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Toolkit for the 21st-Century Urban Sanitation Planner

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1. Executive Summary

The United Nations General Assembly declared 2008 the International Year of Sanitation. The designation is a call to action; it is an effort to incite innovation towards the provision and implementation of effective and sustainable sanitation solutions. Our "Toolkit for the 21st-Century Urban Sanitation Planner" responds directly to the UN's call.

Providing access to improved sanitation to the more than 2.6 billion people who are without, is itself an enormous challenge. However, the challenge is confounded by a growing consensus that the standard approach to providing urban sanitation – flush toilets connected to centralized wastewater treatment plants that dispose into local waterways – is neither economically viable nor environmentally sustainable. Affordable and environmentally sustainable sanitation requires a shift away from schemes that have high economic costs, are energy and resource intensive, and are designed for the disposal of sewage and wastewater, to schemes that are low-cost, produce rather than consume energy, and are designed for the *reuse* of treated sewage and wastewater.

Many governments, planners and engineers continue to adopt conventional "design for disposal" sanitation schemes because these are the most familiar to design and implement. To facilitate a transition to more sustainable alternatives, there is a need for tools which are available to stakeholders, that quantify the tradeoffs between different technology and design options, and that can be used to guide the design of locally tailored, reuse-oriented sanitation schemes. We propose developing and piloting two tools that make up a toolkit for urban sanitation planners and stakeholders. The first tool is a novel sustainability assessment (SA) for evaluating existing sanitation infrastructure. The second is a five-step 'Design for Service' (DFS) planning and decision-making framework for developing locally appropriate sewage handling systems. Our SA for sanitation infrastructure uses 'burden-to-benefit' ratios to capture and quantify the externalities associated with both the absence *and presence* of sanitation systems, as well as the opportunity costs and benefits associated with designing sanitation schemes for reuse versus disposal. The DFS planning approach is grounded in the assumption that sewage waste is a resource. DFS is used to devise sanitation schemes that maximize the extent to which wastewater and resources embodied in sewage, wastewater, and sludge are utilized for the most locally appropriate "services" (e.g., irrigation, industrial reuse, toilet-flushing, fertilizer, cement manufacturing).

Research and development of the SA and DFS planning approach will occur on the UC Berkeley campus, and field testing will take place in China and Senegal. Our approach will be to scale-up our current work in China, and to pilot our toolkit in Africa as "proof of concept" of the global applicability of our sanitation evaluation and planning tools for unserved urban areas. We will pilot the SA in a total of 4 cities in China, including Chengdu where we are currently working, and 1 city in Senegal. We will pilot the DFS planning approach in 2 cities in China, including Chengdu, and 1 city in Africa, likely Senegal.

UC Berkeley's Sustainable Products and Solutions program (SPS) is providing 2 years of financial support to facilitate the research and development of these tools. We believe that both the Sustainability Assessment and the Design for Service Planning Approach have enormous potential for widespread adoption, and high impact results, particularly with the additional

financial and institutional support of local and international partners. We will engage the expertise of a multidisciplinary team of students and faculty from across campus, including urban planners, civil and environmental engineers, economists, and computer scientists. Over the course of two years of SPS funding we will publish several journal articles and practitioner handbooks, present our work at conferences, and outreach to relevant international organizations. Upon expiration of the funding in Year 2, we aim to be in a position to market these tools to cities and agencies around the world that are engaged in the evaluation and monitoring and/or the design and implementation of urban sanitation infrastructure.

2. Sustainability Challenge

Somewhere in Dakar, Senegal a 58 year old woman finds a moment of privacy in a dark corner of her one-room, five-person home, to relieve herself in an old plastic bag. She propels it out the front door; it flies like a helicopter through the air, and lands on top of the ever-growing community trash heap. Somewhere in Chengdu, China an 11 year old girl flushes the toilet in her family's middle-class apartment; a 79 year old man doing *tai chi* by the river below watches tainted water pour out of a big outfall and into the putrefying river. These are not unique snapshots, but examples of a reality shared by more than 2.6 billion people who lack access to improved sanitation and the millions more who live in cities without sufficient wastewater treatment to protect public health and the environment. Every year, more than 1.8 million deaths due to diarrheal disease are attributed to waterborne illnesses; everyday, millions of tons of human waste are dumped into freshwater bodies around the world.

The daunting task of improving global access to complete sanitation is complicated by a growing consensus that conventional approaches – flush toilets connected to centralized wastewater treatment plants that dispose into local waterways – are economically and environmentally unsustainable. The traditional approach to wastewater treatment in urban areas is to first build centralized treatment facilities, followed by a sewer network, and finally to connect individual households to the network [1]. This approach is often referred to as "design for disposal." Simple logic suggests that in rapidly growing low and middle-income cities, installing and operating high cost and energy intensive treatment plants, digging up roads to lay new sewage pipes, and installing proper household connections will be fraught with social, political and economic unwillingness and infeasibility. Alas, the reality in such cities around the world is characterized by under-utilized networks or networks that never get built, faulty connections, and ill-maintained treatment plants [1, 2]. There is a great need for tools that will enable engineers, planners, and decision makers to break from the 19^{th}-century status quo, and to implement sanitation systems that are both sustainable and tailored to the unique circumstances of this modern urban age.

3. Sustainability Solution

To help catalyze the shift to a new, more sustainable sanitation paradigm, we are developing and piloting two separate and complementary tools that make up a toolkit for urban sanitation planners and stakeholders. The first tool is a novel sustainability assessment (SA) for existing sanitation infrastructure, and the second is a five-step 'Design for Service' (DFS) planning and decision-making protocol for developing locally appropriate sewage treatment systems. The tools each have stand-alone functions that make them appropriate for independent applications, or if warranted by the local context, the SA and DFS can be applied sequentially. The purpose and intended uses of the tools are detailed below.

Sustainability Assessment

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> Complex, interlinked problems, such as those associated with sustainable development require integrated approaches and solutions. There is a need to move beyond the usual, more or less exhaustive, lists of individual indicators to integrated or interlinked sets of indicators,
> (Gallopin 109 [3]).

Sustainability assessments, made up of indicators, have emerged over the last decade as an increasingly common device for measuring progress towards sustainable development. An array of organizations and researchers has attempted to develop sets of indicators that can aid stakeholders in developing along a sustainable trajectory. However, *there remains a significant knowledge gap in the operative approach to effectively measuring and monitoring progress towards sustainable development.* There is great need for researchers and practitioners to think more critically about how to formulate sustainability assessments that fulfill their intended purpose of measuring the *impact* of development on the environment [4].

We believe our unique SA for wastewater treatment systems has the potential to substantially advance the practice of sustainability measurement and monitoring within the sanitation sector. We have developed two-dimensional indicators, we call 'burden-to-benefit' ratios, to replace the traditional one-dimensional indicators that by design compartmentalize different components of sustainability (e.g., environmental, economic, social). Our burden-to-benefit ratios are designed to explicitly link urban patterns to the state of the environment, to capture and quantify the externalities associated with both the absence *and presence* of sanitation systems, and to reveal the opportunity costs and benefits associated with designing sanitation schemes for reuse versus disposal (Table 1). The goal of the SA is to clearly communicate trade-offs between different sanitation technology choices, (e.g., lifecycle costs, environmental footprint) and to evoke appropriate policy responses. We believe the results of the SA, when applied to conventional systems, will provide motivation for seeking lower cost, less energy intensive, and more reuse-oriented sanitation schemes.

We will pilot the SA in three cities in China (in addition to Chengdu where we are currently working,) and one city in Africa, likely in Senegal to: 1. Quantify the variability in sustainability of similar wastewater treatment technologies in different contexts; 2. Quantify sustainability of different wastewater treatment technologies in similar contexts; 3. Test the practicality of evaluating each of the sustainability indicators; 4. Understand the trade-offs between the ease of evaluating indicators and the information gained, as data collection is time and resource intensive. See Section 4 for a complete description of the outcomes and goals for this component of the project.

Table 1. Sample of the 'Burden-to-Benefit' ratios that make-up the Sustainability Assessment. Note that 'benefits' are not necessarily captured, but rather may represent foregone or potential opportunities.

BURDEN	BENEFIT
Energy Used to Treat the Wastewater	Theoretical Energy Value Embodied in the Wastewater
Cost of Nutrient Removal	Local Value of Non-Utilized Nutrients in the Wastewater
Acidification Caused by Wastewater Treatment	Eutrophication Avoided by Wastewater Treatment

Design for Service Planning Approach

> Too many activities undertaken with sustainability in mind continue to threaten environmental integrity often further stressing systems that are near or beyond their capacity to function healthily,
> (Wilson 300 [5]).

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That conventional wastewater treatment has imparted numerous benefits to society is not up for debate. The World Health Organization claims that improved sanitation reduces diarrhoeal morbidity by 32%, and a recent meta-analysis of water, hygiene and sanitation interventions found that the latter reduces the incidence of diarrhoeal disease by 22 to 36% [6, 7]. Sewage treatment is also crucial for protecting the aesthetics and biological integrity of natural ecosystems by removing organic matter and nutrients before effluent is released to the environment. However, conventional approaches to sewage management, despite being built in the name of "sustainable development," pose enormous financial burdens, and result in numerous environmental externalities including those that result from their high energy demand, and the production of solids which require further treatment and disposal or reuse.

With the SA to provide the motivation for a new approach to sanitation, *DFS is the first tool to facilitate an iterative process for transitioning to more sustainable, reuse-oriented sanitation schemes.* DFS is a five-step approach to devising sanitation schemes that maximize the extent to which resources embodied in wastewater are utilized for the most locally appropriate "services" (e.g., irrigation, industrial reuse, toilet-flushing, cement manufacturing) (Fig. 1). DFS defines wastewater as a resource, and choices about its reuse inform the infrastructure design. Once the intended reuse is chosen, DFS uses lifecycle analysis (LCA) to quantify trade-offs among relevant treatment technology options.

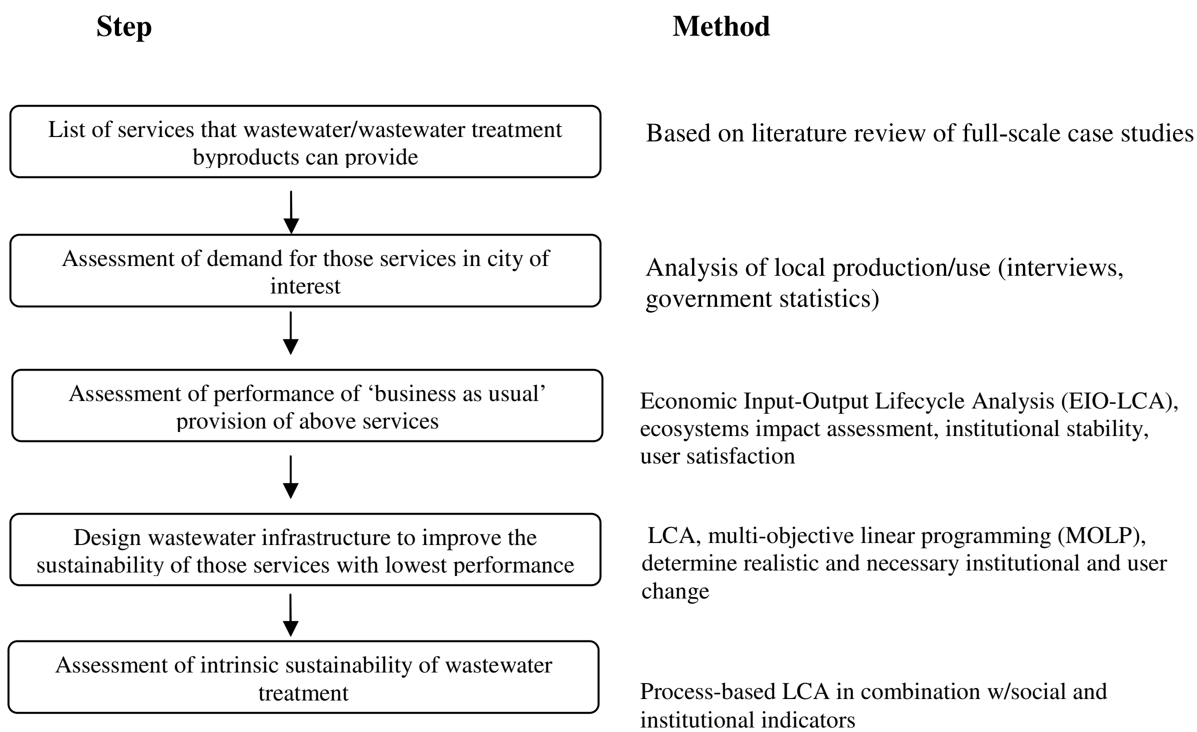

Figure 1. Schematic of Design for Service (DFS) sewage treatment planning framework and corresponding methods.

We seek additional financial support to: 1. Fully develop the methods for both assessing the local demand for different "services," (e.g., irrigation,) and for measuring the performance of their business-as-usual provision (DFS Steps 2 and 3); 2. Compile a database of LCAs for sewage and wastewater treatment technologies that could emerge as options after applying DFS (DFS Step 5); 3. Develop a computer interface for depicting the results of the DFS recommendations; 4. Pilot DFS in two new cities, one in China (in addition to Chengdu where Ashley Murray (PI) is currently working) and one in Africa. See Section 4 for a complete description of the outcomes and goals of this component of the project.

4. Project Approach

Research and development of the SA and DFS planning approach will occur on the UC Berkeley campus, and field testing will take place in China and Senegal. Our approach will be to simultaneously scale-up our current work in China, and to pilot our toolkit in Africa, likely Senegal, as "proof of concept" of the global applicability of our sanitation evaluation and planning tools in unserved urban areas.

China Module

China is arguably the country with the single largest potential market for our urban sanitation planner's toolkit. By 2004 the urban population had reached 540 million people dispersed among 667 cities, and demographers predict that it will increase to 900 million by 2020 [8]. Due to severe environmental deterioration in urban and peri-urban areas, the Chinese government has stipulated that by 2010 at least 50%-70% (depending on city status) of wastewater generated in urban areas be treated.

China's ambitious goals for expanding urban wastewater treatment demand an approach that is cost-effective. Furthermore, with a per capita water availability that ranks 121st out of 153 countries in the world, strategic water management and reuse is essential to China's sustainable future. Alas, most of wastewater treatment facilities built in China to date embody the design-for-disposal mentality, and utilize highly cost- and energy-intensive technologies. Many of the treatment plants built within the last five years are already out of commission because they are too expensive to operate. Time is of the essence to influence a shift in China's fundamental approach to designing and implementing wastewater treatment infrastructure.

We will leverage Ashley's existing network of contacts in the cities of Chengdu and Beijing, as well as our collaboration with the Urban Age Institute, to identify three additional cities in China to apply our SA. Our objective is to pilot the SA in cities that represent four archetypical wastewater treatment scenarios that exist in the country (Table 2). Applying the SA to a total of four cities in China (including Chengdu where Ashley is conducting her dissertation work) will allow us to fulfill the four objectives related to the SA outlined in Section 3. It will enable us to test the sensitivity of the SA to similar technologies operating in different contexts (i.e., differing water stress levels and economic conditions,) and it will also allow us to compare the sustainability of different technologies (i.e., conventional and natural treatment systems) operating in similar economic and environmental conditions.

The results from individual applications of the SA should prove very useful to local authorities in each of the Chinese cities. The outcomes will highlight previously unobserved linkages between the wastewater treatment scheme and the local environment and economy, revealing options for retrofitting existing infrastructure to improve its sustainability. The results will also help to inform future expansion of wastewater treatment in the immediate region. The process of applying the SA in four distinct Chinese contexts will shed light on the trade-offs between the information gained, and the effort that goes into, evaluating each burden-to-benefit ratio. Together, the results of four applications of the SA in China will expose much information about the sustainability and optimality of wastewater handling in China. Through our existing contacts and our partnership with the Urban Age Institute, we will ensure that the results of the SAs are conveyed to national-level authorities who influence wastewater policy in China. Our goal is to effect greater national-level emphasis on: reuse of wastewater and embodied resources (i.e., biogas production and capture, nutrient utilization, productive sludge end use,); the use of lower cost technologies for sewage and sanitation; and integrating sanitation planning into the broader urban context.

Table 2. Description of four archetypical settlements and wastewater management schemes in China that we will seek for piloting our Sustainability Assessment.

Settlement Archetype	**Treatment Scheme**
Middle-income, densely populated, semi-water stressed (Chengdu)	Conventional (Primary Sedimentation, Activated Sludge, Cl/UV disinfection), "design-for-disposal"
Middle/High-income, densely populated, severely water stressed (e.g., Tianjin)	Conventional (Primary Sedimentation, Activated Sludge, Cl/UV disinfection)
Low/Middle-income, peri-urban, semi-water stressed (e.g., peri-urban settlements around Guiyang in Guizhou Province)	Primary sedimentation, Sequencing Batch Reactor (SBR, modified activated sludge for lower flows)
Peri-urban, semi/severely water stressed	Natural treatment systems (constructed wetlands and/or waste stabilization ponds)

We anticipate that one of our three new partner cities in China will emerge as being interested in having DFS applied in an unserved area within their municipality. Thus in Year 2, we will continue to work closely with one of these municipalities, and will apply the fully developed DFS protocol to generate a set of recommendations for their wastewater infrastructure and management. Again, using our existing government relationships and collaboration with the Urban Age Institute, we will seek to make the application of DFS in our partner city a nationally recognized pilot and demonstration project. The official designation as a demonstration project is a very meaningful one in China; if the project is successful, it would position DFS as an influential model for future sanitation infrastructure design and implementation throughout the country.

Africa Module

Behind Eastern and Southern Asia, Sub-Saharan Africa has the largest urban population without access to improved sanitation. While many Asian countries are making progress towards improving access, the trends in Sub-Saharan Africa are less optimistic. Between 1990 and 2004, the absolute number of people in Sub-Saharan Africa without access to sanitation increased from 335 to 440 million people [9]. Because most countries in this region of the world operate with highly constrained water and economic budgets, cost-effective and strategic wastewater and sewage management is critical to the long-term sustainability of sanitation projects and to environmental health.

While we are exploring several options, and will ultimately choose to work in a city with the greatest local interest in collaboration, Senegal appears to be a promising option. Like most of its neighbors, it is plagued with water shortage which is exacerbated by seasonal precipitation and severe surface water pollution from wastewater discharges and agricultural run-off [10]. Our SA and DFS planning approach can deliver the locally tailored sanitation scheme that is necessary to operate sustainably in these conditions. Importantly, the government already has a vested interest in improving access to sanitation as is evidenced by the Water and Sanitation Program for the Millennium, a framework for unified intervention launched by the government in 2005 [11]. In addition, there exists a strong NGO, academic institution, and multilateral agency presence that will provide the institutional support and capacity necessary for making this pilot a success.

We are currently in the process of contacting potential collaborators in Dakar, and Ashley will spend three weeks there in June 2008 meeting potential partners in person. We intend to begin fieldwork in our African partner city in June 2009; by this time, DFS will be fully developed, and we will have acquired experience in China that will improve the quality and efficiency of our work in Africa. Ultimately, our initial work in Africa will seed the scale-up of applying our SA and DFS sanitation planning approach in other parts of Sub-Saharan Africa where the need for tools that improve capacity to plan and implement sustainable sewage handling schemes cannot be overstated.

5. Specific Funding Needs

Financial support for this research will be used to support graduate student researchers (1 year, $35,000/student,) as well as local staff in our partner cities with a salary that is commensurate with local wages. With additional support for three graduate students over two years, and salary for the equivalent of three local staff, we are confident we can achieve the research goals outlined in this proposal. In additional to financial support, we also seek local partners who can assist with accessing relevant stakeholders and data, and help facilitate local implementation. We are happy to discuss producing specific research reports and/or tailoring our research to the interests of potential funders if it is within the scope of the research outlined above, in exchange for financial support.

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