EMERGY SYNTHESIS 4:
Theory and Applications of the Emergy Methodology

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Sustainable Use of Treated Wastewater in Georgia:  
Emergy Evaluation of Alternatives for Wastewater Treatment

Glen R. Behrend

ABSTRACT

As water resources become more limiting, Georgia (USA) is in the process of developing a Statewide Water Plan, which will include a section on Conservation, Efficiency, and Reuse. Questions have been raised about the most appropriate use of wastewater effluent. Often, these questions are answered based on economic indicators that do not adequately measure environmental impacts or services. In this study, an analysis was made based on Emergy in order to quantify both economic and environmental impacts of potential wastewater effluent uses. An analysis was made of a septic tank and drainfield, traditional Land Application System (LAS) where a forest is irrigated with wastewater effluent, wetland treatment prior to discharge to a river, reuse of advanced tertiary treated wastewater effluent via irrigation of recreational turf, and treatment and disposal of effluent in local water bodies both with and without advanced tertiary treatment. Results indicate that the septic tank and land application system have significantly less environmental load via greater use of local environmental resources than the other systems evaluated.

INTRODUCTION

Georgia (USA) has experienced water shortage, especially during times of drought. In 2004, in response to the increasing pressure of population growth with associated strains on water resources, the Georgia legislature passed the Comprehensive State-Wide Water Management Planning Act (HB 237, 50-13-4), which mandates development of a statewide water plan. The act establishes, as a principle, that “Water resources are to be managed in a sustainable manner so that current and future generations have access to adequate supplies of quality water that support both human needs and natural systems” (12-5-522(b)(2)).

Sustainability is not specifically defined in the act. However, sustainability typically entails the ability of a process or action to maintain itself indefinitely. To be complete, sustainability should address economic, social, and environmental factors.

As Georgia pursues sustainable water management, state policy-makers are studying different water policy options. Often, the decisions about which options to pursue are made based primarily on economic considerations that do not fully take into account environmental or social factors. This study is an attempt to use principles of emergy analysis as a method to analyze policy options and determine levels of sustainability. While this study is focused on wastewater treatment, emergy principles have the potential for broad application and could be used to examine other policy options. This study is an evaluation of both traditional systems designed for disposal of wastewater effluent (e.g., septic tank with disposal field, land application of wastewater on forested lands, and stream discharge) and more

*This research is the product of the author. The views and opinions of the author expressed herein do not necessarily state or reflect those of the State of Georgia.
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technologically advanced systems (e.g., advanced wastewater reuse and discharge, wetland treatment, and reuse of effluent via landscape irrigation).

METHODS

Description of Evaluated Systems

Six wastewater treatment and disposal systems were evaluated in this study: septic tank with disposal field, land application of wastewater on forested lands, stream discharge, wetland treatment followed by stream discharge, advanced wastewater reuse and discharge, and wastewater reuse via landscape irrigation.

For the septic tank with disposal field, a tank with baffles receives wastewater. Solids settle in the tank and are periodically removed (approximately every three years). Treated wastewater flows out of the tank and is disposed of in underground trenches filled with gravel or other permeable material to ensure even flow distribution into the soil/groundwater matrix. Remaining pollutants are filtered and treated by soil before exiting the system as groundwater flow. This system differs from the others in that it is decentralized and does not involve a wastewater utility.

The Shoal Creek Wastewater Treatment Facility in Griffin, Georgia is a Land Application System (LAS) designed to treat 2.25 MGD (millions of gallons per day) and treated approximately 1.36 MGD during 2005 (EPD, 2005). Wastewater is treated through mechanical screening and aeration, followed by land treatment by spray irrigation of a forested area. Pretreatment limits from the mechanical portion of the plant are 50mg/L BOD (biochemical oxygen demand), 90 mg/L TSS (total suspended solids). Approximately 777 acres, including buffers, make up the land application area.

The Potato Creek Wastewater Treatment Facility in Griffin, Georgia is designed to treat 2.0 MGD of wastewater and treated approximately 1.81 MGD during the period evaluated (EPD, 2005). Wastewater is mechanically treated via aeration in an oxidation ditch prior to discharge to Potato Creek. Limits vary seasonally from 30 mg/L to 10 mg/L for BOD and from 17.4 mg/L to 4.1 mg/L for ammonia.

The Messerly Wastewater Treatment Facility and constructed wetland in Augusta, Georgia includes a mechanical pre-treatment plant with biological treatment and some nutrient removal. The effluent then flows through approximately 360 acres of constructed wetlands for final treatment before discharge to a tributary of the Savannah River. The facility was permitted to treat 46.1 MGD of wastewater and treated approximately 31.8 MGD during the period evaluated (EPD, 2005). The facility is limited to 10 mg/L CBOD (carbonaceous biochemical oxygen demand) and 1.5 mg/L of ammonia.

The F. Wayne Hill Water Reclamation Facility in Gwinnett County, Georgia is the most advanced facility in Georgia. The advanced treatment plant consists of screening, grit removal, odor control, primary clarification, activated sludge aeration with biological nutrient removal, secondary clarification, high lime phosphorus removal with pH adjustment, granular media filtration, granular activated carbon filtration, and ozone disinfection. Most of the effluent is discharged through 20 miles of pipeline to the Chattahoochee River. This discharge can be considered indirect potable reuse for downstream communities, including Atlanta. A portion of the effluent is also used for landscape irrigation. The facility is currently permitted for 20 MGD of wastewater and treated approximately 18.3 MGD during the period evaluated (EPD, 2005; JJG, 2000). The facility is limited to 0.5 mg/L ammonia, 0.13 mg/L phosphorus, and 25 mg/L COD. Portions of the plant area are set aside for future expansion. An expansion to 40 MGD is planned in the near future.

The Hampton Creek Water Reclamation Facility in Forsyth County, Georgia services a private subdivision development and produces reuse water for golf course and landscape irrigation. A small dedicated drip irrigation field (approximately three acres) is also available for effluent disposal. The facility uses fine screening and a membrane bioreactor for wastewater treatment. Membrane
bioreactors allow for a smaller wastewater treatment plant because aeration and clarification take place in the same membrane bioreactor as wastewater is filtered through the membranes. After treatment, effluent is discharged to a holding pond for irrigation uses. The facility is permitted for 0.344 MGD with capacity for expansion to over 1.0 MGD. The facility treated approximately 0.123 MGD during the period evaluated (EPD, 2005). Facility treatment limits consists of 5 mg/L BOD and 3 NTU (nephelometric turbidity units).

System Diagrams of Evaluated Systems

Systems diagrams of the respective facilities showing emery flows are shown in Figures 1 through 6.

Emergy Evaluation of Wastewater Treatment

Data for each system were gathered from EPD monitoring data, design reports, and discussion with treatment plant staff. The data were assembled and emery accounting tables were developed using previously derived transformities.

In Nelson (1998), the emery of wastewater was assumed to be the emery needed to sustain a person divided by per capita wastewater production. Although this method produces a higher emery result than may be expected, it was employed to allow comparison with previous results. For the purposes of this study, the emery in the influent wastewater was assumed to be a local nonrenewable input. Although water itself is a renewable resource, the vast majority of the emery used to sustain people in highly developed areas such as Georgia is nonrenewable due to the use of fuels throughout the economic system.

Using data from the emery tables, ratios were calculated to assist in comparing the systems. These ratios include the emery investment ratio (EIR), emery yield ratio (EYR), percent renewable emery, transformity (solar emjoules/joule), emery per m³, environmental loading ratio (ELR), and emery sustainability index (ESI).

RESULTS

The results of the emery analysis are shown in Table 7. Using the method from Nelson (1998, described above) with emery of wastewater input calculated as a co-product of the emery needed to sustain a person, the nonrenewable input emery from the influent wastewater is quite high. Even allowing for the difficulty of calculating the transformity of wastewater, the results show a much higher percent renewable emery and a lower environmental loading ratio for the traditional Land Application System and septic tank system when compared with the other treatment methods.

Comparison with other Studies

The transformity of treated wastewater calculated in this study (including input wastewater as a co-product of people) was found to be between 4.70x10⁶ seg/J and 4.83x10⁶ seg/J. Literature values were 3.45x10⁶ sej/J for the Italian municipal wastewater treatment plan (Bastianoni, 2003); 3.45x10⁶ sef/J for the Swedish municipal wastewater treatment systems (Grönlund, 2004); and 4.71x10⁶ sej/J for the University of Florida advanced wastewater treatment plant, 6.85x10⁶ sej/J for the Mexican constructed wetlands, and 4.83x10⁶ sej/J for the Mexican Package Plant (Nelson, 1998). In general, the transformities compare reasonably well with published literature values.
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Figure 1. Augusta Wetland System Diagram. In this diagram, sewage enters the mechanical pre-treatment box on the right and then feeds back to the environmental system of the treatment wetland. The treatment wetland discharges to Butler Creek (surface water, above). Money is exchanged for goods and services necessary for wastewater treatment. Abbreviations: SW = surface water, GW = groundwater, G&S = goods and services, Env = aggregated environment.

Figure 2. Griffin Potato Creek System Diagram. In this system, sewage enters the treatment plant and is then discharged to Potato Creek. Money is exchanged for goods and services necessary for wastewater treatment. The environment represents a small contribution to treatment.
Figure 3. Griffin Shoal Creek System Diagram. In this system, sewage is pre-treated in the mechanical plant and then used to irrigate a forested area (env). Groundwater and surface water enter and exit via groundwater and creek flow. Money is exchanged for goods and services necessary for wastewater treatment. Abbreviations: SW = surface water, GW = groundwater, G&S = goods and services, Env = aggregated environment.

Figure 4. Gwinnett F. Wayne Hill Plant System Diagram. In this system, sewage enters the treatment plant and is then discharged to the Chattahoochee River or used for irrigation. Money is exchanged for goods and services necessary for wastewater treatment. The environment represents a small contribution to treatment.
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Figure 5. Hampton Creek Reuse Plant System Diagram. In this system, sewage enters the treatment plant and is then discharged to the reuse pond for future use. Money is exchanged for goods and services necessary for wastewater treatment. A drip irrigation field is used for wastewater disposal when irrigation is not possible.

Figure 6. Septic Tank with Drainfield System Diagram. In this system, sewage from the household enters the "pre-treatment system," septic tank. The wastewater then feeds back to the environment via discharge to groundwater within the drainfield. The groundwater flows in and out of the system depending on local groundwater gradients. Money is exchanged for goods and services. Abbreviations: GW = groundwater, G&S = goods and services, Env = aggregated environment.
### Table 1. Eergy Ratios for Wastewater Treatment

<table>
<thead>
<tr>
<th>Name of Index</th>
<th>Gwinnett F. Wayne Hill WWTP</th>
<th>Griffin Shoal Creek LAS</th>
<th>Griffin Potato Creek NPDES</th>
<th>Augusta Wetland WWTP</th>
<th>Hampton Creek Reuse Facility</th>
<th>Septic Tank</th>
<th>U. Florida WWTP*</th>
<th>Yucatan Treatment Wetland*</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIR ((P + S)/(N + R))</td>
<td>0.011</td>
<td>0.004</td>
<td>0.003</td>
<td>0.003</td>
<td>0.030</td>
<td>0.014</td>
<td>0.006</td>
<td>0.007</td>
</tr>
<tr>
<td>EYR (Y/(P + S))</td>
<td>88.87</td>
<td>224.30</td>
<td>358.21</td>
<td>288.61</td>
<td>34.22</td>
<td>70.69</td>
<td>159.29</td>
<td>146.02</td>
</tr>
<tr>
<td>% Renewable emergy (100 \times (R/Y))</td>
<td>0.0010%</td>
<td>0.0698%</td>
<td>0.0032%</td>
<td>0.0017%</td>
<td>0.0053%</td>
<td>0.2608%</td>
<td>0.0027%</td>
<td>0.1386%</td>
</tr>
<tr>
<td>Transformity (sej/J)</td>
<td>4.74E+06</td>
<td>4.71E+06</td>
<td>4.70E+06</td>
<td>4.70E+06</td>
<td>4.83E+06</td>
<td>4.77E+06</td>
<td>4.71E+06</td>
<td>6.85E+06</td>
</tr>
<tr>
<td>Eergy per m³ (sej/m³)</td>
<td>2.34E+14</td>
<td>2.33E+14</td>
<td>2.32E+14</td>
<td>2.32E+14</td>
<td>2.39E+14</td>
<td>2.36E+14</td>
<td>2.33E+14</td>
<td>3.39E+14</td>
</tr>
<tr>
<td>ELR ((P + S + N)/(R))</td>
<td>101,176</td>
<td>1,432</td>
<td>30,970</td>
<td>58,370</td>
<td>18,822</td>
<td>383</td>
<td>37,530</td>
<td>721</td>
</tr>
<tr>
<td>ESI ((EYR)/(ELR))</td>
<td>0.0009</td>
<td>0.1566</td>
<td>0.0116</td>
<td>0.0049</td>
<td>0.0018</td>
<td>0.1843</td>
<td>0.0042</td>
<td>0.2027</td>
</tr>
</tbody>
</table>

*Nelson, 1998

### DISCUSSION

#### Assumptions

Calculating the transformity of influent wastewater was problematic. It was assumed from Nelson (1998) that the wastewater is a co-product of people. Hence, all the emergy required to support a person was divided by the amount of wastewater typically produced per person per day (assumed to be 100 gallons per capita per day). It is difficult to determine the amount of emergy that should be assigned to a feedback product from a process (see Björklund, 2000). In addition, this method did not take into account some industrial wastewater flows that are treated by the systems evaluated. It also assumed that the amount of emergy necessary to support a person in Florida (calculated in Odum, 1998) is equal to the amount of emergy required to support a person in Georgia. Despite the problems associated with calculating wastewater transformity, the results of this study appear to be valid because setting the wastewater transformity to zero (0) produced similar relative results when comparing treatment methods. The overall conclusion would not change based on the method of calculating the transformity of wastewater.

The results of the analysis are sensitive to the lifetime chosen. The lifetime of each treatment system was assumed to be 30 years.

#### Limitations

For this study, data were obtained from literature searches, interviews with plant staff, and available EPD data. As with other macro-scale studies, the quality of the result is only as good as the...
input data. Further, questions have been raised about the validity of some of the transformities and other values used in emergy analysis (Björklund, 2000). Some questions involve access to data and potential errors in transformity calculation. Others relate to the complexity of using a systems approach since available data and understandings of self-organizing systems are limited.

The emergy values of co-products of wastewater treatment were not evaluated in this study. These include products that are possible as part of the treatment process, such as crops/timber from the Land Application System (LAS) and sewage sludge (biosolids) that can be used as a beneficial soil amendment. They also include “ecosystem services” (such as biodiversity, wildlife habitat, and flood control) that are offered by natural systems used in wastewater treatment. Typically, energy intensive wastewater treatment processes offer less environmental service to society than natural systems, but quantifying the degree is problematic.

The emergy ratios calculated are by necessity coarse measures of sustainability and do not take all factors into account. The boundary of study was chosen as the actual treatment system including necessary buffers. However, any changes in wastewater treatment methods will likely involve other societal changes that will have concurrent effects. A better measure of sustainability may require a study at the societal scale rather than limiting analysis to the scale of the treatment system. As just one example, a policy that increases septic tanks may require lower housing density, which could require higher transportation costs than a more dense community with a conventional treatment plant. The sustainability of these consequences was not analyzed with this study.

Analysis

The relatively high transformity for treated wastewater shows the potential value of the resource to society. This suggests that the beneficial reuse of wastewater (broadly defined to include environmental reuse) is appropriate.

The Augusta Messerly wetland treatment system had a lower sustainability index than expected. This result was somewhat surprising in that a significant amount of renewable energy is used by the constructed wetlands for final treatment. However, this increase in renewable emergy is apparently offset by the increased nonrenewable emergy, including fuels used for backup generators and wetland maintenance. Results are also affected by the performance of the pre-treatment system. In addition, the wetland is primarily Typha spp. and other wetland grasses with relatively low diversity of habitat when compared with natural wetlands. As noted by Brown (2004), generally, the maintenance of a monoculture requires large energy subsidies.

The high transformity for the Hampton Creek Water Reclamation Facility suggests that the wastewater treatment process has a lower overall efficiency. This result may be due the fact that the plant is under-loaded when compared to design conditions.

Opportunities for Further Study

Given the transformities and emergy per m³ of treated wastewater calculated, it may be possible to compare the reuse of wastewater effluent with other available water sources. This type of comparison could allow water resource planning to include sustainability measures. Buenfil (2001) calculated transformities for a variety of water treatment methods.

Additional evaluations may be necessary to see if the results for these six treatment processes are site specific or are appropriate for generalization of these wastewater treatment options.

Studies of additional ecological engineering approaches may also be useful to find other methods of wastewater treatment with high sustainability. Nelson (1998) suggests that constructed wetlands for wastewater treatment in the coastal Yucatan of Mexico are far more sustainable than conventional sewage treatment due to the use of local nonrenewable and renewable resources. These constructed wetlands use far less nonrenewable resources than the Augusta wetlands. Sikdar (2005)
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studied treatment wetlands for animal wastes at Ohio State University and found that the research-centered wetland evaluated was not operating efficiently, but the sustainability index was higher than conventional treatment systems. In addition to improved efficiency and sustainability, ecological approaches can also provide ancillary benefits including wildlife habitat, aesthetic enhancement, and potential food/fiber crops as co-products.

Potential Implications for Georgia Water Policy

Georgia has a mandate to manage water in a sustainable manner from the Comprehensive State-Wide Water Management Planning Act (HB 237, 50-13-4). Sustainability requires consideration of multiple factors including social, economic, and environmental. Emergy analysis, though limited as previously noted, offers one way to considering these different factors and the associated time scales on a common-basis.

This study highlights the trade-off between use of local environmental lands and renewable energies for waste treatment versus use of imported goods and stored resources. In effect, energy intensive mechanical treatment of wastewater exports environmental impacts by using resources from different time scales (e.g., fossil fuels) and areas (e.g., imported resources and chemicals).

While this study offers an expanded viewpoint that takes into account economic, environmental, and social impacts, it does not directly examine ancillary benefits of different wastewater treatment methods. The high emergy value of wastewater shows a potential value to society. Direct discharge of treated wastewater can replenish depleted river and stream flow. Land application systems offer crops (trees for harvest) and environmental services, such as potential for passive recreation, wildlife habitat, and groundwater recharge. Another potential benefit to society is increased future productivity of the land through building soil storages.

This study suggests that changes in water management aimed at reorienting society towards increased sustainability may require that a large portion of land area be dedicated to waste assimilation, directly or indirectly. The structural changes necessary require a rethinking of societal organization including more localized food supply that is linked more directly to waste assimilation (Björklund, 2000). Due to the uncertain impacts of such significant changes, societal scale evaluations may be necessary before more definitive conclusions can be drawn.

SUMMARY AND CONCLUSIONS

This study was an evaluation of six wastewater treatment methods using emergy techniques. For the systems evaluated the following conclusions were made.

- Wastewater treatment was shown to be emergy intensive.
- Wastewater was shown to have a high emergy value as a resource for society.
- Land application of wastewater via a traditional land application system and septic tanks makes more use of local renewable resources than stream discharge and water reuse systems with mechanical high-emergy treatment. This suggests that low-tech land application may be a more sustainable treatment method in the long term.
- Given the favorable emergy ratios, additional study may be warranted of other ecological engineering approaches to wastewater treatment, such as described by Nelson (1998).
REFERENCES


