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Designing Reuse-Oriented Sanitation Infrastructure: The Design for Service Planning Approach

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> *In any field of human endeavour, policy-makers and practitioners are accustomed by training and experience to thinking within familiar sets of parameters, and while aware of the shortcomings associated with these parameters, find it difficult to step outside them. In principle, radical new thinking is always desired but is rarely produced. When produced, it often meets with resistance even from those who sought it simply because it steps outside those parameters – 'outside the box' – of preset assumptions, experience and capacity.* (SANDEC, 2000, p2)

Abstract

The reuse or utilization of wastewater, faecal sludge and its embodied resources is widely acknowledged in the field of sanitation as a key component of complete sanitation. Reuse, for agriculture and other applications, is conventionally considered a means of mitigating water shortage or abating water pollution. We contend that reuse-oriented sanitation can also be leveraged to improve the long-term efficacy of a treatment scheme by providing tangible and quantifiable incentives for sound operation and maintenance that exceed those associated with running a disposal facility. The standards that need to be met for agricultural reuse

are different from those required for discharge to the aquatic environment. This difference requires a change in the design philosophy and can lead to cost savings in the type of treatment process, the energy demand and the skills needed for operation. So, rather than a more complex system, wastewater treatment designed for agricultural reuse can result in a more appropriate plant for developing countries striving to enhance access to improved sanitation.

To facilitate a culture of designing site-specific and reuse-oriented systems from the outset of the planning process, this chapter introduces a five-step planning tool, Design for Service (DFS). DFS defines wastewater as a resource and choices about its reuse inform the infrastructure design including site and technology selection, and plant scale. We highlight reuse schemes at various stages of implementation in South Africa to exemplify difficulties faced in the absence of accessible planning frameworks. To demonstrate how DFS can be used for rehabilitating schemes that have fallen into disrepair and for the design of new reuse-oriented sanitation systems, we describe projects that are currently underway in Ghana and China, respectively.

INTRODUCTION

The productive use of wastewater, faecal sludge and its embodied resources is increasingly considered integral to comprehensive sanitation, the primary goals of which are to protect public health and the environment (IWA Sanitation 21 Task Force, 2007; UN Millennium Project, 2005). In many regions of the world, reuse is driven by scarcity, where a shortage of water and landfill space incites non-disposal end-use options. In other cases, reuse or capture of embodied resources is practised more for environmental reasons. For example, sludge may be applied to farmland to replace or complement the use of chemical fertilizers, or anaerobic digestion and capture of biogas may be employed to reduce demand for non-renewable energy sources at a treatment plant. While these aforementioned drivers of reuse are not only rational but valid, in our view, reuse should not only be conceived as an option that comes on the heels of wastewater treatment, but as a means of achieving the primary goals of comprehensive sanitation.

Conventional approaches to sanitation and waste disposal see wastewater and faecal sludge as environmental and public-health problems; thus, management solutions comprise costly means of preparing them for unproductive disposal – a fate that will occur regardless of what, if any, treatment they receive. It is no wonder that resource-constrained governments seldom rank sanitation high on their agendas (Stockholm International Water Institute et al., 2008). However, as Jiménez et al. have clearly articulated in Chapter 8, the consequences of inadequate sanitation are dire. In the face of the daunting task of improving global access to improved sanitation, particularly with the legacy and ongoing record of failed waste-disposal schemes, reuse has potential to be leveraged to stimulate robust sanitation solutions that reliably protect public health and the environment.

A reuse-oriented approach effectively shifts the goal of sanitation from being solely the safe disposal of waste to maximizing the extent to which embodied resources are safely captured and allocated. Recognizing wastewater and faecal sludge as resources is the first step towards reuse-oriented sanitation, but implementing this philosophy remains a challenge, as most engineers and planners have been trained to 'design for disposal'. That is, they are trained to design schemes that convey sewage to a centralized treatment plant – often as far from human settlements as land availability permits – where it undergoes mechanical, biological and sometimes chemical purification before discharge to an ocean outfall or surface water. To the extent that reuse is incorporated into a treatment scheme, it is often an afterthought in the planning process. While there are examples of planned reuse occurring around the world, designing for reuse at the outset of a waste-management planning process is often seen as a burden and unnecessary complication from both technical and institutional perspectives (Bahri, 1999; Jenkins and Sugden, 2006; Lazarova et al., 2001). When reuse projects fail it is often because they were conceived without due consideration of the local institutions, market demand and supply chains necessary for them to thrive; planning for reuse from the outset can make the system more sustainable.

Another drawback of conventional waste-disposal schemes is that they represent an enormous financial and skills burden, hence the absence or failure of adequate sanitation in many developing cities (UN Millennium Project, 2005). In addition, popular technologies such as activated sludge have large environmental externalities associated with the energy used to treat the wastewater and with the solids produced, which themselves must then be treated and disposed of. When designing a treatment scheme for reuse in agriculture, on the other hand, it becomes desirable to maintain the embodied nutrients in the water, a factor that can significantly reduce the capital and operational costs of a treatment system in comparison to those required for direct discharge to the aquatic environment.

This chapter takes the position that treatment schemes designed for reuse are more environmentally and economically sustainable as a result of resource recovery. Reuse-oriented waste-management systems are able to deliver the public and environmental health benefits associated with adequate sanitation, while also contributing productively to the local economy and livelihoods. To that end, the chapter endeavours to equip the reader (i.e. engineer, planner, local stakeholder) with a systematic means of implementing sanitation schemes that utilize the resources embodied in waste in ways that are optimized for the local context.

Design for Service is a five-step planning approach for rehabilitating or designing new schemes for reuse, which is intended to facilitate a shift from the design-for-disposal to design-for-reuse paradigm. We utilize case studies from South Africa to show the types of complications faced by projects that retrospectively incorporate reuse and to argue that these difficulties are exacerbated by the lack of planning tools for reuse-oriented sanitation design. We contend that DFS can be used to foster a coherent and deliberate decision-making process, and demonstrate through cases in Ghana and China how one can apply the tool in the context of rehabilitating existing wastewater treatment plants (WWTPs) and designing new ones.

CHALLENGES ENCOUNTERED IN REUSE-ORIENTED SANITATION PLANNING

We use three examples of initiatives to implement reuse-oriented sanitation schemes in the eThekwini Municipality, South Africa, to demonstrate the challenges associated with designing for retrospective reuse in the absence of systematic planning approaches. Like many regions of the developing world where population growth has outpaced deliberate planning processes, eThekwini finds itself with a diverse array of sanitation systems to manage. To be certain, the eThekwini Municipality has a very progressive approach to sanitation both in terms of the technologies that the authorities have implemented (e.g. urine-diverting toilets) and their pursuit of productive end uses for locally produced faecal sludge. Thus, we consider projects that have achieved varying degrees of success to show that even where local decision-makers are motivated to implement reuse-oriented sanitation, practitioners are not equipped with the planning tools to help ensure successful project outcomes.

The first case concerns the emptying of 60,000 ventilated improved pit latrines (VIPs) and the efforts underway to identify an effective means of disposing of or utilizing the faecal sludge. The pits must be emptied every five years and the costs of doing so can be very high, an economic burden that is borne by the municipality (Bhagwan et al., 2008; Gounden et al., 2006). Action-based research best characterizes the municipality's approach to adequate disposal or utilization. In more sparsely populated areas, authorities have arrived at a policy of burying the pit contents on site. However, in dense settlements there is insufficient land for burial and the sludge must be moved off site. Upon determining that discharge into the sewer networks (when available in the vicinity) was too disruptive to the wastewater treatment plants, the municipality has gone on to experiment with several other disposal routes, including trials using chemical or bio-additives to enhance the degradation of the pit contents, mixing with lime and limited discharge in a domestic landfill (Couderc et al., 2008; Foxon et al., 2009). The most feasible method to date appears to be deep trenching with trees being planted in the trenches. Trials are currently in progress to assess the risk of groundwater pollution, the ability of different types of trees and plants to harvest nutrients from the VIP sludge, plant growth rates and pathogen die-off rates (including that of *Ascaris*). The whole pit emptying and disposal process has been designed to create jobs, employing teams from within the served communities, and most of the cost to the municipality for the emptying of the pits is recycled within the user community.

On the one hand, it is encouraging that local authorities are invested in finding a sound alternative to the indiscriminate disposal of the VIP contents. On the other hand, a systematic planning procedure for designing locally tailored reuse schemes would improve the coherence of the design process; it would also provide a protocol for including a broader set of local stakeholders in this process. Currently, decisions about faecal sludge end use in eThekwini are made independently of the region's larger planning agenda and vice versa. For example, there is a parallel city-wide initiative underway to promote woodlots on vacant land to provide livelihoods for local people. Some of the intended uses of the trees include paper-making, fuel, input into medicinal and natural products, and orchards. Ideally, these woodlots would be co-designed for faecal sludge land application and the ultimate end-users of the faecal sludge would be involved in those decisions as primary woodlot stakeholders. However, there is a lack of precedent for such integrated planning and only after the woodlots have been implemented and proven successful without faecal sludge will the possibility of applying the faecal sludge to these trees be explored.

The second case study involves wastewater from a sewered area in Mnini, a district of the eThekwini Municipality, which was treated in a pond system prior to discharge to the Ngane River. The degree of treatment was insufficient, resulting in the degradation of the natural ecology with negative impacts on the river's users. In 2002, two proposals were considered, including one to use the outflow from the ponds for irrigation. By January 2003, an irrigation system was designed by a consultant and was installed. A total of 10,000 banana plants were purchased and 75 per cent had been planted by 2005 on 2ha of land. Mango plantations are planned for over 2ha and two plots (0.6ha in total but extendable to 2ha) have been prepared for vegetables and cash crops. Despite the technical viability of this reuse project, the system has never been commissioned due to institutional barriers. For example, the irrigation system had been installed prior to obtaining permission from all the role-players and stakeholders. The drivers of the reuse project did not get permission from the local traditional leader to use the land; they did not get permission from local households to install an irrigation system and utilize the land for agriculture; they did not get permission from the Department of Agriculture to break virgin ground; and they did not secure the necessary permits from the Department of Trade and Industry or the Department of Water Affairs and Forestry.

Though well intentioned, the ad hoc and top-down procedure of designing and implementing the Mnini reuse scheme is arguably responsible for its failure. Mnini is another testament to the need for a systematic planning approach that guides practitioners through a process of asking the appropriate questions and engaging the appropriate stakeholders – both institutional and individual – to avert failed outcomes. Beyond being technically feasible, a reuse scheme must also be socially, economically and institutionally robust if it is to be sustained, not to mention if it is to incentivize appropriate operation and maintenance of the sanitation scheme itself. The complexity and delays that these additional dimensions add to the planning process is enough to deter most practitioners from designing for reuse at the outset of a sanitation project. Our third case study is an example of exactly this tendency.

Because of the cost and difficulties associated with the servicing of the VIPs already described, the eThekwini Municipality has opted to install dual vault urine-diverting (UD) toilets in the rural areas where there is at least 250m^2 of empty land available for sole use by the householder. The introduction of this sanitation option to the previously unserved includes the provision of a free toilet, free water supply (9kl/household/month) and hygiene education; the householder is responsible for the maintenance of the system (Gounden et al., 2006). Currently, the reuse of the faecal solids and urine is not officially encouraged (Mnkeni and Austin, 2009). It was thought that the introduction of urine diversion is sufficiently different from normal practice that simultaneously incorporating reuse of the urine and solids would distract too much from the goals of improving sanitation and preventing open defecation. It was also considered by the municipality that this sanitation system would be more sustainable than any of the other choices (Flores et al., 2009).

One problem that has emerged since dissemination began is a social stigma attached to the use of UD toilets at the interface of a sewered area and a UD-toilet-serviced area. From the perspective of the rural householders, their UD toilets serve the same single purpose as the waterborne toilets connected to the sewer network: containment of human waste. However, UD toilets are almost unilaterally perceived by users as less modern and of lower status than the waterborne equivalent. The social reluctance to accept UD toilets could have been eased had profitable and productive reuse been incorporated into the project from the start. Let us work through a thought exercise.

What if instead of disseminating UD toilets in the name of sanitation, the effort was alternatively promoted to create new earning opportunities for rural households? With this conceptualization, improved sanitation would be an outcome of the project but not the ultimate goal, and UD toilets would be a means for households to profitably exploit the resource value of human waste. Introducing the UD toilets as new and improved sanitation inevitably sets the technology up for comparison to every other sanitation technology in the vicinity – leading, often, to the negative perceptions described above. Conversely, if economic incentives were used as the centrepiece of the project (e.g. a scheme could be implemented that enables households to sell urine concentrate for phosphate recovery), UD toilets may not be perceived by households as inferior, but as completely different systems with different purposes. The importance of harnessing the economic and agricultural benefits of reuse-oriented sanitation on a large scale has recently gained attention as a key element of simultaneously improving food security and access to adequate sanitation (Bonzi, 2008; World Agroforestry Centre, 2008). Again, taking an end-use and profit-oriented approach to what is traditionally the overt goal of improving hygiene and sanitation requires a shift in the mindset and planning strategies of practitioners. The concept must also be effectively and convincingly communicated to end-users and institutional stakeholders.

The eThekwini Municipality is a leading innovator of sustainable sanitation. Their aggressive search for solutions is a necessary response to the health and environmental problems that have emerged from the vast number of unserved communities. However, from the cases discussed here, we have identified three key issues that an effective planning tool could and must address in order to promote a culture of reuse-oriented sanitation in other regions of the world, and to ease the implementation of reuse in regions where it is already on the agenda. A useful planning framework will:

- foster a process for systematically considering and eliminating an exhaustive list of reuse options as rapidly and efficiently as possible as a coordinated effort among all agencies potentially involved in the reuse project;
- foster an inclusive planning process where outcomes are tailored to the end-users of the waste and treatment by-products, and acceptable to all other stakeholders;
- be accessible to practitioners and quell reluctance to incorporate reuse at the outset of a sanitation project.

THE DFS FRAMEWORK

In light of the illustrative case examples just presented, we introduce DFS to facilitate a coherent and deliberate decision-making process that fosters a culture of designing locally optimized reuse-oriented sanitation systems. DFS is an iterative framework (see Figure 15.1) that consists of the following five steps:

1 Generation of a list of all of the potential ‘services’ (e.g. irrigation, fertilizer, energy-generation) that wastewater, faecal sludge and treatment by-products can provide.
2 Assessment of the demand for those services in and around the city of interest.
3 Assessment of the business-as-usual performance of the provision of those services according to economic, social and environmental indicators.
4 Design of sanitation infrastructure for the provision of that service where it can have the greatest marginal impact.
5 Assessment of the intrinsic environmental and cost characteristics of the technology options available for rendering the wastewater/faecal sludge/treatment by-products suitable for the service of choice.

The last two steps include a life-cycle analysis (LCA) to quantify possible trade-offs among treatment options.

A unique feature of DFS is its grounding in the user-centred design philosophy (Norman, 1990), where sewage and sludge are conceptualized as a product and attention to the needs and limitations of its end-user(s) drives the design of the handling scheme. If reuse is to incentivize and motivate robust sanitation, wastewater and faecal sludge handling schemes must respond to local market demand for the embodied resources, and be sensitive to social norms surrounding their use.

The intended reuses of sewage and its embodied resources inform technology selection, site selection and scale, such that the scheme is tailored to the needs of the end-user while also meeting the needs of households and other stakeholders. To that end, DFS contains many of the characteristics that the sanitation community has deemed critical for a useful sanitation planning tool: it is technology-neutral, it fosters inclusion of multiple stakeholders in the city (e.g. households, entrepreneurs, government officials) and it is demand-driven (IWA, 2008; IWA Sanitation 21 Task Force, 2007; SuSanA, 2008).

APPLICATION OF DFS FOR REHABILITATION OF SANITATION SCHEMES: GHANA CASE STUDY

Though it is ideal to design treatment plants for reuse at the outset of the planning process, DFS can be used for retrofitting existing plants for reuse and for rehabilitating facilities that have fallen into disrepair. One drawback of retrofitting an

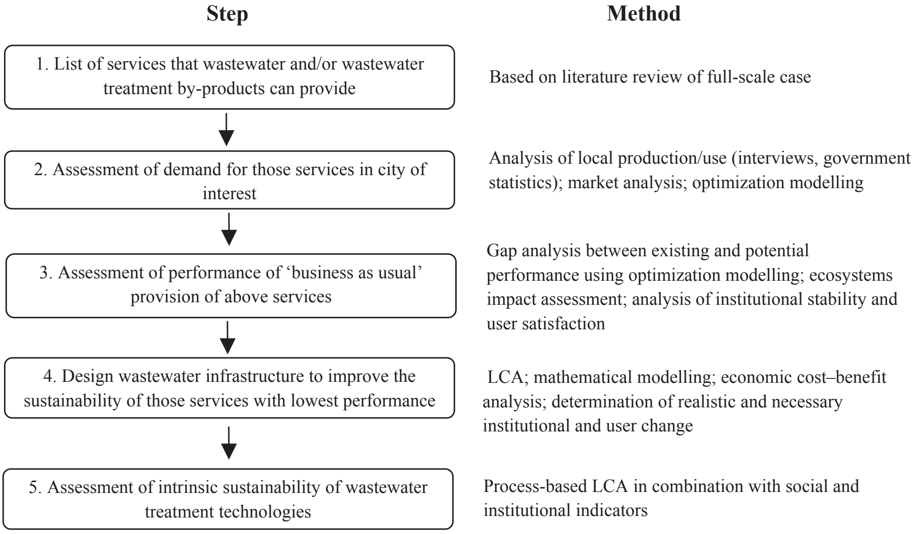

Figure 15.1 *Schematic of Design for Service (DFS) sewage treatment planning framework and corresponding methods*

existing facility is that it may be harder to find a productive end use for all of the effluent or treatment by-products – even with storage – due to circumstances of the plant's location and scale. Applying the DFS approach will help reveal reuse opportunities that take maximum advantage of the waste and the remainder will have to be adequately treated to meet the local requirements for environmental discharge.

Ghana is one location where we believe using DFS to rehabilitate treatment plants has great potential for improving the country's sanitation outlook. In fact, Ghana is not unique; the features that characterize the sanitation sector are similar for many cities of the developing world as highlighted above for the cases in South Africa. Many of the existing sanitation facilities in Ghana are in disrepair and only 10 per cent of the approximately 70 wastewater and faecal sludge treatment plants function as planned (Murray and Drechsel, 2009). Much of the failure can be traced back to limited institutional and financial capacity, but we argue that insufficient support for operation and maintenance persist due to the lack of easy-to-quantify and tangible benefits associated with treatment.

We are using the DFS approach to evaluate the market potential of wastewater, faecal sludge and treatment by-products, and to design sanitation schemes that foster linkages with the private sector and/or other beneficiary groups. The market demand for effluent and by-products, which can be harnessed via payment or in-kind exchange (see Box 15.1), should provide incentives for robust operation and maintenance of waste treatment and handling systems that far exceed the incentives associated with running a facility that is dedicated strictly to disposal.

BOX 15.1 DFS APPLICATION FOR REHABILITATING THE FAILED WASTEWATER TREATMENT PLANT AT PRESBYTERIAN BOYS SENIOR SECONDARY SCHOOL, ACCRA, GHANA

Background: the treatment plant at the Presbyterian Boys Senior Secondary School (Presec) was built in 1976 and serves a population of approximately 2000 students and faculty members who live at the school. The flow is approximately 100m^3/day.

What are the services that wastewater and treatment by-products can provide?

The services that have the most practical application in Ghana include:

- biogas generation for cooking fuel;
- effluent for urban irrigation (and to offset commercial fertilizer);
- land application of treated (e.g. digested, dried or composted) sludge as a fertilizer and soil conditioner in urban agriculture;
- use of sludge as an alternative fuel in industrial processes

What is the local demand for the services that wastewater and sludge can provide?

Since the treatment plant already exists on the Presec campus, the geographic scope of our demand assessment is necessarily narrowed to the close proximity of the facility. Based on a site visit and conversations with the school's headmaster, we estimate that there are 8ha of cultivated land on the school property and adjacent to the treatment plant. To calculate the irrigation demand of this parcel under profit-maximizing conditions, we built a quadratic optimization model using water demand estimates from the FAO's CROPWAT programme, which are tailored to the local climate and soil conditions (Water Resources Development and Management Unit, 1992). According to the results of the model, the annual water requirement to maximize profit is approximately 31,000m^3.

In addition to assessing the irrigation capacity of the surrounding land as a proxy for demand, it is also critical to assess the social and economic demand for the service, as this will reveal the extent to which designing the plant for irrigation can incentivize effective operation and maintenance of the treatment plant. With respect to existing financing, the plant is owned and operated by Presec and serves strictly the school's population; no user fees are collected. The farmer who cultivates the land is the head of the agriculture department at Presec and he expressed a strong desire for access to water for irrigation, noting that his yields were severely crippled without it. He remarked that he would have several potential customers for his surplus crops and believed that the access to irrigation would also support current efforts to engage students in farming. The revenues from surplus crop sales could potentially be put towards the operation and maintenance of the treatment plant.

What is the status of irrigation on this parcel?

While the land is currently cultivated, it is entirely rain-fed because the farmer has no access to water for irrigation. According to our model, gross profit (i.e. excluding any additional labour costs or other inputs) could increase by up to 130 per cent if the full demand for irrigation water was met.

How can we redesign the existing treatment plant to optimally irrigate the adjacent farmland?

Since effluent flows at a fairly steady rate year-round and irrigation requirements will fluctuate, storage reservoirs will need to be built. According to the results of our optimization model, which is built for ease of use by sanitation planners, the maximum accumulation of effluent should be approximately 16,000m^3 per year; a more in-depth analysis of the daily wastewater flow and its temporal fluctuations, as well as discussion with the farmer regarding his intended cropping patterns, will also be used to inform the storage needs.

The layout and size of the storage reservoir(s) will depend on the land topography and availability, the needs of the cultivators and the crops that will be irrigated in light of meeting WHO water-quality standards. For ease of irrigation, it may make most sense to have several reservoirs connected by small overflow pipes scattered throughout the farmland. Crops planted around the last reservoir in the series could be those that require higher effluent quality standards (e.g. crops eaten raw) because that water would have the longest retention time (and thus pathogen reduction), while crops planted around the reservoirs at the beginning of the series (i.e. with a high pathogen concentration) could be ones with less stringent standards (e.g. wheat and maize, that are not eaten raw).

What are the trade-offs among different technology options for rendering the effluent safe for irrigation?

According to the plant's design, wastewater at Presec should flow through a primary settling tank after which the flow should split between two trains in parallel, each consisting of an aeration tank and a final settling tank. The flow should then converge for chlorination prior to discharge to a small stream and underground pipe. Sludge should be discharged to two sludge drying beds. Although wastewater is currently flowing through the facility, the plant has little to no operational capacity. One train is not in use and the remaining aeration tank has gone anaerobic since the aerators were stolen. The water is not being chlorinated and the sludge must be manually removed from the tanks. For our initial analysis, we have narrowed our consideration of different treatment technologies to those that could be incorporated into the existing infrastructure scheme.

To improve the economic and environmental sustainability of the system, re-implementing aerobic treatment is not indicated because of its high operational cost and indirect greenhouse gas emissions. As a rule, tanks that are designed to be aerobic are too small to be converted to anaerobic tanks that achieve the same treatment performance. It will be necessary to monitor the daily flow and influent quality to determine how much larger the tanks must be to effectively operate anaerobically, if at all. Chlorination is also undesirable for effluent used in agriculture; however, adequate pathogen removal is critical. Pathogen removal will be achieved with the installation of a maturation pond, on-farm holding reservoirs and/or a low-cost ultraviolet disinfection system; the logistical and economic trade-offs between these options will inform the final decision.

APPLICATION OF DFS FOR DESIGN OF NEW SANITATION SCHEMES: CHINA CASE STUDY

The full potential of DFS is best realized when it is applied to guide the planning and design process of a new treatment plant. Experiences from a number of reuse projects show that outcomes are far superior when collection, treatment and reuse are integrated into a single planning process (Lazarova et al., 2001). Where DFS is applied at the outset, a treatment plant's precise location and scale (i.e. the decision to build one centralized plant or several smaller plants) can be optimized for the intended end uses of the effluent and treatment by-products. Although designing for reuse adds additional variables to the conventional design for the disposal planning approach, and these are likely to require more time and resources to address, DFS is intended to help stakeholders navigate the more complicated planning and design process. We believe that the long-term benefits of a reuse-oriented design will far outweigh the upfront costs. Box 15.2 provides an example of an application of DFS in China to design an irrigation-oriented wastewater treatment scheme for the peri-urban district of Pixian. Local planners and decision-makers could similarly use the tool and results to tailor their wastewater treatment schemes to suit social, environmental and economic priorities.

BOX 15.2 DFS APPLICATION FOR DESIGNING A REUSE-ORIENTED WASTEWATER TREATMENT SCHEME FOR AN UNSERVED REGION OF THE PERI-URBAN DISTRICT, PIXIAN, CHENGDU, CHINA

Background: the peri-urban district of Pixian, with a population of almost 500,000, is located in the Chengdu municipality, Sichuan Province, China. Pixian is in an environmentally sensitive location, sandwiched between the urban core of Chengdu to the southeast and Dujiangyan to the northwest, which is the source of the municipality's water; thus, 80 per cent of Chengdu's water passes through Pixian. Of the approximately 25,000m^3/d urban wastewater generated, about 30 per cent is treated and the remainder is discharged to surface waters. Expanding wastewater treatment is a local priority, though one that is hindered by limited financial resources.

What are the services that wastewater and treatment by-products can provide in and around Chengdu?

The services that have the most practical application in Chengdu include:

- biogas generation for cooking fuel or conversion to electricity at larger-scale plants;
- wastewater effluent for peri-urban irrigation (and to offset commercial fertilizer), urban landscape, toilet-flushing and industrial cooling;
- land application of treated (e.g. digested, dried or composted) sludge as a fertilizer and soil conditioner in urban agriculture;
- use of sludge as an alternative fuel in industrial processes, particularly cement manufacturing where the non-combustible material is incorporated into the clinker.

What is the local demand for the services that wastewater and sludge can provide?

Urban settlements are growing rapidly in Pixian, yet the population is still 75 per cent rural and more than half of the residents depend on farming for their livelihoods. There are 21,000ha of irrigated farmland in Pixian and cultivated crops include a variety of grains, vegetables, fruits, ornamental flowers and herbs used in traditional Chinese medicine. Reuse of treated effluent for local agriculture is a logical means of managing urban nutrients and bridging urban and rural settlements for mutually beneficial ends.

With respect to the productive end use of sludge, two options appear promising based on local market demands: end use as a fertilizer or end use as an alternative fuel in cement manufacturing. According to government statistics, farmers in the district apply approximately 900 tons of nitrogen (as N) and 300 tons of phosphorus (as P) as fertilizer each year. The nutrient content of sludge generated by WWTPs in the region averages 30kg of nitrogen and 10kg of phosphorus per dry ton, thus local demand for fertilizer is not a limiting factor. Alternatively, the sludge could be delivered to the Lafarge cement plant in Dujiangyan, which has the capacity and willingness to accept up to 140 wet tons (at 20 per cent dry solids) of sludge and a substantially larger volume of dry sludge (≥90 per cent dry solids) per day for use in their cement kilns. Based on the sludge-generation rates for existing WWTPs in Chengdu, Lafarge could accommodate a WWTP with a daily capacity of about 200,000m^3.

What is the business-as-usual performance of irrigation in Pixian?

A performance assessment was developed to evaluate irrigation based on economic indicators, spatial equity, farmer satisfaction and the extent to which the irrigation scheme serves or hinders regional water-management goals and objectives. We built a quadratic simulation and optimization model, similar to that for Ghana, to measure agricultural profitability and equity; surveyed farmers throughout the district to assess their perceptions of the quantity and quality of their irrigation water; and conducted policy analysis and key informant interviews to understand regional water-management goals and objectives. Based on the results of the model, a location effect is evident, where farmers at the tail of the canal have lower yields per area of cropland than those at the head because of more limited access to water. There is up to an 18 per cent lower maximum profit between the head and tail of the irrigation systems. Supporting this finding, insufficient water quantity was reported by over 70 per cent of the surveyed farmers for the months between November and March. Colour, foul smell and turbidity were reported as problems by a large percentage of survey respondents across all irrigation systems: 58 per cent reported mild to severe colour (n = 39), 45 per cent reported mild to severe odour (n = 38) and 68 per cent reported mild to severe turbidity (n = 39). Farmers' dissatisfaction with irrigation water quality should enhance the appeal of using treated effluent for irrigation.

Despite farmers attesting to inadequate water quantity, it was determined that the existing irrigation scheme puts a heavy burden on surface-water ecosystems due to its water intensity. One priority of the Chengdu government is to improve surface-water quality in Chengdu from Class V to Class III on the Chinese water quality scale by 2010, and modelling done by a third party consulting firm has shown that this will require increasing the flow of water in the rivers (Beijing Ecosimulation Technology Company, 2004).

How can we design wastewater treatment in Pixian to optimally contribute to irrigation and also contribute to a broader set of local priorities?

The model was used to conduct a comparative analysis between yields under the existing irrigation scheme and those that could be expected by either supplementing or replacing the current irrigation-water supply with treated wastewater. The designs of the alternative scenarios were informed by the volume of wastewater generated by urban settlements in the immediate vicinity. According to the results of the analyses, there are opportunities to use effluent to improve the equity of irrigation; effluent could be released into the lower reaches of an irrigation system to increase the volume of water available to those farmers. Alternatively, effluent could be used to replace surface-water diversion as a source of irrigation.

For each scenario, we quantified the impact on farmer profits compared to the base case; characterized likely changes in cropping patterns under profit-maximizing conditions; and, where effluent was used to replace existing irrigation, we quantified the volume of surface water that could be conserved. Wastewater generated in towns along the irrigation canals could be used to offset upwards of 50 per cent of the current surface-water diversion for an individual canal, at a loss ranging from 1–10 per cent in farmer profits. Alternatively, wastewater could be used to supplement the irrigation water in this system in order to halve the location effect between farmers at the head and tail of the canal, and to increase profits earned by downstream farmers by nearly 20 per cent. The results of these simulations reveal several attractive options for local decision-makers, whether their priority is improving the economic well-being of farmers or mitigating the burden of water diversion on aquatic ecosystems.

What are the trade-offs among different technology options for rendering the effluent safe for irrigation?

Medium- to large-scale wastewater treatment plants that use activated sludge are becoming the norm in China; in the Chengdu municipality there are more than 20 such treatment plants. With respect to sludge treatment, one plant is equipped with anaerobic sludge digesters and the biogas is flared; the remaining facilities dewater the sludge before disposal at a landfill site. Life-cycle analysis was used to present the environmental and economic costs and benefits of an array of technology options, including conventional and natural systems. For conventional systems treating wastewater for irrigation, designing schemes to minimize nutrient removal can lower the capital and operating cost of a system that is designed for disposal. Furthermore, adding anaerobic sludge-digestion to a conventional process and capturing the biogas for on-site use can lead to substantial long-term cost savings and reductions in emissions. We calculated the payback time for a boiler to convert biogas to electricity at an existing plant in Chengdu to be less than one year. Waste stabilization ponds are an attractive option from an economic and environmental prospective but in urbanizing areas the land requirement can be prohibitive.

CONCLUSIONS

This chapter has argued that reuse-oriented sanitation can provide greater environmental and economic benefits than conventional, disposal-oriented wastewater/faecal sludge management. However, effectively planning and implementing such systems is often difficult given local-level expertise, norms and institutional constraints. In particular, the three cases from South Africa demonstrated that in spite of the urgency to solve some of these problems first, a reuse approach was adopted. This was made even more difficult due to a lack of systematic design processes for implementing wastewater/faecal sludge management schemes that incorporate reuse for agriculture. Properly managed, however, such schemes can provide both employment and revenues associated with the productive use of the treated waste. The success of these schemes depends on close understanding and collaboration between urban planners, sanitation experts and agricultural extension workers from the beginning of the planning process. Simply relying on assumptions about market demand and cost sensitivity for new materials may not provide sufficiently accurate information for the feasibility assessment and design of a reuse scheme.

The DFS planning approach was introduced as an accessible and logical planning framework for facilitating the design and implementation of reuse-oriented systems. Working through DFS should yield a plan for urban wastewater and faecal sludge management that contributes to local sustainability by not only mitigating public and environmental health risks associated with indiscriminate discharge, but by utilizing the resource potential of human waste in ways that have the greatest local benefit. Among other potential institutional and financial barriers to employing DFS, the absence of incentives or platforms for multi-stakeholder communication and cooperation and one-size-fits-all effluent standards may hinder its effective use.

When these challenges are overcome, the example applications of DFS in Ghana and China show the approach can applied for the rehabilitation of existing facilities or for the design of new treatment plants. However, to maximize the efficiency and benefits of reuse, decision-makers are encouraged to incorporate reuse at the outset of a planning process whenever possible.

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