Alternative Technology for Urban Wastewater Treatment: Case Studies and Issues of Implementation and Sustainability

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Abstract

Effective collection and treatment of urban and industrial wastewater is a critical problem in countries such as Sri Lanka and India. Current solutions to these problems have been dominated by “western” approaches such as centralized sewerage based on traditional design criteria and treatment using aerobic processes such as the activated sludge process. However, the solutions are expensive to construct and operate and pose technical and financial challenges for the operating authorities.

This paper examines alternative concepts – such as distributed systems, re-use of treated wastewater and community participation - and technologies – such as simplified sewerage, settled sewerage, septic tanks for primary treatment, anaerobic filters for secondary treatment and constructed wetlands for secondary and tertiary treatment - for the collection and treatment of urban wastewater and describes their performance in various situations in Sri Lanka. It is concluded that these alternative approaches have been successful in a wide variety of applications. In particular, treatment to levels that permit re-use in gardening and vehicle washing has been achieved in several hotels. However, some issues related to long term-operation and maintenance remain to be resolved in the case of application to low-income settlements.

Non-acceptance by professionals and decision makers due to limited knowledge about these systems, overly rigid interpretation of regulations and specifications and the lack of general guidelines relevant to Sri Lanka are some of the hurdles that must be overcome before these technologies are used more widely. The paper concludes with some suggestions for enhanced co-operation between Sri Lanka and India in the development and deployment of these technologies. The similarities in urban problems, climate, and socio-economic factors are such that successful duplication can be expected.
Introduction

The rapid increase in urban population is a major crisis faced by all developing countries today. The Global Water Supply and Sanitation Assessment Report (WHO, 2000) provides a global and regional assessment of the current and future situation. Currently about 400 million people in urban areas are without sanitation, 300 million of those in Asia. Currently this number is much smaller than the approximately 1,600 million Asians in rural areas who lack sanitation. However, the rapid urbanization in Asia will lead to a reversal of the relative situation in a few decades. For example, in order to meet the goal of sanitation for all by 2025 there will have to be an increase of 2,100 million in both the urban and rural population served worldwide.

The City of Colombo – and the associated Greater Colombo metropolitan area – is the major urban area in Sri Lanka. A large proportion of the population of the city of Colombo – estimates range from one-third to one-half – live in what are termed low-income communities (also known as “community gardens”). The proportion of the population in the surrounding urban areas in such communities ranges from 10-15% . The term covers housing units ranging from temporary structures to semi-permanent and even permanent structures. However, all these communities are generally unauthorized, consist of very small lots (ranging from 25-50 m²) and are densely settled.

Most of these housing units do not have individual sanitary facilities and the inhabitants have to use common toilets or defecate in the open. The sanitation coverage of these communities is summarized in Table 1, which gives the overall figures as well as the figures for the communities located next to water bodies and in low-lying areas. In the table the categories “Adequate and Marginal” are defined as less than 10 households to a toilet. The categories “Inadequate” and “Grossly Inadequate” are defined as between 10 and 20, and greater than 20 households per toilet, respectively.

The table shows that the categories “Inadequate and Grossly Inadequate” total over 50% of the population in these areas. Furthermore, the table shows that about 20% of the total population in low-income communities both live near water bodies and marshes and have inadequate or grossly inadequate sanitation facilities. It is very likely that a high proportion of the sewage load from such communities reaches the surface water directly, with consequent impacts on public health and the environment.

About 80% of the City of Colombo and parts of two adjacent cities are sewered. The collected sewage is discharged to the ocean, without any treatment, through two outfalls. Septic tanks with soakage pits is the on-site disposal method for sanitary sewage (black water) used in houses not connected to the network, which includes some houses in the sewered area. Sullage (gray water) is disposed of directly into soakage pits.
Soakage of effluent into the ground fails when one or more of the following conditions are encountered – high density of buildings, high groundwater table, and poor soil conditions. Much of the recent urban expansion has been on filled marshy lands. Many houses in such areas are not able to dispose effluent to the ground. Instead the effluent – including septic tank effluent – is diverted to surface drains. Many low-income communities are also located on such lands. Therefore individual septic tanks and soakage pits are not feasible even if space is available.

It was the potential failure of the individual septic tank / soakage pit system under conditions of high housing density as well as the need to reduce groundwater pollution that motivated the major expansion of the existing 100-year old Colombo sewer network in the 1980s. Extension of this network to cover the outlying areas was considered even at that time. Furthermore development plans for the urban areas surrounding Colombo have called for a sewer network – and treatment when discharge to the ocean is not feasible due to distance. Conventional technology – sewer designs using established criteria, centralized collection and aerobic treatment - were the only options considered in these plans.

The National Water Supply and Drainage Board (NWSDB) – which is the agency that carries out planning and operation of urban sewerage systems – has begun to re-assess these plans in the light of the past 15 years experience with operating and maintaining the Colombo system and recent cost estimates for expansion. For example, an estimate for the Kotte area (population equivalent 250,000) resulted in a cost per capita of about Rs. 17,000 just for the collection network. However this figure was for serving only 70% of the population of the area. The areas left out as uneconomical were most often those low-lying areas where the effluent disposal problem is most acute. The cost of a

### Table 1: Sanitation Coverage of Low-income Communities in Colombo

<table>
<thead>
<tr>
<th></th>
<th>Sanitation Coverage of total population</th>
<th>Sanitation Coverage of population located along canal banks, rivers and coasts, and in low-lying areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adequate and Marginal</td>
<td>Inadequate and Grossly Inadequate</td>
</tr>
<tr>
<td>Colombo</td>
<td>112,000</td>
<td>150,000</td>
</tr>
<tr>
<td>Dehiwala/Mt. Lavinia</td>
<td>10,500</td>
<td>12,500</td>
</tr>
<tr>
<td>All MC areas</td>
<td>122,500</td>
<td>162,500</td>
</tr>
</tbody>
</table>

Source: Greater Colombo Wastewater and Sanitation Master Plan (Engineering Science 1993)
treatment plant – and all the difficulties of finding a suitable site - has to be added to this figure when areas further inland are considered.

Therefore it is clear that alternative solutions to sewage collection and treatment have to be considered in order to provide sustainable complete coverage at an affordable cost. The two main areas of application are to low-income housing communities and standard housing in difficult areas. Some alternative technologies and concepts that are available to solve the problem of urban wastewater disposal are discussed in the next section followed by a summary of how these have performed in various field applications in Sri Lanka. Some obstacles to the wider applications of these alternatives are discussed together with suggestions for co-operation between India and Sri Lanka in this field. The paper concludes with a list of actions that should be taken to develop these technologies.

**Alternatives to Conventional Sewerage and Sewage Treatment**

**Simplified Sewerage (Alternative Design Criteria for Sewerage)** A thorough review of simplified sewerage and a review of worldwide experience to date is given in Mara (1996b). The concepts underlying simplified sewerage had their origins in South America, where the very high costs associated with sewers design using the conventional approach prompted a re-examination of the basic design criteria – such as a minimum “self cleansing velocity” and the calculation of peak flows - that were used by this approach.

As a result the minimum velocity approach was replaced by a more rational approach based on the minimum tractive tension. The peak factors used were found to be far too conservative for small communities and the upper reaches of large networks and were therefore increased. These two changes resulted in smaller pipes at shallower gradients than would result from the conventional approach, with a resulting saving in cost.

The need for manholes was also assessed and it was found that while most manholes are never used in the lifetime of a system, they constitute a significant (30-40%) proportion of the total cost and often cause blockages if they are defective and permit the entry of sand etc. from the surface. There simplified sewerage uses a much smaller number of manholes together with other innovative appurtenances to facilitate cleaning.

Mara (1996a) concludes that simplified sewerage is most appropriate in high-density, low-income communities with a high initial rate of connection. As such it is very well suited to the low-income communities in Colombo. The low cost of the sewer network means that it can be considered as a short term (5-10 year) solution for communities that are subject to relocation or upgrading as well as a longer-term solution.
Alternative Technologies for Sewage Treatment  A thorough review of appropriate technologies, with special reference to Sri Lanka is given in Corea (2001). A description of the applicability of these systems worldwide is contained in Mara (1996a). The brief description here will focus on the application to areas where the standard system of septic tank and soakage pit is not feasible or desirable. The basic principle for treatment is to retain the septic tank as much as possible and to use appropriate secondary and tertiary treatment until the effluent is suitable for discharge to surface waters or for limited re-use.

The septic tank is a sealed unit – consisting of one or more chambers – that is usually located underground. The basic function is that of a settling tank, where solids are removed from the effluent by gravity separation. The septic tank is capable of removing between 30-60% of the organic load of domestic sewage. Typical liquid detention times range from 12 to 48 hours.

The separated solids undergo anaerobic digestion. However, there is a continuous accumulation of sludge, so that periodic removal is necessary. The interval between each removal will depend on the design, loading and climate – in warm countries such as Sri Lanka the de-sludging interval is on the order of 5 to 10 years.

The septic tank is therefore a low-cost, low maintenance and reliable primary treatment unit. The production of sludge is much less than in aerobic systems. As it is buried it does not use up land and can be constructed with available material and skills. The perceived disadvantages of septic tanks usually stem from inappropriate design and application and failure of the soakage pits and fields.

The anaerobic filter has been found to be very useful for the treatment of septic tank effluent. The anaerobic filter consists of a sealed unit filled with a submerged filter medium – which is usually gravel or metal. The flow is directed through the filter – upflow filters have been found to perform best. A bacterial biomass develops in the spaces between the mediums. Fine solid particles are trapped within this biomass and also on the surface of the medium for digestion. Dissolved organic constituents are also absorbed by the biomass.

Construction of anaerobic filters is very similar to that of septic tanks. Typical hydraulic retention times are from 12-24 hours. Detailed performance analysis of an anaerobic filter – Corea et al. (1998) - treating septic tank effluent found that it was able to remove between 60-80% of the organic load. Effluent BOD was generally less than the 30 mg/l which is the standard for discharge into inland surface waters.

The operation and maintenance requirements of anaerobic filters are minimal. Growth of the biomass may eventually clog the filter. Mara (1996a) recommends that they be
drained and flushed with water every two years. However, many filters in Sri Lanka have functioned for over 5 years without any problem.

Therefore the combination of septic tank and anaerobic filter has the potential to remove 80-90% of the organic load in domestic sewage, producing an effluent that can be discharged to inland surface waters. However, it should be noted that this effluent would still contain pathogens and nutrients that are capable of causing public health and environmental problems.

The third technological alternative is a group of systems that include sub-surface flow constructed wetlands and percolation beds. In these systems the effluent is made to flow through a bed made of fine gravel or coarse sand. Flow can be horizontal, vertical or mixed. The unit can be buried or above ground, in which case a suitable species of plant is grown in the medium. Plant roots help keep flow paths open and transfer a certain amount of oxygen to the bed. Treatment is by both aerobic and anaerobic processes.

These systems are capable of producing effluent of such a quality – BOD and suspended solids generally less than 10 mg/l, faecal coliforms about 100 cfu/100 ml or less - that it can be re-used for non-consumptive uses such as toilet flushing, gardening and vehicle washing. The degree of nitrogen removal depends on the specific arrangement and can range from 10-60%. Phosphorous removal is usually negligible.

The planted systems can be used to advantage in hotels etc. as they can be integrated with the landscape. On the other hand they require more maintenance than the buried systems, which are thus more suitable for individual residences.

Another concept is to use natural wetlands for treatment of urban wastewater. The idea is to maximize the retention time in the natural wetland by constructing appropriate flow control structures. The wetland would be able to absorb much of the pollutants from surface water inflows – which in dry weather would consist of sullage and other similar wastewater – and prevent the pollution of canals and other water bodies. In cities such as Colombo, these wetlands can be utilized as pollution buffers in the dry season and as flood detention areas in the wet season while also having values from ecological and aesthetic points of view.

**Distributed Systems.** Conventional concepts of sewage collection and treatment are highly centralized, with the whole flow collected to a few locations for treatment. There are arguments such as economies of scale, difficulties in locating treatment plants, need to lay pipelines only once along roads, etc. in support of this layout.

The alternative would be distributed systems. Here systems – including collection and treatment - would be designed at each locality. Such a concept has the advantage of allowing for different types of systems based on specific site conditions and different
options for the discharge of effluent. These systems could be constructed in response to existing demand rather than being constructed for anticipated conditions a decade or two in the future.

In general the cost of distributed collection systems would be less than centralized collection systems due to smaller size of the collection network and reduced operating costs. The systems would also be more resilient in that a failure of a component would only affect a small area. On the other hand there is a need to operate and maintain several treatment systems may be a disadvantage.

The best solution – as discussed in the Introduction - may be a combined approach, with conventional centralized sewerage for high density, high growth areas and distributed systems for the low-density areas that are expensive to reach using a conventional network.

**Community Participation** Community participation is a concept that has been introduced into the planning, construction, operation and maintenance of systems in low-income communities. The participation of the community is done for purposes of obtaining some cost recovery through community construction and for the purpose of developing a sense of ownership of the system in order to ensure sustainable operation and maintenance.

Developing active participation from the community involves a lot of effort from the institutions responsible for providing services. The general practice is to set up a community-based organization and entrust it with carrying out community consultations, resolving conflicts and organizing the construction. The institution generally provides the design, construction materials and construction supervision. The involvement of non-governmental agencies that have experience working with such communities has greatly facilitated this process.

**Re-use of Treated Wastewater** Re-use of treated wastewater is a concept that is gaining acceptance in areas of some developed countries – such as the United States – that have very water short areas. In Sri Lanka the concept has been initiated at hotels. There are two benefits from such re-use. Firstly, it saves on the cost of obtaining the same quantity of water. Secondly, it reduces problems – such as complaints from communities downstream – about the discharge of effluent.

Re-use of treated wastewater is also potentially useful in individual houses, particularly with the highly progressive water rates in Sri Lanka. A normal high use household would save between 60-80% of the total bill by using recycled water for toilet flushing and gardening. However, public opinion – which considers wastewater as unhealthy and dirty – would have to change before such systems become generally acceptable.
Experience from Sri Lanka

The technologies and concepts described above have been implemented in several locations in Sri Lanka over the past decade or so. This section will summarize the experience so far and identify problem areas that need to be attended to. Most of the material in this section is taken from Corea (2001) and Wikramanayake (2001).

Simplified Sewerage Sewers based on the simplified sewerage approach have been designed and constructed at several low-income housing projects by the National Housing Development Authority (NHDA). The usual practice has been to build modular schemes – each with 40 to 50 households. Only black water is collected. The sewer terminates at a treatment unit consisting of a septic tank and anaerobic filter (performance described below) or connects to the central sewer line.

A comprehensive performance review – including detailed inspections and user satisfaction surveys - of on-site sewage collection and treatment schemes is reported in Wikramanayake (2001). The results showed that the sewers have performed very well. Blockages are usually due to inappropriate objects – such as cloth and sanitary napkins – being discharged into the sewer. There are one or two locations in some of the schemes where blockages are recurrent. These are associated with disturbance of the sewer line due to the later construction of surface drains.

The community is well able to clear blockages without outside assistance. There is a well-established mechanism to report blockages. However, it appears that inappropriate materials – such as steel reinforcing rods! – are sometimes used for cleaning. In general there is a high degree of user satisfaction with this aspect of the schemes.

Simplified sewers – including special connections - have also been selected for a 440 unit housing scheme that is presently under construction. The system includes 11 septic tanks which discharge effluent to a separate pipe network leading to two reed bed systems. Corea (2001) reports an estimated saving of about 40% of the cost of a conventional sewer network.

Anaerobic Filters Anaerobic filters have so far have always been used in conjunction with a septic tank. Corea (2001) reports on several installations in hotels, hostels and individual residences. All the units studied have functioned satisfactorily. No blockage of the filters due to biomass growth has been found even though some systems are over five years old.

Wikramanayake (2001) studied septic tank / anaerobic filter units installed in low-income communities. Thirty-two such systems were surveyed. The age of the systems ranged from 2 to 10 years. The survey showed that 23 systems – including some that were 10 years old – were functioning satisfactorily. While water quality measurements
were not carried out, the effluent from these systems was clear and free from odour. However, the other 9 had been made dysfunctional by the community due to their inability to maintain the system as required.

The agency responsible for the design and construction supervision of the systems has not been able to provide any support in this area. While the communities have been able to maintain the sewer system without much external assistance, they have not been given enough information on the functions and maintenance requirements of the filters.

The community has to request the services of the sanitary department of the local municipality to remove sludge from the tank. After commissioning the systems, removal of sludge became necessary after 2 to 5 years of operation. However, due to a variety of reasons – such as lack of sufficient equipment, size of the septic tank, distance to discharge point, more lucrative offers from higher income areas etc. – the tanks are never de-sludged properly. In most cases, the tank is emptied of liquid while much of the sludge is left behind. This practice results in the long term build up of sludge – with a consequent need for more frequent emptying - and the gradual clogging of the filter.

The personnel of the local municipal have not been given any information or training in the cleaning of the filters. Therefore they are not willing to undertake this work. In some cases the liquid from the tank is discharged over the top of the filter, contributing to its clogging. Faced with a blocked sewage system and no guidance, the community is forced to take drastic measures. Either the filter medium is removed or the filter is short-circuited by making a hole in the tank wall above the level of the filter. Both of these actions allow the direct discharge of septic tank effluent into surface waters, a state of affairs that even the community knows to be unacceptable.

**Constructed Wetlands** The performance of constructed wetlands and percolation beds was studied by Corea (2001). The systems showed satisfactory performance provided sufficient care had been taken in the design stage to ensure uniform flow distribution. Systems where the effluent was exposed to sunlight were prone to failure due to the growth of thick mats of algae, which prevented infiltration. The proper maintenance of the systems – including harvesting plants and maintaining optimum water levels – was also found to be critical.

Some vegetated infiltration trenches were among the systems studied by Wikramanayake (2001). These were not functioning during the time of inspection. Poor – or non-existent maintenance, clogging by soil washed down nearby banks and litter dumped by passers-by was probably the reasons for the failure of the systems. These systems were in two middle-income housing schemes where the residents did not display much concern over the fate of the systems.
Wastewater Re-use  Wastewater re-use – for gardening and vehicle washing - has been implemented at several hotels as reported by Corea (2001). The quality of effluent has been very satisfactory, with a faint yellowish colour being the only indication that it is not tap water. There have been no complaints from the staff using this water. In fact some hotels now advertise the re-use to their foreign clients in order to show that they are “eco-friendly”.

Obstacles to Implementation of Alternative Technologies and Strategies

Lack of Acceptance by Professionals and Decision-makers  The main reason for the lack of acceptance of these alternative technologies is a lack of knowledge on the part of engineers, planners and decision makers. Engineering curricula are based almost completely on Western concepts – which are the conventional technologies discussed in the introduction. In Sri Lanka even the humble septic tank is not given proper treatment in most courses on wastewater engineering. The anaerobic filter, simplified sewerage etc. are not included in any current course.

There are even cases where the ideas discussed here are now accepted in the West but not here. A case in point is the concept of re-use of treated wastewater – now considered important enough to be included in the title of a standard text such as Metcalf and Eddy (1991) but still thought to be a rather farfetched and somewhat disgusting idea in Sri Lanka.

The non-acceptance of these technologies is reinforced by many of the foreign experts and consultants who are involved in the planning and provision of sewerage and sanitation today. The author once worked with one such consultant who insisted that septic tanks have to be de-sludged at least once a year, as is the case in many European countries. Another expert who was promoting constructed wetlands said that “many people talk about anaerobic systems but I have yet to see one that works!”.

Both these misconceptions were due to the simple fact that the performance of anaerobic systems – such as septic tanks and anaerobic filters - is strongly related to the temperature. As a result they are far more efficient in countries like Sri Lanka than in the West. The digestion of sludge in a septic tank is so much faster here that tanks can be designed for de-sludging in 5 to 10 years.

The unfortunate result of this bias on the part of Western texts and experts is that many Sri Lankan decision makers, and even some engineers, are not willing to consider the alternative technologies. Trial applications are looked at very critically, and failures are attributed to flaws in the technology itself, rather than flaws in implementation. Therefore it is very important that a detailed and unbiased performance evaluation of the existing systems is carried out and the results disseminated widely.
**Rigid Adherence to Regulations, Standards, Specifications** As civil engineering is very much an empirical and practical profession, the reliance on regulations and specifications laid down many years ago is another significant obstacle to the development of the alternative technologies.

For example, the Colombo Municipal Council (CMC) interprets the Municipal Ordinance to the effect that domestic sewage can either be discharged to the main sewer network or to the ground after a septic tank. The CMC maintains that the discharge of effluent from septic tank/anaerobic filters to surface waters is not permissible. Permission is not granted even when the discharge is in conformity with the effluent discharge standards laid down by the Central Environmental Authority on the - quite correct - grounds that the discharge is to nearly stagnant water bodies without the required diluting flow. All the systems discussed above have been implemented as special projects under a separate Act.

This interpretation leaves no room for alternative solutions for low-lying areas where the septic tank effluent cannot be discharged to the ground due to high water table or poor soil conditions. The only possible solutions are to extend the sewer network to cover these areas or to collect the effluent in holding tanks and empty by vehicle. However, it is precisely these low-lying areas that are very expensive to cover using a centralized sewer network – a fact that has been recognized by the NWSDB in its planning of extensions to the sewer network.

Therefore, significant changes in the regulations or their interpretation will be necessary before the technologies discussed here can be utilized to serve the tens of thousands of people in Colombo who live in unserved settlements on marginal lands. With regard to water quality it can be said that the quality of effluent from the functioning septic tank/anaerobic filter systems is often much better than waterways to which they are discharged. Planted gravel filters can be used to further improve the quality if necessary.

Another example of the codification of conventional concepts is seen in ICTAD (1986), which are to be followed by all state agencies. The specifications for sewage treatment plant are only concerned with an aerobic treatment plant of the “activated sludge” type. Even the digester for sludge from primary and secondary settlement is required to be aerobic!

**Problems in Implementation** As described above the most significant obstacles to implementation are the non-acceptance by professionals and decision makers and the exclusion of these technologies by existing regulations and standards. These can be overcome by detailed studies of the performance of the systems and disseminating the information.
However, on-going studies have shown that there are also some problems with the ways in which the existing schemes have been implemented and maintained. With regard to the systems in the low-income communities – consisting of simplified sewer, septic tank and anaerobic filter – the most important problem is the lack of support for the removal of sludge from the tanks and backwashing of the filters.

It appears that there is an urgent need to improve the available facilities for the removal of sludge from septic tanks, and indeed all types of sewage treatment plants. The facilities available with the local authorities have not kept pace with the demand, with the result that even high-income areas find it difficult to obtain service. Outside the City of Colombo, where sludge is discharged to the sewer, there is also a need for proper disposal sites for sludge. In many areas the sludge collected from septic tanks or other treatment systems in industries and commercial establishments is dumped at random into wetlands and water bodies.

The issue of *sludge collection and disposal* is of particular importance when comparing the concept of treatment by distributed septic tanks as against sewerage to a central facility, which would also include sludge disposal. Sustainable implementation of the alternative concept for sewage collection and treatment has to include readily available and affordable facilities for this task.

Another area that requires improvement is the quality of community construction. The systems must often be constructed in waterlogged ground with resulting difficulties in construction. Proper training and supervision of those engaged in the work, particularly related to the quality of the concrete and the maintenance of the design levels is critical for good system performance and an absence of unsightly and unsanitary leaks.

Maintenance of the systems is more of a problem in the two middle-income housing schemes than in the low-income schemes. This may be because there has been less effort at developing the community organizations and also because the residents are less inclined to get involved in such issues and expect “somebody else” to get involved.

Finally, and paradoxically, the apparent simplicity of the alternative technologies is often the cause of poor implementation. Everybody thinks that they are experts in septic tanks and hotel management has been known to make arbitrary changes in design and layout without consulting the designers! (Corea, EJH - personal communication). The relaxed guidelines with regard to slope in simplified sewerage is sometimes erroneously interpreted to mean that pipes can be laid without a gradient, resulting in frequent blockages – as has happened on some Maldivian islands.

**Potential Applications** As discussed in preceding sections, low-income housing schemes and treatment to re-use standards at hotels are two areas where there are many potential applications. As there are several of these applications in existence, a good
performance survey should lead to usable guidelines for design and operation. Treatment and re-use of wastewater at the level of individual houses is an area where a larger number of schemes need to be put in operation.

However, the general concept of anaerobic systems and water re-use can be applied in areas that are new to Sri Lanka. An area with very high potential is wastewater – usually with some pre-treatment – from industrial estates. Technologies such as the Upflow Anaerobic Sludge Blanket or Primary Treatment assisted by coagulants with anaerobic treatment of the resulting effluent and sludge appear to feasible, simple and more economical technologies than the activated sludge or oxidation ditch systems that are the norm.

Furthermore, if effluents are treated to the discharge standard of 30 mg/l BOD it should be quite straightforward to achieve re-use quality water with a tertiary constructed wetland. While re-use of water will save on costs, a much greater benefit will accrue from the absence of any discharge, as contamination of rivers that are used for the extraction of drinking water downstream is the key issue today in the siting of industrial estates in Sri Lanka. Therefore such treatment plants should be implemented on a pilot scale to assess their feasibility and cost effectiveness.

**Conclusions and Recommendations**

**Conclusions**

1) Simple, low-cost technologies for sewage collection and treatment have performed well in a variety of applications. Applications in hotels to treat wastewater to re-use standards has been particularly successful.

2) Some issues related to institutional support and community training in operation and maintenance remain to be resolved in the applications to low and middle income housing schemes.

3) These technologies should be considered as potential short and medium term solutions for the problem of urban wastewater disposal where conventional sewerage and treatment is not cost effective. The importance of these alternatives has already been recognized by the NWSDB in planning comprehensive solutions for urban areas.

4) The re-use of treated wastewater for non-consumptive uses is being accepted as an economical and environmentally friendly option, particularly by hotels.

5) The collection and disposal of sludge from septic tanks as well as other wastewater treatment systems is becoming a serious problem as a result of inadequate equipment and disposal sites.
**Recommendations**

1) The on-going work of monitoring the performance – in technical and financial terms - and user-satisfaction of existing systems should be continued.

2) The results of these studies should be used together with relevant experience from other countries to develop guidelines for technology selection, materials and methods, implementation, institutional arrangements and operation and maintenance.

3) There should be increased exchange of knowledge and experience with these technologies between India and Sri Lanka that include the professional and non-governmental sectors.

4) The relevant government agencies should insist that these technologies be considered when planning donor-funded sewerage, housing and infrastructure projects.

5) Information about these technologies should be disseminated at all levels – from political decision makers to professionals to communities. Site visits and visual displays are particularly important.

6) The technologies should be included in engineering curricula at undergraduate, postgraduate and continuing professional development levels.

7) Existing regulations, specifications and standards should be modified to include these technologies.

8) Facilities for the removal and proper disposal of septic tank sludge should be strengthened at the level of the local authority. Privatizing the collection and disposal of sludge should be considered.

9) Pilot projects should be implemented in middle and high-income housing projects and small industrial estates.

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