Auroville

Study on Sustainable Waste Water Management for the Residential Zones I and II

Part Two

-Design Parameters and Recommendations for Treatment Plants, Sewerage and Associated Components-

Jan Imhoff, *Auroville May 2013*

The structure of this study (continued from Part 1)

This study is structured into four major sections. Each section describes an independent activity that forms the basis of the following section.

Part 1. - Surveys and Analysis (completed January 2013)

In this part the base parameters for waste water were established. The existing communities in the study area were surveyed. National and international norms were researched and assessments were made in regard to
a. quantity and quality of wastewater to be treated
b. re-use of recycled water
c. treatment, re-use or disposal of sludge
d. performance of existing treatment plants

Part 2. – Design Parameters and Recommendations (*current volume)*

In this section the findings of the previous chapters are reviewed to formulate the design parameters for
a. New treatment plant(s)
b. Pipe systems
c. Other machinery, pumps
e. Recommendations for upgrading existing plants

Part 3. – Design Concepts

Provides conceptual designs and cost estimates of different choices of treatment systems and system components
a. Treatment plant(s)
b. sewer pipe network
c. and other machinery

Part 4. – Discussion

In this section a detailed comparison and discussion of the options of Part 3 is presented

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Introduction

Waste water is associated by most people with a bad smelling repelling substance that is best not closer examined and disposed off as quickly as possible in the sewer.
But untreated waste water causes pollution in lakes, rivers and ground water, hence treatment methods were devised and specifications formulated so that the waste water should be disposed of safely without degrading the environment
In a time when water becomes more and more scarce the concept of "waste" water has undergone a transformation and it is now viewed as a potentially valuable resource for agriculture and industry. Similarly the target of treatment has shifted from safe disposal to re-use. In tropical-dry countries like Tamil Nadu, India the location of the Study Area, this concept gains even more importance.

If for the layman ever the opportunity offers itself to visit a modern multi stage treatment plant the effort is clearly recommended because it is a fascinating experience. One is able to follow the course of waste water through the plant and observe the transformation from a brownish-grayish liquid into clear odorless water. This is achieved in a series of treatment stages where mechanical, biological and chemical processes are applied to remove and transform the organic and inorganic matter until clean water remains.

A multitude of technologies exist, each with advantages and disadvantages which are mostly expressed in terms of treatment efficiency, retention time, reliability, foot print and capital and operational cost. For different types of waste water different treatment methods can be more, or less beneficial. Similarly geographic location, climate and other factors play a role. Hence there is no single "best" treatment method.

The current Part 2 of the study covers four chapters.
In chapter one a number of treatment methods are described and analyzed as to their suitability for the Residential Zone in Auroville.
In the second chapter guide-lines and considerations are given for the design of the sewage system.
The third chapter gives a description of the status of existing treatment plants in the study area and recommendations for their future operation.
In the fourth chapter recommendations are formulated for the design of the distribution network and for the re-use of the treated water.

In the subsequent Part 3 and 4 of this study three different waste water treatment technologies will be evaluated in detail. For each of them a process chain will be identified. and a conceptual design along with cost estimate will be provided.

Summary and conclusions of Part 1

In the previous part (Part 1) of the study the guide values for the treatment plant were discussed.
The reference values for the design of the treatment plant are given as:

Inlet parameters

PH	6.5-8.5
BOD	250-300 mg/lit.
COD	400-500 mg/lit.
Suspended Solids	200-250 mg/lit.
Oil & Grease	10-15 mg/lit.

It is anticipated that the most likely application of the recycled waste water in the study area will be irrigation. Hence international recognized guide values (WHO) for unrestricted irrigation were adopted as follows:

Effluent parameters – as required for irrigation

E. coli < 10^3 count/100 ml (95% evaluation)
Helminth eggs count < 1 per liter.
BOD5 < 25 mg/l
COD < 125
TSS < 35.0 mg/l
Turbidity < 2 NTU
No unpleasant odor

No limitations for compounds of Nitrate or Phosphorus are prescribed. Their content in irrigation water is considered beneficial for plant growth.
The main restricting factors are e.coli and helmith eggs count as indicators for hygienic requirements.

Quantity

Storm water in the Study Area is to be dealt with separately (percolation at source), hence the treatment plant is to be designed to manage only the domestic sewage. The treatment plant is to be built in phases to provide adequate service as the population grows. Starting from 1000 PE until the final population of 5000 is reached.
The quantity of waste water to be treated per inhabitant is initially assumed with 175 l/PE (1st stage). With higher building density in the Study Area the per capita waste water production will become less. By the time the final target population is reached it can be assumed with to 150 l/PE.

General design considerations of the treatment plant

Typically treatment plants for urban areas are built for large populations, ranging form tens of thousands to millions of PE as they serve entire cities.

There are basic differences in the design considerations of small treatment plants compared to larger plants.
Modern large plants are designed with a high level of process control and automation and often under constraints to minimize the foot print. The additional cost is proportionately small due to the large number of users. Cost of civil works and machinery are subject to economy of scale.
These advantages are lost in smaller plants and thus they have to be simpler in design at the expense of effluent quality, higher maintenance and larger foot print.
More elaborate small systems are being offered as pre-fabricated and/or modular units which are very effective and they have the advantage to be easily installed. They are however quite costly.
These systems are available in sizes ranging from single household to 100-200 PE.
For larger requirements multiple systems can be installed in parallel. In this configuration each module represents an independent treatment unit and a portion of the equipment is being doubled. Beyond a certain size this becomes un-economic.

The proposed treatment plant for the study area is sized in the mid-range. The design concept can either take the approach to up-scale the design of a small treatment systems or down-scale that of a large treatment plant. Some caution has to be exercised as this "scaling" may not always lead to useful results.

The sequence of waste water treatment is typically made up of:
Screening – sedimentation (primary stage) - biological treatment (secondary stage) – sedimentation - filtering, polishing (tertiary stage).
In some cases a treatment stage might be omitted or substituted by another process.
For each phase of treatment numerous different methods and technologies exist and it would go beyond the frame of this study to list every design concept and variation thereof.
In the following a compilation of common treatment methods and technologies is presented and their working principle, advantages and disadvantages are discussed.
They are evaluated to see which process would be the suitable to be adapted in the study area.

Treatment can be achieved by either passing the waste water continuously through a series of trenches and basins while at each point it undergoes a different treatment process, or the waste water is treated in a single tank and different treatment methods are applied sequentially. (see sequential batch reactor)

Considerations for Evaluation and Comparison of Technologies

Provided that all technologies under consideration achieve the required treatment goals then the chief considerations for the evaluation are:

- Proven technology
- Reliability of operation (ruggedness)
- Ease of installation
- Operational requirements – number of persons, level of training
- Maintenance requirements – repair, replacement and spare parts, availability
- Amount of water recovered for re-use
- Expandability (phased construction)
- Cost (capital and operation/maintenance)
- Space requirements
- Nuisance (noise, odor, visual impact)
- Sensitivity to inhibiting substances, recovery
- Additional benefits (water storage, nature enhancement etc)
- Replicable in other communities

In the following discussion the structure adopted in Part 1 is as far as possible maintained:

- description of the technology
- international application
- application in India (see Indian manual on sewage and sewerage treatment)
- Experience in AV

- Followed by a discussion of the advantages and disadvantages of the particular method for the proposed purpose of waste water treatment in the study area

Treatment stages and methods

Screening

At the inflow o the treatment plant there might be a concern that large flotsam or debris in the waste water can cause blockage or damage in the treatment plant. In this case the waste water entering the treatment plant should be directed through a screen or grill.
Physical removal of large sized waste matter at this stage is more efficient than to deal with it at any later stage in the treatment plant. Organic waste of larger size would take a long time to fully degrade and unnecessary extend the sludge processing time. Some plastics do not decay at all.
The screen needs to be cleaned at intervals. A variety of different shapes and arrangements of screens is possible. Chief considerations are to achieve better screening and easier cleaning. For cleaning manual or automated rakes come into use, but also water jets and circulating screens.
The smaller the openings in the screen, the more matter is removed from the waste water, at the same time the screen tends to clog and needs more frequent cleaning.

The raking solids removed from the screen will contain fecal matter and hygienic concerns have to be addressed. Raking goods can be disposed of by incineration or land fill.

Another option is to allow all waste to pass into the primary settler were it is then removed with the sludge and composted. In this case the compost has to be sieved. Since the waste water is of domestic origin the debris size would theoretically be limited to the size of the toilet drains (~110 mm).

Sand removal

Sand and grit in the waste water can cause blockage in the settlers and damage to pumps. Since storm water will not be allowed to enter and mix with the waste water it is not anticipated that harmful quantities of sand will accumulate at the treatment plant.

Flow equalization

Typically domestic waste water generation follows a pattern with periods of peak- and minimum-generations on a 24h cycle.
The size of the study area and the length of the sewage lines of 1-2 km suggest that the flow will not arrive at the treatment plant equalized.
It may also be necessary to flush the sewers at certain intervals to clear the lines. This would cause a peak flow into the treatment plant.
For some treatment processes fluctuations of hydraulic loading can cause a problem. In this case a suitable buffer volume has to be provided. This buffer should retain waste water during times of peak flow and release additional volumes during periods of minimum generation.
Since the flow-velocity is reduced in the equalization tank, solids will start to settle. Waste water left stagnant for more than 1 -2 h without aeration will induce anaerobic processes accompanied by bad smell.
Hence the preferred method to provide the buffer volume depends on the type of treatment in the plant.

a) Anaerobic digester. A covered tank combining equalization with primary settler suggests itself. Gases can be vented off or collected.

b) Aerobic processes. Flow equalization, if needed, should be provided in the secondary treatment stage. Uninterrupted aeration has to be ensured.

Dilution

Sometimes substances are discharged into the sewer that can be harmful for the treatment process if they reach the treatment plant in concentrated form. This could for example be medical residues like antibiotics, or acids and caustics, disinfectants, paints and others. The buffer tank helps to neutralize and dilute these substances. Depending on the position of the buffer in the treatment chain some processes may nonetheless be effected.

Lifting

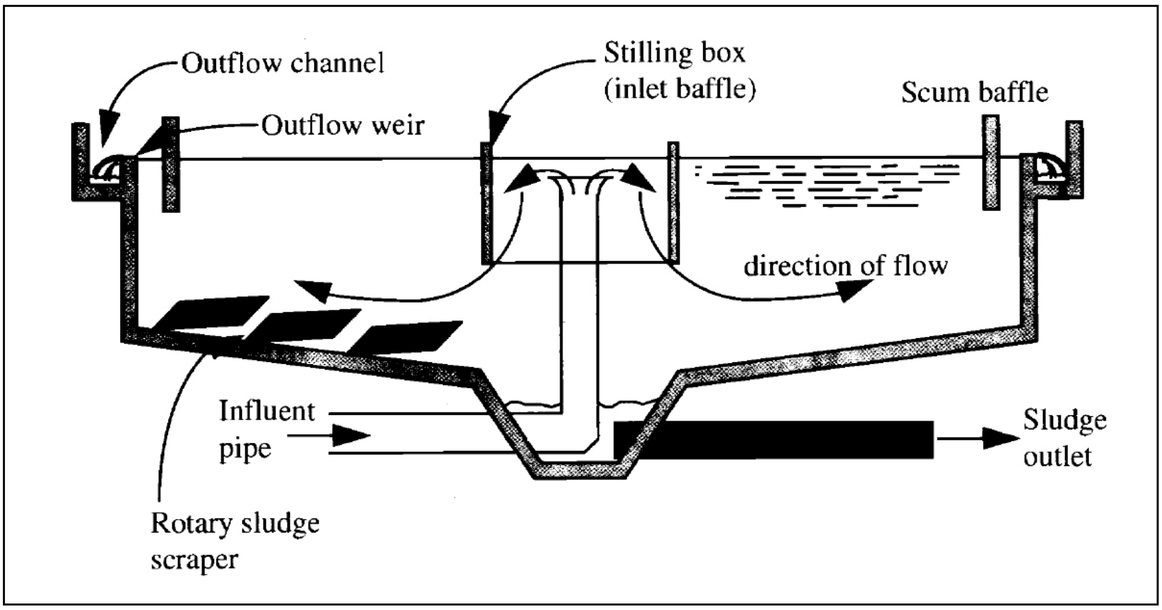
Under the section “pumps” options are discussed to achieve the required hydraulic head within the treatment plant.
In the case that the treatment plant concept requires a pump to increase the water head, then positioning of the pump behind the buffer/equalization would be the preferred location. Uniform flow through the plant can be achieved by adjusting the pumping rate.

Primary Settler

The purpose of the primary settler is to remove pollutants from the waste water by allowing them to sink to the bottom of the basin. This is achieved by reducing the velocity of the incoming waste water flow (<1 m/h). Typically 50-60% of suspended solids are removed in primary settlement tanks. BOD is reduced by 20-50%. The settled sludge can be directed towards a lower central area either by mechanical scraper or the floor is built out slanted so that by gravity the sludge accumulates at the lowest point. From this point it can be pumped off at intervals. The sludge has to be de-watered and further processed.
At the same time floating matter such as oil, fat and foam should be removed and skimmed off in the settler. A submerged wall before the overflow retains the floating matter in the settler.
A variety of different shapes of primary settlers exists. Generally settlers are circular or rectangular shaped basins, three basic shapes and functions are shown below. The direction of flow is either horizontal or vertical (upwards).

Circular radial flow settler

(taken from *EPA ,Publications' Sales, St. Martin's House, Waterloo Rd., Dublin 4)*

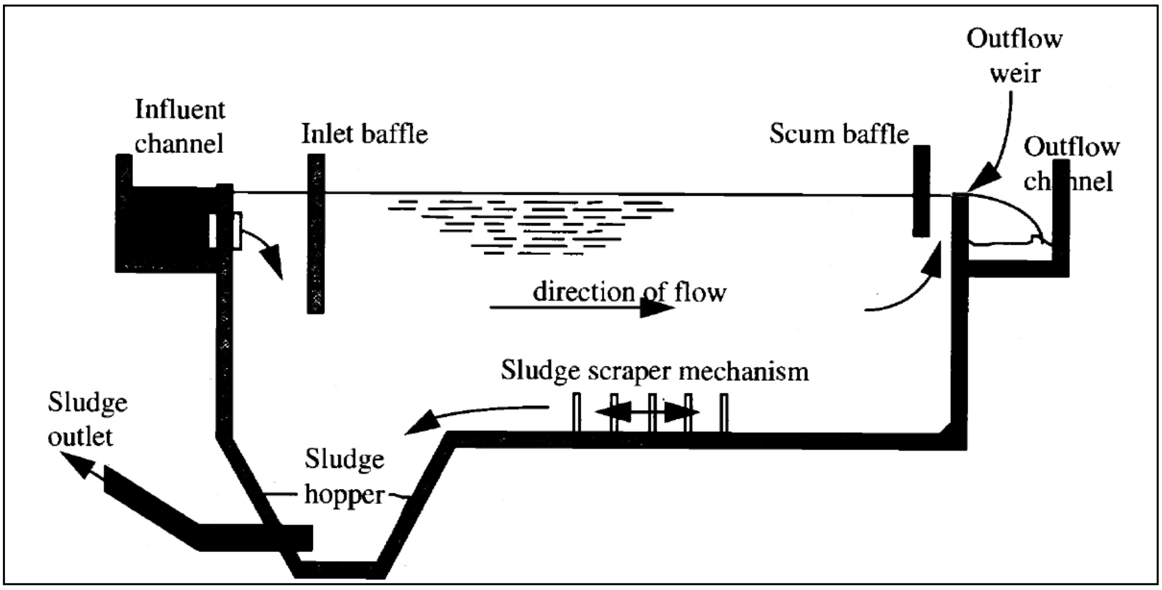


Part	Purpose
Stilling box	Reduces the velocity and distributes flow radially through the tank.

Outflow weir	Ensures equal flow along the periphery of the outflow channel.
Outflow channel	Collects the outflow and carries it to the next treatment stage.
Rotary sludge scraper	Moves the sludge down the floor slope to the collection hopper.
Scum baffle	Extends above the water surface and prevents floating material from reaching the outflow channel. The collected scum is directed by a surface skimmer to a scum box from where it is typically discharged with the excess sludge.

Horizontal flow settler

Section drawing (taken from *EPA ,Publications' Sales, St. Martin's House, Waterloo Rd.,*

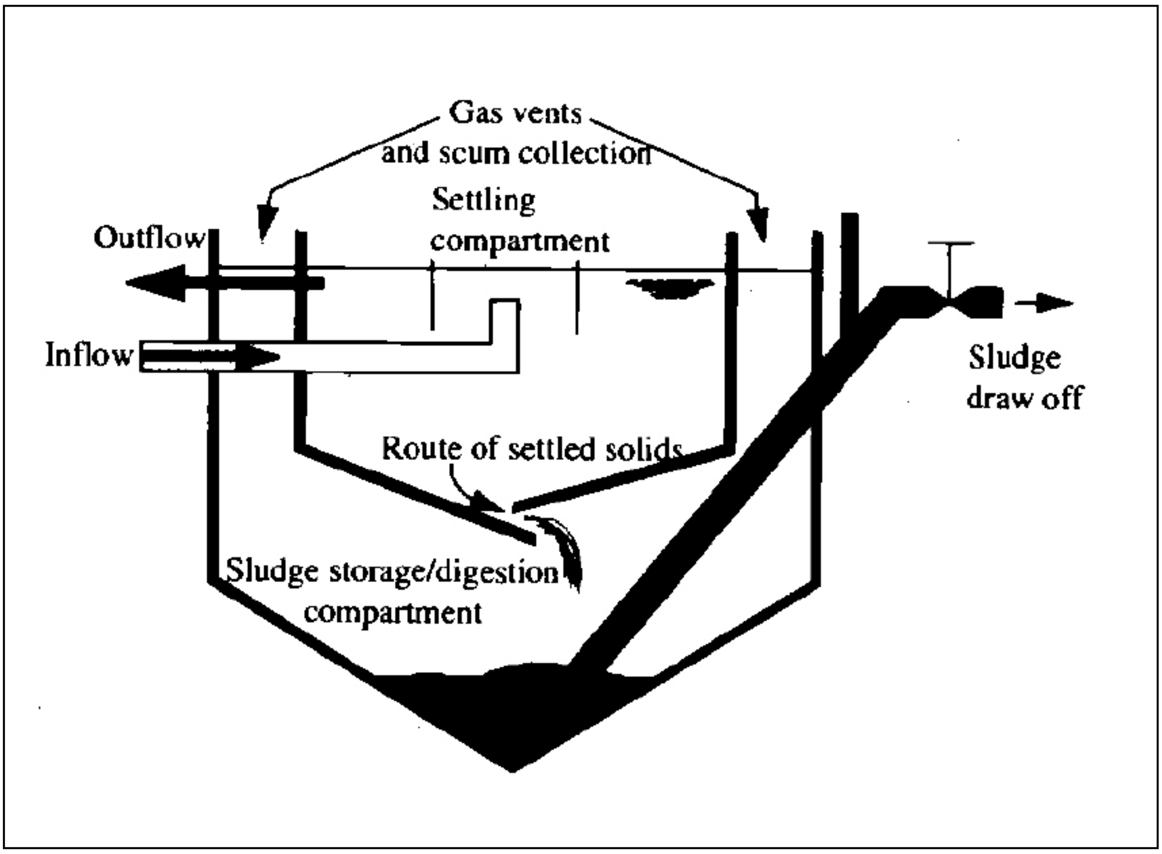


Dublin 4)

Part	Purpose
Inlet baffle	Distributes the inflow evenly and prevents short-circuiting along the tank surface.
Outflow weir	Ensures equal flow along the length of the outflow channel.
Outflow channel	Collects the outflow and carries it to the next treatment stage.
Sludge scraper	Moves the sludge along the floor to collection hopper.
Scum baffle	Extends above the water surface and prevents floating material from reaching the outflow channel. The collected scum is directed by a surface skimmer to a scum box from where it is typically discharged with the excess sludge.

Imhoff Tank

Imhoff Tank is a two storied settler cum sludge digester. Waste water flows through the upper compartment. Solids sink through a slit in the floor into the lower compartment were they are allowed to digest. The compartments are separated by a baffle that prevents digestion gases or sludge particles that rise from the lower section from re-entering the upper section. Gas can be extracted through the gas vent or scum outlet.



The efficiency of the primary settler depends on a number of factors, including:

- Type and source of waste water
- Flow rate.
  Longer retention in the settler allows for more suspended solids to settle. But after some time, as a result of anaerobic conditions, the waste water will start to generate hydrogen sulphide (H_2S), Methane (CH_4) and other gases which rise as gas bubbles. This can counter-affect the settlement of solids.
- Timing of sludge removal.
  Similarly gas will be emitted from the sludge. The sludge has to be removed from single chamber settlers regularly.
- Temperature. The mean temperature in the study area is considerably higher than the usual reference temperature of 15 or 20 degree given in the literature. Hence most bacterial processes will show more rapid growth and at the same time oxygen transfer into the water will be reduced.

The required size of the setter depends on several factors including the type of settler, direction of flow, depth and the nature of waste water.
The optimum retention time for the waste water can be determined experimentally with a settling beacon.
[1]recommends two different methods of dimensioning the settler depending on the predominant type of suspended solids.

1) For flaky particles in basins with a depth in the range of 2 m, a retention time of 1.5 h is recommended.

2) For grainy particles dimensioning is determined based on the surface loading which is given at 1-1.33 m3/m2/hour .

Flow rates are established based on the mean flow during 12 hours daylight.
Dimensioning of the settler of the treatment plant in the study area should follow the 1st method.
Peak flow rates should be verified at the design stage. If they lead to very short retention time then the functioning of the settler would be impeded and make a buffer necessary.

Indian Manual on Waste Water [2] recommends mean surface loading 35-50 m3/m2/day (1.5-2 m3/m2/h), peak loading of 80-120 m3/m2/day (3-5 m3/m2/h) and sites an optimum retention time of 2 – 2.5 h.

Primary sludge is a good feed for anaerobic digestion and bio gas (methane) production,
It is better than activated sludge that has already been substantially digested.

The primary settler can be realized as an open or closed basin.
If it is anticipated that anaerobic digestion will frequently set in (as opposed to occuring occasionally), then the settler should be executed as a closed tank with forced ventilation to prevent foul odors.

The sludge should be removed and de-watered (see further down) and sludge liquor can be returned into the primary settler.

Specialized settler, for example tube and lamella settlers and dissolved air floatation settlers exist. They are designed to reduce the footprint or deal with problematic waste water.

Chemical aided sedimentation

In some cases chemicals such as ferrous sulphate, alum, lime etc can be added to the waste water to improve sedimentation. The chemicals act on colloidals and finely dispersed solids and improve their behavior to form larger particles that settle more easily. Applying this process increases operational costs.
For the proposed treatment plant in the study area a system would be preferred that does not depend on chemicals for sedimentation.

Sludge

Raw sludge formed in the primary settler accounts to about 50% of the total sludge contained in the waste water. When freshly removed it contains 97.5% water. [1] gives the total volume of fresh sludge per PE with 1.8 l/day. When the sludge is allowed to sit for 24 h in the settler (or in a separate tank) to thicken, the volume is reduced to 0.8 l/PE. After 20 days in a digester the volume is further reduced to 0.3 l/PE.

In the final built-out stage of the treatment plant with a population of 5000 PE the primary settler produces a sludge volume of:

V^{2h}_{sl} = 0.5x1.8 l/PE x 5000 = 4.5 m3/day (1a)
V^{24h}_{sl} = 2.25 m3/day (thickened) (1b)
V^{20d}_{sl} = 0.75 m3/day (thickened and digested) (1c)

The sludge has to be removed either by mechanical means (scraper and pump) or by hydrostatic pressure. For the latter the floor/walls of the settler have to be sufficiently inclined so that the sludge slides easily down and collects in the hopper. A low lying outlet is provided to remove the sludge (see drawing ..). The sludge has to be de-watered and further processed.

The values 1a-1c show that with extended retention time of the sludge in the settler there is a substantial reduction in sludge volume. This reflects in reduced efforts of handling and post-processing of the sludge.
Depending on the length of the retention period, additional space has to be provided in the settler for the accumulating sludge. As sludge builds up, the free space in the settler is reduced. This has to be taken into account so that the hydraulic retention time (for the waste water) remains sufficient even when the settler is loaded with sludge.
Because anaerobes digestion sets in, the concept can only be applied in covered systems such as Baffle Reactor and Imhoff Tank.
In open settlers the sludge has to be removed several times per day and processed in a separate closed tank.

Primary Settler in Auroville

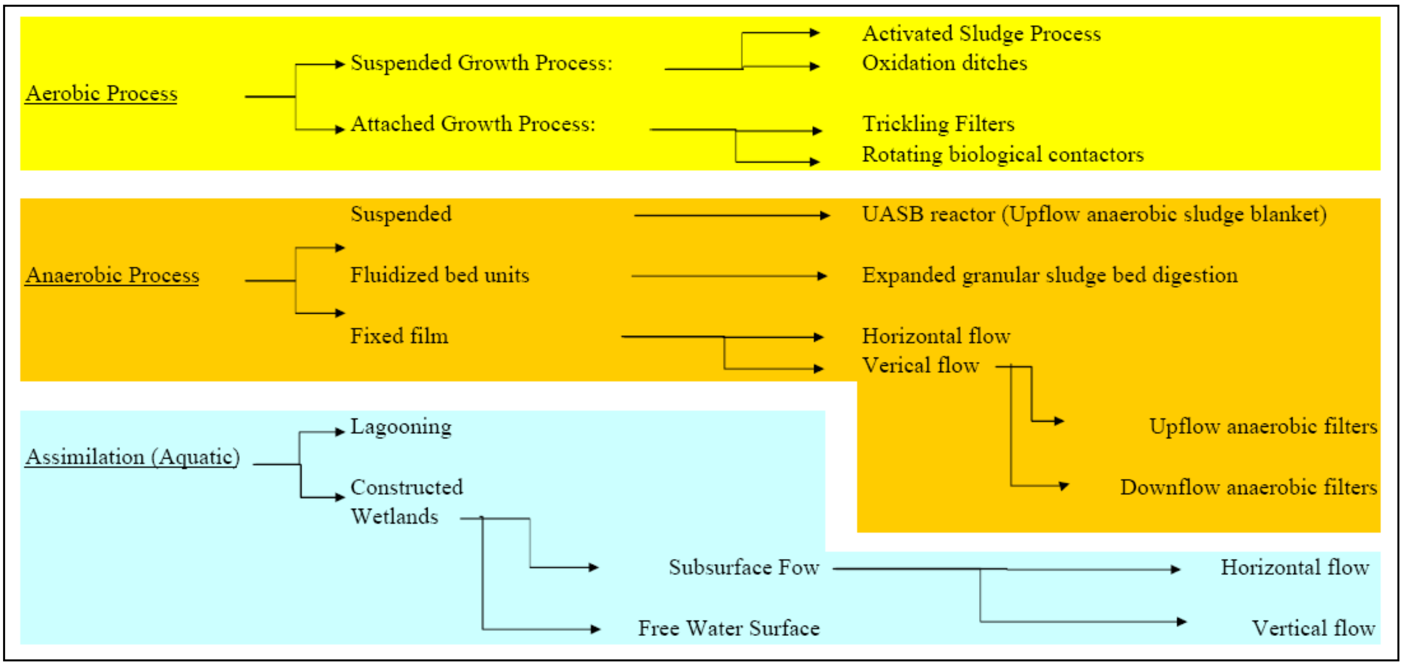
In Auroville a variety of settlers are in use ranging from simple septic tanks to two storied Imhoff tanks. They come into application as pre-treatment stage for planted filters or as stand-alone systems. Several baffle reactors have been built. The system performance varies. (see chapter existing treatment plants) The major shortcoming seems to be the lack of systematic maintenance. Typically the sludge is only cleared once the system is showing signs of malfunctioning such as bad smell, overflowing or blocked inlets. This results in poor performance and the effluent quality is often unsatisfactory.

Secondary treatment

Classification of technologies by type of active bacteria

A multitude of different technologies exists. The classification can be based on different features. Most commonly it is based on the predominant type of bacteria that accomplishes the breaking down of organic components in waste water. These are aerobe, anaerobe or anoxic (mixed).

The sub-classification is based on the method by which the bacteria are brought into contact with the waste water, and a further sub class derives from the direction of flow the waste water takes through the media or tank. This leads to the following diagram.



Another approach is to classify the treatment methods according to their intensity.

Natural techniques,

Processes which can be observed in nature which transform and destroy organic matter are systematically replicated in man-built systems to treat waste water.

- ground filters
- fish ponds

Aided techniques

The same principle as above but the processes are concentrated to operate on a reduced surface area.

- Constructed wetlands
- Reed beds
- USAB

Intensive techniques

Biological processes are further intensified by means of aerating and agitating the waste water. The footprint is further reduced but these techniques require power and operational maintenance.

- Biological Filters
- Rotating Biological Contactors
- Activated sludge

Highly intense techniques

Biological processes are enhanced by techniques like membrane filtration. This involves sophisticated machinery and usual microprocessor control systems.

- Membrane Bio Reactor

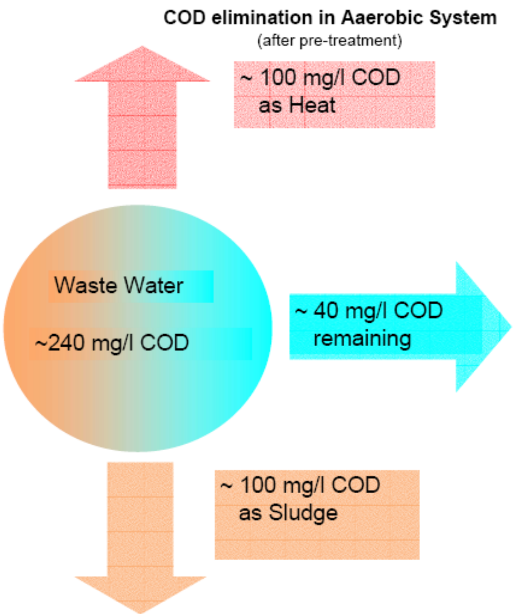
Each technology offers certain advantages, some were developed to treat highly specialized or “difficult” waste water and are not well suited for “thin” domestic sewage.
The following gives a brief description of the processes involved. Technologies which appear most suitable for the study area are described in more detail.

Aerobic treatment chemistry

In aerobic systems bacteria break down organic material like carbohydrates, fats and proteins. During this process they consume oxygen.
These compounds are generally easily biodegradable and provided that there is enough oxygen the bacteria thrive and enjoy high growth rates. Their doubling time can be measured in hours. The two basic reactions can be represented as follows:

$$\textbf{(1) Organic matter} + 0_2 \xrightarrow[\text{enzyme}]{\text{bacteria}} CO_2 + H_2O + \textbf{Energy}$$

$$\textbf{(2) Organic matter} + P + NH_3 + 0_2 + \textbf{Energy} \xrightarrow[\text{enzyme}]{\text{bacteria}} \textbf{New cell material}$$



As cells die off, they turn into sludge.
The heat to sludge ratio in regard to removed COD is in the range of 1:1.
For the purpose of comparison it is in the following assumed that the waste water has passed through the primary settler and remaining COD is in the range of 240 mg/l.
In this process elimination of 85-90% COD can be achieved with indicative ratio as shown above.

Anaerobic treatment

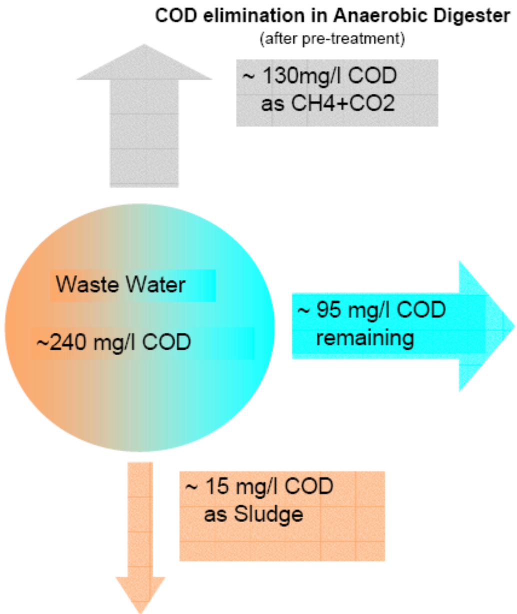
The organic matter contained in waste water consists of carbohydrates, fats, proteins, dissolved and un-dissolved solids. Anaerobic digestion is the fermentation process in which this organic material is degraded in absence of oxygen. Biogas (mainly methane and carbon dioxide) is produced. The waste is dissimilated due to the complex interactions among microorganisms of several different species. Thus the anaerobic degradation pathway is a multi step process of series and parallel reactions.

The stages involved are:

1. Hydrolysis,
2. Acidogenesis,
3. Acetogenesis and
4. Methanogenesis. (for details see EM WATER)

The organic matter in the wastewater is mainly converted to methane, which is a valuable fuel. Very little organic matter (COD) is converted to sludge. The process depends on stable preconditions like constant feed and temperature.

The bacterial process is completed faster in the waste water than in the sludge. Therefore in high rate systems the retention time of the water (10-20 h) is disconnected from the retention time of the sludge (20-30 days). This offers the possibility of higher hydraulic loading.
EM WATER gives the methane to sludge ration as 9:1 of the removed COD.
For pre-treated domestic waste water with a mean COD in the range of 240 mg/l, elimination of 55-65% can be achieved; the indicative COD ratio is shown below.



After treatment the effluent has to undergo further treatment to eliminate E.coli and helminth and to remove odor.
Anaerobic reactions are generally slower than aerobic processes, but they have the advantage to be more resilient in case of toxic freight contained in the waste water (antibiotics, disinfectant etc).

The major advantage of the anaerobic process lies in the fact that it does not require machine- and energy-intensive aeration and offers the possibility of utilizing the bio-gas.

The draw-backs are that the effluent has a higher residue COD and that before the effluent can be used for irrigation it has to undergo further treatment to meet the guide values in regard to hygiene and smell.

Advantages of Aerobic and Anaerobic processes		
	Aerobic	***Anaerobic***
Absolute COD removal	higher	

Rate of COD removal	faster	
Amount of bio gas production		higher
Effluent Dissolved Oxygen	higher	
Vulnerability to pollutants		lower
Recovery after major fault	faster	
Space requirement	less	
Effluent quality	better	
Machinery		less
Power requirements		less
Operational control requirements		less

Although anaerobic digestion is a rather mature technology, poor anaerobic digester performance and system failure still occur, mostly as a result of inadequate operational management. Digester upsets are usually temporary, and in most cases can be solved by taking simple measures. If prompt and adequate measures are not taken, the digester operation will eventually fail. Recovery of a digester can take several months.

Aquatic assimilation

Constructed wetlands are artificial wastewater treatment systems consisting of shallow ponds or channels which have been planted with aquatic plants and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They have impervious clay or synthetic liners and engineered structures to control the flow direction, liquid retention time and water level. Depending on the type of system, they contain an inert porous media such as rock, gravel or sand [US EPA 2000]. Treatment processes in wetlands incorporate several physical, chemical, and biological processes. The major physical process is the settling of suspended particulate matter which is a major cause of BOD reduction.

These systems can be classified as either of two types,

a) free-water surface type; the water level is at the surface
b) subsurface type; the water level is maintained below the surface.

The latter can be further categorized into two sub-types based on the pattern of flow, one with horizontal subsurface and one with vertical subsurface flow (Crites, et. al., 2000). The subsurface type can also be called “reed bed”.

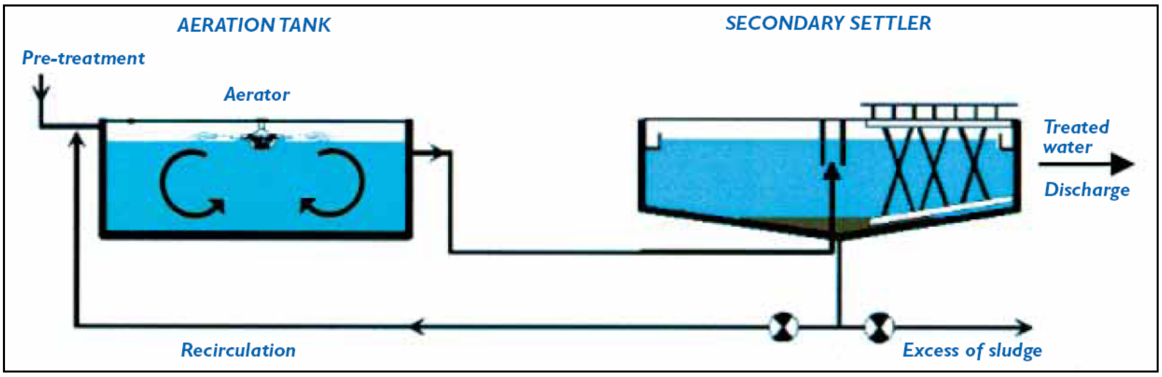
The free-water surface type poses a problem with mosquitoes and due to evaporation a major part of the recycled waste water is lost.

Water loss in subsurface systems is less. Generally the area requirement is about 3-5 m2 per PE. In Auroville, due to high temperatures, a lower value of 2.0-2.5 m2 per PE can be assumed. Nonetheless these systems are space intensive. As principal treatment method (after primary treatment) they are an appropriate technology for small communities in rural and suburban areas.
Several different systems have been built in the study area and other places of Auroville, some of them very successful (see “existing treatment plants”).
In the treatment concept for the planned population of 5000 PE this technology could be considered as additional treatment option (polishing).
Similarly treatment in lagoons, although the technique has been refined in recent years with excellent results, is not further pursued at this point, but rather left as an option for tertiary treatment.

Suspended Growth Process

The Activated Sludge Process is illustrated below. Waste water is introduced into an aerated tank of micro-organisms which are referred to as activated sludge or mixed liquor. Aeration is achieved by submerged diffused compressed air or surface mechanical impellers. The activated sludge is kept in suspension. After a period of contact between the waste water and the activated sludge, the outflow is passed into a secondary settler where the sludge is separated. A part of the sludge is re-circulated into the aeration tank while the excess sludge (due to biological growth) is removed.

(drawing and text Agences de l'Eau , 1999).



In order to achieve the targeted treatment quality three operational parameters have to be met:

c) The concentration at which the mixed liquor is maintained in the aeration tank affects the efficiency of treatment. It is controlled by the amount of activated sludge retuned from the settler.

d) The activated sludge process depends on the activity of aerobic microorganisms. The amount of oxygen added must satisfy the inflow biological oxygen demand
   and
   maintain a concentration of between 1-2 mg/l dissolved oxygen in the mixed liquor.
e) Adequate retention time must be given in the settlement tank to allow good separation of the mixed liquor. Overflow rates are typically 20-30 m3/m2/day.

The ability to respond to changes in inflow loading rates by adjusting the return sludge flow rates is vital to good plant performance. Typically the return flow rates are 50 to 100% of the waste water flow rate for large plants and up to 150% for smaller plants.
If the settled sludge is not returned fast enough to the aeration tank it becomes septic and the treatment efficiency will be affected. The same will happen if the aeration is interrupted for any length of time.
The aeration device must be capable of inducing enough air and of maintaining the activated sludge in suspension in the tank. The power required for mixing varies depending on the tank volume and on the hydraulic pumping efficiency of the aeration equipment. For a rotating impeller in a tank with 500 m3 [1] cites a power consumption of

P=20 W/m3

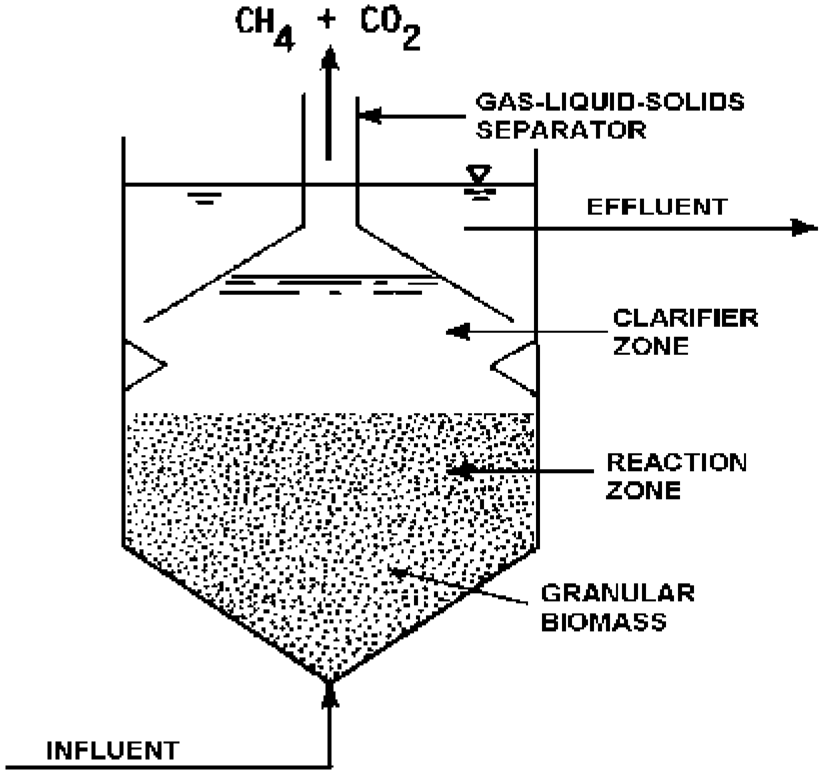
This value is obtained in a cold climate country and will not be exactly transposable to the conditions in the study area.
The power consumption of the return sludge pump has to be added.

According to [1] the required size of the tank can be estimated as follows:
After primary settling the BOD5 = 40 g/PE/d
The mean loading of the aerated tank can be assumed at 1000g BOD5/m3 (without Nitrification)
The permissible load expressed in PE would then be 1000/40 = 25 PE/m3

For 5000 PE an aeration tank of 200 m3 would be required, for example be width x length x depth = 12m x 6m x 2.8m
The power demand for the aeration and mixing would be

20 W/m3 x 200 m3 ~ 4 kW

Up-flow anaerobic sludge blanket reactor (UASB)



Schematic of UASB Reactor (above) [6]

The UASB reactor consists of a tank in which waste water flows in upward direction through an activated anaerobic sludge bed which occupies about half the volume of the reactor. The sludge blanket consists of highly settle-able granules or flocs. During the passage through this blanket the purification takes place by solids removal and then organic matter is converted into biogas and sludge. The produced biogas bubbles transfer to the top of the reactor, carrying water and solid particles (i.e. biological sludge and residual solids). These bubbles strike the degassing baffles at the upper part of the reactor, leading to an efficient gas - Solid separation (GSS). The solid particles drop back to the top of sludge blanket, while the released gases are captured in an inverted cone (GSS) located at the top of the reactor. Water passes through the apertures between the degassing baffles carrying some solid particle which settle there due to increase of the cross sectional area and return back to the sludge blanket, while water leaves the settlers over overflow weirs.
[6] cites an average COD removal is 50-60% at a hydraulic retention time of 18-20 hours.

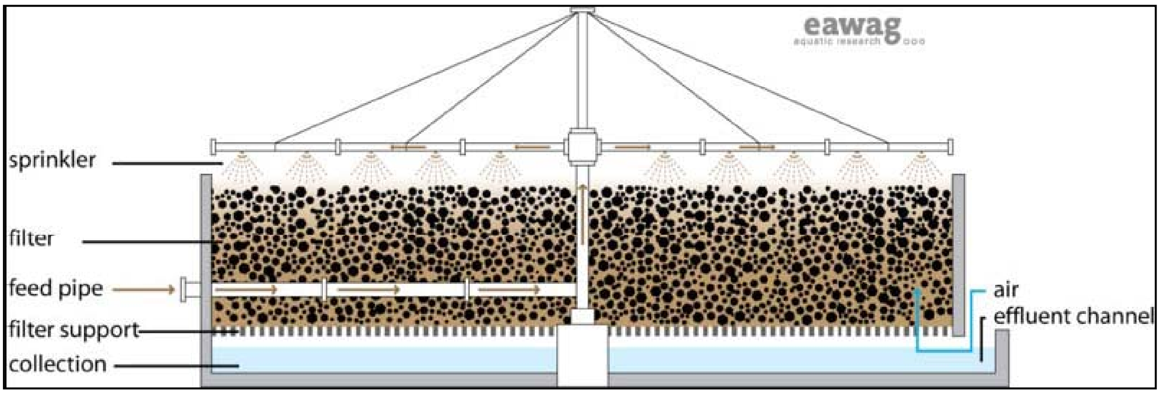
Advantages and drawbacks of anaerobic sewage treatment in high rate systems (below)[6]

Advantages	Drawbacks
No energy is required for the operation. Methane gas can be utilized for energy production. The process can handle high hydraulic and organic loading rates. The technology has a small foot print. The technology is simple in construction and operation Low cost.	Post treatment is required to meet the effluent standards. Considerable amount of biogas, remains in the effluent especially for low strength wastewater. Effluent has no dissolved oxygen and often has a bad odor Produced CH4 during anaerobic sewage treatment is often not utilized for energy production. If released into the atmosphere it represents a greenhouse gas.

Attached Growth Process

Moderately loaded trickling filter

A trickling filter is a fixed bed, biological filter that operates under aerobic conditions. Pre-settled wastewater is 'trickled' or sprayed over the filter. As the water migrates through the pores of the filter, the micro-organisms feed upon and remove the substances contained in the waste water. The media used are highly permeable. The word "filter"
does in fact not imply any straining or separation of solid material. Many variations on the arrangement of structure, media and distribution systems are available.



(drawing source Sandec/Eawag)

Media used include granite or other stone, blast furnace clinker and plastic which vary in size from 4 mm to 200 mm.
A medium is required to have:

- high surface area per unit volume
- low cost
- high durability
- resistance to chemical attack
- consistent size distribution and weight density
- liquid paths which do not easily clog.

Modern media tend to be engineered plastics designed to maximize specific surface area and hence bacterial population.
Waste water is applied to the top of a percolating filter using mechanical distribution equipment. Typically, a rotary distributor, which consists of a central vertical column with two to four arms at right angles to each other, rotates in a horizontal plane above the filter bed. Rotation is achieved by using the applied head of water; 300-600 mm is typically required. Dosing siphons are used to prevent flow when the head falls below that necessary to rotate the arm.
Gradually the layer of micro organism called the "slime layer" becomes thicker until it is sloughed off. Then it is washed out with the percolating water.
At the base of the percolating filter is the under-drain or collecting system. From here the water is directed into a settler to separate the water from the bio film particles.
Oxygen must be supplied continuously either in from the natural draught or blower.
For the proposed waste water treatment plant the low rate filtration would be the preferred method of treatment because it eliminates the worm eggs.

[1] gives the hydraulic loading for low rate filtration as 1.0 m3 waste water per day per m3 filter volume and for high rate at 3.0 m3
[2] gives the following loading parameters

Parameter	Low rate	Intermediate rate	High rate
Hydraulic loading m3/m2 d (1)	1.0 – 3.75	4.0 – 9.5	9.5 – 28.0
Organic loading Kg BOD/m3 d (2)	0.08 – 0.32	0.24 – 0.48	0.48 – 0.96
	(1)Volume of waste water per bed surface area	(2) Kg BOD per volume filter material	

During operation the hydraulic loading can be manipulated by recirculation the outflow. This has two functions:
- to keep the media wet during periods of low flow and
- to maximize the erosion of dead and excessive bio film.

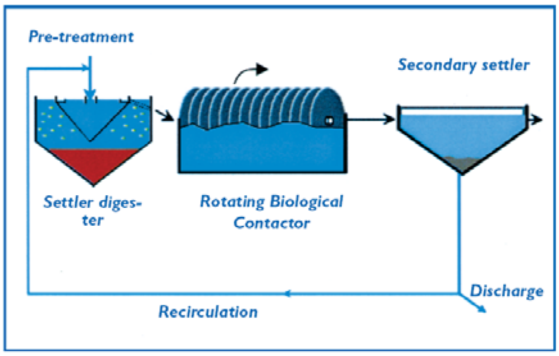
In order to serve the population of 5000 PE, two low rate filters with a 12 m diameter and 3.45 m height would be sufficient.

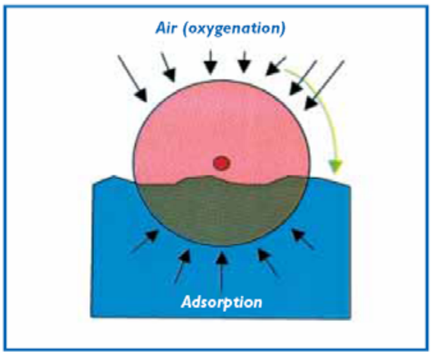
Operational problems that can occur are “ponding” on the percolating filter as a results of clogging of the voids between the media, causing liquid to collect and pond on the surface. An other hydraulic flow problems that can occur is clogging of distribution arms, vent pipes or collection under drains.

The required hydraulic head is the sum of the head required to rotate the distribution arm and the height of the filter. In this case about 4.0 m.
(extracts are taken from EPA Water Treatment Manual)

Rotating Biological contactors

The drawing below shows a schematic of a rotating biological contactors, also termed RBC’s or Biodisks. (*taken from EPA Water Treatment Manual*)





Micro-organisms develop and form a purifying biological film on the surface of the disks. The disks are rotating at 1-2 rpm and are partially immersed, their rotation allows the fixed biomass film to be oxygenated.

The organic load that can be applied (after primary settlement) to achieve the discharge objective (see part 1) is

< 25 mg BOD5/l $\longrightarrow$ 7 g BOD5/m2 d

by applying the organic load of 40 g BOD5/ PE from the earlier example, 5000 PE would require an effective developed surface of

40 g x 5000 PE / 7 g/m2d = 28.500 m2

This is too large to be viable. These systems are generally only adapted for smaller communities.

Advantages of RBC systems are:

- low energy consumption;
- simple operation requiring
- low maintenance
- good settling characteristics of the sludge;
- low sensitivity to load variations and toxins

Pre-fabricated units for up to 750 PE are available.

Submerged (aerated) filters

Submerged filters combine some of the principles of the bio-film and activated sludge processes. A bio-film grows on a submerged medium. An aeration system is required in aerobic processes. (for anaerobic processes see description further down). The direction of flow can be upwards, downwards or horizontal. There is little natural erosion of biomass so backwashing is required at least once per day (for non-nitrifying filters) to prevent the unit from becoming clogged due to excessive biomass growth.
The larger submerged filters tend to be highly engineered units; simpler package versions have been developed for use as small waste water treatment plants.

Loading rates are similar to or higher than those of conventional aeration plants 0.25-2.0 kgBOD/m3 d (2). Hence the size would be similar to that of the activated sludge system.

Table (Upton, 1993) below shows the advantages of up-flow and down-flow submerged filters

	Up-flow submerged filters
Advantages	Good inflow distribution across the bottom of the bed. Reduced localized head loss build-up and increased possible flow velocities. More complete use of the media depth. Suspended solids become trapped throughout the full depth. Wash water reservoir sits above medium so no additional wash water tanks needed. Fewer odors. Off-gases are scrubbed by clean outflow at top of reactor. In down flow, air stripping of volatile compounds can occur with air passing through dirty waste water in the top of the tank. Research on pilot scale has claimed better reaction kinetics probably due to more efficient distribution of air and liquid and hence more effective use of reactor volume.
	Down-flow submerged filters
Advantages	The media acts as a physical barrier to block any debris, such as rags, which could not be accessed at the base of an up flow system. Less intermixing or intergrading of granular media occurs. This allows for more successful stratification for nitrification. Smaller process air volumes and head losses are claimed. Separate backwash water tanks mean a smaller depth of water above the aerators so smaller head losses result. Media and inflow channels are more accessible for maintenance.

Operational problems that can occur are

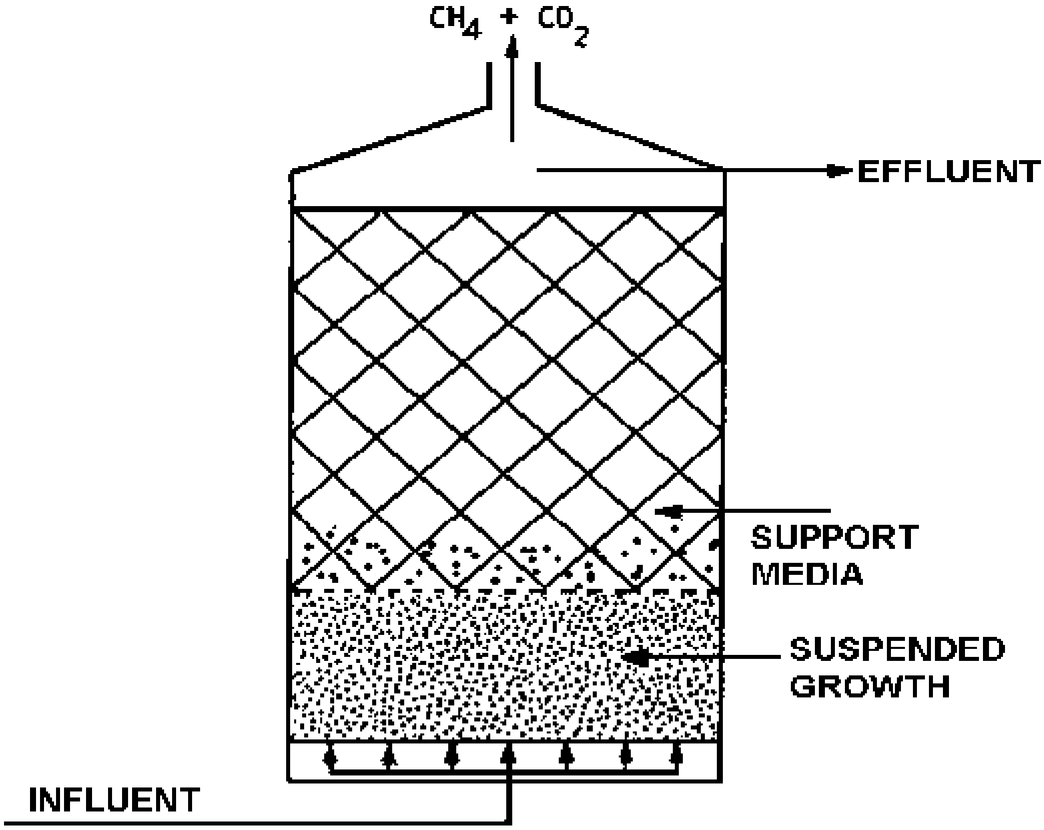
- blockage of the medium or pipes due to sediment or grit buildup, rags, inefficient air or water scour
- uneven distribution of flow between filters.

The difficulty in cleaning a submerged medium once it has become fouled by material such as rags highlights the importance of fine screening of influent waste water where submerged filters are to be used.
The aerobic submerged filter plant will not operate in case of a power failure

Anaerobic filters

Anaerobic fixed-film reactors were developed originally as technology for effectively treating a variety of industrial wastes. In moderate and warm climate countries they have been developed to treat domestic waste water as well
As in aerated filters the direction of flow determines the classification of the filter into horizontal flow, vertical flow (upward or downward). With similar advantages as described above.
An interesting variation is the hybrid reactor design combines a lower section functionally identical to an UASB and an up-flow vertical filter on top, the idea being to combine the strengths of each approach in a single tank. Thus, the lowermost 30 to 50 percent UASB-like portion of the reactor volume is responsible for flocculant and/or granular sludge formation. The upper 50 to 70 percent of the reactor is filled with cross-flow plastic media and behaves as an anaerobic filter.

(from *http://www.engineeringfundamentals.net/AnaerobicFilters/fundamentals.htm*)



Up-flow Hybrid Anaerobic Filter

Aerobic and anaerobic filters in Auroville

A multitude of filters has been built in Auroville.
The most basic concept is the soak pit, which is a rectangular or round masonry box sunk into the ground. The outer walls are slotted and it is filled with broken stones as filter material. The pre-treated waste water is passed into the pit were it filters through the layers of broken stones and then percolates through the slotted wall into the ground. After some time a bacterial layer develops on the filter media and in the earth surrounding the pit. Since the filter is not continuously submerged, bacteria are mostly aerobic.

Baffle Reactor
Several anaerobic filters were built most noticeable the "baffle reactors" by CSR. The water flows through a series of underground tanks which serve as settlers and filters. Detailed research data is available from CSR.

The planted horizontal filters in Auroville are mostly anoxic. In the top layer aerobic bacteria dominate and in the lower submerged parts the process is mostly anaerobic.

Membrane technology

In membrane technology the waste water is pumped through a synthetic membrane with microscopic pores. The pollutants that are too big to pass through the pores are

held back. The purified water passes through. As the pollutants accumulate around the membrane they restrict the flow and have to be washed off either by strong side flow (continuous) or by reversing the direction of flow through the membrane (intermittently). Membrane filters require continuous power supply to maintain the positive pressure on the membrane and for back-washing.
The membrane is suitable for the removal of bacteria and viruses. The membrane pore size dictates the particle sizes which will be removed and will also influence the capital and operating costs.
The table below details the uses of some types of membranes.

Table Membrane type and application

Membrane type	Size (μm)	Suitable to remove
Micro filtration	0.1-1	bacteria and some viruses
Ultra filtration	0.001-0.1	bacteria and viruses
Reverse osmosis	<0.001	bacteria, viruses and inorganic components

Conceptual design should initially decide on the level of disinfection required and then examine the removal efficiencies of the various options.
For example, micro-filtration will remove most viruses and therefore the additional expense of ultra-filtration may not be justified.

Membrane Bio Reactor (MBR)

The MBR is a combination of activated sludge process and membrane technology. It consists of suspended growth basins where membranes are employed for suspended solids separation prior to effluent discharge. More details are given further down.

Sequential batch reactor.

In sequential batch reactors waste water undergoes the different treatment processes in a single tank. The consecutive operations are:
Filling
Aeration (period of bacteria activity)
Settling
Decanting

Advantages are that the systems are small and compact.
Prefab systems of sizes up to 500 PE are available. The system can be expanded by installing several parallel units (battery of systems), or a larger system can be built in situ.

Tertiary treatment - disinfection

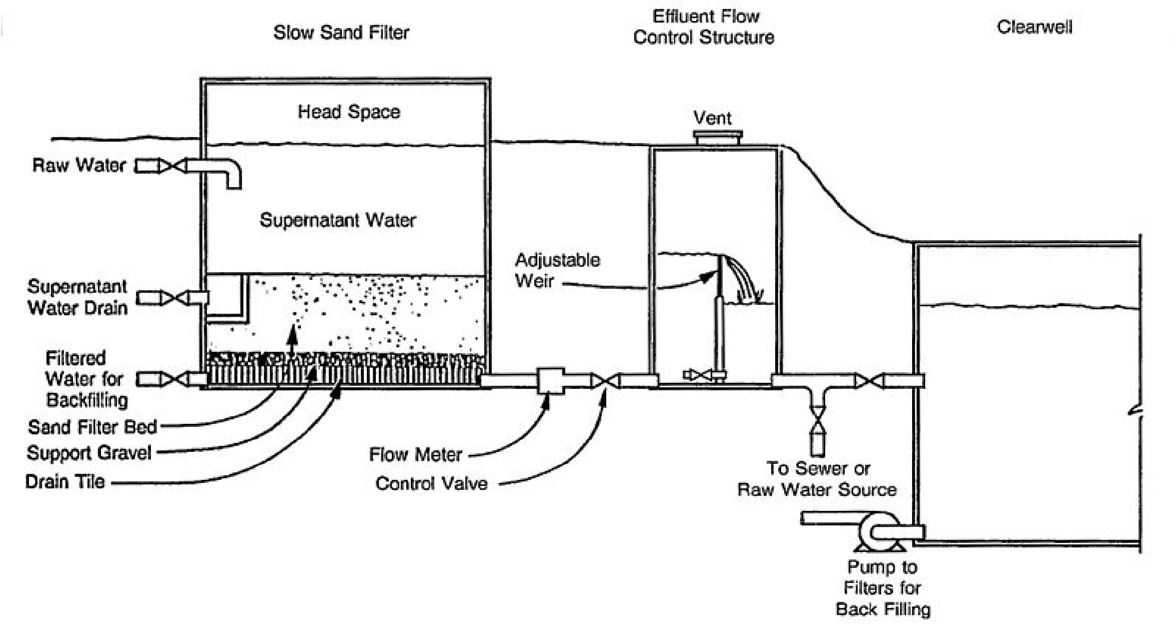
Each of the processes described above for secondary treatment, if properly applied, will achieve the treatment goals in regard to COD and SS removal. However in some cases further treatment is necessary to meet the hygienic requirements to eliminate Helminthes eggs and/or remove remaining odor and coloring.
This can consist of either of the following:

- Moderately loaded trickling filter (described above)
- Low rate sand filtration
- Polishing pond

  or
- A more technological intense method like membrane filtration

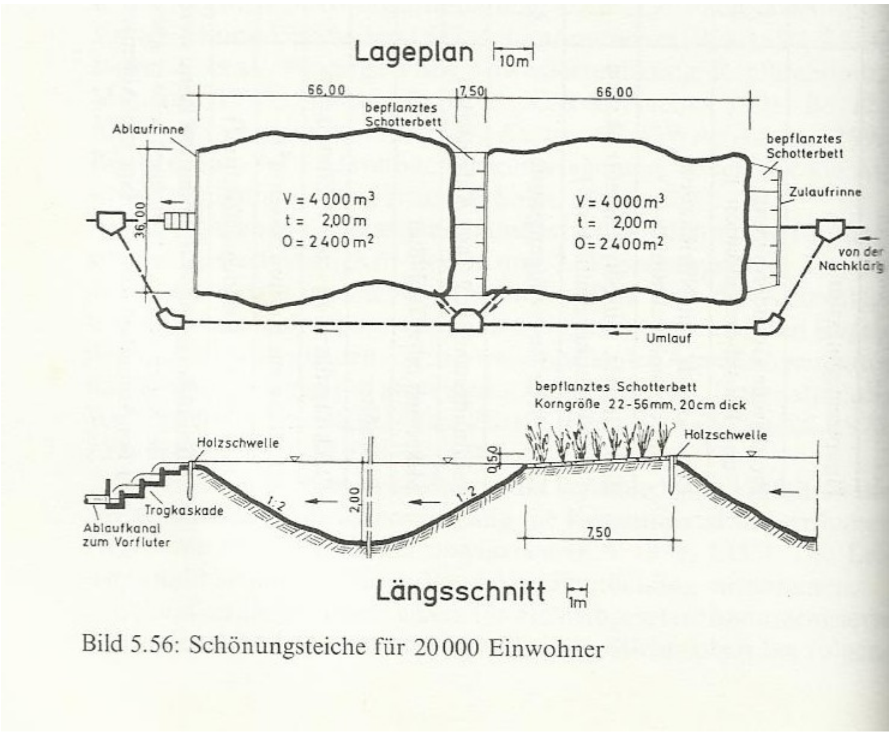
Disinfection through chemicals (chlorination, Ozone or similar) and through UV are not further pursued (see part 1).

Low rate sand filtration *(source EPA)*



Slow sand filters are used in water purification for treating raw water to produce a potable product. They are typically 1 to 2 meters deep, can be rectangular or cylindrical in cross section and are used primarily to treat surface water. The length and breadth of the tanks are determined by the flow rate desired by the filters, which typically have a loading rate of 0.1 to 0.2 meters per hour (or cubic meters per square meter per hour). Although they are often the preferred technology in many developing countries, they are also used to treat water in some of the developed countries such as the UK where they are used to treat water supplied to London. Slow sand filters now are also being tested for pathogen control of nutrient solutions in hydroponic systems.

Polishing pond *(source Imhoff)*



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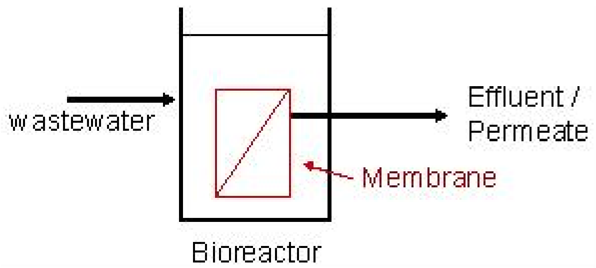
Two polishing ponds separated by a planted filter, designed for 20.000 PE

Polishing ponds are used to improve the quality of effluents from efficient sewage treatment plants like UASB reactors, so that the final effluent quality becomes compatible with desired standards. The residual organic material and suspended solids concentrations in the sewage are reduced, but often the main objective of polishing ponds is to improve the hygienic quality, measured by the concentration of two indicator organisms: helminthes eggs and faecal coli forms.

Membrane Bio-Reactor (MBR) (*source Pierre Le Clech*)



The MBR process combines the use of an activated sludge-bioreactor with a cross-flow membrane filtration loop.
Two types of filtration methods can be distinguished:

a) Internal/submerged

The filtration element is installed in the main bioreactor vessel. The membranes can be flat sheet or tubular or combination of both, and can incorporate an online backwash system which reduces membrane surface fouling by pumping membrane permeate back through the membrane.

b) External/side stream
The filtration elements are installed externally to the reactor, often in a plant room. The biomass is pumped directly through a number of membrane modules in series and back to the bioreactor.

Treatment methods in India

India Infrastructure Report 2011 notes the following about the above systems:
"..The waste stabilization ponds (oxidation ponds, maturation ponds, and duckweed ponds) are most appropriate for small towns having land availability for treatment plants and demand for treated wastewater in agriculture.
In large urban settlements with land scarcity for the establishment of sewage treatment plants and less demand for treated sewage for farm application, mechanical treatment systems viz. activated sludge process, viz trickling filter, UASB, and aerated lagoons are appropriate and produce good results. There are success stories of treatment plants producing reasonably good quality water which is being used in the industrial sector for processes as well as cooling purposes thereby reducing the industrial demand for fresh water…."

Sludge Processing

During primary and secondary treatment sludge is separated from the waste water and accumulates in the settlers. Depending on the treatment method some sludge may be re-circulated (activated sludge process). Excess sludge is removed and further processed. Processing involves de-watering followed by retention of about 20-30 days in an anaerobic digestion. Digestion can be accelerated if the sludge is regularly turned. During this process methane is generated which can be captured for usage. After 20 days in the digester the sludge can be further de-watered and composted. Due to the rainfall pattern in the study area the drying of the digested sludge can not be satisfactory achieved during the period of mid of October to end of December. Hence although the prescribed digestion period is about 20-30 days, the digester has to be dimensioned to handle the accumulating sludge for up to 75 days.

The quantity of sludge that accumulates per capita depends on the waste water treatment process. The volume varies considerably due to the water content. (see paragraph "sludge"). The digester has to be designed to handle the accumulating sludge for the entire digestion period.
Due to the warm climate in the study area the sludge does not require additional heating during digestion.

Similarly since the temperature in the study area is relatively high throughout the year natural drying beds can be used for de-watering and drying of the sludge. Water drained from the sludge should be returned to the primary settler.
[1]gives the following design guide for sludge drying :

Drying beds should have a built up filter of graded layers of aggregate stone, with the lowest layer having the largest stones. The filter thickness is about 25 cm. It is covered with a 10 cm thick layer of sand. Alternatively a layer of bricks can be used to cover the filter. A drainage pipe is laid along the deep end of the bed.
The sludge is brought onto the drying bed in a layer about 25 cm thick. The consistency of the digested sludge when freshly removed from the digester will cause it to float on the drain-water. Hence the sludge liquor can be drained off easily through the filter layer and drain pipe, it is then returned to the settler.
The remaining water evaporates in a matter of days.
The sludge is only brought onto the drying beds fully digested, hence only minimal odor-nuisance will occur on the first day of drying. Flies are not attracted because they find no fresh food. Similarly mosquitoes can not breed on the sludge once it is de-watered. After the sludge is dried it is removed and can be safely used as compost. The sand layer has to be maintained because each time the dry sludge is removed, some of the sand is removed too.

A drying bed undergoes multiple drying cycles during the year. Ideally the drying beds would be operated in a continuous series of cycles of

- Loading with fresh sludge
- Drying
- Clearing of dried sludge

The cycle would only be interrupted for the duration of the winter monsoon (rain). Due to other operational considerations of the treatment plant this may not always be possible. The sludge has to be completely digested before being brought onto the drying bed or it would cause considerable nuisance (bad odor) and attract flies and rodents. Digestion time is typically 20-30 days. This exceeds the drying time. Hence the drying bed may lie unused for some time.
On the other hand considerable quantity of sludge will built up during the rain season when drying is not possible. The drying beds have to be sized accordingly so that they are able to handle the accumulated sludge.

Currently no comprehensive sludge treatment concept exists in Auroville. The sludge removed from the multitude of settlers is brought onto vacant fields or disposed off otherwise.
It should be considered to size the sludge treatment of the Residential Zone so that it can also accommodate the sludge removed from other settlers. In this case a separate sludge digester has to be planned because the sludge from outlying settlers may not always be fully digested. The primary settler of the treatment plant has to be able to handle the additional load through sludge liquor brought from outlying settlers.

[1] gives an indicative size of drying beds of 1 m2 per 6-7 PE. Since this value is for moderate climate it can be set higher in the study area.
It is estimated that for the 1st phase of the treatment plant (1000 PE) two drying beds of 50 m2 each would be required. The beds can be used alternating.

Further methods of de-watering and drying the sludge are centrifuges or filter presses and other high end solutions.

Instrumentation

The treatment plant should be adequately equipped with monitoring and testing instrumentation. This is essential to

- assist efficient and effective operation
- fast fault detection
- determine if corrective measures are successful (in case of unsatisfying performance)
- General performance monitoring (influent and effluent)

Standby equipment

Standby equipment should include a generator for power back up, spare parts for all electrical switch boards and replacement for all types of sludge- and waste water-pumps.

A mobile pump sets to empty tanks and for emergency aeration should be provided.

Renewable energy

The designs should give detail on the use of renewable energy. Bio-gas from the sludge treatment (or other anaerobic phases) can be used to operate gas turbines. Solar Photo Voltaic pump systems should be considered wherever possible.

Design Details of three different treatment plants

Following the detailed description of different treatment method that could come to application, it is proposed that in the 3rd Part of this study the design details for three different systems will be provided:

1) Baffle reactor (USAB, submerged filter, or similar), Vortex (aeration) and polishing pond

2) Primary Settler, low rate trickling filter, polishing pond

3) Membrane Bio Reactor or Sequential Batch Reactor; prefab commercial unit (Chennai)

All three designs should offer a comprehensive process of sludge management.

The design of these systems should be based on Part 1 and Part 2 of this study, in particular:

- Assumptions of inflow quantity and quality of waste water (Part 1)
- Requirements for effluent quality (Part 1)
- Requirement for phased built (Part 1)

The design should offer details on:

- Proven technology
- Ease of installation
- Reliability of operation (ruggedness)
- Operational requirements – number of persons, level of training
- Maintenance requirements – repair, replacement and spare parts, availability
- Sensitivity to inhibiting substances, recovery
- Expandability (phased construction)
- Cost (capital and operation/maintenance)
- Space requirements
- Nuisance (noise, odour, visual impact)
- Replicable in other parts of the community

The design should also provide for

- Intermediate storage of treated water during 24 h for irrigation
- Measures to keep the irrigation water "fresh" during storage
- Details on operational differences during dry season and rain season (de-watering of sludge, effects of temperature, disposal of treated water)
- Alternative means of disposal (ground percolation etc)
- Operation during power outages
- use of renewable energy
- utilization of methane

Each point should be supplemented by conceptual calculations, design drawings and cost estimates.
The design should encompass the entire process of waste water treatment at the site, starting from the point of inflow and ending at the outflow into the pressurized distribution line of recycled waste water, including the processing of pollutants removed from the waste water (sludge).
Management aspects of each process and all resources should be included.

Sewer system

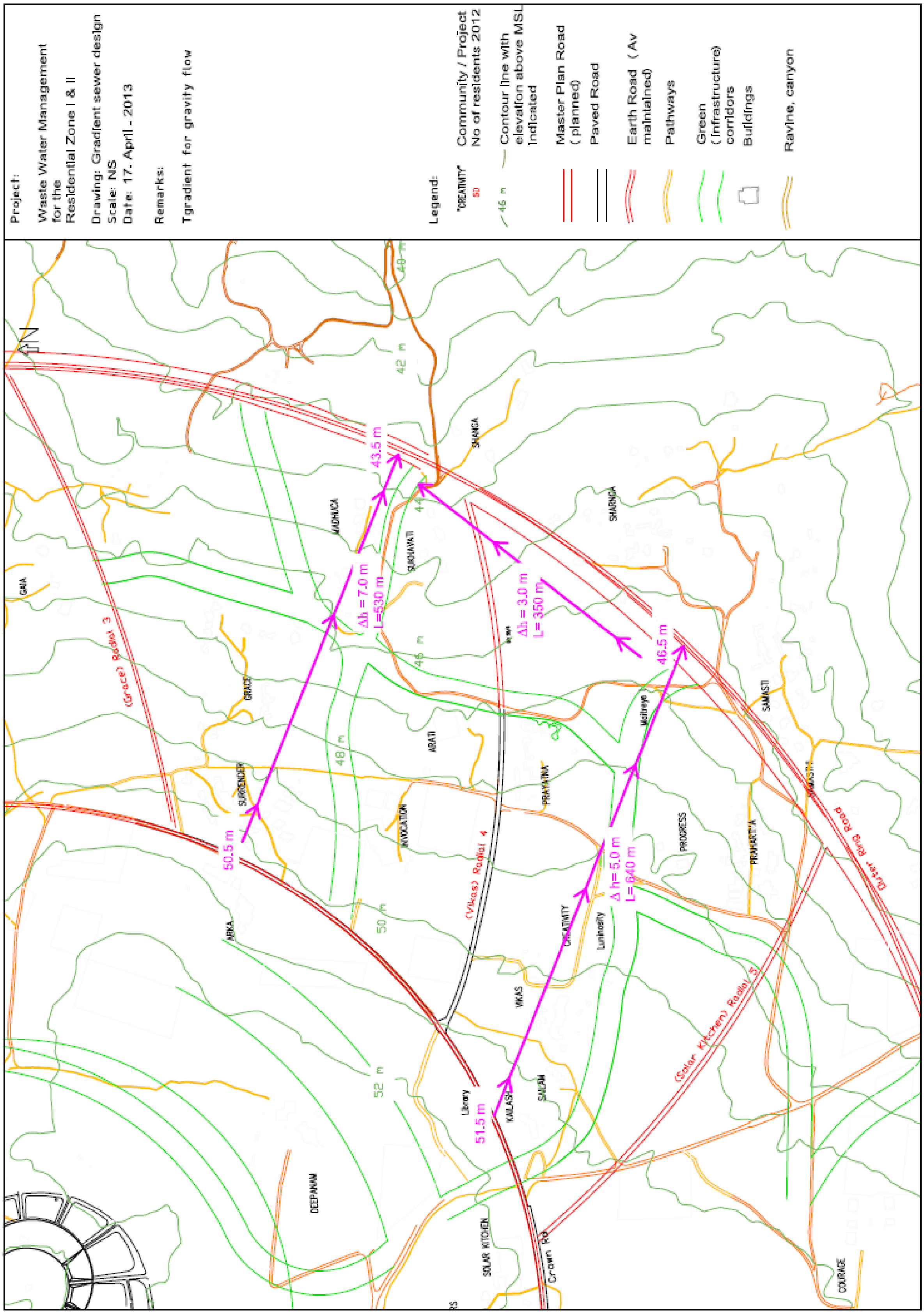
Type of sewer system

The development of the sewer system in the study area is proposed in "sewer separation" method (a separation of sanitary sewer and storm water run-off). Pipes are to be dimensioned to handle only the sanitary waste water.
Combined sewer method is not recommended because it tends to lead to frequent overflows during heavy rains and is underutilized during the dry season.
Hence rainwater should be dealt with independently from the sanitary sewer (preferably retention and percolation on the spot).

The sewer network design.

A gravity flow sewer network consisting of branch sewers and trunk sewer is envisioned. The study area lies on a plateau with an average elevation of 47 m above mean sea level and is slightly tilted from 51 m elevation in the west to 43 m in the east. (see Part 1 Geography)
The sewage system should be designed to flow from West to East. A single treatment plant could be located on the north-eastern corner of the study area. The exact location has yet to be determined.
Sewage pipes should be laid sufficiently deep under-ground so that ground floor apartments in housing projects can connect.
Gravity flow drainage of sub terrain floors (cellars, underground garage facilities etc.) is not envisioned. In such cases pump systems would be installed.

Part One defines the input parameters for the design of the sewer system.
Sewage volumes should be derived from a grid-based density map under the assumption of a mean daily flow of 175 l /PE.



Surface gradient of the study are

Whereas the design of the treatment plant should be modular so that it can be expanded when necessary, the major branch sewers and the trunk sewer should be sized according to the final population estimation. Replacement or enlargement of existing sewers at a later stage is complicated and costly because by-passes for the continuously running sewage have to be built. Peak flow rates should be computed and the design should provide for sufficient additional capacity to allow for a reduction of flow sections due to deposits and to accommodate for development beyond the estimated and planned population. A bare minimum design approach is not recommended.
However pipe diameters should be designed to maintain minimum fill levels. During the initial operation of the sewer system, when the number of connections will be well below the final design population occasional flushing of the sewer system will be required to remove deposits. (Flushing would hopefully be done with re-cycled waste water)

Pipes should be laid maintaining a gradient between 0.4-2.0% to ensure velocity within recommended limits.

A trunk sewer designed to service a population of 2000 PE would under these conditions (minimum velocity of 0.4 m/s, circular pipe profile, half filled, peak flow of 14/24) require approximately a diameter of 330 mm.

Sewer Pipes

Type of pipes - material

A wide range of materials are available. Glazed stone pipes were for many years the first choice because of their resistance to sulfuric compounds contained in waste water (sizes up to 300 mm). Cement/ Concrete pipes come to use, but should have protective coating or lining (purethane, polyurea, HDPE etc) as cement deteriorates under sulfuric acid attack. Resistance is achieved with high alumina cement.
A verity of modern plastics such as nPVC (PVC polyvinyl chloride resins blended with nitrile polymers to provide increased resistance to abrasion), HDPE (high-density polyethylene), GRP (glass-reinforced plastic), PP (polypropylene) come to use. Ductile Iron pipe with hot dip bituminous coating and sometimes cast iron is used.
In addition to chemical resistance the pipes should be resistant to abrasion and to the microorganisms contained in the waste water (early decay) so that a design life of 30 years or more can be achieved.

Pipes have to withstand the load of surrounding earth and traffic load on the surface. Additional protective ducts may be required at road crossings and under pathways.

Importance in the choice of pipe material is to be given to the level of sophistication required for bedding, laying of pipes and jointing.
Joints should be flexible to prevent cracking and loss of seal. They have to be root proof, gas proof and watertight.

Pipe distance to other utility lines

Minimum distance between sewer and other dry utility lines should be observed. This is generally 30 cm (electric, telephone etc).

Special care should be given when designing the alignment in relation to drinking water supply. It is important to recognize that most water supply systems and sewage systems leak. As long as the supply is under continuous positive pressure water will leak out. If the pressure can not be maintained at all times (power cuts, repairs), then contaminated water or even raw sewage could be sucked in.
Therefore due to hygienic considerations sewage pipe should generally be laid below water supply line.

*Indian Manual on Sewerage and Sewage Treatment P*rescribes "…a water supply line must [at least] be 2 m above a sewer line in vertical direction and/or 3m away from the same sewer line in horizontal direction…."

More stringent requirements may be necessary if conditions, such as, high groundwater exists. Generally, water supply line and sewer line are not aligned along the same side of road

Californian Waterworks Standards prescribe:

"..Sewer lines shall not be installed within 25 feet horizontally of a low pressure (5 psi or less pressure) water main.

Water mains and sewer lines shall not be installed in the same trench.

Parallel Construction: The horizontal distance between pressure water mains and sewer lines shall be at least 10 feet.

Perpendicular Construction (Crossing): Pressure water mains shall be least one foot above sanitary sewer lines where these lines must cross.
…"

Connectivity

The study area is still under development and during the coming years many additional branch sewers will be added on to the trunk sewers. A multitude of T or Y junction should be provided in appropriate places. Larger connections should be made as manhole drop, smaller connections as Y or T (turned upwards). Open ends of junctions should be securely capped.
Since it is difficult to foresee the location of all connections a suitable technique should be devised that allows additional connection without interrupting the flow in the trunk sewer. "Saddle joints" would be the preferred options.

An intercepting trap* should be provided at the junction of the house sewer to the branch sewer, so as to prevent entry of odors from of the branch sewer into the house drainage system. Inspection/ cleaning hatches or man holes should be provided at each junction, bend and branch and at a minimum distance of 100 m in straight runs. This is important for fault detection and cleaning. It is preferable to have sewers constructed with a straight alignment between maintenance holes since it is easier to locate a sewer that is running straight
.

Overflow, ventilation and maintenance

Overflow mechanism(s) should be provided to prevent back-flooding into house sewers in case of clogged main sewer. Typically the maximum allowable level of flooding should not exceed 10 cm above road level. If a connections lies below this level, then additional protective valves against back-flow have to be provided.

Ventilation has to be provided. This ensures proper drainage through the pipes and prevents building up of pressure differentials. Stagnating waste water produces methane gases which are flammable, accumulation has to be prevented. Ventilation of branch sewers can be accomplished over the house ventilation connections (over roof top), but should be clearly defined and implemented in trunk sewers via special hatches. Screening has to be provided on all vents to prevent mosquitoes and rodents from entering. In order to consequently implement sewer separation rainwater should be directed away from inspection covers, vents and hatches.

The design should clearly indicate the maintenance requirements, flushing method and periods, inspection etc..

Modular sewer pipe systems with different levels of sophistication are available from different companies.

In order to be able to evaluate the advantages of different designs it is proposed to provide the conceptual design of two different savage systems in part three of this study.

“affordable” - PVC or nPVC

“mid to high range” - Modular sewer pipe systems in HDPE and/or coated concrete

Public awareness

Public awareness towards good waste (water) management practices should be improvement. Domestic sewage systems are designed to hygienically dispose of fecal matter, urine and grey water from kitchen, sinks, bathroom and showers. The water serves as a transport medium. At the treatment plant the water is then separated again from the solids and other harmful waste. This is achieved under considerable technical effort and cost so that the water can be re-used for other purposes like irrigation or is allowed to flow into a stream or the ocean.
Hence it greatly improves the process if certain pollutants can be prevented from entering the water in the first place. Especially if they can be much easier disposed of in solid waste management systems (compost, incineration etc)

For this purposes the following should <u>not</u> be disposed of in the sink or toilet: Fats and oils, solid waste, food waste, articles for hygiene, diapers, tampons, condoms, chemicals, paints, thinners, acid or caustic substances, medicines. These have negative effect as they either damage or clog the sewer or components of the treatment plants, destroy or impair the bacterial population, attract rodents or are harmful in other ways and difficult to remove in conventional treatment systems.

Pumps, types and location

Gravity flow should be targeted in the entire sever network. However certain external conditions of the sewer alignment and network might necessitate a pumping station.
The study area shows an inclination of the terrain of about 6-8 m from west towards the east. Drawing # shows the details of the gradient from E-W and S-N.

Trunk sewers running along these axes of the Study Area would maintain a gradient between 0.8-1.3 %. This would be sufficient to maintain minimum flow velocity.

The sewer should run in all places 80 cm or lower below ground so that ground floor apartments can be connected. In some places the sewer would run considerably deeper in order to maintain the required gradient. At a certain point this can become unpractical. Excavation to lay the sever would need sheeting, man holes would become excessively deep and costly. It is proposed to limit the maximum depth of the sever network to about 3 m below ground.
Under these conditions it may not be possible to connect all residences. Those residences that are located too far away and/or below the level of the main sever would either require a lifting pump, or they should be excluded from the common sewer system. In this case individual treatment systems have to be built. (see chapter)* Pre-treatment at site and discharge (with pump) of the supernatant water into the common sewer could be considered.

The next location that might necessitate a lifting station is the treatment plant.
The hydraulic head required within the treatment plant to facilitate the operation depends on the treatment method and the arrangement of the treatment stages within the plant.
A minimum requirement of 2-6 meter can be assumed.
The waste water enters the treatment plant under free surface flow condition (not pressurized) and in the best case scenario the sewer will be located at the minimum depth of 80 cm below ground.
In order to achieve the hydraulic head the different stages of the treatment have to be either arranged incrementally deeper below ground, or a lifting station has to be provided.

Removal of sludge from the settling chambers would in most cases also require a pump.

After treatment the recycled waste water has to be distribution back into the community through a pump system.

The installation of pumps requires considerable additional attention and effort for the operation and maintenance of the sewerage system. A failure of any of the pumps would disrupt the operation of the system either partially or totally, causes flooding and other nuisances.
Pumps and electrical switch boards have typically a much lower life expectancy than most of the other components of the system and are prone to faults.
Reliable multi stage back-up systems for power, pumps and controls have to be provided. The pumps should be equipped with automated controls for intermittent operation and to prevent them from running dry. An alarm system should be installed to alert the operating staff in case of malfunctioning.
Different types of pumps come to use.

A) Raw-sewage with a high content of solids requires specialized pumps.

- Suction Pump, installed above the wet well.
- Submersible, installed inside the wet well
- Piston displacement pumps
- Screw pumps (Archimedes type)

B) For installation after the primary sedimentation stage and for the distribution of recycled waste water standard centrifugal pumps can be used.

Pumps should be installed so that they are easily accessed for servicing or replacement.
The design of power supply and controls has to take into account the corrosive nature of the environment (moisture, sulfuric content, high temperature). Safety for operating staff has to be ensured.

Autonomous operation during power outage.

The study area on a regular basis experiences power outages lasting several hours per day. During one day per month the utility switches off the power for the entire day (12 hours) for maintenance purposes. In December 2012 the cyclone "Thane" caused extensive damage to the power supply lasting for more than one week.

A disruption of the sewage system and the operation of treatment plant is not acceptable. Hence if pumping stations come to use they have to be designed to operate autonomous for extended time.
In most cases the pumps would run intermittently for 5-30 minute intervals. Repeated start/stop operations are however undesirable for diesel generators. The preferred solution for power back-up would be a battery based system with diesel generator support. The battery bank would supply the power to run the pumps when required. Frequent on and off does not affect the batteries negatively. Only when the battery charge level is low, would the diesel generator be switched on and fully re-charge the battery. In this way the diesel generator will run less often, but for longer time. Solar power should be incorporated. The system should be able to run unattended for several hours.

The fresh water supply in the study area depends on pumping systems as well and the availability of fresh water is incidental to the waste water generation. Hence there is a correlation and if a calamity would cause extensive power outage in the area then emergency power has to be provided in equal measures to both systems.

The sewer system itself offers a limited buffer capacity and settlers and basins in the treatment plant can provide additional intermediate storage. The waste water should normally not be stagnant for more than 30 minutes because anaerobic processes set in and this causes a nuisance (odors). Within a short period solids will separate from the waste water and this has to be taken into account.
Hence in case of a failure of the primary pump system the back-up system should be operational within 30 minutes.

Recommendations for existing waste water treatment plants

There is no standard design of waste water treatment plants being followed in the study area. Within a project the architect implements a design for the waste water treatment of his own or commissions the design to a third party. This has let top a multitude of different designs being built in the past.
The systems are typically non-mechanized except in those cases were recycled water it is used for irrigation, here pumps are installed to provide the working pressure.
The systems consist of a variety of primary settler, anaerobic or aerobic treatment and in some cases constructed wetlands and/or ponds followed by ground percolation wells.

Permit for treatment plants
There is no procedure in place to re-view and clear the design of new treatment plants.

During the process of obtaining a building permit for a new development project the concept of the waste water treatment plant has to be explained to the licensing authority. There is however no process which will review the design of the treatment plant and verify the functionality before it is built. It would be important to introduce an approving authority for waste water treatment systems in the study area. Similarly the functioning of the treatment plants should be regularly monitored, for example at 6 month intervals, so that malfunctioning can be detected within a shorter time and corrective measures can be taken.
Typically the performance data of the existing system in the study area show high fluctuations in the performance over the years. It also shows that at one time or other each system was functioning and it seems that by design most of them should be able to fulfill the basic treatment requirements.
The primary reason for sub-standard or non functionality is the lack of maintenance. (see Part 1).

Survey of existing plants

In February/March 2013 all major treatment plants were inspected. The status report finds the following:

Systems found in good working condition were

1) Arati
2) Grace
3) Vikas

Systems in need of minor maintenance

4) Maduhuca, damaged pipe caps – mosquitoes

Systems in need of major maintenance / dysfunctional

5) Arka
6) Creativity

Sealed systems - performance could not be confirmed

A complete list of the systems is given in the Annexure

Primary observation is that in all cases were the treatment plant has a planted filter, these were completely overgrown and in most cases flooded, with extensive mosquito population (larvae and adults) in the filter and plants. The flooding can be attributed to overflowing settler.
In this case a detailed assessment would only be possible after all plants have been cut and the settler has been emptied of sludge. It would remain to be seen if the planted filter is permanently blocked by over-flowing sludge and has to be replaced (or washed) and replanted, or if it can recover.
Currently there is no comprehensive concept in Auroville for removal of sludge from these treatment plants and a facility for post treatment is needed (see section sludge processing). This has to be urgently addressed.

Once the systems have been made operational again the treatment would in most cases meet the required effluent values (of part 1), except for the Helminthes removal.

Consequently the usage for irrigation has to be restricted, or at a minimum the residents should be informed and advised to maintain appropriate level of hygiene when using the water. This should also be communicated to employed gardeners etc.
In praxis these system have been in operations since many years. At times there has been some smell and discoloration of the recycled water, hence most persons who come into contact with the water are already aware of its source.

Not one of the inspected communities shows any warning signs on the taps, at garden ponds or hose pipes that are used for recycled waste water.
The widely standardized coloring code is purple for pipe systems and taps along with warning displays. Signboards should be installed displaying warning in English and Tamil.
Additional thought has to be given to the fact that young children will play in the gardens. Due to the hot climate in Auroville children are very much attracted to play with water. If the water is not safe this has to be effectively prevented.

It is recommended that either of the following measures are implemented for systems were the effluent does not meet the hygienic standards:

a) the use of recycled water is discontinued in those areas to which the children are likely to have access to and would play in
b) parents should supervise their children to prevent ingestion of the water itself or of the soil that has been watered
c) The use of the system is discontinued and the community is connected to the municipal sewer.
d) Adequate additional treatment is added to achieve required hygiene of the water

For the latter *The Indian Manual on Sewage and Sewerage Treatment* states:"..
Tertiary treatment is mainly needed for meeting coliform and helminth standards which are not met by conventional treatment process. ….Helminth removal can be economically done in 3-celled oxidation ponds (maturing ponds) of short detention 6-7 days (after primary and secondary treatment) or with open sand filters. Filtration is also useful where drip irrigation is proposed to be used…"
Another recognized additional treatment method to achieve helminthes egg removal is a low rate tickling filter (description further down).

The system in Madhuca is equipped with a polishing pond as final treatment stage. This system could technically maintain the effluent guide values for unrestricted irrigation. However the system suffers of maintenance deficit as most other systems.

The recent survey of the treatment systems revealed that almost 70% of the systems are either badly or non-functioning. Considering that the inspection was conducted "ad hoc", it can be assumed that this status reflects the usual situation.

The main reason for this is that the residents in the housing projects are overtaxed with the task of maintaining their treatment system. This is due to several reasons

- On moving into their apartment residents are not informed sufficiently on the necessity of maintenance of the system
- Operation of the treatment plant requires some technical knowledge. In most cases no training has been given

- Everything is “well” until the system malfunctions. Then bad smell develops or in the worst case the system is blocked. At this point it is too late for easy maintenance and extensive and costly repair may be needed.
- No financial provision is made to either maintain or repair the system.

As a consequence large quantities of untreated or insufficiently treated waste water percolate daily into the ground. This causes a thread to the groundwater and nearby wells. Mosquitoes are breeding uncontrolled on stagnating waste water and pose a health risk.

This makes it indispensable that a monitoring and maintenance body is established to oversee the functioning of the multiple existing treatment plants.

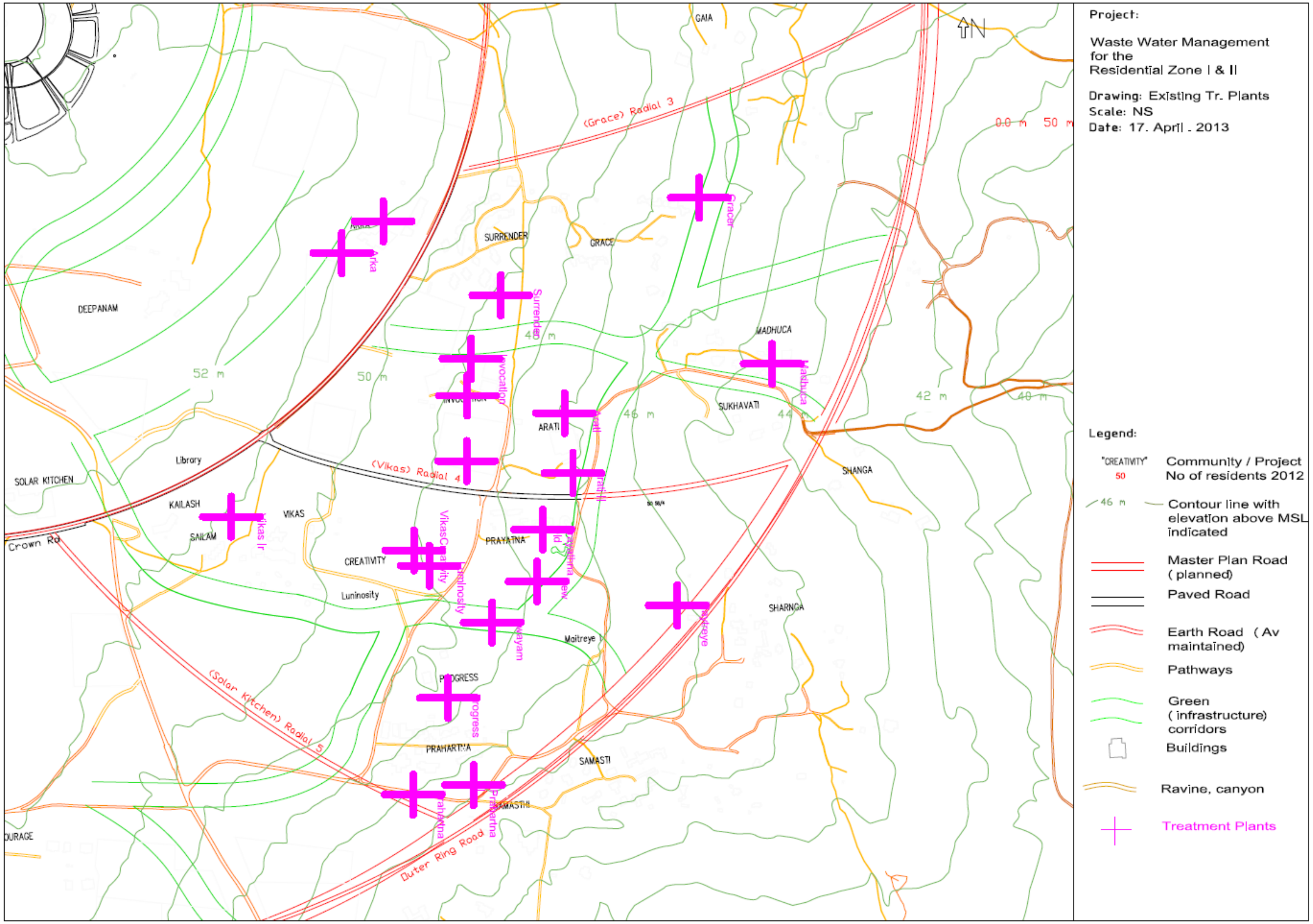
Communities with defunct systems listed under point 3. above two options can be offered:

1. Refurbishing of the system
    a. Removal of sludge from settler
    b. excavation of filter
    c. cleaning and
    d. re-placing of filter material
    e. re-planting
       and
    f. If wanted addition of sterilizing stage

    g. enter into service contract with regular performance monitoring

2. Discontinue use of system
   and
   connect to community system

3. Base Map – location of existing treatment plants



Photos of surveyed treatment plants see Annexure on DVD

Recommended system for communities that can not be connected to the common sewer system:

The above option “1” would be the automatic choice for communities and projects that can not be connected to the common system.

Similarly design recommendations for individual waste water treatment plants should be formulated so that they can be recommended to up-coming projects if they can not be connected to the common system.

Recommendations for the distribution network for re-cycled waste water

In Part 1 it was found that the average fresh water consumption of the existing population in the study area as $Q_{FW,24}$ = 400 l/day/p.
The personal consumption was estimated 205 l/day/p.
It can be assumed that the difference in quantity of 195 l/day/p is mostly used for irrigation.

Requirement for irrigation water is **$Q_{IRR,24}$ = 195 l/d/p. (1)**

Part 1 estimated that of the personally consumed fresh water some 85 % or Q^{WW}_{PE} = 175 l/d is directed as waste water into the sewer. Further losses incur in the treatment plant. These would depend on the treatment method. Assuming a yield of recycled water of 85% ,

the potential for recycled waste water would be about **$Q_{RC\ WW,24}$ = 150 l/d/p (2)**

Hence recycled waste water could replace 150/195 = 77% of the fresh water currently used for irrigation.
This holds true for a growing population until the time when a density is reached were people live primarily in apartments and requirements for irrigation become less.
However alternative uses for the recycled water exist in the multiple green parks.

People who live in communities were currently recycled waste water is offered as gardening water (Prayhatna, Madhuca etc.) show an overall high level of approval of the concept, in fact they complain that there is not enough water.

Intermediate storage and alternative disposal

The demand for water for gardening fluctuates seasonally (dry season / monsoon) and over 24 h. The demand would be high during the morning and late afternoon for manual irrigation and during the night for automated irrigation systems. The requirements would peak in summer and dwindle towards nil during the winter-monsoon rains (October to December).

The availability of re-cycled waste water follows chiefly the usage pattern of domestic freshwater (see Part 1) but it is tagged with a time delay. The delay depends on the length of sewage lines and the treatment process in the plant, it can be assumed 12-36 h.
If the water were to be stored to span seasonal patterns, for example collected during winter monsoon to be taken forward into the dry season, relative large quantities would accumulate this would exceed the scope currently envisioned.

Hence intermediate storage should be provided to buffer the 24 h usage and an alternative means of disposal is required for times of low-demand for recycled waste water.

The 24 hour storage capacity for the 1st Phase with a capacity for 1000 PE should be

$V^{24h}_{\mathbf{storage}} = 1000 \text{ x } 0.150 = 150 \text{ m}^3$

The recycled waste water has to be maintained ”fresh” through recirculation and/or oxygenation because of the remaining COD. The storage could be combined with a polishing pond as proposed for disinfection.

Water that is not used for irrigation or otherwise (intermediate storage, filling of lakes or ponds etc.) has to be disposed of by percolation. The facility for the unused recycled water (soak pits, trenches, percolation pipes) should be adequately dimensioned to perform during the rain season.

Supply method of irrigation water

For obvious reasons the recycled waste water for irrigation has to be provided through a system completely independent from the fresh water distribution system.

Preferably pipes should have a different color from the fresh water pipes and/or markings as to the nature of the water to prevent cross connections with drinking water supply should be provided at close intervals.
Similarly taps should have a different color (internationally purple is most commonly used) to prevent accidental ingestion. Signs (as pictogram and in writing in Tamil and English) should inform people that the water is not suitable for drinking. The markings should be systematic and follow a common standard.

The supply network can be expanded according to demand and availability of funds. Communities who subscribe to the recycled waste water supply can be connected sequentially as the network reaches their location.

Landscaping and garden designs usually provide water taps at fixed distance to be used for irrigation. The common water hose length is 30 m and a total cover is reached with distance of about 50 m between taps.
There are two options of approach to providing the recycled waste water:

a) The water is provided if and when it is available. This requires a certain number of water points to be installed in the gardens of the communities in parallel to the fresh water network. A person who wants to water the garden checks on the appropriate tap if recycled water is available, if not he uses the freshwater tap and waters the garden. This may lead to
    i. taps of the recycled water system will be left open.
    ii. a large percentage of fresh water being used for gardening and recycled waste being underutilized.
    iii. If the recycled water is standing stagnant for a few hours in the pipes it will develop an unpleasant smell.

b) In this option the communities which subscribe to use the recycled waste water for irrigation convert the entire garden water network with appropriate marking. A few additional taps to supply drinking water can be installed.
In this distribution system water is available from all taps at all times.
The recycled waste water is buffered at the treatment plant to match the demand and in the case that the demand exceeds the quantity of available water additional fresh water is pumped into the system.

The water has to be provided under a minimum pressure of about 0.5 bar so that flow rates can be maintained through standard 1” hose pipes .

The second (b) would reduce (by half) the load on the existing fresh water tanks/ lines and machinery. These can be dedicated for exclusive domestic use and free capacities can be assigned to other areas.

Summary

In a time when water becomes more and more scarce the concept of “waste” water has shifted and it is now viewed as a potentially valuable resource for agriculture and industry. Similarly the target of treatment has changed from safe disposal to re-use. This concept gains importance especially in tropical-dry areas like Tamil Nadu and is therefore pursued throughout this study.

Classical waste water treatment plants utilize natural bacterial processes which are enhanced and accelerated to achieve better performance and reduced foot print.
A multitude of technologies exist, each with advantages and disadvantages.
For different types of waste water different treatment methods can be beneficial. Similarly geographic location, climate and other factors play a role. Hence there is no single “best” treatment method.
A major distinction between treatment methods can be made by the predominant type of bacteria, aerobic and anaerobic. Both systems have been used in the past in the study area.
Another approach is to classify the treatment methods according to their intensity (use of machinery and equipment). In the past low-intensive methods have been preferred in Auroville, however with mixed results and the concepts are not necessarily suitable for higher population densities.

The treatment plant is to be built in phases to provide adequate service as the population grows. Starting from 1000 PE until the final population of 5000 is reached. This puts the proposed treatment plant in the mid-sized range. The design concept can either take the approach to up-scale the design of a small treatment systems or down-scale that of a large treatment plant. Some caution has to be exercised as this “scaling” may not always lead to useful results.
Provided that all technologies under consideration achieve the required treatment goals that were formulated in Part I of the study, then additional considerations for the evaluation are:

- Proven technology
- Reliability of operation (ruggedness)
- Ease of installation
- Operational requirements – number of persons, level of training
- Maintenance requirements – repair, replacement and spare parts, availability
- Amount of water recovered for re-use
- Expandability (phased construction)
- Cost (capital and operation/maintenance)
- Space requirements
- Nuisance (noise, odor, visual impact)
- Sensitivity to inhibiting substances, recovery
- Additional benefits (water storage, nature enhancement etc)
- Replicable in other communities

Following the description and discussion of the basic treatment technologies, three of the most promising methods are selected and it is proposed that in the 3rd Part of this study the design details for these three different systems will be provided:

1) Baffle reactor (USAB, submerged filter, or similar) followed by aeration and polishing pond .
2) Primary Settler, low rate trickling filter, polishing pond
3) Membrane Bio Reactor or Sequential Batch Reactor; prefab commercial unit (Chennai) followed by intermediate storage.

The concepts will then be scrutinized under the points for evaluation listed above.

In the second chapter guide lines and considerations are given for the design of the sewage system.
The sewage network can be gravity fed if the layout takes the W-E and S-N gradient of the study area into consideration. This would place the treatment plant at the N-E border of the study area alongside the green belt.
Trunk sewers should be built in the final size as upgrading of sewers at a later stage is very difficult. The connectivity for future branch sewers and communities has to be carefully evaluated. A multitude of T or Y junctions should be provided for this purpose as well as sufficient number of hatches for inspection and maintenance. In order to be able to evaluate the advantages of different designs it is proposed to provide the conceptual design of two different savage systems in part three of this study.

“affordable” - PVC or nPVC

“mid to high range” - Modular sewer pipe systems in HDPE and/or coated concrete

The third chapter provides a description of the status of existing treatment plants in the study area and recommendations for their future operation. A major shortcoming was found in the lack of maintenance of the plants. In particular the removal of sludge and care of the planted filters.
No systematic monitoring of the treatment plants is done, hence in the case of malfunctioning of a plant, this remains unnoticed for a long time and when the fault is finally detected the damage has already progressed into adjoining treatment compartments and repairs become very costly.
It is proposed that a systematic monitoring of all plants at 6 month intervals should be put in place. In the long term this would make the maintenance of the treatment plants more economic, prevent pathogens (and nuisances) through mosquitoes, bad smell and be an effective measure against groundwater pollution.

It is found that no concept for post treatment of sludge is in place.
It is proposed to explore the possibility to process the sludge of the existing systems in the newly planned treatment plant. In this case a separate sludge digester may be necessary. Alternatively an entirely separate sludge treatment facility should be build.

In the last chapter recommendations are formulated for the design of the distribution network for the re-use of the treated waste water. The supply network can be expanded according to demand and availability of funds. Communities who subscribe to the recycled waste water supply can be connected sequentially as the network reaches their location.

It is found that recycled waste water could replace up to 75% of the freshwater currently used for irrigation in the study area. This “freed” fresh water would be available as drinking water for new and upcoming communities.
In the first phase, calculated on the basis of 1000 residents, a storage tank with a capacity of 150 m3 is required to buffer the recycled waste water over 24 hours.

An entirely separate pipe-network has to be installed (or existing network converted). Lines and taps should be properly marked as non-drinking water, following a common standard.
It is recommended that the system should be continuously pressurized with 0.5 bar, opposed to intermittently operated at set times when water is only provided if and when re-cycled water is available. In the case that the consumption exceeds the availability in the system it should be supplemented with fresh water. This will reduce the load on the existing fresh water tanks/ lines and machinery. These can be dedicated for exclusive domestic use and the freed capacities can be used in other areas.

Sources:

[1] Imhoff; Taschenbuch Der Stadtentwaesserung
[2] Indian Manual on Waste Water
[3] Ireland EPA Water Treatment Manual
[4] US EPA 2000
[5] Agences de l’Eau, France
[6] EM Water

Annexure : Photos and GPS positioning of existing treatment plants (see DVD).