3. EXPERIMENTAL FULL SCALE SYSTEMS

3.1. Introduction

This chapter describes the various full-scale systems designed and implemented for the purpose of this study. Sections 3.2 to 3.4 describe the design, construction, operation and maintenance aspects of the systems in general, while sections 3.5 to 3.9 describe the individual projects, on a case by case basis, under the corresponding categories. A table summarizing the main features of the projects under each category is given at the end of each section.

As mentioned previously in section 1.3.2 above, the principal objective of this exercise, was to implement and operate the systems in a variety of different field situations, under real conditions in Sri Lanka, so that their performance, costs, operational aspects and overall suitability may be evaluated in a practical context. In order to achieve this in a realistic manner, the systems were designed and implemented on a client-consultant arrangement, in the competitive environment currently prevailing in the wastewater industry in Sri Lanka. The end-user, developer, or service –provider in each case was the client, who bore the costs of design, construction, operation and maintenance, as would be the usual case in practice. Many of the systems were designed to rectify, or upgrade, existing systems that were failing for one reason or another, while others were ‘green-field’ sites for new developments. A total of 36 original systems were designed during the course of the study, of which 28 were built at a total implementation cost of over SLR 30 million (US$ 400,000). 26 are currently operational. The range of clients included both private as well as public sector users and developers.

Construction was organized and carried out in a variety of methods, depending on client preference and local practice. After commissioning, the system was handed over to the client, who remained responsible for the regular operation and maintenance of the system.

3.2. Design

Each system was designed in sequential steps. Initially, a site visit was carried out to evaluate the existing system, if one existed, and to gather necessary information. This was followed by a conceptual design step where an overall concept for the system was proposed. The process flow and the particular unit processes to be used were determined at this stage. The unit processes were then designed on a preliminary basis and the costs estimated. The overall system was then optimised iteratively with different unit process combinations, geometries etc. to arrive at the least cost option. Once the selection had been finalized in consultation with the client, the detailed designs, layout and construction drawings etc. were produced and the project was implemented.

3.2.1. Site visits

The initial site visit was usually carried out together with the client, or a representative who was familiar with the site and the nature of the problem. The purpose of the site visit was to familiarize oneself with the layout and contours of the site and facility, and to make an assessment of the constraints particular to the site, as well as conditions in the neighbourhood of the site, while collecting the basic information required for the conceptual and preliminary design stages. Subsequent site visits were sometimes made, to obtain specific information for detailed designs. The information typically sought at the initial site visit was as follows.

Site layout

Information on the basic layout of the property, buildings, and existing facilities was gathered by visual inspection, and perusal of site plans and building plans, if available. Property boundaries, ownership and use of neighbouring properties, public access, rights of way and easements etc., were observed and noted. Plans for future developments, subdivision of property etc. was discussed with the client.

Natural drainage and relief

An understanding of the natural drainage patterns and relief of the site was obtained from visual inspection and contour plans. Where streams, canals, drains etc. existed on, or adjacent to, the site, their water levels, flow and quality were noted, qualitatively, and the downstream courses inspected.

Wastewater generation and conveyance

The various points of on-site wastewater generation were located and inspected. Conditions of toilets, kitchens, laundries etc., were observed. Leaking cisterns and taps, if any, were noted. The external plumbing arrangements for the conveyance of wastewater were inspected whenever possible. Particular attention was paid to conditions of manholes, drains, sand and grease traps etc.

Existing system

The existing means of wastewater treatment and disposal (if any) was inspected and the history obtained wherever possible. This was usually from maintenance records or by interviewing on-site personnel. Existing septic tanks, grease traps, etc were measured for size, and inspected for structural condition and general state of repair and serviceability.

Wastewater quality

The quality of the wastewater, both influent and effluent, was assessed wherever possible. This was usually by visual inspection of the wastewater, previous sample analysis reports (if available), and occasionally, on-site sampling and testing.

Wastewater flows

The information needed to estimate wastewater flows was collected from the client and on-site personnel. Particular attention was paid to potential seasonal and diurnal variations in flow, as well as occasional short periods of very high flow[21]. Relatively

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[21] This is a common phenomenon in cities such as Kandy and Nuwara Eliya which host national cultural events such as the annual 'Kandy Perahera' in August and the Nuwara Eliya April festivals. The municipal population of Nuwara Eliya grows instantaneously from 25,000 residents to over 200,000 for a period of two weeks in April.

small urban hotels often have large function halls, which are let for weddings etc., resulting in very high peak flows.

Groundwater table

The height and fluctuation of the groundwater table was ascertained, usually by interviewing on-site personnel and neighbourhood residents. Wells, if present on-site or nearby, were inspected.

Flooding

The potential and frequency of local flooding was assessed by interviewing on-site personnel and neighbourhood residents and by observing the local terrain, inspecting conditions of storm drains, etc. In hilly urban areas, such as in Kandy or Nuwara Eliya, local flooding is very common during rainfall events due to blockage of storm drains by soil, garbage and other debris. Low-lying suburbs in Colombo often experience short term flooding due to poor storm drainage.

Soil conditions

The nature and condition of the soil, and its stability, was assessed, either visually or, where necessary, by field-testing.

Maintenance capability

The maintenance capability of the user was assessed by observing the level of existing equipment and plant, current maintenance personnel, and the general condition of repair of the existing facilities. It was considered important to get an insight into the users' approach to maintenance activity as well as their capability. For example, if an individual house was equipped with a pump for water supply, either from a well, or a sump to tank pump, which was in good operational condition, it was considered likely that the homeowner was capable of, and inclined towards, regular maintenance of pumps and ancillary equipment. Similarly, if the garden was well tended, it could be considered likely that the user would maintain vegetation in a reed bed, or VFPGF.

Options for effluent disposal or reuse

The likely options available for effluent disposal or reuse were investigated during the site visit in consultation with the client. The common options were surface discharge to nearby streams, drains, canals or other water bodies, percolation into the ground, and on-site reuse for gardening, landscaping, vehicle washing, toilet flushing etc. If disposal to a drain was an option, the condition and flow in the drain was observed downstream of the site. In new developments, the client was always encouraged to consider on-site reuse for toilet flushing. In existing developments, the reuse options were usually limited to outdoor uses such as gardening and vehicle washing.

Locations and space for treatment units

The locations and availability of space for treatment units was determined with the aid of site plans and/or by on-site measurements. Preferred locations were discussed with the client, and noted. Access for maintenance activity, such as vacuum tanker access for septic tanks, was given due consideration.

Financial situation

The levels and sources of funding for the project were discussed with relevant personnel, in order to gain an understanding of the ability and willingness to pay for a treatment system.

3.2.2. Conceptual design

During this stage, the most appropriate combination of unit processes was selected, and a basic flow process for the system was proposed, based on the information at hand. Particular attention was given to space, opportunity cost of land and the likelihood of proper maintenance in the long term, as well as cost of implementation.

3.2.3. Unit process design

Once the process flow was finalized, the design flow was calculated, and the various unit processes were designed on a preliminary basis and the cost estimated. Interactive linked spreadsheets were developed and used for this purpose. Table 3-1 shows an example flow estimation spreadsheet for tourist hotels. The values shown in red are required to be input by the designer for each specific case. The flow column is then automatically calculated by the spreadsheet, according to the bases shown in blue.

Table 3-1. Example of flow estimation worksheet for tourist hotels.

Facility	Number	Flow		Basis of flow calculation
No. of Rooms	20	6400	l/d	No of rms x 2 guests/room x 160 l/p/d
Staff (residential)	12	1920	l/d	Res. Staff x 160 l/p/d
Staff (non-residential)	8	320	l/d	nonres. Staff x 40 l/p/d
Kitchen		2064	l/d	no. of meals/d x 12 l/meal
Shops	0	0	l/d	no. of shops x 3 employees/shop x 30 l/p/d
Weddings and Functions (pax/month)	700	300	l/d	(no of meals/month x 12 l/meal) / (28 days/ month)
Pools	0	0	l/d	no. of guests/4 x 10 l/p/d
Laundry (no. of machines)	0	0	l/d	no. of m/c's x 1600 l/ m/c / d
Total WW flow (l/p/d)		11004	l/d	
Total WW flow (m3/d)		11.0	m3/d	
Kitchen ww		2364	l/d	
Grey water other than kitchen ww		6480	l/d	flow from guestrooms and staff x 0.75
Total grey water		8844	l/d	

The results of the wastewater flow calculations are carried on to the next worksheet for the unit process designs. This worksheet was standardized to interactively design each of the five unit processes accordingly.

Table 3-2 shows an example worksheet for septic tank design. The worksheet design is based on Mara (1996) with a few adaptations for local conditions. The values shown in red are to be input by the designer for each individual case. The design flow value is read off the flow estimation work sheet. All other values are computed automatically by the spreadsheet.

Table 3-2. Example of the worksheet for septic tank design.

SEPTIC TANK

1. Flow

Q = 2364 l/d

Population equivalent = 15

2. Time required for sedimentation

t_h = 1.5 - 0.3 log Q > 0.2 days

= 0.4879 days

Set t_h = 0.49

Based on terminal settling velocity of 0.18mm/s

Water height for settling

d_h < t_h * 15.552 [> 0.3 m]

d_h < 0.49 * 15.552 = 7588 / 1000 [> 0.3 m]

d_h < 7.59 m

3. Volume required for settling

V_h = t_h * Q / 1000

V_h = 0.4879 * 2.364 = <u>1.153</u> m^3

4. Surface area for settling

A > V_h / d_h

> 1.153 / 7.588 = <u>0.152</u> m^2

5. Volume required for sludge digestion, V_d

V_d = q_s * t_d * p.e

Where q_s = volume of fresh sludge per day.

q_s = 0.001 m3/p/d

t_d = 1853 $T^{-1.25}$ days   T = 25 ^0C

t_d = 33.1 D

V_d = 0.001 * 33.1 * 15 = <u>0.490</u> m^3

6. Sludge storage volume, V_{st}

V_{st} = R * p.e. * N

Where r = 0.04 m^3/p/yr

n = 5 years

V_{st} = 0.04 * 15 * 5 = <u>2.955</u> m^3

7. Volume of scum =			0.5 V_{st}							
8. Total volume, V										
	V	=	Vh	+	Vd	+	1.5* V_{st}			
		=	1.153	+	0.490+		1.5* 2.955		=	<u>6.076</u> m^3
Min. Area	A_{min}	=	0.152 m^2							
9. Depth	d	<	V	/	A_{min}	=	6.076/	0.152		
						=	39.970			
	d_{max}	=	2.2 m							
Set	d	=	2.200m							
Therefore	A	=	<u>2.762</u> m^2							
Total depth		=	<u>2.500</u> m							

Table 3-3 shows an example worksheet for anaerobic filter design. The appropriate design flow is directly read off the flow estimation worksheet. The filter is sized based on nominal hydraulic retention time with a check for maximum surface loading rate, which was 2.8 m/d. The filter depth was standardized at 1.2 metres except in special cases where this was not practicable.

Table 3-3. Example worksheet for anaerobic filter design

ANAEROBIC FILTER							
Flow		=	11.00	m^3/d			
Surface loading rate		=	2.8	$m^3/m^2.d$			
Required surface area		=	3.93	m^2			
Filter depth		=	1.2	m			
Filter volume		=	4.716	m^3			
HRT		=	0.42857	days	>	1.5	d
Set HRT		=	1.5	days			
Required. Volume		=	16.51	m^3			
Therefore,	Area	x	depth	=	volume		
	13.755	x	1.2=		16.506		

Table 3-4 shows an example worksheet for the design of VFPGF's and Percolation beds, which were sized in much the same manner, according to specific area.

Table 3-4. Example worksheet for VFPGF's and Percolation beds

VFPGF			
flow	=	11000	l/d
p.e.	=	69	
depth	=	0.6	m
specific area	=	0.2	m2/p.e.
area	=	13.755	m^2
set area	=	14	m^2
PERCOLATION BEDS			
flow	=	11000	l/d
p.e.	=	69	
depth	=	0.6	m
specific area	=	0.11	m^2/p.e.
area	=	7.5653	m^2
set area	=	8	m^2

Reed beds were initially designed according to the method prescribed by Reed et al (1988) with appropriate adaptations.

Table 3-5 shows an example worksheet for reed bed design. Here, too, the values in red are to be changed by the designer as necessary and the comments in blue are explanatory notes.

Table 3-5. Example worksheet for Reed bed design

REED BEDS				
Flow	=	11.0	m^3/d	
p.e.	=	15		
bed depth	=	0.6	m	
water depth	=	0.55	m	
inf. BOD	=	150	mg/l	Septic tank effluent
eff. BOD	=	15	mg/l	
N	=	0.4		bed porosity (gravel bed planted with reeds)
K_0	=	1.839	/d	municipal ww
K_{20}	=	1.5004		
T	=	25	^0C	
K_T	=	2.0078		
Reqd. area	=	57.361	m^2	
set area	=	57	m^2	
SLR, q	=	0.1931		
k_o	=	10000	m/d	based on 10 mm media size
K	=	1000	m/d	assuming tenfold reduction due to clogging
L_{max}	=	13.656	m	to prevent flooding
set L	=	13	m	
$S_{b,max}$	=	0.0046		to prevent bed dry out
set S_b	=	0.004		
W_{min}	=	2.3264	m	based on velocity < 8.6 m/d

set W	=	4.4	m				
Area	=	57.2	>	57	check		
select		Length	x	Width	x	depth	bottom slope
		13	m	4.4m		0.8	0.004
						0.2	m freeboard

Once the unit processes had been sized, the subsequent worksheets would interactively design the physical units and generate a Bill of Quantities and Estimate for the proposed system. Sizing requirements for each unit process previously determined in the process design would be automatically carried through to these subsequent work sheets, enabling the designer to try out different physical configurations within the process design requirements.

3.2.4. Optimisation

Once the unit processes had been designed as outlined above, different configurations would be assessed iteratively, quickly and easily, with the aid of the spreadsheets, which would generate quantities and estimates for each case, in order to arrive at the optimum configuration for the particular situation.

3.3. Construction and commissioning

Once designed, the construction of the systems was the clients' responsibility. However, full time construction supervision was provided in most cases. Construction would be by tendered contract, labour contract, or direct labour according to individual preference. Detailed site logs were maintained during the construction period. Once the construction was complete, the systems were started up and commissioned before being handed over to the client.

3.4. Monitoring and evaluation program

The systems, once implemented were monitored at several levels. A few of the systems were monitored intensively, with fortnightly sampling of influent and effluent of the individual unit processes in order to assess the behaviour of the individual processes and their contribution to the overall treatment. Others were sampled purely to check conformity with effluent discharge standards. Some of this latter sampling was done, typically on a monthly basis, by the appropriate regulatory bodies, wherever applicable.

The systems were monitored during regular operation, under field conditions, and normal operation was not interfered with for purposes of testing (e.g. artificial variations of loading, flow etc.). Inspection and effluent sampling, where applicable, was carried out according to usual practice by regulators and users. Records were maintained of all aspects of system operation, maintenance activity, violations and complaints.

Sample analyses were done according to standard methods as follows.

BOD_5	- APHA (1995) Method 5210B
Suspended Solids	- APHA (1995) Method 2540D
Turbidity	- APHA (1995) Nephelometric Method 2130B
Ammonia nitrogen	- APHA (1995) Method 4500-NH_3 D
Faecal Coliforms	- APHA (1995) Method 9222D (membrane filtration)
Helminth eggs	- Modified Bailenger Method (Ayres and Mara, 1995).

3.5. Hotels and restaurants

Hotels and restaurants were considered separately from the other categories under consideration, mainly because wastewater from hotel and restaurant kitchens have a very high grease and fat content in comparison to domestic grey water. Most hotels also have their own laundries, which discharge their wastewater. Both these components of wastewater have been observed to cause problems often leading to failure of conventional wastewater treatment systems. Hotels also have an additional regulatory authority in Sri Lanka, the Ceylon Tourist Board, which has its own wastewater treatment and effluent monitoring requirements. The legend for the process flow diagrams in the subsequent sections is given in Figure 3-1.

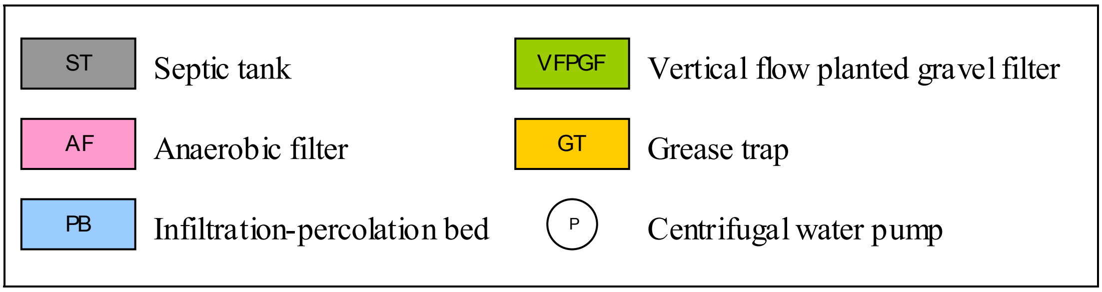

Figure 3-1. Legend for process flow diagrams

3.5.1. The Swiss Residence

The Swiss Residence is a forty-room, upmarket tourist hotel in Kandy, built on steep terrain. Two separate systems were designed and built in two stages. System 1 was put in place when the hotel first opened for business, and was designed to handle all the black water and grey water from the hotel other than kitchen wastewater. The hotel management did not consider it a requirement to treat the kitchen wastewater at the time. Subsequently, upon complaints from neighbouring residents and regulatory authorities, the management requested a second system for the treatment of kitchen wastewater, and System 2 was implemented. Figure 3-2 shows the respective process flow diagrams of the two systems.

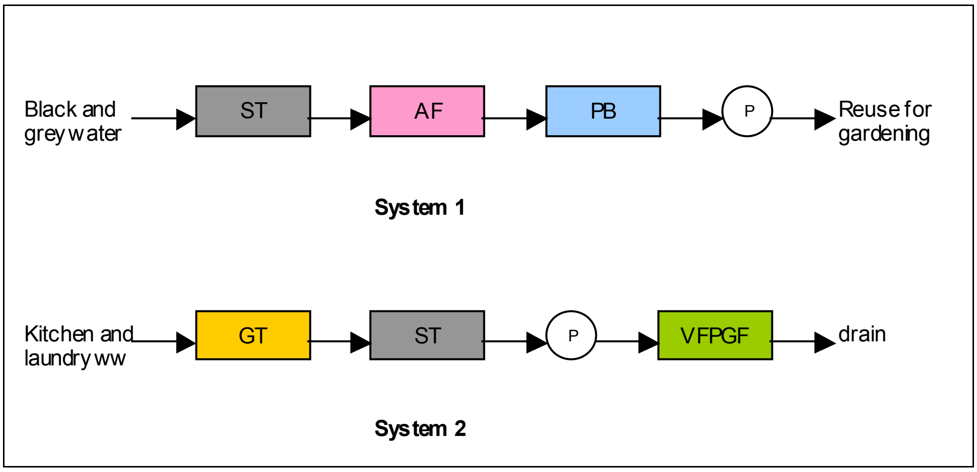

Figure 3-2. Process flow diagrams for The Swiss Residence treatment systems

System 1 comprised a reinforced concrete septic tank with a design sludge storage capacity of 2.5 years. This was followed by a two- stage, upflow – downflow anaerobic filter, also in reinforced concrete, with a nominal design hydraulic retention time of 0.65 days. The effluent from the anaerobic filter was fed to a passive, gravity fed, percolation bed with a 1.5 metre effective bed depth and a specific area of 0.11 m^2/p.e. The treated effluent was collected in a sump and pumped for on-site reuse for gardening. No space had been allocated by the architects for a wastewater treatment plant in the original design of the hotel. Therefore, due to lack of space, the entire system was located underground, under the service access driveway of the hotel, which is adjacent to a busy suburban street. Setback distances of all the units to the road and the hotel buildings were less than 3 metres. Plate 3-1 shows a view of the main hotel building with the treated effluent from system 1 being used for gardening.

Plate 3-1. Main entrance to The Swiss Residence, with treated effluent being used for gardening.

Plate 3-2 shows a view of the service access drive under which the units are located, with the treated effluent being used for vehicle washing. The access manhole to the first stage of the anaerobic filter is visible in the foreground at the bottom right of the picture, and that of the second stage is visible in the centre of the picture. The building to the left, houses drivers' quarters and a restaurant. The suburban street on which the hotel is located is visible in the background of the picture.

Plate 3-2. Service access to the Swiss Residence under which system 1 units are located, with treated effluent being used for vehicle washing

System 2 comprised a grease trap followed by a septic tank and VFPGF unit. The grease trap and septic tank were both in brick masonry and the septic tank was designed for a five-year sludge storage capacity. The VFPGF had an effective depth of 0.6 metres and a design specific area of 0.4 m^2/p.e. The septic tank was buried under a corner of the parking lot. The VFPGF was located at the edge of the parking lot and was designed in an ‘L’ shape to fit into a corner. The treated effluent was discharged to the storm drain running alongside the main entrance driveway of the hotel. Plate 3-3 shows the ‘L’ shaped excavation for the VFPGF unit during construction, and Plate 3-4 shows the unit after commissioning.

Plate 3-3. Excavation for the VFPGF unit for system 2 during construction stage.

Plate 3-4. The VFPGF unit after commissioning

3.5.2. Devon hotel

Devon Hotel is a newly constructed 25-room tourist hotel located in a busy suburb of Kandy. The hotel has a staff of 45, of whom 10 are resident staff. A large function room hosts wedding receptions and banquets which average approximately 1200 pax / month. The building comprises a total of six floors located on a small land plot. The kitchen, pantry, stores and drivers quarters are located in a basement level, below ground.

The treatment system was constructed together with the hotel building and comprised a grease trap and septic tank located under the kitchen floor, to pretreat the wastewater from the kitchen, pantry and drivers restrooms located in the basement, followed by a septic tank, anaerobic filter and percolation bed system located under the entrance forecourt of the hotel. The effluent from the kitchen septic tank was pumped intermittently to the septic tanks of the main treatment system, while the black and grey water from the rest of the building was fed by gravity, direct to the main septic tank units. The final effluent from the percolation bed unit was discharged to the common storm drain adjacent to the hotel, which in turn, discharged into a stream a few metres down. Figure 3-3 shows the process flow diagram of the treatment system.

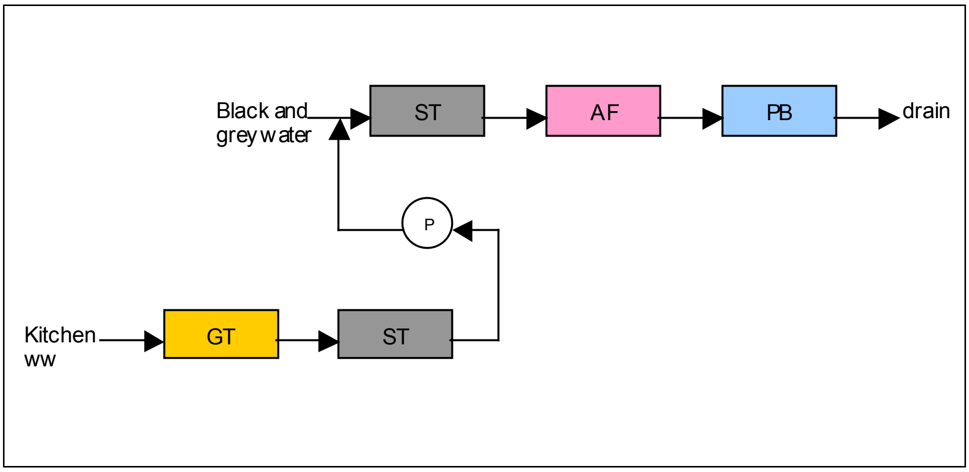

Figure 3-3. Process flow diagram of Devon Hotel treatment system

All the units other than the percolation bed were constructed in reinforced concrete. The main septic tank comprised two units cast together in parallel, and the anaerobic filter comprised four parallel units cast on either side of a central distribution chamber. The septic tanks were designed for a five-year sludge storage capacity and a hydraulic retention time of 1.5 days. The anaerobic filter was designed for a nominal HRT of 1.5 days. The percolation bed had a design specific area of 1.5 m^2/p.e. and an effective bed depth of 1 metre. The bed was laid in a combination of metal chips and gravel. Draft tubes were provided for passive ventilation. Plate 3-5 and Plate 3-6 show views of the hotel building and entrance forecourt area under which the main septic tanks, anaerobic filters and percolation bed are located. The access manholes to the septic tanks are located by the service door at the far corner of the forecourt in Plate 3-5. The distribution chamber of the anaerobic filter units is located under the central landscape feature. The access manhole is open in Plate 3-6, and the cover can be seen behind the potted palm in the foreground of the picture. Plate 3-7 shows the percolation bed being laid during the construction phase. The dark material at the corner of the bed is metal being laid in a reverse filter arrangement around the effluent collector pipe.

Plate 3-5. View of the hotel forecourt area under which the treatment units are located

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Plate 3-6. A view of the hotel building.

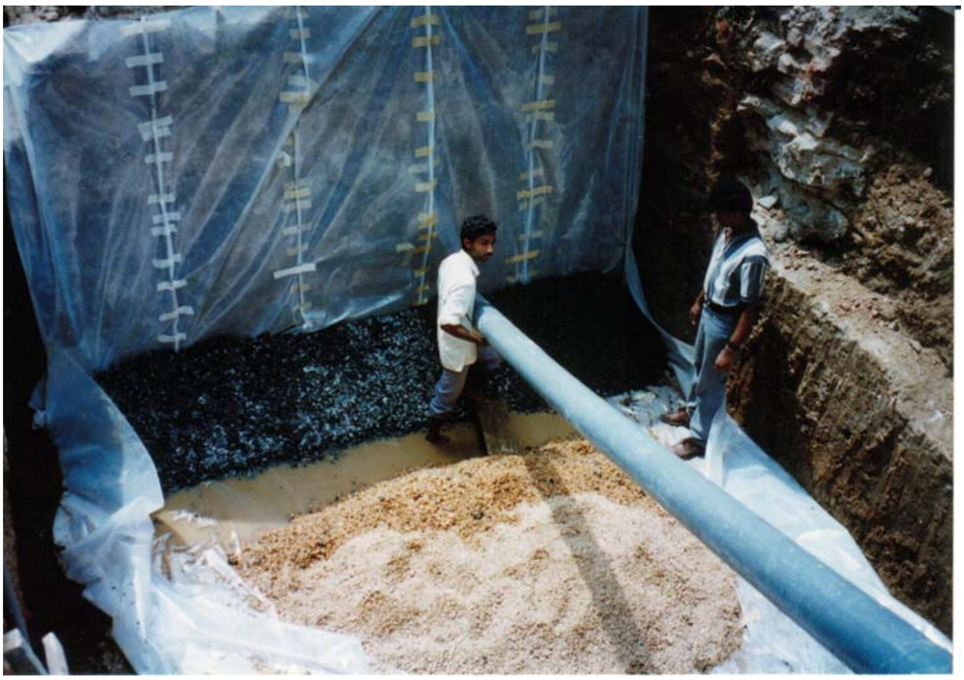

Plate 3-7. Laying of the percolation bed during the construction phase

3.5.3. Devon Rest

The Devon Rest is a ten-room hotel and function hall situated beside the main Kandy Lake. The hotel has a total of 26 staff of which 8 are residential. The function hall is a popular venue for wedding receptions and caters for an average of about 900 pax /month. The hotel had been in operation for about 25 years and previously had a septic tank and soakage pit for black water only. Recent concerns with algal blooms in the Kandy Lake prompted the municipal council to require proper treatment of all the wastewater from the hotel.

The only space available for a treatment system was under the entrance driveway of the hotel. The existing septic tank was located there as well. It was decided to construct a new septic tank for the kitchen wastewater while diverting all other grey water to the existing septic tank. The effluents from both septic tanks were treated by an anaerobic filter and percolation bed located under the entrance driveway. Since the driveway was sloping, the units were located progressively down the incline to facilitate gravity flow while minimizing excavation. The septic tank and anaerobic filter units were reinforced concrete. The final effluent from the percolation bed was discharged to the storm drain beside the main road around the lake on which the hotel is located. The process flow diagram is shown in Figure 3-4.

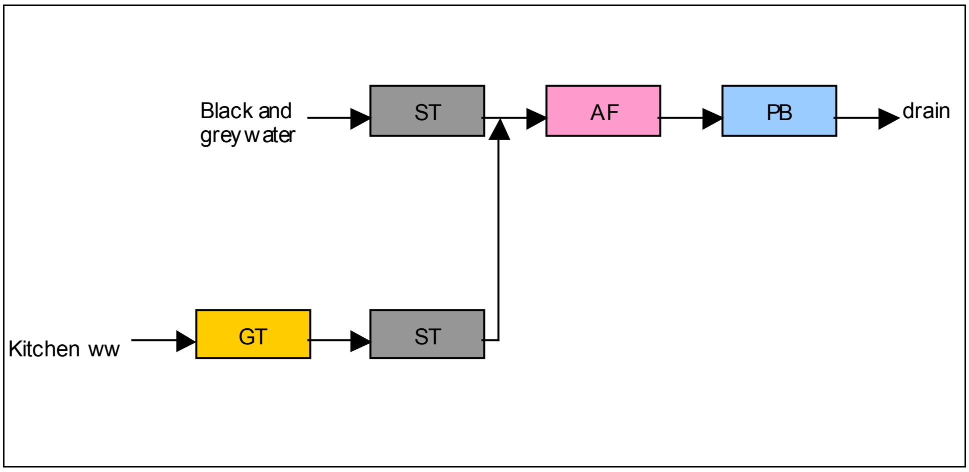

Figure 3-4. Process flow diagram for the Devon Rest treatment system

Plate 3-8 shows the hotel entrance and driveway during construction of the anaerobic filter unit. The septic tank is located under the upper part of the driveway, between the main entrance and the rubble masonry retaining wall visible in the middle of the picture. The percolation bed is located on the lower part of the driveway, at the toe of the retaining wall, beyond the anaerobic filter unit.

Plate 3-8. Hotel entrance and driveway during construction of the anaerobic filter unit.

Plate 3-9 shows a view of the anaerobic filter unit under construction. The Kandy Lake is visible in the background. Plate 3-10 shows the driveway after construction was completed.

Plate 3-9. The anaerobic filter unit during construction.

Plate 3-10. A view of the driveway after construction was completed.

3.5.4. Hotel Thilanka

Hotel Thilanka is a star class tourist hotel in Kandy, located on a steep hillside, over looking the Kandy Lake. It currently has 100 double rooms with 14 more due to be constructed soon. The hotel was originally built around an old mansion and grew to its current size over the past 25 years. The buildings are scattered at many levels across the steeply sloping lot. The original building, or old wing, currently houses 56 double rooms, the lobby, main kitchen, restaurant, and laundry. Another building, the office block, houses the hotel offices, a bar, drivers and guides accommodation, and the staff kitchen. A more recently constructed 'new wing' comprises 43 more double rooms, with a further 14 rooms, a restaurant and satellite kitchen due to be added soon.

The hotel previously had a haphazard collection of septic tanks and soakage pits located in a random manner around the premises, which received the black water from the building. The grey water was discharged to the storm drains. Regulatory authorities required them to install a proper wastewater management system. When designing the system, it was decided to use as many of the existing septic tanks as possible to reduce costs, and to treat the sewage regionally, in order to avoid having to pump raw sewage to a central treatment area across the steeply undulating terrain. The final configuration comprised two main systems located on two opposing sides of the property, with the treated effluent to be reused for gardening and vehicle washing on each side respectively.
Figure 3-5 shows the process flow diagrams for the two systems.

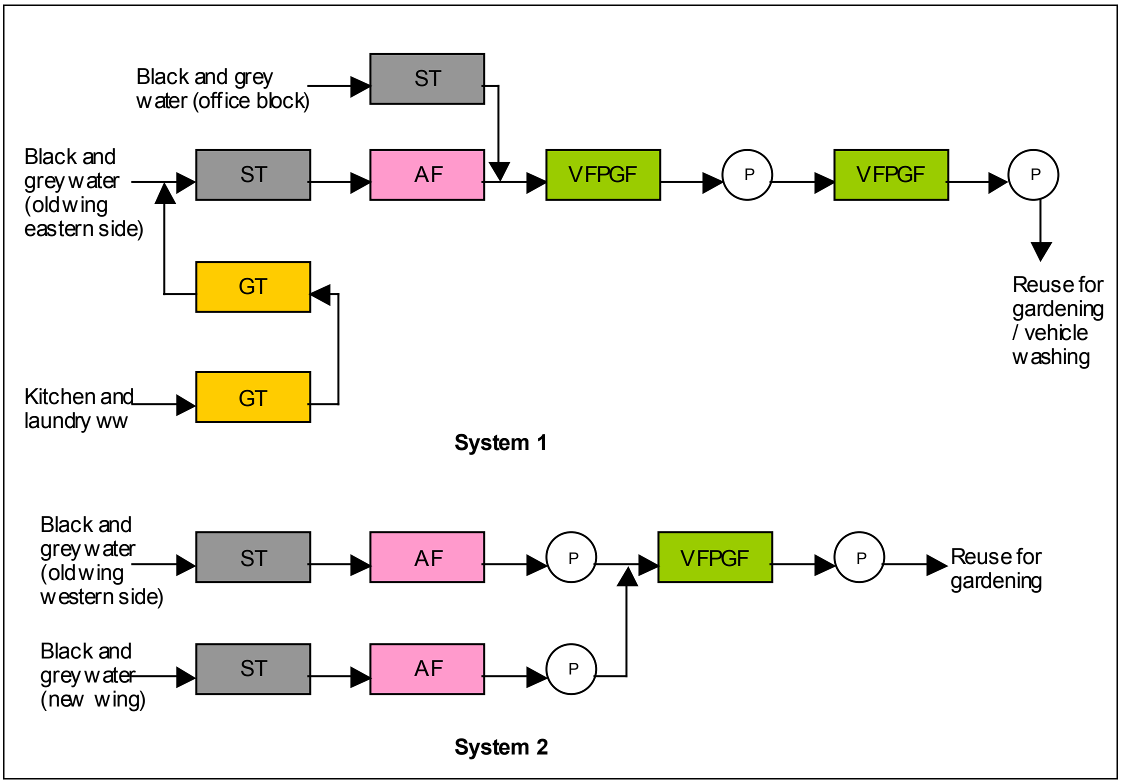

Figure 3-5. Process flow diagrams for Hotel Thilanka wastewater treatment systems

System 1 comprised a new septic tank and anaerobic filter located under the parking lot of the hotel beside the entrance lobby. The septic tank and anaerobic filter were cast together, and configured in three parallel sets of combined septic tank – anaerobic filter units. The septic tanks received both black and grey water from 26 rooms on the eastern side of the old wing, as well as laundry wastewater. The wastewater from the main kitchen was also fed into this unit subsequent to pre-treatment by an existing pair of daily-cleaned grease traps in series. The effluent from the anaerobic filter was further treated by two VFPGF units in series, located on two levels, on a steep slope behind the office block. Two VFPGF units were used, as there was no convenient space large enough to locate a single unit. The first VFPGF was built in three parallel units clustered together, while the second VFPGF was built in two separate parallel units, a few metres apart, due to the steep terrain. The effluent was gravity fed to the lower VFPGF first, by means of simple dosing siphons. The effluent from the lower VFPGF was, in turn, pumped up to the higher VFPGF for further treatment. The final effluent was collected in a sump and reused for gardening and vehicle washing. The wastewater from the office block and drivers' / guides quarters was fed to an existing septic tank behind the building and the effluent fed by gravity through a dosing siphon directly to the VFPGF units.

Plate 3-11 shows a view of the steeply sloping terrain behind the office block where the VFPGF units were located. This kind of steep slope was typical for the property. Plate 3-12 shows a view of the site where the lower VFPGF unit was located, prior to implementation of the project. As can be seen in the photograph, the site abuts a suburban street. Plate 3-13 shows an aerial view of the same site, with the VFPGF unit in place, prior to planting of vegetation. The influent distributor laterals are visible, lying on the surface of the bed. The three parallel units of the VFPGF were separated by HDPE liners, with separate influent distributors for each unit. Plate 3-14 shows a view of the same unit after commissioning and establishment of vegetation. Plate 3-15 shows the second VFPGF during construction. The two parallel units are visible at the top right and centre left of the picture. At the lower left hand corner of the picture, the flow splitter box and dosing siphons to the three parallel units of the lower VFPGF are visible. Plate 3-16 shows the combined septic tank – anaerobic filter during construction under a parking area. Plate 3-17 shows the same area immediately after completion of construction. The access manholes to the units are visible in the picture. Plate 3-18 shows the treated effluent from System 1 being reused for gardening.

Plate 3-11. Steep terrain behind office block where VFPGF units of System 1 were located.

Plate 3-12. Area where the lower VFPGF unit was located prior to construction.

Plate 3-13. A view of the same area with the VFPGF unit in place, prior to planting.

Plate 3-14. The VFPGF unit after establishment of vegetation and commissioning.

Plate 3-15. The second VFPGF during construction.

Plate 3-16. The combined septic tank – anaerobic filter unit during construction under a parking area.

Plate 3-17. The same parking area soon after construction of the septic tank – anaerobic filter unit.

Plate 3-18. The treated effluent from System 1 being reused for gardening.

System 2 was located on the western side of the property, and comprised two anaerobic filter units and a VFPGF unit. The black and grey water from the western side of the old wing, together with the swimming pool wastewater, was diverted to an existing septic tank and the effluent fed to an anaerobic filter located under the western approach driveway of the hotel. The filter was configured in three parallel units. The black and grey water from the new wing was diverted to another existing septic tank, and the effluent fed to an anaerobic filter, located above ground, at the bottom of the garden, on the western side. This filter was configured in two parallel units. The effluent from both anaerobic filters was pumped separately to a VFPGF unit and the treated effluent reused for gardening on the western side. The VFPGF unit was shaped in an arc to fit into the available space and blend with the rest of the landscape. Plate 3-19 shows the VFPGF unit during the construction stage with the excavation complete and the HDPE liner in place. Plate 3-20 shows the unit in operation soon after commissioning. The influent distributor laterals are visible, spraying the influent upwards during the dosing cycle. Plate 3-21 shows the unit some weeks after commissioning with the vegetation fully established. Plate 3-22 shows the treated effluent from the VFPGF being reused for gardening.

Plate 3-19. The VFPGF unit of System 2 under construction.

Plate 3-20. Influent dosing in progress soon after commissioning.

Plate 3-21. The VFPGF unit after complete establishment of vegetation.

Plate 3-22. The treated effluent being reused for gardening.

3.5.5. Ivy Banks

'Ivy Banks' is a small tourist guesthouse situated by the Kandy Lake. It was originally a large house, about forty years old, which had been converted into a guesthouse approximately 25 years ago. As had been the common practice at the time, the original system comprised a septic tank and soakage pit for black water only. The grey water was discharged into the roadside drain. However, due to recent concerns about algal blooms in the lake, the Kandy municipal council required the guesthouse to treat all its wastewater in an appropriate manner.

The guesthouse comprises 5 double rooms and 2 triple rooms with accommodation for 4 drivers. It has 5 resident staff, and a small laundry, which handles an average of ten loads per day. It was decided to treat the kitchen wastewater in a small combined septic tank- anaerobic filter unit located under the front lawn, with the treated effluent percolated into the ground through absorption trenches, also located under the lawn. The other grey water was fed directly to a percolation bed located under an open garage, after pre-treatment by a combined grease trap – grit chamber. The effluent was fed to a soakage pit nearby. Figure 3-6 shows the respective process flow diagrams. A separate system for the other grey water was considered necessary, as diverting the grey water to the kitchen wastewater system would have required major alterations to the plumbing of the building at a disproportionate cost.

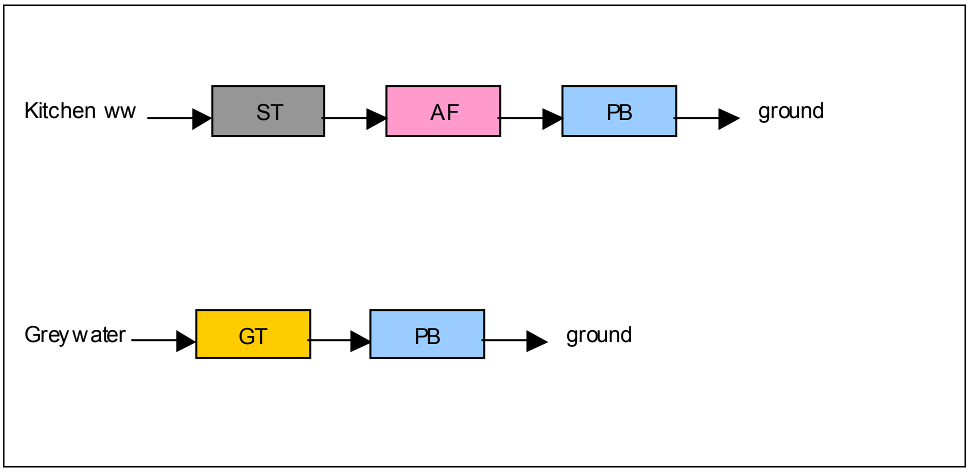

Figure 3-6. Process flow diagram for Ivy Banks wastewater treatment system

The septic tank-anaerobic filter unit was constructed in cement block work.
Plate 3-23 shows the unit being built under the front lawn, with the front entrance to the building just visible in the top right hand corner of the picture. The absorption trenches for the effluent were laid immediately beyond the unit. Plate 3-24 shows the percolation bed being laid under the garage floor.

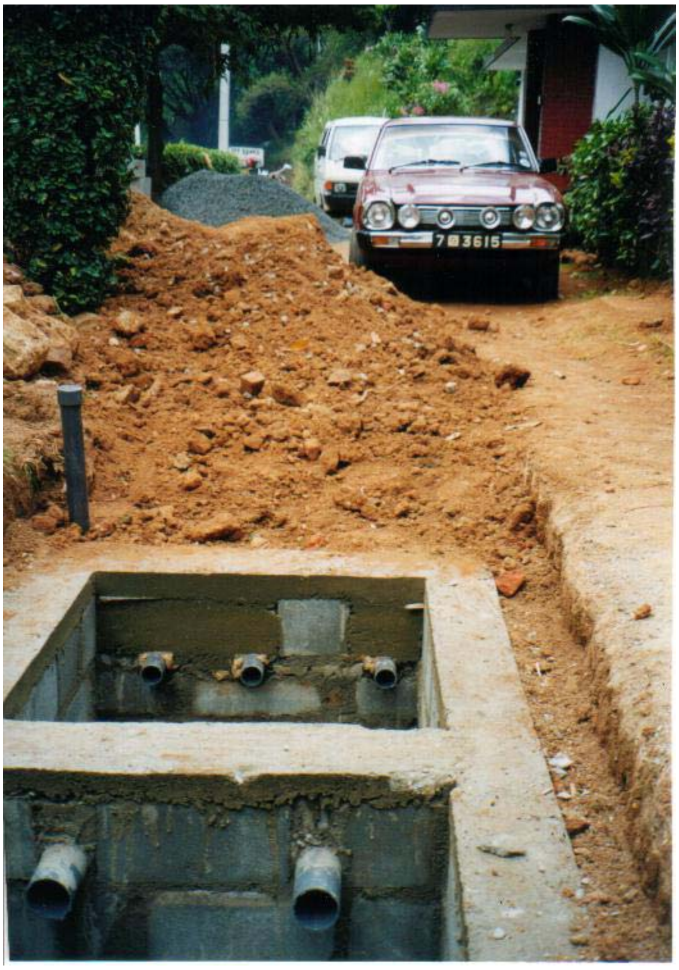

Plate 3-23. The combined septic tank-anaerobic filter unit during construction

Plate 3-24. The percolation bed being laid under the garage floor.

3.5.6. Kings Park

Kings Park hotel is a small upmarket tourist hotel situated beside the Kandy Lake. It has 20 double rooms, a restaurant, and a function room that hosts an average of 700 pax/month. It has 12 resident staff and 8 non-resident staff. It is located on a small, level plot. The water table is less than two metres below ground, as the lake is immediately across the street from the hotel. The hotel previously discharged its grey water directly to the roadside drains and the black water was fed to a septic tank and soakage pit located under the font lawn. However, due to frequent failure of the soakage pit due to the high water table, an over flow pipe had been directed to the drain. It was decided to divert all the wastewater from the hotel directly to the existing septic tank. The soakage pit was removed, and an anaerobic filter and percolation bed was installed under the front lawn. A grease trap and septic tank was built for the kitchen wastewater, under the service entrance of the hotel. The effluent from the kitchen septic tank was pumped to the main septic tank. The effluent from the percolation bed was fed to a VFPGF located on a side of the building. The bottom of the VFPGF was left unlined for percolation of the effluent into the ground, with the excess effluent discharging into the drain.

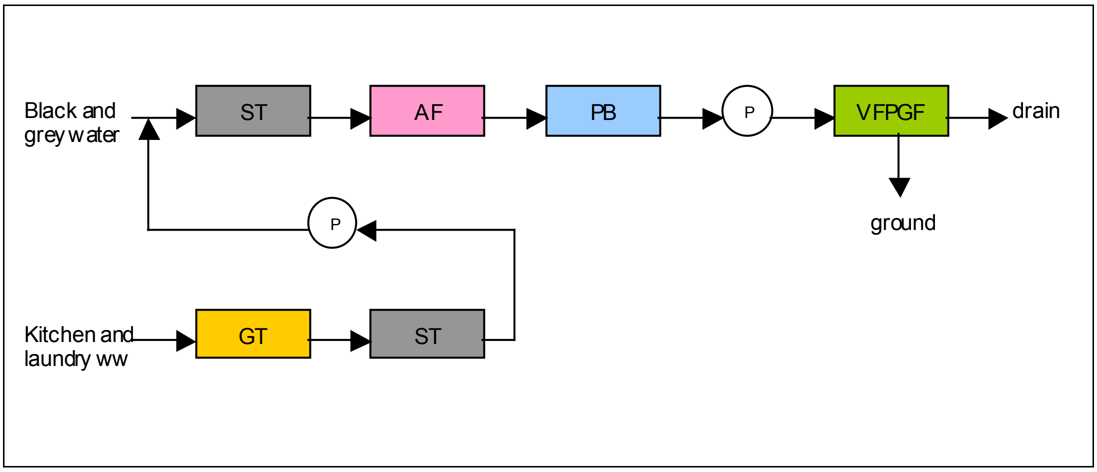

Figure 3-7. Process flow diagram for Kings Park treatment system.

Plate 3-25 shows a view of the hotel building. Plate 3-26 shows the cover slab of the anaerobic filter being laid during construction. The entrance colonnade of the hotel is visible in the upper right of the picture and the front boundary fence on the upper left. The anaerobic filter unit fits in the space between with less than one metre clearance on either side. Plate 3-27 shows the same area after completion of construction and relaying of the lawn. The anaerobic filter lies under the foreground area of the picture and the percolation bed lies immediately beyond, in the background area. Plate 3-28 shows the VFPGF unit immediately after planting and commissioning. Influent dosing is in progress, with the influent being sprayed upwards into the air through the distributor laterals. Plate 3-29 shows the VFPGF unit a few weeks later with the vegetation well established. Broad-leaved plants (C*annas* spp*.,* and *Coleus* spp.) were selected to maximize evapo-transpiration from the bed. This was necessary to minimize discharge of effluent into the roadside drain as much as possible, as the drain was shallow, and of low capacity.

Plate 3-25. A view of the hotel building

Plate 3-26. The cover slab of the anaerobic filter being laid during construction

Plate 3-27. The same area after construction and relaying of the lawn.

Plate 3-28. The VFPGF unit immediately after commissioning.

Plate 3-29. The VFPGF unit a few weeks after commissioning

3.5.7. Coral Sands

Coral Sands is a beachfront tourist hotel located in Hikkaduwa, on the southwest coast of Sri Lanka. The hotel buildings straddle the busy trunk route between Colombo and Galle, with part of the hotel located between the road and the sea, and another part located immediately across, on the opposite side of the road. The hotel comprises 35 double rooms, a small swimming pool, bar and restaurant, a main kitchen and a staff kitchen. It has 10 resident staff and 12 non-resident staff. The black and grey water of the hotel was previously treated in three septic tanks and soakage pits, which were functioning satisfactorily. The hotel required a system to treat the kitchen wastewater. It was decided to install a combined septic tank-anaerobic filter unit under the parking area in front of the hotel building on the land side. The wastewater from the main kitchen and the staff kitchen was pretreated in two separate grease traps and fed by gravity to the septic tank-anaerobic filter unit. The effluent from the anaerobic filter was pumped to a VFPGF located in the rear courtyard. The VFPGF was left unlined to allow percolation of the effluent into the ground. An overflow was provided to the drain for excess effluent in case of a rise in the groundwater table during the rainy season. Figure 3-8 shows the process flow diagram of the system

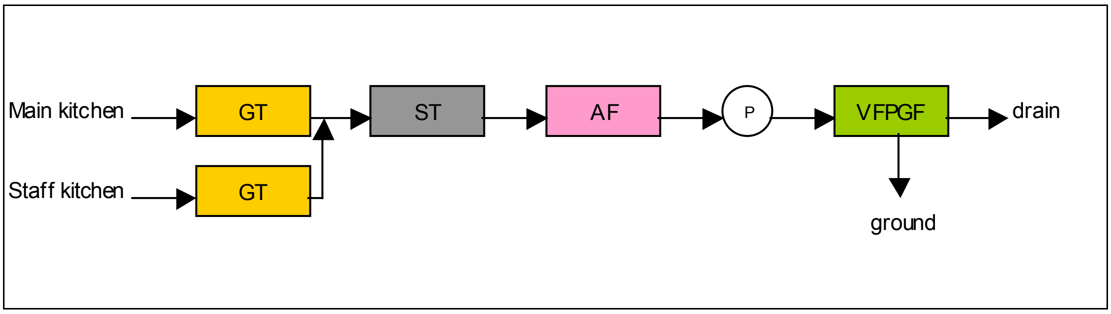

Figure 3-8. Process flow diagram for Coral Sands Hotel treatment system.

Plate 3-30 shows the hotel building located on the seaward side of the main road. The treatment units were located on the opposite side of the road due to lack of space. Plate 3-31 shows the combined septic tank-anaerobic filter unit nearing completion of construction. On the left hand side of the picture is the entrance to the hotel building on the land side of the road. The unit was located immediately in front of the steps and constructed in cement block work with reinforced concrete infill to reduce cost. The access manholes are visible in the picture. These were fitted with heavy-duty covers to withstand the weight of large tourist buses, which are sometimes parked here. Plate 3-32 shows the VFPGF unit with the bed partially laid. A layer of limestone was laid at the bottom of the bed to buffer the pH of the effluent. The limestone layer is visible in the foreground of the picture. The partially laid layer of stone chips, which made up the rest of the bed, is visible in the background. Plate 3-33 shows the VFPGF immediately after planting. Shading of the bed was required, until proper vegetation cover was established, in order to prevent heating up of the stone chips in the bed by the sun. The VFPGF was located just outside the staff accommodation rooms, the windows of which can be seen in the picture. The setback distance was less than a metre.

Plate 3-30. View of the hotel building on the seaward side of the road.

Plate 3-31. Combined septic tank-anaerobic filter unit nearing the end of construction

Plate 3-32. The VFPGF unit with the bed partially laid.

Plate 3-33. The VFPGF unit soon after planting.

3.5.8. Hotel Suisse

Hotel Suisse is a large star class tourist hotel in Kandy, overlooking the lake. It is an old hotel, dating back more than fifty years. It currently has 85 double rooms, 6 shops, a swimming pool, laundry and a banquet hall which hosts an average of 450 pax/month. It has 200 staff, all of whom are non-resident. The kitchen caters an average of 500 meals/day, rising to 750 meals/day during peak season. The hotel had installed an RBC type package treatment plant approximately six years ago. However, it was found that the package plant could not handle kitchen and laundry wastewater, for which the management requested an alternative system. The hotel management had already constructed a small septic tank in an attempt to treat the kitchen wastewater. It was decided to use this existing septic tank and install an anaerobic filter followed by a VFPGF to further treat the kitchen and laundry wastewater. A grease trap was installed to pretreat the wastewater before entering the septic tank. The effluent was to be reused for gardening with the excess discharged to the storm drain. Figure 3-9 shows the process flow diagram for the system.

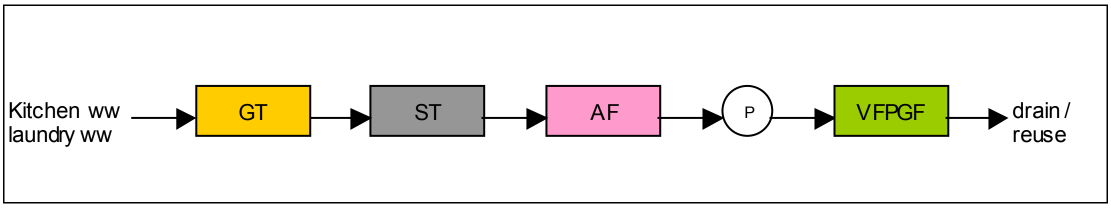

Figure 3-9. Process flow diagram for Hotel Suisse treatment system.

The treatment units were located beside the main hotel building on a patch of terraced garden. Plate 3-34 shows a view of the hotel as seen from a hill on the opposite side of the lake. The steeply sloping terrain is typical of the hillsides surrounding the Kandy Lake. The hotel buildings are in the centre of the picture. The treatment units were located in the garden area immediately to the right of the main building, above the swimming pool, at the third floor level. Plate 3-35 shows the treatment units under construction on a narrow garden terrace. The nearly complete anaerobic filter is visible in the centre of the picture, and the excavation for the VFPGF is partly visible in the foreground. In the background are the windows of the third floor of the hotel building, which open out on to the terrace.

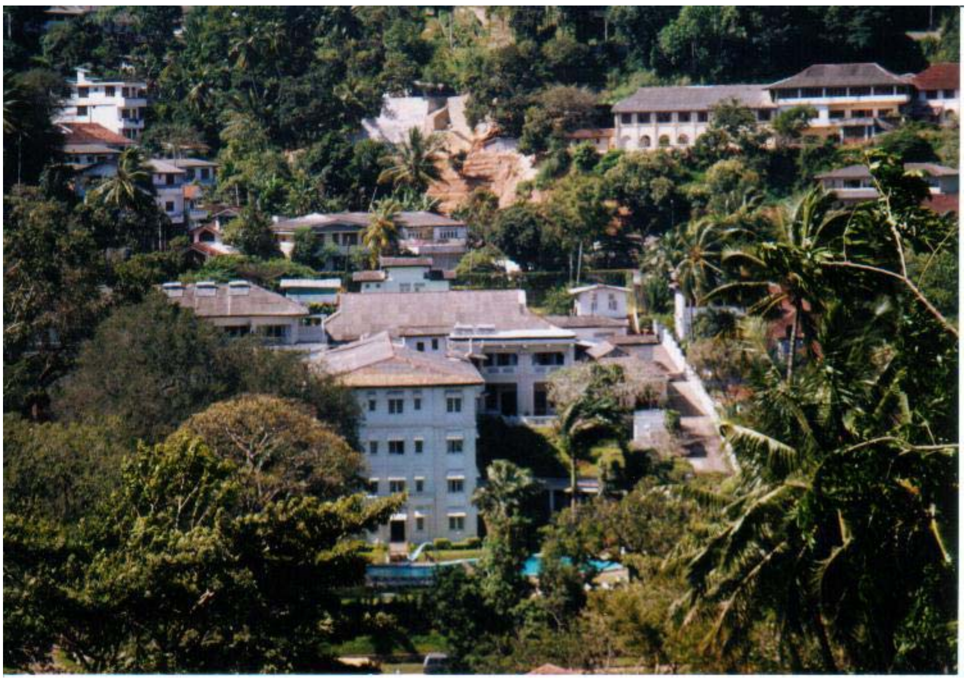

Plate 3-34. A view of Hotel Suisse.

Plate 3-35. The treatment units under construction.

3.5.9. Wattles Inn

The Wattles Inn was a tourist guesthouse in the mountain resort town of Nuwara Eliya. It was due to be upgraded to a tourist hotel, with 30 double rooms, a pool, laundry and restaurant. A completely new treatment system was designed to handle all the wastewater from the hotel. The system comprised a combined septic tank-anaerobic filter unit located under the car park and a VFPGF landscaped into the garden. The wastewater from the main kitchen and satellite kitchen was to be pretreated in a pair of grease traps prior to being fed to the septic tank. The effluent from the anaerobic filter was to be pumped to the VFPGF and the treated effluent reused on-site for gardening and vehicle washing. Figure 3-10 shows the process flow diagram of the system.

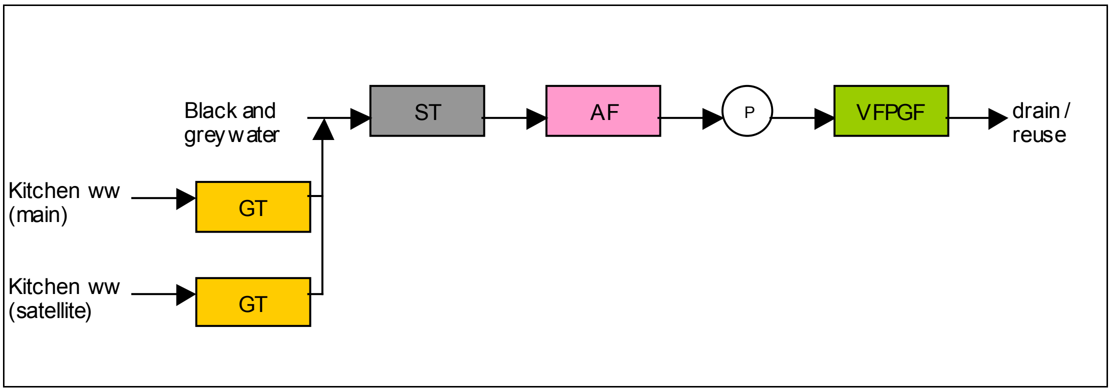

Figure 3-10. Process flow diagram for Wattles Inn treatment system.

3.5.10. Summary of hotel treatment systems

Table 3-6 presents a summary of the hotel treatment systems described in sections 3.5.1 to 3.5.9 above. The population equivalent is based on a flow of 160 l/person/d. The costs are given in year 2000 Sri Lankan Rupees, at a rate of 117 SLR's equal to one Pound Sterling or 76 SLR's equal to 1 US Dollar. The implementation costs given, are the actual construction costs adjusted to year 2000 SLR's. The unit process information given is the design sludge storage period for septic tanks, the design nominal hydraulic retention time for anaerobic filters and the design specific area and bed depth for percolation beds and VFPGF's. ST denotes septic tanks, with KST denoting kitchen septic tanks and MST denoting main septic tanks. AF denotes anaerobic filters, PB denotes percolation beds and VF denotes VFPGF's.

Table 3-6. Summary information of hotel wastewater treatment systems

Treatment system	**Flow m^3/d**	**p.e.**	**Type of wastewater**	**Unit process information**	**Effluent disposal**	**Implementation cost (SLR)**
Swiss residence System 1	22.3	140	Black and grey water other than kitchen and laundry	ST - 2.5 yr. AF - 0.65 d. PB - 0.13 m^2/p.e., 1.5 m bed depth	Reuse for gardening	1,057,000.00
Swiss Residence System 2	7.4	46	Kitchen and laundry wastewater	ST – 5 yr. VF – 0.4 m^2/p.e., 0.6 m. bed depth	Drain	170,000.00
Devon Hotel	17.2	108	Black and grey water	KST – 5 yr. MST – 5 yr. AF – 1.5 d. PB – 0.15 m^2/p.e. 1 m. bed depth	Drain / stream	2,000,000.00
Devon Rest	7.6	48	Black and grey water	KST – 1 yr., AF – 1 d. PB – 0.2 m^2/p.e. 1 m. bed depth	Drain	392,000.00
Hotel Thilanka System 1	49.9	312	Black and grey water	ST – 2 yr. AF – 1 d. VF – 0.2 m^2/p.e. 0.6 m. bed depth	Reuse for gardening, vehicle washing.	1,520,000.00

Hotel Thilanka System 2	27.0	169	Black and grey water	AF – 1 d. VF – 0.2 m^2/p.e. 0.6 m. bed depth	Reuse for gardening	1,280,000.00
Ivy Banks	4.45	28	Grey water	ST – 5 yr. AF – 1.5 d. PB – 0.2 m^2/p.e. 1 m. bed depth	Ground	100,000.00
Kings Park	11.0	69	Black and grey water	ST – 1 yr., AF – 1.5 d. PB –0.11 m^2/p.e. 1 m. bed depth. VF –0.11 m^2/p.e. 0.6 m. bed depth.	Ground / drain	865,000.00
Coral Sands	3.0	19	Kitchen wastewater	ST – 5 yr. AF – 1.5 d. VF – 0.7 m^2/p.e. 0.9 m bed depth	Ground / drain	432,000.00
Wattles Inn	17.3	108	Black and grey water	ST – 2 yr. AF – 1 d. VF – 0.2 m^2/p.e. 0.6 m bed depth.	Reuse for gardening, vehicle washing.	1,070,000.00

3.6. Houses

Treatment systems for individual houses were usually designed at the owner's or developer's request without any pressure from regulatory authorities. In fact, in certain instances, local councils insisted on a plan being submitted with a septic tank soakage pit system in order for planning permission to be granted. The need for an alternative system was usually recognized by either the owner or the builder in order to overcome problems of high groundwater table, or unsuitable soil conditions for soakage, or for the purpose of recovering treated wastewater for on-site reuse. All the houses in this category happened to be urban or suburban middle class houses, which were being newly constructed when the treatment systems were designed and implemented.

3.6.1. Kadugannawa

This was a house being built on shallow bedrock, overlooking a steep cliff, in a quiet suburb of Kandy. The builder envisaged problems with soakage of effluent if a conventional septic tank and soakage pit were to be used. Also, water supply was not reliable at the site, so the idea of wastewater re-use for toilet flushing and gardening was attractive to the owner. A septic tank, reed bed and percolation bed were designed and built to treat both black and grey water from the two-bedroom house. The treated effluent was pumped up to an overhead tank, which supplied the toilets and garden taps through a separate recycled water line. Figure 3-11 shows the process flow diagram of the system.

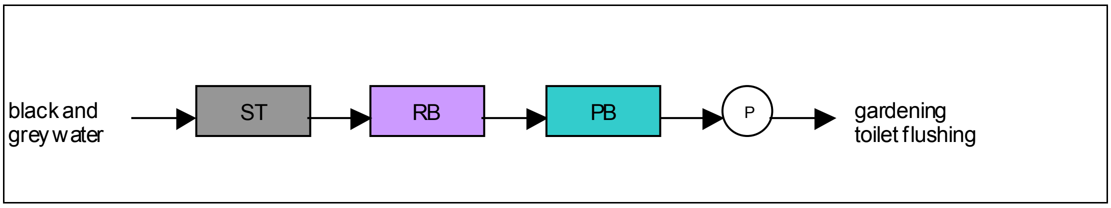

Figure 3-11. Process flow diagram for the Kadugannawa house treatment system

Plate 3-36 shows the house during the early stages of construction, with the site for the treatment units cleared and levelled prior to construction. The land falls away steeply to the right in a near-vertical cliff face. Plate 3-37 shows the treatment system after construction, prior to commissioning. All the units including the septic tank were built above ground due to the presence of bedrock at almost ground level. The percolation bed was kept open. The septic tank unit is on the left, the reed bed is in the centre and the percolation bed is towards the right of the picture. The percolation bed and reed bed were contained in a rubble masonry structure, as rubble was freely available on the site. Several months after commissioning, the percolation bed was converted into a VFPGF at the owner's request, for aesthetic reasons. Plate 3-38 shows the reed bed approximately a year after commissioning. The reeds had been gradually phased out and replaced by flowering plants, mainly *Cannas* spp. and *Coleus* spp. by the owner. The simple swivelling elbow device at the outlet, which is used to control the water level in the reed bed, is visible in the foreground of the picture. Plate 3-39 shows the percolation bed after being converted to a VFPGF.

Plate 3-36. Site for treatment units prior to commencement of construction

Plate 3-37. The constructed treatment system prior to commissioning

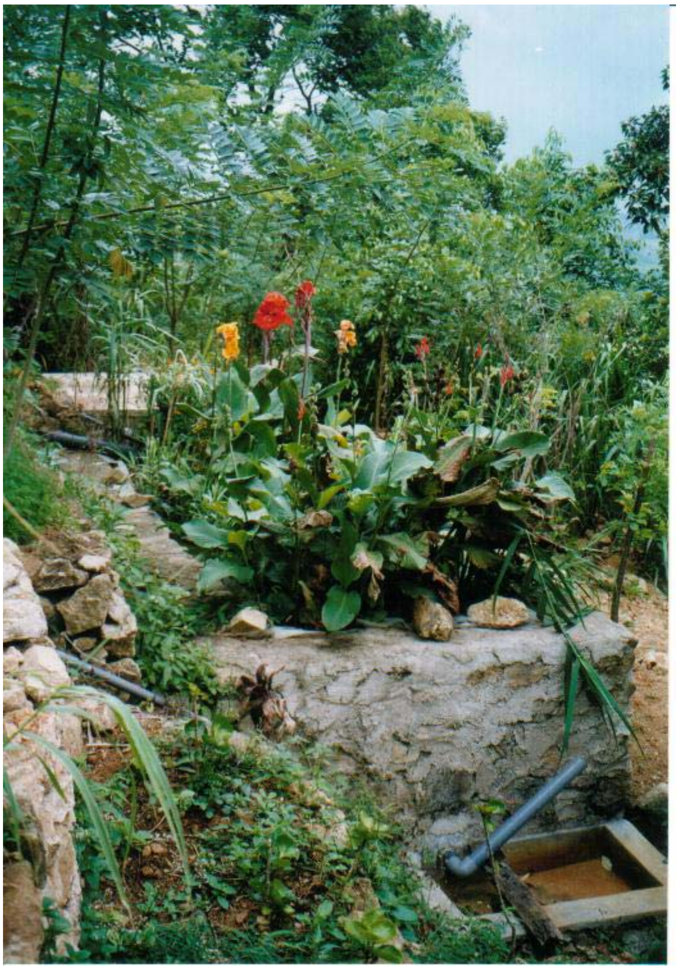

Plate 3-38. The reed bed unit one year after commissioning

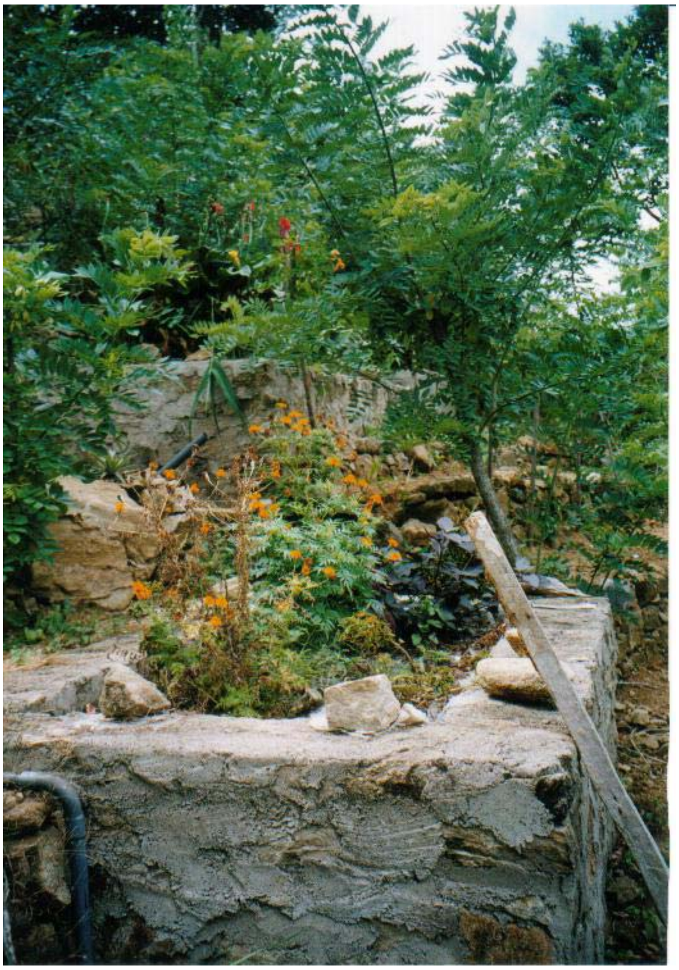

Plate 3-39. The percolation bed unit after conversion to a VFPGF.

3.6.2. Nugegoda

This house was being built in a low-lying residential suburb of Colombo. The area is subject to regular, minor flooding. The groundwater table at the site was about 30 centimetres below the surface. Virtually the entire lot was being built up and occupied by the house. A combined septic tank-anaerobic filter was installed under a small ornamental courtyard, which was virtually the only open space available. The effluent from the anaerobic filter was fed to a shallow percolation bed located under the garage floor. The bottom of the bed was left unlined for maximum soakage of treated effluent into the ground, and an over flow pipe was provided to discharge excess effluent to an adjacent canal. A simple emergency by pass device was provided between the anaerobic filter and percolation bed to divert the anaerobic filter effluent directly to the canal in case the percolation bed were to flood during extreme flooding events. Figure 3-12 shows the process flow diagram of the system. Reuse of effluent for toilet flushing and vehicle washing, though suggested, was not considered acceptable by the owner.

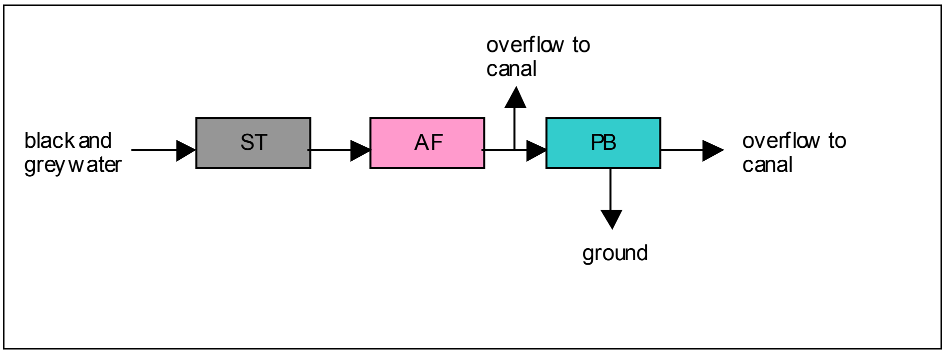

Figure 3-12. Process flow diagram for the Nugegoda house treatment system.

3.6.3. Nawala

This house was being built in a crowded suburb of Colombo. The owner was interested in recovering treated wastewater for toilet flushing and gardening. A septic tank, anaerobic filter and VFPGF were designed to handle all the black and grey water from the house. The septic tank and anaerobic filter were buried under the driveway and the VFPGF was located along an edge of the front yard. Figure 3-13 shows the process flow diagram of the system.

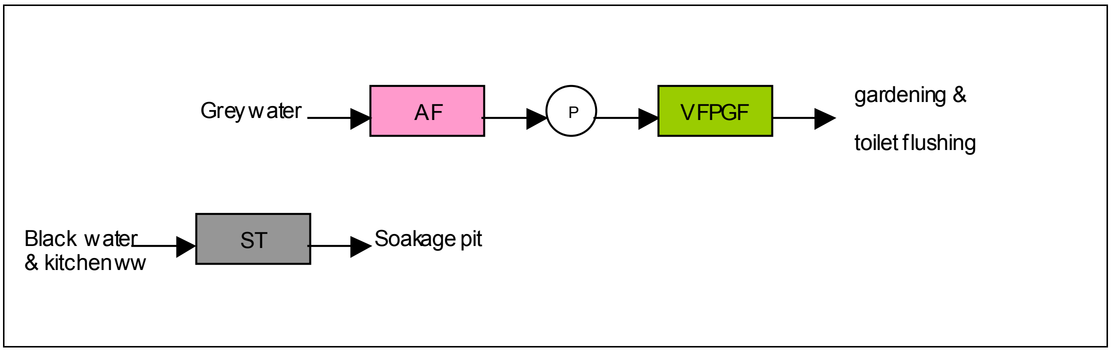

Figure 3-13. Process flow diagram for the Nawala house treatment system.

The black water together with the kitchen wastewater was treated in the septic tank with the effluent sent to a soakage pit. The balance grey water was treated in the anaerobic filter, followed by the VFPGF and the effluent was reused for toilet flushing and gardening. The reason for the dual system was due to the reluctance of the owner to reuse black water.

3.6.4. Kelaniya

This was a house being built in an outer suburb of Colombo. The site had clayey soil, which was thought to be unsuitable for soakage of effluent by the builder. The house also had a well in the yard, which needed to be protected from contamination. A septic tank, anaerobic filter, and percolation bed were designed. All the units were buried under the front lawn, and the treated effluent was discharged to a shallow, unlined roadside drain in front of the house. Figure 3-14 shows the process flow diagram of the system.

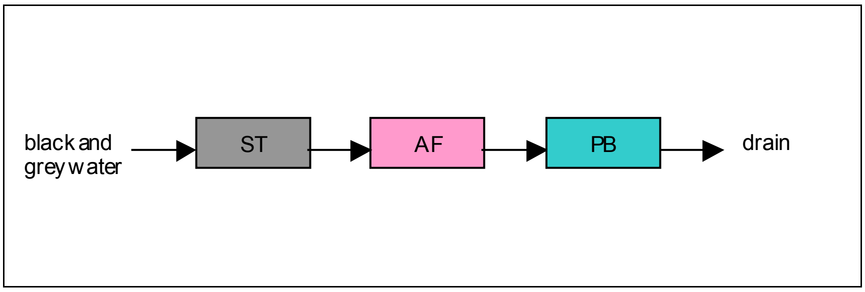

Figure 3-14. Process flow diagram for Kelaniya house treatment system.

3.6.5. Talwatte

This was a small house in a suburb of Kandy, being built on a site with shallow bedrock. The owner recognized the unsuitability of the site for soakage, and requested an alternative system. A septic tank and anaerobic filter were designed and installed, for the house, with the effluent from the anaerobic filter discharging to a drain alongside the property. Figure 3-15 shows the process flow diagram for the system.

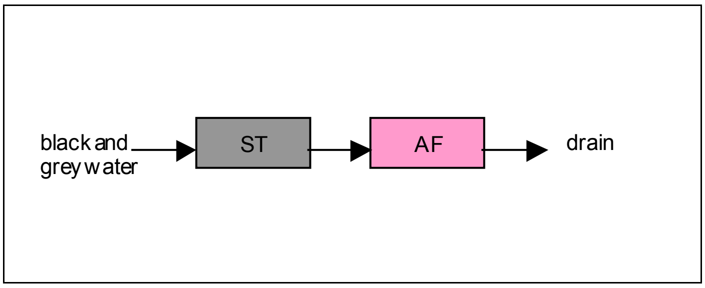

Figure 3-15. Process flow diagram for the Talwatte house treatment system.

3.6.6. Moratuwa

This was another house being built in a crowded suburb south of Colombo. The site was close to the sea and had a high groundwater table with sandy soil. A septic tank, anaerobic filter, and percolation bed were designed and installed. In situ construction was difficult because of the unstable sandy soil and high groundwater table. Therefore, prefabricated polyethylene tanks were buried and used for the septic tank and the anaerobic filter unit. The effluent was discharged to the roadside drain. Figure 3-16 shows the process flow diagram of the system.

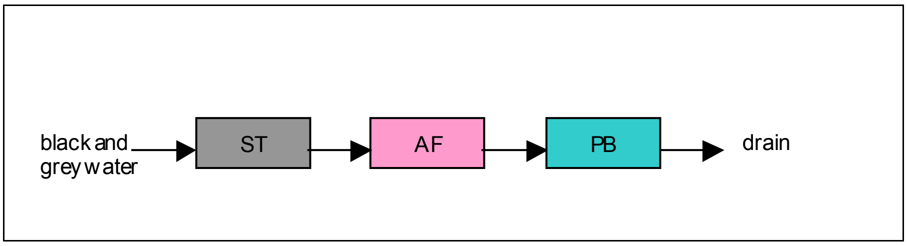

Figure 3-16. Process flow diagram for the Moratuwa house treatment system.

3.6.7. Summary of individual house systems

Table 3-7 summarizes the main features of the systems described in sections 3.6.1 to 3.6.6 above. The design sludge storage period is given for septic tanks, the design hydraulic retention time for anaerobic filters, and the specific area for reed beds, percolation beds, and VFPGF's. All the beds were 0.6 metres deep. ST denotes septic tanks, AF denotes anaerobic filters, PB denotes percolation beds, VF denotes VFPGF's and RB denotes Reed beds.

Table 3-7. Summary of treatment systems for individual houses

Treatment system	p.e.	Type of wastewater	Unit process information	Effluent disposal	Implementation cost (SLR)
Kadugannawa	5	Black and grey water	ST – 5yr. RB –0.4 m^2/p.e. PB –0.2 m^2/p.e.	Reuse for toilet flushing / gardening	100,000.00
Nugegoda	10	Black and grey water	ST –10 yr. AF –0.8 d. PB –0.2 m^2/p.e.	Ground / canal	200,000.00
Nawala	8	Black and grey water	ST –7 yr. AF –0.75 d. VF –0.7m^2/p.e.	Reuse for toilet flushing / gardening	130,000.00
Kelaniya	10	Black and grey water	ST – 5 yr. AF – 1 d. PB –0.2 m^2/p.e.	Drain	130,000.00
Talwatte	5	Black and grey water	ST – 5 yr. AF – 1 d.	Drain	50,000.00
Moratuwa	10	Black and grey water	ST – 5 yr. AF – 0.7 d PB –0.2 m^2/p.e.	Drain	115,000.00

3.7. Housing schemes

Four housing schemes were considered under this category, comprising a total of seven separate systems. Two of the schemes were middle class housing, one was a luxury holiday resort, and one was a low-income community. Two were existing schemes in need of rectification, and two were ‘greenfield’ developments. Wherever possible, simplified and settled sewer systems were considered among the options.

3.7.1. Ranpokunugama

Ranpokunugama was a large, government funded, middle class urban housing development of several hundred housing units, situated in the Gampaha district, 50 kilometres northeast of Colombo. The scheme was approximately 25 years old and had originally been equipped with many large septic tanks and soakage pits serving between 20 to 40 housing units each. However, several of the soakage systems had failed. Two systems were designed and implemented to rectify two of the worst failures. The process flow diagrams of the two systems are given in Figure 3-17.

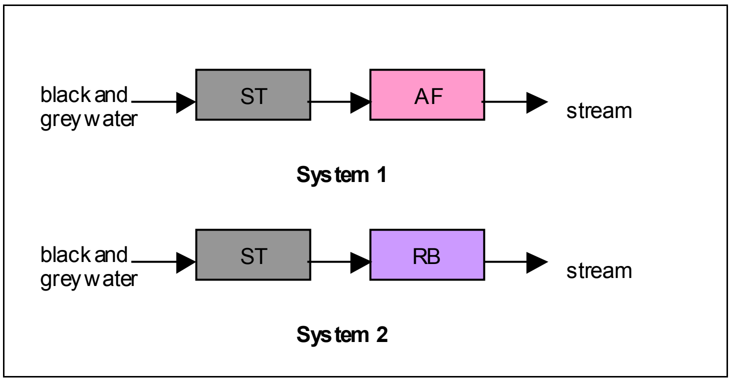

Figure 3-17. Process flow diagrams for the Ranpokunugama treatment systems.

System 1 was to rectify a septic tank with three soakage pits serving 23 housing units in the scheme. The original septic tank and soakage pits were located in the garden of one of the houses. The soakage pits had failed and septic tank effluent was overflowing into the garden and flowing into an adjacent stream. An anaerobic filter, comprising two parallel units, was designed and installed to replace the soakage pits, and the treated effluent was diverted to the stream. The filter unit was located adjacent to the septic tank in the same garden. Plate 3-40 shows the anaerobic filter unit after several months' operation.

Plate 3-40. The anaerobic filter unit at Ranpokunugama after commissioning

System 2 was to rectify a septic tank and three soakage pits serving 30 housing units in another part of the scheme. The original units were located on a patch of bare land adjacent to a stream. The closest dwellings were approximately twenty metres away. The soakage pits had all failed and effluent was overflowing on to the ground and into the stream. As this had been happening for a period of time, the land was sodden with malodorous septic tank effluent. A reed bed system, comprising four parallel beds, was designed and built on the same patch of land to replace the soakage pits. The treated effluent was directed to the stream.

3.7.2. Luisawatte

Luisawatte is a new, lower middle-class, housing development of the National Housing Development Authority of Sri Lanka. With a total of approximately 440 housing units, it would be the densest housing scheme in Sri Lanka. The site is located on a gentle rise sloping down from the centre towards opposite sides of the property. Two systems, comprising septic tanks followed by reed beds, were designed, combined with simplified and settled sewers. A total of 11 septic tanks were designed, each serving between 20 and 55 households. The septic tanks were located at various points in the scheme, and black water from the houses was collected and conveyed to the septic tanks by simplified sewers. Two reed bed systems were designed and located on two sides of the property. Two settled sewer networks conveyed the effluent from the septic tanks to the two reed bed systems. A total simplified sewer length of 3245 meters and a total settled sewer length of 550 metres was installed. Figure 3-18 shows the process flow diagram for both systems. The effluent was to be discharged to a stream on one side, and a drain on the other.

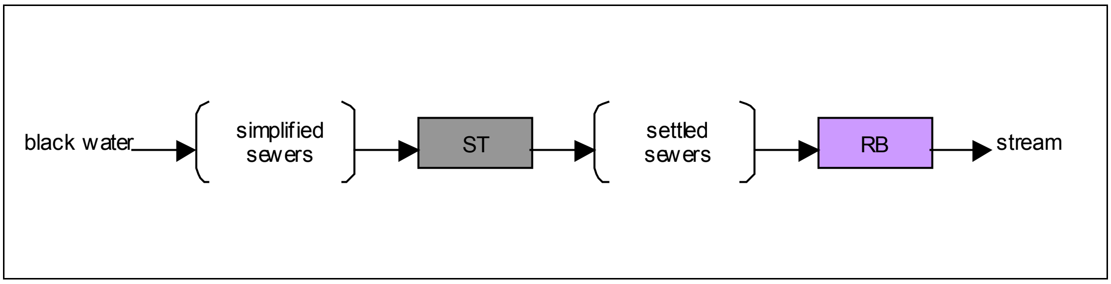

Figure 3-18. Process flow diagram for Luisawatte treatment systems.

Plate 3-41 shows a view of the housing scheme nearing completion. Plate 3-42 shows one of the septic tank units under construction. Hard lateritic soil, which was present below one metre depth at the site, is visible in the picture. This soil is highly impermeable and precluded any option for soakage. Plate 3-43shows one of the reed bed systems during early stages of construction. The beds were contained within cement block work walls, with the individual channels being separated by HDPE liners. Plate 3-44 shows a simplified sewer line being laid along an alleyway, and Plate 3-45 shows the ‘Wye’ junctions with removable cleaning doors, which were used for house connections. These fittings are available locally, and this was the first time they were introduced in a large housing scheme in Sri Lanka.

Plate 3-41. Luisawatte housing scheme under construction

Plate 3-42. A septic tank unit under construction

Plate 3-43. One of the reed bed systems during early stages of construction.

Plate 3-44. A simplified sewer line being laid.

Plate 3-45. House connections with removable cleaning doors during installation.

3.7.3. Ceylinco Leisure

The Ceylinco sports and leisure complex was a private, luxury housing scheme with a central sports and shopping complex, being developed on a 'greenfield' site, in a suburb of the central resort town of Nuwara Eliya. The scheme comprised 16 luxury houses and a central complex containing 5 luxury apartments, sports complex, pool, offices and shops. The site was situated on a hillock with the ground steeply sloping down, away from the centre. Therefore, two treatment systems were proposed, located on either end of the property, in order to avoid pumping of raw sewage. The treatment systems each comprised a septic tank, anaerobic filter, and percolation bed, with the treated effluent being pumped up to a central overhead tank and distributed via a separate recycled water network for toilet flushing, gardening, vehicle washing etc. Since the area suffered from severe seasonal water shortages, the developers welcomed the idea of recovering treated wastewater. The black and grey water from the complex was to be collected and conveyed to the respective treatment sites via a simplified sewer network. Figure 3-19 shows the process flow diagram for the two treatment systems.

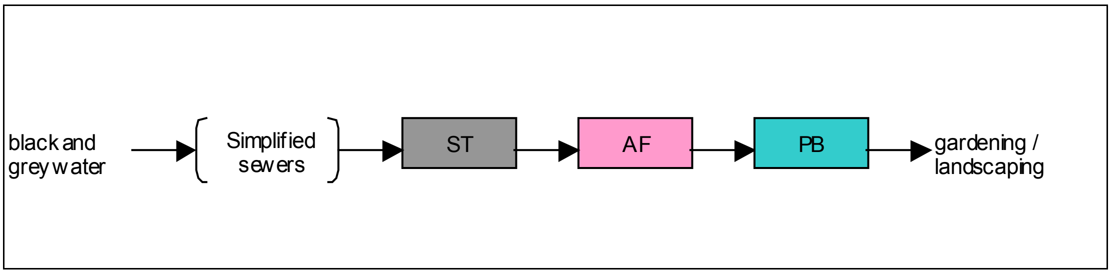

Figure 3-19. Process flow diagram for the Ceylinco treatment systems.

3.7.4. Poorwarama

Poorwarama was a low-income housing settlement situated beside a canal in Colombo. The site had originally been allocated for squatter families displaced by a highway project in Colombo. Each family had been allocated an undeveloped lot of 50 m^2, to build a house for themselves. After a few years, many of the houses were permanent, structures with flush toilets, with an occupancy of up to 10 persons per house. The resulting densely crowded settlement of 110 houses, on a flat site adjacent to an urban canal, had no possibility of individual systems for sewage disposal. A septic tank, anaerobic filter and VFPGF were designed to treat the black water from the scheme. The first two units were located under a community play area, and the VFPGF was located adjacent to the canal to which the treated effluent was to be discharged. A simplified sewer network was installed to collect and convey the black water from the houses to the treatment site. Figure 3-20 shows the process flow diagram for the system. Since the settlement had a strong sense of community spirit, with good community based leadership, it was considered likely that they would adequately maintain the pump and VFPGF unit.

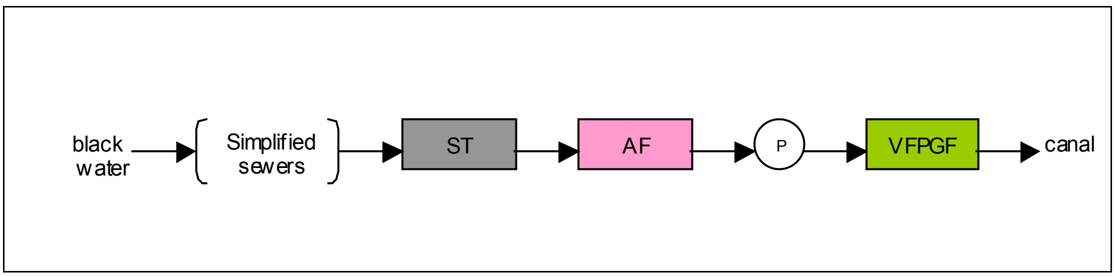

Figure 3-20. Process flow diagram for Poorwarama treatment system.

3.7.5. Summary of treatment systems for housing schemes

Table 3-8 summarizes the main features of the treatment systems implemented for housing schemes described in sections 3.7.1 to 3.7.4 above. The notation is the same as that of Table 3-7.

Table 3-8. Summary of treatment systems for housing schemes

Treatment system	p.e.	Type of wastewater	Unit process information	Effluent disposal	Implementation cost (SLR)
Ranpokunugama System 1	115	Black and grey water	AF – 0.6 d	Stream	300,000.00
Ranpokunugama System 2	150	Black and grey water	RB –1.1 m^2/p.e.	Stream	486,000.00
Luisawatte System 1	344	Black water	RB –0.9 m^2/p.e.	Stream	1,056,000.00
Luisawatte System 2	172	Black water	RB –0.9 m^2/p.e.	Drain	575,000.00
Ceylinco System 1	141	Black and grey water	ST – 5 yr. AF – 0.75 d PB –0.5 m^2/p.e.	Reuse for toilet flushing & gardening	1,300,000.00
Ceylinco System 2	79	Black and grey water	ST – 5 yr. AF – 0.75 d PB –0.5 m^2/p.e.	Reuse for toilet flushing & gardening	925,000.00
Poorwarama	275	Black water	ST – 1 yr. AF – 0.6 d VF - 0.2 m^2/p.e.	Canal	1,650,000.00

3.8. Schools and halls of residence

Four systems were considered under this category. Two were large student dormitories at the University of Peradeniya, near Kandy, one was a University staff hostel, and the other was a residential girls school.

3.8.1. Ladyhill

Ladyhill Hall was formerly a tourist hotel, which had been converted into a University staff hostel about ten years previously. It is located in a crowded residential suburb of Kandy. The original building is about 30 years old. It currently houses approximately 50 people on a residential basis. It has a function hall and guest rooms as well, which when let for functions, results in an occasional rise in occupancy to more than double the normal figure. It originally had a septic tank and soakage pit system for the black water, with the grey water being discharged to the storm drains. The septic tank and soakage pit were located under a small backyard. The failing soakage pit was replaced by an anaerobic filter unit located under the same back yard, while the septic tank, which was originally brick, and in poor repair, was lined with reinforced concrete. The treated effluent from the anaerobic filter was discharged to the roadside drain. Figure 3-21 shows the process flow diagram of the system.

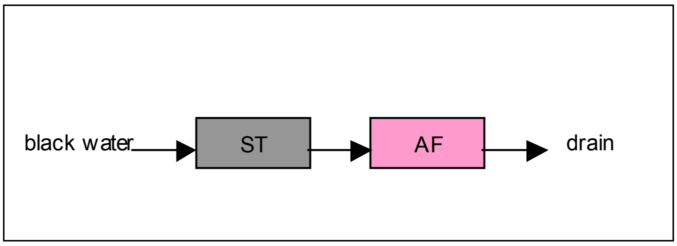

Figure 3-21. Process flow diagram for Ladyhill treatment system.

Plate 3-46 shows a view of the building from the rear. The treatment system is buried under the back yard. Plate 3-47 shows the anaerobic filter unit with clothes hung out to dry above it. The setback distance to the unit and the effluent discharge point from the closest room is less than 3 metres.

Plate 3-46. A view of Ladyhill staff hostel

Plate 3-47. The anaerobic filter unit.

3.8.2. Akbar-Nell Hall

Akbar-Nell Hall is one of the largest student halls of residence in the University of Peradeniya, near Kandy. It comprises four separate dormitory wings and a central wing housing the kitchens, canteen, dining hall, lobby etc. An average of 710 male students are accommodated here. Originally, a number of septic tanks and soakage pits handled the black water from the hall toilets. However, with rise in student numbers to over double the original capacity, the old systems failed. A new system was installed, with seven septic tanks located outside each toilet block. The septic tank effluent was fed by gravity to a two-stage reed bed system, located across the road from the hall, by a stream. The effluent from the reed beds was discharged to the stream. Figure 3-22 shows the process flow diagram of the system.

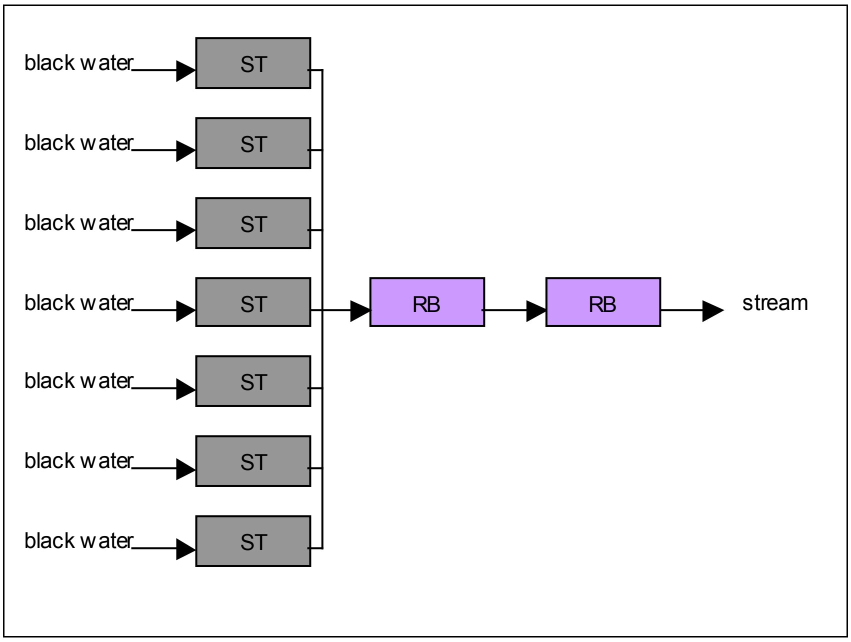

Figure 3-22. Process flow diagram for Akbar-Nell Hall treatment system.

The reed beds were built entirely above ground level, with four parallel channels each, contained within rubble masonry walls. The bottom of the beds was lined with a layer of puddle clay and an HDPE liner, and the beds were laid with stone chips. Plate 3-48 shows one of the reed bed stages after completion of construction, before vegetation was established. Plate 3-49 shows a reed bed channel after establishment of vegetation and several months' operation. Plate 3-50 shows a septic tank being built beside one of the dormitory wings of the Hall.

Plate 3-48. One of the reed bed stages at Akbar-Nell, soon after construction.

Plate 3-49. A vegetated reed bed channel at Akbar-Nell.

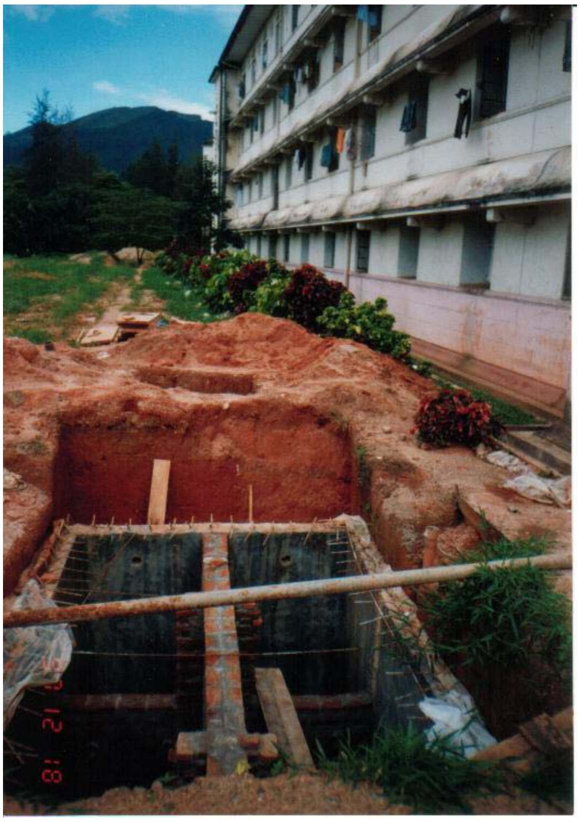

Plate 3-50. A septic tank under construction outside one of the dormitory wings.

3.8.3. Jayathileke Hall

Jayathileke Hall is another student hall of residence. Much smaller than Akbar-Nell, it accommodates an average of 255 students, and is situated in the central, park area of the campus. A septic tank with three parallel units, followed by a reed bed with four parallel channels was designed and built to rectify the old septic tank – soakage pit system, which had collapsed. The reed bed was located in front of the Hall in the lower part of the garden, with the effluent discharged to a nearby stream. The system was designed for black water only. Figure 3-23 gives the process flow diagram for the system.

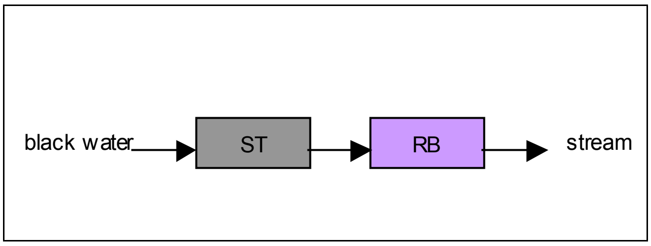

Figure 3-23. Process flow diagram for Jayathileke Hall treatment system.

3.8.4. Kal Eliya

This was a 100 percent residential girls school, situated in the Gampaha district, about 50 kilometres northeast of Colombo. The school comprised a total of 22 buildings with just over a thousand students. The existing system comprised many soakage pits scattered around the premises. Since the school obtained its water supply from a well on the premises, it was considered a priority by the board of management to install an appropriate sewage disposal system. The new system comprised a simplified sewer network, which conveyed the black water and kitchen wastewater to five septic tanks located around the premises, followed by a settled sewer network, which conveyed the septic tank effluent to an anaerobic filter and VFPGF unit situated in a corner of the premises. The treated effluent was to be reused for gardening, with any excess discharged to an adjacent stream. Figure 3-24 shows the process flow diagram for the system.

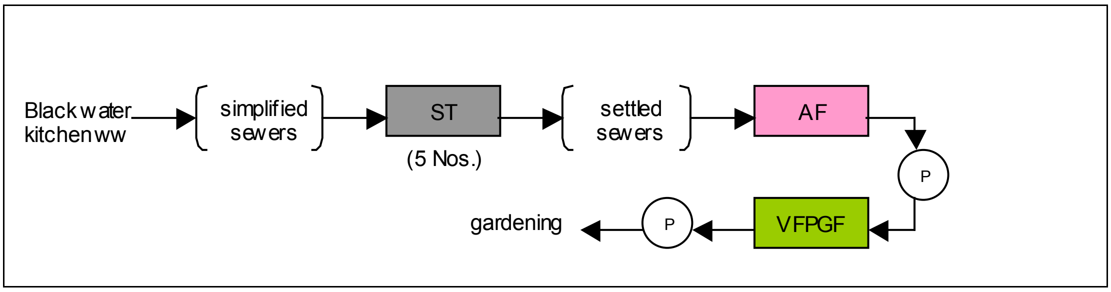

Figure 3-24. Process flow diagram for Kal Eliya treatment system.

The sewer network comprised a total of 500 metres of simplified sewers and 300 metres of settled sewers.

3.8.5. Summary of systems for schools and Halls of residence

Table 3-9 summarizes the main features of the treatment systems described in sections 3.8.1 to 3.8.4 above. The unit process information given is the design sludge storage period for septic tanks, nominal hydraulic retention time for anaerobic filters and design specific area for reed beds and VFPGF's. ST denotes septic tank, AF denotes anaerobic filter, RB denotes reed bed and VF denotes VFPGF. The implementation cost given for the Kal Eliya system, includes the cost of the sewer network.

Table 3-9. Summary information of treatment systems for schools and halls of residence.

Treatment system	p.e.	Type of wastewater	Unit process information	Effluent disposal	Implementation cost (SLR)
Ladyhill	12	Black water	AF – 1.5 d	Drain	65,000.00
Akbar-Nell	160	Black water	ST – 7 yr. RB-1.2 m^2/p.e.	Stream	2,700,000.00
Jayathileke	58	Black water	ST – 7 yr. RB – 0.9 m^2/p.e.	Stream	1,067,000.00
Kal Eliya	325	Black water Kitchen ww	ST – 5 yr. AF – 0.75 d. VF – 0.3 m^2/p.e.	Reuse for gardening	1,900,000.00 (including sewer network)

3.9. Day-time occupancy buildings

This category comprises any building, which is mainly occupied during the day, and discharges non-industrial sewage. A total of six systems are included under this category. The last is a soft drinks bottling plant, where the treatment system was for the staff toilets only. The bottling process had its own wastewater treatment plant.

3.9.1. Avanhala

Avanhala is a building complex situated by the Kandy Lake, which comprises a traditional craft centre, function hall and a restaurant, which also hosts its own functions. The restaurant has a staff of 20 employees, all of who are non-resident. It caters an average of 75 meals per day and hosts functions averaging 350 pax/month. The craft centre and function hall employs 19 staff, of whom 6 are resident. The function hall hosts an average of 650 pax/month. The building had a septic tank and soakage pit to handle the black water, which was functioning satisfactorily. The grey water was previously being discharged to the storm drains. However, due to its location beside the Kandy Lake, the municipal council required the centre to install an appropriate treatment system for the grey water. A combined septic tank and anaerobic filter system was designed and built to treat all the grey water from the building. The system was buried under a part of the garden between the road and the building. Figure 3-25 shows the process flow diagram of the system.

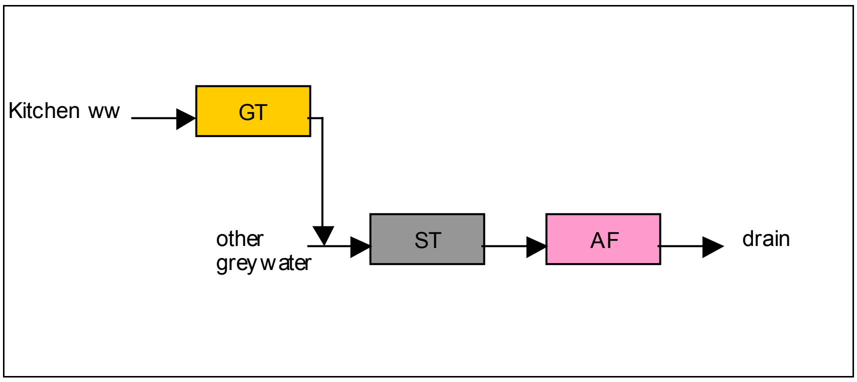

Figure 3-25. Process flow diagram for Avanhala treatment system.

The wastewater from the restaurant kitchen was pretreated in a grease trap before being fed to the septic tank. The treated effluent was discharged to the drain. The entire system was designed to be gravity flow, even though this meant that the septic tank and anaerobic filter unit had to be buried as much as one and a half metres below the ground. This was done because it was not considered likely that the centre staff would be capable of adequately maintaining a pumped system. Plate 3-51 shows the combined septic tank-anaerobic filter unit under construction. The unit was built as two parallel systems. Plate 3-52 shows the access manholes, which were raised by approximately one and a half metres to bring them up to ground level. The building complex is visible in the background.

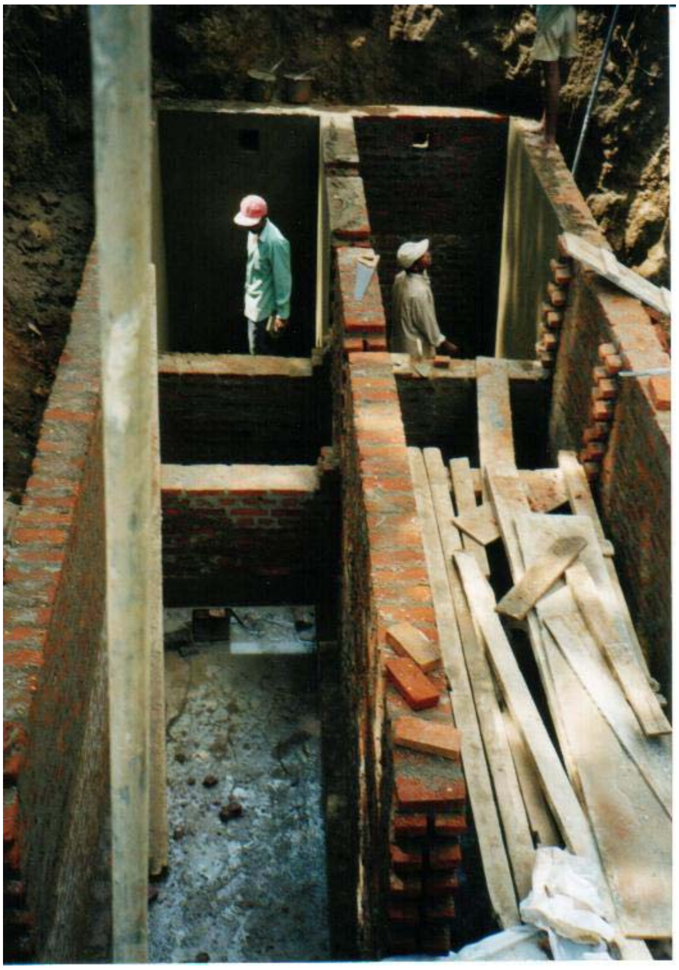

Plate 3-51. The combined septic tank-anaerobic filter under construction.

Plate 3-52. The raised access manholes of the septic tank-anaerobic filter.

3.9.2. Sampath Hall

Sampath Hall is a function hall which is let for wedding receptions, conferences etc., and is located beside the Kandy Lake. The function hall hosts an average of 1000 pax/month. It has no kitchen facilities, and food is brought from outside for the functions. It has a small office on the premises with a staff of five and one resident security guard. It had an existing septic tank and soakage pit for black water only. The Kandy Municipal Council, however, required it to install an appropriate system to treat the grey water, which was previously being discharged to the storm drain. The grey water was diverted to the existing septic tank, and the soakage pit was replaced by an anaerobic filter, located adjacent to the septic tank, under the entrance forecourt of the building. The treated effluent from the anaerobic filter was discharged to the roadside drain. Figure 3-26 shows the process flow diagram of the system.

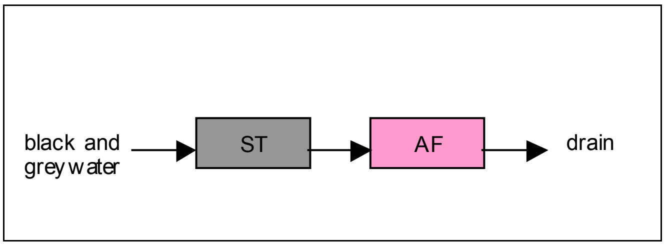

Figure 3-26. Process flow diagram for Sampath Hall treatment system.

Plate 3-53 shows a portion of the Sampath Hall building, with the anaerobic filter under construction under the entrance forecourt. The setback distance to the entrance hall is approximately two metres. Plate 3-54 shows the entrance forecourt after completion of construction.

Plate 3-53. The anaerobic filter under construction at Sampath Hall.

Plate 3-54. The entrance forecourt after completion of construction

3.9.3. Seeduwa warehouse and showroom complex

This was a new warehouse and showroom complex being built in a crowded urban area, beside a main road in Seeduwa, which is a coastal town approximately 20 kilometres north of Colombo. The site was flat, and the groundwater table was approximately one metre below the surface. Noting problems with soakage of effluent in neighbouring properties, a septic tank soakage pit system was ruled out by the design engineer for the project. An alternative system of a septic tank followed by an anaerobic filter to handle all the black and grey water from the complex was designed and installed. The only space available for the units was under the service access to the warehouse, which would be used by heavy container trucks on a regular basis. Consequently the units had to be designed to withstand heavy vehicle loads.

The effluent was discharged to the roadside storm drain. Figure 3-27 shows the process flow diagram of the system.

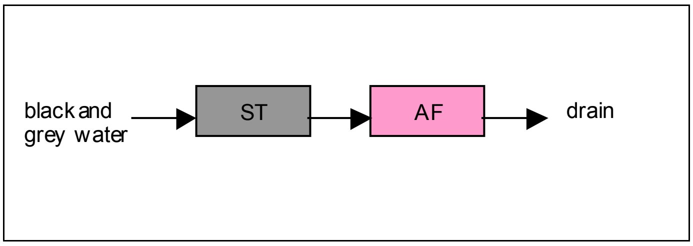

Figure 3-27. Process flow diagram for the Seeduwa treatment system.

3.9.4. Engineering library complex

This was a new library and lecture hall complex for Engineering students at the University of Peradeniya, near Kandy. Approximately 500 students and staff of the Engineering Faculty would use the complex on a daily basis. The site was a former paddy field, with poor drainage, and was often waterlogged. A septic tank followed by an anaerobic filter was designed and installed to treat the black water from the toilets of the building, with the effluent being discharged to a ditch. Figure 3-28 shows the process flow diagram of the system.

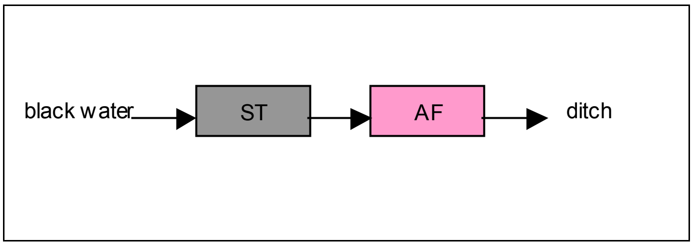

Figure 3-28. Process flow diagram for the Engineering Library complex treatment system.

Plate 3-55 shows a view of the Engineering Library Complex. The septic tank and anaerobic filter are visible in front of the tree in the picture. Setback distances to the building and the frequently used footpath on the left of the picture are less than two metres each.

Plate 3-55. A view of the Library complex.

3.9.5. PGIA library and auditorium complex

This was a new library and auditorium complex for the Post Graduate Institute of Agriculture of the University of Peradeniya. High groundwater table and clayey soil conditions were encountered when excavating for a soakage pit while the building was being constructed. An anaerobic filter was designed and built under a side lawn, with the effluent being discharged to an adjacent storm drain. Figure 3-29 shows the process flow diagram for the system.

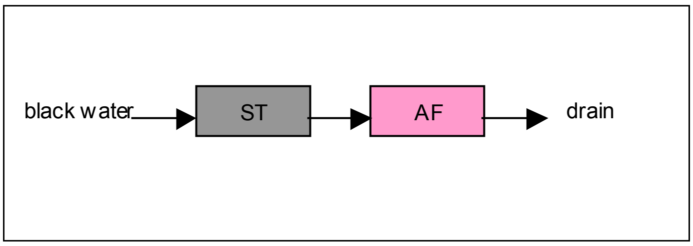

Figure 3-29. Process flow diagram of the PGIA treatment system.

Plate 3-56 shows a part of the library and auditorium complex. The top slab of the anaerobic filter unit is visible on the lawn to the right of the picture. The effluent is discharged to a drain running along the edge of the lawn on the right. Plate 3-57 shows a view of the drain at the point of effluent discharge.

Plate 3-56. A view of the PGIA Library complex with the anaerobic filter beside it.

Plate 3-57. The discharge point of the PGIA anaerobic filter

3.9.6. Ceylon Cold Stores factory complex

This was a soft drinks production and bottling plant, in the northeastern Greater Colombo area. A treatment system was required for the black water from the staff toilets due to failure of the existing soakage pits. An average of 250 workers were employed at the complex. A combined septic tank-anaerobic filter, followed by a VFPGF and a reed bed in series was designed. Additional flow was allowed for in the design, as some of the toilet cisterns were observed to be running continuously, and appeared to be the common condition at the factory. Figure 3-30 shows the process flow diagram of the system.

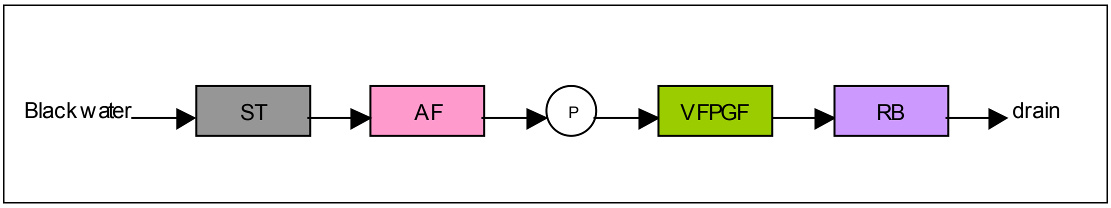

Figure 3-30. Process flow diagram of the Ceylon Cold Stores treatment system.

3.9.7. Summary of systems for day-time occupancy buildings

Table 3-10 summarizes the main features of the treatment systems for daytime occupancy buildings described in sections 3.9.1 to 3.9.6 above. The unit process information given is design sludge storage period for septic tanks, nominal hydraulic retention time for anaerobic filters, and design specific area for reed beds and VFPGF's. ST denotes septic tanks, AF denotes anaerobic filters, RB denotes reed beds and VF denotes VFPGF's.

Table 3-10. Summary of information on treatment systems for daytime occupancy buildings.

Treatment system	p.e.	Type of wastewater	Unit process information	Effluent disposal	Implementation cost (SLR)
Avanhala	36	Grey water	ST – 1 yr. AF – 1.5 d.	Drain	300,000.00
Sampath Hall	11	Grey water	AF – 1.5 d.	Drain	90,000.00
Seeduwa	50	Black and grey water	ST – 5 yr. AF – 1.5 d.	Drain	625,000.00
Engineering library	18	Black water	AF – 1.5 d.	Drain	165,000.00
PGIA	18	Black water	AF – 1.5 d	Drain	85,000.00
Ceylon Cold Stores	113	Black water	ST – 5 yr. AF – 0.75 d. RB – 0.1 m^2/p.e. VF – 0.1 m^2/p.e.	Drain	850,000.00