INCORPORATING SUSTAINABILITY INTO ASSET MANAGEMENT THROUGH CRITICAL LIFE CYCLE COST ANALYSES

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ABSTRACT

Asset management is about managing assets more effectively – which is really about making better decisions about and for assets, both existing and future. The main key to achieving better decision-making is having the right kind of information available from which to make the decisions. The goals that better decision making are trying to reach are service levels that are met, risks, including public health, safety, financial, and environmental, that are reduced, and costs that are optimized.

One analysis method used for asset management that facilitates long-term cost optimization is the use of life cycle cost analyses (LCCAs). A typical life cycle cost analysis (LCCA) includes evaluating the costs incurred by an asset over its useful life to find the least cost solution. However, since the goals of asset management are to meet level of service (LOS) standards and reduce risk as well, the typical LCCA solution often times does not meet these needs. This has led to the development of the critical LCCA, which meets asset management goals by incorporating LOS, condition, criticality, vulnerability, risk, and remaining useful life into the analysis. The goal of a critical LCCA is not merely the least cost solution but the least cost solution to meet the asset management goals or the "optimal" cost solution. The assets with the greatest gap between LOS and condition and the assets with the highest risk are therefore the highest priority. In order to make the critical LCCA as robust as possible, these environmental and social or sustainability principles and costs need to be included with the economic costs and the LOS and risk goals. The potential exists for the results of a critical LCCA to be significantly different if sustainability costs are incorporated, favoring the traditionally more economically costly sustainable alternative to the standard solution.

Sustainability is the concept of managing natural resources in a manner that does not cause harm to the ecosystem and allows it to be as fruitful as possible, while permitting human activity to be productive and long lasting as well. Some of the specific sustainability ideas can specifically be integrated into critical LCCAs that are applicable to the water and wastewater industry. There are two potential ways that will be discussed to incorporate sustainability principles in a critical LCCA. The first method is to change the way a critical LCCA is developed – by looking not just at one asset but at a whole system. For example, rather than analyzing and optimizing just one pump, the analysis would include the entire pumping system – pumps, motors, piping, valves, etc. The second technique is to quantify environmental and social costs, through specific tools such as the Ecological Footprint, and add them into the critical LCCA. By integrating these

concepts with life cycle cost analyses, asset management programs can help agencies make cost optimizing decisions that are more sustainable for meeting long term goals.

KEYWORDS

Asset management, sustainability, critical life cycle cost analyses.

INTRODUCTION

Sustainability can be defined as meeting "…the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1992). It is based on the recognition that when resources are consumed faster than they are produced or renewed, the resource is depleted until it no longer exists. In a sustainable world, society's demand on nature is in balance with nature's capacity to meet that demand (www.globalfootprint.org). Global and U.S. trends toward more sustainable practices, emerging contaminants of concern and future regulations, rising energy costs and other natural resource limits, climate change, financial considerations, and public pressure are driving the water and wastewater industry to consider sustainability in their decision-making. Sustainability requires that decision-making criteria be expanded to include social and environmental impacts, as well as broader economic impacts; and to consider those impacts over generations, a longer period of time than considered for most decisions agencies made today.

Asset management programs are designed to improve decision-making about assets in order to manage both existing and future assets more effectively. Effective asset management ensures that service levels are met; risks, including public health, safety, financial, and environmental, are minimized; and costs optimized.

Better decision-making is crucial to achieve both asset management and sustainability goals. One key to making better decisions is having the right information available at the right time to support the decision-making process. Energy efficiency expert Joseph Romm reports that for a typical building, by the time "1% of the project's up-front costs are spent, up to 70% of its life cycle costs may already be committed" (Hawken, Lovins, and Lovins, 1999). Clearly, there is a need to have the right information to be able to understand the impacts on life cycle costs before any decisions are made.

One analysis method used for asset management that facilitates long-term cost optimization is the use of life cycle cost analyses (LCCAs). A typical life cycle cost analysis (LCCA) includes evaluating the costs incurred by an asset over its useful life and comparing it to other assets in order to find the least cost solution. These costs generally include acquisition, installation, operations, maintenance, and disposal costs. However, since the goals of asset management also include meeting level of service (LOS) standards and reducing risk, the solution with the lowest life cycle cost (LCC) is frequently not the optimal solution.

The "critical" LCCA meets asset management goals by incorporating LOS, condition, criticality, vulnerability, risk, and remaining useful life into the analysis. The goal of a critical LCCA is not merely the least cost solution but the least cost solution that meets the asset management goals, or the “optimal” cost solution. In order to incorporate LOS goals into the critical LCCA, the existing condition and desired LOS of an asset must be compared to determine if any gap exists. This gap identification provides the basis for determining which assets need to be improved to meet the target LOS and, conversely, which assets can potentially sustain a decrease in their LOS target. Incorporating risk, a mathematical combination of criticality and vulnerability, and managing its reduction involves identifying assets that need to have their current risk levels reduced and, conversely, assets that can potentially sustain an increase in risk level. Analyzing risk and LOS goals allows priority assets to be identified. The assets with the greatest gap between LOS and condition and those assets with the highest risk are the highest priority. These high priority assets can then be managed more closely and effectively, and decision-making can include critical LCCAs.

While critical LCCAs address asset management goals beyond least cost, they do not generally consider potential costs or benefits to the environment or society. In order to make the critical LCCA as robust as possible, environmental and social costs and benefits should be considered with the economic, LOS, and risk management goals. A more robust critical LCCA may lead to significantly different decisions in an asset management program.

METHODOLOGY

Sustainability is the concept of managing natural resources in a manner that does not cause harm to the ecosystem and allows it to be as fruitful as possible, while permitting human activity to be productive and long lasting as well. Consider this: “if everyone in America integrated these…technologies (premium efficiency motors and electronic ballasts) into all existing motor and lighting systems in an optimal way, the nation’s $220-billion-a-year electric bill would be cut in half” (Lovins, Lovins, and Hawken, 1999). And “only 1% of the energy consumed by today’s cars is actually used to move the driver”, and through the use of low priced but less efficient transformers, $1 billion dollars is wasted each year (Lovins, Lovins, and Hawken, 1999). Additionally, “every day…U.S. farmers and ranchers draw out 20 billion more gallons of water from the ground than is replaced by rainfall” and only about 5% of the waste Americans produce is recycled (“The Natural Step to Sustainability”, 1997). Including sustainability goals, such as zero waste, zero toxics, and energy and water efficiency, into an asset management program can lead to cost savings and innovative solutions.

Sustainability is a simple idea and should not be thought of as a separate or stand-alone discipline, but rather that the concepts and goals should infuse all aspects of planning and design activities. There is a variety of sustainability conceptual frameworks, metrics, and design guidelines that have been developed, including The Natural Step, ecological design, industrial ecology, Leadership in Energy and Environmental Design Green Building Rating System (LEED), eco-effectiveness/Sustainable Design Protocol, Natural Capitalism, and the Ecological Footprint, that are designed to integrate sustainability into decision-making.

The Natural Step

The Natural Step is a sustainability methodology that focuses on “building awareness and understanding”, conducting a “Sustainability Analysis”, developing “a strategy and action plan”, and supporting "step by step implementation" (www.naturalstep.org). It has four system components:

- "Substances from the Earth's crust must not systematically increase in nature",
- "Substances produced by society must not systematically increase in nature",
- "The physical basis for the productivity and diversity of nature must not be systematically diminished",
- "Just and efficient use of energy and other resources" ("The Natural Step to Sustainability", 1997)

The Natural Step is based on the concept that as demand increases and resources decrease, a funnel is created where productivity will be limited by the walls of the funnel. Many states, counties, cities, and governmental organizations across the U.S. are adopting and implementing this framework.

Ecological Design Principles

Ecological design principles include:

- "Solutions grow from place"
- "Make nature visible"
- "Design with nature"
- "Ecological accounting informs design"
- "Everyone is a designer" (www.ecodesign.org)

By understanding the local geography and conditions, designs can complement and cause no harm to the natural environment. Making nature visible allows for a better understanding of the ecosystem and human impacts to it. By designing with nature, natural diversity is sustained and protected, and the ecosystem continues to function as it should, returning all "waste" back into the natural elements. Understanding the material and energy flow provides the opportunity to develop ecologically sustainable designs.

Industrial Ecology

The goal of industrial ecology is to "incorporate the cyclical patterns of ecosystems into designs for industrial production processes that will work in unison with natural systems" (**www.sustainable.doe.gov/business/parkintro.shtml**). The U.S. Department of Energy has outlined six principal elements, including:

- Industrial ecosystems
- Balancing industrial input and output to the constraints of natural systems
- Dematerialization of industrial output
- Improving the efficiency of industrial processes
- Development of renewable energy supplies for industrial production
- Adoption of new national and international economic development policies

These principles are targeting a closed-loop system among industries to produce no waste, a decrease in the amount of materials and energy consumed, the redesign of industrial processes, and the identification of non-harmful interactions with the ecosystem.

Leadership in Energy and Environmental Design Green Building Rating System

Developed by the US Green Building Council, LEED is a framework for developing high quality, sustainable buildings, whose goals are to develop a common "green" measurement system, promote whole building design, recognize leadership, and raise awareness (www.usgbc.org). LEED has developed standards for commercial, institutional, and residential buildings, including new construction and renovations. The measurement system awards credits for each "green" feature under the following categories:

- "Sustainable sites"
- "Water efficiency"
- "Energy and atmosphere"
- "Materials and resources"
- "Indoor environmental quality"
- "Innovation and design process" (www.usgbc.org)

Based on the points earned, "green" buildings are awarded different levels of certification.

Eco-effectiveness

Eco-effectiveness is a concept of sustainability in which both humans and the environment are productive and regenerative "within cradle-to-cradle life cycles" (McDonough and Braungart, 1998). Its formative strategy is that waste equals food and that biological nutrients" return to the organic cycle and "technical nutrients" are recycled in technical processes that allow them to maintain their physical integrity and quality (McDonough and Braungart, 1998). "Biological nutrients" are substances that do "not contain mutagens, carcinogens, heavy metals, endocrine disrupters, persistent toxic substances, or bio-accumulative substances" (McDonough and Braungart, 1998). "Technical nutrients" could be provided as a product or a service, where the customer purchases the use of the product and the manufacturer takes back the product at the end of its useful life for recycling, saving the manufacturer from having to purchase additional raw materials. Additional strategies include:

- Respecting diversity
- Using solar energy
- Restoring accountability
- Making prices reflect costs
- Making conservation profitable
- Getting business out of government (McDonough and Hawken, 1993)

A proprietary tool, the McDonough Braungart Index of Sustainability, "evaluates a product's materials and processes so that redesign for sustainability can take place" (www.mbdc.com).

Natural Capitalism

Natural Capitalism lays out four principles to achieve sustainability. They are:

- Increase natural resource productivity
- Biologically inspired models

- Solutions based model
- Invest in natural capital (Lovins, Lovins, and Hawken, 1999)

Strategies to increase natural resources productivity include: changing the design perspective to a "whole-systems" design process; counting all "multiple" benefits; taking the right steps at the right time and in the correct order; and incorporating new technologies (Hawken, Lovins, and Lovins, 1999). For example, shifting to biological-inspired production models involves using methods such as closed-loop manufacturing to prevent waste production or in other words, any material that is left over as waste is completely reused in the next production cycle (Lovins, Lovins, and Hawken, 1999). A solutions-based model is one where a service, rather than a product, is supplied to the customer. For example, a pesticide company would provide crop protection to a farmer rather than sell pesticides, and be responsible for maintaining the absence of pests with the incentive of making greater profit by using fewer chemicals. Investing in natural capital is, simply, "…restoring, sustaining, and expanding…natural habitat and biological resource base" (Lovins, Lovins, and Hawken, 1999).

Ecological Footprint

The Ecological Footprint (EF) measures many external and difficult to quantify costs to the environment, and thus society as well. The EF measures the bioproductive area required to produce all the resources consumed, and absorb all the wastes produced, by a person, group, or process, expressed in standardized acres and normalized by biological productivity (Baumberger and Hansel, 2004). This metric allows comparison of the relative ecological impacts of differing alternatives, accounting for the life cycle impacts of construction materials, transportation energy, chemicals, and energy for operations, and emissions, such as methane and carbon dioxide (**www.rprogress.org**).

RESULTS

These sustainability frameworks all work towards developing and sustaining a system where the use of resources is restorative and non-harmful, allowing both humans and the ecosystem to thrive. They strive to accomplish this goal by creating little or no damage to natural ecosystems, sustaining natural resources and increasing their productivity, understanding the environmental impacts of different choices, creating little or no waste, and rethinking current design practices. A few of these ideas can specifically be integrated into critical LCCAs that are applicable to the water and wastewater industry.

Based on these frameworks, two potential methods will be discussed for incorporating sustainability principles in a critical LCCA. The first method is to change the way a critical LCCA is developed – by looking not just at one asset but at a whole system design, as outlined by Natural Capitalism. For example, rather than analyzing and optimizing just one pump, the analysis would include the entire pumping system – pumps, motors, piping, valves, etc. The second technique is to quantify environmental cost, through specific use of the Ecological Footprint, and loosely integrate it into the critical LCCA.

DISCUSSION

Whole System Design

The theory of whole system design contradicts the concept of diminishing returns and is, to a large part, based on expanding returns, the idea that it can actually cost less to save a greater amount of resources than a smaller amount, referred to as "tunneling through the cost barrier" (Hawken, Lovins, and Lovins, 1999). For example, building a house with thicker insulation and more efficient windows can eliminate the need for a furnace, as well as its ongoing operations and maintenance costs, such as fuel and electricity, which saves substantially more money than the additional capital cost of the insulation and the windows (Hawken, Lovins, and Lovins, 1999). Typically, each asset or component of a system is optimized for cost, energy use, and performance in isolation, rather than optimizing an entire system as a unit and considering all resulting benefits, which tends to make the entire system less efficient and optimal, and at the same time more expensive. This concept of rethinking design processes can be achieved either when designing new infrastructure, or through rethinking or piggybacking on planned renovations or improvements (Lovins, Lovins, and Hawken, 1999).

Two specific examples of the benefits of whole systems design applicable to the water and wastewater industry involve reducing friction and changing the order in which equipment layout is developed. In 1997, Interface Corporation, a commercial flooring manufacturer, was building a new factory (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). Before construction began, Jan Schillham, an Interface engineer, made two changes to the plans (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). First, he redesigned the pumping system, choosing fatter pipes and smaller pumps, resulting in reducing power requirement from 95 horsepower to 7 horsepower, a 92% power reduction (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). The fatter pipes create less friction and therefore need less pumping energy, which translates into smaller pumping equipment (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). The reason this design was originally overlooked was that the higher capital cost of the fatter pipe was compared only to the savings in energy use. When the lower capital cost of the smaller pumping equipment was included in the comparison, it was a less expensive alternative. (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). When Schillham optimized the whole system, the additional capital cost of the fatter pipe was offset by the lower capital cost of the pumping system equipment, making the new design not only less expensive to operate, but also less expensive to build than the original design (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999).

The other change Schillham made was to reverse the order of pipe and equipment layout. He laid out the pipe system as straight as possible in the building before positioning the equipment, the opposite of how design normally conducts business, resulting in an overall shorter length of pipe and fewer fittings, and therefore lower capital costs (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). Friction was further reduced due to the shorter pipes and fewer bends/fittings, which again resulted in smaller pumping equipment and less pumping energy, and therefore both capital and operating savings (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). The pipes were faster to install, which reduced labor costs, because the lengths were shorter and there were fewer fittings. Finally, the pipes were easier to insulate, because they were shorter and easier to access, which resulted in lower capital and operating costs as well (Hawken, Lovins, and Lovins, 1999; Lovins, Lovins, and Hawken, 1999). The new design was less expensive to build and operate than the original, easier to build, used less floor space, was easier to maintain, had fewer parts to fail, was more reliable to operate, and had overall better performance (Hawken, Lovins, and Lovins, 1999). It should be noted that laying out pipe before placing equipment and whole system evaluation of using fatter pipe and smaller pumps are two steps that can be taken to reduce friction in pipes, and friction is only one of the forces that must be overcome by a pumping system (Hawken, Lovins, and Lovins, 1999). Similar ideas can be incorporated into R&R decisions as well.

Changing the design framework to consider whole systems can support good decisions about where to spend resources, such as on fatter pipes, to realize multiple benefits. This requires that the "right steps be taken in the right order" (Lovins, Lovins, and Hawken, 1999). Downstream changes can create much larger upstream savings, "for example, saving one unit of liquid flow or friction in an exit pipe saves about 10 units of fuel, cost, and pollution at the power station" (Lovins, Lovins, and Hawken, 1999). Developing critical LCCAs by looking at a whole system rather than just one asset is a fundamental change in the boundary conditions, and thus costs, of developing a critical LCCA, and it can result in less expensive systems that are more efficient and use fewer materials. By looking at a whole system design, the "optimal" cost solution is quite often more sustainable, with fewer negative impacts to society and the environment.

Ecological Footprint

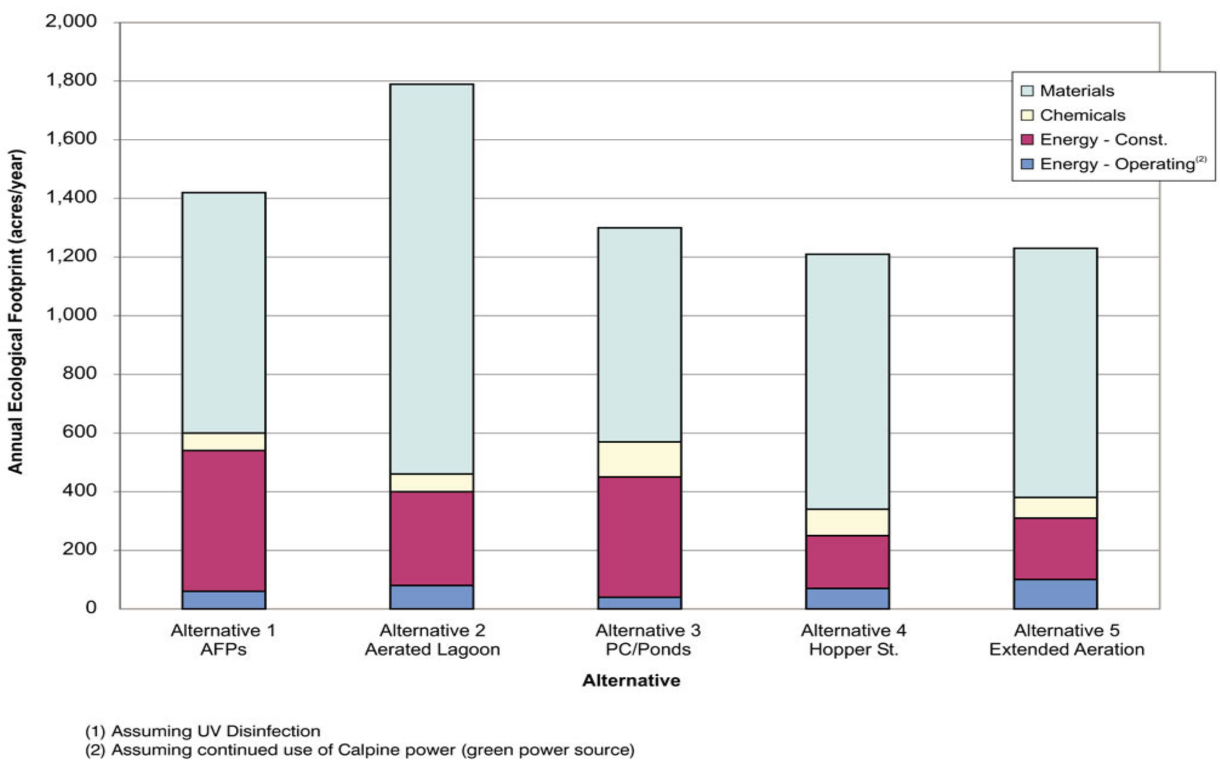
By quantifying costs through an EF, a critical LCCA can result in a more robust analysis by including environmental and societal costs. The premise of an EF is that it quantifies the impacts of resource consumption and waste production assimilation for given populations or activities. It covers renewable resources only, as well as the greenhouse gas impacts of burning fossil fuels. It does not address toxicity, biodiversity loss, or depletion of non-renewable resources. The EF is based upon five major assumptions:

- "It is possible to keep track of most of the resources people consume and the wastes people generate"
- "Most of these resource and waste flows can be converted into biological productive area that is required to maintain these flows"
- "These different areas can be expressed in the same units (hectares…) and… scaled proportionally to their biomass productivity"
- "These areas stand for mutually exclusive uses, and each standardized acre represents the same amount of biomass productivity, and they can be added
- This area for "total human demand can be compared with nature's supply of ecological services, since it is also possible to assess the area on the planet that is biologically productive" (**www.redefiningprogress.org/programs/sustainabilityindicators/ef/methods/calculating.htm**).

These assumptions allow the EF to be taken in strict mathematical terms, based on readily available data, by allocating land to biologically productive uses. The three major components are total food and fiber (crop demand, forest products, grass fed animals, and fish), total energy (fuel wood, nuclear, hydro, and CO_2 from fossil fuels), and built up land (www.redefiningprogess.org). These categories are added to get an EF value in global acres or acres per year.

While the EF value is not in monetary terms, it can be used to compare different projects or decisions. For example, if a critical LCCA completed for several assets or projects and two have the same life cycle cost, an EF value can be calculated for each alternative and then compared to allow the more sustainable project, with the lower EF value, to be chosen.

The City of Petaluma, CA recently incorporated EF methodology into their decision making process for selection of treatment alternatives for their new water recycling plant. The EF was considered in addition to more traditional evaluation criteria, such as lifecycle costs and reliability, to select a treatment process. The City is environmentally aware and based their final decisions on both cost and sustainability. EF values were calculated for each alternative, and categorized based on materials, chemicals, and energy consumption, for construction and operation, required for each alternative, as shown in the figure below.

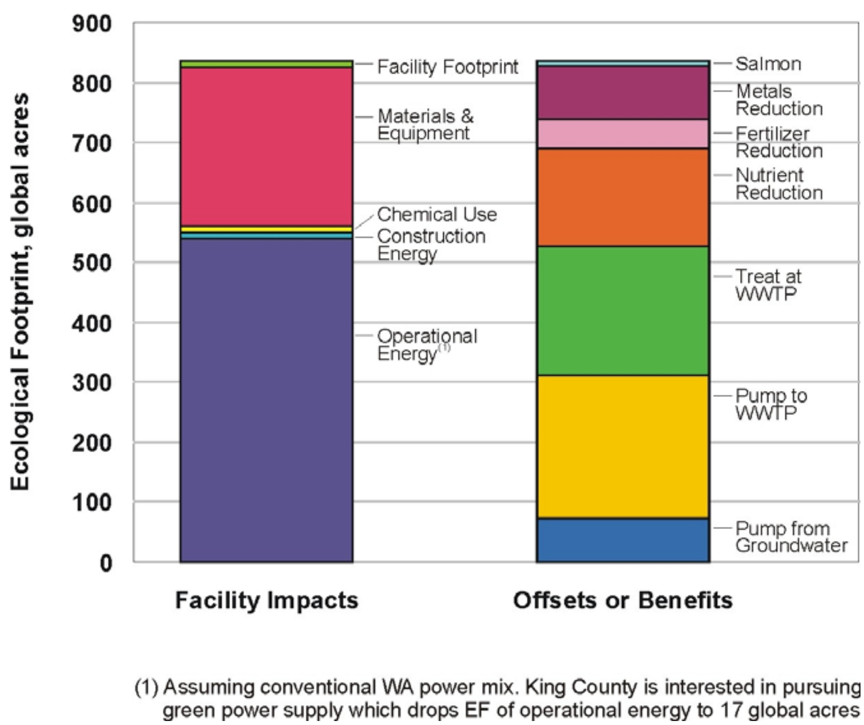


(Holmes, Ban, Fox, et al, 2004)

Alternative 5, extended aeration, was chosen because of its lower EF, even though it was the second most expensive alternative (Holmes, Ban, Fox, et al, 2004). Vegetated treatment wetlands and ultraviolet disinfection were also chosen instead of dissolved air flotation and chlorine disinfection, respectively, based on their sustainability factors, expressed by EF values (Holmes, Ban, Fox, et al, 2004). It should be noted that the results of this study cannot be extrapolated to other situations, since local factors such as sources of energy, and transport distances for materials, supplies and biosolids disposal affect calculation of the EF.

King County, WA has used EF analysis in a slightly different way to answer the question " Does this water reuse project increase overall sustainability?" for decisions regarding the design and construction of their Sammamish Reclaimed Water Production Facility (Holmes, Ban, Fox, et al, 2004). By directly incorporating both the costs and the benefits into a decision with an EF, King County was able to consider more comprehensive environmental impacts in their decision analysis.

As shown in the figure below, the EF cost of building a recycled water facility to the EF benefits of increasing water supply locally are roughly equal with the assumption that a typical energy supply of coal, natural gas, and hydroelectric power would be supplied (Holmes, Ban, Fox, et al, 2004). In this figure, the costs are approximately equal to the benefits, but, if King County is able to obtain "green" power (i.e., small-scale hydro, solar, wind, etc.), as expected, the operational energy component of the facility impacts decrease from over 500 to 17 global acres (Holmes, Ban, Fox, et al, 2004). In this case, the EF benefits greatly outweigh the EF costs, indicating that reuse may be the best alternative from an ecological standpoint.



(Holmes, Ban, Fox, et al, 2004)

CONCLUSIONS

Critical LCCAs that integrate whole system engineering and EF methodologies can provide more comprehensive information on which to base decision-making. Applying the hidden synergies leading to efficiency improvements possible through whole systems design, coupled with the relative ecological impact assessments provided by the EF to asset management programs, can help agencies make better "optimal" cost decisions that are also more sustainable. The implementation of these decisions can help agencies not only meet LOS goals, reduce risk and costs, but also meet environmental goals to sustain our ecosystems for current and future generations.

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