EMERGY SYNTHESIS 2:
Theory and Applications of the Emergy Methodology

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An environmental accounting of water resources production system in the Samoggia creek area using emergy method

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ABSTRACT

The purpose of this study was to evaluate the real value of water resources of a specific area using emergy analysis. Emergy has the ability to calculate different types or quality of energy in one form, the solar emergy joule. Therefore, products and services are evaluated on the environmental efforts necessary to generate them.

First part of the study is focused on an analysis of the natural resources. We evaluated the emergy flow that supports local surface water, calculating the environmental inputs that are necessary to sustain the Samoggia Creek. Groundwater reservoirs are also present in the area. Transformities reported in literature are based on global processes. In the present study, to better evaluate local resources, we suggest a new method for calculating them case by case. The new method considers as primary variables the recharge time of the storage and the watershed area necessary for its direct refill.

The last part of the study consisted of an emergy analysis of the domestic water distribution system of the six municipalities present in the area in order to underline the role of nonrenewable inputs in the production of potable water. We consider all products and services necessary to extract water from reservoirs, to treat it and to provide it to consumers.

Results obtained were translated in Emlire values through the emergy money ratio. By transforming the solar emergy joules in economical values, Emlire, we obtained a value that takes into account environmental works. The result, since it is not based on traditional economic rules, shows the real value of water in different realities.

INTRODUCTION

The concept of sustainable development applied to water resources management should consider water as the most precious resource in the whole planet. Water is essential not only for human primary necessities and other activities that support our survival (e.g., agriculture) but, water is the essential element to life on earth. Water is usually considered a “free” resource with little or no value because of its availability.

Sustainability applied to water resources should consider efforts toward reducing pumping from natural storage, toward reintroducing water as near as possible to its extracting zones and with characteristics as similar as possible to natural ones. Most frequently, values of natural resources are based upon their commercial value, not taking into account the environmental services necessary to make them available for our needs.

In this study, in order to assess the environmental contribution, we apply emergy analysis, first to natural water sources and then to a potable water distribution system. This allows us to obtain a comprehensive value of material and energy flows required to produce water, and make it accessible for human consumption.

The system we analysed for the evaluation of the sustainability of water resources management is the area of the Samoggia River, in the Province of Bologna (Italy).
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METHODS

Description of the System

Samoggia creek mountain water basin extends over 29 km encompassing 170 km² on the west side of the Bologna province (central Italy). The area includes six municipalities and is characterized by hill and pre-apennine geography. In this area the Samoggia creek is not artificially constrained. The area is scarcely populated, dependent mainly on agriculture and not stressed by productive activities.

Water consumption in year 1999 was $9.05 \times 10^6$ m³ (3.54 x $10^6$ m³ (39%) for domestic use, 3.75 x $10^6$ m³ (41%) for industrial use and 1.76 x $10^6$ m³ (20%) for agriculture (Province of Bologna, 2000). Samoggia creek itself and its minor tributaries supply most of agricultural water demand. Industry satisfies its demand from a variety of small groundwater reservoirs within the system boundaries. The most important groundwater resource in the area is located in the Bazzano municipality along the Panaro River delta and is extracted only for domestic use.

System Diagrams and Emergy Table

The system is diagrammed by using energy systems language. Connection between natural and artificial system in the use and management of water are shown in Figure 1. The main flows and storages and their variables are then evaluated and presented in the emergy tables.

Data reported in the tables were obtained from technical reports, literature, personal interviews and, when necessary, from assumptions established in accordance with experts supervising the area. Explanations of the assumptions are indicated in tables.

An accurate mass balance of the supply pipeline, and of the sand that covers it, was performed. The results are listed in the emergy table.

Emergy tables, representing both natural system (surface and ground water) and the artificial

![Figure 1. Energy system diagram of Samoggia creek mountain basin area. Systems not evaluated in the emergy analysis are colored in gray.](image-url)
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one, were made listing inputs from the system diagrams. Each input was multiplied by its transformity (or emergy-per-unit) in order to convert it in solar emergy joules. Transformities (or emergy-per-unit) reported in the tables are taken from literature, calculated in the present work or calculated in a previous work (Bastianoni, 2001) (full calculations are available from the authors).

**Emmoney Evaluation**

The final part of the analysis consisted in translating flows of solar emjoule in economic value by dividing the emergy value of environmental services by the emergy money ratio index. Due to the unavailability of the total emergy flow through the area, the index used is referred to the Province of Modena, a Province very similar to Bologna’s. The index represents the total emergy used in driving the economy of the area in year 1999. The emergy values are expressed as \( \text{emlire} \) to provide units more familiar with the public and to compare them with the commercial costs of the services in the area.

**RESULTS AND DISCUSSION**

Figure 1 is an overview of the energy system diagram of the Samoggia creek mountain basin area. Natural and artificial systems are kept separated and their interaction is clearly demonstrated. Emergy analysis was carried out first on the natural flows and storage of water resources within the system boundaries. The results obtained were then reported in the analysis of the potable water distribution system.

**Superficial Aquifer Analysis**

The emergy evaluation of the Samoggia creek was achieved by calculating all the inputs necessary to support the system: solar energy, rain, deep earth heating and spring water (Table 1). The watershed covers 170 km\(^2\), a semi-permeable surface that collects precipitation to the water stream. Emergy flows through the territory due to the Samoggia creek were calculated at 1.80x10\(^{19}\) sej/year.

The output of the system is the amount of water that flows every year in the river, 5.93x10\(^{7}\) m\(^3\) (Table 1). The main emergy input to the territory is rain. This is because the amount of water flowing in the Samoggia creek mainly depends on precipitation collected by its watershed.

**Table 1.** Emergy evaluation of the Samoggia creek surface water (see footnotes for detailed calculations).

<table>
<thead>
<tr>
<th>Item</th>
<th>Raw unit</th>
<th>Unit</th>
<th>Solar Transformity (sej/unit)</th>
<th>Emergy Flow (sej/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Insolation</td>
<td>5.60x10(^{17})</td>
<td>J</td>
<td>1</td>
<td>5.60x10(^{17})</td>
</tr>
<tr>
<td>2 Precipitation</td>
<td>7.90x10(^{14})</td>
<td>J</td>
<td>1.82x10(^{4})</td>
<td>1.44x10(^{19})</td>
</tr>
<tr>
<td>3 Earth heat</td>
<td>5.36x10(^{14})</td>
<td>J</td>
<td>6.01x10(^{5})</td>
<td>3.22x10(^{18})</td>
</tr>
<tr>
<td>4 Spring water</td>
<td>1.09x10(^{13})</td>
<td>J</td>
<td>4.10x10(^{4})</td>
<td>4.47x10(^{17})</td>
</tr>
<tr>
<td>Total emergy</td>
<td></td>
<td></td>
<td></td>
<td>1.80x10(^{19})</td>
</tr>
<tr>
<td>5 Surface water</td>
<td>5.93x10(^{13})</td>
<td>g</td>
<td>3.04x10(^{5})</td>
<td></td>
</tr>
</tbody>
</table>
Emergy per mass was found to be $3.04 \times 10^5$ sej/g, which is comparable to the value in Odum 2000 ($4.00 \times 10^5$ sej/g) even though the two values were calculated at local and global scales.

**Potable Water Distribution System**

Water extractions within the area ($7.15 \times 10^5$ m$^3$) satisfy only 20% of the total domestic water uses ($3.52 \times 10^6$ m$^3$). The local distribution network (707 km), which is a subsystem of the Bologna aqueduct (6.3 km), directly provides the main part of the water demand of the area.

Emergy evaluation of the aqueduct supplying potable water in the Samoggia area is presented in Table 2. Local extractions mainly depend on groundwater. The $2.00 \times 10^5$ m$^3$ of surface water was evaluated by applying emergy per mass value obtained in this analysis. To avoid double counting, only 20% of goods and services were included in the analysis, since the emergy per mass of imported water ($1.78 \times 10^6$ sej/g) from the Bologna aqueduct already includes such inputs.

The emergy per mass estimated at $2.16 \times 10^6$ sej/g, represents the emergy flow that supports extraction, treatment and distribution of drinking water.

**Em£ Evaluation**

Emergy flows calculated in Tables 1 and 2 were translated into Em£ values by using the emergy money ratio of the Modena Province in 1999 ($7.26 \times 10^8$ sej/£). Results are shown in Table 3. The emvalue of potable water per m$^3$ is $2,973$ Em£, a value that is almost seven times higher than superficial water ($418$ Em£/m$^3$). The difference is due to the nonrenewable resources that are used to make water available for human consumption. On the other hand, the large amount of water flow in the Samoggia river ($5.93 \times 10^7$ m$^3$/year), compared with domestic use ($3.54 \times 10^6$ m$^3$/year), results in a higher final emlire value for surface water ($24.79$ and $8.42$ billions of Em£, respectively).

In 1999 the price of drinking water in the area was $1,483$ £ per cubic meter, about half of the emvalue calculated in this study. Policy makers are presently discussing to revise such price in order to reduce consumption of potable water.

**Ground Water Resources Analysis**

Hereafter we suggest a revised method for calculation of groundwater transformity, since literature value ($4.10 \times 10^4$ sej/J) (Brown and Arding, 1991) is based on global processes and not evaluated locally.

Natural maintenance of a reservoir mainly depends on two parameters: precipitation on land and water amount of superficial aquifers on the corresponding drainage area. Precipitation causes a rise of water table, while superficial aquifers can both receive or confer water to the underground storage. Both events occur with a time delay, as is shown in Figure 1, with small boxes on the pathways.

In overall water balances, the flow domain is considered to be vertical, from the soil surface to the impermeable base of the groundwater reservoir (Boonstra, 1995). As a result water table level is dependent on soil porosity and on the extension of the permeable area to which precipitation and superficial aquifer flow. The last important variable for the formation and maintenance of a reservoir, is the time required to fill it once extractions are carried out (turnover time of recharge), since natural refills occur with a time delay.

Inputs of the system therefore are: rain on the drainage area, amount of water carried by the
superficial stream in the area and sedimentary materials that filtrate water. Those inputs must be considered for every year necessary to recharge the aquifer. The output is quantity of groundwater in the reservoir.

**Table 2.** Emergy evaluation of the system supplying potable water in the Samoggia area, Italy. See footnotes for detailed calculations and text for full explanation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Raw unit</th>
<th>Unit</th>
<th>Solar Transformity (sej/unit)</th>
<th>Emergy flow (sej/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface water</td>
<td>2.00x10^{11}</td>
<td>g</td>
<td>3.04x10^5</td>
<td>6.08x10^{17}</td>
</tr>
<tr>
<td>Ground water</td>
<td>2.54x10^{12}</td>
<td>J</td>
<td>4.10x10^4</td>
<td>1.05x10^{17}</td>
</tr>
<tr>
<td>Imported water (Bologna aqueduct)</td>
<td>2.83x10^{12}</td>
<td>g</td>
<td>1.78x10^6</td>
<td>5.03x10^{18}</td>
</tr>
<tr>
<td>2 Pipeline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyethylene</td>
<td>1.58x10^6</td>
<td>g</td>
<td>5.87x10^9</td>
<td>9.30x10^{15}</td>
</tr>
<tr>
<td>Asbestos cement</td>
<td>2.70x10^6</td>
<td>g</td>
<td>1.54x10^9</td>
<td>4.16x10^{15}</td>
</tr>
<tr>
<td>Steel</td>
<td>7.06x10^6</td>
<td>g</td>
<td>4.65x10^9</td>
<td>3.28x10^{16}</td>
</tr>
<tr>
<td>PVC</td>
<td>7.61x10^4</td>
<td>g</td>
<td>5.85x10^9</td>
<td>4.45x10^{14}</td>
</tr>
<tr>
<td>Pig iron1.</td>
<td>62x10^6</td>
<td>g</td>
<td>2.65x10^9</td>
<td>4.29x10^{15}</td>
</tr>
<tr>
<td>Other</td>
<td>4.22x10^5</td>
<td>g</td>
<td>3.91x10^9</td>
<td>1.65x10^{15}</td>
</tr>
<tr>
<td>3 Electricity</td>
<td>1.98x10^{12}</td>
<td>J</td>
<td>1.43x10^5</td>
<td>2.83x10^{17}</td>
</tr>
<tr>
<td>4 Fuels</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasoline</td>
<td>2.61x10^{11}</td>
<td>J</td>
<td>6.60x10^4</td>
<td>1.72x10^{16}</td>
</tr>
<tr>
<td>Diesel</td>
<td>6.47x10^{11}</td>
<td>J</td>
<td>6.60x10^4</td>
<td>4.27x10^{16}</td>
</tr>
<tr>
<td>5 Machinery</td>
<td>1.48x10^6</td>
<td>g</td>
<td>6.70x10^9</td>
<td>9.90x10^{15}</td>
</tr>
<tr>
<td>6 Human Labour</td>
<td>5.28x10^9</td>
<td>J</td>
<td>7.38x10^6</td>
<td>3.90x10^{16}</td>
</tr>
<tr>
<td>7 Tanks (concrete)</td>
<td>4.04x10^7</td>
<td>g</td>
<td>1.54x10^9</td>
<td>6.22x10^{16}</td>
</tr>
<tr>
<td>8 Sand surface</td>
<td>4.23x10^8</td>
<td>g</td>
<td>1.00x10^9</td>
<td>4.23x10^{17}</td>
</tr>
<tr>
<td>Total emergy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Potable water</td>
<td>2.83x10^{12}</td>
<td>g</td>
<td>2.16x10^6</td>
<td></td>
</tr>
</tbody>
</table>

Footnotes can be found at end of chapter.

Transformity, or emergy-per-mass, can be evaluated as:

\[
\tau_x = \frac{\text{Emergy flow (water + sedimentary materials) \times turnover time}}{\text{water in the aquifer}}
\]

If we consider different aquifers bearing the same amount of water we will likely obtain higher transformity when:
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- Drainage area is larger and
- Turnover time of recharge is greater.

Therefore this method is strictly dependent on location and landscape characteristics. Due to the unavailability of the required set of local data, only a theoretical approach is presented here. Groundwater transformity used in the previous calculations is taken from literature.

Table 3. Em£ evaluation of the Samoggia creek and of local drinking water distribution facilities (see footnotes for detailed calculations).

<table>
<thead>
<tr>
<th></th>
<th>Samoggia creek</th>
<th>Potable water supply system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emery flow (sej/year)</td>
<td>$1.80 \times 10^{19}$</td>
<td>$6.11 \times 10^{18}$</td>
</tr>
<tr>
<td>Emliire value (billions of Em£)</td>
<td>24.79</td>
<td>8.42</td>
</tr>
<tr>
<td>Value per m$^3$ (Em£/m$^3$)</td>
<td>418</td>
<td>2,973</td>
</tr>
<tr>
<td>Current price in 1999 (£/m$^3$)</td>
<td></td>
<td>1,483</td>
</tr>
</tbody>
</table>

Footnotes can be found at end of chapter.

Once the required set of data would be available we could apply the Em£ evaluation, as reported in Table 3, in order to estimate the real value of groundwater resources and to compare it with commercial value currently given to them.

CONCLUSIONS

A deep knowledge of all materials and energy sources that support either natural or artificial cycle is fundamental for a sustainable management of water resources. Results demonstrate how the natural cycle is strictly dependent on renewable environmental energy sources, and, on the other hand, how the artificial cycle is strictly dependent on nonrenewable resources. In this way reducing consumption of drinking water means preventing waste of energy.

Preserving water storage from pollutants becomes more important if we consider the use of nonrenewable resources in treatment process. Even though groundwater transformity has not been fully calculated we expect it to be higher than that of surface water, a result mainly triggered by the time period involved in the maintenance of the reservoir. Higher transformity would also be in accordance with the higher quality of groundwater.

Non renewable inputs required in producing drinking water can be reduced if:

1. the quality of extracted water is high (treatment processes will require less inputs);
2. leaks in distribution system are minimized (more output);
3. extractions are as close as possible to consumers (less distribution facilities).

REFERENCES


Footnotes to Table 1.

1) Insolation
Solar insolation on Samoggia watershed = 1.70x10^8 [m², watershed area] (Hydrological annals, 1978/79) x 4.12x10^9 [J/m², insulation] (Geophysical observatory, Italy) x (1-0.2) [% albedo given as decimal] (Henning, 1989) = 5.60x10^17 J. Solar transformity by definition 1 sej/J.

2) Rain
Precipitation on area = 1.70x10^8 m² [m², watershed area] (Hydrological annals, 1978/79) x 0.94 [m, mean annual rainfall] (ARPA, environmental protection agency Italy; personal communication) x 4.94 [J/g, Gibb’s free energy] = 7.90x10^14 J. Solar transformity from Odum (1996).

3) Earth heat
Earth heat energy on area = 1.70x10^8 m² [m², watershed area] (Hydrological annals, 1978/79) x 3.15x10^6 [J/m², heat flow per area] (Loddo and Mongelli, 1978) = 5.36x10^14 J. Solar transformity from Odum (1996).

4) Spring water
Energy of spring water in river = 2.21x10^6 [m³, amount of water] (our estimate) x 1.00x10^6 [g/m³, water density] x 4.94 [J/g, Gibb’s free energy] = 1.09x10^13 J. Solar transformity groundwater from Brown and Arding (1991).

5) River water
Quantity of water in the Samoggia creek = 1.88 [m³/s, mean annual river flow] (Hydrological annals, 1978/79) x 3.16x10^7 [s/yr, second per year] x 1.00x10^6 [g/m³, water density] = 5.93x10^13 g.

Footnotes to Table 2.

1) Water
• Quantity of water extraction from surface aquifer = 2.00x10^5 [m³, amount of water] (Seabo, Province of Bologna Energy Supplying Company) x 1.00x10^6 [g/m³, water density] = 2.00x10^11 g. Solar energy per mass resulting from calculations in this work.
• Quantity of water extraction from groundwater aquifer = 5.15x10^5 [m³, amount of water] (Seabo) x 1.00x10^6 [g/m³, water density] x 4.94 [J/g, Gibb’s free energy] = 2.54x10^12 J. Solar transformity from Brown and Arding (1991).
• Quantity of water imported from the bologna aqueduct = 2.83x10^6 [m³, amount of water] (Seabo) x 1.00x10^6 [g/m³, water density] = 2.83x10^12 g. Solar energy per mass from Bastianoni et al. (2001).

2) Pipeline
water resources = 20.2% of $7.84 \times 10^6$ g = $1.58 \times 10^6$ g. Solar energy per mass from Buranakarn (1998).

- Asbestos cement mass in pipeline = $2.85 \times 10^4$ [m, pipeline length] (Seabo) x $2.34 \times 10^4$ [g/m, mean mass per meter of pipeline] (aqueduct mass balance) / $50$ [yr, pipes lifetime] (our estimate) = $1.34 \times 10^7$ g. Amount of input referred to local water resources = 20.2% of $1.34 \times 10^7$ g = $2.70 \times 10^6$ g. Solar energy per mass for concrete from Buranakarn (1998).

- Steel mass in pipeline = $2.40 \times 10^5$ [m, pipeline length] (Seabo) x $7.28 \times 10^3$ [g/m, mean mass per meter of pipeline] (aqueduct mass balance) / $50$ [yr, pipes lifetime] (our estimate) = $3.49 \times 10^7$ g. Amount of input referred to local water resources = 20.2% of $3.49 \times 10^7$ g = $7.06 \times 10^6$ g. Solar energy per mass from Odum (1983).

- PVC mass in pipeline = $1.15 \times 10^4$ [m, pipeline length] (Seabo) x $1.64 \times 10^3$ [g/m, mean mass per meter of pipeline] (aqueduct mass balance) / $50$ [yr, pipes lifetime] (our estimate) = $2.77 \times 10^6$ g. Amount of input referred to local water resources = 20.2% of $2.77 \times 10^6$ g = $5.64 \times 10^5$ g. Solar energy per mass from Buranakarn (1998).

- Pig iron mass in pipeline = $1.05 \times 10^4$ [m, pipeline length] (Seabo) x $3.82 \times 10^4$ [g/m, mean mass per meter of pipeline] (aqueduct mass balance) / $50$ [yr, pipes lifetime] (our estimate) = $8.02 \times 10^6$ g. Amount of input referred to local water resources = 20.2% of $8.02 \times 10^6$ g = $1.62 \times 10^6$ g. Solar energy per mass from Buranakarn (1998).

- Unknown = $2.10 \times 10^4$ [m, pipeline length] (Seabo) x $4.93 \times 10^3$ [g/m, mean mass per meter of pipeline] (aqueduct mass balance) / $50$ [yr, pipes lifetime] (our estimate) = $2.09 \times 10^6$ g. Amount of input referred to local water resources = 20.2% of $2.09 \times 10^6$ g = $4.22 \times 10^5$ g. Solar energy per mass evaluated as an average of aqueduct materials.

3) Electricity

Electricity used = $9.80 \times 10^{12}$ J (Seabo). Amount of input referred to local water resources = 20.2% of $9.80 \times 10^{12}$ J = $1.98 \times 10^{12}$ J. Solar transformity from Bastianoni et al. (2000).

4) Fuel

- Energy content of gasoline used = $4.00 \times 10^3$ [l, fuel] (Seabo) x $734$ (g/l, gasoline density) x $4.40 \times 10^5$ [J/g, net calorific value] = $1.29 \times 10^{12}$ J. Amount of input referred to local water resources = 20.2% of $1.29 \times 10^{12}$ J = $2.61 \times 10^{11}$ J. Solar transformity from Odum (1996).

- Energy content of diesel used = $9.00 \times 10^3$ [l, fuel] (Seabo) x $833$ (g/l, diesel density) x $4.27 \times 10^5$ [J/g, net calorific value] = $3.20 \times 10^{12}$ J. Amount of input referred to local water resources = 20.2% of $3.20 \times 10^{12}$ J = $6.47 \times 10^{11}$ J. Solar transformity from Odum (1996).

5) Machinery

- Steel content in cars = 9 [cars number] (Seabo) x $7.15 \times 10^5$ [g, car mass] (Seabo) x $0.95$ [steel content as percentage] / $15$ [yr, lifetime] (our estimate) = $4.08 \times 10^5$ g.

- Steel content in trucks = 11 [trucks number] (Seabo) x $3.50 \times 10^6$ [g, truck mass] (Seabo) x $0.95$ [steel content as percentage] / $15$ [yr, lifetime] (our estimate) = $2.44 \times 10^6$ g.

- Steel content in pumps = 39 [pumps number] (Seabo) x $1.00 \times 10^6$ [g, pump mass] (Seabo) / $15$ [yr, lifetime] (our estimate) = $2.60 \times 10^6$ g.

- Steel content in tractors = 7 [tractors number] (Seabo) x $4.00 \times 10^6$ [g, tractor mass] (Seabo) / $15$ [yr, lifetime] (our estimate) = $1.87 \times 10^6$ g.

- Total steel content of machinery = $4.08 \times 10^5$ g + $2.44 \times 10^6$ g + $2.60 \times 10^6$ g + $1.87 \times 10^6$ g = $7.32 \times 10^6$ g. Amount of input referred to local water resources = 20.2% of $7.32 \times 10^6$ g = $1.48 \times 10^6$ g. Solar energy per mass for concrete from Brown and Arding (1991).

6) Human labor

Energy in human labor = $2.00 \times 10^3$ [h, working hours] (Seabo) x $5.23 \times 10^3$ [J/h, metabolism ener-
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7) **Concrete in tanks**

Concrete in tanks = 1.00x10^10 [g, concrete mass] (Seabo) / 50 [yr, lifetime] (our estimate) = 2.00x10^8 g.

Amount of input referred to local water resources = 20.2% of 2.00x10^8 g = 4.04x10^7 g. Solar transformity from Buranakarn (1998).

8) **Sand surfaces**

Sand mass used in pipeline = 2.10x10^11 [g, sand] (estimated from pipeline mass balance) / 100 [yr, lifetime] (our estimate) = 2.10x10^9 g. Amount of input referred to local water resources = 20.2% of 2.10x10^9 g = 4.23x10^8 g. Solar transformity from Odum (1996).

9) **Potable water**

Amount potable water distributed = 2.83x10^6 m^3 (Seabo).

**Footnotes to Table 3.**

**Samoggia creek:**

Total economical value = 1.80x10^19 [sej, Year emergy flow] (Table 1) x 7.26x10^8 [sej/£, Emergy money ratio of Modena Province] (unpublished manuscript) = 24.79x10^9 Em£.

Economical value per m^3 = 24.79x10^9 [Em£] / 5.93x10^7 [m^3, Samoggia creek flow] (Hydrological annals, 1978/79) = 418 Em£/m^3.

**Potable water supply system:**

Total economical value = 6.11x10^18 [sej, Year emergy flow] (Table 2) x 7.26x10^8 [sej/£, Emergy money ratio of Modena Province] (unpublished manuscript) = 8.42x10^9 Em£.

Economical value per m^3 = 8.42x10^9 [Em£] / 2.83x10^6 [m^3, drinking water distributed] (Seabo, 1999) = 2,973 Em£/m^3.