (R/Y)
22	**Ratio of Emergy benefit to the purchaser (in 2000)**			
	Em$ value of water:	Em$/yr	609.6	(Y)/(sej/$ ratio)
	Annual cost desalinating 4.0 gal/day:	$/yr	194.5	(money flow of items 3 &14)
	Emergy Benefit to the Purchaser (EBP):		3.13	(Em$) / ($)

Table B-11--continued.

23	**2000 Em-dollar value of potable water per m^3**			
	2000 Em\$/m^3:		111.37	(Y)/[(sej/2000\$ ratio)(potable m^3/yr)]
24	**Transformity of potable water, sej/J**			
	Transformity of potable water:	sej/J	2.05E+07	(see note 16)
25	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.01E+14	(Y)/(m^3 produced/yr)

Table B-12. Notes for the emergy evaluation of the potable water produced by desalination using a 1.0 m^2 solar distiller (footnotes for Tables 45 and 46).

Notes

1 **Solar radiation, J**

Avg. surface solar radiation in FL:	kcal/m^2/y	1.29E+06	(Odum, et al., 1998; p. 396)
Avg. surface solar radiation in FL:	J/m^2/yr	5.40E+09	(kcal/m^2/yr)(4186 J/kcal)
Evaporating surf. area per distiller unit:	m^2	1.0	(Tiwari and Rao, 1985; p. 1352)
Avg. solar radiation per unit per year:	J/yr	5.40E+09	(J/m^2/yr)(m^2)
Transformity:	sej/J	1.0	(by definition)

2 **Salty water, J**

Avg. fresh water produced per day:	L/m^2-day	2.9	(Tiwari and Rao, 1985; p. 1355)
Evaporating surf. area per distiller unit:	m^2	1.0	(Tiwari and Rao, 1985; p. 1352)
Fresh water produced per unit per yr:	L/yr	1,059	(L/m^2-day)(365days/yr)(m^2)
Salty water conversion to fresh water:	%	50	assumed
Salty water used per year:	L/yr	2,117	(L/yr)/(%/100)
Mass of salty water used per year:	g/yr	2.2E+06	(L/yr)(1,020 g/L)
avg. TDS of salty water used:	ppm	25,000	assumed (for estuarine water)
Avg. Gibbs Free Energy of water:	J/g	1.38	[(8.33 J/mol/C)(290 K)/(18 g/mole)] *ln (1E6-TDS in ppm / 965,000 ppm)
Energy of salty water used:	J/yr	2.99E+06	(g/yr)(J/g)
Transformity:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)

3 **Construction & operation costs, $**

Total cost of water production:	$/L	0.017	(Tiwari and Rao, 1985; p. 1356)
Fresh water produced per unit per yr:	L/yr	1,059	from note 2 above
Annual cost of water production:	$/yr	17.6	($/L)(L/yr)
Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)

4 **Work to carry seawater to distiller, J**

Salty water required per week:	L/week	41	(2,117 L/yr from note 2) / (52 weeks/yr)

Since this is a low energy-intensive potable water unit, it is assumed that no electricity, pumps, and pipes would be used to deliver the salty water to the distiller. Thus, it is assumed that people will be in charge of filling the distiller with salty water everyday. This work is assumed to be equivalent of 15 minutes of work per week (three 5 min trips carrying 15 L each time). This work is considered an emergy split of the daily metabolic emergy of an individual.

Weekly time to carry salty water:	min/wk	15	assumed
Calories required for seawater transport:	kcal/day	4.5	(3,000 kcal/day)(min/week)/(10,080 min/week)
Work required for seawater transport:	J/yr	6.8E+06	(kcal/day)(4,186 J/kcal)(365 day/year)
Transformity (metabolic energy):	sej/J	6.76E+06	for an avg. worker in FL
Emergy/person per year in FL:	sej/cap/yr	3.1E+16	(Odum et al., 1998)
Avg. metabolic energy per cap:	J/cap/yr	4.58E+09	(3,000 kcal/day)(365 day/yr)(4,186 J/kcal)
Transformity (metabolic energy):	sej/J	6.76E+06	(sej/cap/yr)/(J/cap/yr)

5 **Work required to clean glass cover, J**

To maximize distillation efficiency, it is recommended to clean the glass cover of the distiller at least once per week. This work is considered an emergy split of the daily metabolic emergy of an individual.

Daily time to clean the glass cover:	min/week	7	assumed for cleaning 1.0 m^2 of glass
Calories required to clean the cover:	kcal/day	2.1	(3,000 kcal/day)(min/week)/(10,108 min/week)
Work required to clean the glass cover:	J/yr	3.2E+06	(kcal/day)(4,186 J/kcal)(362 days/year)
Transformity:	sej/J	6.76E+06	see note 4 above

Table B-12--continued.

6	**Fiberglass base, g**			
	a) bottom side:	cm^2	12,100	110 cm x 110 cm (Tiwari and Rao, 1985; p. 1353)
	b) avg. area of lateral sides:	cm^2	8,800	(20 cm x 110 cm)x4 (Tiwari and Rao, 1985; p. 1353)
	Total area of fiberglass:	cm^2	20,900	(a + b)
	Avg. thickness:	cm	2.5	Estimated from (Tiwari and Rao, 1985; p. 1356)
	Volume of fiberglass:	cm^3	52,250	(cm^3)(cm)
	Density of fiberglass:	g/cm^3	1.2	(Beer and Johnston, 1992; p. 703)
	Weight of fiberglass:	g	62,700	(cm^3)(g/cm^3)
	Useful life of solar distillation unit:	year	10	assumed
	Annualized weight of fiberglass:	g/yr	6,270	(g)/(yr)
	Emergy per unit:	sej/g	7.60E+08	Assuming twice the transformity of plastic, from Brown et al. (1992)
7	**Black polythene, g**			
	surface area inside distiller:	m^2	9,900	110 cm x 90 cm, from Tiwari and Rao (1985; p. 1352)
	Thickness of polythene:	cm	2.0	assumed
	Volume of polythene:	cm^3	19,800	area * thickness
	Density of polythene:	g/cm^3	0.91	assumed same as rubber (Beer and Johnston, 1992; p. 703)
	Weight of polythene used:	g	36,036	(cm^2)(cm)(g/cm^3)(2 polythene sheets per distiller)
	Useful life of solar distillation unit:	year	10	assumed
	Prorate annual weight of polythene:	g/yr	3,604	(g)/(yr)
	Emergy per unit:	sej/g	4.30E+09	assumed the same as rubber, (Odum et al., 1987; p. 159)
8	**Jute cloth, g**			
	In this type of distillation systems jute cloth is used to maximize the surface area inside the unit, thus increasing seawater evaporation.			
	Surface area inside distiller:	cm^2	9,900	110 cm x 90 cm, from Tiwari and Rao (1985; p. 1352)
	Thickness of cloth:	cm	0.3	inferred from Tiwari and Rao (1985; p. 1352)
	Volume of cloth:	cm^3	2,475	(cm^2)(cm)
	Density of cloth:	g/cm^3	0.4	assumed
	Weight of cloth liner used:	g	1,980	(cm^2)(cm)(g/cm^3)(2 cloths per distiller)
	Cloth replacement time per year	rplacmt/y	1	(Tiwari and Rao, 1985; p. 1354)
	Prorate annual weight of polythene:	g/yr	1,980	(g)(1 replacement/yr)
	Energy of cloth:	J/yr	1.92E+06	(g/yr)(2.0 kcal/g)(4,186 J/kcal)
	Transformity:	sej/J	2.85E+06	Assumed = 75% of textile transformity from Odum et al. (1987b)
9	**Solar collector (glass), g**			
	glass volume:	cm^3	20,000	(estimated from 2m x 1m x 1cm)
	Density of glass:	g/cm^3	2.2	(Beer and Johnston, 1992; p. 703)
	weight of glass used:	g	44,000	(cm^3)(g/cm^3)
	weight of glass used:	g/yr	4,400	(g)/(10 yrs)
	Emergy per mass:	sej/g	8.40E+08	(Odum et al., 1987b)
10	**Concrete & cement, g**			
	weight of concrete used:	g	15,000	assumed
	weight of concrete used per year:	g/yr	1,500	(kg)/(10 yrs)
	Emergy per mass:	sej/g	1.23E+09	(Buranakarn, 1998; page 175)

Table B-12--continued.

11	**Land lease, $**			
	Land required:	m^2	3.0	assuming 3 time the distiller area
	Land lease:	\$/m^2/yr	2.0	Assuming avg. land rents for \$2000/1000 m^2 per yr.
	Land lease:	\$/yr	6.0	(m^2)(\$/m^2/yr)
	Emergy per dollar ratio in 2000:	sej/$	9.10E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
12	**Drinking Water Produced, m^3**			
	Total potable water produced:	m^3/yr	1.06	(L/m^2-day)(1.0 m^2)(365 day/yr)(1 m^3/1000 L) (for 2.9 L/m^2-day from Tiwari and Rao, 1985; p. 1355)
	Total emergy yield:	sej/yr	1.21E+14	(sum of items 1 through 11)
	Emergy per volume of drinking water:	sej/m^3	1.14E+14	(total emergy yield/yr) / (m^3/yr)
13	**Potable Water Produced, J**			
	Total drinking water produced:	m^3/yr	1.06	(from Note 12 above)
	Total energy of water:	J/yr	5.23E+06	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy yield:	sej/yr	1.21E+14	(sum of items 1 through 11)
	Transformity of potable water:	sej/J	2.31E+07	(total emergy yield/yr) / (total J water/yr)
14	**Potable water produced, g**			
	Total drinking water produced:	m^3/yr	1.06	(from Note 12 above)
	Total weight of water:	g/yr	1.06E+06	(m^3/yr)(1 E6 g/m^3)
	Total emergy of water produced (Y):	sej/yr	1.21E+14	(sum of items 1 to 11)
	Emergy per mass of potable water:	sej/g	1.14E+08	(sej/yr) / (g/yr)
15	**Potable water produced with-out services, J**			
	Emergy of potable water w/out servs.:	sej/yr	3.14E+13	(total emergy) - (human services) = Y - S
	Energy of potable water:	J/yr	5.23E+06	(same as note 13 above)
	Transformity with-out services:	sej/J	6.00E+06	(sej/yr) / (J/yr)
16	**Emergy Investment Ratio (EIR)**			
	P = Items 6+7+8+9+10		3.1287E+13	(P = goods & materials)
	S= Items 3+4+5+11		8.9173E+13	(S = human work & services)
	N = negligible		0	(N = local non-renewable resources)
	R = Item 1 & 2		1.01E+11	(R = renewable resources)
	Emergy Investment Ratio (EIR):		1195.6	(P+S) / (N+R)
17	**Emergy Yield Ratio (EYR)**			
	Y = items 1 through 11	sej/yr	1.21E+14	
	Emergy Yield Ratio (EYR):		1.0008	(Y) / (P+S)
18	**Percent Renewable Emergy**			
	% Renewable emergy:		0.08	100 x (R/Y)
19	**Ratio of Emergy benefit to the purchaser (in 2000)**			
	Em$ value of water:	Em$/yr	132.5	(Y)/(sej/$ ratio)
	Annual cost desalinating 0.8 gal/day:	$/yr	23.6	(money flow of items 3 &11)
	Emergy Benefit to the Purchaser (EBP):		5.60	(Em\$) / (\$)

Table B-12--continued.

20	**2000 Em-dollar value of potable water per m^3**			
	2000 Em\$/m^3:		125.19	(Y)/[(sej/2000\$ ratio)(potable m^3/yr)]
21	**Transformity of potable water, sej/J**			
	Transformity of potable water:	sej/J	2.31E+07	(see note 13)
22	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.14E+14	(Y)/(m^3 produced/yr)

Table B-13. Notes for the emergy evaluation of bottled water. A=tap water source & B=spring water source (footnotes for Tables 47 and 48). Swanson, 2000, personal communication with S. Swanson, Culligan bottled water plant manager; July 26, 2000.

Notes				
1	**Tap water used for the purified bottled water, J**			
	Avg. daily bottled water produced:	gal/day	1.4E+04	(Swanson, 2000)
	RO recovery rate:	%	5.0	(Swanson, 2000)
	Avg. daily tap water used:	gpd	270,000	(gpd)/(%recovery)*100
	Annual energy:	J/yr	1.84E+12	(gals/day)(365 day/yr)(1 m^3/264.17 gals) *(4.94 J/g)(1 E6g/m^3)
(A)	Transformity #:	sej/J	2.95E+05	(Table 25) Murphree Plant
	# Since Ocala's water treatment plant is very similar to the Murphree plant in Gainesville, it was assumed that Ocala's tap water has the same transformity as Gainesville's tap water			
(B)	Transformity **:	sej/J	1.66E+05	(Table 19) Floridan aquifer
	** Assuming that the bottling company would use spring water from the Floridan aquifer instead of tap (drinking) water from the city of Ocala			
2	**Operation & Maintenance (including electric costs), $**			
	Tot. $ for operation & maintenance:	$/yr	865,600	(Swanson, 2000)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
3	**Marketing & advertisement, $**			
	Tot. $ spent for marketing & advert:	$/yr	180,000	(Swanson, 2000)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
4	**Electricity, J**			
	Energy for water produced/month:	kWh	15,949	(Swanson, 2000)
	Electricity used:	J/yr	6.89E+11	(total kWh/month)(12 months/yr)(3.6 E6 J/kWh)
	Transformity:	sej/J	1.60E+05	(Odum, 95; p.305)
5	**Fuels (mainly diesel to operate delivery trucks), J**			
	Total $ spent on diesel/day (1999):	$/day	560	(Swanson, 2000)
	Total diesel used :	gal/yr	107,852	($/day)(5 days/wk)(52wk/yr) / ($1.35 / gal of diesel)
	Total annual fuel energy used:	J/yr	1.6E+13	(gal/yr)(14.77E7 J/gal of diesel)
	Transformity:	sej/J	6.60E+04	(Odum, 1996; p.308)
6	**Filter (RO, C, and micron) replacement + Chemicals (soap for washing bottles, label ink, etc), $**			
	Total annual $ paid for chemicals:	$/yr	32,960	(Swanson, 2000)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
7	**Plastic, kg**			
	Households-businesses served:		12,000	(Swanson, 2000)
	Avg. no. of bottles/household:		2.5	(Swanson, 2000)
	Avg. replacement time of bottles:	yr	2.5	(Swanson, 2000)
	Total bottles in circulation/yr:	bottl/yr	12,000	(12,000*2.5/2.5)
	Weight per plastic bottle:	kg	0.45	(Swanson, 2000)
	a) Weight/yr of plastic bottles:	kg/yr	5,455	(no. of bottles in circulation/yr)(kg/bottle)
	Tot. weight of polyet. storage tanks:	kg	2,000	[estimated for one-6,200 gal tank & two-1,000 gal tanks]
	Expected life-span of storage tanks:	yr	10	assumed
	b) Weight of storage tanks/yr:	kg/yr	200	(kg/yr)
	Total annual weight of plastic used:	kg/yr	7,351	(a+b) * 1.3 [assuming 30% additional plastic used by pipes, etc.]
	Emergy per mass of plastic:	sej/kg	3.8E+11	(Brown et al., 1992)

Table B-13--continued.

8	**Assets (cost of total infrastructure to be constructed), $**			
	Total cost for constructing the plant:	$	1,800,000	(Swanson, 2000)
	Avg. useful life-span of plant:	yr	20	assumed
	Annualized cost of plant:	$/yr	90,000	($/yr)
	Emergy per dollar ratio in 1999:	sej/$	9.60E+11	(Projected from the 1993 sej/$ ratio in Odum (1996; p.314) using 5.7% decrease/yr)
9	**Total concrete (with out services), kg**			
	Prorated concrete assets:	kg/yr	(Total assets in kg)/(yrs)	
	Constructed area of plant:	ft^2	20,000	(Swanson, 2000)
	Total steel & iron assets:	kg	4.0E+05	[assuming 20 kg/ft^2)
	Avg. useful life of assets:	yrs	20	assumed
	Annualized concrete assets:	kg/yr	2.40E+04	(kg/yr)*1.2 [assuming 20% additional concrete parking lot, etc]
	Emergy per mass of concrete:	sej/kg	1.23E+12	(Buranakarn, 1998; p. 175)
10	**Total steel and iron, kg**			
	a) Plant's annual steel & iron assets:	kg/yr	2.40E+03	[assuming 10% of annual weight of concrete above)
	Steel of trucks:	kg	1.80E+05	(10,000 kg/truck)(18 trucks)
	Avg. useful life for each truck:	yrs	10	assumed
	b) Annualized steel in trucks:	kg/yr	1.80E+04	(kg/yr)
	Total steel and iron:	kg/yr	2.65E+04	(a+b)*1.3 [assuming 30% additional steel & iron used]
	Emergy per mass of steel:	sej/kg	1.80E+12	(Odum, 1996; p. 192)
11(A)	**Purified bottled water produced, m^3**			
	Avg. daily bottled water produced:	m^3/day	51.1	2,700 bottles @ 5 gal/bottle*0.003785 m^3/gal (Swanson, 2000)
	Total bottled water produced:	m^3/yr	1.87E+04	(m^3/day)(365 d/yr)
	Total emergy of bottled water (Y):	sej/yr	2.91E+18	(item 1(A) + sum of items 2 to 10)
	Emergy per m^3 of bottled water:	sej/m^3	1.56E+14	(sej/yr) / (m^3/yr)
11(B)	**Purified bottled water produced, m^3**			
	Avg. daily bottled water produced:	m^3/day	51.1	2,700 bottles @ 5 gal/bottle*0.003785 m^3/gal (Swanson, 2000)
	Total bottled water produced:	m^3/yr	1.87E+04	(m^3/day)(365 d/yr)
	Total emergy of bottled water (Y):	sej/yr	2.67E+18	(item 1(B) + sum of items 2 to 10)
	Emergy per m^3 of bottled water:	sej/m^3	1.43E+14	(sej/yr) / (m^3/yr)
12 (A)	**Purified bottled water produced, $**			
	Total emergy of bottled water (Y):	sej/yr	2.91E+18	(item 1(A) + sum of items 2 to 10)
	Tot. purified bottled wat. produced:	gal/yr	4.93E+06	(Swanson, 2000)
	1999 retail price per 5-gal bottle:	$/bottle	4.75	(Swanson, 2000)
	Tot. $ paid for the bottled water:	$/yr	4.68E+06	($/bottle)(gals/yr) / (5 gal/bottle)
	Emergy per 1999$ of bottled water:	sej/$	6.21E+11	(sej/yr) / ($/yr)
12 (B)	**Purified bottled water produced, $**			
	Total emergy of bottled water (Y):	sej/yr	2.67E+18	(item 1(B) + sum of items 2 to 10)
	Tot. purified bottled wat. produced:	gal/yr	4.93E+06	(Swanson, 2000)
	1999 retail price per 5-gal bottle:	$/bottle	4.75	(Swanson, 2000)
	Tot. $ paid for the bottled water:	$/yr	4.68E+06	($/bottle)(gals/yr) / (5 gal/bottle)
	Emergy per 1999$ of bottled water:	sej/$	5.70E+11	(sej/yr) / ($/yr)

Table B-13--continued.

13 (A)	**Purified bottled water produced, J**			
	Total bottled water produced:	m^3/yr	1.87E+04	(Swanson, 2000)
	Total energy of bottled water:	J/yr	9.21E+10	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of bottled water (Y):	sej/yr	2.91E+18	(item 1(A) + sum of items 2 to 10)
	Transformity of bottled water:	sej/J	3.16E+07	(sej/yr) / (J/yr)
13 (B)	**Purified bottled water produced, J**			
	Total bottled water produced:	m^3/yr	1.87E+04	(Swanson, 2000)
	Total energy of bottled water:	J/yr	9.21E+10	(m^3/yr)(4.94 J/g)(1E6 g/m^3)
	Total emergy of bottled water (Y):	sej/yr	2.67E+18	(item 1(B) + sum of items 2 to 10)
	Transformity of bottled water:	sej/J	2.90E+07	(sej/yr) / (J/yr)
14 (A)	**Purified bottled water produced, g**			
	Total bottled water produced:	m^3/yr	1.87E+04	(Swanson, 2000)
	Total weight of bottled water:	g/yr	1.87E+10	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of bottled water (Y):	sej/yr	2.91E+18	(item 1(A) + sum of items 2 to 10)
	Emergy per weight of bottled water:	sej/g	1.56E+08	(sej/yr) / (g/yr)
14 (B)	**Purified bottled water produced, g**			
	Total bottled water produced:	m^3/yr	1.87E+04	(Swanson, 2000)
	Total weight of bottled water:	g/yr	1.87E+10	(m^3/yr)(1 E6 g/ m^3)
	Total emergy of bottled water (Y):	sej/yr	2.67E+18	(item 1(B) + sum of items 2 to 10)
	Emergy per weight of bottled water:	sej/g	1.43E+08	(sej/yr) / (g/yr)
15 (A)	**Purified bottled water produced with-out services, J**			
	Emergy of potable water:	sej/yr	1.79E+18	(total emergy - services) for (A) = Y-S for (A)
	Energy of potable water:	J/yr	9.21E+10	(same as note 13 (A))
	Transformity with out services:	sej/J	1.94E+07	(sej/yr) / (J/yr)
15 (B)	**Purified bottled water produced with-out services, J**			
	Emergy of potable water:	sej/yr	1.55E+18	(total emergy - services) for (B) = Y-S for (B)
	Energy of potable water:	J/yr	9.21E+10	(same as note 13 (B))
	Transformity with out services:	sej/J	1.68E+07	(sej/yr) / (J/yr)
16 (A)	**Emergy Investment Ratio (EIR)**			
	P=4+5+7+9+10	sej/yr	1.24E+18	(P = Electricity, Fuels, goods & materials)
	S= 2+3+6+8	sej/yr	1.12E+18	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = [Item 1(A)*(%R/100 ^)]	sej/yr	3.05E+17	(R = renewable resources)
	Emergy Investment Ratio (EIR):		7.75	(P+S) / (N+R)
	^ %R of the potable water produced at the Murphree plant in Gainesville (Table 26)			
16 (B)	**Emergy Investment Ratio (EIR)**			
	P=Itms 4+5+7+9+10	sej/yr	1.24E+18	(P = Electricity, Fuels, goods & materials)
	S= Item 2+3+6+8	sej/yr	1.12E+18	(S = services -all money flows-)
	N= negligible	sej/yr	0	(N = local non-renewable resources)
	R = Item 1(B)	sej/yr	3.06E+17	(R = renewable resources)
	Emergy Investment Ratio (EIR):		7.73	(P+S) / (N+R)

Table B-13--continued.

17 (A)	**Emergy Yield Ratio (EYR)**			
	Y=(item 1(A)+sum of items 2 to 10)	sej/yr	2.91E+18	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.23	(Y)/(P+S) for (A)
17 (B)	**Emergy Yield Ratio (EYR)**			
	Y=(item 1(B)+sum of items 2 to 10)	sej/yr	2.67E+18	(Y = total emergy of potable water)
	Emergy Yield Ratio (EYR):		1.13	(Y)/(P+S) for (B)
18 (A)	**Percent Renewable Emergy**			
	% Renewable emergy:		10.5	100 x (R/Y) for (A)
18 (B)	**Percent Renewable Emergy**			
	% Renewable emergy:		11.5	100 x (R/Y) for (B)
19 (A)	**Ratio of Emergy benefit to the purchaser (in 1999)**			
	Em$ value of water:	Em$/yr	3.03E+06	(Y)/(sej/$ ratio) for (A)
	Total bottled water produced:	gal/yr	4.93E+06	(Swanson, 2000)
	Em $ value per gal of bottled water:	Em$/gal	0.61	(Em$/yr) / (gals produced/yr) for (A)
	1999 retail price per 5-gal bottle:	$/bottle	4.75	(Swanson, 2000) not including plastic container
	$ obtained from bottled wat. in 1999:	$/gal	0.95	($/bottle)/(5 gal/bottle)
	Emergy Benefit to the Purchaser (EBP):		0.65	(Em$/gal) / ($/gal)
19 (B)	**Ratio of Emergy benefit to the purchaser (in 1999)**			
	Em$ value of water:	Em$/yr	2.78E+06	(Y)/(sej/$ ratio) for (B)
	Total bottled water produced:	gal/yr	4.93E+06	(Swanson, 2000)
	Em $ value per gal of bottled water:	Em$/gal	0.56	(Em$/yr) / (gals produced/yr) for (B)
	1999 retail price per 5-gal bottle:	$/bottle	4.75	(Swanson, 2000) not including plastic container
	$ obtained from bottled wat. in 1999:	$/gal	0.95	($/bottle)/(5 gal/bottle)
	Emergy Benefit to the Purchaser (EBP):		0.59	(Em$/gal) / ($/gal)
20 (A)	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/$m^3$:		171.34	(Y)/[(sej/2000$ ratio)(potable m^3/yr)] for (A)
20 (B)	**2000 Em-dollar value of potable water per m^3**			
	2000 Em$/$m^3$:		157.28	(Y)/[(sej/2000$ ratio)(potable m^3/yr)] for (B)
21 (A)	**Transformity of potable water, sej/J**			
	Transformity of bottled water:	sej/J	3.16E+07	(see note 13 (A))
21 (B)	**Transformity of potable water, sej/J**			
	Transformity of bottled water:	sej/J	2.90E+07	(see note 13 (B))
22 (A)	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.56E+14	(Y)/(m^3 produced/yr) for (A)
22 (B)	**Emergy per m^3 of potable water, sej/m^3**			
	Emergy per m^3 of potable water:		1.43E+14	(Y)/(m^3 produced/yr) for (B)

APPENDIX C

ASSET CALCULATIONS

This appendix contains tables used to calculate the concrete/cement and steel/iron infrastructure of several water treatment systems. Other materials, such as wood, aluminum, glass, plastic, rubber, etc. were not included in these asset calculations since these materials represent only a small fraction of the total mass of materials used by the public supply systems evaluated. Tables C-1 and C-2 show the asset calculations for the facilities in West Palm Beach and Gainesville, respectively. Table C-3 shows the asset calculation for the aqueduct systems operated by the Florida Keys Aqueduct Authority. The asset calculation of Gainesville's Regional Utility potable water distribution system is given in Table C-4.

Table C-1. West Palm Beach Water Treatment Plant assets. Blakeney, 2000, for personal communication with K. Blakeney, department of engineering director, City of West Palm Beach Water Treatment Plant; July 7, 2000, West Palm Beach. Lottinville, 2000, for personal communication with J.J. Lottinville, project manager of engineering, the Crom Corporation, a firm specialized in prestressed composite tanks; July 12, 2000, Gainesville.

A) Concrete used

A-1. Reinforced concrete storage tanks.

tank size (a) (E6 gal)	no. of tanks (a)	avg. wall (b) thickness (in)	height (b) (ft)	diameter (b) (ft)	wall x-sec (c) are (m^2)	circum- (d) ference (m)	walls (e) vol. (m^3)
5	1	9.12	37.8	150.0	2.67	144.4	385.9
3	2	7.72	35.5	120.0	2.12	115.6	245.3
2	4	7.22	34.1	100.0	1.91	96.4	183.7
1	3	5.81	26.7	80.0	1.20	77.1	92.5

no. of tanks (a)	base surf. (f) are (m^2)	base (g) vol. (m^3)	cover surf (h) area (m^2)	cover (i) vol. (m^3)	total (j) vol. (m^3)	mass (k) per tank (kg)	Tot mass (l) (kg)
1	1659.3	168.58	1741.7	132.72	687.23	1.6E+06	1.8E+06
2	1062.5	107.95	1116.0	85.04	438.29	1.0E+06	2.3E+06
4	738.8	75.07	776.9	59.20	317.93	7.4E+05	3.4E+06
3	472.9	48.05	497.3	37.89	178.45	4.1E+05	1.4E+06
						total concrete in storage tanks:	**9.0E+06**

density of concrete:	2.32E+03	kg/m^3 (Beer and Johnston, 1992; p. 703)
Floor (slab) thickness:	4.0	inches (Lottinville, 2000)
Dome thickens:	3.0	inches (Lottinville, 2000)

(a) Blakeney, 2000.
(b) Lottinville, 2000.
(c) (wall thickens in inches * 1ft/12in)(wall height in ft)(1m/3.28 ft)^2
(d) (2*3.1416) * [(diameter in ft * 1m/3.28ft) + (wall thickens * 0.0254 m/in)]
(e) (area in m^3)(circumference in m)
(f) (3.1416 / 4) * [diameter in ft * 1m/3.28ft + (circumference in inches *0.0254 m/in)]^2
(g) (base surface area in m^2)(floor slab thickens i.e. 4.0 in * 0.0254 m/in)
(h) 3.1416 * [(((wall thickness * ft/12in + diameter/2) * m/3.28ft)^2) + (0.1* diameter in ft * m/3.28ft)^2]
(i) (dome thickens i.e. 3.0 in * 0.0254 m/in)(cover surface area in m^2)
(j) (wall volume + base volume + cover volume)
(k) (total volume in m^3)(2.23 E3 kg/m^3)
(l) (total mass per tank)(no. of tanks)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

Table C-1--continued.

A-2. Reinforced concrete slabs to support storage tanks.

tank size (a) (E6 gal)	no. of (a) tanks	top thick (b) (in)	height (b) (m)	slab (d) radius (m)	slab area (e) (m)	slab (f) vol. (m^3)	slab (g) mass (kg)
5	1	3.0	10.8	25.6	2059.2	313.8	8.4E+05
3	2	0.5	8.5	22.6	1605.6	244.7	6.5E+05
2	4	3.0	7.0	19.5	1199.6	182.8	4.9E+05
1	3	3.0	4.0	18.3	1057.1	161.1	4.3E+05
			total concrete of slabs supporting the storage tanks:				**2.4E+06**

Density of concrete: 2.32E+03 kg/m^3 (Beer and Johnston, 1992; p. 703)
Thickness of slab (inches): 6.0 inches (Lottinville, 2000)

(a) Blakeney, 2000.

(b) Lottinville, 2000.

(d) (tank radius + 2.0 m) for 5 and 3 E6 gal tanks, (tank radius + 1.0 m) for < 3 E6 gal tanks (Lotinville, 2000)

Tank radius = [(tank size in gal)(0.003785 m^3/gal)/(tank height in m / 3.1416) $]^{0.5}$

(e) $[(3.1416)(\text{slab radius})]^2$

(f) (slab thickens in inches * 0.0254 m/in)(slab area)

(g) (slab volume)(2.70 E3 kg/m3)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

A-3. Concrete used to build the treatment plant (excluding storage tanks & supporting slabs).

a) Concrete used in rapid mixing, coagulation and settling basins.

length (a) (m)	width (a) (m)	depth (a) (m)	total volume (b) (m^3)	% concrete of tot. vol.	concrete vol. (c) (m^3)	mass (d) (kg)
80	35	4	11200	10	1120	2.60E+06

b) Concrete used in filter basins.

length (a) (m)	width (a) (m)	depth (a) (m)	total volume (b) (m^3)	% concrete of tot. vol.	concrete vol. (c) (m^3)	mass (d) (kg)
40	10	3.5	1400	10	140	3.25E+05

c) Assumed concrete of offices and other buildings : kg 6.7E+06

d) Additional assumed concrete used for pavement, roads, etc.: kg 5.00E+06

Total mass of concrete used to build the treatment plant (sum): kg **1.47E+07**

(a) Blakeney, 2000.

(b) (length * width * depth)

(c) (total volume)(0.1), assuming that 10% of all total volume of these basins is "filled" with concrete.

(d) (concrete volume in m^3)(2.23 E3 kg/m^3)

Table C-1--continued.

A-4. Total mass of concrete used for producing and storing water at the West Palm Beach Treatment Facility (a): **2.74E+07** kg

(a) (total concrete from tanks + total concrete for the rest of the plant)(1.05), assuming 5% extra for miscellaneous uses.

B) Steel & Iron used

B-1. Iron and steel used for producing and storing water at the West Palm Beach Facility.

vol. of rebars in slabs & tanks m^3 (a)	mass of rebars (b) in slabs & tanks (kg)	mass of rebars in (c) buildings & treatment basins (kg)	Total iron in concrete (d) (kg)	Total iron & steel (e) used for treatment (kg)
126.2	9.21E+05	4.8E+05	1.40E+06	**1.62E+06**

Assume 5% of reinforced concrete volume is occupied by reinforcing iron rods.
(a) (total volume of concrete tanks + tot. vol. of slabs)*0.05
(b) (volume of rebars in m^3)(7.3 E3 kg/m^3)
(c) (total concrete in buildings and treatment basins: A-3a + A-3b + A-3c)*0.05
(d) (mass of reebars in slabs & tanks + mass of rebars in buildings & treatment basins)
(e) (total kg of iron and steel in reinforced concrete)(1.15), assuming 15% more iron required for pumps, valves, bolts, braces, fittings and other miscellaneous steel and iron uses.

Table C-2. Murphree Water Treatment Plant assets.

A) Concrete

A-1. Reinforced concrete storage tanks.

tank size (a) (E6 gal)	no. of tanks (a)	avg. wall (b) thickness (in)	height (b) (ft)	diameter (b) (ft)	wall x-sec (c) area (m^2)	circum- (d) ference (m)	walls (e) vol. (m^3)
5	3	9.12	37.8	150.0	2.67	144.4	385.9
2	1	7.22	34.1	100.0	1.91	96.4	183.7
1	1	5.81	26.7	80.0	1.20	77.1	92.5
0.5	3	5.31	23.7	60.0	0.97	57.9	56.4

no. of tanks (a)	base surf. (f) area (m^2)	base (g) vol. (m^3)	cover surf (h) area (m^2)	cover (i) vol. (m^3)	total (j) vol. (m^3)	mass (k) per tank (kg)	Tot mass (l) (kg)
3	1659.3	168.58	1741.7	132.72	687.23	1.6E+06	5.5E+06
1	738.8	75.07	776.9	59.20	317.93	7.4E+05	8.5E+05
1	472.9	48.05	497.3	37.89	178.45	4.1E+05	4.8E+05
3	266.7	27.10	281.1	21.42	104.87	2.4E+05	8.4E+05
						total concrete in storage tanks:	**7.7E+06**

density of concrete:	2.32E+03	kg/m^3 (Beer and Johnston, 1992; p. 703)
Floor (slab) thickness:	4.0	inches (Lottinville, 2000)
Dome thickness:	3.0	inches (Lottinville, 2000)

(a) Murpree Water Treatment Plant, 1996.

(b) Lottinville, 2000.

(c) (wall thickness in inches * 1ft/12in)(wall height in ft)(1m/3.28 ft)^2

(d) (2*3.1416) * [(diameter in ft * 1m/3.28ft) + (wall thickness * 0.0254 m/in)]

(e) (area in m^3)(circumference in m)

(f) (3.1416 / 4) * [diameter in ft * 1m/3.28ft + (circumference in inches *0.0254 m/in)]^2

(g) (base surface area in m2)(floor slab thickness i.e. 4.0 in * 0.0254 m/in)

(h) 3.1416 * [(((wall thickness * ft/12in + diameter/2) * m/3.28ft)^2) + (0.1* diameter in ft * m/3.28ft)^2]

(i) (dome thickness i.e. 3.0 in * 0.0254 m/in)(cover surface area in m2)

(j) (wall volume + base volume + cover volume)

(k) (total volume in m^3)(2.23 E3 kg/m^3)

(l) (total mass per tank)(no. of tanks)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

Table C-2--continued.

A-2. Reinforced concrete slabs to support storage tanks.

tank size (a) (E6 gal)	no. of (a) tanks	height (b) (m)	slab (d) radius (m)	slab area (e) (m)	slab (f) vol. (m^3)	slab (g) mass (kg)
5	3	10.8	25.6	2059.2	313.8	8.4E+05
2	1	8.2	19.1	1149.8	175.2	4.7E+05
1.1	1	7.2	15.6	760.4	115.9	3.1E+05
1	1	7.0	15.1	717.3	109.3	2.9E+05
0.5	3	4.0	14.3	639.2	97.4	2.6E+05
		total concrete of slabs supporting the storage tanks:				**2.2E+06**

Density of concrete:	2.32E+03	kg/m^3 (Beer and Johnston, 1992; p. 703)
Thickness of slab (inches):	6.0	inches (Lottinville, 2000)

(a) Murpree Water Treatment Plant, 1996.

(b) Lottinville, 2000.

(d) (tank radius + 2.0 m) for 5 E6 gal tanks and (tank radius + 1.0 m) for 1.1 E6 gal tank.

Tank radius = $[\text{ (tank size in gal)}(0.003785\ m^3/\text{gal})/(\text{tank height in m} / 3.1416)\ ]^{0.5}$

(e) $[(3.1416)(\text{slab radius})]^2$

(f) (slab thickness in inches * 0.0254 m/in)(slab area)

(g) (slab volume)(2.70 E3 kg/m^3)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

A-3. Concrete used to build the treatment plant (excluding storage tanks & supporting slabs).

Assumed proportional to the concrete used to build the West Palm Beach plant (A-3 in Table C-1):

facility	flow (mgd)	concrete (kg)
WPB	25	1.47E+07
Murphree	21	**1.23E+07** *

* (21 mgd)(1.47 E7 kg) / (25 mgd)

A-4. Total mass of concrete used for producing and storing water at the Murphree Facility (a): **2.33E+07** kg

(a) (total concrete from tanks + total concrete from slabs + concrete used in the treatment plant)(1.05), assuming 5% extra for miscellaneous uses.

Table C-2--continued.

B) Steel & iron

B-1. Steel storage tank used for filters backwashing.

tank size (a) (E6 gal)	no. of (a) tanks	bottom (b) thickens (in)	top (b) thick. (in)	height (b) (m)	radius (c) (m)	tank wall (d) area (m^2)	circumf. (e) (m)	wall (f) vol. (m^3)
1.1	1	1.25	0.5	10.8	11.1	0.24	69.6	16.7

tank size (a) (E6 gal)	no. of (a) tanks	base surf (g) area (m^2)	base (h) vol. (m^3)	cover surf (i) area (m^2)	cover (j) vol. (m^3)	total (k) vol. (m^3)	mass (l) (kg)	Total (g) mass (kg)
5	4	387.2	2.46	385.9	2.45	21.6	1.7E+05	2.0E+05
							total steel in storage tanks:	**1.95E+05**

Density of high strength steel:	7.86E+03	kg/m^3 (Beer and Johnston, 1992; p. 701)
Cover and bottom thickness:	0.25	inches (Lottinville, 2000)

(a) Murpree Water Treatment Plant, 1996.
(b) Lottinville, 2000.
(c) [(tank size in gal)(0.003785 m^3/gal)/(tank height in m / 3.1416)]$^{0.5}$
(d) [(0.0254 m/in)*((bottom thickness - top thickness)/2 + top thickness)] * (tank height in m)
(e) (2*3.1416) * (radius in m)
(f) (area in m^3)(circumference in m)
(g) [3.1416 * (radius + (bottom thickness * 0.0254 m/in))]^2
(h) (base surf. Area in m)(bottom thickness in inches)(0.0254 m/in)
(i) [3.1416 * (tank radius + (top thickness * 0.0254 m/in))]^2
(j) (cover surf. Area)(cover thickness in inches * 0.0254 m/in)
(k) (no. of tanks) * (tank volume + base volume + cover volume)
(l) (total volume in m^3)(8.0 E3 kg/m^3)
(m) (mass in kg)(1.15), assuming 15% extra for miscellaneous iron uses.

B-2. Iron and steel used for treating water at the Murphree Facility.

vol. of rebar in slabs & tanks m^3 (a)	mass of rebar (b) in slabs & tanks (kg)	mass of rebar in (c) buildings & treat. basins (kg)	Total iron in concrete (d) (kg)	Total iron & steel (e) used for treatment (kg)
105.0	7.67E+05	6.2E+05	1.38E+06	**1.59E+06**

Assume 5% of reinforced concrete volume is occupied by reinforcing iron rods.
(a) (total volume of concrete tanks + tot. vol. of slabs)*0.05
(b) (volume of rebar in m^3)(7.3 E3 kg/m^3)
(c) (total concrete in buildings and treatment basins)*0.05
(d) (mass of rebar in slabs & tanks + mass of rebar in buildings & treatment basins)
(e) (total kg of iron and steel in reinforced concrete)(1.15), assuming 15% more iron required for pumps, valves, bolts, braces, fittings and other miscellaneous steel and iron uses.

B-3. Total steel and iron used at the Murphree plant (a): $\boxed{\textbf{1.79E+06}}$ **kg**
(a) sum of total iron and steel from B-1 and B-2 above.

Table C-3. Florida Keys Aqueduct Authority assets. Higley, 1999, for personal communication with A. Higley, maintenance department director, Florida Keys Aqueduct Authority; June 23, 1999, Key West.

A) Concrete

A-1. Prestressed concrete storage tanks.

tank size (a) (E6 gal)	no. of (a) tanks	bottom (b) thickness (in)	top (b) thick. (in)	height (b) (m)	radius (c) (m)	tank wall (d) area (m^2)	circumf. (e) (m)	tank wall (f) vol. (m^3)
5	1	6.0	3.0	10.8	23.6	1.23	148.3	183.1
1	3	6.0	3.0	7.9	12.3	0.91	77.4	70.1
0.5	7	6.0	3.0	7.0	9.3	0.80	58.2	46.6
0.2	1	6.0	3.0	4.9	7.0	0.56	44.0	24.7

Tank size (E6 gal)	No. of tanks	base surf (g) area (m^2)	base (h) vol. (m^3)	cover surf (i) area (m^2)	cover (j) vol. (m^3)	total (k) vol. (m^3)	mass (l) (kg)	Total (g) mass (kg)
5	1	1772.7	270.16	1761.3	268.42	721.6	1.7E+06	1.9E+06
1	3	488.7	74.48	482.8	73.58	654.6	1.5E+06	1.7E+06
0.5	7	278.5	42.44	274.0	41.76	915.9	2.1E+06	2.4E+06
0.2	1	160.8	24.51	157.4	23.99	73.2	1.7E+05	2.0E+05
						total concrete in storage tanks:		**6.3E+06**

Density of concrete: 2.32E+03 kg/m^3 (Beer and Johnston, 1992; p. 703)
Cover and bottom thickness: 6.0 inches (Lottinville, 2000)
(a) Malgrat & Doughtry, 1996.
(b) Lottinville, 2000.
(c) [(tank size in gal)(0.003785 m^3/gal)/(tank height in m / 3.1416)]$^{0.5}$
(d) [(0.0254 m/in)*((bottom thickness - top thickness)/2 + top thickness)] * (tank height in m)
(e) (2*3.1416) * (radius in m)
(f) (area in m^3)(circumference in m)
(g) [3.1416 * (radius + (bottom thickness * 0.0254 m/in))]^2
(h) (base surf. Area in m)(bottom thickness in inches)(0.0254 m/in)
(i) [3.1416 * (tank radius + (top thickness * 0.0254 m/in))]^2
(j) (cover surf. Area)(cover thickness in inches * 0.0254 m/in)
(k) (no. of tanks) * (tank volume + base volume + cover volume)
(l) (total volume in m^3)(2.65 E3 kg/m^3)
(m) (mass in kg)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

Table C-3--continued.

A-2. Reinforced concrete slabs to support storage tanks.

tank size (a) (E6 gal)	no. of (b) tanks	height (c) (m)	tank (d) radius (m)	slab (e) radius (m)	slab area (f) (m)	slab (g) vol. (m^3)	slab (h) mass (kg)
5	5	10.8	23.6	25.6	2059.2	313.8	8.4E+05
3	1	8.5	20.6	22.6	1605.6	244.7	6.5E+05
1	6	7.0	13.1	14.1	625.5	95.3	2.5E+05
0.5	11	4.0	12.3	13.3	552.7	84.2	2.2E+05
0.2	1	2.0	11.0	12.0	450.1	68.6	1.8E+05
			total concrete of slabs supporting the storage tanks:				**2.2E+06**

Density of concrete: 2.32E+03 kg/m^3 (Beer and Johnston, 1992; p. 703)
Thickness of slab (inches): 6.0 inches (Lottinville, 2000)
(a) Malgrat & Doughtry, 1996.
(b) sum of concrete (A-1) and steel (B-2) tanks
(c) Lottinville, 2000.
(d) [(tank size in gal)(0.003785 m^3/gal)/(tank height in m / 3.1416) $]^{0.5}$
(e) (tank radius + 2.0 m) for 5 and 3 E6 gal tanks, (tank radius + 1.0 m) for < 3 E6 gal tanks (Lotinville, 2000)
(f) $[(3.1416)(\text{slab radius 1 m})]^2$
(g) (slab thickness in inches * 0.0254 m/in)(slab area)
(h) (slab volume)(2.70 E3 kg/m^3)(1.15), assuming 15% extra for miscellaneous concrete and cement uses.

A-3. Total concrete used (a): $\boxed{\textbf{1.85E+07}}$ **kg**

(a) (total mass of storage tanks + total mass of supporting slabs
+ 1.0 E7kg of estimated treatment plant and other buildings)

B) Steel & iron

B-1. Mass of ductile iron main.

pipe size (a) (in)	length (a) (miles)	length (b) (m)	surface (c) area (in^2)	surface (d) area (m^2)	volume (e) (m^3)	mass (f) (kg)	Total (g) mass (kg)
36	36	57600	14.19	0.0092	527.2	3.85E+06	4.23E+06
30	43	68800	11.83	0.0076	525.1	3.83E+06	4.22E+06
24	42.7	68320	9.47	0.0061	417.6	3.05E+06	3.35E+06
18	4.3	6880	7.12	0.0046	31.6	2.31E+05	2.54E+05
12	16	25600	4.76	0.0031	78.6	5.74E+05	6.31E+05
					total ductile iron in pipeline:		**1.27E+07**

Table C-3--continued.

Legend for B-1 above.

steel only used on bridges, thus assume ductile iron is the principal material

density of ductile iron: 7.30E+03 kg/m^3 (Beer and Johnston, 1992; p. 701)
pipe thickness: 0.25 inches (Higley, 1999)
(a) Malgrat & Doughtry, 1996.
(b) (mile)(1,600 m)
(c) [((inches + pipe thickness) / 2 $)^2$ - (pipe inches / 2 $)^2$] * (3.1416)
(d) (pipe size in^2)(2.54 / 100$)^2$
(e) (length in m)(surface area in m^2)
(f) (m^3)(7.86 E3 km/m^3)
(g) (kg)(1.1), assuming 10% more iron required for pumps, valves, bolts, braces, fittings etc.

B-2. Steel storage tanks.

tank size (a) (E6 gal)	no. of (a) tanks	bottom (b) thickness (in)	top (b) thick. (in)	height (b) (m)	radius (c) (m)	wall (d) area (m^2)	circumf. (e) (m)	tank wall (f) vol. (m^3)
5	4	1.25	0.5	10.8	23.6	0.24	148.3	35.6
3	1	1.25	0.5	8.5	20.6	0.19	129.5	24.5
1	3	1.25	0.5	7.0	13.1	0.16	82.4	12.8
0.5	4	1.25	0.5	4.0	12.3	0.09	77.1	6.9

tank size (a) (E6 gal)	no. of (a) tanks	base surf (g) area (m^2)	base (h) vol. (m^3)	cover surf (i) area (m^2)	cover (j) vol. (m^3)	total (k) vol. (m^3)	mass (l) (kg)	Total (g) mass (kg)
5	4	1754.7	11.14	1751.9	11.12	231.4	1.8E+06	2.1E+06
3	1	1338.2	8.50	1335.8	8.48	41.4	3.3E+05	3.7E+05
1	3	542.6	3.45	541.0	3.44	59.1	4.6E+05	5.3E+05
0.5	4	474.9	3.02	473.5	3.01	51.5	4.05E+05	4.7E+05
						total steel in storage tanks:		**3.47E+06**

Density of high strength steel: 7.86E+03 kg/m^3 (Beer and Johnston, 1992; p. 701)
Cover and bottom thickness: 0.25 inches (Lottinville, 2000)
(a) Malgrat & Doughtry, 1996.
(b) Lottinville, 2000.
(c) [(tank size in gal)(0.003785 m^3/gal)/(tank height in m / 3.1416) $]^{0.5}$
(d) [(0.0254 m/in)*((bottom thickness - top thickness)/2 + top thickness)] * (tank height in m)
(e) (2*3.1416) * (radius in m)
(f) (area in m^3)(circumference in m)
(g) [3.1416 * (radius + (bottom thickness * 0.0254 m/in))$]^2$
(h) (base surf. Area in m)(bottom thickness in inches)(0.0254 m/in)
(i) [3.1416 * (tank radius + (top thickness * 0.0254 m/in)) $]^2$
(j) (cover surf. Area)(cover thickness in inches * 0.0254 m/in)
(k) (no. of tanks) * (tank volume + base volume + cover volume)
(l) (total volume in m^3)(8.0 E3 kg/m^3)
(m) (mass in kg)(1.15), assuming 15% extra for miscellaneous iron uses.

Table C-3--continued.

B-3. Iron mass in reinforced concrete.

volume of (a) rebar in slabs and tanks m^3	mass of rebar (b) in slabs & tanks kg	mass of rebar (c) in buildings kg	Total iron in (d) reinforced concrete kg
158.6	1.16E+06	5.0E+05	**1.66E+06**

Assuming that 5% of the concrete volume is occupied by reinforcing iron rods.
(a) (total volume of concrete tanks + tot. vol. of slabs)*0.05
(b) (volume of rebar in m^3)(7.3 E3 kg/m^3)
(c) (concrete mass of buildings and treatment plant)*0.05
(d) (mass of rebar in slabs & tanks + mass of rebar in buildings)

B-4. Total cast iron/steel used in the FKAA system (a): **1.78E+07** **kg**

(a) (iron mass in ductile iron main + total mass in steel tanks + total iron mass in reinforced concrete)
B-1 + B-2 + B-3

Table C-4. Gainesville Regional Utility water distribution system assets.

A) Transmission system

A-1. Pipe type: ductile iron.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
3	0.78	1,243.6	1.23	0.0008	1.0	7.19E+03
4	5.07	8,117.6	1.62	0.0010	8.5	6.19E+04
6	153.76	246,019.7	2.41	0.0016	381.8	2.79E+06
8	147.16	235,453.3	3.19	0.0021	484.7	3.54E+06
10	1.64	2,627.3	3.98	0.0026	6.7	4.92E+04
12	150.22	240,350.6	4.76	0.0031	738.3	5.39E+06
14	0.56	899.7	5.55	0.0036	3.2	2.35E+04
16	35.14	56,226.1	6.33	0.0041	229.7	1.68E+06
20	9.95	15,915.8	7.90	0.0051	81.2	5.92E+05
24	13.49	21,583.6	9.47	0.0061	131.9	9.63E+05
30	6.0	9,573.9	11.83	0.0076	73.1	5.33E+05
Total:	523.76			total ductile iron mass:		**1.56E+07**

density of ductile iron:	7300	kg/m^3 (Beer and Johnston, 1992; p. 701)
pipe thickness:	0.25	inches (Higley, 1999)

A-2. Pipe type: galvanized steel.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
2	70.4	112,713.3	0.83	0.0005	60.7	4.77E+05
3	56.8	90,886.7	1.23	0.0008	72.0	5.66E+05
Total:	127.25			total galvanized steel mass:		**1.04E+06**

density of galvanized steel:	7,860	kg/m^3 (Beer and Johnston, 1992; p. 701)
pipe thickness:	0.25	inches (Higley, 1999)

A-3. Pipe type: PVC.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
2	67.11	107,369.1	0.83	0.0005	57.8	8.32E+04
3	2.03	3,248.5	1.23	0.0008	2.6	3.70E+03
4	5.54	8,871.2	1.62	0.0010	9.3	1.34E+04
6	65.56	104,896.4	2.41	0.0016	162.8	2.34E+05
8	141.77	226,830.0	3.19	0.0021	466.9	6.72E+05
12	0.28	448.5	4.76	0.0031	1.4	1.98E+03
Total:	282.29				total PVC mass:	**1.01E+06**

density of PVC:	1,440	kg/m^3 (Beer and Johnston, 1992; p. 703)
pipe thickness:	0.25	inches (Higley, 1999)

Table C-4--continued.

A-4. Pipe type: asbest - cement.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
4	0.45	727.3	1.62	0.0010	0.8	1.23E+03
6	1.57	2,519.1	2.41	0.0016	3.9	6.35E+03
8	1.42	2,269.7	3.19	0.0021	4.7	7.59E+03
Total:	3.45				total cement-asbest mass:	**1.52E+04**

density of asbest - cement: 1,624 kg/m^3

assuming 70% of cement density--2,320 kg/m^3-- (Beer and Johnston, 1992; p 703)

pipe thickness: 0.25 inches (Higley, 1999)

A-5. Pipe type: concrete.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
30	1.01	1,616.0	11.83	0.0076	12.3	2.86E+04
					total concrete mass:	**2.86E+04**

density of concrete: 2,320 kg/m^3 (Beer and Johnston, 1992; p 703)

pipe thickness: 0.25 inches (Higley, 1999)

B) Fire main

B-1. Pipe type: ductile iron.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
6	0.02	32.0	2.41	0.0016	0.0	3.62E+02
					total ductile iron mass:	**3.62E+02**

density of ductile iron: 7,300 kg/m^3 (Beer and Johnston, 1992; p. 701)

pipe thickness: 0.25 inches (Higley, 1999)

B-2. Pipe type: PVC.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
2	0.03	51.5	0.83	0.0005	0.0	3.99E+01
6	0.20	318.2	2.41	0.0016	0.5	7.11E+02
8	0.28	442.4	3.19	0.0021	0.9	1.31E+03
Total:	0.51				total PVC mass:	**2.06E+03**

density of PVC: 1,440 kg/m^3 (Beer and Johnston, 1992; p. 703)

pipe thickness: 0.25 inches (Higley, 1999)

Table C-4--continued.

B-3. Pipe type: cast iron.

(a) pipe diameter (in)	(a) pipe length (miles)	(b) pipe length (m)	(c) x-sec area (in^2)	(d) x-sec area (m^2)	(e) volume (m^3)	(f) mass (kg)
4	0.02	36.4	1.62	0.0010	0.0	2.74E+02
6	2.63	4,213.9	2.41	0.0016	6.5	4.71E+04
8	1.28	2,040.6	3.19	0.0021	4.2	3.02E+04
12	0.02	24.2	4.76	0.0031	0.1	5.36E+02
Total:	3.95			total ductile iron mass:		**7.81E+04**

density of cast iron: 7,200 kg/m^3 (Beer and Johnston, 1992; p. 701)
pipe thickness: 0.25 inches (Higley, 1999)

C) Total assets of the distribution system

C-1. Steel and Iron

Total iron and steel x 1.2 = (A-1 + A-2 + B-1 + B-3)(1.2): $\boxed{\textbf{2.01E+07}}$ **kg**

assuming miscellaneous materials (e.g. fire hydrates, valves, bolts, braces, fittings) represent 20% of the total mass of the pipes.

C-2. Concrete and cement

i) Total mass of cement pipes x 1.2 = (A4 + A5)(1.2): 5.25E+04 kg

assuming miscellaneous materials (e.g. fire hydrates, valves, bolts, braces, fittings) represent 20% of the total mass of the pipes and that asbestos-cement has the same transformity as cement.

ii) Concrete used to secure and install all pipes in the distribution system:

Total length of all pipes in the system (km):	1507.7	Richardson, 2001
Total mass of concrete to install the system (kg):	1.51E+06	assuming 1kg of concrete is required per m of pipe:

Total concrete/cement used in the distribution system (i + ii): $\boxed{\textbf{1.56E+06}}$ **kg**

C-3. PVC

Total mass of PVC pipes x 1.2 = (A3 + B2)(1.2): $\boxed{\textbf{1.21E+06}}$ **kg**

Legend:

(a) Personal communication with D. Richardson, water and wastewater administrator and engineer, Gainesville Regional Utility. March 13, 2001; Gainesville, Florida.
(b) pipe length in m: (miles)(1,600 m/mile)
(c) pipe cross-sectional area in in^2: (3.1416) * [((diameter + pipe thickness) / 2)^2 - (diameter / 2)^2]
(d) pipe cross-sectional area in m^2: (area in inches2)(0.025 m/in)2
(e) volume: (area in m^2)(length in m)
(f) total mass: (volume in m^3)(7,300 kg/m^3)

APPENDIX D

TRANSFORMITIES

Appendix D contains a list of transformities that were used in this work. Table D-1 shows all the transformities used in this study. References are given to document the source of transformities calculated elsewhere whereas table numbers are given for the transformities calculated in this study. A list of calculated water transformities is given in Table D-2.

Table D-1. Transformities (sej/J), emergy per mass (sej/g) and emergy per volume (sej/m^3) used in the study.

Item	(sej/J)	(sej/g)	(sej/m^3)	Source
Miscellaneous transformities				
sunlight	1			(Odum, 1996)
Wood	3.50E+04			(Odum & Arding, 1991)
Diesel and oil-derived fuels	6.60E+04			(Odum, 1996)
Electricity	1.60E+05			(Odum, 1996)
Metabolic energy of avg. person in FL	6.76E+06			(Odum at al., 1998)
Cloth/textiles	2.85E+06			(Odum et al., 1987b)
Carbon dioxide		5.28E+07		(Table F-1, note 25)
Plastic		3.80E+08		(Brown et al., 1992)
PVC & fiberglass (assumed twice the sej/g of plastic)		7.60E+08		(Brown et al., 1992)
Glass		8.40E+08		(Odum et al., 1987b)
Steel and iron		1.80E+09		(Odum, 1996)
Vitreous china (assumed the same as concrete)		1.85E+09		(Buranakarn, 1998)
Chemicals		1.00E+09		(Odum, 1996)
Concrete		1.23E+09		(Buranakarn, 1998)
Rubber		4.30E+09		(Odum et al., 1987)
Appliances/machinery		6.70E+09		(Brown et al., 1992)
Copper pipes		6.80E+10		(Brown et al., 1992)
RO filter membranes (assume the same as silk)		7.20E+10		(Odum, 1996)
Global water storages				
Global water vapor in clouds	3.54E+03	1.75E+04	1.75E+10	Table 8
Global atmospheric vapor	3.59E+03	1.77E+04	1.77E+10	"
Global soil & subsoil water	2.19E+04	1.08E+05	1.08E+11	"
Global freshwater lakes	4.59E+04	2.27E+05	2.27E+11	"
Global biological water	4.94E+04	2.44E+05	2.44E+11	"
Global rivers and streams	6.54E+04	3.23E+05	3.23E+11	"
Global wetland water	1.66E+05	8.21E+05	8.21E+11	"
Global fresh groundwater	2.12E+05	1.05E+06	1.05E+12	"
Global avg. of freshwater resources	6.39E+05	3.15E+06	3.15E+12	"
Global polar ice and glaciers	1.05E+06	5.21E+06	5.21E+12	"
Global water flows				
Global evaporation	3.96E+03	1.95E+04	1.95E+10	Table 9
Global precipitation	3.96E+03	1.95E+04	1.95E+10	"
Global evaporation from oceans	4.57E+03	2.26E+04	2.26E+10	"
Global precipitation on oceans	4.99E+03	2.46E+04	2.46E+10	"
Global temperate rain	7.46E+03	3.68E+04	3.68E+10	"
Global tropical rain	8.43E+03	4.16E+04	4.16E+10	"
Global precipitation on land	1.91E+04	9.44E+04	9.44E+10	"
Global temperate rain on land	2.43E+04	1.20E+05	1.20E+11	"
Global evaporation from land areas	2.94E+04	1.45E+05	1.45E+11	"
Global tropical rain on land	3.19E+04	1.57E+05	1.57E+11	"
Global surface runoff to oceans	5.79E+04	2.86E+05	2.86E+11	"
Global groundwater recharge	2.12E+05	1.05E+06	1.05E+12	"
Global ice melt	9.55E+05	4.72E+06	4.72E+12	"

Table D-1--continued.

Item	(sej/J)	(sej/g)	(sej/m^3)	Source
Florida surface water				
Intertidal water in Florida	3.19E+04	4.42E+04	4.50E+10	Table 10
River water in Florida	4.26E+04	2.03E+05	2.03E+11	Table 11
Lake water in Florida	5.64E+04	2.69E+05	2.69E+11	Table 12
Avg. surface water in Florida	5.76E+04	2.19E+05	2.19E+11	Table 14
Wetland water in Florida	7.09E+04	3.38E+05	3.38E+11	Table 13
Florida groundwater				
Groundwater, Surficial aquifer	4.43E+04	2.10E+05	2.10E+11	Table 15
Groundwater, Sand & gravel aquifer	4.71E+04	2.25E+05	2.25E+11	Table 16
Groundwater, Biscayne aquifer	6.02E+04	2.85E+05	2.85E+11	Table 17
Groundwater, Intermediate aquifer	1.13E+05	5.35E+05	5.35E+11	Table 18
Groundwater in Florida, weighted average	1.46E+05	6.81E+05	6.81E+11	Table 19
Groundwater, Floridan aquifer	1.66E+05	7.75E+05	7.75E+11	Table 20
Public supply systems				
Potable water, West Palm Beach (lake water source)	1.39E+05	6.85E+05	6.85E+11	Table 21
Potable water, West Palm Beach --without services--	1.27E+05			"
Potable water, Tampa (river water source)	1.87E+05	9.23E+05	9.23E+11	Table 23
Potable water, Tampa --without services--	1.66E+05			"
Potable water, Gainesville (groundwater source)	2.95E+05	1.46E+06	1.46E+12	Table 25
Potable water, Gainesville --without services--	2.75E+05			"
Potable water, Tampa Bay (water conservation)	3.06E+05	1.51E+06	1.51E+12	Table 27
Potable water, Tampa Bay conservation --w/out serv.--	2.74E+05			"
Potable water, Dunedin (groundwater source; RO)	3.80E+05	1.88E+06	1.88E+12	Table 29
Potable water, Dunedin --without services--	3.46E+05			"
Potable water, Tampa Bay (salty water source, RO)	4.57E+05	2.26E+06	2.26E+12	Table 31
Potable water, Tampa Bay RO --without services--	3.83E+05			"
Potable water, FL Keys Aqueduct (surficial gw source)	5.45E+05	2.69E+06	2.69E+12	Table 33
Potable water, FL Keys Aqueduct --without services--	3.28E+05			"
Potable water, Stock Island (seawater source, RO)	1.39E+06	6.79E+06	6.79E+12	Table 35
Potable water, Stock Island --without services--	1.32E+06			"
Home purification systems				
Potable water, home filter (groundwater source)	5.19E+06	2.56E+07	2.56E+13	Table 39
Potable water, home filter --without services--	1.71E+06			"
Potable water, boiling (groundwater source)	1.98E+07	9.76E+07	9.76E+13	Table 41
Potable water, boiling --without services--	1.42E+07			"
Potable water, solar still (salty water; hum/dehum)	2.05E+07	1.01E+08	1.01E+14	Table 43
Potable water, solar still (hum/dehum)--w/out serv.--	1.26E+07			"
Potable water, solar distiller (salty water source)	2.31E+07	1.14E+08	1.14E+14	Table 45
Potable water, solar still --w/out services--	7.05E+06			"
Potable water, bottled water (tap water source)	3.16E+07	1.56E+08	1.56E+14	Table 47
Potable water, bottled water --without services--	1.94E+07			"

gw= groundwater

Otherwise specified, water transformities listed are for the chemical potential energy of freshwater relative to seawater.

Table D-2. Summary of water transformities calculated in this study.

Water type	Transformity (sej/J)
Global water vapor in clouds	3,545
Global atmospheric vapor	3,590
Global evaporation	3,956
Global precipitation	3,956
Global evaporation from oceans	4,572
Global precipitation on oceans	5,055
Global temperate rain	7,459
Global tropical rain	8,426
Global precipitation on land	18,199
Global soil & subsoil water	21,879
Global temperate rain on land	24,298
Global evaporation from land areas	29,399
Global tropical rain on land	31,862
Intertidal waters in Florida	31,917
Global freshwater lakes	45,862
River water in Florida	42,586
Groundwater, Surficial aquifer	44,300
Groundwater, Sand & gravel aquifer	47,103
Global biological water	49,391
Lake water in Florida	56,427
Surface water in Florida, weighted average	57,630
Global surface runoff to oceans	57,907
Groundwater, Biscayne aquifer	60,206
Global rivers and streams	65,443
Wetland water in Florida	70,905
Groundwater, Intermediate aquifer	113,170
Potable water, West Palm Beach (lake water source)	138,696
Groundwater in Florida, weighted average	145,580
Groundwater, Floridan aquifer	166,010
Global wetland water	166,168
Potable water, Tampa (river water source)	186,822
Global groundwater (fresh)	227,492
Potable water, Gainesville (groundwater source)	295,462
Potable water, Tampa Bay (water conservation)	305,691
Potable water, Dunedin (groundwater source; RO)	379,595
Potable water, Tampa Bay (salty water source, RO -new tech.-)	456,872
Potable water, FL Keys Aqueduct (groundwater source)	544,730
Global average of freshwater resources	639,382
Global ice melt	955,466
Global polar ice and glaciers	1,054,307
Potable water, Stock Island (seawater source, RO -old tech.-)	1,391,252
Potable water, home filter (groundwater source)	5,185,670
Potable water, boiled water (groundwater source)	19,760,835
Potable water, advanced solar distillation (salty water source)	20,515,674
Potable water, traditional solar distillation (salty water source)	23,062,184
Potable water, bottled water (tap water source)	31,562,459

APPENDIX E

COEFFICIENTS AND REFERENCES FOR THE WATER ALLOCATION MODEL

Table E-1. Flows and calibration values for the simulation of water allocation in Florida.

		flow or		biophysical		Calibration	
Note	Description	**fraction**	Equation	value	Units	calibration value	k-value
1	Average insolation reaching Florida	J (%)	constant	1.70E+21	J/yr	10	
2	Albedo and remainder of insolation	R (%)	= J/[1+(k2*Fa*AW*FF*S2+k1*Fe)]	6.80E+19	J/yr	4	
3	Total goods, fuels, energy and services used in Florida	FF (sej)	= k10*Pu + k11*Pa + k12*Pe	3.81E+23	sej/yr	20	
4	Solar energy driving environmental photosynthesis	J_1(%)	= k1*R*Fe	6.80E+19	J/yr	4	1.11
5	Solar energy driving agricultural photosynthesis	J_2 (%)	= k2*R*(Fa*AW)*(FF*S2)	3.40E+19	J/yr	2	9.47
6	Total production from the urban sector	Pu (g/yr)	= k3*(FF*S1)*(Fu*AW)	1.4E+13	g/yr	0.075	0.504
7	Total production from the agricultural sector	Pa (g/yr)	= k4*R*(FF*S2)*(Fa*AW)	8.7E+12	g/yr	0.045	0.215
8	Total production from the environment	Pe (g/yr)	= k5*R*Fe	1.92E+14	g/yr	1.0	0.277
9	Fraction of renewable water used in the urban sector	**Fu**	=1-Fa-Fe			0.053	
10	Fraction of renewable water used in the agricultural sector	**Fa**	=1-Fu-Fe			0.044	
11	Fraction of renewable water used by the environment	**Fe**	=1-Fa-Fu			0.903	
12	Fraction of FF used in the urban sector	**S1**	= 70% for initial conditions			0.14	
13	Fraction of FF used in the agricultural sector	**S2**	= 30% for initial conditions			0.06	
14	Fraction of exported urban products to imported goods	**k10**	= $exported u / $imported			2.2	
15	Fraction of exported ag. products to imported goods	**k11**	= $exported a / $imported			1.26	
16	Fraction of exported env. products to imported goods	**k12**	= $exported e / $imported			0.07	
17	Fraction of water allocated to Environment	**fal2E**	= 80% for initial conditions			0.8	
18	Available water (renewable fresh surface & ground water)	**AW**	= k6*Pe			0 to 1	
19	Index of total production in Florida	TP	= k14*(Pe*Pa*Pu)				
20	Index of tot. emergy-based production in Florida (empower)	TEP	= (Pe*te)+(Pa*ta)+(Pu*tu)				

Notes

1 Average insolation reaching Florida (J): 1.70 E21 J/yr (Odum et al., 1998; p. 395)

2 Albedo and remainder of insolation: assumed 40% of J

3 Total fuels, goods & services (imported & domestic) used by Florida (FF): 3.81 E23 sej/yr (Odum et al., 1998; p. 312).

4 Solar energy driving environmental photosynthesis: assumed 40% of J

5 Solar energy driving agricultural photosynthesis: assumed 20% of J

6 1999 Florida GSP: $380.6 E9 (Florida Statistical Abstract, 1999)
Assuming 85% of the GSP is generated by the urban sector: 0.85*3.8 E11 $/yr = 3.23 E11 $/yr
dividing by an avg. cost per weight of miscellaneous goods of 22.5$/kg (Brown, 1980): (3.23 E11$/yr)/(22.5$/1000 g) = 1.44 E13 g/yr

Notes for Table E-1--continued.

7 Total food and livestock feed produced in FL in 1998 = 1.74E13 g (Florida Agricultural Facts, 1999)
This value is assumed to be for wet biomass, thus divide by 2 to get dry g of agricultural biomass: 8.70E12 g/yr

8 (Area of FL: 1.50E11 m^2 from Fernald and Puerdum, 1996)*(avg. net production 3.5 g/m^2/day, assumed)*(356 day/yr) = 1.92 E14 g/yr

9 Renewable daily flow of fresh water in Florida: 150.0E9 gal/day (rain) + 25.0E9 gal/day (gw & surface water from GA & AL)
- 100.0E9 gal/day (ET) = 75.0E9 gal/day numbers from Fernald and Purdum (1996; p. 49)
Urban water use: 1.16E9 gal/day (surface water) + 2.81E9 gal/day (gw) = 3.97E9 gal/day from Fernald and Purdum (1998; p. 130)
Fraction of renewable water used in the urban sector (Fu): (3.97E9 / 75.0E9) = 0.053

10 Agricultural water use: 1.72E9 gal/day (surface water) + 1.53E9 gal/day (gw) = 3.25E9 gal/day from Fernald and Purdum (1998; p. 130)
Fraction of renewable water used in the agricultural sector (Fa): (3.25E9 / 75.0E9) = 0.044

11 Fraction of renewable water used by the environment (Fe): 1 - (0.053 + 0.044) = 0.903

12 Fraction of FF used in the urban sector: assumed 70% for initial conditions

13 Fraction of FF used in the agricultural sector: assumed 30% for initial conditions

14 Fraction of price of exported urban products to the price of imported goods, fuels and services:
$exported u = price for exported urban products, 5.0 E-6 $/cal (Constanza, 1979)
$imported = price of imported goods, fuels and services, 2.27 E-6 $/cal (Brown, 1980)
$exported u / $imported = 2.2

15 Fraction of exported agricultural products to the price of imported goods, fuels and services:
$exported u = price for exported urban products, 5.0 E-6 $/cal (Constanza, 1979)
$exported a = price for exported agricultural products, 2.86 E-6 $/cal (Constanza, 1979)
$exported a / $imported = 1.26

16 Fraction of exported forestry products to the price of imported goods, fuels and services:
$exported u = price for exported urban products, 5.0 E-6 $/cal (Constanza, 1979)
$exported e = price for exported forestry products (assuming they are equivalent to environmental services), 1.67 E-7 $/cal (Constanza, 1979)
$exported e / $imported = 0.07

17 fal2E = Fraction of water allocated to Environment from the water left after urban appropriation.
This constant was used to split the water left after urban appropriation between agriculture and the environment. To set the initial simulation conditions, it was assumed that the environment receives 80% and the ag sector 20% of the water letf after urban appropriation (i.e. fal2Eo = 0.8).

18 Water available (WA) = k6*Pu, where k6 is a constant to make WA = 1 when Fu equals 0% and WA = 0 when Fu equals 100%

19 Index of total production in Florida: k15*(Pe*Pa*Pu)

20 Index of total emergy-based production in Florida (empower): (Pu*tu + Pa*ta + Pe*te). The transformities used for calibration were: te=1, ta=100 and tu=1000. Although these are not transformities per se, these numbers are proportional to actual average transformities from each sector.

APPENDIX F

ENVIRONMENTAL IMPACTS OF POTABLE WATER PRODUCTION

Several environmental impacts for the public supply alternatives and small scale water purification systems evaluated are given in tables F-1 and F-2, respectively. The assumptions and estimates made to evaluate these impacts are provided in the notes below each table. The evaluated impacts shown in these tables were considered the most important, yet are only some of the possible impacts caused by the treatment processes.

Table F-1. Emergy evaluation of environmental impacts resulting from the production of potable water.

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E18 sej/yr)	Emergy (sej) per m^3 (E10)	Em\$/m^3 * year 2000 (Em\$/m^3)
West Palm Beach Water Treatment Facility							
1	Water extracted from the environment	J	1.9E+14	5.6E+04	10.96	28.25	0.31
2	Loss of ecosystem productivity	J	9.1E+13	9.0E+03	0.82	2.11	0.02
3	CO_2 emissions from electricity used	g	8.7E+09	5.28E+07	0.46	1.18	0.01
							0.35
Hillsborough River Water Treatment Plant							
4	Water extracted from the environment	J	4.5E+14	4.3E+04	19.2	22.51	0.25
5	Loss of ecosystem productivity	J	7.2E+13	9.0E+03	0.65	0.76	0.008
6	CO_2 emissions from electricity used	g	2.5E+10	5.28E+07	1.33	1.56	0.02
							0.27
Murphree Water Treatment Plant in Gainesville							
7	Water extracted from the environment	J	1.42E+14	1.66E+05	23.65	81.80	0.90
8	Loss of ecosystem productivity	sej	1.3E+17	-	0.13	0.46	0.01
9	CO_2 emissions from electricity used	g	1.5E+10	5.28E+07	0.81	2.81	0.03
							0.93
Water Conservation Program							
10	Solid waste from replaced materials	g	2.10E+09	9.20E+08	1.93	5.73	0.06
11	CO_2 emissions to run the program	g	4.2E+11	5.28E+07	22.15	65.79	0.72
							0.79
City of Dunedin RO Water Treatment Plant							
12	Water extracted from the environment	J	3.08E+13	1.53E+05	4.70	72.05	0.79
13	Loss of ecosystem productivity	sej	3.53E+16	-	0.04	0.54	0.01
14	CO_2 emissions from electricity used	g	6.4E+09	5.28E+07	0.34	5.18	0.06
							0.85
Tampa Bay RO Desalination Facility							
15	Rain water to dilute concentrate	J	1.70E+14	5.06E+03	0.86	2.48	0.03
16	CO_2 emissions from electricity used	g	1.1E+11	5.28E+07	5.84	16.91	0.19
							0.21
Florida Keys Aqueduct Authority							
17	Water extracted from the environment	J	9.6E+13	6.0E+04	5.78	34.78	0.38
18	Loss of Everglades productivity	sej	3.3E+18	-	3.30	19.85	0.22
19	CO_2 emissions from electricity used	g	1.5E+10	5.28E+07	0.81	4.88	0.05
							0.65
Stock Island RO Desalination Facility							
20	Rain water to dilute concentrate	J	2.03E+13	5.06E+03	0.10	2.47	0.03
21	CO2 emissions from electricity used	g	2.9E+10	5.28E+07	1.53	36.88	0.41
							0.43

* (sej/m^3) / (9.10 E11 sej/\$)

Notes for Table F-1

West Palm Beach

1 **Water extracted from the environment, J**

water pumped per year:	gals/yr	1.04E+10	(Blakeney, 2000)
Annual chemical energy or water used:	J/yr	1.94E+14	(gals/yr)(1 m^3/264.17 gals)(4.94 J/g)(1 E6 g/m^3)
Transformity of lake water:	sej/J	56,427	(Table 12)

2 **Loss of ecosystem productivity from maintaining high water levels in catchment area, J**

A 49.7 km^2 marshy catchment area supplies water to Lake Mangonia and Clear Lake, which supply the raw water to the treatment facility. It is assumed that by maintaining water levels relatively high in the catchmetn area the marsh often behaves as a shallow lake instead of a typical fresh water marsh with fluctuating seasonal hydroperiods. Therefore, it is assumed that the Net Primary Production (NPP) of the catchment area is 10% less than the original fresh water mash that did not received water from Lake Okeechobee (via the M-canal).

Catchment area:	m^2	4.97E+07	(City of West Palm Beach, 2000)
Fresh water marsh NPP:	g C/m^2/day	1.5	assume the same for *Juncus*
Fresh water marsh NPP:	J/m^2/yr	1.83E+07	(g C/m^2/day)(8 kcal/g C)(4186 J/kcal)(365 days/yr)
Assumed decrease in NPP:	%	10	assumed due to change in the marsh hydroperiod
NPP loss from hydroperiod change	J/yr	9.11E+13	(J/m^2/yr)(% / 100)(m^2)
Transformity:	sej/J	9,000	assumed the same as estuarine net production (Odum, 1996; p. 311)

3 **CO_2 emissions from electric power required for the treatment process, g**

Although CO_2 is not a contaminant per se, it is assumed that CO_2 emissions contribute to global warming, which could have very detrimental effects to the environment and society.

Electric power used for treatment:	kWh/yr	8.32E+06	(Blakeney, 2000)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	8.7E+09	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Hillsborough River Water Treatment Plant

4 **Water extracted from the environment, J**

water pumped per year:	gals/yr	2.44E+10	(HRWTP, 1996)
Annual energy:	J/yr	4.50E+14	(gals/yr)(1 m^3/264.17 gals)(4.88 J/g)(1 E6 g/m^3)
Transformity (river water):	sej/J	4.26E+04	(Table 11)

5 **Loss of ecosystem productivity from maintaining high water levels in catchment area, J**

The dam next to the water treatment plant stores water for treatment, yet has flooded approximately 1.23 km^2 of floodplain land within approximately 10 km upstream from the dam. The Hillsborough River floodplain vegetation is typically composed of mesic hardwoods, swamps, and hammocks with palmetto understor (Jue, 1989). It is assumed that the flooding of these land has decrease the productivity of the floodplain. This loss in productivity is assumed to be the difference between avg. river NPP and riparian swamp NPP.

Dam-induced flooded riparian swamp A:	m^2	1.22E+06	Estimated from quadrangle map (USGS., 1995)
Avg. NPP (dry grams) of streams:	g/m^2/yr	250	(Whittaker, 1975)
Avg. NPP (dry grams) of riparian swamps:	g/m^2/yr	2000	(Whittaker, 1975)
Loss in ecosystem production:	g/m^2/yr	1750	difference in NPP
Total loss in productivity b/c flooding:	g/yr	2.14E+09	(m^2) (g/m^2/yr)
Total loss in productivity b/c flooding:	J/yr	7.17E+13	(8 kcal/g)(4,186 J/kcal)(g/yr)
Transformity:	sej/J	9,000	assumed the same as estuarine net production (Odum, 1996; p. 311)

Notes for Table F-1--continued.

6 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	2.41E+07	(HRWTP, 1996)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	2.5E+10	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Murphree Water Treatment Plant in Gainesville

7 **Water extracted from the environment, J**

Env. impacts of groundwater extraction include soil subsidence, greater $CaCO_3$ dissolution, and reduced spring outflow.

Water pumped per year:	gals/yr	7.68E+09	(Murphree Water Treatment Plant, 1994)
Annual chemical energy of water:	J/yr	1.42E+14	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
Transformity:	sej/J	1.66E+05	(from Table 19)

8 **Expected loss in ecosystem productivity from lower water tables, sej**

Fischl (1994) modeled the drawdown of groundwater at the Murphree wellfield. The projected 1988 drawdowns at the center of the cone of depression were 1.1 and 45 ft for surficial and upper Floridan groundwater, respectively. The extension of land area affected by drawdowns from the surficial aquifer (i.e. water table) was estimated to be approximately 230 ha in 1988 (Fischl, 1994). It is assumed that lower water tables would decrease the average productivity of the pine flatwood ecosystem over the wellfields. The decrease in ecosystem productivity is assumed to equal 25% of the gross primary production (GPP) of the 230 ha of pine flatwoods.

GPP for pine flatwoods:	sej/ha/yr	2.30E+15	(Hodges, 1992)
Area of water table decrease:	ha	230	estimated from Fischl (1994)
Loss of productivity:	sej/yr	1.32E+17	(GPP)(Area of water table decrease)(25%)
Transformity:	-	-	since units are already in sej/yr

9 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	1.48E+07	(Murphree Water Treatment Plant, 1994)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	1.5E+10	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Water Conservation Program

10 **Solid waste generated from replacing appliances with water-efficient units, kg**

Tot. kg of appliances & materials replaced:	kg/yr	2.997E+06	(sum of items 2 to 7 in Table 27)
% of materials reused:	%	30	assumed
Total materials going to landfills:	g/yr	2.098E+09	(kg/yr)(1000 g/kg) * [(100- %)/100]
Emergy per mass of solid waste:		9.20E+08	assumed the same as scrap ferrous metals (Odum et al., 1987b).

Notes for Table F-1--continued.

11 **CO_2 emissions related to the water conservation program, g**

Avg. per capita time receiving water conservation info in the Bay area:	min/yr	10	assuming that on average each person spends 10 min. per year watching conservation propaganda on TV
1996 population affected by program:	people	1,786,500	(Ayres Associates, 1997; Chapter 2, p. 9)
Total hr of mass media reception:	hr/yr	1.49E+05	(min/yr)(hr/60 min)(people) (50%) 50% from assuming 2 people per TV set
CO_2 emissions per hr of TV watching:	g of CO_2	291	(Barnwell, 1990)
(a) Total CO_2 emissions from TVs:		4.33E+07	(hr/yr)(g of CO_2 / hr of TV)

Assuming 200 g of CO_2 are released for each kg of materials replaced (for manufacturing, delivery and installation of new units plus replacement and disposal of old units):

CO_2 emissions from replacement and installation of water saving units:	g CO_2/kg	200	assumed
(b) CO_2 emission from materials:	g of CO_2	4.20E+11	(200 g of CO_2 / kg of materials)(kg materials/yr, note 10)
Total CO_2 emissions:		4.20E+11	(a) + (b)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

City of Dunedin RO Water Treatment Plant

12 **Water extracted from the environment, J**

Env. impacts of groundwater extraction include soil subsidence, greater $CaCO_3$ dissolution, and reduced spring outflow.

Fresh groundwater extracted:	J/yr	3.40E+13	from Table 29
Fresh gw used for treatment (% of total)	%	90	(City of Dunedin, 1997)
Transformity (fresh groundwater):	sej/J	1.66E+05	gw from the Floridan aquifer, (Table 19)
Brackish groundwater extracted	J/yr	2.32E+12	from Table 29
Brackish gw used for treatment (% of total)	%	10	(City of Dunedin, 1997)
Transformity (brackish groundwater):	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)
Prorated average groundwater extracted:	J/yr	3.08E+13	(fresh J/yr)(% fresh) + (brackish J/yr)(% brackish)
Prorated transformity:	sej/J	1.53E+05	(fresh sej/J)(% fresh) + (brackish sej/J)(% brackish)

13 **Expected loss in ecosystem productivity from lower water tables, sej**

Assuming groundwater pumping lowers water tables proportionally to the murphree wellfield.

GPP for pine flatwoods:	sej/ha/yr	2.30E+15	(Hodges, 1992)
Area of water table decrease:	ha	61	(5.6 mgd/21 mgd)*(230 ha for Murphree's wellfield) 230 ha estimated from Fischl (1994)
Loss of productivity:	sej/yr	3.53E+16	(GPP)(Area of water table decrease)(25%)
Transformity:	-	-	since units are already in sej/yr

14 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	6.13E+06	(City of Dunedin, 1997)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	6.4E+09	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Tampa Bay RO Desalination Facility

Several studies have shown that there are no significant effects from discharging RO concentrate to seawater on seagrass beds and other benthic communities surrounding the areas of discharge (Hammond et al., 2000; Blake et al., 1996; Smith, 1995). Hammond et al. (2000) investigated the effects of disposing the concentrate discharge, from a 1.3 mgd RO facility in Antigua, on near shore benthic communities to evaluate the potential environmental impacts of Tampa Bays' desalination facility. The authors reported no significant signs of salinity build up and essentially no effect to seagrases, macroalgae, benthic foraminifera, benthic microalgae, and macrofauna from the concentrate discharge (1.8 mgd). Although the benthic community in Antigua (in the Caribbean) is similar to Florida's benthic community, the concentrate

Notes for Table F-1--continued.

discharge of the Antigua plant is only about 10% of the brine expected to be discharged by the Tampa facility. The study time lasted about 8 months, which may not represent long term effects of several years of brine discharge expected to occur in Tampa Bay. Furthermore, the shallow and poor mixing conditions of Tampa Bay may not resemble the mixing conditions of the study site in Antigua. Therefore, it is possible that the brine discharge can induce negative, long term, effect on the benthic community near the point of discharge. Nevertheless, based on this thorough study, it is assumed that no significant loss of benthic production will occur from discharging the RO concentrate in to Tampa Bay.

15 **Rain required to dilute the brine back to average TDS of seawater**

Qp = Permeate (product) water flow:	m^3/yr	3.5E+07	(Stone & Webster, 1999)
Plant recovery rate:	%	60	(Stone & Webster, 1999)
Qf = Feed (sea water) flowrate:	m^3/yr	5.76.E+07	Qp / (%/100)
Qc = Concentrate (brine) flowrate:	m^3/yr	2.3E+07	Qf * (1 - %/100)
Cp = TDS of Qp:	ppm	180	(Stone & Webster, 1999)
Cf = TDS of Qf:	ppm	26,000	(Big Bend site, Stone & Webster, 1999)
Cc = TDS of Qc:	ppm	64,730	(Qf*Cf)-(Qp*Cp) / Qc
		from mass balance:	(Qf)(Cf) = (Qc)(Cc) + (Qp)(Qp)
Cr = TDS of rain water:	ppm	10	Average rain water TDS
Qr = Rain needed to dilute the brine:	m^3/yr	3.43E+07	(Qc*Cc - Qc*Cf) / (Cf - Cr)

from mass balance: (Qr)(Cr)+(Qc)(Cc) = (Cf)(Qc+Qr), where Qc = concentrate flow;
Cc = concentrate concentration; and Cf = feed (seawater) flow

Chem. Potential energy of rain water:	J/yr	1.70E+14	Qr * (4.94 E6 J/m^3)
Transformity, chem. potential energy of rain:	sej/J	5.06E+03	chemical energy, rain on oceans (Table 9)

16 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	1.06E+08	(Stone & Webster, 1999)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	1.1E+11	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Florida Keys Aqueduct Authority

17 **Water extracted from the environment, J**

Env. impacts of groundwater extraction include soil subsidence, greater $CaCO_3$ dissolution, and reduced spring outflow.

Total gw pumped for treatment:	gal/yr	5.17E+09	(Malgrat & Doughtry, 1996)
Annual energy:	J/yr	9.60E+13	(gals/year)(1 m^3/264.17 gals)(4.9 J/g)(1E6 g/m^3)
Transformity:	sej/J	60,206	groundwater from the Biscayne aquifer, (Table 17)

18 **Expected loss in ecosystem productivity from lower water tables, sej**

Groundwater pumping near Florida City creates a cone of depression over the wellfield. Since the Biscayne aquifer is a surficial aquifer system, the cone of depression lowers water table over the entire area of this cone. It is assumed that low water tables would decrease the average productivity of the Everglades. The decrease in ecosystem productivity is assumed to equal 25% of the gross primary production over the cone of depression.

Cone of depression radius (r):	mi	4.5	estimated from a regional water table map
Impacted area:	m^2	1.65E+08	(3.1416)(r in mi)^2(2.592 E6 m^2/mi^2)
Emergy of Everglades:	sej/yr	6.480E+20	Total environmental emergy of Everglades National Park (Odum, 1996; p. 120)
Area of the Everglades:	m^2	3.240E+09	(Odum, 1996; p. 120)
Everglades empower density:	sej/m^2/yr	2.000E+11	(sej/yr) / (m^2)
Assumed loss of productivity:	sej/yr	3.30E+18	(25%)(sej/yr/m^2 of the Everglades)(impacted area m^2)
Transformity:	-	-	since units are already in sej/yr

Notes for Table F-1--continued.

19 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	1.47E+07	(Malgrat & Doughtry, 1996)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	1.5E+10	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

Stock Island RO Desalination Facility

Based on the studies of Hammond et al. (2000), Blake et al. (1996) and Smith (1995) it is assumed that no significant loss of benthic production occurred from Stock Island's concentrate discharge.

20 **Rain required to dilute the brine back to average TDS of seawater**

Qp = Permeate (product) water flow:	m^3/yr	4.1E+06	(Water Services, 1981)
Plant recovery rate:	%	30	(Water Services, 1981)
Qf = Feed (sea water) flowrate:	m^3/yr	1.38.E+07	Qp / (%/100)
Qc = Concentrate (brine) flowrate:	m^3/yr	9.7E+06	Qf * (1 - %/100)
Cp = TDS of Qp:	ppm	400	(Water Services, 1981)
Cf = TDS of Qf:	ppm	38,000	(Water Services, 1981)
Cc = TDS of Qc:	ppm	54,114	(Qf*Cf)-(Qp*Cp) / Qc
		from mass balance:	(Qf)(Cf) = (Qc)(Cc) + (Qp)(Qp)
Cr = TDS of rain water:	ppm	10	Average rain water TDS
Qr = Rain needed to dilute the brine:	m^3/yr	4.10E+06	(Qc*Cc - Qc*Cf) / (Cf - Cr)

from mass balance: (Qr)(Cr)+(Qc)(Cc) = (Cf)(Qc+Qr), where Qc = concentrate flow;
Cc = concentrate concentration; and Cf = feed (seawater) flow

Chem. Potential energy of rain water:	J/yr	2.0264E+13	Qr * (4.94 E6 J/m^3)
Transformity:	sej/J	5.06E+03	chemical energy, rain on oceans (Table 9)

21 **CO_2 emissions from electric power required for the treatment process, g**

Electric power used for treatment:	kWh/yr	2.77E+07	(Water Services, 1981)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	2.9E+10	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.3E+07	see note 22 for calculation of CO_2 sej/g

22 **Calculation of emergy per mass of carbon dioxide, sej/g**

It is assumed that global CO_2 in the atmosphere is a co-product of the global empower base (9.44 E24 sej/yr).

Biosphere to atmosphere CO_2 flux	E15 g/yr	60	(Miller and Thompson, 1970; p. 7)
Oceans to atmosphere CO_2 flux:	E15 g/yr	100	(Miller and Thompson, 1970; p. 7)
Man's contribution to atmosph. CO_2	E15 g/yr	15.8	adapted from Miller and Thompson (1970; p. 7)
		to reflect a 2.63 increase in anthropogenic CO_2 emissions between 1965 (Miller and Thompson, 1970) and current (2000) emissions.	
CO_2 into atm. from cultivated land:	E15 g/yr	3.0	adapted from Miller and Thompson (1970; p. 7)
Total flux of CO_2 to the atmosphere:	E15 g/yr	179	sum
Global empower base:	E24 sej/yr	9.44	(Odum, 1996)
Global emergy per mass of CO_2:	sej/g	5.28E+07	(sej/yr) / (g/yr)

Table F-2. Emergy evaluation of environmental impacts resulting from the small scale production of potable water.

Note	Item	Unit	Energy Data (unit/year)	Emergy per unit (sej/unit)	Solar Emergy (E12 sej/yr)	Emergy (sej) per m^3 (E12)	Em$/$m^3$* year 2000 (Em$/m^3)
Home filtration							
1	Water extracted from the environment	J	6.8E+07	1.5E+05	9.86	0.71	0.78
2	Loss of ecosystem productivity	sej	6.3E+10	-	0.06	0.005	0.01
							0.79
Boiling water							
3	Water extracted from the environment	J	1.5E+07	1.46E+05	2.17	0.78	0.86
4	Loss of ecosystem productivity	sej	1.4E+10	-	0.01	0.01	0.01
5	CO_2 emissions from electricity used	g	3.3E+05	5.28E+07	17.37	6.29	6.91
							7.78
Advanced Solar distillation							
6	Water extracted from the environment	J	1.68E+08	3.19E+04	5.36	0.98	1.08
7	CO_2 emissions from electricity used	g	2.4E+05	5.28E+07	12.59	2.30	2.53
8	Loss of ecosystem productivity	sej	4.1E+11	-	0.41	0.08	0.08
							3.69
Traditional solar distillation							
9	Water extracted from the environment	J	2.99E+06	3.19E+04	0.10	0.09	0.10
10	Loss of ecosystem productivity	sej	7.8E+11	-	0.78	0.74	0.81
							0.91
Bottled Water							
11	Water extracted from the environment	J	1.84E+12	1.66E+05	305,939	16.40	18.03
12	CO_2 emissions from diesel combustion	J	1.07E+09	5.28E+07	56,683	3.04	3.34
13	CO_2 emissions from electricity used	g	2.0E+08	5.28E+07	10,559	0.57	0.62
							21.99

* (sej/m^3) / (9.10 E11 sej/$)

Notes

Home filtration

1 **Water extracted from the environment, J**

Potable water produced per year:	gals/yr	3,650	(Culligan, 2000)
Annual chemical energy of water used:	J/yr	6.77E+07	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
Transformity:	sej/J	1.46E+05	assumed = avg. groundwater in FL (Table 20)

2 **Expected loss in ecosystem productivity from lower water tables, sej**

Assuming groundwater pumping lowers water tables proportionally to the Murphree wellfield (Table F-1, note 8).

GPP for pine flatwoods:	sej/ha/yr	2.30E+15	(Hodges, 1992)
Groundwater used:	gals/yr	3,650	(Culligan, 2000)
Groundwater used:	mgd	1.00E-05	(gal/yr)(yr/365 days)(1E-6 gal/day / mgd)
Area of water table decrease:	ha	1.10E-04	(1E-5 mgd/21 mgd)*(230 ha)
			230 ha for Murphree plant's wellfield, estimated from Fischl (1994)
Loss of productivity:	sej/yr	6.30E+10	(GPP)(Area of water table decrease)(25%)
Transformity:	-	-	since units are already in sej/yr

Notes for F-2--continued.

Boiling

3 **Water extracted from the environment, J**

Groundwater boiled per year:	gals/yr	803	(2.2 gal/day)(365 day/yr)
Annual chemical energy of water used:	J/yr	1.49E+07	(gals/yr)(1 m^3/264.17 gals)(4.90 J/g)(1 E6 g/m^3)
Transformity:	sej/J	1.46E+05	assumed = avg. groundwater in FL (Table 20)

4 **Expected loss in ecosystem productivity from lower water tables, sej**

Assuming groundwater pumping lowers water tables proportionally to the Murphree wellfield (Table F-1, note 8).

GPP for pine flatwoods:	sej/ha/yr	2.30E+15	(Hodges, 1992)
Groundwater used:	gals/yr	803	(2.2 gal/day)(365 day/yr)
Groundwater used:	mgd	2.20E-06	(gal/yr)(yr/365 days)(1E-6 gal/day / mgd)
Area of water table decrease:	ha	2.41E-05	(2.21E-6 mgd/21 mgd)*(230 ha)
			230 ha for Murphree plant's wellfield, estimated from Fischl (1994)
Loss of productivity:	sej/yr	1.39E+10	(GPP)(Area of water table decrease)(25%)
Transformity:	-	-	since units are already in sej/yr

5 **CO_2 emissions from electric power required for the treatment process, g**

Although CO_2 is not a contaminant per se, it is assumed that CO_2 emissions contribute to global warming, which could have very detrimental effects to the environment and society.

Electric power to boil water:	kWh/yr	3.15E+02	from Table 41
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	3.29E+05	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.28E+07	from Table F-1, note 22

Solar distillation (hum/dehum)

6 **Water extracted from the environment, J**

Energy of salty water used:	J/yr	1.68E+08	from Table 43, note 2
Transformity:	sej/J	3.19E+04	Assume = to intertidal waters (Table 10)

7 **CO_2 emissions from electric power required for pumping salty water, g**

Electric power used to pump salty water:	kWh/yr	2.28E+02	from Table 43, note 5
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	2.38E+05	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.28E+07	from Table F-1, note 22

8 **Loss of ecosystem productivity**

Since the freshwater conversion efficiency from salty water is only about 5% for this solar distiller (Nawayseh et al., 1997; p. 283) the concentration of the brine is only slightly higher than the input water. Thus, it is assumed that no decrease in ecosystem production results from the brine byproduct generated by this water purification system. However, it is assumed that the area under the solar collector will lose 90% of its GPP.

Land productivity:	sej/ha/yr	2.30E+15	assumed the same as pine flatwoods (Hodges, 1992)
Land productivity:	sej/m^2/yr	2.3E+11	(sej/ha/yr)/(1000 m^2/ha)
GPP loss from solar collector:	sej/yr	4.14E+11	(sej/m^2/yr)(2.0 m^2)(0.9)
Transformity:	-	-	since units are already in sej/yr

Notes for F-2--continued.

Solar distillation

9 **Water extracted from the environment, J**

Energy of salty water used:	J/yr	2.99E+06	from Table 45, note 2
Transformity:	sej/J	3.19E+04	Assume the same as intertidal waters (Table 10)

10 **Loss of ecosystem productivity**

It is assumed that the brine byproduct leaving the solar still is discarded by simply throwing it to the ground adjacent to the solar still, thus stressing plants on the affected area. It is assumed that 50% of the GPP over this area is lost due to the high salinity of the brine. Furthermore, it is assumed that the area underneath the distiller loses 90% of its GPP.

Land productivity:	sej/ha/yr	2.30E+15	assumed the same as pine flatwoods (Hodges, 1992)
Land productivity:	sej/m^2/yr	2.3E+11	(sej/ha/yr)/(1000 m^2/ha)
impacted land area:	m^2	5.0	(estimated from the brine volume produced)
(a) GPP loss from impacted area:	sej/yr	5.75E+11	(sej/m^2/yr)(5.0 m^2)(0.5)
(b) GPP loss from the distiller area:	sej/yr	2.07E+11	(sej/m^2/yr)(1.0 m^2)(0.9)
Toal GPP loss:	sej/yr	7.82E+11	(a) + (b)
Transformity:	-	-	since units are already in sej/yr

Bottled Water

11 **Water extracted from the environment, J**

Culligan's bottling Co. uses 100 L of tap water to produce just 5 L of bottled water. This is because their RO recovery rate is just 5% to reduce power costs to operate the RO units (Swanson, 2000). Although tap water (e.g. drinking water) from the city of Ocala is used as the water source, the water extracted from the environment is groundwater (from the Floridan aquifer system). Therefore, the transformity used is that of groundwater from the Floridan aquifer instead of drinking water.

Avg. daily bottled water produced:	gal/day	1.4E+04	(Swanson, 2000)
RO recovery rate:	%	5.0	(Swanson, 2000)
Avg. daily tap water used:	gpd	270,000	(gpd)/(%recovery)*100
Annual energy:	J/yr	1.84E+12	(gals/day)(365 day/yr)(1 m^3/264.17 gals) *(4.94 J/g)(1 E6g/m^3)
Transformity:	sej/J	1.66E+05	(Table 19) groundwater, Floridan aquifer

12 **CO_2 emissions from diesel combustion during the delivery of bottled water, g**

Total diesel used :	gal/yr	107,852	From Table 47, note 5.
Total diesel used :	L/yr	408,219	(gal/yr) (3.785 L/gal)
CO_2 emissions per L of combusted diesel:	g of CO_2	2,630	(Greenpeace.org, 2001)
CO_2 emissions from diesel combustion:	g/yr	1.07E+09	(L of diesel / yr)(g of CO_2 / L of diesel)
Emergy per mass of CO_2:	sej/g	5.28E+07	from Table F-1, note 22

13 **CO_2 emissions from electric power required for the treatment process, g**

Electricity to produced bottled water:	kWh/yr	1.91E+05	(Swanson, 2000)
CO_2 emissions per kWh:	g of CO_2	1,045	for coal power plants (Barnwell, 1990)
CO_2 emissions from electricity used:	g/yr	2.00E+08	(kWh/yr)(g of CO_2/kWh)
Emergy per mass of CO_2:	sej/g	5.28E+07	from Table F-1, note 22

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BIOGRAPHICAL SKETCH

Andrés Antonio Buenfil was born in Mexico City on October 23, 1971. Andrés has a bachelor's degree in civil engineering (with an environmental engineering concentration) and a minor in anthropology from the University of South Florida in Tampa. He obtained a Master of Engineering degree in the Energy Analysis/Systems Ecology Program of the Environmental Engineering Sciences Department at the University of Florida (UF). He was nominated for a Graduate Assistance in Areas of National Need (GAAN) Fellowship for his doctoral research, which was conducted in collaboration with the Center for Wetlands and Water Resources, also at UF. In the summer of 1998 he was selected to participate in the Young Scientist Summer Program of the International Institute of Applied Systems Analysis, in Austria, where he conducted research on environment and population issues in southern Africa. His research interests include ecological engineering, wetlands ecology, ecological restoration, sustainable management, energy analysis and systems ecology