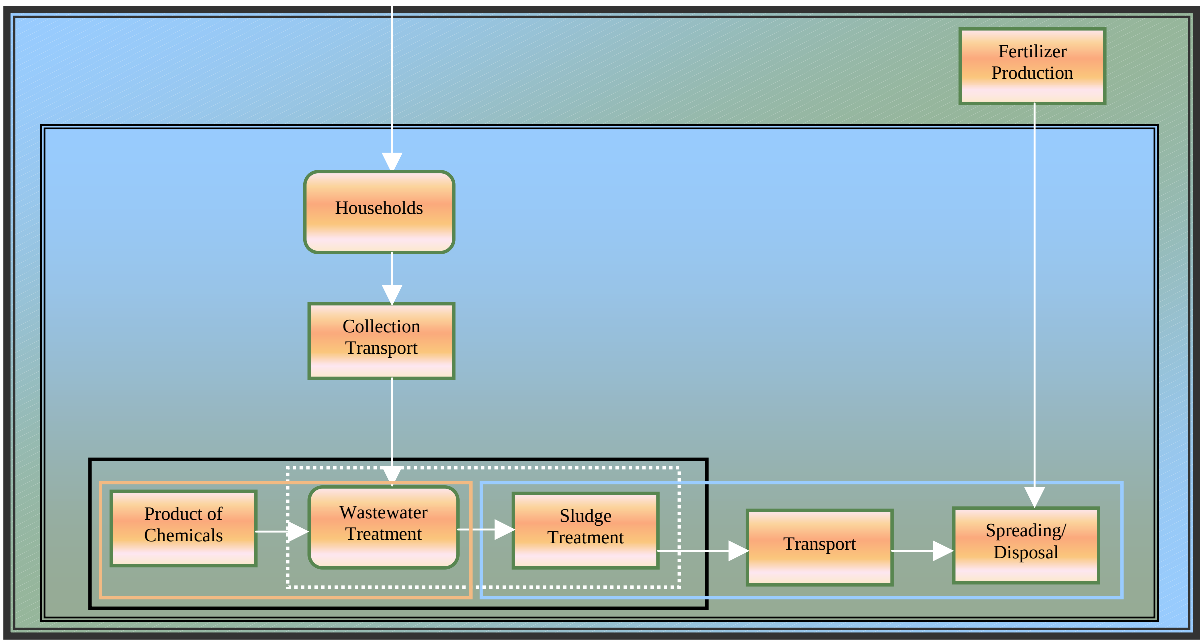
National Decentralized Water Resources
Capacity Development Project



Methods for Comparing Wastewater Treatment Options

Oceans Arks International
Burlington, Vermont

April 2005

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Submitted by Ocean Arks International Burlington, Vermont

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ABSTRACT

Present methods used in the US for evaluating the consequences of wastewater treatment systems typically use economic criteria and environmental criteria which only take into account the direct effect of effluent on receiving waters, disregarding indirect and cumulative economic and environmental effects. As a result, the true environmental and social costs of wastewater treatment are often not included in decision making.

Many communities face decisions regarding centralized versus decentralized wastewater treatment as well as numerous strategies and technologies available within the centralized and decentralized sectors. In this report, analytical tools and methods are evaluated that have the potential to capture the environmental consequences of such wastewater alternatives in non-monetary units for US communities. Methods are classified into the broad methodologies of environmental impact assessment (EIA), open wastewater planning (OWP), and life-cycle assessment (LCA).

- EIA is a framework for identifying, predicting, evaluating, and mitigating the biophysical, social, and other effects of proposed projects or plans and physical activities
- OWP is an approach to wastewater decision making that broadens the boundaries of options considered and expands typical evaluation criteria to include indirect environment impacts
- LCA is a method of accounting the environmental impacts of a product, service, or process over the course of its life cycle from extraction of materials to disposal or reuse of the final product

EIA, OWP, and the following LCA methods are examined in detail:

- Eco-indicator 99 (EI 99), an LCA method with a high level of aggregation based on the International Standard Organization (ISO) 14000 guidelines
- The Sustainable Process Index (SPI), an ecological evaluation system that characterizes mass flows by their use of solar energy
- TRACI, an ISO-based method created by the United States Environmental Protection Agency (US EPA) for evaluating the potential environmental and human health impacts of processes under US conditions
- URWARE, a material and energy flow analysis and assessment method used by wastewater researchers in Sweden

The strengths and weaknesses of each method are described. One of the greatest barriers to using each method is the amount of data required. Ways to streamline data needs while still reliably answering central questions about wastewater treatment alternatives are described.

Potential users of the methods examined include state, local, or city policymakers, non-profits concerned with environmental protection, and ”green building” certifiers. Some methods would be of interest in regions of the US where land-use and economic development planning are becoming more important, where recharging groundwater is a priority, or where sustainability is a broad goal.

The following were determined from the evaluation of methods:

- Of the methodologies, EIA and OWP are broader frameworks for assessment and planning, within which LCA methods may be used to more completely account impacts,
  - OWP was developed specifically for wastewater decision making and offers more flexibility in the breadth and depth of analysis and formality.
  - EIA is already in use in the US for wastewater treatment, but it is not clear how much it affects choice of treatment alternatives.
  - LCA is currently most suitable for policy-level studies, and requires a significant investment in data development to be useable in the US.
- URWARE is an advanced material and energy flow analysis tool developed for modeling complex waste and water treatment scenarios but characterizes impacts for European conditions
- Combining the inventory of life-cycle data generated within URWARE with the US-specific impact characterization of TRACI would provide for in-depth analysis and assessment of the environmental and social impacts of US wastewater treatment options
- EI 99 could be used in place of TRACI if aggregation of impacts into a single ecological indicator were desired; however, like URWARE, the impact characterization is modeled on European conditions
- SPI also provides aggregation into a single indicator of sustainability. It does not provide as detailed of an analysis of impacts as do EI 99 and TRACI, which permits less investment in data gathering

The following next steps are among those recommended:

- Imitate national demonstration projects that apply LCA to local decisions, followed by an evaluation of how the data generated could be used in future decisions and how future LCAs could be simplified
- Investigate whether and how EIA information generated under NEPA or the corresponding state laws affects choice of wastewater treatment alternatives

- Use OWP also as the subject of demonstration projects in communities
- Communities espousing sustainability should immediately adopt a process similar to OWP for their wastewater planning
- Generate a longer list of potential parameters to use in evaluating wastewater treatment options and use it to direct the use of the more open-ended, less formal OWP approach

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1 INTRODUCTION

Historically, the effectiveness of wastewater treatment facilities has been judged on the basis of contaminant removal per unit cost and in terms of net improvement in receiving water quality. The net impact of treatment technologies on the total physical environment has not been adequately considered. As a consequence of this somewhat myopic approach to environmental management, many air and land pollution problems have been and are being created in the pursuit of stringent water quality objectives.

—Antonucci and Schaumburg (1975)

Background

Moving Problems in Space or Time

Historically, many changes in water and wastewater infrastructure have moved problems in space or time or changed their character, rather than solving them. This was recognized as early as 1907, when sanitary engineer Moses N. Baker explained, “The general rule observed by American cities of all sizes is to discharge their sewage into the nearest available water until the nuisance becomes intolerable to themselves, and then to divert it from their own shores, resting content with inflicting their waste on neighbors below, until public protest or lawsuits make necessary adoption of remedial measures.” (U.S. Department of Commerce and Labor 1907 as cited in Tarr 1996). Later in the century, at least one city (Kristiansand, Norway) even started discharging its untreated sewage into its own drinking water supply and continued doing so for more than 30 years (Holte and Randøy 1992).

Changing the character of environmental and public health problems in ways often unanticipated, or at least undebated, has been a hallmark of decisions to introduce water pipelines or sewers. Running water has repeatedly been introduced into cities with no provision for carrying away the increased wastewater. When the convenience of running water led to the widespread use of the water toilet and water consumption per capita increasing 25–50 times, the existing cesspools and gutters were overwhelmed by the wastewater. Untreated sewage flowed out into the streets and over sidewalks (Tarr 1996; Illich 1986; and Holte and Randøy 1992). In more recently built infrastructure, infiltration and inflow to sewers have drained away large amounts of potable groundwater and rainwater that was potential groundwater recharge.

For example, the Massachusetts Water Resources Authority (MWRA) estimated that 60% of the water reaching its Deer Island Treatment Works, or 230 million gallons per day (mgd) (8.7 million m^3/day), is infiltrated groundwater or rainwater runoff. This total represents over 40% of the combined flows of the Charles River and the three others that flow into Boston Harbor. While all this groundwater and rainwater are being channeled directly to the treatment plant, the Boston region is experiencing potable water shortages and rivers that run very low or dry up (Zimmerman 2002).

Moving problems in time is often associated with changing the problems' nature and moving them in space. For example, when public health problems associated with wastewater have been addressed by moving the wastewater away from the buildings where it is generated and into sewers draining to surface waters, lakes and rivers can potentially become undrinkable, clogged with algae growing on excessive nutrients, and even unswimmable. The effect does not occur right away, but over time, due to cumulative impacts (for example, Wetzel 2001).

One of the first attempts to grapple systematically with the effects of water infrastructure was a 1975 paper by David Antonucci and Frank Schaumburg (1975). Antonucci and Schaumburg examined the centralized wastewater treatment plant at South Lake Tahoe, California representing an advance in wastewater technology at the time it opened. The plant used primary clarification, secondary treatment with activated sludge, and tertiary treatment using lime coagulation, air stripping of ammonia (NH_3) at the resulting high pH, pH neutralization, mixed media filtration with alum coagulation, activated carbon filtration, and chlorination. The result was a final effluent with 1 mg/l biochemical oxygen demand (BOD_5), 0 mg/l suspended solids, 0.1 mg/l phosphate phosphorus, and 3.5 mg/l ammonia nitrogen. Despite the low values for effluent parameters, Antonucci and Schaumburg questioned whether the net environmental effects were positive.

The authors did not dispute that the receiving water was spared environmental impact because of the treatment plant. However, some processes just moved pollutants around, like the air stripping of ammonia, which changed the ammonia from the aqueous to the gaseous phase for transport to the atmosphere. (How much of the ammonia returned to the receiving water from the atmosphere is not addressed in the paper.) Furthermore, the South Lake Tahoe plant was responsible for off-site environmental impacts, for example, the lime used in the facility came from a production plant in northern California, which produced air emissions and solid waste.

Antonucci and Schaumburg also showed a steeply increasing energy use to achieve improved effluent quality, from 10 million British Thermal Units (BTUs) per million gallons (BTU/Mgal) of water treated for primary treatment alone to over 100 million BTU/Mgal for the complete treatment train (Figure 1-1). They also documented the steeply increasing amounts of materials consumed and contaminants produced as the treatment intensity increased (Table 1-1 and Table 1-2). Despite the inventory they produced of direct and indirect energy use, materials consumed, and contaminants produced, Antonucci and Schaumburg concluded that "it is not yet possible to determine whether advanced waste treatment processes effectively reduce the net level of degradation in the total environment. Further research is needed to develop a common denominator by means of which various types and amounts of contaminants emitted to different phases of the environment may be quantitatively compared."

Table 1-1
Material Consumption During Operation of the South Tahoe Treatment Plant (Per Million Gallons of Wastewater Treated)

Materials Consumed	Stage of Treatment		
	Primary	***Secondary***	***Tertiary***
Natural Resources			
Natural gas, l	328	643	1657
Fuel oil, kg			218
Salt, kg		50	77
Sodium bicarbonate, kg		0.5	0.7
Limestone, kg			1452
Wood charcoal, kg			29
Bauxite, kg			45
Sulfuric acid, kg			39
Processed Chemicals*			
Chlorine, kg		19	29
Lime, kg			726
Alum, kg			154
Activated carbon, kg			14

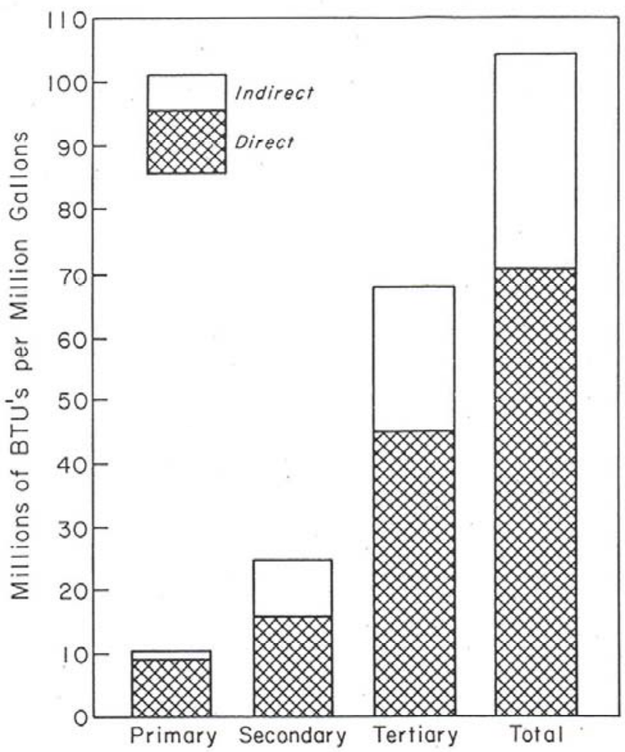
* These processed chemicals were derived from the natural resources noted in the first section of this table. For example, approximately 3,200 lb (1,450 kg) of limestone are to produce 1,600 lb (725 kg) of lime.

Adapted from Antonucci and Schaumburg (1975)

Table 1-2
Production of Contaminants at Various Stages of Treatment (Per Million Gallons of Wastewater Treated)

Contaminant	Stage of Treatment		
	Primary	***Secondary***	***Tertiary***
Unused heat × 104 kcal	0.2	2.6	3.6
Cooling water, l	273	3350	4360
Nitrogen oxide ($NO_{x)}$, g	227	1900	2990
Sulfur dioxide (SO_2), g			680
Carbon monoxide (CO), g			18
Miscellaneous organic gases, g			9
Particulates, g			680
Solid waste, kg		0.3	19
Hypochlorous acid (HOCL), g		45	45
Sodium bicarbonate ($NaHCO_2$), g		45	45
Chlorinated organics, g		136	136
Low alum wastewater, l			132
High total dissolved solids water, l			15

Adapted from Antonucci and Schaumburg (1975)



Source: Antonucci and Schaumberg (1975)

Figure 1-1
Direct and Indirect Energy Consumption of Wastewater Treatment at South Lake Tahoe

Framing the Right Questions

Forty years after Antonucci and Schaumburg's investigation of South Lake Tahoe, universal agreement on a common denominator has not yet been achieved (Oers and Huppes 2001; Guinee 2001; Narodoslawsky and Krotscheck 1995; Goedkoop and Spriensma 2001; and Steen 1999). In most decisions about wastewater infrastructure, a detailed inventory of energy and material use and contaminant production is not conducted. Even when the energy, material, and contaminant inventory of every bit of wastewater infrastructure is performed in as much detail as at South Lake Tahoe, important questions may be missed, for example, what is the dewatering potential of the sewer infrastructure?

Condensing all environmental impacts to a single measurement or indicator of environmental performance leaves out much detail, and it may not be necessary to expedite decision making. To choose wastewater treatment alternatives that solve more problems than they create, it may be simply enough to raise a broader array of questions in the design and evaluation stages:

- Would the Lake Tahoe facility have been built differently if someone had calculated the energy and material use necessary to achieve tertiary treatment?
- Would wastewater collection have been provided in urban areas at the same time running water was introduced if there had been public debate about the fetid, open sewers that would result?
- Would more areas have chosen decentralized wastewater treatment or other means of recharging aquifers if the groundwater impacts of centralized sewers had been better studied?

While the answers to any or all of these questions might be “No,” posing the questions allows decision-makers to request alternatives that create fewer problems and to influence the debate about alternatives—regardless of whether a single denominator is used. Several “open” methods of assessment will also be reviewed in this report.

Objectives of This Study

In this study, methods for comparing the non-monetary costs of wastewater treatment options are evaluated. Methods are evaluated for their use in comparing centralized and decentralized approaches and for comparing conventional and alternative technologies within the centralized and decentralized sectors. Materials used in various wastewater technologies are also considered. A key question is which models are most appropriate for use in the US.

The detailed objectives of this project are to:

- Explore the advantages and disadvantages of using various formal analytical models to shed light on wastewater treatment alternatives, including the choice between centralized and decentralized solutions, and how the models show whether problems are solved or merely moved in space or time or changed in nature
- Describe the barriers to using the models
- Recommend whether any of the models should be brought into use
- Describe and prioritize the steps, costs, and pathways to completing the analyses
- Consult with decision-makers about the usefulness of the models

Criteria used to evaluate each tool include data availability, ease of use, interest and usefulness to decision-makers, and capture of relevant environmental and social factors.

Target audiences for this report include local and state decision-makers on wastewater questions; water policymakers at the regional, state, and national level; citizen groups that seek to influence wastewater decisions and water policy; organizations that set standards for green buildings; and anyone who performs or funds future research in this area.

2 RESEARCH APPROACH

Defining the Decisions To Be Guided by Decision-Making Methods

Choosing representative decision situations in which the methods identified would be of use to US communities illuminates the types of questions that need to be answered and, in particular, the types of data, that need to be gathered.

Three decision situations were chosen:

- Small rural village
- Large town
- New subdivision or community

For each decision situation, a number of wastewater treatment alternatives were identified. These wastewater treatment alternatives then encompassed the range of technologies about which data would be necessary to apply the methods covered in the study. Descriptions of these decision situations can be found in Appendix A.

Finding Formal Analytical Models

After identifying what types of decisions were to be examined, the next step was a critical literature review of formal analytical models used for analyzing wastewater treatment alternatives. The literature review summarized the following specific items:

- Input data required for each method and the effort and cost required for gathering it
- System boundaries that define the processes, time-span, and area under which analyses take place
- New information that would be provided by each model and identification of the decision situations that were most likely to benefit from such analyses

Details of how the literature was identified can be found in Appendix B

Preliminary Evaluation

After generating a list of methods to be considered (listed in Appendix C), a preliminary evaluation was conducted to quickly establish which of the methods identified in the literature review might be most appropriate for US decision-making situations. Information pertaining to each of the methods was collected and cataloged, including general description, objectives, necessary input data, expected results, software availability, strengths, weaknesses, and procedure. Each method was evaluated on its appropriateness for wastewater treatment decision making under US conditions, and the most suitable methods were selected for further evaluation. Three broad methodologies—life-cycle assessment, environmental-impact assessment, and open-wastewater planning emerged—and numerous methods within those methodologies were identified.

Describing the Barriers to Use in the US

To use the methods identified, appropriate data sources need to be located.

Data Availability

With the methods chosen for detailed investigation, availability of data for using those methodologies was assessed by

1. Developing a checklist of the types of data needed

2. Categorizing the data into data specific to each wastewater treatment system site (town, neighborhood, or backyard) and data that is generalizable across different sites

3. Querying potential sources of the generalizable data in the US to see whether the potential sources have those data

4. Noting which of the site-specific data are generated in the normal course of considering a wastewater treatment alternative

The LCA Extended Data Needs table in Appendix E includes a listing of the types of data needed, categorized as site-specific, and generalizable. A discussion of general data types is included in Chapter 5. A discussion of data availability can be found in Chapter 7, and other barriers to implementing comparison methods are described in Chapter 8.

Data Search

The search for relevant data consisted of:

1. Examining literature identified in the literature review (see Preliminary Evaluation Section)

2. Searching the Internet for databases and data sources
3. Surveying European and US impact assessment practitioners for databases and data sources

Details of the Internet data search are described in Appendix B.

In-Depth Evaluation

The in-depth evaluation of the methods selected was performed by means of a more extensive and intensive review of relevant literature. The literature was obtained by search methods similar to those described in the Data Search section; however, the searches were expanded, targeting authors of key papers and referenced articles. Additionally, the keywords were expanded to include the selected methods. The in-depth evaluations are described in Chapter 6 and the details of the literature search are described in Appendix B.

Consultation With Decision-Makers

External documentation for judgments about the usefulness of each method is provided through interviews with people involved in wastewater treatment decisions or policy. Interviewees were chosen from regulators, planners, employees of environmental non-profits, and green building certifiers. This survey is not intended to be statistically significant, but rather a narrative indicating where there are promising areas of use for these methods. Summaries of these interviews can be found in Appendix H.

Investigation of Streamlining

The demanding data needs of many of the methods were found to be a key barrier to ease-of-use of the methods in the US. In order to identify easier ways to use the methods in the US, the literature on streamlining life-cycle assessment methods was searched and reported. Techniques for streamlining are described in Chapter 9.

3 CHARACTERIZATION OF THE BASIS FOR DECISION MAKING

What role could different tools for evaluating the non-economic consequences of wastewater alternatives have in wastewater community decisions and policy? That question is best examined in the context of how decisions and policy are made in the US today.

Wastewater Decisions and Policy

The authors are not aware of a body of literature that addresses how local wastewater decisions are made. As a result, this chapter is written primarily by relying on experience and discussions with others who work with wastewater management. Green Mountain Institute for Environmental Democracy (2003) recently reported on the results of two workshops, which, in part, addressed how local wastewater decisions are made. That report has helped guide the following discussion of decision and policy making.

Local Level

At the local level, every community and every state is different in the details of how decisions are made and what factors influence those decisions. Given that caveat, local decisions are generally driven by a number of factors. Regulatory pressures from state or local health authorities usually stimulate local awareness. With the increasing application of the Clean Water Act's Total Maximum Daily Load (TMDL) requirements on watercourses and water bodies that are listed as impaired, addressing impairments has also become a stimulus to address wastewater issues.

Concern for clean water can also lead communities to push their own initiatives for wastewater treatment, even ahead of regulations. This often occurs in areas where tourism, commercial fishing, or other types of commerce depend on clean lakes, rivers, or ocean waters. It can also happen where the community's drinking water aquifer is potentially threatened.

Growth is frequently a concern of communities looking for new wastewater treatment options. Some communities look for new wastewater options when their plans for growing denser downtown areas run up against limitations in wastewater treatment capacity. Less frequently, wastewater treatment capacity, in the form of sewer extensions, is used as a tool for directing growth along specific corridors. In other instances growth is such a controversial issue that, when confronted with public health or environmental reasons to upgrade wastewater treatment, decision-makers look for solutions that have no impact on growth potential.

Green building certification such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program may also be an influence on decision-makers considering onsite treatment for new or renovated buildings. The handling of waste and water resources are key components of the certification process, and the documentation of direct and indirect environmental impacts is integral to parts of the certification process of LEED (LEED 2003).

Cost matters, too. Especially with federal grant assistance for wastewater projects no longer routinely available, communities typically look for the least expensive alternative that meets regulatory requirements. Often the source of funding includes restrictions of the use of funds, minimizing the opportunity to consider some impacts.

A word that captures well the concept of making decisions that solve problems, rather than move them in time and space, is "sustainability." US communities that have adopted sustainability principles include Berkeley, California; Seattle, Washington; Boulder, Colorado; Burlington, Vermont; and Philadelphia, Pennsylvania (Earth Charter USA Campaign 2003 and International Council for Local Environmental Initiatives undated). Using sustainability principles to steer planning decisions stimulates communities to make decisions based on more than local environmental or public health effects and financial costs. Effects more distant in space or time, like global warming from fossil fuel use, are also considered. Whether the sustainability principles have been used in these or other US cities to influence decisions on wastewater treatment was not investigated, but the potential is there.

State Level

At the state level, wastewater regulations are generally driven by Clean Water Act and Safe Drinking Water Act requirements, concern for public health, state planning objectives, (for example, Massachusetts' Interbasin Transfer Act or Maryland's Chesapeake Bay watershed nitrogen control), and fiscal policy.

Most states have accepted primacy for implementing the provisions of the Clean Water Act through agreements with the US Environmental Protection Agency (US EPA). As such, the environmental or health department or agency of the state is acting on behalf of the federal government to ensure compliance. Protection of surface waters to meet the "fishable, swimable, and drinkable" standards that represent the core of the Clean Water Act become embedded in state laws and in regulations related to both decentralized and centralized wastewater treatment systems.

In addition to clean water, states address public health issues. Historically, wastewater has contaminated surface water because of inadequate or non-existent treatment plants, resulting in negative public health effects. Naturally, such failures also can have dramatic effects, though sometimes short in duration, on water quality. For centralized plants, then, both local water quality and public health are central policy objectives for most states.

Though more localized in nature, failed decentralized systems may have similar impacts on the family of a property owner or on nearby families. As a result, the design of decentralized wastewater systems is regulated. In most places, these systems would have little overall impact on a water body's health, unless many systems fail. Thus, for decentralized systems, public health is a primary concern. In most instances ensuring clean water is an important, but lesser, policy objective. Planning objectives vary widely among the states. Some have no centralized planning effort and little policy developed within the laws of the state. Others have strong state planning objectives that municipalities must adhere to. As a result, the impact of planning goals on wastewater treatment systems, centralized or decentralized, varies widely.

Land use is an example of the differing roles of states in this area. In more densely populated states, how land is used (smart growth vs. sprawl), is generally of high importance. As such, many states are developing planning objectives that are linked to the development of wastewater systems, to ensure that their planning goals are supported by the infrastructure developed. In the more rural states of the country, there is generally much less concern with land-use issues.

Economic development policy is also closely linked with infrastructure development. Many states use infrastructure development, such as wastewater treatment plants, to encourage development of new growth areas. These states believe that investment in basic infrastructure such as water supply, wastewater, and transportation systems is essential to successful economic development. Other states leave such choices to local municipalities or regional government entities.

Fiscal policy is emerging as an important factor in state decision making. Much of the policy guiding wastewater infrastructure development was crafted in the 1970s. During this time, a great amount of federal grant funding was available to develop infrastructure. In the 1980s, most federal grant programs were replaced by loans. Additionally, new fiscal pressures have emerged to clean up impaired waters, to address storm water, and to restore stream banks. Each is an expensive venture, and the traditional source of wastewater funding, the revolving loan funds, are being looked at to help solve these new challenges. As a result, state legislators and policymakers are beginning to look at wastewater choices anew to determine if the historic balance of centralized versus decentralized treatment is still appropriate today.

Federal Level

At the federal level, the Clean Water Act is the guiding law for wastewater policy. It has not been reauthorized since 1987—well beyond its six-year authorization cycle. As a result, rule making by executive branch departments and agencies, congressional line-item appropriations, specific issue attachments to other bills, and case decisions by the judicial branch have filled the void for updating water law in this country.

The Role of New Non-Economic Comparison Tools in Today's Policy World

With federal subsidies to wastewater treatment greatly reduced from their levels in the 1970s and 1980s, cost continues to be crucial in deciding on wastewater treatment options. The focus on protecting public health from water-borne diseases and protecting water quality will continue, as well—especially in areas where surface water is or may soon be subject to TMDLs. For these reasons, past tools for understanding consequences of wastewater treatment alternatives (dollars, pathogen levels, and various water quality indicators) will continue to be used and be useful.

In regions where planning land use and the economic development impacts of growth is a priority, tools that illuminate the impacts of a wastewater treatment alternative on growth potential may add pertinent new information to the debate. In those places where "sustainability" is used as a guide for planning and design, there is room for considering impacts to parts of the environment other than water, as well as impacts on the environment that occur in other places, for example, in the production of energy and process chemicals.

Another possible application of new methods is in the green building certification industry.

The next chapter discusses the range of non-economic parameters that have been addressed for wastewater treatment alternatives and shows different ways to define the boundaries of a wastewater treatment system.

4 PARAMETERS AND SYSTEM BOUNDARIES

As illustrated previously, decisions about water and wastewater have led to moving problems in space or time or merely changing the problem's character: steep increases in off-site energy generation to supply a state-of-the-art treatment plant, discharge of wastewater into drinking water supplies, flows of untreated sewage onto streets and sidewalks, and dramatic depletion of aquifers and river flows. Has the net effect of these decisions, nonetheless, been positive? Those comparisons have rarely been made formally.

Formal analytical models are needed to help make that determination. The models need to encompass the boundaries of all systems of interest and to encompass all the parameters of interest. As a Swedish proverb puts it, "You get the answers to the questions you ask." If there is concern with whether a new wastewater treatment plant will deplete groundwater, that question needs to be included within the model used. If there is a need to know how much various treatment options contribute to acid rain or global warming, the models must address those questions.

Important steps in constructing or choosing formal analytical models are

1. Setting the boundaries on what is to be modeled
2. Choosing the parameters to be modeled
3. Determining the depth to which those parameters will be analyzed

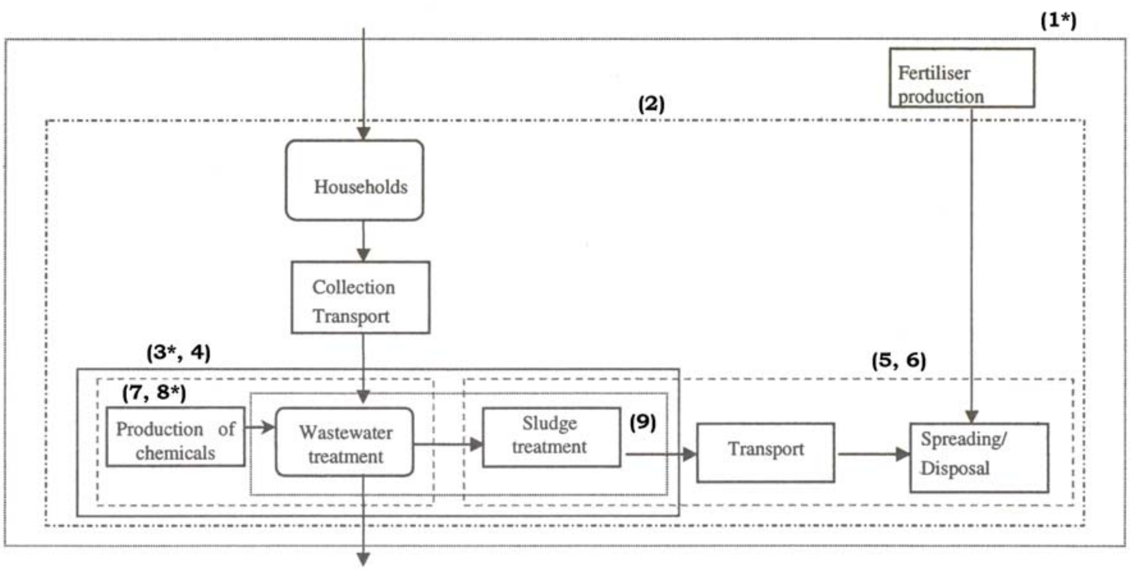
System boundaries define the extent, in space and time, of the system that is being evaluated. Parameters define the effects that are being monitored. To put it another way, system boundaries define the actor, and parameters define the actions evaluated—for example, a wastewater treatment system acts by discharging 10 tons nitrate-nitrogen per year to the receiving water.

Framing the Question

Establishing appropriate system boundaries is crucial for results, since setting system boundaries in different ways can tip the scales in favor of one technology over another. Examples of system boundaries are illustrated in Figure 4-1, which shows a simple model of wastewater treatment. Figure 4-1 shows how system boundaries have been drawn around this simple model in at least eight different ways in nine publications. Each publication is designated by one of the numbers next to the boundary that is used in the publication.

This illustration shows primarily the spatial extent of the systems. The only time element captured in Figure 4-1 is whether system construction has been included, or only the operations phase—the two publications marked with an asterisk consider the environmental impacts of system construction. Another time element to be considered in drawing system boundaries is how far into the future are effects projected. For example, if wastewater sludge is deposited in a landfill, it may continue to affect the environment for decades through the loss of nutrients and other substances into leachate and the production of methane from the anaerobic breakdown of organic matter. Since Figure 4-1 does not indicate this time element, the nine publications may actually represent nine non-overlapping sets of system boundaries.

1. Tillman *et al.* 1998
2. Neumayr *et al.* 1998
3. Sonesson *et al.* 1997
4. Matsuhashi *et al.* 1997
5. Dennison *et al.* 1997
6. Emmerson *et al.* 1995
7. Ødegaard 1995
8. Roeleveld *et al.* 1997
9. Mels *et al.* 1998



Adapted from Lundin, Bengtsson, and Molander (2000)

Figure 4-1
A Simplified Sketch of Parts of a Wastewater Treatment System, Showing Different Ways To Draw System Boundaries

Parameters are most easily clarified through examples. Balkema *et al.* (1998) reviewed 15 publications that evaluate technology with respect to sustainability and found a total of 35 parameters used, in the categories of economic criteria, environmental criteria, technical criteria, and socio-cultural criteria (Table 4-1). Many, but not all, of the publications reviewed are specifically focused on wastewater treatment. The table is complicated; it shows the great variety of questions that can be asked about a technology in seeking to understand its sustainability. Even if environmental sustainability is considered alone, 21 parameters were identified.

Table 4-1
An Overview of Parameters Used in the Literature to Compare Wastewater Treatment

Source: **Aa** = Aalbers 1997; **Az** = Azar 1996; **Be** = Bengtsson 1997; **Bu** = Butler 1997; **D** = DTO 1994; **Em** = Emmerson 1995; **E** = ETC 1996, **F** = Finnson 1996; **I** = Icke 1997; **J** = Jacobs 1996; **L** = Langeveld 1997; **N** = Niemcynowicz 1994; **O** = Otterpolh 1997; **S** = STOWA 1996; **Ø** = Ødegaard 1995

Note: The numbers in the table indicate the used weighting factors, the abbreviations refer to the terms used in the publications; C = costs, Cn = concerns, E = environmental efficiency, P = principles for sustainability, S = sustainability factors, St = steering variables, T = target, Te = technical paradigm, V = variables in the LCA input-output table, * = LCA study.

	Aa	Az	Be*	Bu	D	Em*	E	F	I	J	L*	N	O	S*	Ø*
Economical criteria:															
Costs	2				C		S	P		E	C				E
Environmental criteria:															
Accumulation		P							T						
Biodiversity / land fertility		P			100		S	P					P		
Dissication													Cn		
Export of problems in time & space									T	S			P		
Extraction		P													
Integration in natural cycles							S						P		
Land area required / space	2				1										
Odour/ noise / insects/ visual	0.5														
Optimal resource utilisation / reuse:		P		S			S	P	St	S		P	P		
Water	2			S	1000		S	P	St		V		Cn		
Nutrients	2		V	S			S	P	St				Cn		
Energy	2		V		100	V	S	P			V		Cn	V	V
Raw materials			V		10	V	S	P			V		Cn	V	
Pathogen removal / health	1			S	1000		S	P			V				
Pollution prevention				S			S	P				P	P		
Emissions:															
BOD / COD	1		V		1000	V	S				V			V	V
Nutrients	1		V		100		S				V			V	V
Heavy metals	1				1000	V	S				V			V	
Others	1		V			V	S				V			V	
Sludge / waste production			V		1000	V	S				V			V	V
Use of chemicals			V		10		S								
Technical criteria:															
Durability				S			S								
Ease of construction / low tech	1											P			
Endure shock loads / seasonal effects	1												Cn		
Flexible / adaptable				S			S								
Maintenance	2												Cn		
Reliability / security	1						S	P							
Small scale / onsite / local solution				S						Te	V	P			
Social-cultural criteria:															
Awareness / participation							S			S					
Competence / information requirements	1						S	P							
Culturally accepted							S								
Institutional requirements	1						S	P							
Local development				S											
Responsibility								P							

Source: Balkema *et al.* (1998)

System boundaries and parameters are distinct; any of the systems defined by the boundaries shown in Figure 4-1 could, in principle, be evaluated with respect to any combination of parameters from (Table 4-1).

The concepts of system boundaries and parameters help illuminate why wastewater decisions may only move problems in time and space, rather than solve them. In the US, environmental parameters considered have generally consisted only of the quality of the receiving waters, including levels of pathogens, nutrients, and organic matter. Effects on land-use patterns are sometimes considered, but often not. Effects on soil quality of spreading sludge or septage are seldom considered (perhaps because federal and state regulations governing land application are considered to protect public health and the environment sufficiently).

System boundaries are generally drawn so that environmental impacts elsewhere, for example, to the waters where a key input is manufactured, or to the air or soil anywhere, are not counted. Recall how for the South Lake Tahoe treatment plant, described by Antonucci and Schaumburg (1975) in Chapter 1, increased water treatment performance was achieved through steeply increasing inputs of energy and chemicals. The environmental effects of the energy transformation and chemical use were probably not considered by permitting agencies or other decision-makers—the generation of electricity and manufacture of chemicals took place outside the boundaries of the system being evaluated.

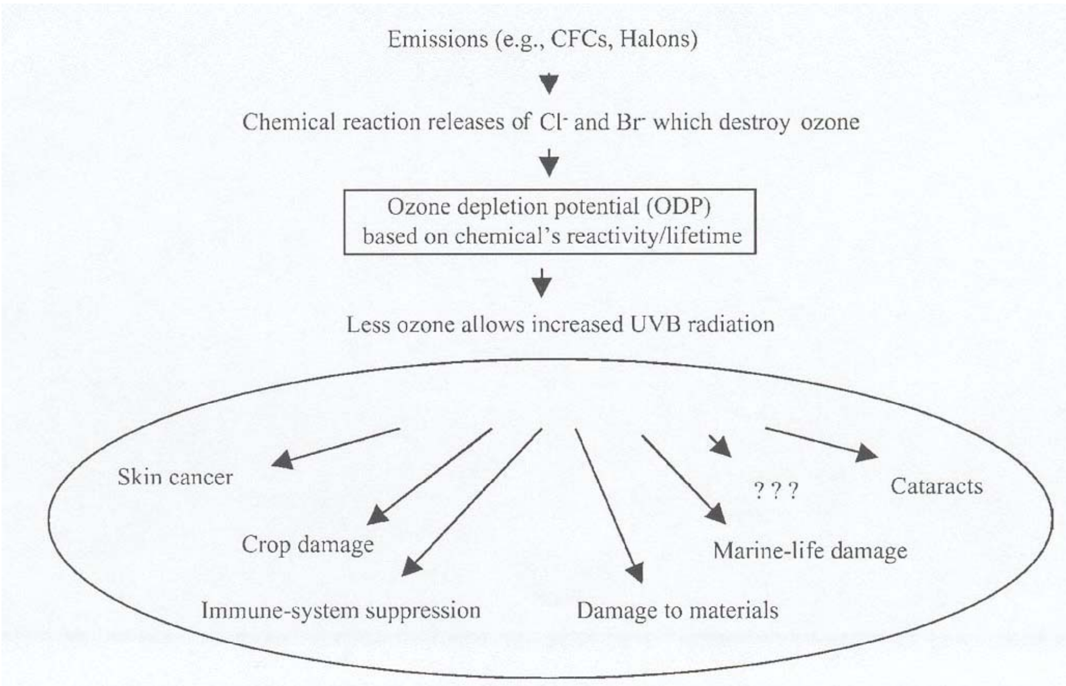
System boundaries in time are generally drawn to consider effects of a wastewater treatment alternative immediately after it opens. The onsite wastewater treatment system is installed according to specifications, and probably functions well the day it starts up, or after a short time, when the microbial communities become established. The many jurisdictions that do not have any sort of management program for onsite systems implicitly either assume that the system will continue to perform like new without regular maintenance or do not count environmental effects that occur after a number of years. Similarly, with centralized wastewater treatment plants, the effects of short-term overflows, infiltration and inflow, and pipe breakages are sometimes not considered.

Sludge handling also appears different if viewed over a longer time perspective. If the sludge is to be landfilled, the environmental effects of leachate are a long-term issue not generally captured in snapshots of environmental impacts. Similarly, once in the landfill, the sludge also generates methane, which contributes strongly to global climate change if it escapes into the atmosphere. If methane effects are not considered, this could be because the system boundary in time excludes them, or because the parameter of global climate change is not considered, or both.

Defining system boundaries and parameters to be evaluated can have a profound impact on the results obtained. Appendix D gives further detail on issues to consider when defining system boundaries and parameters. Two case studies described there show how including or excluding the fertilizer value of wastewater nutrients recycled to agriculture can change the ranking of alternatives.

Choosing the Depth of Analysis

In addition to establishing the system boundaries and parameters of the study, decision-makers choose the depth to which the parameters are analyzed. The assessment of parameters generally follows the path of relationships, termed the cause-effect chain, between a process action and final impact. An example of a cause-effect chain is shown in Figure 4-2. The figure describes the causes and effects of ozone depletion. Chlorofluorocarbons (CFCs) and halons are emitted from a process resulting in ozone depletion, which eventually leads to human and ecosystem damages, such as skin cancer and DNA alteration of marine-life (oval boundary). These damages are commonly referred to as endpoint impacts or effects, which differ from midpoint effects that occur further up the cause-effect chain. The midpoint effect chosen in this case is the ozone depletion potential (rectangular boundary). The endpoints chosen here could also be extended further, for example crop damage could be extrapolated to starvation and so on. The obvious consequence of characterizing effects further along the cause-effect chain is additional analysis.



Source: Bare *et al.* (2003)

Figure 4-2
Midpoint and Endpoint Effects of Ozone Depleting Chemicals in a Cause-Effect Chain

The choice to extend the analyses to model endpoint effects has been widely debated. A strong argument for endpoint modeling is that damages to human or ecosystem health are easier for decision-makers to understand and value, while midpoint effects—often described as impact potentials—tend to be vague and esoteric. Additionally, when end effects are estimated it is possible to compare similar parameters without weighting based on value choices of the general populous and still produce results that would be accepted by a wide audience.

Unfortunately, this increased degree of sophistication requires additional effect modeling, introducing additional factors of error and less agreement on which methods to use. Bare *et al.* (2003) argue that midpoint effect modeling maintains agreement among the widest audience of users. They also point out that for the US, endpoint models are only available for some parameters generally considered by decision-makers. Typically human health parameters are more consistently modeled to endpoints than ecosystem health parameters. Modeling ecosystem health impacts with a limited number of endpoint models may miss important impacts captured at the midpoint level.

Conclusion

With this understanding of parameters, system boundaries, and possible depths of analyses, a range of formal analytical models that could be used to explore the non-economic costs of wastewater treatment alternatives is considered next.

5 SCOPING OF METHODS AND DATA

Method Descriptions

Three general methodologies have been identified for comparison of non-monetary impacts of processes or services associated with wastewater treatment:

- Life-cycle assessment (LCA)
- Environmental impact assessment (EIA)
- Open wastewater planning (OWP)

Both the LCA and EIA methodologies were developed to evaluate the environmental impacts of human actions. OWP was developed specifically to evaluate wastewater treatment alternatives using a wider framework for consideration. The primary methodological difference between LCA and EIA is that LCA attempts to provide a systematic method for accounting for all environmental impacts, while EIA provides more of an interpretive process. Through comprehensive analysis and aggregation, LCA is designed to expose when environmental problems are merely changed in nature or displaced in space or time, as discussed in Chapter 1. EIA is much less standardized in its quantification of impacts and instead changes its analyses in response to the uniqueness of place and process. OWP tends to be less formalized and may be adapted to either the LCA degree of analysis or EIA style of interpretation.

Each of these methodologies may be thought of as conceptual frameworks for analysis of environmental impacts. However, LCA may also be closely associated with various standardized impact characterization methods. Since LCA is sometimes used as a framework and sometimes as a specific set of methods, serious confusion can arise when discussing LCA and LCA studies if care is not taken to note precisely how the analyses were conducted.

The descriptions of LCA, EIA, and OWP methods listed in the following sections will demonstrate and clarify the differences of the specific analyses between methods.

Life-Cycle Assessment (LCA)

Environmental life-cycle assessment (ELCA), commonly referred to simply as life-cycle assessment or life-cycle analysis (LCA), is a method of accounting for the environmental impacts of a product, service, or process over the course of its life cycle. In its broadest definition, LCA is a summation of all environmental burdens that occur from "cradle to grave" during a product's or service's life cycle:

- Extraction of raw materials
- Transportation
- Manufacturing
- Operation
- Maintenance
- Reuse
- Disposal

The environmental burdens generally include use of land, energy, water, and other materials and the release of substances (harmful and beneficial) to the air, water, and soil. This evaluation typically proceeds as follows:

1. **Goal and scope definition**. This phase includes the purpose of the study, the system boundaries, and the functional unit. A material and energy flow chart is also mapped.

2. **Life-cycle inventory (LCI).** In this phase, all information on emissions and the resource consumption of the activities in the system under study are cataloged.

3. **Life-cycle impact assessment (LCIA).** In this phase, the environmental consequences of the inventory are assessed and sensitivity analyses are developed. This typically includes aggregation of the inventory into impact categories.

4. **Interpretation.** This fourth but controversial step occasionally included by some LCA methods is the interpretation of the results, which may include normalization, weighting, and/or additional aggregation.

Several variations and simplifications of this approach have been offered, a few of which are examined in this report.

The concept of life-cycle assessment first emerged in the late 1960s, but did not receive much attention until the mid-1980s (Ecobilan undated). In 1989, the Society of Environmental Toxicology and Chemistry (SETAC) became the first international organization to begin oversight of the advancement of LCA. In 1994, the International Standards Organization (ISO) began developing standards for the LCA as part of its 14000 series standards on environmental management. The standards address both the technical details and conceptual organization of LCA (Guinee 2001).

- ISO 14040—A standard on principles and framework
- ISO 14041—A standard on goal and scope definition and inventory analysis
- ISO 14042—A standard on life-cycle impact assessment

- ISO 14043—A standard on life-cycle interpretation

Several of the methods described as LCA methods follow the LCA framework defined in ISO 14040, involving an inventory similar to that described in ISO 14041, and assessment of impacts to some degree as described in ISO 14042, while a smaller number take on the normalization and weighting also discussed in ISO 14042. Still, methods based on the ISO standards may differ greatly, given that the ISO standards allow flexibility to customize characterization and normalization factors and weighting methods to suit the values and conditions of a particular location or sector.

Environmental Impact Assessment (EIA)

Environmental impact assessment can be defined as a process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of proposed projects or plans and physical activities prior to major decisions and commitments being made. EIA as a procedural concept was introduced in response to the US National Environmental Protection Act (NEPA) of 1968 and the US Environmental Quality Improvement Act of 1970, which mandated that all federal agencies systematically integrate environmental concerns into the planning and decision making for all federal projects, plans, and activities. Since then, the NEPA-like policies have been adopted and adapted by 20 of the 50 states for state-level projects and by many countries world-wide, including the European Community (Kontos and Asano 1996).

The general procedure for EIAs includes the following steps:

1. **Scoping.** Identify key issues and concerns

2. **Screening.** Decide whether an EIA is needed (for example, is there a significant environmental impact?)

3. **Identify Alternatives.** List the alternatives, sites, and techniques; and describe the affected environment

4. **Assess Impacts.** Assess the social and environmental impacts of each alternative

5. **Mitigation Measures.** Develop mitigating actions to prevent or reduce potential impacts

6. **Issue Environmental Statement.** Produce a non-technical report on findings of the EIA

Steps 2, 5, and 6 are unique to EIAs when compared to LCA. Step 3 is similar to the LCI step of LCA, but in practice it has been much less comprehensive.

Open Wastewater Planning (OWP)

Open wastewater planning is a newer, less well known, and less formalized method than LCA or EIA. It has been developed especially for wastewater treatment decisions. OWP begins by setting goals for the wastewater treatment process to achieve. The decision-makers may be guided in their goal setting by a third party (for example, a consultant and/or state or federal regulators), but it is crucial that the decision-makers take ownership of the goals. When the goals are set, a third party generates a diverse set of design alternatives that meet most or all of those goals and presents them simply, at the level of a feasibility study. The ways in which the alternatives affect the goals set up in the beginning are described briefly, and decision-makers use the material as a decision aid.

OWP has been used on a limited basis in Sweden, and a document describing the process in English has been distributed to promote OWP as a model to use throughout the Baltic Sea region (Ridderstolpe 1999). The details of the model are presented in Chapter 6.

Initial Method Comparisons

Based upon the initial literature review and previous experience, the methods were reviewed by examining and comparing the general concept, necessary input data, objectives, expected results, software availability, strengths, weaknesses, and procedures of each method considered.

The methods prioritized for more detailed evaluation were:

- Life-cycle assessment (four variations):
  - **Eco-indicator 99 (EI 99)—**an LCA method with a high level of aggregation based on the ISO 14000 guidelines
  - **The Sustainable Process Index (SPI)—**an ecological evaluation system that characterizes mass flows by their use of solar energy
  - **TRACI—**an ISO-based method created by the United States Environmental Protection Agency (US EPA) for evaluating the potential environmental and human health impacts of processes under US conditions
  - **URWARE—**a material and energy flow analysis and assessment method used by wastewater researchers in Sweden
- Environmental impact assessment
- Open wastewater planning

Rationale for Methods Included

The Eco-indicator 99 method is widely used in Europe and is one of few ISO-based methods that characterize endpoint impacts and weigh and aggregate impacts into a single value. There are advantages and disadvantages to characterizing endpoint impacts, and impact aggregation that continue to be debated among LCA practitioners and are discussed in Chapter 4. TRACI, the US ISO-based equivalent of EI 99, characterizes mostly midpoint impacts. Therefore, EI 99 was chosen for comparison purposes, despite the fact that the EI 99 characterization factors are modeled for Western Europe. Additionally, EI 99 has been used in several studies to assess waste and wastewater treatment (Rihon *et al.* 2002, Lassaux *et al.* 2001, and Lassaux *et al.* 2002).

The Sustainable Process Index was chosen because it represents a different and somewhat simplified approach to inventory and impact assessment, possibly reducing the time and resources required to perform an assessment. Also, like EI 99, the SPI aggregates impacts into a single value, which could be beneficial for some wastewater decision-making situations.

TRACI was an obvious choice for the in-depth evaluation, because it represents the latest attempt in the US to establish a detailed LCA methodology that is consistent with national and international standards. TRACI is the only ISO-based methodology identified that characterizes impacts for US conditions. Additionally, TRACI is unique among ISO-based methodologies, because it characterizes impacts to counties, states, and regions if the locations of releases are known.

The URWARE model was also an obvious selection, since it represents the only LCA-type method developed specifically for evaluating water and wastewater treatment systems or scenarios and is the only method that combines detailed material and energy flow analysis with ISO-based impact characterization. Although URWARE contains default values for Swedish conditions, it is likely easily adaptable to US conditions if complementary US values are available.

Environmental impact assessment is used for evaluating the environmental impacts of any planned new or upgraded wastewater treatment facility receiving federal funding and is used by numerous states for state-funded projects as well.

Open wastewater planning was chosen on the basis that it was developed specifically to assist small communities in making more informed and more sustainable wastewater treatment decisions. It has been applied in several European communities and represents a potentially simplified alternative to the LCA and EIA methodologies.

A discussion of the rationale for methods excluded from the in-depth analysis is included in Appendix C.

Discussion of Different Types of Data Needs

During the scoping review of methods it became helpful to distinguish between the types of data needed for the assessment of treatment alternatives for the purposes of comparing methods, establishing system boundaries, and cataloging data.

Material-Level, Component-Level, and System-Level Data

Material-level data provide basic building blocks for life-cycle comparisons of the environmental investment in the physical components of wastewater-treatment options. These data include all of the emissions released and resources consumed in the production of a material, for example, steel, concrete, or PVC. Material-level data are typically the most commonly available data, since they are the least aggregated and most useful to the broadest audience of users. Data of this category are commonly provided by industry organizations such as the Association of Plastic Manufacturers–Europe (APME) and the International Institute of Steel Industry (IISI). Material-level data may be useful when complete system-level data are unavailable, for example, for new designs or unique variations.

Component-level data include all of the impacts associated with the equipment and materials. These data may be considered aggregations of material-level data, plus the impacts associated with the manufacturing, transportation, installation, operation, decommissioning, and disposal of the equipment and materials. For passive components like pipes, the production and/or disposal of the materials can provide the greatest portion of the impacts. In situations where component production data are not available, it may be possible to estimate the impact of producing a component by summing the impacts of the materials. One way of testing the validity of this estimation is to use an input/output (I/O) model to compare the production of the materials to the production of the component (Matthews 2004). (See the discussion of streamlining methods in Chapter 9 for more detail.) As with material-level and component-level data, component-level data may be useful when complete system-level data are unavailable, for example, for new designs or unique variations.

System-level data can again be considered aggregations of the component impact data, with additional operational performance data and other characteristics that are only revealed as a complete system. These data typically include operational energy use, chemical inputs, and pollutant removal; footprint of the system; noise, smell, and aesthetic effects; complexity of operation; and other data. Additionally, these data embody information about the configuration of unit processes and components, such as system design.

In instances where complete system-level data are available, the social and environmental impacts of wastewater treatment alternatives may be accounted or reported with relative ease. However, where system-level data is not complete, which is the case for almost all wastewater treatment options, practitioners must increasingly aggregate impacts at the component and/or material levels.

When system boundaries for comparisons are drawn to ignore the investment in the physical structure of a treatment option, focusing solely on operation, or when a comparison method itself is limited to operation, material-level data is not needed. Historically, LCA has been characterized by its assessment of both the material investment and the operation, while EIA and OWP have focused on the operational and site impacts. However, EIA and OWP are not limited methodologically to this practice and likewise LCA can assess the operational impacts exclusively. In fact, one of the LCA methods, URWARE, was developed for evaluating solely the operational activities of water and waste treatment.

Site-Specific Versus Generalizable Data

Another important data type distinction is the existence of both site-specific and generalizable data. System-level data have the potential to be highly site- and design-specific. That is, the system-level data vary enough between sites and designs that they must be generated for each situation in which an alternative is proposed. Such data are characteristic of data generated for EIAs. For LCAs, practitioners attempt to draw from data that are generalizable to decrease the need for primary data; however, for the US wastewater industry it is difficult to make assumptions about how generalizable system level data are, due to the scarcity of actual performance data available. An in-depth review of treatment system performance of all system types and other limiting factors, such as climate (Werker *et al.* 2002), is needed to accurately assess consistency in system performance. A report to be issued by the National Decentralized Water Resources Capacity Development Project in 2005, entitled *Variability and Reliability of Test Center and Field Data: Definition of Proven Technology from a Regulatory Viewpoint*, may shed some light on the connection between test center data and field data. For now, however, some system-level data are likely generalizable, but the distribution of performance is poorly understood.

It is expected that component-level data are generalizable for a given component and use. For example, the energy use for a given pump used for pressure distribution of effluent from a four-bedroom home is relatively constant from site to site, barring anomalies like pumping effluent uphill a long distance. However, according to a recent review of energy saving strategies for wastewater treatment, poor engineering design is common, and pump and blower systems can be severely oversized, operated improperly, or fouled and worn out over time (Elliot 2003). Improper operation or poor design is difficult to estimate and factor. Like judging system reliability, operator and designer reliability are difficult to assess and have not been incorporated into previous assessments.

Extended system data includes impact data about processes occurring outside the core system boundary. Numerous studies have stressed the importance of including extended systems in wastewater treatment assessments, but often extended processes are excluded because they multiply the data collection for processes that are not considered directly relevant to wastewater treatment (Lundin *et al.* 2000, Balkema *et al.* 1998, and Kärrman 2000).

6 CLOSER EXAMINATION OF METHODS

LCA–Life-Cycle Assessment

The International Standards Organization (ISO) defines LCA as a “compilation and evaluation of the inputs and outputs and potential environmental impacts of a product system throughout its life cycle” (quoted in Guinee 2001). Benefits of this methodology include that it attempts to be holistic in terms of its environmental evaluation and is largely quantitative in nature. As a result, LCA may be effectively accounting for the full environmental cost—avoiding processes or practices that shift environmental problems from one medium or sector to another (Guinee 2001). Because of efforts to standardize LCA procedures, the general LCA method is appropriate for conducting comparisons of products, services, or plans, or—in this case—wastewater treatment options. See Table 6-1 for a list of appropriate decision situations for LCA.

Table 6-1
Appropriate Decision Situations for LCA

Situation	Role of LCA
Global exploration of options	The LCA study is performed to get a first impression of the environmental effect of certain options
Company-internal innovation	The LCA study is performed to assess the environmental impact of company internal processes, product development, or technical innovations
Sector-driven innovation	Similar to the above, except that it is sector-oriented (in a formal organization representing the industry or chain of companies, it can be regarded as an internal activity)
Comparison	The LCA study is performed to assess whether a product or system meets certain environmental standards, or whether it is more environmentally sustainable than another product or system
Comparative assertion disclosed to the public	The LCA study aims to provide an environmental claim regarding the superiority or equivalence of one product over another competing product (i.e., "green" labeling)

Adapted from Guinee (2001)

Although LCA's holistic nature is referred to as a benefit above, it is also a limitation; the broad scope of LCA results in a tremendous amount of costly data collection (Guinee 2001). Likewise, while the standardization of life-cycle assessment is perceived as a benefit, it greatly limits LCA's ability to address localized impacts. Note that the characterization of local impacts generally requires site-specific modeling, outside the normal purview of LCA. This is not to say that an LCA of local impacts could not be performed, but it would be an extended or customized, not standardized, procedure.

Such customization is not new to LCA, particularly in LCAs of wastewater treatment systems. Nearly half of the studies reviewed were based on life-cycle inventory (LCI) and life-cycle impact assessment (LCIA) methods that were developed of impact categories and impact characterization methods from various sources (Brix 1999, Dixon *et al.* 2003, Jimenez-Gonzalez *et al.* 2001, Mels *et al.* 1999, Tillman *et al.* 1998, Ashley *et al.* 1999, Antonucci and Schaumberg 1975, Roeleveld *et al.* 1997, and Vidal *et al.* 2002). In general, the categories and methods were selected to best address the scope and goals of the assessment, yet were mostly consistent with the ISO guidelines. The standardized methods also allow for some customization, since impact categories may be dropped if they have been deemed insignificant by a scoping assessment.

Appendix F describes the details of most of the studies reviewed. In its wastewater applications, LCA has been used by researchers to understand environmental impacts of different alternatives and has been used to gain information useful at a policy level. LCA has not been used to decide among specific alternatives. A project planned for 2005 by the city of Gothenburg, Sweden will use an LCA method (URWARE) to make wastewater policy decisions for the city. This may be the first instance of a municipality financing a wastewater LCA for decision-making purposes.

Other general limitations of LCA are (Guinee 2001 and Bare *et al.* 2003)

- It does not provide the framework for a complete risk assessment study.
- It does not account for reliability, although durability is sometimes considered.
- It models normal operation and does not account for accidents.
- Most studies reflect a limited number of defined alternatives, although modeling of alternatives is increasing, which allows the user to interactively tweak the alternatives modeled.
- LCA is focused primarily on environmental impacts. Some studies include a few human health, nuisance, and economic effects, but LCAs are not holistic in this regard.
- Availability of data and cost. (The availability of data is a key limitation to all of the methods considered and is discussed in greater detail in Chapter 7.)

Two primary categories dictate the cost of analyses. First, the cost of software, databases, and peer review, and second, the personnel cost of collecting disparate data and conducting analysis (Suh 2004). Typically, LCA software with embedded databases ranges from $1,000 to $10,000 USD (see Chapter 7), but more may be spent on additional databases. Personnel costs are generally the greatest expense. Estimating the person-days necessary to collect the disaggregated data (data mining) is difficult without a clear definition of the expected level of quality of the

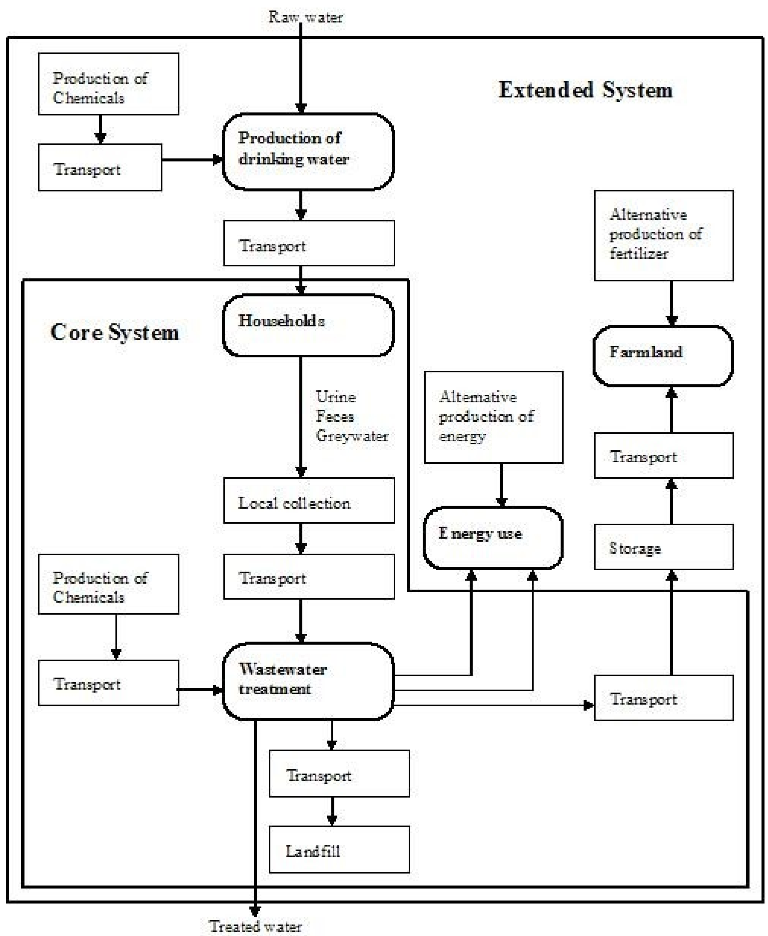
LCI and scope of work. Communication with stakeholders and interpretation of results typically adds considerably more personnel costs. There is a significant range in the levels of detail and scope of previous wastewater LCA studies (see the comparison of LCA wastewater studies in Appendix F). This range will also be true for the US, unless strict standards are developed for the US wastewater industry.

In general, LCA studies range from one-half million USD for a detailed assessment of an automobile (Suh 2004) to a few thousand USD for a basic assessment of construction materials. Costs may be reduced through streamlining the data requirements and assessment criteria. Further discussion of such techniques can be found in Chapter 9.

Finally, LCA is not intended to replace the decision-making process, but rather to inform and structure part of the decision-making process (Guinee 2001). This suggests that general LCA be included with other tools such as risk and reliability assessment, social and economic assessments, as well as detailed process models and analyses (for example, material flow analysis). Additionally, it seems appropriate that such extended analyses be incorporated by a means of a multi-criteria analysis tool, which again should not serve to replace decision making but may structure and inform the decision discussion.

Applying LCA: A Swedish Case Study

The LCA component of the Swedish ECO-GUIDE project, described in Tillman *et al.* (1996) and Tillman *et al.* (1998), is one of the most frequently cited wastewater life-cycle comparison studies largely because the authors made a distinct effort to include processes outside of the typical wastewater treatment system boundary (Björklund *et al.* 2001, Jönsson 2002, Kärrman 2000, Lundie *et al.* 2004, Lundin *et al.* 2000, and Vidal *et al.* 2002). The study included a life-cycle comparison of wastewater treatment options for two Swedish towns: Bergsjön, a suburb of Gothenburg, and the coastal village of Hamburgsund. Understanding that changes in the existing wastewater facilities could result in a decrease in drinking water use from low flow collection; energy consumption, through biogas production; and use of chemicals fertilizers, by way of agricultural use of urine and treated solids, Tillman *et al.* (1998) included additional technical systems in what they labeled the extended system apart from the core wastewater treatment system (Figure 6-1). The boundaries were expanded to more accurately compare the environmental impacts of wastewater treatment options focused on conserving and recovering water, energy, and nutrients in wastewater treatment.



Adapted from Tillman *et al.* (1998)

Figure 6-1
Flow Chart of the Core Wastewater Treatment and Extended System Boundaries

The primary purpose of the study was to determine the environmental impacts of changing the existing systems to more localized treatment with increased recycling of nutrients. A second, but important, intention of the study was to compare the environmental impacts associated with construction of the system components (investment) with those associated with the operational activities of the system.

In Bergsjön, the existing wastewater treatment system was a conventional centralized system with denitrification and biogas production. Hamburgsund had a small conventional system, with sludge transported to a larger facility for processing. For each case, the existing system was compared with two decentralized options:

1. Utilizing the existing collection system, solids are collected at the residences and transported to local digestion and drying facilities, while the liquids are treated in sand filter beds. Treated solids are then used as fertilizer.

2. Graywater, urine, and feces are separated using source separating toilets and plumbing and the graywater is treated in sand filter beds. Feces, flushwater, and graywater solids are collected at the residences and digested and dried locally. Treated solids and stored urine are used as fertilizer.

After defining the goal and scope of analysis, Tillman *et al.* (1998) compiled an extensive inventory of resources used, substances emitted, and wastes produced for each activity contained within scope of analysis. This compilation included inventories of the investment in (Table 6-2) and operation of (Table 6-3) the core system as well as an inventory of the operation of the extended system. The inventory of operations resulted from an analysis of the material and energy flows across the system boundaries to and from nature as well to and from other components of the technical system.

Table 6-2
Inventory Results of the Investment of the Bergsjön's Core System (per person equivalent/yr)

Natural resources	Bergsjön			Emissions	Bergsjön		
	Alt 0	Alt 1	Alt 2		Alt 0	Alt 1	Alt 2
Energy				*To air*			
Electricity, MJ	7.6	8.8	8.9	CO_2, kg	2.6	2.8	3.4
Fossil fuels, MJ	45.7	49.3	62.2	CH_4, g	0.8	0.8	0.9
				SO_2, g	11.7	12.6	16.5
Raw materials				NO_x,g	13.6	15.5	18.9
Fe, kg	0.26	0.098	0.26	Hydrocarbons, g	10.1	10.5	15.0
Ni, g	1.1	0.7	6.1	CO, g	2.3	2.7	2.9
Cr, g	3.6	2.2	19.5	Particulate, g	2.4	2.6	3.5
Sand, kg	1.9	1800	1400				
Rock, kg	3.3	77.5	64.8	*To water*			
Kaolin/fieldspar/quartz, kg	0.54	0.54	0.37	COD, g	0.54	0.54	0.95
Limestone, kg	1.7	3.6	3.0	N-tot, g	0.0071	0.0062	0.0177
NaCl, g	317	320	322	P-tot, g	0.00011	0.00008	0.00031
				Waste			
				Solid waste, kg	0.15	0.12	0.44
				Hazardous waste, g	0.55	0.56	0.57

Adapted from Tillman et al. (1998)

Table 6-3
Inventory Results of the Operation of Bergsjön's Core System (per person equivalent/yr)

	Bergsjön				Bergsjön		
	Alt 0	Alt 1	Alt 2		Alt 0	Alt 1	Alt 2
Natural resources				**Emissions**			
Fossil fuels, MJ	17.6	39.9	68.0	*To air*			
Bauxite, kg	0.12	0	0	CO2, kg	0.89	3.04	5.36
Limestone, kg	2.0	0	0	CH4, g	0	0	0
Sand, kg	0	590	230	SO2, g	5.4	6.0	10.5
NaCl, kg	0.05	0	0	NOx,g	16.7	50.5	88.9
				Hydrocarbons, g	1.1	8.1	14.2
Inflows from extended system				CO, g	13.6	11.6	20.5
Electricity, MJ	167	97.2	24.8	Particulate, g	1.8	3.9	6.9
Drinking water, m3	73.0	73.0	54.8				
Hydrogen peroxide, g	0.013	0	0	*To water*			
NaClO, g	460	0	0	BOD, kg	0.94	0.05	0.08
				COD, g	2.08	2.3	0.96
Outflows to extended system				N-tot, kg	2.37	3.2	0.31
Heat in wastewater, MJ	3076	0	0	P-tot, kg	0.11	0.21	0.13
Biogas, MJ	19.0	155	221				
Nitrogen to agriculture, kg	0.48	0.47	4.31	*Waste*			
Phosphorous to agriculture, kg	0.96	0.96	1.17	Solid waste, kg	2.0	0	0
				Hazardous waste, g	0.05	0	0
				Sludge, kg	3.21	0	7.6
				Red mud, kg	0.09	0	0

Adapted from Tillman *et al.* (1998) [1]

Tillman *et al.* (1998) employed an LCI process that reflects the LCI needed for most LCA methods assessing the environmental consequences of wastewater treatment options. While future studies may choose other LCA methods to extend or lessen the system boundaries, Tillman *et al.* offered an appropriate base perspective from which to begin. Likewise, the Tillman inventory offers a list of general data needs, which are indicative of what US decision-makers will require for conducting similar comparisons.

While these lists are indicative, they are not comprehensive. At least one group of data not included in Table 6-3 is heavy metals and other toxics. The Tillman study did not have data on the metals content of the wastewater and assumed that metals content would be insignificant for the local domestic systems. For larger centralized systems that include industrial and/or storm water, toxics may be an important consideration. Other studies, including those utilizing the URWARE method described later, have evaluated the fate of heavy metals through the system and reported them as an important impact for consideration of options (Jeppsson and Hellström 2002, and Eriksson *et al.* 2002).

[1] Alt 0 is the no change (existing conventional system) alternative, Alt 1 is the decentralized sand filter alternative, and Alt 2 is the decentralized urine separation alternative. Each alternative is described in greater detail in the text.

To compare the three scenarios for each of the two towns, Tillman *et al.* (1998) employed a customized LCA methodology. Their approach generally follows the ISO guidelines for goal and scope definition and inventory analysis, but for the core system stops short of impact assessment of the inventory results, a step that is typically taken to help decision-makers make sense of the extensive inventory so that they can begin to weigh the information. Instead they focused primarily on dominance and sensitivity analysis of system components' and processes' effects on the inventory results. In this way the inventory results were used directly for discussion, avoiding some of the subjectivity introduced by assessment methods but also requiring that the decision-makers be able to characterize the resultant impacts of the emissions and resource uses they are comparing.

From a research perspective, the inventory dominance and sensitivity analyses described by Tillman *et al.* (1998) are useful for guiding future studies. However, making sense of such analyses for a large list of inventory parameters may be asking too much of most US decision-makers. Therefore impact assessment methods and/or weighting may be applied to assist decision-makers in valuing inventory results.

For the analysis of the inventory results of the extended system, impact assessment and weighting methods were applied. The details of this analysis are not extensively reported except to say the impact assessment and weighting were not used to rank the options, but rather to determine the most important parameters for discussion.

The following findings and conclusions were reported (Tillman *et al.* 1998).

Core System:

- Investment-related impacts are primarily related to fossil fuel consumption, where the dominant activities included sanitary goods and piping in connection with the buildings, and tanks associated with the source separation alternative
- Within the system operation, electricity consumption was less for the local and source separated systems, but was replaced in part by fossil fuel use for transportation
- For the small town of Hamburgsund, the operational impact was clearly larger than that of the investment
- For Bergsjön where scale was considerably larger, the distinction was less apparent
- The impacts of investment varied less over the alternatives than those of the operation

Extended System:

- For Hamburgsund, most parameters favored the source separating system above the sand filter beds with existing piping, which was ranked higher than the existing system
- For Hamburgsund, large reductions in environmental impact are possible for the existing system, for instance through the use of treated solids for agriculture

- For Bergsjön, where the alternatives were more closely matched, the weighting methods valued the results differently, resulting in different rankings
- Emphasis on CO_2 emissions favored the source-separating alternative over the sand filter alternative, which was ranked above the centralized plant
- Emphasis on nitrogen emissions to water again favored the source-separating alternative, which was followed by the centralized plant
- Emphasis on phosphorus emissions to water favored the existing system slightly over the source-separating alternative

This study provides an appropriate indication of what types of comparisons are possible, what data are needed, and what parameters may be important for any LCA of wastewater treatment options.

LCA Variations

A number of variations on the LCA methodology may be and, in some cases, have been employed similarly to the Swedish case study above.

EI 99–Eco-Indicator 99

The Eco-indicator 99 (EI 99) methodology was released by PRé Consultants in the Netherlands as an update to the Eco-indicator 95 (EI 95) methodology. EI 99 and EI 95 are both available in the globally popular SimaPro LCA software and were developed to specifically address the most controversial subject in life-cycle impact assessment—weighting of impact categories. This method is unique in comparison to the other LCA methods in that its methodology has been built from the weighting step, but it still follows the ISO standards.

The general procedure of EI 99 is as follows (Goedkoop and Spriensma 2001):

1. Goal definition and scoping
2. Inventory of resource consumption and emissions
3. Classification of inventoried impacts and resource, land-use, and fate analyses to determine total concentrations and changes in resource availability
4. Characterization of classified impacts into human and environmental damages through the effect and exposure analysis
5. Aggregation of potentials into total human health, ecosystem quality, and mineral and fossil fuel resource damages

6. Normalization for adjustment to impact context

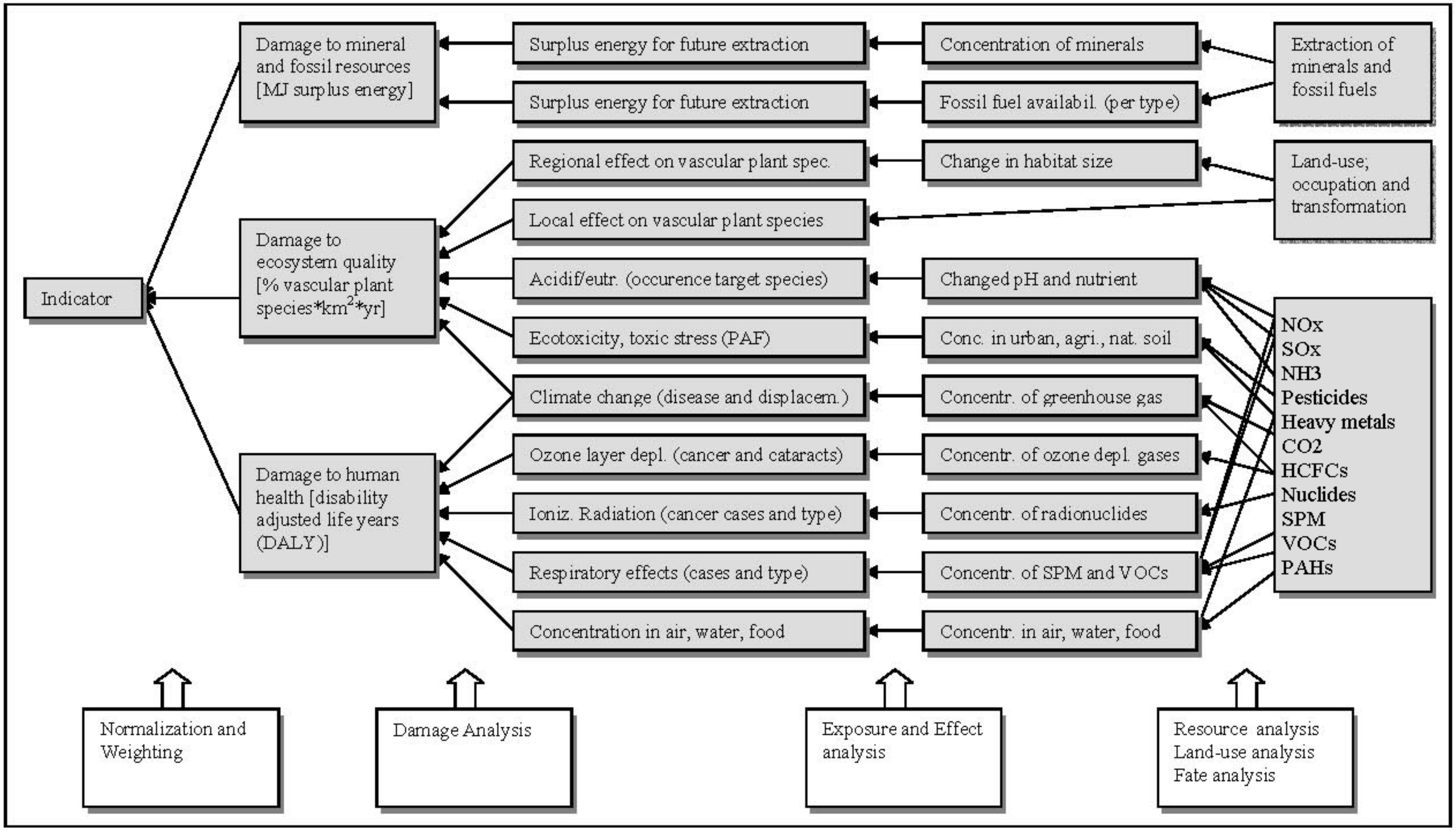
7. Weighting to reflect the values of stakeholders in the assessment

8. Final aggregation into a single value—the Eco-indicator

EI 99 has been developed as an LCA weighting method for product design. EI 99 provides a framework

- To inventory releases and resource consumption associated with a product or service
- That provides methods for characterizing and normalizing the endpoint damages
- For weighing the normalized damages to achieve an overall indicator of environmental impact known as an Eco-indicator

To make the weighing process easier, the EI 99 method aggregates the damages into three endpoint categories: human health, ecosystem health, and resources. The developers felt that these three categories would be much easier for decision-makers to value than eight or more vague impact categories like global warming and acidification potentials.



Adapted from Goedkoop and Spriensma (2001)

Figure 6-2
General Representation of the EI 99 Methodology

The flow diagram in Figure 6-2 depicts the procedures (white boxes) and intermediate results (gray boxes) of the EI 99 methodology. There are four general procedures that are required to transform an inventory of releases and resources consumed into a single indicator of total ecological impact.

The objective of EI 99 is to conduct complete or partial (scoping) LCAs and to aggregate the impacts into easily understandable units, which may be used to compare the environmental impact of products or services. The results of the EI 99 LCA include inventory, classification, and characterization tables for each life-cycle component and impact type as well as their contributions to each of the three endpoint categories. Following the weighting of the endpoint categories, the final result is a single Eco-indicator value by which to compare environmental impacts.

Advantages of this method include that EI 99 (Pré 2004)

- Employs the most current European impact characterization models
- Conducts analysis of endpoint damages, providing a more detailed account of environmental risks
- Aggregates to a single unit, providing a simple, positive information source for public discussion and consensus building
- Separates data uncertainties and model uncertainties
- Provides three methods (perspectives) for dealing with method uncertainties
- Gives an opportunity to weight three simplified impact categories, providing communities with an opportunity to plug in barrier issues or not when considering options

Disadvantages of the method include

- Characterization of endpoint damages may generalize impacts that are typically site-specific
- Characterization factors are Europe-specific
- Weighting of impact categories is controversial
- Impact categories do not include water use or biotic resource use

EI 99 requires an inventory of all of the emissions released and resources consumed in producing, using, and/or disposing of all items associated with a product or service. Additionally, it requires choices of impact characterization method (what degree of impacts are included) and weighting method. EI 99, like all ISO-based methods, requires an intensive inventory of resources consumed and emissions to air, water, and soil for all processes and components contained within the defined system boundaries.

A detailed list of data needs specific to using the method for comparing wastewater treatment options in the US is given in Appendix E.

EI 99 is available in the SimaPro 5.1 software package, which includes a large number of embedded databases. Unfortunately, most of these data are currently focused on Western Europe (specifically, the Netherlands, Germany, and Switzerland). Furthermore, the characterization and normalization factors are also based on Western European conditions. However, EI 99 is still used globally. This use is likely due to its availability and that, generally speaking, European LCA databases are mostly sufficient for cataloging the environmental burdens of the materials, transportation, and energy incorporated in the process. Details of the operational performance of wastewater are published for some processes. However, for detailed analyses, published LCA data are unlikely to meet the needs of most wastewater treatment comparisons (Todd and Gaddis 2003). See Chapter 7 for further discussion general LCA data availability.

EI 99 was developed as a design tool for lessening the environmental impact of products. It is widely used for that purpose, particularly in Europe, but also globally. It is commonly used in LCA studies requested within industries and for research applications where characterization of damages is desired. EI 99 has been used in several scoping LCA studies of waste and water treatment systems at the University of Leiden (Lassaux *et al.* 2002, Lassaux *et al.* 2001, and Rihon *et al.* 2002). None of these studies discussed limitations or benefits of the method chosen for their studies.

Aside from the European characterization factors, the largest issues in considering EI 99 are endpoint characterization of impacts and weighting. These are both the method's greatest strengths and weaknesses. See Chapter 4 for further discussion of these issues.

SPI–Sustainable Process Index

The Sustainable Process Index is an ecological evaluation system that measures the total environmental impact of human activities of various kinds. The general concept of the SPI is to compare mass and energy flows induced by human activities with natural mass flows on a variety of scales. The SPI was especially developed as a means to evaluate industrial-type processes.

The SPI concept is founded on the assumption that solar energy (more exactly: solar exergy)[2] is the only sustainable basis of an economy. The conversion of solar energy to services requires area. Hence, area may be regarded as the main limiting factor for a sustainable economy. The materials and energy needed for an industrial process may thus be converted into the land area needed to maintain the related material and energy flows in a sustainable way (Haberl and Schandl 1999).

[2] Exergy is a measure for energy quality. Exergy is the property of a system, which gives the maximum power that can be extracted for the system when it is brought to a thermodynamic equilibrium state from a reference state. The exergy transfer can be associated with mass flow, work interaction, and heat interaction. (Hellström and Kärrman 1997)

The SPI is then equal to the area needed for the process (A_{TOT}) divided by the mean land area per capita in the relevant region of analysis (A_{IN}), where

$$A_{TOT} = A_R + A_E + A_I + A_S + A_P \text{ (m}^2\text{)}$$

and

A_R –Area required to produce renewable and nonrenewable raw materials necessary for the process

A_E –Area required to supply energy (from non-fossil or nuclear fuel sources)

A_I –Area required to install the process into the landscape (including direct and indirect land-use)

A_S –Area required to house and feed the staff of the process

A_P –Area required to accommodate products and by-products into the landscape after they are used, as well as the area needed to assimilate emissions from the process (Narodoslawsky and Krotscheck 1995)

Like all methods within the life-cycle assessment category, the SPI requires an inventory of the material and energy inputs as well as an inventory of the releases to air, soil, and water for the process under evaluation. These data, which are assumed by the SPI developers to be available from process, design engineers, but for wastewater treatment they have been difficult to obtain (Todd and Gaddis 2003). The SPI data needs differ from traditional LCA methods because the SPI allows the life-cycle impacts of materials used in the process (expressed as land area) to be estimated using only the cost of the material. This “streamlined” approach eliminates inventorying the detailed LCA impacts of the materials, which can account for a large portion of the LCI data required by most LCA methods.

However, SPI does require some unique data that are not typically necessary for other LCA methods. SPI compares the impacts of a process with the ability of the natural environment to provide renewable resources (for example, energy) and mitigate wastes. The data needed include: the energy used for planting and harvesting a renewable raw material, the flow of renewable raw material necessary to substitute fossil raw materials, the yield of raw material, the fossil raw material flow, and the yield of sedimentation. Default values for these additional data needs are available for Western Europe (Krotscheck and Narodoslawsky 1996). These default values are most likely spatially and temporally inaccurate for the US. The US natural environment data needed exists, but it is disparate and should be compiled in a US SPI database for SPI to be useful as a simplified LCA tool.

Table 6-4 describes the general data needs of the SPI.

Table 6-4
SPI General Data Needs

Area Consumed By	Inputs Required	Units
Raw Materials		
Nonrenewable	specific yield of biomass resource	$kg/m^2/yr$
	quantity of resource used	kg/yr
Nonrenewable	energy demand of supplying material	
	price of material	$/kg
	price of energy	$/kWh
	mean industrial energy yield	$kWh/m^2/yr$
	quantity of resource used	kg/yr
Process Energy		
	quantities of energy used	$kWh/m^2/yr$
	quality of energy used	kg/yr
	source of energy	heat, elec., mech.
Installation		
Direct use of land	land area occupied during operation	m^2
Indirect use of land	energy demand of installation	kWh/yr
	price of installation	$
	price of energy	$/kWh
	life-span of facility or unit process	yr
	mean industrial energy yield	$kWh/m^2/yr$
Staff		
	number of workers employed in the process	cap/yr
	residential yield (area required to sustain staff)	$cap/m^2/yr$
Product/By-products		
	By-product sink potential (for air, water, soil compartments)	$kg/m^2/yr$
	rate of renewal of environmental compartment	$kg/m^2/yr$
	concentration of by-product in environmental compartment	kg/kg

To date, the SPI has only been used for research projects. It has been used to compare different energy provision systems. Energy provision systems are at the core of almost all human activities and are certainly of special significance in industrial processes (Narodoslawsky and Krotscheck 2004). Additionally, the SPI has been used for evaluation of an aquaculture wastewater system in Sweden (Guterstam and Roggenbauer, 1999). However, a manuscript of this study was unavailable for this report, limiting an assessment of SPI's previous successes or failures in capturing the environmental impacts of wastewater treatment systems.

TRACI—Tool for the Reduction of Chemical and Other Environmental Impacts

TRACI is a "stand-alone" life-cycle assessment method and software recently released (2002/2003) by the US EPA and will soon be available in the popular SimaPro software released by PRé Consultants of the Netherlands (Bare *et al.* 2003 and Oele 2004). The method evaluates the potential environmental and human health impacts of facilities, processes, services, and products. It was developed to optimize and standardize life-cycle assessments within the US and to include spatial information for regional impact considerations. TRACI combines the most recent, suitable LCA methods for US policies, regulations and conditions to characterize environmental stressors, which affect the following impact categories (Bare *et al.* 2003):

- Acidification
- Eco-toxicity
- Eutrophication
- Fossil fuel production
- Global warming
- Human health—cancer
- Human health—criteria pollutants
- Human health—noncancer
- Land use
- Smog formation
- Water use

The software requires location-specific data about materials and processes used. The format and choices available cater to industrial production or commercial services. For many of the impact categories, the developers chose to quantify midpoint impacts on the cause-effect chain. The US EPA recognized that if the base program characterized the impacts to the midpoints, individual users could continue the analyses down the cause-effect chain to meet their individual concerns. However, this would impose a considerable amount of additional work on the user if he or she intended to assess the actual damages.

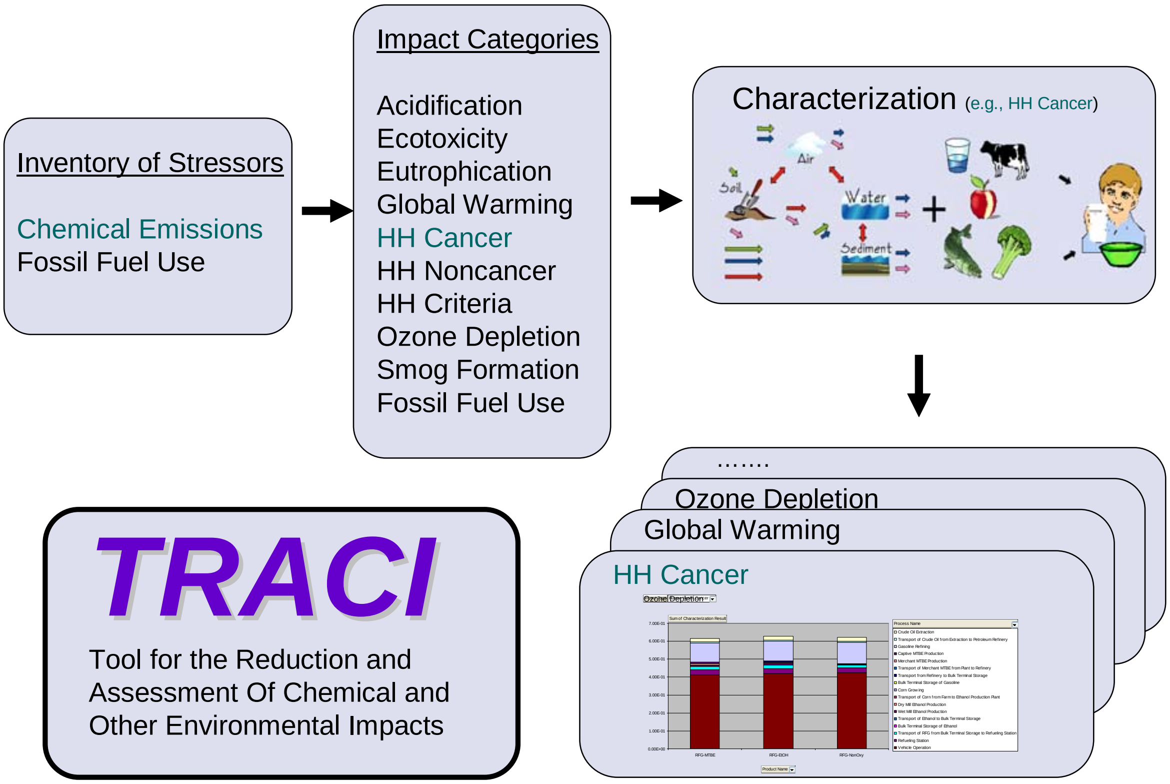
TRACI inventories chemical releases and limited resource consumption (LCI) and characterizes impacts (LCIA) for a wide range of system boundaries including cradle-to-grave and gate-to-gate evaluations. The results of the TRACI model are summations of the potential impact for each impact category based on region-specific characterization factors (Table 6-5). Results are available as inventory, classification, or characterization tables for each life-cycle stage and impact type.

Table 6-5
Impact Characterization Locations for TRACI

Impact Category	US	East or West of the Mississippi River	US Census Region	State	County
Ozone Depletion	x				
Global Warming	x				
Acidification	x	x	x	x	x
Eutrophication	x	x	x	x	x
Photochemical Smog	x	x	x	x	x
Human Health—Cancer	x				
Human Heath—Noncancer	x				
Human Health—Criteria Pollutants	x				
Ecotoxicology	x			x	
Fossil Fuel Use	x				
Land use	x	x	x	x	x
Water Use	x				

Adapted from US EPA (2002)

The impact assessment process begins by classifying a stressor as a resource use or chemical emission, which is then directed to its appropriate impact category. For the case shown in Figure 6-3 the emission is a known cancer-causing chemical. TRACI's internal carcinogenicity characterization model then calculates the potential carcinogenicity of that chemical quantity released in a specific location to a specific media and the result is communicated through various forms, including the bar graphs representing sensitivity analyses as shown in Figure 6-3.



Source: Bare *et al.* (2003)

Figure 6-3
TRACI's Framework Depicting the Process of Inventorying, Characterizing, and Communicating the Cancer Threat of a Product or Service

Like EI 99, TRACI may be used to perform scoping LCAs to determine which aspects of the process or which impact categories are most significant, where more intensive analyses can be focused. This approach may be of interest to decision-makers eager to simplify or streamline LCA methods. Streamlining is discussed in more detail in Chapter 9.

Other characteristics of TRACI include:

- TRACI's modular design allows for the most advanced and most suitable LCA methods to be applied independently to each category and allows for those methods to be updated as they become obsolete
- The format and choices available cater to industrial production or commercial services
- The impact categories do not include mineral and biotic resource consumption
- The land- and, particularly, water-use categories are characterized by simplified characterization methods

- TRACI does not estimate actual risk or damages
- Uncertainty or variability analyses are not included

The input data required for TRACI are similar to that of other ISO-based LCAs. The data required are highly dependent on system boundaries established for assessment, but in general TRACI requires an intensive inventory of resources consumed and emissions to air, water, and soil for all processes and components contained within the defined system boundaries. A detailed list of data needs specific to using the method for comparing wastewater treatment options is given in Appendix E. As mentioned previously, TRACI may require further development of analyses to achieve endpoint impacts if a comparison of actual damages is desired. While this would not necessarily greatly increase the data requirements, it could greatly increase the user's time and effort to complete the analysis depending on his or her familiarity with LCA methodology.

Since TRACI was released last year, there have been no LCA studies published using TRACI except for two examples provided by TRACI's developers. To date, TRACI has not been used for comparisons or evaluations of wastewater treatment systems.

URWARE–URban WAter REsearch Model

URWARE is a substance flow model developed in Sweden using the general simulation platform Matlab/Simulink. URWARE can be described as a library of interconnected mathematical models, currently including:

- Anaerobic digestion
- Composting
- Drinking water production
- Households
- Incineration
- Landfill
- Transports
- Wastewater treatment

All models are combined into an overall model of the specific scenario under investigation.

URWARE evolved from the simulation model ORWARE (ORganic WAste REsearch model) developed to evaluate the environmental impacts of different systems for managing organic waste. Special emphasis had been placed on assessing the environmental impacts of anaerobic digestion systems and wastewater systems. The development of the ORWARE model was a cooperative effort between three institutions: the Royal Technical University in Stockholm, the Swedish Institute of Agricultural and Environmental Engineering in Uppsala, and the Swedish Environmental Research Institute in Stockholm. More recently, the Swedish Sustainable Urban Water Management (SUWM) program has expanded the scope of the ORWARE model to include a more complete model of urban water systems, resulting in the URWARE model. The overall goals of the URWARE project were to develop a systems analytical tool for analyzing the environmental sustainability criteria of urban water and waste systems and to apply this tool to the model cities of the SUWM program.

The objective of URWARE is to be a systems analytical tool for analyzing environmental sustainability criteria of urban water, wastewater, and solid waste systems. The model also includes critical technical systems associated with the production, treatment, and disposal of water, wastewater, and solid wastes (for example, chemical, energy, and fertilizer production, landfills, and agricultural operations). Such external or auxiliary processes have been identified as important when comparing the life-cycle impacts of alternative wastewater treatment systems that employ nutrient and water recycling and reuse. (For more explanation see Chapter 4). The typical case is to compare different scenarios of wastewater management for a specific settlement, municipality, or region. URWARE mixes theoretical and empirical relations of substance flows. The model handles average yearly data and is therefore useful for strategic planning (not for optimizing or designing treatment processes for a treatment plant).

Results from URWARE are basically the same as from conventional LCIs and LCAs; methods for impact assessment have been transferred from LCA. The simulation provides non-aggregated outflows (emissions to air, soil, and water) or aggregated environmental impacts of the studied system structure. One difference is, however, that URWARE only considers the environmental impacts from the operation phase of the wastewater systems; it does not consider the entire life cycle of the systems. The results of the URWARE method make it possible to compare different urban water structures in order to

1. Find out the typical properties of each system structure

2. Investigate the applicability of different systems structures dependent on local conditions

Unlike the other LCA methods examined, URWARE has a highly controlled inventory framework. In all URWARE simulations, input vectors consisting of 88 elements are used (Table 6-6). Those elements include substances in the water, wastewater, and solid waste inflow; for example, organic matter, nutrients, heavy metals, and other substances. As a result, URWARE's data needs are somewhat different than those of more traditional LCAs. URWARE requires both detailed influent data and models of the technical system processes; for example, the various water, wastewater, and solid waste treatment systems in use, as well as the extended process, in order to obtain detailed fate analysis of substances flowing through the model community. As noted previously, detailed wastewater treatment system performance data are often difficult to obtain, and modeling the site-specific system operations for URWARE can be time consuming. However, the results of URWARE are generally of a higher degree of detail than typical LCA studies. Therefore, this method is most likely to give the most accurate life-cycle comparison of wastewater treatment operation and likely the most accurate modeling of the larger community context or extended system.

During Phase 1 of the SUWM program, URWARE was developed for hypothetical comparisons of combined and source-separated systems structures in a newly developed portion of a model city. Other published studies employing the ORWARE and URWARE models have also evaluated combined and source separated systems, including urine separation (Jönsson 2002, Jeppsson and Hellström 2002, and Kärrman and Jönsson 2001). Several of these studies examined the effects of extending the analysis to include sludge treatment, (Jeppsson and Hellström 2002 and Jönsson 2002). Jönsson (2002) performed the most extensive analysis, including extended processes of energy production, amendment-chemical production, and fertilizer production (Jönsson 2002) recovery and reuse as well as centralized and decentralized options (Kärrman 2000 and Jeppsson and Hellström 2002).

Table 6-6
URWARE Elements (Complete List)

• Total organic carbon	• Total Sulfur	• Paper newsprint
• Total biological carbon	• Sulfur-SOx	• Paper journals
• Carbon-slowly degradable	• Total phosphorus	• Paper fine
• Carbon-rapidly degradable	• Total chlorine	• Mixed paper
• Carbon-fats	• Total potassium	• PE plastics
• Carbon-proteins	• Total calcium	• PP plastics
• BOD	• Total lead	• PVC plastics
• Volatile substances	• Total cadmium	• PS plastics
• Total solids	• Total mercury	• PET plastics
• CO_2-fossil origin	• Total copper	• Mixed plastics
• CO_2-biological origin	• Total chrome	• Rubber-incl. tires
• Methane	• Total nickel	• Textile
• VOCs	• Total zinc	• Wood
• Halogenated volatiles	• Carbon-medium rate degradable	• Electronic waste-not incinerated
• Halogenated organic compounds	• Suspend. solids (water)/Particles (gas)	• Hazard. waste-burnable but not incin.
• Polyaromatic hydrocarbons	• COD	• Hazard. waste-not burnable/ not incin.
• CO	• N - soluble material	• MFA-not incinerated
• Phenols	• Total fossil carbon	• COD-dissolved biodegradable material
• PCBs	• Particulate sulfur	• COD-dissolved inert material
• Dioxins	• Void volume	• COD-particulate biodegr. material
• Total oxygen	• Magnetic metals	• COD-particulate inert material
• Total hydrogen	• Light metal	• P-PO4
• Water	• Yellow metal and stainless steel	• P-particulate material
• Total N	• Colorless glass	• N-particulate material
• N-ammonia and ammonium	• Colored glass	• Temperature
• N-NOx	• Other inerts-not incl. ash	• Exergy-chemically based
• N-nitrate and nitrite	• Ash	• Exergy-heat based
• N-N_2O	• Paper containers, cardboard, etc.	

Table 6-6 is a complete list of the substances tracked by URWARE through a model community to evaluate and compare the life-cycle environmental and human health impacts of different configurations of waste and water treatment technologies and management strategies. The model can be adjusted to reflect many different centralized and/or decentralized approaches.

In previous studies, the URWARE and ORWARE models have been tested in environmental systems analysis of organic waste management and wastewater management (Dalemo 1999 and Kärrman 2000). Several Swedish towns and cities, including Surrahamar (population 10,200), Hammarby-Sjöstad (planned population 15,000), Uppsala (population 127,000), and Stockholm (population 1.25 million) have been modeled and various waste and wastewater treatment alternatives were evaluated successfully using these methods (Jeppsson and Hellström 2002 and Eriksson *et al.* 2002). While the Swedish default values and models used are most likely unsuitable for US conditions, the analysis framework of URWARE could be quite useful for town-, city-, or regional-scale decision making.

While monetary evaluation methods are not directly considered in this report, it should be noted that the URWARE model also contains a parallel life-cycle costing tool such that the inputs and process models related to environmental impacts as well operational costs.

The URWARE tool is most applicable to communities large enough to be served by waste and water utilities, but may include onsite treatment practices. URWARE could be used by large town and city planners concerned with optimizing the long-term environmental performance of their waste and water utilities, while identifying opportunities to lower costs and liability. URWARE might also be of interest to planners and policymakers at a large watershed, regional, or state level concerned with the cumulative regional and global effects of employing various centralized and decentralized strategies across multiple communities, in order to promote appropriate treatment, reuse, and disposal practices for various scales of operation.

Summary Comparison of LCA Variations

Table 6-7 and Table 6-8 summarize and contrast some of the key characteristics of the four LCA variations considered. In Table 6-7 it is clear that only TRACI was developed specifically for US conditions and that only EI 99 completely models through to endpoint impacts and employs weighting. Note that while three of the methods cover similar impact categories, the SPI differs significantly with regard to emissions. Emissions are characterized by the biological land area required to assimilate them without negative impact.

Table 6-8 describes the general data needs for each LCA variation with regard to comparisons of wastewater treatment options over both the construction and operation phases. An extended list of data needs is included in the Appendix E. Note that only URWARE requires influent data, that only a few of the methods consider water and land use, and that none of the systems consider reliability, although durability may be factored in. Also note again that URWARE only considers the impacts associated with operation of the system.

Table 6-7
LCA Methods Comparison Summary

		Methods			
		EI99	***SPI***	***URWARE***	***TRACI***
Country of Origin		NL	AT	SE	US
Date Released		1999	1995	2002	2002
Regions Characterized		W. EUR	EUR	SE	US
Inventory Framework		x	x	limited*	x
Impact Characterization	Midpoint		x	x	x
	Endpoint	x			limited**
Weighting	Distance to target	x			
	Panel-values	x			
Impact Aggregation		x	x		
Impact Normalization			x		x
Impact Categories					
Resource Use					
Mineral		x			
Fossil Fuel		x			x
Energy			x	x	
Materials				x	
Renewable			x		
Non-Renewable			x		
Water				x	x
Land—Change In Habitat		x		x	x
Land—Occupied By Operations			x	x	x
Land—Occupied By Staff			x		
Land—Assimilation of Emissions			x		

* The URWARE inventory is comprised of 88 specific elements.

** Only a few of the TRACI impacts are characterized to endpoint damages.

Table 6-7
LCA Methods Comparison Summary (Cont.)

	Methods			
	EI99	***SPI***	***URWARE***	***TRACI***
Emissions-Ecological Effects				
Acidification	x		x	x
Eutrophication	x		x	x
Ecotoxicity	x		x	x
Global Warming			x	x
Emissions - Human Effects				
Climate Change	x			
Photochemical Smog			x	x
Human Health—Cancer				x
Human Health—Non-Cancer				x
Human Health—Criteria Pollutants				x
Human Health—Toxicological			x	
Human Health—Non-Toxicological			x	
Ozone Layer Depletion	x		x	
Radionuclides	x			
Particulates and VOCs	x			
Carcinogens	x			

Table 6-8
LCA Methods Data Needs Comparison Summary

		Datum Type	Methods			
			EI99	*SPI*	*TRACI*	*URWARE*
Site-Specific Data		Social Conditions				
		Environmental/Site Conditions		x		
Generalizable Data	**Operation**	Treatment Inputs*	x	x	x	x
		Material/Product Transportation	x	x	x	x
		Influent				x
		Treatment Releases	x	x	x	x
		Effluent	x	x	x	x
		Recycling	x	x	x	x
		Process Reliability				
		Durability	x		x	
		Water Use			x	x
		Land-use	x	x	x	
	Manufacturing/ Construction	Extraction/Processing Inputs*	x	x	x	
		Material/Product Transportation	x	x	x	
		Construction Inputs	x	x	x	
		Extr./Process./Constr. Releases	x	x	x	
		Extr./Process./Constr. Water Use			x	
		Extr./Process./Constr. Land-use	x	x	x	

* Inputs refer to the materials and energy required by the process.

See the extended list of data needs of the LCA methods compared in Appendix E.

US EIA–US Environmental Impact Assessment

Environmental Impact Assessment (EIA) is a tool used by decision-makers to evaluate the impacts that various alternatives for conducting an action will have on the human environment. It is used for projects undertaken or funded by the US federal government. Since wastewater treatment decisions are generally made by state and/or local authorities, the National Environmental Protection Act (NEPA) process is generally not used in those decisions. In 20 states, environmental laws like the California Environmental Quality Act (CEQA) have been inspired by NEPA (Kontos and Asano 1996) and are more routinely applied to wastewater treatment decisions.

This section first describes the NEPA process, and then discusses how the CEQA process differs from NEPA.

Environmental Impact Assessment is the process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of a proposed action, during the initiation and planning stages of a proposed action (Canter 1977). With NEPA, there are three types of studies:

1. Environmental Impact Statements (EIS)

2. Categorical Exclusions (CE)

3. Environmental Assessments (EA)

Under NEPA, an EA is performed when it is unclear whether there are significant impacts involved with conducting an action. The result of an EA may be a Finding Of No Significant Impact (FONSI), in which case the project is approved, or an EIS. Another way to arrive at project approval is through the CE, which is the documentation that is done on projects of a type that historically have shown to not have a significant impact. For instance, the Federal Highway Administration has said that the following categories of action do not typically have significant impact: bridge rehabilitations, planning studies, pedestrian paths, and other actions. During the CE preparation, potential impacts are still assessed; there is still a project purpose and need statement, project description, and explanation of any required mitigation.

If a project is not eligible for a CE and an EA does not lead to a FONSI, then an EIS is begun. Documents are used with other relevant materials to plan actions and make decisions. It is not uncommon to stop or abandon an EA, along with the proposed action, when it is apparent that there would be significant environmental impacts.

The objectives of an EIA are to ensure that environmental considerations are addressed during the decision-making process; provide decision-makers with all the relevant data about an action's potential for impact; minimize and avoid, if possible, adverse significant effects; protect the productivity and capacity of natural systems and ecological processes; and promote sustainable development (International Association for Impact Assessment and Institute of Environmental Assessment UK 1999).

One of the most crucial steps in the NEPA EIA process is scoping of the proposed action. Scoping is the process for determining the issues to be addressed and for identifying the significant issues to the proposed action. NEPA regulatory guidelines suggest that early on in the process the lead agency invite participation from affected agencies, Native American tribal organizations, proponents of the action, and other interested parties. With the participants, lead agencies determine the scope of the assessment and the issues to be analyzed in the EIS. At this time, issues that are not significant or those that have been covered in previous environmental reviews are eliminated from further consideration. However, evidence needs to be presented as to why these issues are not to be included. Lead agencies then assign responsibilities for the preparation of the EIS and determine the schedule for decision making and report preparation.

The key elements of an EIS, the most advanced form of an EIA, as interpreted by the Department of Energy in its regulations implementing NEPA are as follows (Council on Environmental Quality 2004):

- **Summary:** An EIS will include a summary that will state the major findings, areas of conflict, and issues that need resolution.
- **Purpose and Needs Statement:** The most important part of an EIS. This statement is the underlying reason for which the assessment has been conducted.
- **Alternatives:** The body of the EIS. Alternatives are stated for the proposed action, and this section presents the basis for choice among the options for the interested parties. In this section, the EIS shall explore all reasonable alternatives, with evaluations for each from the sections on Affected Environment and Environmental Consequences. It will also include alternatives that are not to be considered and reasons for excluding these options from consideration. Each alternative should be reviewed in enough detail so that they may all be fairly compared against each other. The array of alternatives should include those within and outside the jurisdiction of the lead agency, plus the "No Action" alternative. This section also identifies the agency's preferred alternative or alternatives and includes any mitigation measures that are not already described in the proposed action.
- **Affected Environment:** A succinct description of the environment of the areas that would be affected by the proposed action, including relevant data and analyses.

- **Environmental Consequences:** The basis for comparison of the alternatives section. Discussion will include the environmental impacts of the alternatives, any adverse effects that cannot be avoided, the relationship between short-term uses of the environment and the maintenance and enhancement of long-term productivity, and any irreversible or irretrievable commitments to resources. Broadly, the section should include both direct and indirect effects, as long as the indirect effects are "reasonably foreseeable." Specifically, it should include
  - Any conflicts between the proposed action and the objectives of federal, state, or local land-use plans, policies or controls for the area included in the action
  - Environmental effects of each alternative (the basis for the comparison in the alternatives section, above)
  - Energy requirements and conservation potential of each alternative, plus mitigation possibilities
  - Natural resource requirements and conservation potential of each alternative, plus mitigation possibilities

Cumulative impacts are also investigated. Cumulative impacts are those impacts that are minor from individual projects but whose cumulative effects, from many projects, are significant.

Following the submittal of an EIS or other environmental document to the US EPA, the document is posted for public comment for a specific period of time. After this period, the lead agency must respond to all comments. The time from start to finish for an action to go through the NEPA process can be on the order of years.

State Laws Modeled on NEPA

CEQA was inspired by NEPA and passed in 1970, signed into law by California Governor Ronald Reagan. CEQA applies in California to any project, that is, any activity that requires discretionary approval by a government agency, undertaken by state or local public agencies, if the project may cause a direct or indirect change in the environment.

State laws like CEQA or the state of New York's State Environmental Quality Review Act (SEQR) often combine the environmental review functions of NEPA with a review of land-use impacts (Groveman 2004).

Applying EIA: A Californian Case Study

The Draft Environmental Impact Report (EIR) prepared for a wastewater treatment plant in Willits, California, provides an example of a state NEPA-like process (Planwest Partners *et al.* 2002). The city's wastewater treatment plant has a capacity of 1.3 million gallons per day and was 25 years old at the time the EIR was prepared; much key equipment was wearing out or close to wearing out. The wastewater collection system was wearing out as well, and high levels of inflow and infiltration occurred during the winter rainy season. Furthermore, the plant had exceeded 75% of design capacity, an indicator used by the local regulators to show a need for upgrading for future demand increases. It also was regularly violating its discharge permit limit of 1% of the hydraulic flow of the receiving water, Outlet Creek. After a three-year facility plan process, the proposed project was selected and an EIR was prepared. The EIR cost about $250,000 and took about two years to produce (Herman 2004).

Overall goals were set for any improvements in the wastewater treatment system:

- "Provide wastewater treatment and disposal (sic) to accommodate 20 years of expected growth in the City of Willits service area."
- "Develop and operate the wastewater treatment and disposal (sic) system in ways that protect public health and safety and promote the wise use of water resources."

In addition, project objectives were defined, addressing such things as cost effectiveness, reliability, and providing recreational opportunities on the open space used for wastewater treatment.

Through review of recent engineering documents, a proposed project was developed, along with three alternatives and a "no project" alternative. The proposed project included:

- Changing from a mechanical extended aeration activated sludge process to an oxidation pond and constructed wetland on a larger site
- Changing the disinfection method from chlorination to ultraviolet light
- Adding longer onsite retention
- Moving the points of discharge and storage downstream

The disadvantages of the "no project" alternative were described, and the proposed project and alternatives were evaluated according to a host of criteria, including

- Aesthetics and visual resources
- Agricultural resources and land conversion
- Air quality
- Aquatic biological habitat and species
- Biosolids
- Cultural resources
- Cumulative impacts
- Geology and soils
- Growth-inducing impacts
- Hydrology and water quality
- Irreversible effects (including energy consumption)
- Land use
- Noise
- Population and housing
- Public facilities and services
- Public health and hazards
- Recreational resources
- Socioeconomics
- Transportation

The “environmentally superior alternative” was selected, without considering non-environmental factors like cost and access to the site. After hundreds of pages of considering the above impacts, the justification for selecting the proposed project as the environmentally superior alternative was surprisingly short: “Due to reduced hydrological and wetlands impacts, and other factors, compared to the other alternatives, the Proposed Project is considered the environmentally superior alternative.”

Effect and Data Needs of NEPA and Similar State Laws

The Council on Environmental Quality conducted a review of the effectiveness of NEPA 25 years after the act was passed (1997). In interviewing those who have worked with NEPA, both those who support the law and those who are critical of it, the study authors conclude that NEPA has worked as “a framework for collaboration between federal agencies and those who will bear the environmental, social, and economic impacts of agency decisions.” On the other hand, they reported, “Study participants also stated that frequently NEPA takes too long and costs too much, agencies make decisions before hearing from the public, documents are too long and technical for many people to use, and training for agency officials at times is inadequate.” Some main conclusions on the use of science include that

- More emphasis on monitoring and adaptive management once a project is underway could replace the tendency to seek an answer in advance to every potential environmental question.
- Conducting a EIS for different projects on the ecosystem level could help achieve environmental quality objectives more realistically and cost effectively than conducting individual EISs for each project.

At both the federal and state level, the effectiveness of the EIA process in assuring environmental quality depends on who is leading the process from the relevant agencies and who in the public is reviewing the process (Groveman 2004 and Council on Environmental Quality 1997). The laws can be applied in a pro forma way, or they can be useful in mitigating impacts. One of the most common outcomes of the process is a mitigated FONSI, that is, a finding that there will be no significant impact from the project if specified mitigation measures are taken. The process of agreeing on the mitigation measures includes public input and results in environmental benefits (Groveman 2004). Simply expanding the range of alternatives considered has been described as key to making better environmental decisions (O’Brien 2000).

Data for an impact assessment are obtained on a needs basis and vary greatly with geographical location and the proposed action. When a potential for an impact is determined, personnel with relevant expertise are employed to determine the presence or absence of a resource and the potential extent of the impact. In a typical action, determinations of impacts may be gathered from wetlands scientists, fish and wildlife officers, non-game and natural heritage specialists, archaeologists, architectural historians, traffic engineers, hydrologists, and regional planning officials. Under the direction of the lead agency, determinations of impact can steer the assessment process towards one alternative over another. Guidelines for using the NEPA process differ in different federal agencies, and some states specify the categories considered (Groveman 2004).

Because of considerable variation in the system boundaries and extents of analysis among EIA studies, a clearly defined listing of data needs has not been established as it was for the more rigidly structured LCA methods (Table 6-4, Table 6-5, Table 6-8, and Appendix E). EIA could potentially capture all of the listed LCA data needs, but many of these data needs have been excluded in practice. An indication of data needs may be obtained from the EIA case study previously discussed and the comparison of EIA studies listed in Appendix F.

A strength of the US model for EIA is its multidisciplinary approach. It requires the input from specialists, different government agencies, proponents of the proposed action, and the public. The EIS can use such diverse tools as wetland delineation, planning models, traffic models, noise studies, and archaeological surveys. Mitigation measures are also presented through the EIA process. The process of EIA is flexible, and so it can be tailored to meet specific needs in a context.

This flexibility, however, can also be a hindrance to more widespread use, as the data gathered in an EIA are largely site specific. That is, it is difficult to transfer data from one EIA to another in a different location. When data need to be generated anew each place an EIA is performed, the cost of the EIA increases.

Another aspect of the flexibility is that the choices of analytical tools, including how quantitative the analysis is, are not standardized.

In EIA as it is practiced, the boundary of impacts is generally limited to local/regional issues; global concerns are not assessed. Since assessment of “indirect impacts” is specifically called for, however, an EIA as described in statute and regulations could consider global concerns like climate change. Consideration of energy efficiency under CEQA (Planwest Partners *et al.* 2002) is a move in that direction. So while current practice does not commonly use many LCA impact categories in EIA, in theory, any of the LCA impact categories could be used.

Open Wastewater Planning

A major goal for this study has been to identify methods that can be used to improve the basis for comparing wastewater treatment alternatives on non-economic grounds. Many formal methods have been identified, and they each have defined ways of approaching the comparison. Even the customized LCA has clearly defined ways of defining the problem to be studied and gathering data to shed light on it.

The most useful tools address the priorities of the decision-makers. Ridderstolpe has developed a method for identifying decision-makers’ priorities and finding information that addresses their concerns, and used it to help find a wastewater treatment option for the community of Vadsbro in Sweden. He calls the method “open wastewater planning” (Ridderstolpe 1999). Open wastewater planning (OWP) begins with a set of goals for the wastewater treatment process to achieve. From there, a diverse set of design alternatives that meet most or all of those goals is generated and presented simply, at the level of a feasibility study. The ways in which the alternatives affect the goals set up in the beginning are described briefly, and decision-makers use the material as a decision aid.

Open wastewater planning can be seen as a combination of a facilities plan and a small-scale environmental impact assessment. As in a facilities plan, numerous alternatives are considered, with no preferred alternative selected at the beginning of the process. As in EIA, many different types of environmental impact may be considered. OWP is flexible enough to consider environmental life-cycle assessment data, as well. What is unusual about OWP in relationship to, say, the process Willits went through with three years working on a facilities plan followed by two years for an EIR on the project proposed in the facilities plan is:

1. Economic, social, and environmental impacts are all given consideration together from the beginning to the end of the process

2. The preferred alternative is selected only after information has been collected on all the economic, social, and environmental impacts

Ridderstolpe says that in Sweden, where an EIS is required for all wastewater projects, it is very easy to write the EIS after the OWP process has been completed, using much of the data from the OWP document.

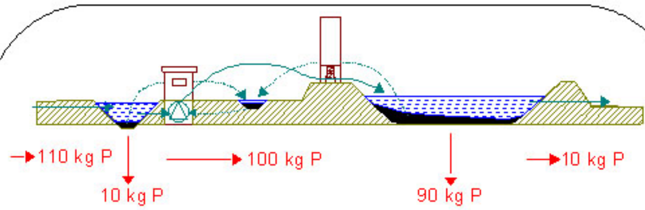
Applying OWP: A Swedish Case Study

Open wastewater planning has worked well in Vadsbro, Sweden. Vadsbro is a village of 40 households, in the same region as Stockholm. The village renovated the sewer system connecting it to a wastewater treatment plant. Their next step was to upgrade the treatment plant. The regulatory authority, the municipality's Environmental and Public Health Committee, believed that a package treatment plant was the appropriate solution, but they wanted to work with someone to confirm that choice. They embarked on a two-month process of OWP, which cost them 35,000 kronor (about $4,400) in consulting fees (Ridderstolpe 2004).

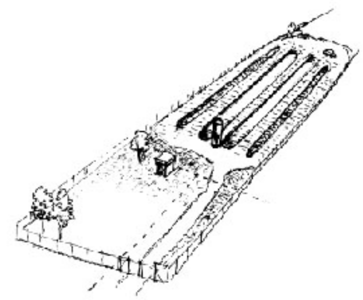
Ridderstolpe began by asking the committee what their goals for the wastewater treatment plant were. They identified measurable goals in the areas of cost, nutrient and BOD removal, potential for recycling nutrients, energy use, chemical use, and public health, as well as qualitative goals that the solution fit in with local conditions and that responsibility and maintenance requirements be clear. Ridderstolpe then developed six alternatives, including the package treatment plant, which more or less met the criteria. The other alternatives were quite different from one another:

- Land application of wastewater: energy forest irrigation
- Stabilization pond with calcium hydroxide precipitation
- Packed media filter plus biofilter ditch (a long, narrow wetland)
- Land application of wastewater: crop-wetland rotation
- Sand filter

The committee was surprised that the criteria could be fulfilled by such widely varying options. They were aided in deciding among all the options by a report with two-page spreads on each alternative. The first page was a textual description of the alternative with information about how it fulfilled the chosen criteria. The second page contained a sketch or sketches of the system and a short summary of how the system performed on the criteria (Figure 6-4).



	Phosphorus	Nitrogen	BOD	Org. toxins
Reduction:	>90%	50%?	>90%	High
Recycling:	<90%	<20%		
Health risks:	Acceptable			
Economics:	Inexpensive to build (totally 55 000 USD), more expensive to operate			
Local suitability:	Good			
Responsibility:	Requires buying land			
Control:	Simple to operate			
Other:	- Robust and well tested - Great potential for phosphorus recycling			



Source: Ridderstolpe (1999)

Figure 6-4
Open Wastewater Planning: A Summary Sketch of Vadsbro's Alternative 2: Stabilization Ponds With Chemical Precipitation

The relative strengths and weaknesses of the alternatives were compared on a single chart (Figure 6-5). The chart is not a formal decision-making tool; there are no specific definitions for the differences between two plusses and three plusses, for example, and there is no method for adding the plusses and minuses together. Rather, the chart is a type of mnemonic tool. The descriptions of each treatment alternative provide the details of the way the alternative performs according to each criterion; the chart in Figure 6-5 merely provides an overview to be used in deliberations. The Committee used all of these aids in discussing their way to a decision: the filter bed followed by a biofilter ditch—a type of long, thin wetland.

	Alt. 1 Irrigation	Alt. 2 Ca-precip.	Alt. 3 Bioditch	Alt 4. Rotation syst	Alt. 5 Sandfilter	Alt 6 Treat. plant
Economy	+++	+++	++	++	-	--
Reduction	+++	++	++	++	++	+
Potentials for recycling	++?	++	++	+++	++	++
Hygienic safe	-	++	++	-	++	-
Local adaptation	--	+	++	++?	+	++
Responsibility /Control	-	++	++	-	+++	+++
Conclusion	Very efficient and cheap but hygienic hazards Landscape impact	Efficient Robust service demanding	Efficient Cheap Flexible Robust	Not proved but very interesting	Efficient but quite expensive	Not cost efficient Simple planning

Source: Ridderstolpe (1999)

Figure 6-5
A Comparison of the Alternatives Considered in Vadsbro, Sweden, Using Open Wastewater Planning

Open wastewater planning is more than a formal analytical model of the type that most of this report has concentrated on. It is a decision-making method, from framing the problem to choosing among alternatives. The beauty of OWP lies in its simplicity and its adaptation to local conditions, as well as its flexibility in identifying various non-economic criteria to use in judging wastewater treatment alternatives. By helping the decision-makers identify which criteria are most important to them, it is possible to concentrate data gathering on information that will make a difference for the decision. It is also possible to gauge the level of sophistication needed in the analysis to provide useful information. The analysis can then use any of the methods discussed in this report, or others, and streamline any LCA component as appropriate. The method has been used in relatively small decisions like Vadsbro; Ridderstolpe (2004) reports that he has used OWP for communities of up to 500 persons. The larger the project and the larger the constellation of interest groups, the greater the demand is likely to be for a more formally documented process. As the formal documentation increases, the OWP process begins to resemble environmental impact assessment more.

In the Vadsbro case, Ridderstolpe (2002) suggested to the committee the criteria they used. The method could be made more generally applicable by creating a long list of criteria for the decision-makers to select from.

As with EIA, a clearly defined listing of data needs has not been established for OWP. OWP could potentially capture all of the listed LCA data needs (Table 6-4, Table 6-5, Table 6-8, and Appendix E), but typically does not. A list of the assessment criteria used in Vadsbro is given in the comparison of EIA and OWP studies listed in Appendix F.

Comparison of Methods

This section provides a detailed comparison of various methods discussed in this chapter.

LCA Versus EIA Versus OWP

From a methodological perspective, the primary difference between EIA and LCA is that EIA is a framework for conducting assessments, not a method for analysis (Kärrman 2000). For most practical purposes, LCA is associated with specific methods of analysis. Within EIA there are no assigned or standardized categories or methods of analysis for those categories.

This difference between EIA and LCA is due to differences in the scope of assessment between the two methods. EIA generally addresses localized impacts and allows for the most appropriate methods for the uniqueness of the site and significant impacts. However, in practice, this flexibility combined with less attention to system boundaries allows some indirect and cumulative impacts to be skipped, particularly those that affect other locations or that are regional or global in scale. The standard LCA methods, on the other hand, are virtually incapable of detailing most local impacts (Guinee 2001).

These distinct differences could lead to an easy choice between the two; however, the environmental impacts of wastewater treatment occur at both local and global scales and environmental sustainability generally requires considerations of both (Balkema *et al.* 1998). Fortunately the EIA and LCA do not appear to be mutually exclusive; in fact they are likely complimentary (Kärrman 2000). In fact, for LCA to be successfully included in US decision making in a systemic way, some complimentary association of these items is likely necessary as EIA is the means to meeting environmental laws; with LCA providing broader implications analysis to the dialogue.

Open wastewater planning may adopt characteristics of both LCA and EIA, but is most similar to EIA. OWP may adopt the extended system boundaries global or regional impact characterization characteristic of LCA, but its flexibility to adapt to the decision-making needs and context mimic the framework of EIA. An aspect that is unique to OWP is that it is a methodology developed specifically for wastewater treatment and that is practical for smaller communities, particularly those with less monetary and human resources. OWP, however, is more vulnerable to allowing decision-makers to ignore externalities.

Comparing the LCA, EIA, and OWP cases studies, with respect to the decision-making situations (described in Appendix A), the town of Bergsjön from the perspective of Gothenburg, most closely represents the decision-making situation of the growing town, where as Hamburgsund more closely represents the small rural village. The use of LCA in the case of the large town appears appropriate; however, for the small town human and financial resources required might be taxing for an independent assessment. Unfortunately, no account of the cost or duration of the study was reported by Tillman *et al.* (1998).

The town of Willits, California is similar to the large town scenario. As EIA is already in use by large towns in the US, this environmentally successful example suggests EIA is an appropriate method for guiding such towns towards more sustainable decisions through the consideration of indirect environmental and social impacts.

Given the similarities of Vadsbro in comparison to the small rural village decision-making situation, OWP applied with a criteria list more closely resembling those of the Willits, California case study, appears to be an appropriate alternative to the more formalized EIA and LCA methods for communities of a smaller scale.

TRACI Versus EI 99

Two primary distinctions between TRACI and EI 99 are the extent of impact characterization and degree of aggregation and weighting. Previously, it was mentioned that EI 99 characterizes all of its impact categories to the endpoint level of damages to humans, ecosystems, or the availability of resources (Goedkoop and Spriensma 2001). Conversely, TRACI characterizes most of its impacts to the midpoint level (US EPA 2002). There are distinct advantages and disadvantages to both.

Endpoint characterization introduces a higher degree of discrepancy or disagreement in characterization methods. The advantage of endpoint characterization is the ease with which decision-makers can understand and value damages versus potentials. However, Bare *et al.* (2003), the developers of TRACI, point out the endpoint characterization requires additional effect modeling. This modeling generally has a lesser degree of consensus, and there are fewer models for damages to ecosystem health than human health, excluding impacts that were otherwise included in the midpoint effects.

As mentioned earlier, weighting is considered an optional fourth step of LCA and is the most controversial topic in LCA. There is even some debate as to whether it may be considered a valid component of an ISO-compliant assessment (Goedkoop and Spriensma 2001). The concern of most critics is that values differ considerably between decision-makers both within assessments and between assessments, and that the weighting may add an unreasonable amount of subjectivity to the assessment. Goedkoop and Spriensma (2001) argue that although controversial, the weighting step is critical and should be formally included in LCA studies. Their argument is that if a formal, transparent standardized weighting step is not included in the method, decision-makers will weight the impacts on their own in a much less transparent way.

EI 99 was developed specifically to address weighting. TRACI does not include weighting options, but this does not preclude users from applying formal weighting methods to TRACI results or developing their own weighting method using multi-criteria analysis.

An obvious disadvantage of EI 99 for use in the US is the fact it is based on western European characterization, though prior to TRACI's release, this did not prevent its use in the US and EI 99 continues to be used around the world. In the US, however, TRACI presents a strong case as it not only has US-specific characterization factors for all of its impact categories, it will also characterize impacts for regions, states, and counties for certain categories if location data are included in the life-cycle inventory. This is a unique attribute among LCA methods. See Table 6-5 for a complete list of the characterization locations for each category in TRACI.

Another unique advantage of TRACI is the inclusion of a water-use impact category. While the majority of TRACI's and EI 99's impact categories are roughly equivalent, only TRACI accounts for the impacts to water resources, and only EI 99 characterizes the impacts to mineral material resources. From the wastewater treatment perspective, water resources impacts are more critical for comparisons of alternatives. Unfortunately, the characterization of water-use impacts in TRACI is simply an aggregation of total water use over the life cycle, and considerably more detail about water-resource impacts is need by decision-makers, such as the quantity of water displaced from local aquifers or basins.

SPI Versus TRACI and EI 99

The Sustainability Process Index is streamlined in comparison to detailed LCA methods like TRACI and EI 99. The SPI simplifies LCA by assuming that the ultimate determinate of sustainability of a process is a factor of the land area required to perform that process with renewable resources. Accordingly, SPI counts only those impacts that contribute directly or indirectly to the quantity of land for that process. This removes a significant portion of the inventory data and the traditional impact assessment methods from the analysis, but this simplification comes at a cost in terms of impacts missed from the analysis.

Otherwise the SPI is comprehensive considering that it has a single unit of analysis (land area) for all of the impacts it factors. However, compared to TRACI and EI 99, important impacts such as ozone depletion, water use, and scarcity of resources other than land or any human or ecological health effects are not directly accounted.

The SPI requires that decision-makers understand and value ecosystem services, exergy, and a solar exergy-based economy. This may not seem dissimilar from the requirement of TRACI users to understand and value vague impact categories such as global warming and acidification potentials. However, ecosystem services and exergy are still nearly exclusive to academic discussions of ecological economics. Thus only regions and communities with a particular focus on sustainability or states or regions interested in imposing sustainable water practices may find these tools of utility.

Currently, there are no known practitioners of the SPI in the US and few world-wide; however, those familiar with life-cycle assessment and especially Ecological Footprint analysis[3] (see Appendix C) would have little trouble understanding and calculating the SPI, or at least would not be limited by lack of training. Likewise there are, currently, few TRACI practitioners in the US; however, those familiar with EI 99 and other ISO-based LCA practitioners can probably adapt to TRACI without difficulty.

URWARE Versus TRACI and EI 99

URWARE is also unique among standardized LCA methods. URWARE's uniqueness arises from its specificity and detailed inventory framework. By combining a detailed material flow analysis model, specific to waste and water resources, with ISO-based LCIA, the developers of URWARE have created an LCA tool specifically for water and wastewater decision making and strategic planning. Although it was not developed with this intent, URWARE also provides a much better tool for ecological wastewater design development than other generic LCA tools.

URWARE's capacity as a design development tool is largely due to its use of dynamic materials flow analysis modeling. Typically LCA models (such as TRACI and EI 99) are steady-state or static and linear in nature (Guinee 2001), that is, they are snap shots in space and time of the impacts of processes that are dynamic and consisting of cyclical relationships. In most decision situations this is not an issue. Inventories are units of average quantity of impact per year per functional unit, and for most wastewater decision situations, this is appropriate. Researchers, policymakers, and designers who are working to improve the overall environmental performance of wastewater treatment systems will find dynamic modeling of LCA applications to be useful (Guinee 2001).

Including materials flow analysis into LCA is not unique to URWARE. Essentially, all LCAs of processes require some degree of material and energy flow analysis to develop the LCI, though more generic LCA methods such as TRACI and EI 99 leave it to the user to apply a formal materials flow analysis. Similar material flow models were also developed in ORWARE, the precursor to URWARE. These include much information about solid waste, however, and thus are of less use to US wastewater decision-makers.

[3] Ecological Footprint analysis is an evaluation of the environmental impact of a human population or economy by characterizing resources consumed and wastes released as a quantity of ecosystem services used, in units of ecologically productive land area, similar to the SPI. (Wackernagel and Rees 1996)

7 DATA AVAILABILITY

"Indeed databases are being developed in various countries and the format for databases is being standardized. But in practice data are frequently obsolete, incomparable, of unknown quality. More in particular, data is generally available at the level of building blocks, i.e., for combinations of process such as 'electricity production' or 'aluminum production' rather than for the individual constituting processes themselves."

—Guinee (2001)

Unfortunately, Guinee's account of the state of general life–cycle assessment (LCA) data availability in Europe in 2001 is similar to that in the US in 2004, and rapid growth in data availability is unlikely anytime soon, given the continuous need for "building block" data to be regenerated or updated. This situation is especially true considering that the US demand for LCA data is lagging well behind Europe. Thankfully, European databases are increasing their scope steadily as the acceptance and number of LCA and environmental impact analysis (EIA) studies increases across industry sectors, suggesting that there is hope for an eventual increase in data availability in and transfer of data collection methods to the US.

There are, however, varied data resources available to US decision-makers evaluating the impacts of wastewater treatment options. The following chapter reviews both common sources of data for the methods compared as well as the availability of the types of data commonly needed by the methods.

Unlike the LCA-specific data available to European impact-assessment practitioners, much of the US data tends to be highly aggregated and/or highly disaggregated, both of which can present challenges to US practitioners. US impact-assessment data provided by the US EPA is typically broken down into industry sectors by Standard Industry Classification (SIC) indices. Unfortunately, industry sectors represent a high level of aggregation, which is imprecise for detailed impact assessments. At the same time these and other sources of information are disaggregated in terms of impact categories, often focusing on one or a few parameters, requiring impact-assessment practitioners to search for and compile data from multiple sources in order to obtain a complete inventory for each process or material considered.

Data Sources

The scoping review of data availability was focused on four sources of data: published literature, technical reports, online databases, and databases embedded in software packages. Only data that was publicly available was sought. Many LCA databases either require paid subscriptions or purchase of software, or charge individually for each data set. For these, a list of the data types or data categories included was easily attainable. The databases were then evaluated on the basis of those lists. Also, LCA studies frequently use proprietary data. Willingness to share proprietary data is completely dependent on the individual company. Little attempt was made to obtain proprietary data for any wastewater technology.

Published Literature

Journal articles can be appropriate sources of inventory data, but it is rare that a significant amount of inventory data is published in a journal article. It is often too aggregated or the system boundaries or methods are not defined well enough in the article to make use of the data. Transparency is critical for maintaining data quality, given the variety of techniques available to LCA practitioners. Journal articles are most useful because they point to reports and references where more detailed information can be obtained.

Researchers are likely to find more useable data from published books on wastewater treatment system performance and design, though the “perishability” of this data varies and it should be used at the analyst’s discretion. For example, one of the most extensive sources for wastewater treatment system energy performance was performed by Owen; however, it was published in 1982 (Owen 1982). Such data may be used as long as the quality remains transparent to decision-makers. Data more than 15 years old are generally considered out of date (Matthews 2004). Still, such determinations should be made case-by-case, process-by-process.

Data from journal articles and books are available at the cost of purchasing the publication or borrowing them from public and university libraries.

Technical Reports

Reports of LCA or inventory studies are superior sources of data since they typically contain the complete set of inventory data and are more transparent in terms of the methods used. However, reports are generally more difficult to obtain, because they are often performed privately within companies. In the case of wastewater, most of the life-cycle analyses performed are done so in the public domain (for example, the 22 studies described in Appendix F are publicly available), making them somewhat easier to acquire. Unfortunately, nearly all wastewater impact studies have been conducted for European conditions and little of the data are directly applicable to the US.

Life-cycle inventory (LCI) or eco-profile reports released by national and international industry organizations such as the Association of Plastic Manufacturers in Europe (APME) and International Iron and Steel Institute (IISI) are helpful, in part because they offer industry average values as opposed to individual plant or system values. Again, many of these are European or global values that should be scrutinized individually to ensure compatibility with US processes and conditions. It is also important to note that when modeling an unknown or hypothetical system or process, aggregated industry average values are more likely to be accurate than the detailed process values of an individual plant or system (Matthews 2004 and IISI 2004).

LCA reports are typically available at the cost of a printing and shipping fee.

Online Databases

A number of online databases are publicly available to US decision-makers interested in comparing the environmental impacts of systems, products, or services. Some of these include LCA- and LCI-specific databases like the Swedish SPINE@CPM, the Swiss Ecoinvent, and the US EPA's Global LCI Directory. Others like the US EPA's AirData, Toxic Release Inventory (TRI), and Sector Notebooks databases are focused solely on pollution emissions of US industries, while the Better Assessment Science Integrating Point and Non-Point Sources (BASINS) and National Water Quality Assessment (NAWQA) programs provide environmental site conditions, which may be particularly helpful for US EIA studies.

These online databases make up the bulk of data available to US practitioners and provide hope for the implementation of new analytical methods such as EIA and LCA in the US. An exciting addition to the bank of US-specific data is the development of a new US LCI database. The National Renewable Energy Laboratory (NREL) has recently teamed with the three most prominent LCA database developers in North America, Athena, Sylvatica, and Franklin Associates to develop an LCA database for 25 primary processes and materials. The Athena Sustainable Materials Institute has developed the Athena software with an extensive embedded database of common building materials relevant to North America. Sylvatica was instrumental in the development of TRACI and has developed an input/output database similar to Environmental Input/Output Life-Cycle Assessment (EIOLCA). Franklin Associates released a database of primary materials in 1998 that has been available through the SimaPro software. The 1998 Franklin associates database is considered nearly obsolete and will be replaced by the new US LCI database (Matthews 2004). This new database is under review and will soon be available online and embedded in the latest version of SimaPro LCA software (Oele 2004).

Little data, specific to the US wastewater industry, is available in the form of databases online or other. The Wastewater Information Exchange (WWIX) is the only known national wastewater treatment system performance database. WWIX provides basic performance information for primarily centralized systems including average flow, design flow, population served, permitted and actual biochemical oxygen demand (BOD_5), total suspended solids (TSS), chloride (Cl_2), Ammonium (NH_4), Nitrate (NO_3), phosphorus (P), and fecal coliforms of the final effluent and a list of the unit processes contributing to that final effluent quality (Harrington 2004b). Considerably more detail is needed for the methods described in this report; however, WWIX also maintains a directory of data providers from whom additional data, such as energy performance, chemical usage, sludge quantity and quality, and other details of unit processes may be obtained through custom surveys. Currently, WWIX is only up-to-date with data from the Northwest region and portions of California, but is intended to serve as a national database (Harrington 2004a). Future expansion of this database to include performance details at the unit process level and for all regions of the US would be invaluable to US decision-makers concerned with sustainability of wastewater treatment systems.

Most online databases such as SPINE@CPM and Ecoinvent have free access to browse and search the data categories, but the complete datasets must be purchased. Individual datasets may be purchased from SPINE@CPM for about $17–$135 USD depending on data quality and degree of aggregation. (Note: Aggregated data are cheaper.) Ecoinvent datasets are available for download with a $1,470 USD individual membership or with the purchase of some LCA software. See the discussion of embedded databases that follows this section.

Descriptions of online databases including web addresses are contained in Tables G-1 through G-5 in Appendix G.

Embedded Databases

The other major sources of US-specific data are imbedded in software such as the EIOLCA model and the Missing Inventory Estimation Tool (MIET). Both are input/output models that model the US economy and utilize the most recent industrial emissions and consumption data available from the EPA. By estimating the value of the material, component, or service used, these models can produce estimations of the impacts associated with the production of the quantity of product or service. This technique can be useful when data are too difficult or too costly to obtain; however, it is to be avoided where possible given that there is a considerable loss of detail when using the models' highly aggregated sectors (Matthews 2004).

Other popular LCA software packages, such as the Dutch SimaPro and German GaBi, may contain numerous embedded databases. While these software packages claim to be global in scope, the data are primarily from Western European sources and should be assumed inapplicable unless carefully reviewed.

Some embedded databases, such as those found in SimaPro and GaBi LCA software are available with the purchase of the software license (for example, Ecoinvent is available with the SimaPro indefinite developer license ($8,940 USD), and APME is available in the professional license GaBi ($9,300 USD), while others may be added at an additional fee (for example, the Franklin Database may be added to SimaPro for $496 USD, and 13 additional integrated databases ranging from $670 to $4,600 USD are available for GaBi).

Descriptions of embedded databases are contained in Table G-1 through Table G-5 in Appendix G.

Data Availability

EIA are already conducted in the US for wastewater treatment alternatives. Processes are, therefore, clearly in place to generate needed data for each specific study and to provide any more general data that can be used in multiple studies. This section focuses on data that would be needed to conduct some sort of LCA of wastewater treatment—whether that LCA is incorporated into open wastewater planning (OWP) or an EIA, or whether it stands alone.

Despite some significant differences in the LCA methods compared, the data needs of the methods for comparing wastewater treatment options are largely the same. As previously mentioned, it is the determination of system boundaries and parameters for analysis that appear to have the greatest impact on inventory data needs. This relationship makes the task of evaluating data availability more manageable, but by no means easy.

Material and Energy Flow Data

Material and energy flow data for wastewater treatment systems are critical to any assessment of the environmental impacts of wastewater treatment (WWT) options, yet they are most often the most difficult information to obtain, especially at the level of detail needed for most methods. Locating system-level data is inherently difficult, largely because of variability in system design and configuration, but also because detailed process information may be proprietary (EBN 2002).

For centralized treatment systems it was found that manufacturers and process designers are reluctant to provide detailed material and energy flow information for research, though they may be considerably more willing to assist potential clients in their decision-making processes. When contacted directly, treatment plant operators have also typically been reluctant to provide actual operation data for research purposes (Todd and Gaddis 2003), though through encouragement from wastewater associations and the benefits of data sharing, the WWIX program has proven successful in obtaining some material and energy flow data (Harrington 2004b). Many published sources of material and energy flow data relevant to the US are potentially out of date for comparisons of new systems and/or are disaggregated from a life-cycle assessment perspective. For example, Water Environment Federation's manual of practice, *Energy Conservation In Wastewater Treatment Facilities* (Kennedy 1997), lists energy requirements for basic unit processes in four centralized plants at six different scales, but does not include the relative effluent quality or removal rate and references energy-use data from US EPA studies released in 1973 and 1978.

For decentralized systems, Middlebrooks *et al.* (1981) has published an extensive report on energy requirements of small scale systems, which includes direct and indirect energy use relative to effluent quality. However, the report focused specifically on wastewater treatment in intermountain region and the data was published in 1981. Once again, such data must be used with discretion and transparency.

Recent material and energy flow data for decentralized systems are reasonably well documented for a few systems. There are some published and standardized evaluations of decentralized wastewater treatment and disinfection system material and energy flow available through the National Science Foundation (NSF) and EPA's Environmental Technology Verification Centers and through the Massachusetts Alternative Septic System Test Center, as well as several academic publications. However, the systems tested are a subset of those available in the US and are based on controlled conditions. Little long-term field-test data is currently published. It is helpful that decentralized systems are typically simpler and more consistent in design and operational requirements, requiring less data needs to obtain a full account of material and energy flows. Additionally, onsite system manufacturers have been less reticent to provide material and energy flow data when they are available.

Sludge production, both quantity and quality, is one of the most critical data needs for both centralized and decentralized systems. It is associated with energy-intensive transport and treatment and can have significant local environmental consequences. Sludge quantity may be estimated from wastewater design textbooks (for example, Tchobanoglous *et al.* 1991 and Water Environment Federation 1998), though operational data from similar plants operating under similar conditions are likely to be more accurate (Water Environment Federation 1998). Details of sludge quality are more difficult to obtain or estimate, because they are often situation specific (Tchobanoglous *et al.* 1991). Variances in user operation and design can greatly affect this parameter at both the centralized and decentralized level, making it one of the greater challenges to assessment of wastewater treatment options.

At the component level, recent material and energy flow data may be more available. Manufacturers regularly supply energy-efficiency data and these account for a major portion of the operational data required. These data may then be aggregated to estimate the total system material and energy flow. This method is more time intensive and less accurate than using up-to-date system-level data. If used, it should be used consistently across the comparison.

Below is a listing of material and energy resources specific to US conditions, which may serve as a starting point for making comparisons within the US of the non-monetary impacts of wastewater treatment options, especially in cases where more recent system- or location-specific data are not available.

US EPA Technical Report: ***Energy Conservation in Municipal Wastewater Treatment***
(Wesner *et al.* 1978)

- Energy use for unit processes, grouped unit process configurations, and basic treatment systems, relative to basic effluent quality (for example, BOD_5, TSS, and in some cases NH_4, nitrogen (N), or P)
- Chemical use for unit processes
- Sludge production for treatment types
- Plants sizes ranging from 0.1 to 100 mgd

Energy in Wastewater Treatment (Owen 1982)

- Energy use for grouped unit process configurations and basic treatment systems relative to basic effluent quality
- Plant sizes ranging from 1 to 100 mgd
- Indirect energy use—for production of wastewater chemicals
- Indirect energy use—for production of wastewater construction materials
- Indirect energy use—for wastewater construction activities

Energy Requirement for Small Wastewater Treatment Systems (Middlebrooks *et al.* 1981)

- Energy use for unit processes and 13 treatment-system configurations for the US intermountain region
- Plant sizes ranging from 0.05 to 5 mgd
- Indirect energy use—for production of wastewater chemicals
- Indirect energy use—heating and cooling of buildings
- Sludge production for treatment types

Material/Component Production Data

As Guinee observed, the highest quality and most recent environmental impact data are available at the level of material, or "building blocks," and much of the data available for material production are European. Steel, concrete, gravel, sand, and plastics are among the most critical materials for considering the impacts of the investment in the structural components of a wastewater system. Currently, the Franklin Associates US LCI database, BEES US construction materials database, and a small portion of the Ecoinvent database comprise the primary sources of these data for US conditions, but they are limited to a subset of the "building block" materials needed, and US component-level production data are nearly non-existent.

As the name suggests, input/output models like the MIET and its sister, the EIOLCA model, are considered suitable substitutes for generating these data when all other resources have been exhausted (Matthews 2004). The method for taking this data-gathering shortcut is explained in more detail in the streamlining discussion (Chapter 9). This approach is a crutch and should be avoided wherever possible.

Transportation and Construction Data

If the material investment in the system is included in the scope, the evaluation, excavation, and installation impacts must also be considered. They may vary significantly, depending on site conditions. These impacts may be estimated based on hours of operation or quantities of material moved. Values for excavation and installation equipment are reasonably well documented in Europe, but not in the US. Similarly, transportation LCA values, typically expressed in units of impact quantity per ton-mile, are well documented in European databases, but in the US complete LCI data are limited to a few basic modes such as gas and diesel trucks and ocean freighters.

Process Data for Extended Systems

The processes found to be of greatest significance to impact analyses of extended systems are electricity production, heat production, amendment-chemical production, and fertilizer production (Jeppsson and Hellström 2002). Fortunately, these extended processes are generally better documented in the US than wastewater treatment processes. Also industry average data are suitable (Matthews 2004), whereas detailed process and performance information is needed for the wastewater treatment processes compared. The EIOLCA and MIET models are also suitable for generating these impact data, when sufficient average industry data are not available. As mentioned previously, average industry data are most desirable. Scott Matthews of Carnegie-Mellon's Green Design Initiative suggests that even the impacts of the sector-aggregated industrial processes generated within the input/output models are likely to be more representative than modeling the impacts of a single plant (Matthews 2004)

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8 BARRIERS TO NEW METHODS

As was shown in the previous chapter, data availability is a formidable barrier to using new methods for evaluating wastewater treatment alternatives. In this chapter, other barriers are examined.

Barriers to Using LCA

Barriers to wider adoption of life-cycle assessment (LCA) in the world were identified by a report to the United Nations Environmental Program (The Centre of Environmental Science at Rijksuniversiteit Leiden 1999), as cited in Curran (undated). The three main barriers found were:

1. Under-appreciation of the importance of the life-cycle concept

2. Difficulty accessing life-cycle inventory data and assessing its quality

3. Lack of comprehension of impact assessment

Those barriers are also obstacles to wider use of LCA methods for wastewater treatment policy or decisions in the US. Environmental life-cycle assessment is so little understood or even recognized in the US that, even at environmental conferences, people frequently confuse economic life-cycle costing with environmental life-cycle assessment.

The lack of understanding of LCA in the US is, perhaps, related to the lesser concentration on “sustainability” as a policy goal. As was pointed out in Chapter 3, some US cities and towns have adopted Earth Charter or Local Agenda 21 principles of sustainability. Most communities and states, however, do not even discuss sustainability. LCA is an attractive way to begin answering the question, “How can we make our processes more sustainable?” When sustainability is not on the agenda, ascertaining whether environmental impacts are only moved elsewhere—or whether new impacts felt only at the regional or global level are created—is not part of the calculus of local decisions, and LCA is a solution in search of a problem.

The lack of understanding of LCA does not reflect a lack of motivation to tackle environmental issues. Surveys in the US consistently show that most people consider themselves environmentalists; a recent survey showed that three-fourths of the people in the US believe that “if we don’t act now, we’ll never control our environmental problems,” and a clear majority declared, “At heart, I’m an environmentalist” (Levine and Morgan 2004). For whatever reason, concern for the environment in the US has been expressed in the language of sustainability less often than in many European countries.

The barrier of data availability is discussed at length in Chapter 7. Possibilities for streamlining the LCA process to overcome this barrier are discussed in Chapter 9. Much LCA data can be reused from other studies. For this reason, compared with European countries, the lack of LCA data availability is exacerbated in the US because LCA is not in widespread use.

The lack of comprehension of impact assessment is probably, at most, secondary to the lack of data availability at this point in the US. The EPA's TRACI model provides a relatively simple way to conduct impact assessment, at least for the impact categories it covers. Once people become aware of the concept of life-cycle impacts, impact assessment is fairly easy to explain to them, and that TRACI provides a useful first tool for conducting the impact assessment. As use of and sophistication with LCA grow in the US, the disputes over what methods to use for impact assessment that are prevalent in Europe (Curran undated.) will probably arise here, and there will be a need for other tools.

Finding the political will to fund LCA studies at the level of municipal wastewater decisions may be difficult. As remarked by one organizer of the US EPA's workshops on asset management for water and wastewater treatment, small amounts of funding for planning can be much more difficult to come by than large amounts of funding for construction. Also, asset management planning is something that has the potential to save money in the short-run for the people doing the planning. LCA, by identifying ways to solve rather than move or delay environmental problems, also has the potential to identify ways to save money, though perhaps over a longer period and for people other than those who have paid for the planning.

Barriers to Using EIA

Environmental impact assessment (EIA) methods have fewer barriers to more widespread use than LCA methods. Since EIA could be considered an extension of the usual water quality and public health considerations that have governed wastewater treatment policy and decisions, people are already familiar with the concept. Also, the connections between actions and impacts are easier to understand in EIA than in LCA. No advanced understanding of impact categorization theory is needed to understand that installing sewers in an area served by onsite wastewater treatment systems will reduce local groundwater recharge.

Funding at the local level is probably a barrier for EIA. However, where problems that an EIA could help address have grown acute, it may be easier to appropriate local funds or procure state grants. For example, as Michelle Drury explained during an interview with her (see Appendix H), a version of EIA was already used in eastern Massachusetts, where reduced groundwater recharge has become an acute problem.

Data availability for EIA is more closely tied to funding for individual studies than it is for LCA. EIA relies on site-specific data to a larger extent than LCA. Site-specific data, almost by definition, must be generated for each EIA. Within EIA there is much room for borrowing methods of data collection from other EIA studies, but less scope for transferring data from one study to another than in LCA.

Barriers to Using OWP

For open wastewater planning (OWP), barriers related to data availability vary depending on whether the OWP draws more on LCA or EIA. The more LCA-like an OWP process becomes, the more the lack of data in the US becomes a barrier. The size of the community may be another barrier. OWP has been used in communities of less than 500. Larger communities may demand more formalized methods than OWP, in order to guarantee input from various stakeholder groups. The authors' experience in working with communities one or two orders of magnitude larger than that suggests that they often have enough flexibility in their planning processes to allow something like OWP. In fact, the initial goal-setting exercise of OWP is similar in spirit to the mission statements that a number of these communities have generated for their wastewater planning processes.

The most significant barrier to OWP's widespread use may be a shortage of engineers and other consultants trained in designing and evaluating centralized and decentralized alternatives on an equitable basis.

Overcoming the Barriers

A number of people around the US involved in wastewater policy were interviewed to assess their interest in using the methods identified in this report to address issues they confronted (see Appendix H). The interviewees were selected based on finding people who were most likely to be interested in new information that could drive wastewater-treatment decisions. Nonetheless, two of the five people interviewed indicated little or no interest in the suite of methods described. The three who showed interest represented state government and a non-profit environmental organization in Massachusetts, where hydrologic effects of sewering large areas are particularly acute, and a representative of an energy efficiency utility's green building program. The two interviewees in Massachusetts indicated that sustainability is an important term in the water-policy discussions. The green building representative may not have used the term "sustainability," but the organization's mandate is to promote buildings that are more environmentally friendly, a goal that is as difficult to define and measure as sustainability.

The difficulty of defining terms like environmental friendliness and sustainability can lead to repeated attempts to answer the question, "What do we mean by sustainability?" The question opens the doors for using different methods in answering it, like EIA, LCA, and OWP. Consequently, places where environmental friendliness or sustainability are actively and sincerely promoted as goals (and not just used as buzzwords) in wastewater-policy discussions may be the ones most open to using the methods described in this report.

Another route to overcoming the barriers may be found in Curran's (undated) observation, "The governments within the European Union have been much more willing [than those in the US] to use life-cycle assessment approaches in developing policies." If federal, state, and local governments in the US use LCA more, they may raise awareness of the life-cycle concept and stimulate greater use among industry as well, thus making more data potentially available (Curran undated).

LCA in Europe spread at much different rates within different industries (Tillman 1996). When significant companies in a given industry applied LCA to their production processes, their competitors tended to follow. Could an industry like wastewater treatment, then, possibly make great advances in using LCA before many other industries had adopted it? It is difficult to know which actors have the potential to play the role in the wastewater-treatment industry that industrial giants like ABB Group[4] played in Europe.

Perhaps the stimulus to the wastewater industry could come from academia rather than industrial actors. Sweden may be the country most advanced in using LCA to inform wastewater-treatment policies and decisions. (See, for example, the Sustainable Urban Water Management program, http://www.urbanwater.org/default_eng.htm.) There, university researchers have done most of the work in developing and applying the methods. The studies have tended to be directed towards policy development, not concrete decisions. Many hypothetical cases have been explored or actual cases with alternatives not seriously considered by decision-makers.

In Switzerland, the Netherlands, and the United Kingdom, university scientists have also played a leading role in applying LCA to wastewater issues.

A strong case can be made for using academic and policy-level researchers to perform enough and the right LCA studies that general conclusions can be drawn. Some impacts revealed by LCA occur at such great time and distance from local decision-makers that they are more naturally the province of policymakers and academics. Also, funding for wastewater LCAs may flow most easily to academics and policymakers—at least by default. Since commerce in wastewater treatment is not concentrated in the way that it is in manufacturing sectors, it may be hard to find private sector actors to spread LCA. Since local funding even for planning that gives direct financial payback is hard to come by, LCAs funded by local decision-makers are not likely to occur often—unless state or federal funds are earmarked to encourage that.

The next chapter, on streamlining the LCA process, contains suggestions for ways to streamline the LCA process and thereby minimize the need for data, consistent with providing reliable answers to relevant questions. The final chapter, on recommendations and next steps, contains additional suggestions for overcoming the barriers identified in this chapter.

[4] The ABB Group is an international conglomerate assisting utilities and industries in reducing environmental impact through power and automation technology (ABB Group, Undated).

9 STREAMLINING LCA

Gathering life-cycle inventory (LCI) data is likely to remain the most difficult and costly step of life-cycle assessment (LCA), even with a great increase in the use of LCA in the US and the availability of updated, region-specific data on basics like energy and common materials. There will still remain considerable product- or process-specific data for each LCA carried out, and much of it may be proprietary.

The costs and difficulties of gathering LCI data could lead to the method being out of reach for many who would like to use it. For that reason, various approaches to streamlining the LCA process have been explored.

The Society of Environmental Toxicology and Chemistry (SETAC) commissioned a group to define and document a shortened process for LCA (Todd and Curran 1999). The group quickly realized that all LCAs are shortened in some way during the goal definition and scoping phase of the project. If that were not the case, a cradle-to-grave LCA for a product would follow production upstream to extraction of the raw materials used, and then continue upstream to consider production of all products used in extracting the raw materials, and so on. Similarly, downstream, the LCA would be quite branched. Even if the final fate of the entire product were to be put into a landfill, an LCA would consider the impacts of producing the landfill liner, including back upstream to production of all the equipment used to make the liner and all other components. Even the time during which environmental effects from the product's residence in a landfill are followed is typically limited, for example, to 100 years.

When the SETAC group understood that all LCAs were streamlined through the goal-and-scope process, they set about to provide guidance on using the definition of goals and scope to streamline the LCA, while still providing the study team with the answers they were looking for. They also described specific ways streamlining has been used, investigated the effects of various ways of streamlining on the final results, and recommended ways to streamline.

Streamlining Through the Definitions of Goal and Scope

The SETAC group's recommendations on connecting the definition of scope and goals with the issues the study team is trying to address are helpful in screening out unnecessary data gathering (Todd and Curran 1999). One example that they use is that if an LCA is intended to compare the environmental impact from using virgin versus recycled materials, then the downstream process from the manufacturing probably can be omitted.

This report has primarily been considering using an LCA of wastewater treatment systems to provide comparisons between two or more alternatives for use in a specific site. (LCA could also be used at a policy level as part of the decision whether to permit a certain type of onsite wastewater treatment system or for making broad decisions about whether to pursue onsite versus centralized options for a region.) The following discussion contains the authors' thoughts on tailoring the SETAC group's suggestions to the specific goal of comparing wastewater treatment alternatives for a specific site.

Who Is the Audience and What Do They Want To Do With the Data?

The audience is likely to be a citizen's wastewater advisory group, local elected officials and civil servants, and probably state regulators. They want to use the data to compare a small number (probably two to five) of wastewater treatment alternatives whose financial costs and effects on water quality are known, documenting outstanding environmental advantages and/or disadvantages elsewhere in the lifecycle. The audience may decide to make a different choice than they would have based only on cost and discharges to water of the various alternatives, if other, significant life-cycle impacts are documented and the choice is fiscally fundable.

System Function and Functional Unit

LCA comparisons are made by comparing environmental impacts from equivalent amounts of product or services. For example, in comparing roofing materials, an LCA study may choose to present environmental impacts per 100 m^2 of roof covered, since roof coverage is the service provided. This basic unit for which impact is analyzed is called the "functional unit."

For wastewater treatment, the choice of functional units is not as clear as for roofing material. Wastewater treatment systems often produce more than the single service of treating wastewater. As discussed elsewhere in this report, sludge produced may be applied to land—substituting for commercial fertilizer—or incinerated to produce district heat and electricity—substituting for another fuel. The functional unit for a study is chosen on the basis of the primary function of interest. In our case, that function is treating wastewater.

The functional unit chosen would most likely be person equivalent (p.e.) of wastewater or person served. The p.e., defined by volume of wastewater or mass of pollutant loading per person, could be used as the functional unit if these are expected to be identical per person in all alternatives. If composting or urine-separating or ultra low-flush toilets are used in one or more alternatives, the alternatives are likely to differ at least in water volume generated. In that case, person served would be a more appropriate functional unit.

If the purpose of the study is to help decide among wastewater treatment alternatives that serve the same region and number of people, the functional unit could even be defined as the system as a whole. However, it is useful to compare a study's results to other, similar studies to see whether there are any major differences and, if so, why. The other studies may even be sources of data for the current study. Such comparisons and reuse of data are easier if the functional unit is the same in all the studies. Therefore, we recommend that person served be used as the functional unit for all wastewater LCAs, as it is the most generalizable across alternatives and, therefore, useful in the most number of studies.

System Boundaries

As has been discussed earlier, Lundin *et al.* (2000) show that choice of system boundaries can affect the ranking of alternatives. This work shows that the environmental impact of fertilizer production is an important part to include inside the system boundary, when wastewater treatment alternatives recycle differing amounts of nutrients to agriculture. A number of studies (for example, Lundin *et al.* 2000 and Tillman *et al.* 1998) show that district heating or electricity produced as a by-product of wastewater treatment has an important effect on the overall results; it should be included. Transportation impacts of wastewater by-products or components, like sludge and urine, also have a significant impact on results (Lundin *et al.* 2000, European Commission DG Environment 2001; and Poulsen and Hansen 2003), and therefore should be included.

If the system boundaries were drawn to include operation of systems only, it would save a lot of work in data gathering. Are environmental impacts from manufacturing and construction significantly different among alternatives? Two studies from Chalmers University in Sweden show that manufacturing and construction have a proportionally larger impact in smaller scale systems than larger systems, but that they are similar among the examined alternatives at the same scale. Tillman *et al.* (1998), Lundin *et al.* (2000), and Dixon *et al.* (2003) find, over a range of small-scale systems, that a package treatment plant has larger economies of scale than a reed-bed system. At present, too little is known to warrant excluding the manufacturing and construction phases without further justification. Future LCAs should include manufacturing and construction, so that they advance our understanding of when they can be omitted without affecting the final ranking of alternatives.

Good general guidance about what features of system boundaries are important to LCA is found in Barnthouse *et al.* (1997), as paraphrased by Todd and Curran (1999):

- "A system-wide perspective embodied in the term "cradle-to-grave" that implies efforts to assess the multiple operations and activities involved in providing a product or services."
- "A multimedia perspective that suggests that the system include resource inputs as well as wastes and emissions to all environmental media, such as air, water, and land."
- "Functional unit accounting system that normalizes energy, materials, emissions, and wastes across the system and media to the service or product provided."

Data Choices

Gather only data that will be used for analysis. This sensible-sounding rule can be most easily followed if the life-cycle impact assessment is designed at the beginning of the study, after the scoping. When the LCIA is designed, it will be clearer which data are needed to perform the impact assessment.

Table 9-1
Methods for Streamlining

Streamlining Approach	Application Procedure
Removing upstream components	All processes prior to final material manufacture are excluded. Includes fabrication into finished product, consumer use, and post-consumer waste management.
Partially removing upstream components	All processes prior to final material manufacture are excluded, with the exception of the step just preceding final material manufacture. Includes raw materials extraction and precombustion processes for fuels used to extract raw materials.
Removing downstream components	All processes after final material manufacture are excluded.
Removing upstream and downstream components	Only primary material manufacture is included, as well as any precombustion processes for fuels used in manufacturing. Sometimes referred to as a "gate-to-gate" analysis.
Using specific entries to represent impacts	Selected entries are used to approximate results in each of 24 impact categories, based on mass and subjective decisions; other entries within each category are excluded.
Using specific entries to represent LCI	Specific entries from the individual processes comprising the LCI that correlate highly with full LCI results are searched for; other entries are excluded.
Using "showstoppers" or "knockout criteria"	Criteria are established that, if encountered during the study, can result in an immediate decision.
Using qualitative or less accurate data	Only dominant values within each of 6 process groups (raw materials acquisition, intermediate material manufacture, primary material and product manufacture, consumer use, waste management, and ancillary materials) are used; other values are excluded, as are areas where data can be qualitative or otherwise of high uncertainty.
Using surrogate process data	Selected processes are replaced with apparently similar processes based on physical, chemical, or functional similarity to the datasets being replaced.
Limiting raw materials	Raw materials comprising less than 10% by mass of the LCI totals are excluded. This approach was repeated using a 30% limit.

Source: US EPA (1997) as reproduced in Todd and Curran (1999)

Methods for Streamlining

The US EPA (1997) commissioned a study by the Research Triangle Institute (RTI) and Franklin Associates, Ltd. (FAL) to perform a full LCA of 26 products in 10 product categories, and then to streamline the LCA in different ways. The study, as described by the SETAC group (Todd and Curran 1999), reported how the rankings from the streamlined methods compared with the full LCAs. The results did not differentiate between a minor shift in rankings, for example, switching of two products in the middle of the ranking list, and a major shift, such as a product going from top to bottom.

The major finding was, unsurprisingly, that streamlining methods that were the closest to full LCA produced rankings that were the most similar to those of full LCA, and that excluding data that dominated the life-cycle inventory gave less similar results (Todd and Curran 1999). The approach tested by the US EPA that produced results most like a full LCA was the historical "sensitivity analysis" approach. This requires that a complete flow diagram be developed, with materials-flow quantities in place, based on estimates, secondary data, or generic data from commercial databases. A preliminary LCI using rough data, but covering all major life–cycle stages, is performed at this point. Sensitivity analysis can then be applied. In this process, each LCI entry is examined and the percent contribution of each process to the total is calculated. For those processes that contribute a large percentage of the total, the best data possible is required. For those processes that contribute little to the total, estimates or surrogates are acceptable. This process also leads to an analysis of product system structure, which is also an aid to selecting appropriate streamlining methods.

There are currently enough LCAs on wastewater treatment from Europe (see Appendix F) to provide data for a historical sensitivity analysis approach. It is recommended that US researchers performing LCA consider using this streamlining approach.

Hybrid Approaches

A method for streamlining not considered in the RTI/FAL study has been described by Suh *et al.* (2004). Suh and his colleagues suggest "hybrid approaches" to use economic input-output analysis to complement process-based LCA data when system boundaries are set. They confront the dilemma that ISO standards for LCA require that the boundaries be set either where "elemental flows" enter or leave the system—virtually impossible in today's interconnected world—or that the boundary be set in a way that does not significantly affect the results. These standards are problematic, Suh *et al.* argue, because it is logically impossible to say that the system boundary excludes only insignificant processes, without actually doing the analysis of the excluded parts that the system boundary is designed to exclude. They present three approaches that may allow incorporation of data on environmental impact of various economic processes to test whether the system boundaries truly do exclude only insignificant processes.

The most reliable of the three hybrid approaches that Suh *et al.* (2004) describe is also one which is "relatively complex to use" and imposes "high data and time requirements" on the user. Their simplest approach, the "tiered hybrid" approach, has a built-in problem of double counting some environmental impacts, but it is easy to use. LCA researchers may consider using the tiered hybrid approach as a screen. If the tiered hybrid approach shows that no significant additional environmental impacts occur outside the system boundaries, then the system boundaries are at least encompassing enough, and perhaps could be narrowed. If the tiered hybrid approach does find significant additional environmental impacts beyond the boundaries, it would not be immediately clear whether they are from double counting or actually represent something that would be captured by closer study of the processes. The research team could then decide whether to use the information to conduct a more complicated hybrid study of the present system boundaries, expand the system boundaries and apply the tiered approach again, take some other action, or take no action other than to note the result of the tiered approach in the report.

The streamlining methods described above apply to LCA inventory data. The SETAC group (Todd and Curran 1999) also considers a way to streamline impact assessment, the US EPA's Pollution-Prevention (P2) Factors method. Since then, the US EPA has developed the software package TRACI, which is likely the most up-to-date method for streamlining impact assessment in the US.

10 CONCLUSIONS AND RECOMMENDATIONS

Many changes made to wastewater infrastructure historically have moved problems in time and space, or just changed their character, rather than solving them. Starting with this perspective, this report has explored how decision-makers might document a wider range of the non-monetary impacts that wastewater treatment alternatives have. The broader knowledge of non-monetary impacts may make it possible to choose wastewater-treatment options that improve the quality of water locally with minimal degradation of water quality elsewhere and of air and/or land quality. Avoiding the impacts becomes possible only when the impacts are understood.

Summary and Conclusions

Wastewater decisions in the US are often made on the basis of an analysis of the core system for wastewater treatment (from the collection system leading from the buildings where wastewater is produced to the wastewater treatment plant) looking at the effects on surface water quality only. A broader analysis of the core system than is usually conducted today would, in addition, consider materials and energy used onsite. Significantly more information about the environmental effects of wastewater treatment may be gained by extending the analysis beyond the core system. Following materials and energy upstream, that is, to the environmental impacts from producing and transporting the materials and energy used onsite, may add enough new information to reverse a relative environmental ranking of two alternatives. Information gained from following materials and energy downstream from the core system to where water or nutrients are recycled or simply returned to the environment, may have a similar effect.

Money spent to improve environmental quality by treating wastewater is not necessarily well spent if the treatment process degrades the environment elsewhere. Antonucci and Schaumburg (1975) showed how lime used in South Tahoe’s treatment plant was responsible for air emissions and solid waste in northern California, where the lime was produced. Similarly, local environmental side-effects of treatment decisions can be profound. Residents of eastern Massachusetts have experienced drinking water shortages and seen their rivers reduced in flow, or even dry up part of the year, due to hydrological changes caused by sewers (Zimmerman 2002).

Studies in Europe, where preserving non-renewable phosphorus resources is a priority, have shown environmental advantages for treatment alternatives that close the nutrient loop by recycling nutrients from wastewater as fertilizer in agriculture. Recycling nutrients means that less fertilizer needs to be produced and transported; the relative ranking of treatment alternatives' environmental impacts can be reversed when the comparison includes the reduced impacts from avoided fertilizer production and transport (see the discussion of system boundaries in Appendix D). Attention to this sort of impact in US treatment decisions has the potential to increase interest in treatment options like urine-diverting toilets and microflush toilets with blackwater diversion, since they allow increased nutrient recycling (Etnier *et al.* Submitted). Where land application of septage and/or sewage sludge is controversial, awareness of the range of environmental benefits from closing the nutrient loop may influence the debate.

In addition to environmental impacts, there are many other non-monetary impacts of wastewater treatment. A community's choice of wastewater treatment method can affect land-use, aesthetics, even types of recreation available (for example, a constructed wetland can double as a wastewater treatment facility and a park).

Methodologies, Methods, and Data Needs

In this report, three methodologies have been described that are used for documenting the non-monetary impacts of wastewater treatment systems:

1. Environmental impact assessment (EIA)

2. Life-cycle assessment (LCA)

3. Open wastewater planning (OWP)

Environmental Impact Assessment

Of these three, EIA is the only methodology now in use in the US for wastewater treatment decisions. EIA is a process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant effects of a proposed action during the initiation and planning stages of a proposed action. EIA began with the US National Environmental Protection Act (NEPA), affecting federal agencies, and NEPA-like policies have been adopted and adapted by 20 states for state-level projects. The NEPA-inspired laws at the state level often include land-use impacts. While consideration of local environmental impacts is the norm, the EIA framework is flexible enough to include regional and global impacts, if desired. Social and cultural impacts may also be considered. Some impact categories to be investigated are generally defined by the regulations governing the EIA, and additional categories may be added for a specific decision.

At both the federal and state level, the effectiveness of the EIA process in assuring environmental quality depends on who is leading the process from the relevant agencies and who in the public is reviewing the process (Groveman 2004 and Council on Environmental Quality 1997). The laws can be applied in a pro forma way, or they can be useful in mitigating impacts.

The case study of applying the California Environmental Quality Act (CEQA) to a wastewater treatment decision in Willits, California illustrated how hundreds of pages of information about impacts of various alternatives in many different categories may be summarily analyzed. The entire text of the analysis was: "Due to reduced hydrological and wetlands impacts, and other factors, compared to the other alternatives, the Proposed Project is considered the environmentally superior alternative." This particular application of CEQA was clearly aimed at justifying the Proposed Project rather than comparing alternatives. However, because the earlier process of choosing and designing the Proposed Project [before the CEQA Environmental Impact Report (EIR) was written] was undertaken with an eventual CEQA review in mind, the process may have reduced environmental and other non-monetary impacts in ways not documented in the EIR.

Life-Cycle Assessment

LCA is a method of accounting for the environmental impacts of a product, service, or process over the course of its life cycle. In its broadest definition, LCA is a summation of all environmental burdens associated with the extraction of raw materials; transportation; and manufacturing; operation, maintenance, and reuse; and disposal that occurs during a product's or service's life cycle—from "cradle to grave." The environmental burdens generally include use of land, energy, water, other materials, and the release of substances, harmful or otherwise, to the air, water, and soil.

As applied in manufacturing and purchasing decisions, LCA has been the basis for many concrete choices. In its application to wastewater treatment, LCA has been used by researchers to understand environmental impacts of different alternatives and has been used to gain information useful at a policy level. LCA has not yet been used to decide among specific wastewater alternatives

Standard LCA practices encompass only environmental impacts, excluding economic, social, or cultural impacts.[5] In life-cycle inventory (LCI), the material and energy flows associated with the process being analyzed are cataloged. LCI is often followed by life-cycle impact assessment (LCIA), in which the results of the inventory are aggregated into impact categories and consequences are assessed. In both phases, impacts anywhere on the planet are considered equally. When the impact assessment is interpreted, then regional differences are considered.

The International Standards Organization (ISO) has guidelines that many researchers have followed when applying LCA. Other methods examined in detail here that implement LCA include Eco-Indicator 99, Sustainable Process Index, Tool for Reduction and Assessment of Chemical Impacts (TRACI), and URban WAter REsearch (URWARE).

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[5] LCA researchers and institutions continue to develop methodologies for characterizing indicators of social and socio-economic health for inclusion in LCA, but they are far from agreeing on any form of standard practice. Life cycle costing (LCC) uses a similar approach to establishing system boundaries in time and space and around the process chain, but evaluates alternatives by purely economic means. Like LCA, LCC system boundaries may be adjusted to consider various degrees of long-term and indirect impacts and/or externalities.

Combining URWARE and TRACI appears to offer the quickest route to using an ISO-based LCA for wastewater treatment decisions. URWARE is unique in that it contains a wastewater-specific material and energy flow analysis that precedes an ISO-based life-cycle impact assessment. To date URWARE has only been used in Sweden, and thus the process models and impact characterizations reflect Swedish conditions. There is a distinct opportunity for URWARE to be adapted to the US using TRACI's LCIA along with an updated library of models and default values representative of US systems and conditions. URWARE is designed to model a much larger system boundary than is typically chosen for making wastewater decisions. The simulation could be used for a community to model a greater range of water resource issues, not just wastewater alternatives.

As noted earlier, URWARE only accounts for the operational impacts of systems. The marriage of URWARE and TRACI would not preclude accounting for the investment of the system in the total environmental impact. Resources consumed and emissions associated with the investment of the system could be inventoried, aggregated, and assessed with TRACI outside of URWARE.

Every LCA requires some amount of material and energy flow analysis to generate the life-cycle inventory. URWARE contains dynamic material and energy flow models of the processes associated with wastewater treatment and provides the framework for linking the processes and conducting a life-cycle inventory. This adaptable model could be valuable to US wastewater decision making if it more closely reflected US conditions.

Re-tooling URWARE to make it compatible with US conditions represents the major investment for this approach. URWARE is now built around processes in the city of Uppsala, Sweden. The URWARE team is working on making the program more portable. At present, it may be simpler to adapt URWARE to one or more demonstration locations in the US, rather than trying to change its architectures so that it will be flexible enough to use anywhere in the country.

The Sustainable Process Index (SPI) offers a highly streamlined approach to LCA. It could be used by smaller communities, companies, and organizations to assess the environmental sustainability of wastewater-treatment systems with less inventory data than is needed for the other LCA approaches. For practical and more widespread applications of SPI to decision making, a user-friendly software, populated with data on the US regional agricultural yields, natural stocks, and pollutant assimilation values, will need to be developed. Much of the effort of computing the SPI is devoted to gathering these values, which are not commonly found among LCA databases. Providing this data to US users could make this variation of environmental life-cycle analysis more available to a greater range of users than the more detailed methods.

SPI does not provide a complete assessment of sustainability and takes considerable short-cuts in the inventory and impact analysis, but may still be helpful in distinguishing between options.

Eco-Indicator 99 is an endpoint impact evaluation tool. It may be useful as a model for characterizing impacts further down the cause-effect chain than tools such as TRACI, which utilize primarily midpoint impacts. However, because its characterization factors are modeled for European conditions, TRACI is probably superior to Eco-Indicator 99 for any use in the US.

Open Wastewater Planning

OWP has been developed for wastewater-treatment decisions and has been used by a number of small communities in Sweden (population less than 500). OWP begins by setting goals for the wastewater-treatment process to conduct a more holistic evaluation of alternatives and to consider a broader range of options. The criteria for evaluation have been similar to the impact categories in EIA. The ultimate decision-makers may be guided in their goal setting by a third party, but it is crucial that the decision-makers take ownership of the goals. When the goals are set, a third party generates a diverse set of design alternatives that meet most or all of those goals and presents them simply, at the level of a feasibility study. The ways in which the alternatives affect the goals set up in the beginning are described briefly, and decision-makers use the material as a decision aid.

Specific tools used in OWP may be borrowed from both LCA and EIA, but OWP is more similar to EIA. OWP may adopt the extended system boundaries with global or regional impact characterization characteristic of LCA, but its flexibility to be adapted to the decision-making needs and context mimics the framework of EIA. An aspect that is unique to OWP is that it is developed specifically for wastewater treatment and practical for smaller communities, particularly those with fewer monetary and human resources. OWP, however, is more vulnerable to allowing decision-makers to ignore externalities, since there are no mandatory categories of impact to consider.

Differences and Similarities Among the Methodologies

Standard LCA addresses environmental impacts only, while OWP and EIA consider a wider variety of non-monetary impacts. For environmental consequences, LCA assesses impacts at the regional and global levels. Local impacts are included in the aggregated impacts on the same basis as non-local impacts, so it is virtually impossible to distinguish them in the results. [6] OWP and EIA have the potential to consider both local impacts and regional or global impacts.

The tools of LCA may be used to augment either OWP or EIA, but not the other way around. The LCA methods have the most formalized methodologies and narrowest focus. The formality of EIA varies in different jurisdictions, but flexibility in including various impact categories is possible. OWP is the most flexible method, since it starts in each application by setting up what the other two methodologies have, at least to some extent, pre-established: the impact categories to be evaluated.

OWP can draw on the tools of both LCA and EIA. In addition to the non-monetary impacts considered, cost may be expected to be included in an OWP study.

[6] One exception is the TRACI impact assessment tool, which allows some impacts to be characterized down to the county level within the US.

The facilities planning process in the US, if an EIA and community involvement elements are included, bears some resemblance to OWP. Key differences are that, in OWP, local decision-makers specify the impact categories to be considered and decide themselves which alternative is preferred on the basis of the evidence in the OWP assessment. US facilities plans are often put together without the broad exploration and equitable comparison of options that are the heart of OWP; rather, they focus on which centralized alternative to use. The engineering community in the US has focused on centralized wastewater solutions as the only viable technology to meet their municipal clients' needs. While often required to include an alternatives analysis, these analyses rarely look closely at decentralized alternatives, usually summarily rejecting them as unproven, not reliable, and temporary by nature. The same barriers that stand in the way of equitable comparison of centralized and decentralized options in the facilities planning process may stand in the way of widespread application of OWP. [7] (Those barriers, in fact, could work against any of the other methods examined here, since the methods are only useful when decisions are based on facts.)

Data Needs and Availability

EIA are already conducted in the US for wastewater treatment alternatives. Processes are, therefore, clearly in place to generate needed data for each specific study and to provide any more general data that can be used in multiple studies.

Since the impact categories considered in each OWP process may differ, each has its own set of data needs. The more OWP relies on LCA to assess impact categories, the more the discussion of data for LCA is applicable.

Data needed for LCA include data on the environmental impacts of manufacturing and transporting all components, as well as well as the impacts of energy and chemicals used by the wastewater treatment process. Data are generally specific to a place and time, since mining and manufacturing processes change over time at a given place and may vary from place to place. LCA is easiest to do when many other LCA studies have been done in a similar environment, so data from recent, relevant studies can be reused. Since LCA is not yet widely used in the US, data are not as readily available as in Europe.

For specific types of LCA data, the following availability was found:

- **Material and energy flow analysis:** The most comprehensive data sources are more than 20 years old, probably too old for meaningful LCA.
- **Material/component production data:** LCA data are available on the materials used, not on finished components. Streamlining tools are available to make estimates.

[7] The barriers include: decentralized solutions are smaller, with less prestige; profit margins are lower for decentralized; engineers are less comfortable with the design of decentralized systems; clients are easier to sell on centralized, both because they are more familiar with it and engineers are more comfortable selling it; financial assistance programs are biased in favor of assisting centralized solutions; and engineers learn little about decentralized wastewater treatment in college and beyond.

- **Transportation and construction data:** LCA data are available for a few basic modes of transportation, like gasoline- and diesel-powered trucks and ocean freighters.
- **Process data for extended systems:** For the processes most significant in extended systems analysis of wastewater treatment, data are more abundant in the US than for the wastewater treatment core system. Streamlining tools were also identified that could fill in data gaps with reasonable estimates.

Barriers To Adopting the Methods Reviewed

For EIA, the major barrier is the funding to conduct the studies. EIA data are not as transferable between studies as is the case for LCA data, so each local study must generate its own data.

For OWP, barriers related to data availability vary, as noted above, depending on whether the OWP draws more on LCA or EIA. The size of the community may be a barrier, as well. OWP has been used in communities of less than 500. Larger communities may demand more formalized methods than OWP, in order to guarantee input from various stakeholder groups, but there is surely room for use of OWP in communities one or two orders of magnitude larger than it has been used on so far. The most significant barrier to OWP's widespread use may be a shortage of engineers and other consultants trained in designing and evaluating centralized and decentralized alternatives on an equitable basis.

For use as a wastewater decision-making tool in US communities, LCA is constrained by its limitations in assessing localized impacts, and the fact that currently LCAs cannot be substituted for EIAs. Historically, it has been used as a wastewater research and policy tool, not as a tool for deciding between specific alternatives, even in countries where LCA has been used frequently in addressing wastewater questions. LCA as a part of facilities planning may become practical in the next five years in countries like Sweden, which have invested a lot in wastewater LCA, but for now it is limited to policy discussions and long-term planning. From policy, research, and long-term or large-scale planning perspectives, lack of data and trained practitioners presents the greatest challenge. Data-related barriers to using LCA to illuminate the environmental impact of component design choices are somewhat lower. An LCA today of the relative environmental impacts of polyethylene versus concrete septic tanks, for example, could probably be done in a way that would be applicable over several states or even a larger region of the country.

A number of methods for streamlining LCA studies are available to reduce barriers related to time, cost, and data availability. The historical "sensitivity analysis" approach produced results most like a full LCA in a US EPA test of many streamlining methods (Todd and Curran 1999). There are currently enough LCAs on wastewater treatment from Europe to apply this approach. Using this approach has the potential to dramatically reduce initial costs of LCA for wastewater treatment in this country. The tiered hybrid approach described by Suh *et al.* (2004) is another promising streamlining approach and may be individualized to each specific study. The Missing Inventory Estimation Tool (MIET) and Economic Input Output Life-Cycle Assessment (EIOLCA) can be used with the tiered hybrid to screen elements, eliminating categories of data that are least likely to be significant. Then the limited set of elements could be scrutinized by detailed process analysis or the more intensive hybrid approaches.

In addition to limiting system boundaries, decision-makers may also limit impact assessment categories for those that have been shown to have little variation between options and/or those whose degree of impact is of little significance to the decision. The assessment methods used for screening should be the same as those used for detailed analysis, thus the US EPA’s TRACI program likely offers the US LCA practitioners the most appropriate tool for screening impact-assessment categories.

The places most suitable to overcoming the barriers may be those where terms like “sustainability” or “environmentally friendly” frame the debate about wastewater alternatives. The very difficulty of defining these terms can open the doors for using different methods in answering it, like EIA, LCA, and OWP. A small number of interviews with decision-makers identified water-policy people in Massachusetts, both in state government and in non-profit environmental organizations, as likely candidates to pioneer greater use of these methods. Green building certification organizations may be candidates to use LCA, in particular, to assess the relative “greenness” of different onsite wastewater treatment choices.

For LCA to achieve more widespread use, it may take significant federal government use of the method—as was the case for such diverse technologies as nuclear power, computers, and photovoltaic cells. In Europe, where LCA is more frequently used than in the US, the governments have more frequently employed LCA to make policy decisions. European academic researchers have also played prominent roles in using LCA; federal and state initiatives using academic scientists and graduate students have the potential to build up the community of trained practitioners and infrastructure of useful data that facilitates use of LCA in any field.

Recommendations

Of the three methodologies reviewed, EIA is presently used in the US for wastewater treatment decisions. OWP could be adopted immediately, though it would be more difficult to apply where decision-makers called for more LCA-related measures to be used. LCA is mature as a methodology for applying to wastewater-treatment decisions, but the infrastructure of data and practitioners is lacking in the US. Each of these methods has something valuable to contribute to wastewater decisions, either at the level of local facilities plans or at the policy level, by putting on the table environmental impacts that would probably otherwise be overlooked.

LCA, in particular, is unlikely to be used at present by local decision-makers. There is a significant investment required to use the methodology in the US, and its most profound result is to illuminate environmental impacts outside the local area. Local governments do not have a strong history of investing a lot to find out how to protect someone else’s environment. For this reason, state and federal authorities ought to fund initiatives using LCA for wastewater treatment.

The initial costs of applying LCA to wastewater decisions in the US are the most significant barrier to using it more widely. National demonstration projects applying LCA to local decisions would train US practitioners in using the methods and generate a basic set of data that could be used in subsequent applications. Uses of LCA for wastewater treatment in other countries have primarily been for analyzing hypothetical alternatives to the existing situation, not tied into any tight timeline for a decision. A similar approach in the US would allow researchers time and flexibility to learn as they use the methods. A set of three to five demonstration projects should be conducted, followed by an analysis of how to use the data generated for future decisions, and what sort of simplifications can be made with minimal sacrifices of accuracy in the analysis.

Specific initiatives that would advance the use of LCA include:

- Adapt URWARE to US conditions and connect the output to TRACI in one or more model communities.
- Compare SPI with an ISO 14040-based LCA, for example, using TRACI, in one or more communities. (Organizations generally interested in promoting LCA in the US may also be interested in seeing a comparison of SPI with ISO 14040 LCA, even if they are not directly interested in wastewater treatment. Much of the work put into developing the databases for a wastewater-related SPI evaluation could be used in SPI evaluations of other sectors.)
- For university engineering courses, develop class projects that use either SPI or ISO 14040 LCA to evaluate wastewater treatment options for a given area. Organizing a contest among different universities to do this, similar to decentralized wastewater-treatment design contests, may increase students' interest.
- Perform an LCA comparing various common designs of decentralized wastewater-treatment systems, with the potential of using the information in obtaining green building certification.

A question about EIA, which is in use at this point, is whether and how much the information generated is used in choosing among alternatives or modifying the proposed alternative to mitigate its environmental impact. The Council on Environmental Quality (1997) published a report on the effectiveness of the National Environmental Quality Act after 25 years. A similar report should focus on the effectiveness of NEPA and the state equivalents specifically for wastewater, providing useful information about how to improve the effectiveness of EIA in promoting genuine alternatives.

OWP as such is untested in the US, but elements of the approach have been used in many communities, and no further methodological development is necessary. A state or federal wastewater-financing agency ought to finance OWP demonstration in a number of communities. Successful demonstrations would give a basis for deciding whether to require a process like that as a condition for financing.

Communities or counties interested in sustainability should carry out an exercise in open wastewater planning, even without outside funding. The Earth Charter USA Campaign and the Local Agenda 21 staff at the International Council for Local Environmental Initiatives could help identify communities with an expressed commitment to sustainability that also have a significant number of onsite wastewater-treatment systems and may be facing decisions about whether to change their wastewater-treatment infrastructure.

Finally, as has been discussed, all of these methods presume a fact-based decision-making process, where alternatives are considered to be on an equal footing, until shown otherwise. Engineers have little skill or experience in comparing alternatives on equal footing, especially decentralized alternatives and centralized alternatives. A project identifying and finding ways to overcome the barriers to equitable comparison of centralized and decentralized alternatives is being undertaken by the Water Environment Research Foundation, and its results ought to be considered by anyone promoting alternative methods of analyzing wastewater-treatment options.

Looking Ahead

The new methods presented for comparing wastewater treatment options offer tools for considering, more holistically and quantitatively, the direct and indirect impacts of wastewater treatment in the US. Currently, none of these methods considers the complete set of sustainability concerns facing decision-makers, but combining the complementary aspects of LCA and EIA concepts would likely be the most comprehensive assessment method. Before that happens, LCA needs to be developed for use in US wastewater decisions. Both EIA and OWP are ready to use today.

The barriers to implementing or increasing the use of the methods identified are challenging but are not insurmountable. The strategic actions this report recommends to address these barriers could be the next steps towards realizing sustainable wastewater treatment in communities across the US.

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12 ACRONYMS AND ABBREVIATIONS

APME	Association of Plastic Manufacturers in Europe
BEES	Building Environmental and Economic Sustainability
BOD_5	Biological Oxygen Demand (a measure of organic matter in water)
BTU	British Thermal Unit (a measure of heat)
CE	Categorical Exclusion
CEQ	California Environmental Quality Act
Cl_2	Chlorine gas
CML	Centrum voor Milieuwetenschappen Leiden (Institute of Environmental Sciences, Leiden, Netherlands)
CMLCA	Chain Management Life-Cycle Assessment
CPM	Centre for Environmental Assessment of Product and Material Systems (at Chalmers University of Technology)
DOE	Department of Energy
EA	Environmental Assessments
EDIP	Environmental Design of Industrial Processes
EI	Eco-indicator
EI 95	Eco-indicator 95
EI 99	Eco-indicator 99
EIA	Environmental Impact Assessment
EIOLCA	Economic Input Output Life-Cycle Assessment

EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ELCA	Environmental Life-Cycle Assessment
EPS	Environmental Priorities Strategy
FONSI	Finding Of No Significant Impact
GIEE	Gund Institute of Ecological Economics
HDPE	High density polyethylene
I/O	Input/output
IAIA	International Association for Impact Assessment
IISI	Institute of International Steel Industry
ISO	International Standards Organization
LCA	Life-Cycle Assessment
LCC	Life-Cycle Costing
LCI	Life-Cycle Inventory
LCIA	Life-Cycle Impact Assessment
MEPA	Massachusetts Environmental Protection Act
MFA	Material Flow Analysis
mg/l	Milligram/liter
Mgal	Million gallons
MIET	Missing Inventory Estimation Tool
MIPS	Material Input for Provided Services
MWRA	Massachusetts Water Resources Authority
NAWQA	National Water Quality Assessment

NEPA	National Environmental Policy Act
NH_3	Ammonia
NH_4	Ammonium
NREL	National Renewable Energy Laboratory
OAI	Ocean Arks International
ORWARE	ORganic WAste REsearch model
PVC	Polyvinyl chloride (often called “vinyl”)
QAPP	Quality Assurance Project Plan
SEA	Strategic Environmental Assessment
SELCA	Social and Environmental Life-Cycle Assessment
SETAC	Society of Environmental Toxicology and Chemistry
SIA	Social Impact Assessment
SIC	Standard Industry Classification
SPI	Sustainable Process Index
SPINE	Sustainable Product Information Network for the Environment
SPINE@CPM	SPINE database at CPM
SPOLD	Society for the Promotion of Life-Cycle Development
SUWM	Sustainable Urban Water Management
TMDL	Total Maximum Daily Load
TMR	Total Material Requirements
TRACI	Tool for Reduction and Assessment of Chemical and Other Environmental Impacts
TSS	Total Suspended Solids
URWARE	URban WAter REseach program

US EPA	United States Environmental Protection Agency
USGBC	US Green Building Council
WEF	Water Environment Federation
WWIX	Wastewater Information Exchange
WWT	Wastewater treatment

13 GLOSSARY

Alternative	One of multiple options available to decision-makers.
Analysis	The examination of the component parts of a whole.
Assessment	The act of accounting or examining.
Cause-effect chain	The environmental mechanism by which life-cycle assessment inputs or outputs are translated into impacts, for example, chlorofluorocarbon emissions lead to ozone depletion that leads to increases in human mortality from skin cancer.
Characterization	The process in LCA impact assessment of quantifying the contribution of each input and output to its impact categories and summing up the impacts in each category.
Core system	In life-cycle assessment of wastewater treatment, the core system is bounded by the house as a source of wastewater to the wastewater-treatment system. Also referred to as the base system.
Eco village	An intentional community established with the intent of reducing the environmental impact of the community as a whole.
Exergy	A measure for energy quality that is the property of a system, which gives the maximum power that can be extracted for the system, when it is brought to a thermodynamic equilibrium state from a reference state. The exergy transfer can be associated with mass flow, with work interaction, and with heat interaction.
Extended system	In life-cycle assessment of wastewater treatment, the extended system includes the core system and enough upstream, downstream, and separate systems to enable fair comparison among the alternatives. See Chapter 4 on system boundaries.
Framework	The fundamental structure that embodies a concept or intention.
Functional unit	The unit of product or service by which to quantifiably compare the performance or impact of product or service systems.

Investment	All the operations prior to operation of a system, including mining of raw material, manufacturing, transport, and installation or construction.
Method	"A means or manner of procedure, especially a regular and systematic way of accomplishing something." (American Heritage® Dictionary of the English Language, Fourth Edition)
Methodology	"A body of practices, procedures, and rules used by those who work in a discipline or engage in an inquiry; a set of working methods." (American Heritage® Dictionary of the English Language, Fourth Edition)
Normalization	The process in life-cycle assessment (LCA) impact assessment of relating the data for each category in the LCA inventory assessment to the total anthropogenic, environmental impact for that category.
Scoping LCA	A cursory life-cycle assessment (LCA) conducted to assess the most significant components of the inventory or impact categories to direct detailed data collection and analyses to those areas. Also referred to as screening LCA.
Weighting	The process in life-cycle assessment (LCA) impact assessment of assigning a factor to a number to make the number's effect on the impact calculation reflect its importance.

A DECISION-MAKING SITUATIONS

This appendix describes a series of decision situations and the wastewater-treatment alternatives for each situation.

Situation 1—Small Rural Village

Situation 1 is characterized as a small village of approximately 100 people with many failing or inadequate onsite septic systems. The community is concerned with nitrate and pathogen contamination of local surface and subsurface water resources. Centralized treatment is not a feasible option, since no opportunities exist to connect to sewers of adjacent towns. There are no direct physical limitations to installing new land-based systems, thus most decentralized cluster or onsite systems could be feasible.

Wastewater Treatment Alternatives

- **Alternative 0**—No action
- **Alternative 1**—Cluster system with various treatment/disposal alternatives, conventional materials
- **Alternative 2**—Cluster system with various treatment alternatives, but source separation and reuse, plus alternative materials
- **Alternative 3**—Onsite, with various treatment/disposal alternatives and conventional materials
- **Alternative 4**—Onsite, with various treatment alternatives using source separation and reuse, plus alternative materials

Situation 2—Large Town

Situation 2 is characterized as a large town of approximately 30,000 people experiencing growth and water availability issues. The town is peripherally expanding in both its residential and commercial sectors. The existing wastewater treatment infrastructure consists of a conventional centralized treatment and sewer system that is at capacity. The existing system currently discharges into a local river, and dramatic decreases in surface and groundwater levels in recent years have caused concerns about the sustainability of local water resources.

Wastewater Treatment Alternatives

- **Alternative 0**—No action
- **Alternative 1**—Centralized, with various conventional collection, treatment, disposal, and materials
- **Alternative 2**—Centralized, with various treatment alternatives using source separation and reuse plus alternative materials
- **Alternative 3**—Cluster system with various conventional treatment/disposal alternatives, conventional materials
- **Alternative 4**—Cluster system with various treatment alternatives with source separation and reuse plus alternative materials
- **Alternative 5**—Onsite, alternative with various treatment alternatives with source separation and reuse plus alternative materials

Situation 3—New Subdivision or Intentional Community

Situation 3 has been developed, not for assessing data availability but to guide discussion of what possibilities exist for future development. In this case a new subdivision or intentional community is planned. There are no direct physical constraints to the type of system that could be employed; however, the developer, planners, and/or residents are concerned about long-term sustainability and global-scale environmental impacts of their decisions.

The wastewater treatment alternatives for Situation 2 cover a plausible range of options for Situation 3, as well. No new ones were added.

B DETAILS OF LITERATURE SURVEYS

Information was sought through several different means, including books, journals, organizations, and a data search.

Books

All books consulted are contained in the References section.

Journals

The scoping literature review was conducted to quickly establish what methods were available for assessing the environmental and social impacts and sustainability of technical systems and to establish which of these methods had been used in the context of water and wastewater treatment. The search for relevant literature was conducted on two fronts, 1) general search engines available on the world-wide web and 2) journal search engines, also available on the world-wide web. Below is a list of search engines and keywords used in the literature searches.

General Search Engines

- Google–www.google.com
- Dogpile–www.dogpile.com

Literature Search Engines

- Web of Science
- BIOSIS
- Environment Abstracts
- Water Resources Abstracts
- Environmental Sciences and Pollution Management
- Cambridge Scientific Abstracts
- Water Environment Federation Library

Keywords

Keywords included combinations of:

Water, waste, wastewater, sewage, septic

And

Life cycle, impact, environmental impact, ecological impact, social impact, sustainability, true cost

And

Assessment, analysis, inventory, evaluation, comparison

Organizations

- The Society of Environmental Toxicology and Chemistry (SETAC) acts as an advisory group to advance the science, practice, and application of life-cycle assessments (LCAs). They publish the LCA newsletters and other materials relative to the use and advancement of LCA.
- The Carnegie Melon Green Design program, which produced and maintains the Economic Input Output Life-Cycle Assessment (EIOLCA) software, has considerable experience in obtaining the LCA data for US conditions and provides a tool for estimating unknown impacts.
- The Gund Institute of Ecological Economics (GIEE), University of Vermont, works to capture both monetary and non-monetary benefits of ecosystem services and the costs of products and services to ecosystems and society.
- US EPA National Risk Management Research Laboratory (NRMRL). The NRMRL is a regulatory and research agency that seeks to develop methods for air, water, and land pollution prevention and reduction and ecosystem restoration. The NRMRL's Sustainable Technology Division is responsible for developing systems analysis tools for environmental decision making including the LCA tool, TRACI, and LCAccess, a directory of global life-cycle inventory (LCI) data.

Data Search

The search for relevant data consisted of:

1. Examining literature identified in the literature review (see above)
2. Searching the Internet for databases and data sources

3. Contacting European and US LCA practitioners about databases and data sources
4. Querying web databases based on the identified data needs

Search Engines

- Google–www.google.com
- Dogpile–www.dogpile.com

Keywords

Keywords included combinations of:

Water, waste, wastewater, sewage, septic

And

Testing, evaluation, performance

Or

Life cycle, environmental impact, ecological impact, social impact, sustainability, true cost, emissions, releases, performance

And

Data, database, inventory

Organizations

- National Renewable Energy Laboratory (NREL) is a laboratory for renewable energy research and development under the US Department of Energy and a leading laboratory for energy efficiency research and development. NREL is currently sponsoring Athena, Sylvatica, and Franklin Associates in the development of the US LCI database.
- Water Environment Federation (WEF) is non-profit technical and educational development organization committed to preserving and enhancing the global water environment. WEF maintains an extensive library of wastewater-related research and technical guidance and also sponsors the Wastewater Information Exchange (WWIX)

C COMPLETE LIST OF METHODS CONSIDERED

Life-Cycle Assessment (LCA) Methods

This appendix discusses what investigation methods were considered and why each was either included or excluded.

CML 2001

CML 2001 is a European LCA method based on the ISO 14040-42 standards, released by the Institute of Environmental Sciences (CML) at Leiden University in the Netherlands, for characterizing and weighting life-cycle impacts. CML 2001 provides a framework for inventorying releases and resource consumption associated with a product or service, characterizing and normalizing midpoint impacts, and weighing the normalized damages. The CML method has been a standard method in the LCA industry since 1992 and was most recently updated in 2001.

Eco-Indicator 99

Eco-indicator 99 (EI 99) is an updated version of the Eco-indicator 95 (EI 95) methodology, which was developed by PRé Consultants in the Netherlands as an ISO-based LCA characterization and weighting method for product design. EI 99 provides a framework for inventorying releases and resource consumption associated with a product or service, characterizing and normalizing the endpoint damages for European conditions, and weighing the normalized damages to achieve an overall indicator of environmental impact known as an Eco-indicator (EI). In order to make the weighing process easier, the EI 99 method aggregates the damages into three endpoint categories: human health, ecosystem health, and resources.

Ecological Footprint Analysis

Ecological footprint analysis was developed by Wackernagel and Rees in 1996 to evaluate the environmental impact of a human population or economy by characterizing resources consumed and wastes released as a quantity of ecosystem services used. The quantity of ecosystem services used is related in terms of the area of ecologically productive land consumed for the built environment, gardens, cropland, pasture, forested land, or land “appropriated” by fossil fuel use.

EIOLCA

The Economic Input Output Life-Cycle Assessment (EIOLCA) is based on an economic input/output model that represents the US economy. Any purchase of products or services from a particular industry sector directly results in some amount of resource consumption and environmental releases by that sector and indirectly induces some quantifiable amount of environmental impacts. Thus, by tracking economic transactions, the EIOLCA model is able to estimate the total resource requirements and environmental emissions associated with producing a product or service.

Exergy Analysis

Exergy is a measure for energy quality. Exergy analysis evaluates the exergetic performance of a system. Exergy is the property of a system that gives the maximum power that can be extracted from the system when it is brought to a thermodynamic equilibrium state from a reference state. The exergy transfer can be associated with mass flow, with work interaction, and with heat interaction. Exergy analyses may be conducted like energy analyses as simplified measures of sustainability.

MIET

The Missing Inventory Estimation Tool (MIET) v.2.0 was recently released by the Institute of Environmental Sciences at Leiden University in the Netherlands, and is based on an input/output model of the US economy like the EIOLCA model. It has been expanded to include small- to medium-sized businesses, which allows for more accurate estimation of a product or services environmental impact.

MIPS-Ecological Rucksack

Material Input for Provided Services (MIPS) measures how much material must be moved in the production of a service. The ecological rucksack is the “invisible” portion of the material input, that is, the portion that does not show up in the finished product or service. The total MIPS is then normalized, that is, compared to or described as a fraction of the Total Material Requirements (TMR). TMR is the aggregate of the material input for an entire community, typically the national economy.

SELCA

Social and Environmental Life-Cycle Assessment (SELCA) is an analytic tool that assesses both the social and environment impacts of a technical development. The method provides a framework for inventorying, characterizing, and weighting quantified environmental burdens, describing and assessing qualified social processes, and evaluating the influences of the two on each other to arrive at an overall assessment. The ultimate intention for this tool is to direct and coordinate social action and technology toward sustainable outcomes within the system or sector evaluated.

SPI

The Sustainable Process Index (SPI) is an ecological evaluation system that measures the total environmental impact of human activities of various kinds. The SPI was especially developed as a means to evaluate industrial processes. The general concept of the SPI is to compare mass and energy flows induced by human activities with natural mass flows on a global as well on a local scale. These flows are characterized by their use of solar exergy.

TRACI

The Tool for Reducing and Assessing Chemical and Other Environmental Impacts (TRACI) is an ISO-based method released in 2002 by the US EPA for evaluating the potential environmental and human health impacts of facilities, processes, services, and products under US conditions. The software provides a framework for inventorying releases and resource consumption and computes the potential of environmental stressors to affect thirteen environmental and human health impact categories using local, regional, and national models characteristic of the US.

URWARE

The Urban Water Research (URWARE) model is a substance flow model developed in the general simulation platform Matlab/Simulink. URWARE can be described as a library of interconnected mathematical models, currently including: households, drinking water production, transports, wastewater treatment, digestion, incineration, and landfill, which are combined into an overall model of the specific scenario under investigation. The model provides an inventory of impacts that are then classified and characterized following the Nordic Guidelines for LCA.

Methods Included

See Chapter 5 for a discussion of the methods used in this study, especially the section "Rationale for Methods Included." The methods included in this study were

- Eco-indicator 99
- Environmental Impact Assessment
- Open Wastewater Planning
- Sustainable Process Index
- TRACI
- URWARE

Rationale for Methods Excluded

CML 2001

CML 2001 was excluded because of its similarity to TRACI. CML 2001 is an ISO-based method that characterizes impacts to a midpoint level, but it does so for European conditions. TRACI does the characterization for US conditions.

Ecological Footprint Analysis

Ecological footprint analysis is one of the more widely known impact assessment methods in the US; however, it is most typically used to evaluate lifestyles or practices, particularly for comparisons of communities or regions and is very similar in approach to SPI. Additionally, unlike SPI, ecological footprint analysis has not previously been used to evaluate wastewater treatment systems.

EIOLCA

The Environmental Input-Output LCA method provided by Carnegie-Mellon University is likely to be a valuable tool for assessing the environmental impact of systems or processes auxiliary to the wastewater treatment system under valuation (that is, in the extended system, not the core system) and for assessing the environmental impact of the investment of the wastewater treatment system (that is, materials and components embodied in the treatment system). However the EIOLCA method was not included, because the operation of systems has been identified as the most critical portion of the life-cycle impacts of wastewater treatment (Azar, Holmberg, and Lindgren 1996; Balkema, Weijers, and Lambert 1998; Brix 1999; Dixon, Simon, and Burkitt 2003; Aalbers 1997; Lundin, Bengtsson, and Molander 2000; Kärrman 2000), and EIOLCA does not offer multiple wastewater treatment systems to choose from or allow the wastewater treatment model to be modified or updated.

Exergy Analysis

Although Exergy Analysis has been used to evaluate the sustainability of wastewater systems (Hellström and Kärrman 1997), it does not capture the range of environmental impacts evaluated by most LCA methods. For this reason and because Exergy Analysis is included to varying degrees in both URWARE and SPI, it was not included in the in-depth evaluation.

MIET

The Missing Inventory Estimation Tool was excluded upon the same rationale that the EIOLCA model was excluded, because the operation of systems has been identified as the most critical portion of the life-cycle impacts wastewater treatment and MIET does not offer multiple wastewater treatment systems to choose from or allow the wastewater treatment model to be modified or updated.

MIPS/Ecological Rucksack

The MIPS/Ecological Rucksack, like the SPI method, does represent an alternative measure of sustainability that is somewhat simplified from the ISO-based LCA methodology. Because it focuses entirely on evaluation of material flows, it does not account directly for emissions to air, soil, or water, which are particularly important for considering the impacts of wastewater treatment.

SELCA

The Social and Environmental LCA methodology is ambitious in its attempt to characterize the impacts of technological developments on human society. Most ISO-based LCA methods consider the human health impacts of products and services, but none have endeavored to include the impacts on social structure and function as did SELCA. Unfortunately, the LCA community identified significant methodological problems in combining social and environmental LCA, arising in part from the need for precisely defined system boundaries in ELCA and the difficulty defining social system boundaries based on stakeholder input. According to the method's creator, SELCA has not been employed since its introduction in 1996 (O'Brien 2004).

Other methods evaluated and excluded:

CMLCA	Chain Management LCA
EDIP	A Danish ISO-based method similar to CML 2
Energy Analysis	A measure of embodied energy in manufacturing and transportation
EPS	Similar to EI 99, but less commonly used

SEA	Strategic Environmental Assessment
SIA	Social Impact Assessment

D ISSUES TO CONSIDER WHEN DEFINING SYSTEM BOUNDARIES AND PARAMETERS

System boundaries are drawn in the initial stages of a study, as part of scoping and goal definition. The issue to be addressed—and thereby the breadth of the range of alternative solutions—plays a large role in where system boundaries are set.

Setting System Boundaries

Consider a given wastewater treatment plant that produces a given quality and quantity of sludge. A decision is to be made among three sludge treatment options (Figure D-1). The system boundaries may include

- An incinerator and its emissions
- A landfill, its leachate, and its methane emissions.
- Land application and its effects on surface waters and groundwater

In this example, the system evaluated does not include anything upstream from the sludge production (for example, production of drinking water, collection of wastewater, or any details of the wastewater treatment process), since anything upstream is assumed to be identical in all alternatives and is not considered within the system boundaries of sludge-treatment alternatives.

To make a fair comparison among the above three options for sludge treatment, however, the system boundaries are extended to include other services that the treatment produces. Say the heat from sludge incineration or from burning landfill methane is used to offset the use of some other energy bearer—for example, the heat is used for district heating to buildings, and natural gas would otherwise be burned to supply that heat. In that case, there are environmental benefits to the incineration or landfilling alternatives equal to the avoided environmental costs of burning an equivalent amount of natural gas. To make a fair comparison of the incinerator and landfill alternatives with land application, the system evaluated is extended to include natural gas production and transport (Figure D-1). If the alternatives being considered were all different variations on land application of the sludge, for example, with or without composting first, then the core systems would be sufficient.[8]

[8] The paper from which Figure D-1 and Figure D-2 were reproduced defined “base system” in the same manner that “core system” has been defined in this report and other papers.

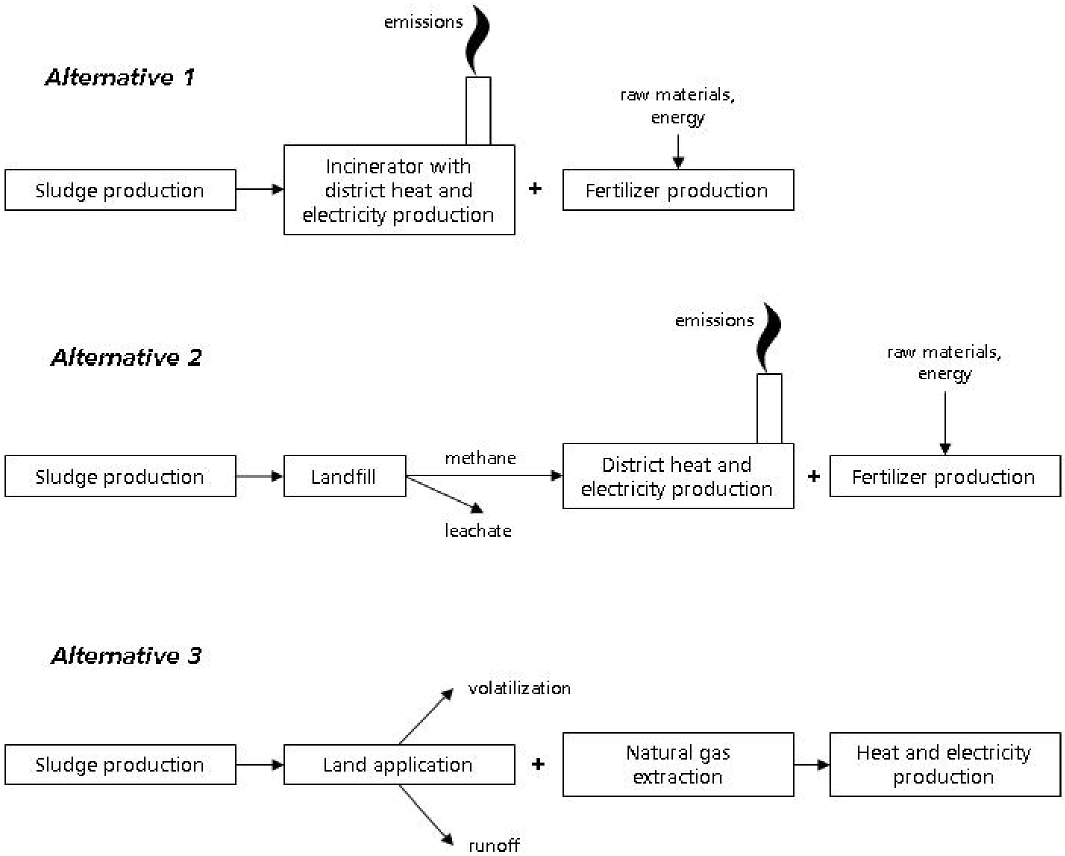
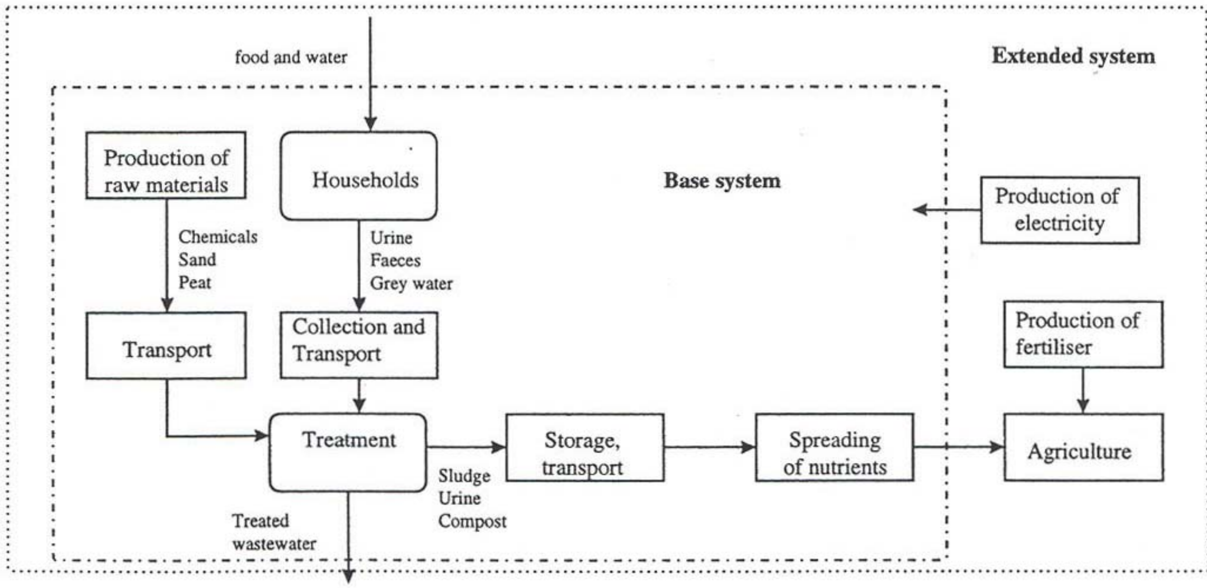


Figure D-1
Three Alternatives for Treating Sewage Sludge

Figure D-1 depicts the process flow diagram of the three alternatives for sewage sludge treatment: incineration, landfilling, and land application. To compare the environmental effects of the three alternatives in life-cycle assessment (LCA) framework, other systems are included in the scales. The land application alternative provides a fertilizer benefit, for example, so the environmental effects of producing that extra fertilizer are considered for the other two alternatives.

Defining system boundaries more or less inclusively can tip the balance of a comparison between alternatives. Lundin *et al.* (2000) illustrate how this can work with two cases where one wastewater treatment alternative results in significantly more nutrients being returned to agriculture. In one case—Horn, Sweden—a small centralized wastewater treatment plant is compared with liquid composting the blackwater for use as fertilizer and treating the graywater in sand filters. In the second case, in the Swedish city of Luleå, a large centralized treatment plant for mixed domestic wastewater is compared with keeping the urine separate and using it as fertilizer, while the feces and graywater are treated in the centralized plant. In all cases, the environmental impact is measured as per person equivalent of wastewater.

Figure D-2 shows the boundaries around the “core system,” composed of the wastewater treatment system itself, and the “extended system,” which also includes production of electricity and fertilizer.



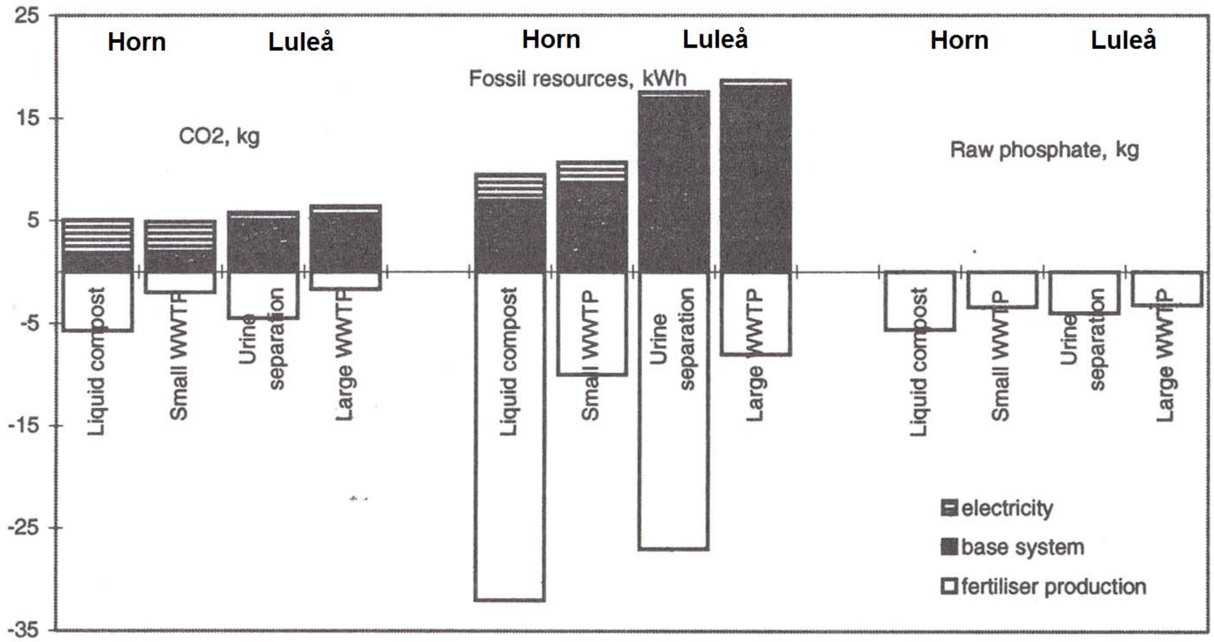
Source: Lundin *et al.* (2000)

Figure D-2
Material Flows in a Wastewater Treatment System, Showing the Boundaries for the Core System and the Extended System

If only the core system is considered, the liquid composting alternative in Horn is calculated to have roughly the same environmental impact as the small wastewater treatment plant, and the large wastewater treatment plant in Luleå is calculated to have less environmental impact than the urine separation alternative. However, if the environmental costs of electricity production and the benefits of avoided fertilizer production and transport are included, the liquid composting alternative and the urine separating alternative clearly have less environmental impact than their respective wastewater treatment plant alternatives (Figure D-3).

For example, in Horn, the two alternatives are roughly equal in carbon dioxide (CO_2) production, with about 2 kg/person/year, when only the core system (black part of the bar) is considered. When the CO_2 production associated with electricity production (striped bar) and fertilizer production (white bar) are included, both alternatives show a net increase in CO_2/person/year from electricity production, while the recycling of nutrients to agriculture results in a net decrease in CO_2 produced, because the wastewater product substitutes for a chemical fertilizer whose production would otherwise release CO_2. The liquid composting alternative has a greater nutrient recycling potential, however, so that when all three parts of its CO_2 bars are added together, the net result is about 0 kg/person/year. For the small wastewater treatment plant, the net CO_2 production is about 3 kg/person/year.

Similar analyses can be made from the figure for the kWh/person/year for fossil fuel resources and the kg/person/year for raw phosphate.



Source: Lundin *et al.* (2000)

Figure D-3
Environmental Impacts of Four Wastewater Treatment Alternatives in Two Locations

Choosing Parameters

Questions thought to be important have a strong impact on the parameters chosen. In places that have adopted principles of sustainability, global concerns (for example, amount of resources used or contribution to global climate change) are more likely to be parameters of interest. The parameters of interest may also be expanded by asking about the system, “What next?” If the planners of the 19th century had considered the question, “What happens next when pressurized water inside the home replaces hand-pumped wells outside the home?” would they have realized that water consumption might increase to the point where wastewater quantities would become an issue? An open process of asking “What next?” with many stakeholders can document connections that the planner had overlooked (Belt and Dietz 2004).

Finally, data availability is likely to have a large influence on the choice of parameters and system boundaries. Questions that are thought to be important about wastewater treatment alternatives may be seen as less important if the cost of obtaining data to answer the questions is too high.

E LCA EXTENDED DATA NEEDS TABLES

This appendix lists the type of data needed for detailed investigation categorized as site-specific and generalizable. See Chapter 6, *Closer Examination of Methods*, for a discussion of investigation methods.

Table E-1
Extended Comparison of Method Data Needs

	Datum Type	Method			
		EI 99	*SPI*	*TRACI*	*URWARE*
Site-Specific Data					
Construction/Site Development					
	Erosion and compaction				
	Excavation and backfill energy	x	x	x	
	Construction material delivery	x	x	x	
Environmental/Site Conditions					
	Geographic location			x	
	Topography				
	Bathymetry				
	Process material delivery	x		x	
	Proximity to water resources				
	Proximity to biologically sensitive areas				
	Proximity to human activities				
	Facilities heating	x	x	x	x
	Facilities cooling	x	x	x	x
	Current land-use				
	Existing infrastructure	x	x	x	

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	***SPI***	***TRACI***	***URWARE***
	Soils				
	Biological resources		x		
	Ecological sensitivities				
	Details of local hydrological cycle				
Generalizable Data					
Operation					
	Treatment Inputs				
	Energy—Fossil	x	x	x	x
	Energy—Renewable		x		x
	Raw material—Fossil	x	x	x	x
	Raw material—Non-renewable	x	x	x	x
	Raw material—Renewable	x	x	x	x
	Material/Product Transportation				
	Energy—Fossil	x	x	x	x
	Energy—Renewable	x	x	x	x
	Location			x	
	Influent				
	Temperature				x
	Organic carbon				x
	Biological carbon				x
	COD				x
	BOD				x
	Total water				x
	Potable water				
	Non-potable water				

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	***SPI***	***TRACI***	***URWARE***
	VSS				x
	TSS				x
	VOCs				x
	Toxic organics				x
	Nitrogen compounds				x
	Sulfur compounds				x
	Phosphorus compounds				x
	Chlorine compounds				x
	Metals				x
	Treatment Releases				
	Carbon compounds	x	x	x	x
	Sulfur compounds	x	x	x	x
	Nitrogen compounds	x	x	x	x
	Metals	x	x	x	x
	Organic Toxins	x	x	x	x
	Effluent				
	Unused heat				x
	Temperature				x
	Organic carbon				x
	Biological carbon				x
	COD			x	x
	BOD		x	x	x
	Total water				x
	Potable water				
	Non-potable water				

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	*SPI*	*TRACI*	*URWARE*
	VSS				X
	TSS				x
	VOCs	x		x	x
	Toxic organics	x		x	x
	Nitrogen compounds	x		x	x
	Sulfur compounds	x		x	x
	Phosphorus compounds	x		x	x
	Chlorine compounds	x		x	x
	Metals	x		x	x
	Recycling				
	Nitrogen recycled				x
	Phosphorus recycled				x
	Water reused				x
	Water discharged to local aquifer				
	Water discharged to surface waters (in special conditions)				
	Process Reliability				
	BOD removal				
	Nitrogen removal				
	Phosphorus removal				
	TSS removal				
	Pathogen reduction				
	Other				
	Durability				
	System				

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	***SPI***	***TRACI***	***URWARE***
	Components	x		x	
	Water Use				
	Water used for waste collection			x	x
	Water removed local hydrologic cycle				
	Land Use				
	Threatened/endangered species habitat	x		x	
	Physical footprint	x	x	x	
	Carbon sequestration		x		
	Nitrogen assimilation		x		
	Phosphorus assimilation		x		
	Chemical assimilation		x		
	Metal assimilation		x		
	Renewable resource production		x		
	Landfill		x		
Investment					
	Extraction/Processing Inputs				
	Energy—Fossil	x	x	x	
	Energy—Renewable		x		
	Raw material—Fossil	x	x	x	
	Raw material—Non-renewable	x	x		
	Raw material—Renewable		x		
	Material/Product Transportation				
	Energy—Fossil	x	x	x	
	Energy—Renewable		x		

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	***SPI***	***TRACI***	***URWARE***
	Location			x	
	Extr./Process./Constr. Releases				
	Unused heat				
	Organic carbon				
	Biological carbon				
	COD			x	
	BOD			x	
	Total water				
	Potable water				
	Non-potable water				
	VSS				
	TSS				
	VOCs	x		x	
	Toxic organics	x		x	
	Nitrogen compounds		x	x	
	Sulfur compounds	x	x	x	
	Phosphorus compounds	x	x	x	
	Chlorine compounds	x		x	
	Metals	x		x	
	Extr./Process./Constr. Water Use				
	Water used				
	Water removed local hydrologic cycle				
	Extr./Process./Constr. Land Use				
	Threat./endang. species habitat	x		x	

Table E-1
Extended Comparison of Method Data Needs (Cont.)

	Datum Type	Method			
		EI 99	***SPI***	***TRACI***	***URWARE***
	Physical footprint	x	x	x	
	Carbon sequestration		x		
	Nitrogen assimilation		x		
	Phosphorus assimilation		x		
	Renewable resource production		x		

F STUDY COMPARISON TABLES

This appendix provides the details of most of the studies reviewed. See Chapter 6, *Closer Examination of Methods*, for a discussion of these methods.

Table F-1
Comparison of EIA Studies

		Kontos and Asano-1	Kontos and Asano-2	Poulsen and Hansen	Ridderstolpe
Date		1996	2003	2003	1999
Location		US	Denmark	US	Sweden
System Boundaries Include:	Investment	no	no	yes	no
	Decommissioning	no	no	no	no
	Water Treatment	yes	no	yes	yes
	Sludge Treatment	no	yes	no	yes
	Auxiliary Input Production	no	energy	no	no
	Auxiliary Process Offset	no	no	no	no
Treatment Systems Evaluated	Alternative 0	no action	no action	no action	
	Alternative 1	water reclamation for landscape irrigation-major reuse	water reclamation plant for landscape irrigation, industrial cooling and groundwater recharge (w/ reverse osmosis)	sludge drying w/ reuse in cement	onsite treatment including: reactive sand filter, composting toilet w/ aerobic sand filter, blackwater separation, and urine separation
	Alternative 2	water reclamation for landscape irrigation–moderate reuse		sludge composting and land application	energy forest irrigation following primary treatment and winter storage

Table F-1
Comparison of EIA Studies (Cont.)

		Kontos and Asano-1	Kontos and Asano-2	Poulsen and Hansen	Ridderstolpe
	Alternative 3	water reclamation for landscape irrigation–minor reuse		land application	stabilization ponds w/ chemical precipitation
	Alternative 4			sludge, drying, incineration and land filling	trickling filter w/ biofilter ditch
	Alternative 5			sludge, drying, incineration and land filling	trickling filter w/ crop-wetland rotation
	Alternative 6			land filling	sand filter w/ denitrifying wetland ponds
	Alternative 7				sequencing batch reactor w/ denitrifying wetland
OWP Assessment Criteria	Phosphorus reduction				x
	Nitrogen reduction				x
	BOD reduction				x
	Organic toxin reduction				x
	Phosphorus recycling				x
	Nitrogen recycling				x
	Health risks				X
	Economics				x
	Local suitability				x
	Responsibility				x
	Control				x

Table F-1
Comparison of EIA Studies (Cont.)

		Kontos and Asano-1	Kontos and Asano-2	Poulsen and Hansen	Ridderstolpe
	Energy use				x
	Chemicals use				x
EIA Impact Categories	Water quality		x		
	Groundwater	x			
	Surface water	x			
	Abiotic depletion			x	
	Energy consumption	x	x		
	Chemical consumptions	x			
	Construction	x			
	Land use	x			
	Landfill use			x	
	Climate change			x	
	Flora and fauna	x			
	Geology	x			
	Soils	x			
	Socioeconomic	x			
	Public health	x	x		
	Aesthetics	x			
	Archaeology/History	x			
	Odors	x			
	Noise		x		
	Transportation		x		
	Public services and utilities		x		
	Growth inducing impacts	x	x		

Table F-1
Comparison of EIA Studies (Cont.)

		Kontos and Asano-1	Kontos and Asano-2	Poulsen and Hansen	Ridderstolpe
	Cumulative		x		
	Irreversible changes	x			
	Unavoidable impacts	x	x		

Table F-2
Comparison of LCI Studies—Methods, Boundaries, and Systems Evaluations

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
Date		1999	2003	2001	1999	1998
Location		UK, US	UK	US	UK	Sweden
Software			SimaPro 5.0			
Methods	Inventory Method	custom LCI	custom LCI	custom LCI	custom LCI	custom LCI
	Assessment Method	no	no	no	no	no
	Normalization Method	no	no	no	no	custom
	Weighting Method	no	no	no	no	EPS, env. themes, ecoscarcity
System Boundaries Include:	Investment—Treatment System	no	yes			yes
	Investment—Sewer System	no				yes
	Decommissioning	no	no			no
	Water Treatment	yes	yes			yes
	Sludge Treatment	no	no			yes
	Auxiliary Input Production	no	energy			chemicals, fertilizer, energy, drinking water

Table F-2
Comparison of LCI Studies—Methods, Boundaries, and Systems Evaluations (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	Auxiliary Process Offset	no	no			fertilizer, energy, drinking water
Treatment Systems Evaluated	Alternative 0					centralized activated sludge with chemical treatment and anaerobic sludge digestion
	Alternative 1	Stensund wastewater aquaculture system with hydroponic plant production			activated sludge with chemical pre–precipitation and post-flocculation and anaerobic sludge digestion	decentralized with septic tanks and sand filter beds using existing piping
	Alternative 2	advanced ecologically engineered system (living machine)			activated sludge with chemical pre–flocculation, anaerobic sludge digestion, and rapid sand filtration	decentralized source separated system with graywater, blackwater, and urine treatment including composting, sand filters, and septic tanks

Table F-2
Comparison of LCI Studies—Methods, Boundaries, and Systems Evaluations (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	Alternative 3	surface flow wetlands				
	Alternative 4	subsurface flow constructed wetlands				
	Alternative 5	extended aeration				
	Alternative 6	sequencing batch reactor				
	Alternative 7	carousel oxidation ditch				

Table F-3
Comparison of LCA Studies 1—Methods, Boundaries, and Systems Evaluated

		Jeppsson and Hellström	Jönsson	Kärrman and Jönsson	Kärrman *et al.*	Stromberg and Paulsen	Suh and Rousseaux
Date		2002	2002	2001	2004	2002	2002
Location		Sweden	Sweden	Sweden	Sweden	Russia	France
Software		URWARE	ORWARE	ORWARE	URWARE	SimaPro 5.0	
Methods	Inventory Method	URWARE	ORWARE	ORWARE	URWARE	CML	CML
	Assessment Method	no	Nordic Guidelines	Nordic Guidelines	ISO 14042	CML	CML
	Normalization Method	no		custom–Swedish	no	custom EI95–Russian	custom—W. European
	Weighting Method	no			no	distance to target	yes
System Boundaries Include:	Investment—Treatment System	no	no	no	no	yes	no
	Investment—Sewer System	no	no	no	no		no
	Decommissioning	no	no	no	no	yes	no
	Water Treatment	yes	yes	yes	yes	yes	no
	Sludge Treatment	yes	yes	yes	yes	yes	yes
	Auxiliary Input Production	water	yes		no	energy, chemicals	

Table F-3
Comparison of LCA Studies 1—Methods, Boundaries, and Systems Evaluated (Cont.)

		Jeppsson and Hellström	Jönsson	Kärrman and Jönsson	Kärrman *et al.*	Stromberg and Paulsen	Suh and Rousseaux
	Auxiliary Process Offset	no	yes		no	no	
Treatment Systems Evaluated	Alternative 0	activated sludge w/ denitrification, chemical precipitation and anaerobic digestion			activated sludge with biol. and chem. P removal and anaerobic digested sludge	activated sludge with denitrification and chemical phosphorus removal	
	Alternative 1	source separated stormwater, graywater, and urine		mech., biol., and chem. treatment w/denitrification	activated sludge with biol. and chem. P removal and anaerobic digested sludge w/ some home composting		incineration and landfill
	Alternative 2	biol. and chem. treatment of graywater and liquid composting of blackwater		mech. and biol. treatment w/ winter storage	blackwater digestion, graywater and industrial waste treated with activated sludge with biol. and chem. P removal and anaerobic digested sludge		lime stabilization and landfill

Table F-3
Comparison of LCA Studies 1—Methods, Boundaries, and Systems Evaluated (Cont.)

		Jeppsson and Hellström	Jönsson	Kärrman and Jönsson	Kärrman *et al.*	Stromberg and Paulsen	Suh and Rousseaux
	Alternative 3			liquid composting and mech., biol., and chem. treatment of graywater			lime stabilization and land applied
	Alternative 4			urine separation and mech., biol, and chem. treatment of feces and graywater			composting and land applied
	Alternative 5						anaerobic digestion and land applied

Table F-4
Comparison LCA Studies 2—Methods, Boundaries, and Systems Evaluated

		Roeleveld *et al.*	**Vidal *et al.***	**Clausen-Kass *et al.***	**Lassaux *et al.***	**Rihon *et al.***
Date		2002	2002	2001	2002	2002
Location		Spain	Spain	Denmark	Belgium	Belgium
Software		LCA Inventory Tool	LCA Inventory Tool	custom LCI		
Methods	Inventory Method	custom LCA	custom LCA	EDIP	EI99	EI99
	Assessment Method	custom LCA	custom LCA	EDIP	EI99	EI99
	Normalization Method	custom—W. European	custom—W. European	no	EI99	EI99
	Weighting Method			no	EI99	EI99–Hierarchist
System Boundaries Include:	Investment—Treatment System	no	no	no	yes	yes
	Investment—Sewer System	no	no	no	yes	yes
	Decommissioning	no	no	no	no	no
	Water Treatment	yes	yes	yes	yes	yes
	Sludge Treatment	yes	yes	yes	no	yes
	Auxiliary Input Production	no	no	energy	energy, chemicals	water
	Auxiliary Process Offset	no	no	biogas	no	no

Table F-4
Comparison LCA Studies 2—Methods, Boundaries, and Systems Evaluated (Cont.)

		Roeleveld *et al.*	Vidal *et al.*	Clausen-Kass *et al.*	Lassaux *et al.*	Rihon *et al.*
Treatment Systems Evaluated	Alternative 0	activated sludge	activated sludge			not defined
	Alternative 1	activated sludge w/ additional Ludzack-Ettinger system	activated sludge w/ additional Ludzack-Ettinger system		centralized, with chemical treatment	
	Alternative 2	activated sludge w/ additional oxidation ditch	activated sludge w/ additional oxidation ditch		decentralized without chemical treatment	

Table F-5
Life-Cycle Inventories

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
Date		1999	2003	2001	1999	1998
Location		UK, US	UK	US	UK	Sweden
Method		custom LCI	custom LCI	custom LCI	custom LCI	custom LCI
Inventories	**ENERGY USE**	x	x		x	
	Fossil energy					
	Oil					x
	Oil (r)					x
	Natural gas					x
	Natural gas (r)					x
	Diesel, total					x
	Diesel, w/ em					x
	Diesel, w/o em					x
	Electricity			x		x
	Digester methane					x
	District heat					x

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	OTHER RESOURCE USE					
	Bauxite					x
	Limestone					x
	Sand					x
	Rock salt					x
	Water					x
	Fe					x
	Ni					x
	Cr					x
	Zn					x
	Rock					x
	Kaolinite					x
	Feldspar					x
	Quartz					x
	Limestone					x

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	Colemanite					x
	H_2O_2					x
	NaCl					x
	NaClO					x
	Land use		x			
	Chemical use				x	
	EMISSIONS TO AIR					
	CO_2		x	x		x
	CO					x
	CH_4					x
	HC					x
	Dust					x
	Particulates					x
	SO_2					x
	NO_x					x

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	N_2O					x
	NH_4					x
	Tot-N					x
	Cl_2					x
	EMISSIONS TO WATER					
	HCl					x
	COD			x		x
	BOD					x
	Tot-N					x
	Tot-P					x
	K					x
	Cd					x
	Cu					x
	Hg					x
	Pb					x

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	Oil					x
	Phenols					x
	TSS				x	
	NaOH			x		
	EMISSIONS TO EARTH					
	Solid waste					x
	Ash					x
	Hazardous waste					x
	Biosolids		x	x	x	
	To Agriculture					
	Sludge					x
	Tot-N					x
	Tot-P					x
	Cd					x
	Cu					x

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	Hg					x
	Pb					x
	To Landfill					
	Sludge					x
	Tot-N					x
	Tot-P					x
	Cd					x
	Cu					x
	Hg					x
	Pb					x
	OTHER CRITERIA					
	P fertilizer avoided					x
	N fertilizer avoided					
	Loading rate	x				
	BOD removal	x				

Table F-5
Life-Cycle Inventories (Cont.)

		Brix	Dixon *et al.*	Jimenez-Gonzalez	Mels *et al.*	Tillman *et al.*
	TN removal	x				
	TP removal	x				
	Nutrient recycling	x				
	Relative market value				x	

Table F-6
Comparison LCA Studies 1—Impact Categories

		Jeppsson and Hellström	**Jönsson**	**Kärrman and Jönsson**	**Kärrman *et al.***	**Stromberg and Paulsen**	**Suh and Rousseaux**
Date		2002	2002	2001	2004	2002	2002
Location		Sweden	Sweden	Sweden	Sweden	Russia	France
Method		URWARE	ORWARE	ORWARE	URWARE	CML	CML
LCA Impact Categories	**RESOURCE USE**	not published				not published	x
	Abiotic depletion		x				
	Energy use			x	x		
	Fossil fuel depletion						
	Land use		x				
	Landfill use						
	Mineral depletion						
	Water use		x				
	ECOTOXICITY		x				
	Aquatic ecotoxicity			x	x		
	Chronic toxicity						
	Freshwater aquatic ecotoxicity						x

Table F-6
Comparison LCA Studies 1—Impact Categories (Cont.)

		Jeppsson and Hellström	Jönsson	Kärrman and Jönsson	Kärrman *et al.*	Stromberg and Paulsen	Suh and Rousseaux
	Marine aquatic ecotoxicity						x
	Terrestrial ecotoxicity			x	x		x
	HUMAN HEALTH						
	Human health toxicity		x				x
	Human health non-toxicity		x				
	Human health work environment		x				
	Respiratory effects						
	Respiratory effects (inorganic)						
	Respiratory effects (organic)						
	Carcinogenic substances						
	OTHER IMPACTS						
	Climate change		x	x			x
	Acidification		x	x			x

Table F-6
Comparison LCA Studies 1—Impact Categories (Cont.)

		Jeppsson and Hellström	Jönsson	Kärrman and Jönsson	Kärrman *et al.*	Stromberg and Paulsen	Suh and Rousseaux
	Eutrophication		x	x	x		x
	Photochemical ozone creation		x	x			x
	Ozone layer depletion		x				
	Slag and ashes						
	Recycling of N and P			x	x		
	Habitat and biodiversity		x				
	Inflows not accounted		x				
	Outflows not accounted		x				

Table F-7
Comparison LCA Studies 2—Impact Categories

		Roeleveld *et al.*	Vidal *et al.*	Clausen-Kass *et al.*	Lassaux *et al.*	Rihon *et al.*
Date		1997	2002	2001	2002	2002
Location		Netherlands	Spain	Denmark	Belgium	Belgium
Method		custom LCA	custom LCA	EDIP	EI99	EI99
LCA Impact Categories	**RESOURCE USE**					
	Abiotic depletion		x			
	Energy use					
	Fossil fuel depletion	x				x
	Land use					
	Landfill use					
	Mineral depletion	x				x
	Water use					
	ECOTOXICITY			x	x	x
	Aquatic ecotoxicity	x				
	Chronic toxicity			x		
	Freshwater aquatic ecotoxicity					

Table F-7
Comparison LCA Studies 2—Impact Categories (Cont.)

		Roeleveld *et al.*	Vidal *et al.*	Clausen-Kass *et al.*	Lassaux *et al.*	Rihon *et al.*
	Marine aquatic ecotoxicity					
	Terrestrial ecotoxicity	x				
	HUMAN HEALTH					
	Human health toxicity	x	x	x		
	Human health non-toxicity					
	Human health work environment					
	Respiratory effects					x
	Respiratory effects (inorganic)				x	
	Respiratory effects (organic)				x	
	Carcinogenic substances				x	x
	OTHER IMPACTS					
	Climate change	x	x	x	x	x
	Acidification	x	x	x	x	x
	Eutrophication	x	x	x	x	x

Table F-7
Comparison LCA Studies 2—Impact Categories (Cont.)

		Roeleveld *et al.*	Vidal *et al.*	Clausen-Kass *et al.*	Lassaux *et al.*	Rihon *et al.*
	Photochemical ozone creation	x				
	Ozone layer depletion	x				x
	Slag and ashes			x		
	Recycling of N and P					
	Habitat and biodiversity					
	Inflows not accounted					
	Outflows not accounted					

G DATABASE COMPARISON TABLES

This appendix describes online databases available to US decision-makers. See Chapter 7, *Data Availability*, for a discussion of online databases.

Table G-1
US-Specific Databases 1

	US-Specific Databases (page 1)			
Database	**AIR DATA**	**BASINS**	**BEES**	**EIOLCA**
Database Type	Raw data	Metadata/ directory	embedded data	embedded data
Origin	US	US	US	US
Source	US EPA	US EPA	NIST, US EPA	Carnegie-Mellon University
Region	US	US	US	US
Data Format	n/a	n/a	n/a	n/a
Software	EIOLCA	BASINS 3.0	BEES	Web-based
Website	http://www.epa.gov/air/data/	http://www.epa.gov/OST/BASINS/	http://www.bfrl.nist.gov/oae/software/bees.html	http://www.eiolca.net/
Data Types	Air emissions data	US water resource metadata	Complete LCI data	Complete LCI data
Data Categories	**Industry Sectors**	**Spatially Distributed Data**	**Building Materials**	**Industry Sectors**
	Agricultural	Land use/land cover	Roof sheathing	Agricultural
	Amusements	Urbanized areas	Exterior wall finishes	Amusements
	Apparel	Populated place locations	Wall Insulation	Apparel
	Appliances	Reach File Version 1 (RF1)	Framing	Appliances
	Audio and Video	Soils (STATSGO)	Wall sheathing	Audio and Video
	Automotive	Elevation (DEM)	Roof coverings	Automotive

Table G-1
US-Specific Databases 1 (Cont.)

	US-Specific Databases (page 1)			
Database	**AIR DATA**	**BASINS**	**BEES**	**EIOLCA**
	Batteries and Other	Major roads	Ceiling insulation	Batteries and Other
	Chemicals	USGS hydrologic unit boundaries	Partitions	Chemicals
	Cleaning	Dam sites	Fabricated toilet partitions	Cleaning
	Communications	EPA regional boundaries	Lockers	Communications
	Components	State boundaries	Interior wall finishes	Components
	Computers	County boundaries	Floor coverings	Computers
	Construction	Federal and Indian Lands	Ceiling finishes	Construction
	Containers	Ecoregions	Table tops	Containers
	Drugs		Slab on grade	Drugs
	Education and Social Services	**Environmental monitoring data**	Basement walls	Education and Social Services
	Electrical	Water quality monitoring station summaries	Beams	Electrical
	Electronic	Water quality observation data	Columns	Electronic
	Engines	Bacteria monitoring station summaries	Soil treatment	Engines
	Equipment	Weather station sites	Parking lot paving	Equipment
	Equipment	USGS gauging stations	Transformer oil	Equipment
	Fabrics	Fish consumption advisories		Fabrics
	Finance	National sediment inventory (NSI)		Finance
	Food	Shellfish classified areas		Food

Table G-1
US-Specific Databases 1 (Cont.)

	US-Specific Databases (page 1)			
Database	**AIR DATA**	**BASINS**	**BEES**	**EIOLCA**
	Forestry and Fishery	Clean water needs survey		Forestry and Fishery
	Furniture			Furniture
	Glass	**Point source data**		Glass
	Goods	Industrial Facilities Discharge (IFD) sites		Goods
	Government	BASINS 3 Permit Compliance System (PCS) sites and loadings		Government
	Health Services	BASINS 2 Permit Compliance System (PCS) sites and loadings		Health Services
	Heating and Plumbing	Toxic Release Inventory (TRI) sites		Heating and Plumbing
	Hotels	CERCLIS-Superfund National Priority List (NPL) sites		Hotels
	Industry	Resource Conservation and Recovery Information System (RCRIS) sites		Industry
	Instruments	Mineral industry locations		Instruments
	Insurance and Real Estate			Insurance and Real Estate
	Iron and Steel			Iron and Steel
	Leather			Leather
	Lighting			Lighting
	Livestock			Livestock
	Lumber and Wood			Lumber and Wood
	Machinery			Machinery

Table G-1
US-Specific Databases 1 (Cont.)

	US-Specific Databases (page 1)			
Database	**AIR DATA**	**BASINS**	**BEES**	**EIOLCA**
	Metal			Metal
	Miscellaneous Manufacturing			Miscellaneous Manufacturing
	Mining			Mining
	Nonferrous			Nonferrous
	Ordnance			Ordnance
	Other Metal			Other Metal
	Other Services			Other Services
	Paints			Paints
	Paper			Paper
	Personal and Repair Services			Personal and Repair Services
	Petroleum			Petroleum
	Plastics			Plastics
	Power			Power
	Products			Products
	Products			Products
	Products			Products
	Restaurants			Restaurants
	Rubber			Rubber
	Screws and Stampings			Screws and Stampings
	Service			Service
	Services			Services
	Special			Special
	Stone and Clay			Stone and Clay

Table G-1
US-Specific Databases 1 (Cont.)

	US-Specific Databases (page 1)			
Database	**AIR DATA**	**BASINS**	**BEES**	**EIOLCA**
	Textile			Textile
	Textile			Textile
	Tobacco			Tobacco
	Trade			Trade
	Transportation			Transportation
	Vehicles			Vehicles
	Water			Water

Table G-2
US-Specific Databases 2

	US-Specific Databases (page 2)		
Database	**Franklin US LCI**	**NAWQA**	**Sector Notebooks**
Database Type	Raw data	Raw data	Raw data
Origin	US	US	US
Source	Franklin Associates	USGS	US EPA
Region	US	US	US
Data Format	SPOLD	n/a	n/a
Software	SimaPro 5.0	n/a	n/a
Website	http://www.pre.nl/simapro/default.htm	http://infotrek.er.usgs.gov/servlet/page?_pageid=543&_dad=portal30&_schema=PORTAL30	http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/
Data Types	Complete LCI data	Chemical concentrations in water, bed sediment, and aquatic organisms; site characteristics; daily stream flow; and groundwater levels	Air, water, and soil pollutant releases and industrial process data
Data Categories	**Materials and Processes**	**Basins**	**Industry Sectors**
	Primary fuel production and combustion	New England Coastal Basins	Agricultural Chemical, Pesticide and Fertilizer Industry (2000)
	Energy for transportation	Connecticut, Housatonic, and Thames River Basins	Agricultural Crop Production Industry (2000)
	Energy sources for electricity generation	Hudson River Basin	Agricultural Livestock Production Industry (2000)
	Steel	Long Island-New Jersey Coastal Drainages	Aerospace Industry (1998)
	Aluminum	Delaware River Basin	Air Transportation Industry (1997)
	Plastics	Lower Susquehanna River Basin	Dry Cleaning Industry (1995)

Table G-2
US-Specific Databases 2 (Cont.)

	US-Specific Databases (page 2)		
Database	**Franklin US LCI**	**NAWQA**	**Sector Notebooks**
	SBR rubber	Delmarva Peninsula	Electronics and Computer Industry (1995)
	Natural rubber	Potomac River Basin	Fossil Fuel Electric Power Generation Industry (1997)
	Paper and paperboard	Allegheny and Monongahela Basins	Ground Transportation Industry (1997)
	Glass containers	Kanawha-New River Basin	Inorganic Chemical Industry (1995)
		Lake Erie-Lake Saint Clair Drainage	Iron and Steel Industry (1995)
		Great and Little Miami River Basins	Lumber and Wood Products Industry (1995)
		White River Basin	Metal Casting Industry (1997)
		Upper Illinois River Basin	Metal Fabrication Industry (1995) (html)
		Lower Illinois River Basin	Metal Mining Industry (1995)
		Western Lake Michigan Drainage	Motor Vehicle Assembly Industry (1995)
		Upper Mississippi River Basin	Nonferrous Metals Industry (1995)
		Red River of the North Basin	Profile of the Non-Fuel, Non-Metal Mining Industry (1995)
		Albemarle-Pamlico Drainage	Oil and Gas Extraction Industry (1999)
		Upper Tennessee River Basin	Organic Chemical Industry 2nd Edition (2002) (new)
		Santee Basin and Coastal Drainages	Petroleum Refining Industry (1995)

Table G-2
US-Specific Databases 2 (Cont.)

	US-Specific Databases (page 2)		
Database	**Franklin US LCI**	**NAWQA**	**Sector Notebooks**
		Apalachicola-Chattahoochee-Flint River Basin	Pharmaceutical Industry (1997)
		Georgia-Florida Coastal Plain	Plastic Resins and Man-made Fibers Industry (1997)
		Southern Florida	Printing Industry (1995)
		Kentucky River Basin	Pulp and Paper Industry 2nd Edition (2002) (new)
		Mobile River and Tributaries	Rubber and Plastic Industry (1995)
		Mississippi Embayment	Shipbuilding and Repair Industry (1997)
		Acadian-Pontchartrain	Stone, Clay, Glass and Concrete Industry (1995)
		Lower Tennessee River Basin	Textiles Industry (1997)
		Eastern Iowa Basins	Transportation Equipment Cleaning Industry (1995)
		Ozark Plateaus	Water Transportation Industry (1997)
		Canadian-Cimarron River Basins	Wood Furniture and Fixtures Industry (1995)
		Trinity River Basin	
		South Central Texas	
		Central Nebraska Basins	
		Kansas River Basin	
		Upper Arkansas River Basin	
		Middle Arkansas River Basin	
		Southern High Plains	

Table G-2
US-Specific Databases 2 (Cont.)

	US-Specific Databases (page 2)		
Database	**Franklin US LCI**	**NAWQA**	**Sector Notebooks**
		South Platte River Basin	
		North Platte River Basin	
		Cheyenne and Belle Fourche Basins	
		Yellowstone Basin	
		Upper Colorado River Basin	
		Rio Grande Valley	
		Northern Rockies Intermontane Basins	
		Great Salt Lake Basins	
		Upper Snake River Basin	
		Central Arizona Basins	
		Central Columbia Plateau	
		Yakima River Basin	
		Puget Sound Basin	
		Willamette Basin	
		Sacramento Basin	
		Nevada Basin and Range	
		San Joaquin-Tulare Basins	
		Santa Ana Basin	
		Oahu	
		Cook Inlet Basin	

Table G-3
US-Specific Databases 3

	US-Specific Databases (page 3)		
Database	**Toxic Release Inventory**	**US LCI (under development)**	**Wastewater Information Exchange**
Database Type	Raw data	Raw data	Raw data
Origin	US	US	US
Source	US EPA	NREL	WWIX, WEF
Region	US	US	US (Northwest)
Data Format	n/a	n/a	n/a
Software	EIOLCA	SimaPro (2005)	n/a
Website	http://www.epa.gov/triexplorer/	http://www.nrel.gov/lci/	http://www.wwix.com
Data Types	Toxic emissions to air, water, soil, and underground injection	Complete LCI data	Wastewater performance data with associated unit processes, flow, and design information
Data Categories	**Industry Sectors**	**Materials and Processes**	**Design Parameters**
	Agricultural	Petroleum refining*	Location
	Amusements	Wood combustion in industrial boilers*	Average summer flow
	Apparel	Diesel fueled ocean freighter*	Design flow
	Appliances	Residual oil fueled ocean freighter*	Staff
	Audio and Video	Electricity generation—US average*	Population served
	Automotive	Fuel precombustion	Designers
	Batteries and Other	Hydropower	Effluent Quality
	Chemicals	Biomass	BOD
	Cleaning	Wind	TSS
	Communications	Solar	CL_2
	Components	Geothermal	NH_4
	Computers	Steel	NO_3

*Completed data set

Table G-3
US-Specific Databases 3 (Cont.)

	US-Specific Databases (page 3)		
Database	**Toxic Release Inventory**	**US LCI (under development)**	**Wastewater Information Exchange**
	Construction	Aluminum	Phosphorus
	Containers	Plastic resins—basic polymers	Fecal Coliform
	Drugs	Structural wood	Unit Processes
	Education and Social Services	Structural steel	Collection
	Electrical	Limestone mining	Preliminary treatment
	Electronic	Soda ash mining	Primary treatment
	Engines	Salt mining	Secondary treatment
	Equipment	Chlorine/caustic soda production	Secondary aeration
	Equipment	Iron casting	Secondary solids separation
	Fabrics	Steel	Disinfection
	Finance	Lost foam aluminum casting	Odor control
	Food	Precision sand aluminum casting	Advanced treatment
	Forestry and Fishery	Semi-permanent mold aluminum casting	Effluent use
	Furniture		Sludge stabilization
	Glass		Sludge thickening
	Goods		Sludge dewatering
	Government		Biosolids use
	Health Services		Natural treatment or reuse
	Heating and Plumbing		
	Hotels		
	Industry		
	Instruments		
	Insurance and Real Estate		
	Iron and Steel		

Table G-3
US-Specific Databases 3 (Cont.)

	US-Specific Databases (page 3)		
Database	**Toxic Release Inventory**	**US LCI (under development)**	**Wastewater Information Exchange**
	Leather		
	Lighting		
	Livestock		
	Lumber and Wood		
	Machinery		
	Metal		
	Miscellaneous Manufacturing		
	Mining		
	Nonferrous		
	Ordnance		
	Other Metal		
	Other Services		
	Paints		
	Paper		
	Personal and Repair Services		
	Petroleum		
	Plastics		
	Power		
	Products		
	Products		
	Products		
	Restaurants		
	Rubber		
	Screws and Stampings		

Table G-3
US-Specific Databases 3 (Cont.)

	US-Specific Databases (page 3)		
Database	**Toxic Release Inventory**	**US LCI (under development)**	**Wastewater Information Exchange**
	Service		
	Services		
	Special		
	Stone and Clay		
	Textile		
	Textile		
	Tobacco		
	Trade		
	Transportation		
	Vehicles		
	Water		

Table G-4
Global Databases

	Global Databases			
Database	**Ecoinvent 2000**	**LCA Search Tool**	**SPINE@CPM**	**US EPA Global LCI Directory**
Database Type	Raw data	Directory	Directory	Directory
Origin	Switzerland	Netherlands	Sweden	US
Source		PRé Consultants	Chalmers University of Technology	US EPA
Region	Global	Global	Global - focused on Europe	Global
Data Format	EcoSPOLD	Varies	SPINE	SPINE
Software	web-based and SimaPro, GaBi, Umberto, Umberto, PEMS, and EMIS	Web-based	Web-based	Web-based
Website	http://www.ecoinvent.ch/en/index.htm	http://www.pre.nl/LCAsearch/default.htm	http://www.globalspine.com/	http://www.epa.gov/ORD/NRMRL/lcaccess/
Data Types	Complete LCI data and IPCC 2001, CED, EI 99, Eco-scarcity 1997, and Impact 2002 impact assessment results	Various—i.e., LCA studies, raw data, industry averages, methodology reports and other LCA information	Complete LCI data and impact assessment results	Complete and partial LCI data
Data Categories	**Production Processes**	**n/a**	**Materials and Processes**	**Production Processes**
	Agricultural means of production		Freight transports	Agriculture and forestry
	Agricultural production		Energyware production	Apparel
	Biomass		Electricity	Beverage and tobacco Product
	Chemicals		Heat	Chemical
	Construction materials		Fuels	Computer and electronic product
	Construction processes		Production of selected materials	Construction

Table G-4
Global Databases (Cont.)

	Global Databases			
Database	**Ecoinvent 2000**	**LCA Search Tool**	**SPINE@CPM**	**US EPA Global LCI Directory**
	Cooling		Chemicals	Electrical equip., appliance
	District heating		Natural materials	Fabricated metal product
	Electricity		Polymers	Food
	Food industry		Fertilizers	Furniture and related product
	Glass		Metals	Leather and allied product
	Hard coal		Building materials	Machinery
	Heat pumps		Road material	Mining (except oil and gas)
	Hydro power		Electronic component groups	Mining oil and gas extraction
	Insulation materials		Steel products	Mining support activities
	Lignite		Miscellaneous	Miscellaneous
	Metals		Waste management	Nonmetallic mineral product
	Mortar and plaster			Other
	Natural gas			Paper
	Nuclear power			Petroleum and coal products
	Oil			Plastics and rubber products
	Others			Primary metal
	Paintings			Printing
	Paper & cardboard			Retail trade
	Photovoltaic			Textile mills
	Plastics			Textile product mills

Table G-4
Global Databases (Cont.)

	Global Databases			
Database	**Ecoinvent 2000**	**LCA Search Tool**	**SPINE@CPM**	**US EPA Global LCI Directory**
	Private consumption			Transportation
	Solar collector systems			Transportation equipment
	Transport systems			Utilities
	Washing agents			Wood product
	Waste management			
	Water supply			
	Wind power			
	Wood energy			
	Wooden materials			
	Elementary Flows			
	Air			
	Resources			
	Soil			
	Water			

Table G-5
General European Databases

	General European Databases		
Database	**APME Eco-Profiles**	**ETH-ESU 96**	**BUWAL 250**
Database Type	Raw data	Raw data	Raw data
Origin	Europe	Swiss	Swiss
Source	Assoc. of Plastics Manufacturers in Europe		
Region	Europe	Switzerland and Western Europe	Switzerland and Western Europe
Data Format			SPOLD
Software	SimaPro	SimaPro	SimaPro
Website	http://www.apme.org/dashboard/business_layer/template.asp?url=http://www.apme.org/media/public_documents/20011009_164930/lca_summary.htm	n/a	n/a
Data Types	Complete LCI data		
Data Categories	**Plastic Production**	**Materials and Processes**	**Materials and Processes**
	ABS	Electricity Supply	Plastics
	Styrene copolymer	Electricity Transmission	Glass
	Acetone	Transport Services	Pulp and cellulose
	Acetone cyanohydrin	Waste Treatment	Graphic paper
	Acrylonitrile	Copper	Cardboard
	Ammonia	Aluminum	Packaging paper
	Benzene	Steel	Liners and fluting for corrugated cardboard
	Butadiene (updated July 2003)	Glass	Corrugated cardboard

Table G-5
General European Databases (Cont.)

	General European Databases		
Database	**APME Eco-Profiles**	**ETH-ESU 96**	**BUWAL 250**
	Butanes (updated July 2003)	Concrete	Aluminum
	Crude oil (updated July 2003)	Gravel	Steel and tin plate
	Electricity (onsite average)	Plastics	Municipal landfill
	Ethylene (cracker) (updated July 2003)		Municipal waste incineration (1995)
	Ethylene (pipeline) (updated July 2003)		Municipal waste incineration (2000)
	Hydrogen (cracker) (updated July 2003)		Swiss waste treatment (1995)
	Hydrogen cyanide		Electricity generation
	Liquid epoxy resins		Thermal energy production
	MDI (Diphenylmethane-diisocyanate)		
	Methyl methacrylate (MMA)		
	Naphtha (updated July 2003)		
	Natural gas (updated July 2003)		
	Nylon 6 and Nylon 6 glass filled		
	Nylon 66		
	Nylon 66 glass filled		
	Pentane		
	PET bottles (stretch blow molding)		
	PET film (packed)		

Table G-5
General European Databases (Cont.)

	General European Databases		
Database	**APME Eco-Profiles**	**ETH-ESU 96**	**BUWAL 250**
	PET film production		
	PET resin (amorphous)		
	PET resin (bottle grade)		
	PET resin (terephthalic acid) (revised September 2002)		
	Polybutadiene		
	Polycarbonate		
	Polyethylene (blow molded containers)		
	Polyethylene (HD) (updated July 2003)		
	Polyethylene (LD) (updated July 2003)		
	Polyethylene (LDPE film)		
	Polyethylene (LLD)		
	Polyethylene (pipe-extrusion)		
	Polymer dispersions (latexes)		

H INTERVIEWS WITH DECISION-MAKERS

Following the review of literature and in-depth evaluation of methods, several individuals directly involved in wastewater decision making were approached with the authors' findings and surveyed about their interest in the methods found to be most applicable to US conditions. The interviewees were selected to obtain perspectives from a variety of wastewater-related issues and different roles within the wastewater decision-making process. The authors chose the interviewees to be indicative of the types of decision-makers who might be receptive to new methods for comparing wastewater-treatment options, not to be statistically representative of anything.

The interviewees were all queried on their organization's role in wastewater decision making, their personal role in wastewater decision making, the factors they felt were most important, and why they thought those factors important. They were then asked questions about wastewater and sustainability issues specific to their region. Finally, the authors shared with them briefly the methods under investigation and environmental issues they might be able to address. Particularly, the authors noted the ability of the methods to assess the overall sustainability of wastewater-treatment options. Interviewees were then asked if they or other decision-makers they worked with would have interest in such models or methods.

The following are summary accounts of responses that the authors received. These responses were used to confirm or refute the original assumptions and to direct recommendations for future action.

County Planner

David Brownlee—Principal Environmental Planner, Department of Planning and Zoning, Calvert County, Maryland

Mr. Brownlee was chosen because of his 15 years of experience in wastewater planning at the county level and his familiarity with nitrogen issues in the Chesapeake Bay watershed. He has been involved with several studies examining the impact of onsite septic systems on the bay's nitrogen loading. A current modeling study, also involving Erica Gaddis and the Gund Institute for Ecological Economics, indicates that the contribution of nitrogen from septic systems to the bay is insignificant in comparison to atmospheric deposition. However, both the state and county pursue and promote technologies and techniques that reduce effluent nitrogen discharged to ground and surface waters, with no apparent concern for the indirect nitrogen released into the region or elsewhere as a result of the manufacturing, installation, and operation of such technologies. These findings were discussed in addition to Calvert County plan's stated concern for nitrogen released from septic systems, and the potential for life-cycle assessment methods to estimate the total nitrogen contribution of systems, which may or may not be different for systems using different materials and operations. Mr. Brownlee was doubtful that tools such as LCA would be helpful to him at the county level, since the county had already conducted extensive regional modeling and monitoring, and he had most of the non-point source nitrogen-related data that he felt he needed. The potential of LCA and EIA to evaluate indicators of the overall sustainability of wastewater treatment systems was also discussed. Mr. Brownlee agreed that such information might be of interest to policymakers at the state and county level, but based on his account, there does not appear to be an overarching sustainability policy at the state or county level to drive such interest.

State Technical Advisor 1

Michelle Drury—Water Resources Planner, Massachusetts Office of Water Resources Management (OWRM)

Ms. Drury was chosen based on her 16 years of experience as a water resources planner and her familiarity with wastewater related water-use issues, particularly involving the Ipswich River. She oversees the Interbasin Transfer Act, which mandates that any wastewater collection and treatment system that transfers water from one basin to another must be approved by the state. The approval process currently includes a Massachusetts Environmental Protection Act (MEPA) environmental impact assessment (similar to the NEPA EIA), inflow/infiltration (I/I) plan, and infrared (IR) analysis. It may also include any other methods of analysis that further demonstrate that all measures to conserve water resources are taken. The OWRM mandates the analyses that are required. Discussion topics included the growing concern of the scarcity and quality of water resources in the region and the need for new methods that synthesize water resource impacts. Ms. Drury pointed out that they are beginning to consider "cumulative environmental impacts" in their list of water resource sustainability criteria. The potential for life-cycle assessment thinking to assist in such analyses was discussed, but the fact that only one standardized LCA method assesses water resources beyond the discharge of pollutants into ground and surface waters, and does so solely through accounting water use, severely limits its usefulness currently. Ms. Drury indicated that, in general, a serious interest exists within the Massachusetts state agencies for tools that help decision-makers, particularly policymakers, assess the sustainability of their alternatives.

State Policy Maker/ Non-Profit

Mark Smith—Director, Northeast/Caribbean Freshwater Program, The Nature Conservancy and former Executive Director, Massachusetts Water Resources Commission

Mr. Smith was chosen based primarily on his experience as a water-resources policymaker, but his non-profit perspective of water resource issues was also a significant factor. As a water policymaker, Mr. Smith led a joint governmental and public group that addressed water policy and regulation within Massachusetts. He has witnessed that wastewater decisions are most often water quality and economics based, but that other environmental impacts, especially hydrologic effects, are playing an increasingly important role. He noted that these concerns are championed by watershed associations and government agencies, rather than the general public.

Mr. Smith confirmed that the MEPA EIA is the primary tool for assessing the environmental impacts of wastewater treatment projects within the state. While he considers Massachusetts to be on the cutting edge of this issue in the US, he stressed that there is a need for new techniques for evaluating the impacts of wastewater treatment. He also mentioned that the Massachusetts Department of Environmental Protection is very interested in decentralized systems and those new methods for analyzing the sustainability of systems would be of great interest for making the case for such alternatives. Additionally, he suggested that non-profits involved in wastewater decision making, such as watershed associations, are particularly ripe for such tools, as are the USGS, the Army Corps of Engineers, and the US EPA. It is important to note that Mr. Smith attributes Massachusetts' interest in these tools and readiness and willingness of its agencies to pursue broad issues of sustainability to the existence of the Office of Environmental Affairs. He believes that this umbrella organization facilitates the unification and dissemination of sustainability issues throughout the agencies, creating the climate and providing the tools for the pursuit of sustainability.

State Technical Advisor 2

Robert Vincent—Environmental Administrator, Bureau of Water Programs, Florida Department of Health

Mr. Vincent was chosen based on his nine years of experience as onsite wastewater regulator at the Charlotte County Department of Health and his familiarity with onsite treatment and phosphorus issues of Florida. Initially, discussion involved the environmental impact of phosphorus mining in Florida and possible interest in wastewater technologies that could potentially decrease the demand for chemical fertilizers. It was apparent the issue is far too disconnected from most Florida decision-makers, since the phosphorus mining is limited to three counties and localized impacts outside the decision-makers' immediate location are of little concern. In fact, Mr. Vincent found that, in most situations, economics and pathogen removal were considered nearly exclusively in deciding on wastewater options. However, he noted that eco-tourism representatives have begun to speak up for environmental concerns as they relate to wastewater and could be a driver for exploring the environmental impacts of wastewater-treatment options more comprehensively. Additionally, two-thirds of the counties have passed septic ordinances more stringent than the state and a few required aerobic treatment units in coastal areas. Still, he was skeptical that there would be much interest in new methods for analysis at the county level. He cited uninformed public, uninformed contractors, the lobbying of developers, and resistance to anything that threatens to increase cost or responsibilities. He mentioned that the county has a big problem simply with coastal flooding and septic system washouts occur all the time, yet they cannot get the ordinances changed. He doubts that broader issues of sustainability could be addressed under this regulatory climate. Despite this sober view of county issues, Mr. Vincent does believe that there would be interest in these new methods at the state level to develop policy and provide guidance, as concerns about non-point source pollution grow.

Green Building Program Representative

Peter Schneider—Vermont Builds Greener, a Program of Efficiency Vermont; Burlington, Vermont

Vermont Builds Greener is Vermont's certification organization for "green buildings," that is, those buildings that use better-than-average construction materials and techniques to achieve energy efficiency and other environmental goals. The organization has set up a list of criteria for new construction to fulfill. Buildings that accumulate a high number of points are eligible for certification as green buildings. The certification carries no immediate monetary reward to the builder or owner, but Schneider says that there are indications that the certification increases resale value of the buildings.

In the rural state of Vermont, a large percentage of homes use onsite wastewater-treatment systems. The discussion with Schneider focused on whether and how LCA would be useful to Vermont Builds Greener in its certification process. Schneider initially said that LCA "comes into every aspect of what we deal with." He gave the example of vinyl siding, which has a number of desirable properties: it is durable—and so the environmental cost of replacing it is one incurred less frequently—and it requires little or no painting to keep it looking good, reducing all environmental impacts related to production, transport, and use of paint. On the other hand, vinyl production is associated with production of such quantities of toxins that Vermont Builds Greener does not include vinyl as an environmentally friendly product. By considering the cradle of the product, they were able to make a more informed choice than if they had just considered the product in use.

At present, Vermont Builds Greener uses LCA qualitatively. Schneider would like to see more examples of the quantitative type of LCA described in this report. He gave the example of flooring, and wonders how bamboo flooring stacks up, environmentally, to flooring from local hardwoods. He wants to know the environmental cost of transporting that bamboo or the finished product to Vermont from where it is grown or manufactured.

Schneider was not familiar with aerobic treatment units (ATUs). However, when ATUs and their potential role in reducing nitrogen to water were described, he said he would be interested in seeing LCA numbers comparing nitrate emissions from generating the electricity used to power the ATUs with the water-borne nitrogen removed by the ATUs. That sort of information, plus LCA information on materials used in plumbing and wastewater-treatment systems, could give them guidance in revising their certification criteria for wastewater-treatment systems. The revised criteria, in turn, could affect decisions made by builders or homeowners who valued having an environmentally friendly home.

When asked about the usefulness of an LCA inventory by itself versus results in impact categories, Schneider thought that both would be useful. Right now Vermont Builds Greener uses annual carbon dioxide emissions as a basis for comparing heating systems, and homeowners find that easy to understand. Some sort of inventory assessment would fit right into that approach. On the other hand, simplifying complex inventories into impact categories could also provide useful information to them.

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