Sustainable Wastewater Treatment and Reuse in Urban Areas of the Developing World

Written April 2003 for the requirements of
CE 5993 *Field Engineering in the Developing World*

by

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Introduction

The increasing scarcity of water in the world along with rapid population increase in urban areas gives reason for concern and the need for appropriate water management practices. Very little investment has been made in the past on sewage treatment facilities; water supply and treatment often received more priority than wastewater collection and treatment. However, due to the trends in urban development, wastewater treatment deserves greater emphasis. Currently there is a growing awareness of the impact of sewage contamination on rivers and lakes; wastewater treatment is now receiving greater attention from the World Bank and government regulatory bodies.

According to the World Bank, "The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes" (Looker, 1998). It is crucial that sanitation systems have high levels of hygienic standards to prevent the spread of disease. Other treatment goals include the recovery of nutrient and water resources for reuse in agricultural production and to reduce the overall user-demand for water resources (Rose, 1999).

In order to achieve ecological wastewater treatment, a closed-loop treatment system is recommended. Many present day systems are a "disposal-based linear system". The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. Using organic waste nutrient cycles, from point-of-generation to point-of-production, closes the resource loop and provides an approach for the management of valuable wastewater resources. Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that instead of being used in agricultural for food production, fill rivers with polluted water. The development of ecological wastewater management strategies will contribute to the reduction of pathogens in surface and groundwater to improve public health. "The goal of ecological engineering is to attain high environmental quality, high yields in food and fiber, low consumption, good quality, high efficiency production and full utilization of wastes"(Rose, 1999).

In the growing number of conflicts between agricultural and domestic use of scarce water resources, an increased use of treated wastewater for irrigation purposes is vital. Wastewater is composed of over 99% water. In a developing urban society, the wastewater generation is usually approximately 30-70 m^3 per person per year. In a city of one million people, the wastewater generated would be sufficient to irrigate approximately 1500-3500 hectare (SIDA, 2000). Innovative and appropriate technologies can contribute to urban wastewater treatment and reuse. Based on extensive successful experience in Canada and elsewhere on cost effective and environmentally sound practices of sludge application on agricultural land, there is tremendous potential for the *safe* disposal of sewage sludge on agricultural land (Looker, 1998).

Problem Statement

Problems concerning water sanitation stem from the rise in urban migration and the practice of discharging untreated wastewater. The uncontrolled growth in urban areas has made planning and expansion of water and sewage systems very difficult and expensive to carry out. In addition, many of those moving to the city have low incomes, making it difficult to pay for any water system upgrades (Looker, 1998). In developing countries, 300 million urban residents have no access to sanitation and it is mainly low-income urban dwellers who are affected by lack of sanitation infrastructure. Approximately two-thirds of the population in the developing world has no hygienic means of disposing excreta and an even greater number lack adequate means of disposing of total wastewater (Rose, 1999). It is a common practice to discharge untreated sewage directly into bodies of water or put onto agricultural land, causing significant health and economic risks. While the number of households with access to drinking water supply has increased (approximately eighty percent in Latin America and the Caribbean), the percent connected to urban sewage collection systems is only five percent (Looker, 1998).

The effects of inadequate treatment can be detrimental to a community on economic, cultural and health levels. The costs of poorly managed domestic waste are very high. In India, the 1994 plague epidemic resulted in a loss of tourism revenue estimated at $ 200 USD million; in Peru, a recent cholera epidemic resulted in an estimated loss amounting to three times the expenditure on water and sanitation for the entire country over the preceding 10 years; and in Shanghai, China, a recent major outbreak of hepatitis A was attributed to sewerage contamination (Rose, 1999). Water contaminated by human, chemical or industrial wastes can cause a number of diseases through ingestion or physical contact. Water-related diseases include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever. Consequently, no other type of intervention has greater impact upon a country's development and public health than the condition of clean drinking water and the appropriate disposal of human waste (SIDA, 2000).

The benefits of reusing treated wastes must also be measured against the cost of not doing so at both the economic and environmental level. The costs of implementing zero-discharge organic waste to agriculture recycling schemes may not be expensive. Full-scale implementation of urban organic waste to agriculture systems could cost as little as $5-6 USD million for a city of 1 million people (Rose, 1999).

The problem with the current treatment technologies is they lack sustainability. The conventional centralized system flushes pathogenic bacteria out of the residential area, using large amounts of water and often combines the domestic wastewater with rainwater, causing the flow of large volumes of pathogenic wastewater. In fact, the conventional sanitary system transfers a concentrated domestic health problem into a diffuse health problem for the entire settlement and/or region. In turn, the wastewater must be treated where the cost of treatment increases as the flow increases. The abuse of water use for diluting human excreta and transporting them out of the settlement is increasingly questioned and being considered unsustainable (van Leir, 1998). The negative effects of centralized treatment are summarized in Table 1.

Table 1: Negative effects of Centralized Wastewater Treatment (Rose, 1999)

- **Contamination of water downstream, causing public health hazards if treatment has a low efficiency.**
- **Loss of nutrient resources (N, P, K, and S) and trace nutrients in domestic waste**
- **Loss of opportunity to maintain the fertility of the soil through wastewater reuse. This leads to the need to purchase inorganic fossil fertilizer.**
- **Results in contaminated sludge not suitable as fertilizer for agriculture.**

Another reason many treatment systems in developing countries are not successful and therefore unsustainable are that they were simply copied from Western treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often local engineers educated in the Western development programs supported the choice for the inappropriate systems. Many of the implemented installations were abandoned due to the high cost of running the system and repairs (van Leir, 1998).

On the other hand, conventional systems may even be technologically inadequate to handle the locally produced sewage. For example, in comparison to the US and Europe, domestic wastewater in arid areas like the Middle East are up to five times more concentrated in the amount of oxygen demand per volume of sewage. This is extremely high and may cause a large amount of sludge production (van Leir, 1998).

Appropriate Treatment Technology

Based on experience from past mistakes in sewage treatment technology, the definition of what is sustainable is clearer. Developers should base the selection of technology upon specific site conditions and financial resources of individual communities.
Although site-specific properties must be taken into account, there are core parts of sustainable treatment that should be met in each case. The criteria for sustainable technology are summarized in Table 2.

Table 2: Criteria for sustainability in the treatment of wastewater (van Lier, 1998)

1) No dilution of high strength wastes with clean water.

2) Maximum of recovery and re-use of treated water and by-products obtained from the pollution substances. (i.e. irrigation, fertilization)

3) Application of efficient, robust and reliable treatment/conversion technologies, which are low cost (in construction, operation, and maintenance), which have a long life-time and are plain in operation and maintenance.

4) Applicable at any scale, very small and very big as well.

5) Leading to a high self-sufficiency in all respects.

6) Acceptable for the local population.

One approach to sustainability is through decentralization of the wastewater management system. This system consists of several smaller units serving individual houses, clusters of houses or small communities. Black and gray water can be treated or reused separately from the hygienically, more dangerous excreta. Non-centralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases (Schertenlieb, 2000). This approach leads to treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and mineralized nutrients) in the direct location of the settlement.

Communities must take great care when reusing wastewater, both chemical substances and biological pathogens threaten public health as well as accumulate in the food chain when used to irrigate crops or in aquaculture. In most cases, industrial pollution poses greater risk to public health than pathogenic organisms. Therefore, more emphasis is being placed on the need to separate domestic and industrial waste and to treat them individually to make recovery and reuse more sustainable. The system must be able to isolate industrial toxins, pathogens, carbon, and nutrients (Rose, 1999).

Sustainable Treatment Types

Now that the requirements for a sustainable wastewater treatment system have been presented, there are several options one can choose from in order to find the most appropriate technology for a particular region. This paper will discuss sustainable wastewater treatment systems including lagoons/wetlands, USAB (anaerobic digesters), Hybrid reactor, and SAT technologies.

Lagoons and wetlands

In wetland treatment, natural forces (chemical, physical, and solar) act together to purify the wastewater, thereby achieving wastewater treatment. A series of shallow ponds act as stabilization lagoons, while water hyacinth or duckweed act to accumulate heavy metals, and multiple forms of bacteria, plankton, and algae act to further purify the water. Wetland treatment technology in developing countries offers a comparative advantage over conventional, mechanized treatment systems because the level of self-sufficiency, ecological balance, and economic viability is greater. The system allows for total resource recovery (Rose, 1999). Lagoon systems may be considered a low-cost technology if sufficient, non-arable land is available. However, the availability of land is not generally the case in big cities. The demand of flat land is high for the expanding urban developments and agricultural purposes (van Leir, 1998).

The decision to use wetlands must consider the climate. There are disadvantages to the system that in some locations may make it unsustainable. Some mechanical problems may include clogging with sprinkler and drip irrigation systems, particularly with oxidation pond effluent. Biological growth (slime) in the sprinkler head, emitter orifice, or supply line cause plugging, as do heavy concentrations of algae and suspended solids (Metcalf, 2002). Other disadvantages are listed in Table 3.

Table 3: Disadvantages of Lagoon systems in arid climates (van Leir, 1998)

- **High demand for large area of arable, flat land.**
- **Often characterized by significant odor problems in anaerobic and facultative ponds.**
- **Loss of valuable greenhouse gas (methane) to the atmosphere.**
- **Evaporation of huge quantities of valuable water.**
- **Increase of the inorganic salt content due to evaporation.**
- **The system is non-flexible towards an increase in the population.**

Anaerobic Digestion

Another treatment option available, if there is little access to land, is anaerobic digestion. Anaerobic bacteria degrade organic materials in the absence of oxygen and produce methane and carbon dioxide. The methane can be reused as an alternative energy source (biogas). Other benefits include a reduction of total bio-solids volume of up to 50-80% and a final waste sludge that is biologically stable can serve as a rich humus for agriculture (Rose, 1999).

Table 4: Advantages of Anaerobic Digestion Treatment (van Leir, 1998)

- **No, or very low energy demand**
- **Production of valuable energy in the form of methane**
- **Low investment costs and low space requirement**
- **Applicable at small as well as large scale**
- **Low production of excess sludge, which is well stabilized**
- **Low nitrogen and phosphorus requirements**
- **High loading capacity (5-10 times that of aerobic treatment)**
- **High treatment efficiencies**
- **Suitable for camps with long term periods without discharge of wastewater**
- **Effluents contain valuable fertilizers (ammonium salts)**

So far, anaerobic treatment has been applied in Colombia, Brazil, and India, replacing the more costly activated sludge processes or diminishing the required pond areas. In various cities in Brazil, they show an interest in applying anaerobic treatment as a decentralized treatment system for "sub-urban", poor, districts (van Leir, 1998). The beauty of the anaerobic treatment technology is that it can be applied to a very small and very big scale. This makes it a sustainable option for a growing community.

There are different types of digesters available, some have been proven effective over time, and others are still being tested. One of the most suitable digesters for tropical conditions is the USAB (upflow anaerobic sludge blanket). In tropical conditions, there are reductions in BOD of 75%-90%. UASB technology is feasible in an urban, developing world context because of its high organic removal efficiency, simplicity, low-cost, low capital and maintenance costs and low land requirements. Typically, USAB's have low sludge production and low energy needs (Rose, 1999). Since nitrogen and phosphorus are not effectively reduced in anaerobic technologies, this primary treatment approach works well with agriculture or aquaculture. However, they are not completely effective at removing all pathogens, the wastewater needs a post treatment option to meet discharge standards, such as composting digested sludge, wetland systems, or stabilization ponds (Rose, 1999).

The UASB reactor essentially consists of a gas-solids separator (to retain the anaerobic sludge within the reactor), an influent distribution system, and effluent draw-off facilities (Kansal, 2003). See figure 1 below for a schematic of a UASB reactor. It is constructed with entrance pipes delivering influent to the bottom of the unit and a gas solids separator at the top of the reactor to separate the biogas from the liquid phase (water and sludge); overall, this prevents sludge washout (Rose, 1999).

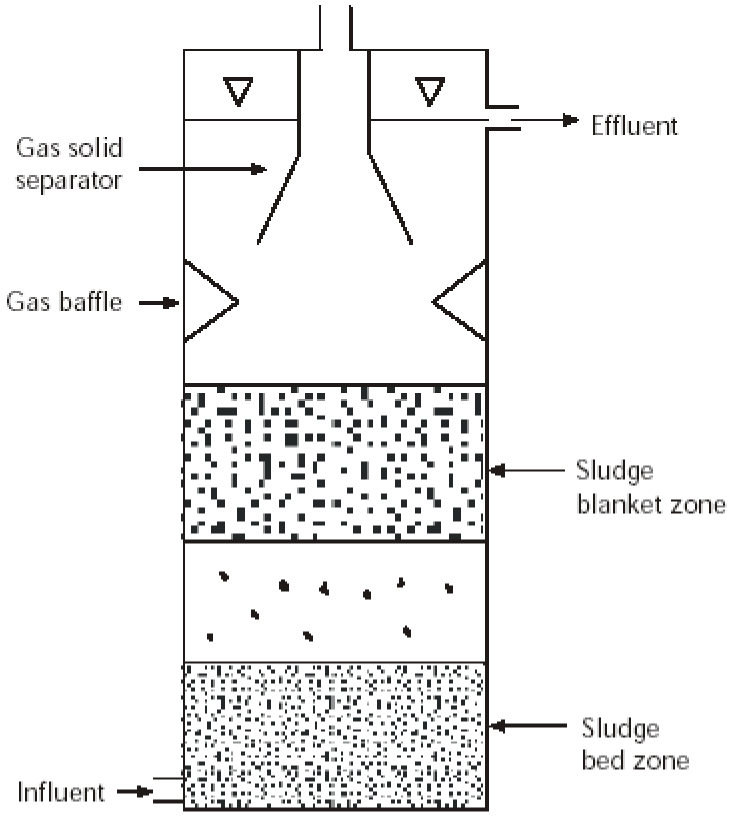

Figure 1: Schematic of USAB reactor (Kansal, 2003)

The UASB system with a stabilization pond for secondary treatment can cost $4 USD per person equivalent compared to $8 USD per person equivalent for activated sludge treatment. These costs would be for a system scale of 50,000 person equivalents if the land cost is less than $20 USD (Rose, 1999).

The hybrid reactor is an improved version of the UASB system and combines the merits of the upflow sludge blanket and the fixed film reactors. The advantages include simplicity of design and operation; it also is more economical than a fixed bed system (Kansal, 2003).

Soil Aquifer Treatment

SAT (soil aquifer treatment) is a geopurification system where partially treated sewage effluent artificially recharges the aquifers, and then withdrawn for future use. By recharging through unsaturated soil layers, the effluent achieves additional purification before it is mixed with the natural groundwater. In water scarce areas, treated effluent becomes a considerable resource for improved groundwater sources. The Gaza Coastal Aquifer Management Program includes treated effluents to strengthen the groundwater, in terms of both quantity and quality. With nitrogen reduction in the wastewater treatment plants, the recharged effluent has a potential to reduce the concentration of nitrates in the aquifer. In water scarce areas such as in the Middle East and parts of Southern Africa, wastewater has become a valuable resource that, after appropriate treatment, becomes a commercially realistic alternative for groundwater recharge, agriculture, and urban applications (SIDA, 2000).

SAT systems are inexpensive, efficient for pathogen removal, and operation is not highly technical. Most of the cost associated with an SAT is for pumping the water from the recovery wells, which is usually $20-50 USD per m^3. In terms of reductions, SAT systems typically remove all BOD, TSS, and pathogenic organisms from the waste and tend to treat wastewater to a standard that would generally allow unrestricted irrigation. The biggest advantage of SAT is that it breaks the pipe-to-pipe connection of directly reusing treated wastewater from a treatment plant. This is positive attribute for those cultures where water reuse is taboo (Rose, 1999).

The pretreatment requirements for SAT vary depending on the purpose of groundwater recharge, sources of reclaimed water, recharge methods, and location. Some may only need primary treatment or treatment in a stabilization pond. However, pretreatment processes should be avoided if they leave high algae concentrations in the recharge water. Algae can severely clog the soil of the infiltration basin. While the water recovered from the SAT system has much better water quality than the influent, it could still be lower quality than the native groundwater. Therefore, the system should be designed and managed to avoid intrusion into the native groundwater and use only a portion of the aquifer. The distance between infiltration basins and wells or drains should be as large as possible, usually at least 45 to 106 m to allow for adequate soil-aquifer treatment (Metcalf, 2002).

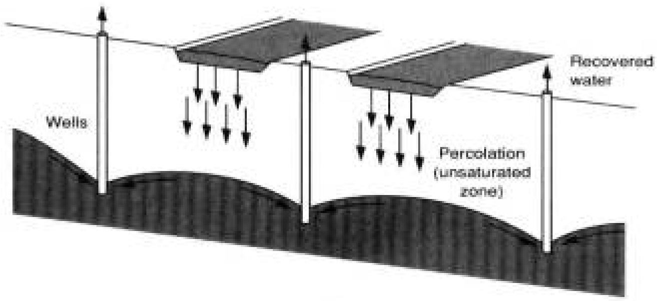

Figure 2: The design of an SAT system (Metcalf & Eddy, 1991)

All the systems described allow for the reuse of treated wastewater in order to have a cyclic, sustainable system. These treated wastewaters provide essential plant nutrients (nitrogen, phosphorus, and potassium) as well as trace nutrients. Phosphorus is an especially important nutrient to recycle, as the phosphorus in chemical fertilizer comes from limited fossil sources. The application of treated wastewater, as well as sludge, has considerable potential in a cyclical approach to crop applications, provided health risks and quality restrictions are taken into consideration (SIDA, 2000). Public health is the most critical issue regarding reclaimed wastewater.

Treated Wastewater Reuse

Wastewater reuse must meet certain controls. First, wastewater treatment to reduce pathogen concentrations must meet the WHO (1989) guidelines in Table 5. Second, crop restrictions must be specified to prevent direct exposure to those consuming uncooked crops as well as defining application methods (irrigation) that reduce the contact of wastewater with edible crops. Finally, control of human exposure is needed for workers, crop-handlers and final consumers (Rose, 1999).

Table 5: Guidelines for Treated Wastewater in Agricultural Irrigation (Rose, 1999)
Source: International Reference Centre for Waste Disposal by WHO (1989)

Reuse Process	**Intestinal nematodes (Arithmetic mean no. of eggs per liter)**	**Fecal coliforms (Geometric mean no. per 100 ml.)**
Restricted Irrigation (Irrigation of trees, industrial crops, fodder crops, fruit trees and pasture)	Less than or equal to 1	N/A
Unrestricted Irrigation (Irrigation of edible crops, sports, fields, and public parks)	Less than or equal to 1	Less than or equal to 1,000

Benefits of safely recovering and reusing human wastes include a reduction in effluents to bodies of water, and the opportunity to re-build soil with valuable organic matter. The nitrogen in reclaimed water can replace equal amounts of commercial fertilizer during the early to midseason crop-growing period (see Table 6). Excessive nitrogen in the latter part of the growing period may be detrimental to many crops, causing excessive vegetative growth, delayed or uneven maturity, or reduced crop quality. If alternate low-nitrogen water is available, a switch in water supplies or blending of reclaimed water with other water supplies can been used to keep nitrogen under control. In reclaimed water that is chlorinated, chlorine residuals of less than 1 mg/L do not affect plant foliage, but chlorine residuals in excess of 5 mg/L can cause severe plant damage when sprayed directly on foliage (Metcalf, 2002).

Table 6: Nutrients in human waste compared to commercial fertilizer (Rose, 1999) *(Data from Worldwatch Institute, 1998)*

Country	Nutrient Equivalent in Commercial Fertilizer Applied (percent) **Assumes 50% loss of nitrogen due to volatilization*
Kenya	136
Tunisia	25
Indonesia	49
Zimbawe	38
Columbia	31
Mexico	31
South Africa	29
Egypt	28
India	26

Strategies for Implementing New Treatment Technology

A wastewater treatment developer must perform an appropriate risk assessment before implementing the reuse of wastewater. Proper consideration to the health risks and quality restrictions must be a part of the assessment. Source-point measures rather than end of pipe solutions are essential. Source-point measures require extensive industrial pre-treatment interventions, monitoring and control programs, and incentives to the community not to dispose of any harmful matter to the sewers (SIDA, 2000).

For the implementation and promotion of new technology, strategies must include local participation as well as municipal. The importance of local participation is a positive growing trend in government projects. The participation must fit with the local population to meet particular local needs. Local communities can contribute indigenous, valid ideas for cost savings in the project. Agreement on key issues between design engineers and the local residents is necessary early on in the project, and if local participation is extensive, capital costs can ultimately be reduced. According to the Inter-American Development Bank, “Citizen participation, properly channeled, generates savings, mobilizes financial and human resources, promotes equity and makes a decisive contribution to the strengthening of society and the democratic system” (Looker, 1998).

There is a strong sense of ownership by members of the community in their projects. This pride in the new development helps to ensure the sustainability of the water supply and sanitation systems. Once the project is implemented, local participation contributes to the community’s confidence in the new technology and allows them to take on other challenges such as accessing financial aid for other infrastructure projects (Looker, 1998).

On the governmental level, institutional strengthening is usually needed to assist small to medium-sized cities in dealing with new administrative and financial management responsibilities. One program that has been developed to address the problems associated with decentralization is RIADEL (Local Development Research and Action Network). It is a network for sharing information about local community development in Latin America. It includes decentralization and the training of social leaders and civil servants (Looker, 1998).

Case studies and current research activities

There are several research and development projects on wastewater treatment, some have been successful and sustainable and some have not. The reasons for success or failure most often depend on the appropriateness of the implemented technology.

The following description is a perfect example of the inappropriateness of adapting Western technology without making adjustments for the local environment. In the 1970s, a foreign country donated a conventional activated sludge plant to the city of Amman, Jordan. Due to the arid climate, however, sewage in Jordan has extremely high concentrations of organic matter. This caused several problems in the plant such as: high-energy consumption for aeration, high volume of sludge production, operational problems in the operational plant, and high consumption of polymers and clean water for drying the sludge after digestion. Next, they implemented another unsustainable technology by constructing one of the world's largest stabilization ponds. Soon after the pond was installed, the plant was operating at loading rates double that of the design load causing very poor effluent quality. Recently, another Western program installed off-gas treatment to prevent odor by placing surface aerators in the maturation ponds. However, operation costs of the aerators were too high and the system stopped after two months. Not only was it expensive, but it also didn't fix the odor problems since the odorous gases were coming off the anaerobic ponds and there was little improvement in effluent quality. Unfortunately, all of the reasons for not installing a stabilization pond, mentioned in Table 3, were present in this situation (van Leir,1998). One alternative treatment technology that would have supported the high COD quality of the influent would have been anaerobic digestion. As explained previously, anaerobic digesters are generally low-tech, have low energy usage, and are less expensive to maintain.

The next case study, on the other hand, attempts to find a proper system for the country at a low cost to the community, and shows that in areas like the Middle East and Southern Africa where there is a shortage of water, groundwater recharge and agricultural/urban applications of treated effluent can be sustainable solutions. In this case, Windhoek, Namibia is the location for a successful project implementing treated wastewater reuse. Because the arid climate and water shortage were taken into account when determining the technology, the project incorporated SAT systems to recharge the groundwater and water demand management, based on IWRM (Integrated Wastewater and Recycling Management). The required volume of water used to irrigate parks, sports fields, etc. has lowered since 1987, even though the population has doubled from approximately 105,000 to 202,000 over the same time. The artificial recharge of aquifers was beneficial due to the lower evaporation, which allowed for water supply during droughts. In addition, a feasibility study showed the system's total investment cost would be recovered within five years (SIDA, 2000).

Conclusions

This paper discussed several options to achieve sustainability in wastewater treatment. The first was by decentralizing the treatment rather than installing expensive sewer systems that combine and increase the volume of the waste. The next involved choosing an appropriate treatment technology for the community, where several types proposed included lagoons/wetlands, USAB (anaerobic digester), hybrid reactor, and SAT. (Appendix A includes a flowchart that summarizes the available technologies from an IDRC report). The common characteristic of all of the described types is that they encourage “zero-discharge” technology. This cyclical, rather than linear approach includes the reuse of the treated effluent for agricultural reuse. The reuse of the wastewater decreases the money spent on fertilizers and it is considered safe, since it has been treated for pathogens.

To come to the point, the urban areas of many developing countries are growing rapidly, ecological sanitation systems must be implemented that are sustainable and have the ability to adapt and grow with the community’s sanitation needs. In order to decide what the appropriate treatment system is, the developer must consider the area’s climate, topography, and socioeconomic factors. There are still plenty of needs in this area for research to improve or optimize the current methods of wastewater treatment. The result of increased attention to this topic will improve the health, economic, and agricultural factors of a developing community.

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Appendix A: Overview of Technology of Wastewater Treatment and Reuse
(Image Source: IDRC report by Gregory Rose, 1999)