Auroville

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

Part One

-Survey and Analysis-

Jan Imhoff, *Auroville November 2012*

Foreword

India has major problems to manage the sewage. It is estimated[1] that more than 70% of raw waste water of major cities is discharged into lakes, rivers and coastal waters. This is an environmental disaster, a major cause for lasting groundwater pollution and source of disease amongst humans and animals.

In many aspects Auroville, as a city in the making has been a forerunner in sustainable development.
Different decentralized waste water treatment systems (DEWATS) have been tried out and experiments were made with reuse of recycled waste water for irrigation.
As Auroville develops it has to be seen if these type of systems would be suitable for higher population numbers and densities or if a centralized system with a sewer networks prove to be more efficient.
In order to be able to evaluate different systems that might come into use, at a first instance, the basic parameters of quantity and quality of waste water along with predictions for the future development of the area have to be established. Targets for the use and quality of recycled water have to be set. Based on this the designs of treatment plants and related systems can be compared.

This study was commissioned in 2012 under the purview of the Town Development Council and the findings were shared with members from various water related organizations within Auroville for discussion and review. The fourth and last part of the study was completed in 2016.

I express my high appreciation to Prof. Dr.-Ing. Klaus R. Imhoff for his time and valuable input to this study. His “Handbook of Urban Drainage and Wastewater Disposal” was an indispensable tool.

I thank Lars for his work on monitoring the existing treatment plants.

Introduction

Auroville as an emerging city is faced with numerous challenges in regard to planning and implementation. The master plan envisions a population of 50.000 residents. Currently 2500 people live in Auroville. Settlements are wide spread and experience uneven growth. New communities materialize in previously undeveloped areas and infrastructure has to be provided.
Some settlements were founded more than 30 years ago and often the infrastructure is outdated and in need of repair.
This situation poses several difficulties
In order to provide adequate infrastructure that remains relevant for future development, a proportionately high investment is required so that sewer and treatment systems can be expanded when necessary.
Some essential basic town planning parameters have not yet been finalized and a high degree of flexibility in the system design is required so that modifications of zoning parameters and population distribution can be accommodated.

Auroville experiences long spells of dry weather and water shortages. One of the key parameters in the concept of this study is the re-use of recycled waste water for irrigation and other purposes. This requires a secondary water distribution system with pipe- and pump-networks and water storage facilities.

End of April 2012 L'Avenier, the civic body of Auroville responsible for town planning and development issued a brief [2] to commission the current study and provide a concept for waste water infrastructure and management for the Residential Zone I and II.

The study is presented in four parts, available as separate booklets. This current volume contains part 1.

Objective of the study

The study aims at providing design concepts and development guidelines in regard to waste water management in the study area. A range of different systems and sub-systems are explored as well as phased implementation so that these systems can be expanded if and when required. The task is:

- to provides medium- and long-term predictions for the quantity and quality of waste water to be treated, according to progressing development in the two Residential Zones
- to offer an evaluation of the existing waste water treatment plants in the area as to their status and to formulate recommendations either for upgrading or disuse of these systems.
- to discuss the possibility of re-use of recycled water with the aim to reduce the overall fresh water consumption.
- To examines the possibility to re-use the sludge that is removed from the waste water as compost.
- To design a sewer systems for waste water collection and a distribution network for the re-cycled water.
- To provide conceptual designs and cost estimates for different options for centralized and/or decentralized waste water treatment plants.

Conceptual Outline

Includes points of the meeting held on Feb 17th 2012

0 Base Map

0.1 accuracy horizontal
0.2 vertical

1 Base parameters "Wastewater cycle"

1.1 Quantify and qualify amount of wastewater to be treated

1 year 3 years 5 years 10 years

1.2 Quantify and qualify re-use of recycled water — time wise (during 24 hours); seasonal
general gardening, Vegetables, by pipe, by sprinkler
in-house, toilet flushing

1.3 Quantify and qualify re-use/ disposal of sludge
1.3.1 disposal of raking solids

2 Base parameters " Treatment Plant(s)"

2.1 Required quality of effluent from 1.1, 1.2 and 1.3
2.2 Determine different processes that can be utilized to achieve 1.2
2.2.0 Continue use of existing plants and/or upgrade
Design concept for new treatment plant
2.2.1 Plant type A
2.2.2 Plant type B
2.2.3 Plant type C

	Size (PE)		
	1000	2500	5000
2.3.1 Determine Unit cost for each Plant Type			

2.3.2 Space requirement
2.3.3 Maintenance requirement
2.3.4 Operating Cost
2.3.5 Other relevant parameters
2.4 Determine location parameters for the Treatment Plant
2.4.1 Land availability (with possibility of extension)
2.4.2 minimum distance from residences (smell and noise)
2.4.3 Short sewer distance
2.4.4 gravity-flow or pump system
2.4.5 Distance to return recycled water for distribution
2.4.6 continue use of existing plants and/or upgrade

3 Base parameters "Sewer system"

3.1 How are communities and residences connected
3.2 Gravity flow
3.3 Pump stations
3.4 Assume single plant
3.4.1 Trunk Sewer
3.4.2 Branch Sewer
3.5 Assume multiple plants
3.5.1 Trunk Sewer
3.5.2 Branch Sewer

4 Base Parameters "Recycled Water distribution System"

4.1 Type of system

pressurized	through tank
	through pump
availability	morning and evening
	24 h

4.2 Type of pipe
4.3 Distribution network

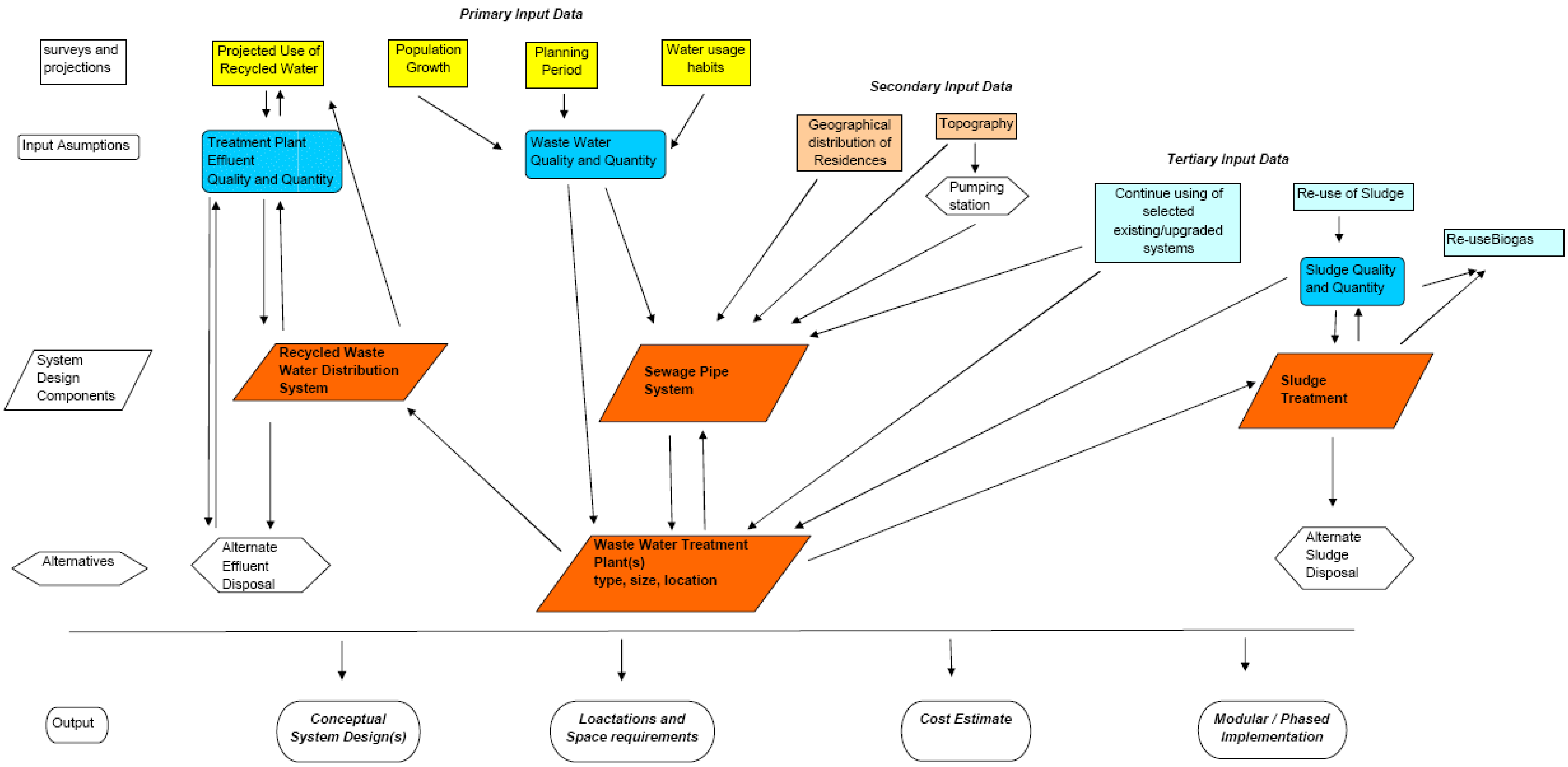
5 Develop Comparison Matrix

6 Formulate recommendations

6.1 Option A
6.2 Option B
6.3 Option C

Flow Diagram

The outlined parameters show a high degree of cross-dependencies:



Structure of this study

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

In this part the base parameters are established. The existing communities in the study area are surveyed. National and international norms are researched and assessments are 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

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
e. recommendations for upgrading existing plants

Part 3. – Design Concepts and Cost Estimates

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

Summary, Part 1 to Part 4

In April 2012 L'Avenier commissioned this study to provide a sustainable concept for waste water management for the Residential Zone I&II in Auroville.
The study is structured into four parts and although each part forms an independent activity, the four parts are built-up logically upon each other.
After completion of each part the findings were presented to L'Avenier for discussion. Based on this approval the procedures for the following part were decided.
In the following a brief summary of the findings is give.

In Part 1 of this study the population distribution and development in the area was analyzed and projections for immediate and mid-term requirements were computed.
The Residential Zone 1 and 2 cover an area of 60 hectare and currently about 600 people live there. The final population target is 3500 residents.
The existing waste water treatment plants in the area were surveyed and it was found that

- most of them are not working satisfactorily in regard to achieved treatment level and nuisance control (odor, mosquitoes and flies)
- they require a lot of maintenance
- only a fraction of the water that enters the plant is available for re-use after treatment
- they occupy a large space

It was found that in many cases there is no schedule to remove the sludge that accumulates in the settlers of the treatment plants. Frequently the sludge builds up to the point that it overflows from the settler into the following treatment structures, blocking the system. This leads to major fault of the plant.
There is currently no satisfying method in place for treating the sludge once it is removed from the plants and disposing of it.
An assessment was made between the options of continuing the current practice of building multiple small on-site treatment plants, repairing and upgrading the existing plants, or, creating a canalization network and a state-of-the-art single treatment plant.
Although building up a canalization network poses considerable investment there are several benefits. In larger plants the cost of water treatment per capita, in terms of investment, operation and maintenance is significantly reduced compared to small plants. A further advantage is that a large plant can be equipped with a hygienic sludge processing unit located on site. This is not feasible in smaller plants
Based on these findings it was decided to design a single community treatment plant along with a canalization network. The treatment plant would initially be sized for 1000 PE[1] and should be expandable to meet the projected end-requirement of 5000 PE. The plant should also be capable of processing the sludge from other small treatment plants from outlying communities so that it could be brought there for processing.

Water usage patterns in the communities were analyzed and it could be shown that about 50% of the drinking water which is currently drawn from the fresh water supply system is used for watering the gardens and other non-residential purposes. The survey showed that there is a high level of awareness amongst community members towards the need of saving water and a willingness to use re-cycled waste water for gardening.

It stands therefore to reason that if the re-cycled waste water would be brought back into the communities for watering the gardens, then an almost equal amount of valuable drinking water would be freed and be available for domestic purposes and other higher uses.
Hence it was decided that the waste water would have to treated to a level to render it safe for irrigation and, in the case of percolation, it should be ground water neutral.
The parameters for the treatment goal were set accordingly. EU norms and WHO guidelines were adopted for this purpose.

In Part Two of this study a multitude of different treatment technologies were examined. The area in which the project is to be located is situated in rural Tamil Nadu, South India. There are frequent power fluctuations and outages and the plant and machinery needs to be able to accommodate this. The level of education, training and capacity of local staff has to be taken into account and their ability to repair faults. Replacement machinery has to be readily available.
The plant needs to be able to handle fluctuating inflow quantities and should be easily expandable to accommodate the growing demand
Of the different technologies four types of systems were selected to be compared against each other in more detail.
These are:

- Anaerobe Baffle Reactor
- Activated Sludge System
- Activated Sludge System with bio media
- Trickling Filter

Different methods for sewage evacuation were considered and it was found that a system could be implemented based on gravity flow, that would avoid the need of any pumping station.
Classical sewage system design, based on an alignment along other existing infrastructure routes was compared to “simplified sewerage”. A variety of commercial sewer pipe systems and materials were studied.

Based on these findings a basic sewer system network was designed, that would allow all communities to be connected. A phased approach for the implementation was suggested.

Methods to further process the sludge were discussed and it was recommended to sun-dry the digested sludge and then compost it. Co-composting with shredded plant matter would provide additional carbon and further improve the end product so that it can be used in gardens and parks as valuable fertilizer.

Based on these design considerations the requirements for the location of the treatment plant were formulated.

In Part Three commercial offers were sought for the short listed systems and a detailed design and cost estimation was prepared.

In Part Four of the study, the designs developed in Part Three are evaluated against each other.
It could be shown that for this particular project the waste water treatment system based on trickling filter technology bears significant advantages over the other systems:

Cost	It requires the lowest initial capital investment. It is significantly cheaper in any of the expansion phases than the other systems
Simplicity of technology	The required materials and workmanship are locally available
Variation in flow	The system can manage large inflow variation
Operation and maintenance	The system operation and maintenance is easy and straight forward
Expansion	The system expansion can be managed flexibly to accommodate increasing population and changing requirements, while the other systems can only be expanded by duplication
Emergency operations	In the event of a major fault, like a disruption in the flow path within the plant, or a lasting power outage, the system offers alternative treatment routes so that it can continue to perform with very little additional input
Sludge management	the system offers fully integrated, hygienic sludge processing were the operating staff has no contact with the raw sludge.
Power	power consumption is low and, power outages can be easily bridged with a UPS or small generator
Interim solution	By February 2016 a number of new residential projects in the study area have almost been completed. They do not have access to waste water treatment. The proposed system is well suited to be built in stages so that an interim solution for waste water treatment can be provided in a very short time.

The location of the treatment plant was finalized.

The chief criteria to select a suitable location for the plant are:

- elevation (gravity flow in the sewer pipe can be maintained)
- access during construction and later-on for the delivery of sludge by truck
- passage for the sewer pipe and the return pipe for irrigation water and electrical line
- closeness to exit point of the main sewer (Vikas Radial)
- sufficient large plot size to accommodate the treatment plant and the extension phases
- sufficient distance from existing residences to minimize impact
- the land should preferably already be owned by Auroville

Based on this the general area for the treatment plant was placed on the border of the Residential Zone II, to the Green Belt.
A feasible location has been determined in the triangle formed by the Ring Road , the Vikas Radial and Maitreye. The location has an adequate (and equal) buffer distance to all residences in the area.

A gravity flow sewage network system was designed as well as the return pipe system for the recycled water.

Abstract Part 1

In this first Part of the study the population distribution and development in the area are analyzed and projections for immediate and mid-term requirements in regard to waste water management are formulated.

The existing waste water treatment plants in the area were surveyed.

Guide values for the design and management of new and existing treatment plants are discussed and standardized reference values are determined.

Different possible uses for the recycled waste water are discussed and recommendations are given to which extend the waste water should be treated depending on the planned application.

General Note

Relevance of norms

The purpose of applying any norm to an engineering project is to simplify the task by providing a set of basic parameters and a unified approach so that systematic conclusions are reached and results can be verified.
However the result achieved by applying a norm can only be realistic if the relevance of the norm is first established.

World-wide there are many norms to be found on any subject. Often they differ quite significantly, but they have one aspect in common, they evolved out of experience gained in the specific country they have been written for.
The population of Auroville consists of a mix of different nationalities with a variety of backgrounds and traditions. Hence the daily habits of the residents of Auroville differ from those of most average Indian communities. At the same time any international norm may also have limited relevance because of the specific conditions of the country, topography and climate found in Auroville.

Hence when looking at norms, the relevance for Auroville and the particular study area has to be established.

During the course of this study an analysis of available information is applied in the following sequence

1. Relevant Indian Norms
2. International Norms (European, US and others)
3. Studies and research done in Auroville
4. Analysis of which of the above would be most relevant for Auroville, in terms climatic conditions, socio-economic habits, architecture, master plan etc.

References and Sources

When references are given in the text to third sources, studies or norms etc. they are marked by (ii) ii is the numbering in sequenced of appearance in the text.
The source is given at the end of each part.

References in the text to tables, graphs, formulas etc. to other parts of this study, will have the nomenclature [Pi,ii] were “Pi” refers to the Part of this study (ie Part 1, Part 2) and ii is the page number.

Surveys

The current section is divided into five chapters.

a) General survey
b) Quantity and quality of wastewater
c) Re-use of recycled water
d) Performance of existing treatment plants
e) Recommended guide values for Auroville

General Surveys

Base Map

Auroville Town Planning Office provided an AutoCAD Map[3] which forms the basis for physical parameters in form of layers for this study.

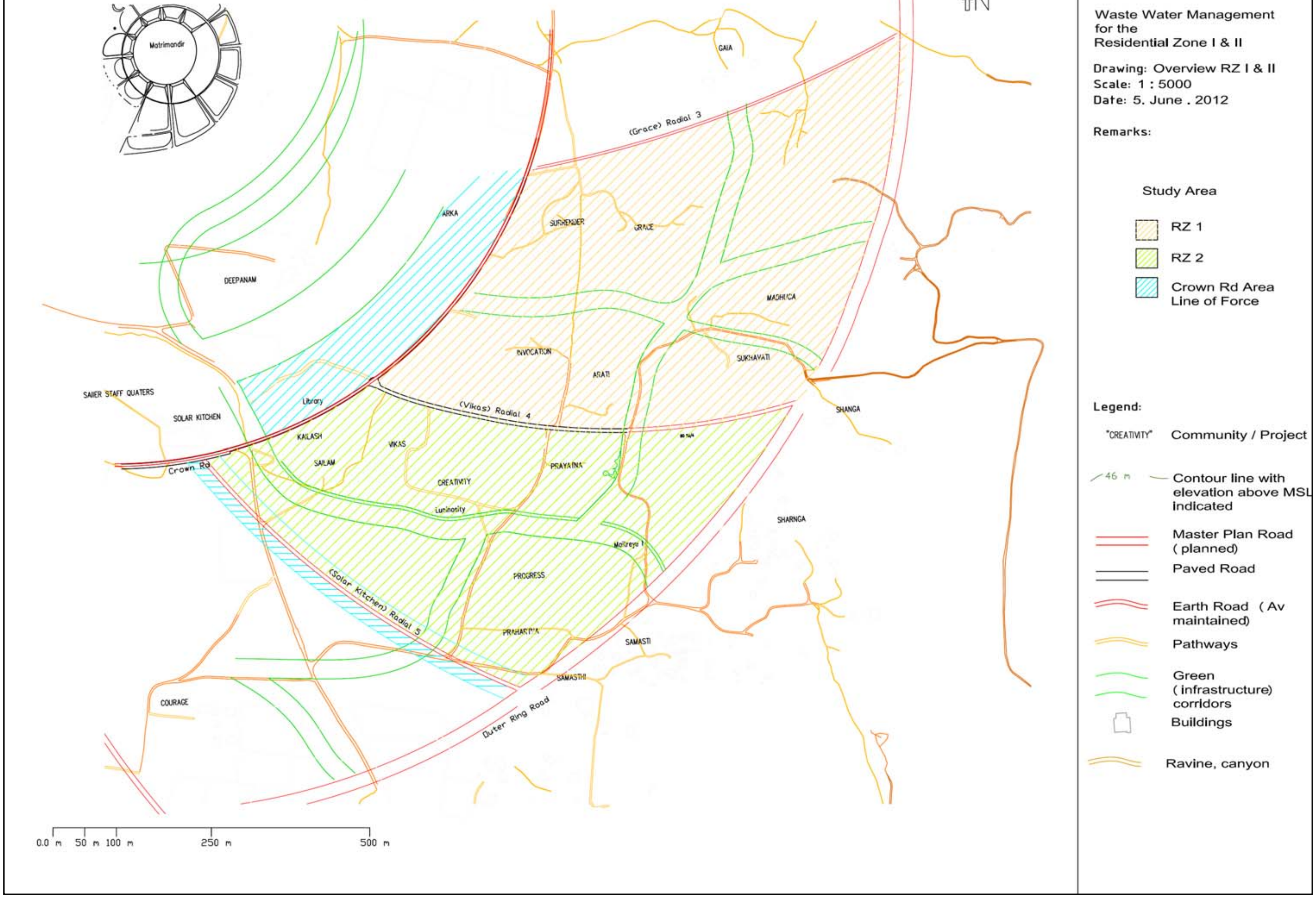
The base map contains the general lay-out of the study area, topography, roads and other physical parameters as well as planned roads and parks as per the approved Master Plan[4], or in some cases as proposed.
Spot checking reveals a high variation in accuracy for different horizontal parameters. Location of buildings (existing projects) was cross checked with aerial photography and the accuracy was found in the range of +/- 1 meter. Accuracy of the Vikas Radial was found to be 1 meter. Location of the Crown Road was found to be accurate within the pixel size (50 cm) of the photography.
It is estimated that elevations (contours) are within +/- 20 cm accuracy.
This level of accuracy is sufficient for the purpose of this study. The position of detailed planning items (laying of pipes for example) in relation to other existing structures should be verified on the ground before implementation.

For all planning details, when absolute coordinates are required, it is recommended that the location be referenced to the GPS survey 2010 (layer GPS 2010). The accuracy is estimated at 20 cm horizontally and 10 cm vertically

Description of the Study Area

Auroville is located on the east coast of Tamil Nadu. The town map of Auroville is presented in a circular and zonal lay-out. Two ring roads form concentric circles around the centre, the Matrimandir, and provide the main traffic routes. The zones are arranged between these ring roads. To each zone a different activity is attributed, these are Cultural (educational), Residential, International and Industrial.
The Residential Zone is the larges of the four zones and is divided into five sub-zones.
[2] defines the study area as the Residential Zone 1 and 2. These are located in the East and South-East sub-zones.
The shape of the study area can roughly be described as a quarter of a torus, or doughnut. The boundaries inscribe 60 hectare (575000 m2). An additional band of development area of 100 meter width along the inner side of the Crown Road where the Library, Health Centre, Arca and Mahalakshmi Home are located has been added. Waste water generated from these sites should to be considered as well for the purpose of his study.
The extent of the Study Area from SW to NE is about 1 km and from NW to SE 600 m.
In recent years the main focus on housing development has been on these two sectors.
Currently approximately 550 Residents live here and it is planned to expand the capacity to 5000 Residents.

Map of the Study Area



Geography/ Geology

The study area lies on a plateau with an average elevation of 47 m above mean sea level and is slightly tilted with 51 m elevation in the west and 43 m in the east.
Auroville has no perennial rivers or stream, there are several canyons and during the monsoon time surface water run-off is observed through these canyons towards the sea which lies 3 km towards the East.
The ground is predominantly sandy laterite soil with a very characteristic red color. It is covered with a 20-30 cm layer of loose sandy "top soil". Below the top soil layer the ground becomes hard and has excellent cohesion during the dry season. The soil can be excavated vertically for trenching or foundation work without sheeting support.
The bearing capacity of the soil is high but with the extreme difference in dry and wet seasons (see chapter climate below) some settling and even swelling of intermixed clay has to be anticipated.

The underlying Alluvium layers[5] consists of brownish red lateritic sandstone (named Cuddalore Sandstone after the nearby district 20 km to the South). Typically there are 2 distinct aquifers which are separated by a mostly impermeable layer of clay (Manaveli clay) with a thickness of 12-18 meter. The level of ground water (top aquifer) is subject to seasonal variation and lies between 14-17 meter below ground level.

Ground water from these two aquifers presents the main source of fresh water supply for the area.

Climate

Auroville lies on the 12th parallel north of the equator and has sub-tropical climate. Annual mean temperature are at 24 C. Maximum temperatures in summer can reach up to 39-41 C, minimum temperature in winter ca 16 C. [6]

The area is subject to distinct trade winds, the south-west monsoon (April-September) and the north-east monsoon (October-March). These winds cause a seasonal rainfall of 1400-1800 mm annually (mean and max data from 2001-2011). About 2/3 of the precipitation occur during the month of October to December. During this period heavy flooding can frequently be observed. During the summer month on the other hand the area experiences long spells of dry and hot weather.
Humidity is generally high and lies between 65% relative humidity in the dry season and 95% during the monsoon season.

Renewable energy

Wind speeds in the study area are low, mean annual wind speed[7] is 4.2 m/s.
Annual mean solar radiation is given with 5.15 kWh/m2

Other Factors

Power shortage.

The area is prone to frequent and extensive power outages.
This is due to:

- General shortfall in power in India
- Inadequate supply lines (prone to break down)
- Seasonal power production through wind and hydro power

Power outages can occur on a daily basis and range from 1-8.
Due to fast growing economy in India the power consumption is continuously increasing and although concerted efforts are being made by the Government to fill this gap, it can be assumed that the situation will not improve in the near future.

Natural disasters like cyclones (cyclone “Thane” struck the Auroville Dec 30th, 2011) and flooding occur occasionally and can then lead to power outages that last for several days.

Mosquito

The area of Auroville is prone to mosquitoes. These breed in open water bodies, but also in severs and septic tanks if these are not adequately covered (mosquito netting).
Mosquitoes are vectors for a variety of disease like malaria (not common in the area), filariasis and chikungunya (common).

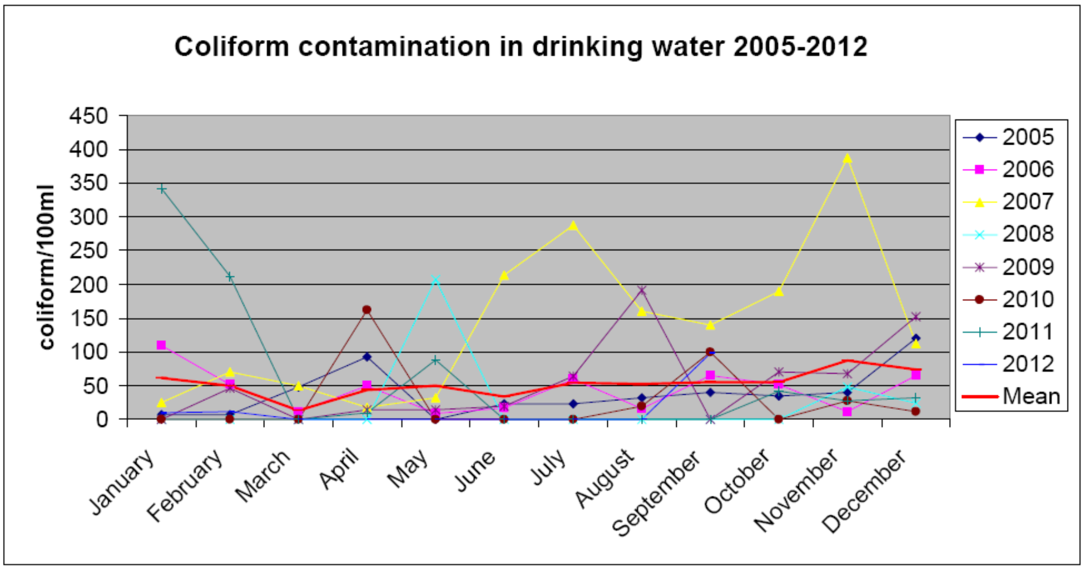
Rationale of waste water treatment

While it might seem obvious that any type of pollution should be avoided or at least minimized and that waste water should be treated, there are some compelling reasons that go beyond general environmental concerns.
Current practice in Auroville is that after initial treatment in septic tanks (aerobic or anaerobic digesters), the waste water is passed either directly into “soak pits” or in some cases via planted filters. It then percolates into the ground or is used for irrigation (during the summer months only).
When the waste water penetrates through the top layers of the ground the water is purified through bacterial activity. Once it reaches lower lying layers, the bacterial density rapidly decreases and the purifying capability is much lower.
In rural areas with low population densities, and if the system is properly dimensioned this method of disposal can achieve adequate results. [8]
If however a treatment system is under-dimensioned, or when during the winter month heavy rains cause flooding, then this impedes the functioning of the treatment systems and soak pits. Some of the waste water is carried away with surface run-off and and/or percolation is accelerated and the waste water reaches the lower soil layers without having been sufficiently purified.

Hence a residential waste-water systems can be a source of contamination for the ground water, including bacteria, viruses, nitrates from human waste, and organic compounds. Effluent from these systems is of particular concern if located close to drinking water wells. [P 2, 32]

Below is an example of typical monthly sampling for coliform in drinking water from a well in Auromodele [9] over several years. While the data shows no definite trend, it can be seen that bacteria contamination is present during most of the time.
It should be noted that the samples were taken at a residence and pollution could have occurred also at other points, for example the water-pipe or the water tank.

Chart 1



It has been observed in cities close to Auroville, like Chennai (120 km north of Auroville) and Pondicherry (9 km to the South), that the quality of ground water has declined during the past 20 years through chemical and biological contamination [10] to the point that today water from this source is often not suitable for drinking any more.
This can largely be attributed to man-made pollution.
It was pointed out earlier that the main fresh water source in the Study Area is ground water, hence in order to it maintain a good quality of ground water it is essential to provide effective treatment of the waste water.

Surveys of existing communities

The existing communities in the study area were surveyed and in a series of interviews with architects and project holders a data base of existing and planned projects was established. [11]
The researched parameters for existing projects were:

- Number of residents
- Classification of waste water system and performance.
- Interval of maintenance of the system

- Whether recycled waste water is being used for irrigation or other purposes and/or the willingness to do so in future.

Similarly projects under construction or in planning were evaluated. Here additional parameters to the above points were

- whether a phased implementation is planned
- to established a time line for completion
- determine the number of apartments already booked

Quantity of waste water to be treated

For the purpose of this study a definition of waste water (to be treated) is required.

Waste water is here defined as the water that has been used for various purposes inside residences (shower, toilet, kitchen, washing machine etc.) and collected in sewer systems. Technically water used on the premises for washing a car or motorcycle is also considered waste water. But since it is presently not collected for treatment and there is no plan in place to provide such facility it is excluded from the above definition.

Similarly rain water that accumulates in form of run-off from roads and other sealed surfaces should be dealt with independently. Widespread work has been done in the study area to reduce surface water run-off. For this purpose an extensive system of small earth dams has been created. These "bunds" follow the contour lines of the land and prevent surface water flow to lower lying areas. The water is retained and then percolates into the ground.

Quantities of waste water per capita vary widely from country to country and even from State to State within a country. Literature [12] recommends that for technical installations such as a sewage treatment plants, sewer systems etc., the quantity of waste water should be established by metering. Is this not possible, due to high costs and other constraints then other means of establishing the quantity should be applied.

In Auroville the habits of water usage differ from those of average Indian and/or Western communities. The population of Auroville consists of a mix of different nationalities with different water usage practices. At the same time domestic utilities like washing machines and dishwashers, quite common in the west and which lead to considerable water savings are not (yet) so widely spread.

This point was researched in more detail in Iran by *Almasi Ali* et.al. . (Presented at International Conference on Water Resources & Arid Environment 2006) [13]
By comparing three residential communities with different socio economic status, they show that there is a close relationship between water consumption (and wastewater generation) and socioeconomic status.

Considering the diversity of Auroville, the approach of applying an Indian, or any other standard to determine the quantity of waste water would probably not lead to reliable figures.

Table 1 *–Almasi Ali et.al. (Iran) Water Resources & Arid Environment 2006, Ratio of waste water to fresh water, in communities with different economic statu.s*

Area	Economic status	Load BOD	Wastewater Winter	Wastewater Summer	Fresh Water Winter	Fresh Water Sum	Ratio Winter	Ratio Summer
-	-	g/cap. /day	lit./capita/day	lit./cap./day	lit./cap/day	lit./cap./day	Waste water/ water	
A1	low	56	112	170	140	188	80%	90%
A2	medium	62.4	158	204	188	291	84%	70%
A3	high	62	170	220	200	398	85%	55%
						average	83%	72%

The amount of waste water currently produced in the Study Area could not be measured directly.
Waste water is often collected in multiple pipe systems (separate pipes for kitchen, bath rooms etc.)
Meters to measure flow of untreated waste water are not readily available.
Access to the underground sewer lines to install these meters is difficult and metering the large number of small treatment systems would require an effort that surpasses the capacity of this study
In order to acquire meaningful data, long term data-logging would have to be conducted This would exceed the frame of this study.

The Study Area is almost exclusively residential therefore the quantity of waste water per day can be described by

$Q^{ww}{}_{,24} = Q^{ww}{}_{PE} \times P$

With $Q^{ww}{}_{PE}$ = the average amount of waste water produced per resident (PE)
and

P = Number of residents in the study area

Monthly / seasonal fluctuation of waste water quantity has to be considered.
During the hot season it can be assumed that people will shower more often then in the rainy season. On the other hand during the hot season part of the population travels to cooler places and some residences are vacant for this periods. This trend reverses in December – March when Auroville receives a lot of visitors.

The amount of waste water created by a community has a correlation to the fresh water consumption. In most European countries the billing for waste water is oriented on the metered fresh water consumption.

Table 1 shows that during the time of year when water is used almost exclusively for domestic purposes (winter), the ratio of waste water to fresh water consumption is

80-85% (1),

irrespective of the socio economic status of the analyses community. Similar values are found in other literature sources.

The option of determining the waste water quantity through the fresh water consumption was therefore further explored.
In Central and Western Europe the quantity of waste water produced lies between 150-250 l/d/P. In North America the figure is even higher.

The table [2] below shows water consumption guide-values according to national and international standards:

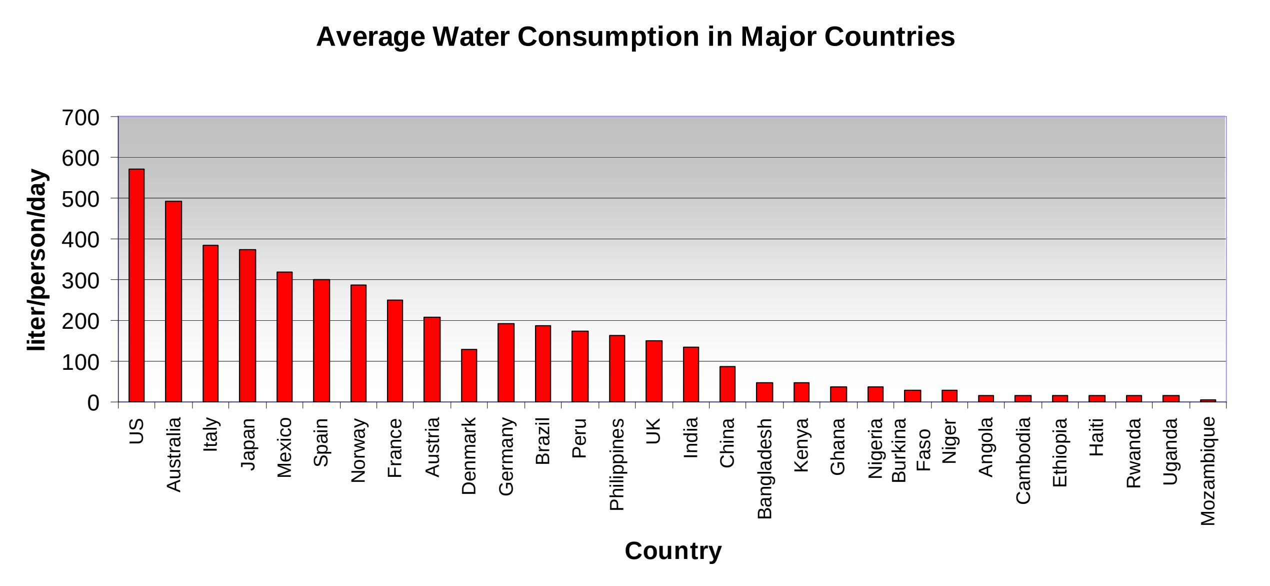
		Average water consumption per person and day
1	Indian Standard CPHEEO [21] IS (BIS) 1172-1993 (1998)[22]	 135 l/day 150-200 l/day
2	Germany/Switzerland/Austria (PE)	200 l/day

	American standards	Average amount of waste water produced per person and day
3	high rise buildings	190 l/day*
4	low rise building	245 l/day*
	Mean	217 l/day

*(*The American guide values correspond to measured flow of waste water per apartment.)*

Institute of Environmental Technologies University of Bremen (Germany) cites that lacking any accurate measurements the amount of waste water produced per person in Germany can be assumed as 150 l/d/P. Further values are given in the chart below.

Chart 2 - Table of water consumption in major countries.

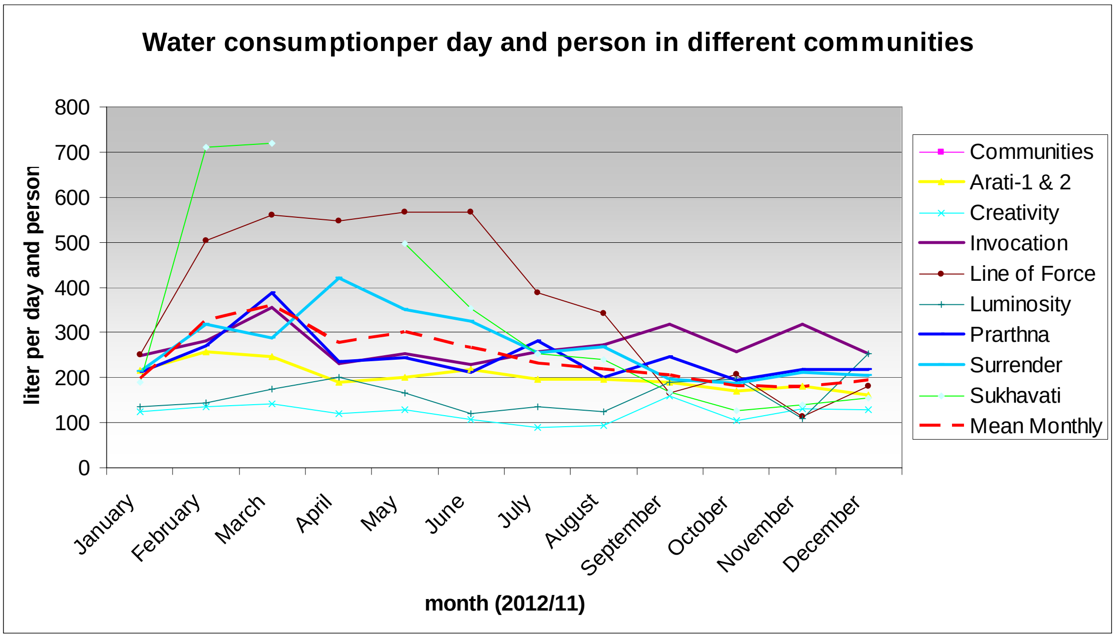


(United Nations Development Program- Human Development Report 2006)

As expected both the table and chart show a high variation from country to country and therefore a more accurate approach is required.

The fresh water consumption of most communities in the study area is being metered. This data was collected and analyzed and compared with other standards.

The first data set was obtained from the meter reading of the main water tank in the study area. The water tank covers the supply of 2/3 of the residences in the study area.
The data in *Chart [3]* covers 12 month (-).



Data indicates the daily water consumption varies strongly seasonally and from community to community. The average consumption is in the range of

$Q^{FW}_{,24}$ = 400 l/day

However this figure includes:
- water used for gardening and other than residential purposes
- malfunctioning water meters
- leaks in the supply line

The data covers approximately 300 residents (as per master list).
It should be noted that this does not necessarily reflect the actual number of residents. It does not include children and it does not reflect if some residents are out of town for extended periods.
Given the relatively small sampling volume, a difference in actual number of residents to the number of assumed residents has a large impact.
If for example 40 people would travel abroad during the summer month, then the overall water consumption would drop. Since the data does not show their absence, it would indicate that the per capita consumption during this period is reduced – which is obviously false.
It was concluded that the data from this source can not be taken as an indicator.

More accurate figures can be arrived at by using individual meter readings at residences were freshwater is used almost exclusively for residential purposes as described above. Here the data collected from the community "Payhatna-West" was very useful[14]. This community is representative for Auroville in terms of resident's lifestyles, nationalities and age. Since meters are installed close to the residences, water losses do not play a major role. Long-term absence will reflect in the reduced water consumption of the particular house hold.
Meter readings have been taken accurately during the past 4 years.
The community is connected to a joint waste water treatment system that offers recycled water for gardening hence it can be assumed that the meter readings represent reasonably accurately the amount of water used for residential purposes.

The monthly variation of fresh water usage over 4 years is shown below.

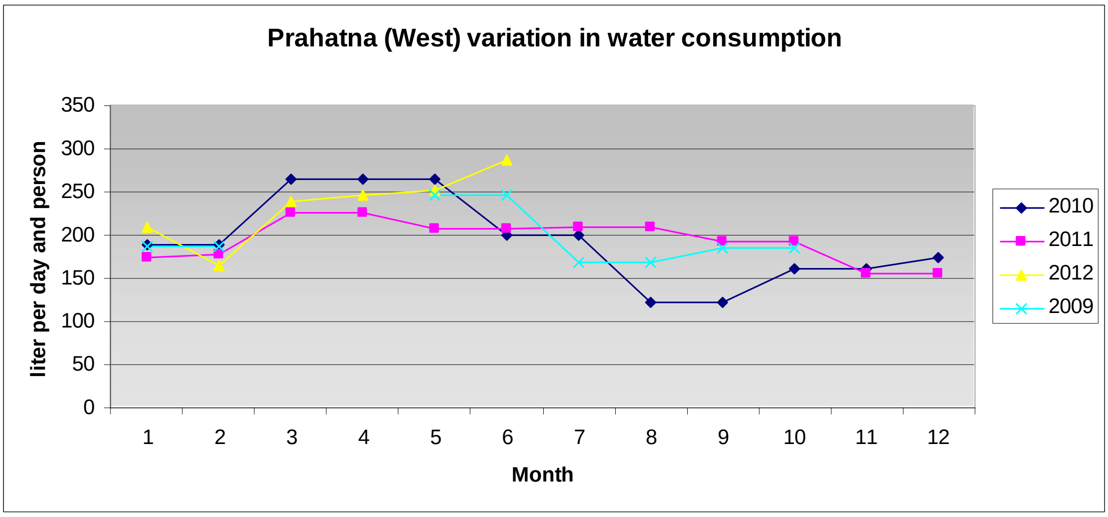


***Chart** [4] water consumption Prayhatna-West*

The average consumption lies by 205 l/day/p. (summer 226 l, winter 176).
It may be noted that the data is close to the data found in Table 1 (study of *Almasi Ali*).
line 3 (summer 220 l, winter 170).

Although the chart shows residential water usage, there are applications were water is used that is then "lost" and not directed back into the sewer.
Examples are water for cleaning purposes in and around the residences, laundry, evaporation (re-filling of water trenches and ponds) etc.

The ratio multiplier (1) is applied. Then the "losses" are 15 % and the remaining 85% of water is directed back into the sewer for treatment.

(2) $\mathbf{Q^{ww}_{PE}}$ = .85 x 205 = **175 l/d** (rounded)

It seems to be realistic to assume in the following that the data derived from the measured water consumption in the sample community within the study area is accurate enough to be used as guide value for further calculations. Since no definite trend of variation in summer/winter consumption can be observed the above figure is assumed as a mean value through the year.

Change in usage pattern

In establishing long-term predictions for waste water management and it should be considered that usage patterns will change over time.
This may be due to general factors such as

- installation of water efficient devices for domestic appliances (toilet flushes, washing machines, facets etc..
- increase in fees for water usage
- increased consciousness for natural resources

But also due to location specific constraints such as

- power shortage
- water shortage, long periods of droughts

The Chart [5] below shows that the average consumption of water in Germany has declined in the past 20 years by 15 % from 147 l/d/p to 122 l/d/p.

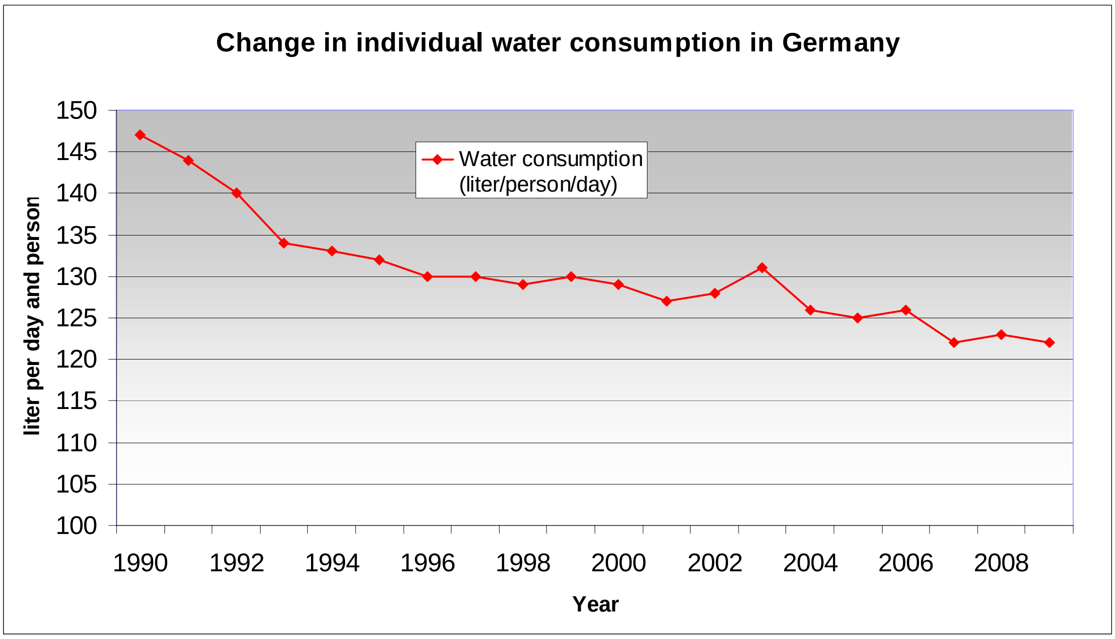


Chart 5: individual water consumption Germany, source Federal Statistics Office, BDEW

It can be assumed that the water usage habits in Auroville will undergo a similar process. The future development in the study area will take the form of higher densities and smaller residences (see chapter population density). The per capita consumption is related to the size of residences. People living in a smaller space use less water than people living in larger spaces. (see Table 2 - US Standards).
Hence as reference for long term planning it is assumed that the amount of waste water per inhabitant will decrease by 15-20% to

$$(3) \qquad Q^{ww}_{PE,long\text{-}term} = \mathbf{150\ l/d}$$

At this point it is worth mentioning that “bigger is not always better“, at least in the context of waste water management. An over-dimensioned sewer system will clog when minimum fill levels are not maintained. Then fresh water has to be pumped into the sewer at regular time intervals to flood out deposits.
Similarly a biological waste water treatment plant that is run under capacity for extended time will not work well because bacteria are “starved”. To build an oversized system is a waste of money. Hence it is recommended to use a conservative figure for the per capita waste water generation.

Population

Current population in the study area is given with

(3) P = 530 persons (April 2012)

The average amount of waste water produced per day in the study area can be assumed as:

(4) $Q^{ww}_{,24} = Q^{ww}_{PE} \times P = 175 \times 530 * 10^{-3} = 93$ m3 / day

Estimation of population growth

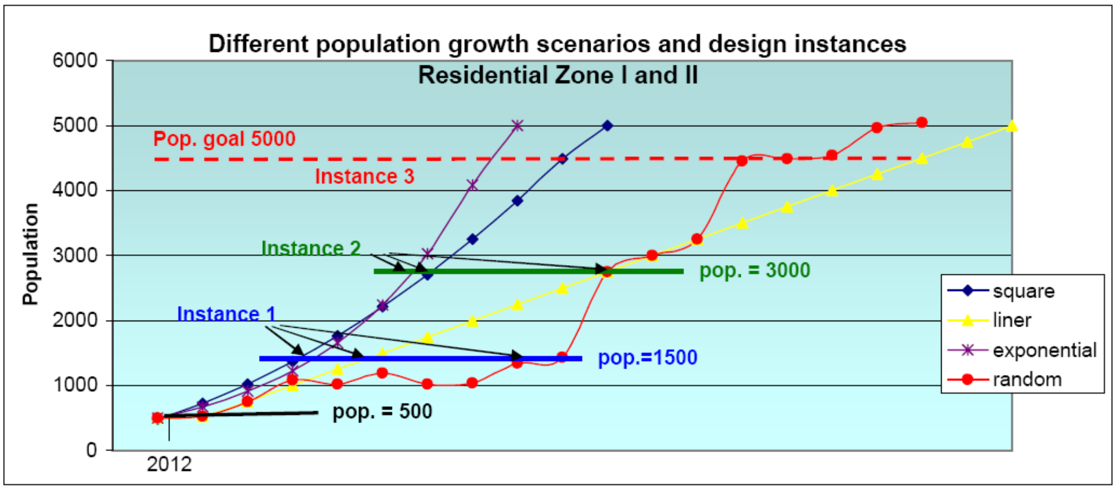
To arrive at an accurate prediction for population growth for the Study Area has proven difficult.
Generally population increase is governed by child birth/ death rate and migration.
Usually growth of cities is effected by economics (job opportunities), availability of housing, cost of life, quality of life (social, environment, climate, education and health facilities, crime-rate etc)
Many of these factors can be influenced by setting planning goals and taking active control measures.
Auroville however has the primary goal of creating a spiritual township as outlined by the founders.
Hence some people contemplating migrating to Auroville may be appealed by the outlined factors, but not find their call towards the spiritual side.
Population growth rate in Auroville during 2009 -2012 was in fact negative[15]

Auroville's population-age structure shows a healthy base of many young people but a general trend can be observed that young people after completing their second grade school education often leave Auroville to pursue further studies and explore the world. Some return to Auroville at a later point and settle permanently. In this case population growth through the positive birth rate is reduced by negative migration.
On the other hand there are a number of people already living in Auroville who wish to move into the Study Area but can presently not be accommodated because there is a shortage of housing. In many cases lack of funds is a major inhibiting factor.
Over the past two years there has been a concerted effort to provide more housing.
In April 2012 four apartment projects with an additional capacity for 200 residents were under construction and site permissions and/or building permissions for further apartments for 350-450 residents have been given. (offices and similar non-residential spaces are here treated as residences)
The survey [8] shows most of the projects planned in phases and booking of apartments had only been partially filled. The time frame for occupancy of all planned apartment is vague.

Hence the standard methods to arrive at a population-time line by interpolating historic data and/or projected growth does not lead to satisfying results.

Here a different approach is offered that abandons the time-line altogether and takes the absolute population figures as reference.

The current population in the Study Area is about 500 Residents.
Planning provides in [1] for a projected final population is 5000 Residents
The population growth may follow any mathematical pattern (linear, exponential) or be random.



Chart[6]

For the purpose of waste water management the absolute figure of population at a given time is relevant. In the following we assume 3 population benchmarks which would constitute the relevant trigger to expand the waste water infrastructure:

Instance 1 at 1500p. This benchmark corresponds to the number of residents expected once the residential projects that have up to date been approved or proposed are completed.

Instance 2 at 3000p. Arbitrarily chosen benchmark for the purpose of phased development of the waste water infrastructure. Sub-division into smaller increments is possible (ie 2000, 2500 etc)

Instance 3 at 5000p. Population goal benchmark

At any given point in time when one benchmark is reached, the waste water infrastructure needs to be extended. It is not relevant how much time passes between two benchmarks, as long as the expanded capacity is made available at the time when it will be needed.

Construction of apartment projects takes typically 2-3 years from the point when building permission is given to the point when a resident can move into the new apartment.

This time is considered sufficient to complete the extension of the waste water treatment system.

Population distribution within the Study Area

In order to provide the waste water management concept under this study, the targeted population distribution has to be established. This is essential to determine the lay-out and dimensions of the sever line network, treatment plants and other systems.

The typical hierarchy in planning involves

- Master Plan
- Zonal Plan ↓ *increased detail*
- Layout Plan

While a detailed lay-out plan is not required for this study, a base-map in form of a zonal plan is needed.

A base-map for the lay-out of the waste water treatment concept would be designed in the following manner

Step 1 Establish a zoning plan by

- Identifying different development areas, for example Zone A, B, C ;
- Establishing the overall appearance of each zone and
  Assigning “main appearance” such as residential, commercial etc. or mixed
- Deciding on main access roads and road reserve
- Decide on public areas, parks, and others
- Setting development parameters such as plot size, ground cover (sealed area), set back (distance of buildings from roads and adjoining buildings), height of buildings.
- Identifying targeted population such as singles, couples, and families with children (this would decide the type of buildings) and/or social-economic status of residents that one wants to attract.
- Publishing the lay-out map with
  - Plot size
  - Min and max ground cover
  - No of floors, max building height
  - Set back
  - Build up Area Index
  - and other relevant parameters

Step 2 Establish population density grid map with suitable gird size

Step 3 Draw sewer network with branch sewers and trunk sewers using road alignments and other possible corridors.

Step 4 Distribute and assign each raster element of Step 2 to a convenient branch of the infrastructure network

Step 5 Calculate flow-rates, flow delay, treatment plant size and other parameters.

Zonal Plan

No finalized zonal plan exists as yet for the Study Area. Some studies have been made projecting ground coverage and building height.
In a proposal of November 2011 a study was presented showing plot-wise residential distribution in the study area with a total projected population of 7280.
The document "Reference Master Copy 14.12.2011" by L'Avenier suggests a distribution with a targeted population of 3330 people. This was reviewed in the paper "Land development plan" June 2012 (Bertrand, Sindhuja and Dorle)[16], which shows a target population 4529 residents. This includes a Line of Force with a 1000 residents that is to be build over the Radial no 5 (Solar Kitchen). Allthough the absolute figures in these studies vary significantly, they have in common that they indicate an increasing population density from the Outer Ring Road towards the Inner Crown and a corresponding increase in building height. An exception is the project "Progress" in the RZ II located close to the Outer Ring Road with 8 floors and the "Line of Force" along the Solar Kitchen Radial.

However a detailed analysis[17]of these studies shows that basic assumptions such as targeted number of residents, build-up area, FAR [18] and carpet area do not correlate and therefore population density distribution could not be established conclusively based on these studies.

Population Distribution

In the following the population density distribution is computed based on the target population proposed in [1]

RZ I and RZ II = 1500 +3500 = 5000 Residents (1)

and the available "free" land in the Study area.

The Study Area inscribes 57.5 hectares. (2)
The road reserve space on each side of the center line of the main access roads (Crown Road and Radials) is 9 meters.

The net area is 50.2 hectares (3)

The land-use plan (base Map [3]) shows 8 green corridors with an approximate width of 30 meter bisecting the Study Area.

The Green Corridors occupy 6.9 hectares. (4)

These can be used as infrastructure corridors, but will remain largely free of buildings. Existing projects show generally a low ratio of build up area to plot area with a population density of 67 people per hectare. Since the quality of construction (material, aging) is generally good it can be assumed that existing projects will remain for some time and not yield to higher density buildings.
Existing projects are mostly set back from the access roads (Radials) and spaced apart so that only limited additional development within each projects could be accommodated but no further development in the set-back area.
Although some buildings are attached or semi-attached within projects, the architecture is mostly such that a continuation with attached buildings is not possible. A reserve space (buffer space) around existing projects will be required towards future development. The buffer zone is assumed as 10 m on all sides of existing projects. This leads to a figure of

13.2 hectares occupied space. (5)

According to AASHTO [19] residential roads and road reserve in urban development are estimated to use 10 - 20 percent of the available area. Since the Study Area is lined on all sides with access roads (Radials) the space requirement for inner distribution roads in the undeveloped areas can be assumed with the lower factor of

10% road reserve. (7)

This leaves

27.1 hectare available land (8)
for future projects in RZ I and II.

Table [3] shows the above calculation for density-distribution separately for RZI and RZII:

Text reference	Free and occupied areas		RZ 1 (hectare)	% of total	RZ II (hectare)	% of total	RZ I + II (hectare)	% of total
3	Total available area minus outer access road reserve		28		22.2		50.2	
4	Green corridors		-3.8		-3.1		-6.9	
5	Existing building and b. under construction.(occupied space with 10 m buffer zone)		-5.7	26%	-7.5	42%	-13.2	33%
6	Available land		18.5		11.6		30.1	
7	Minor distribution road reserve	10%	-1.8		-1.2		-3.0	
8	Remaining land for building		**16.6**	74%	**10.4**	58%	27.1	67%

Current population including planned apartments under construction is about 920 people[20].

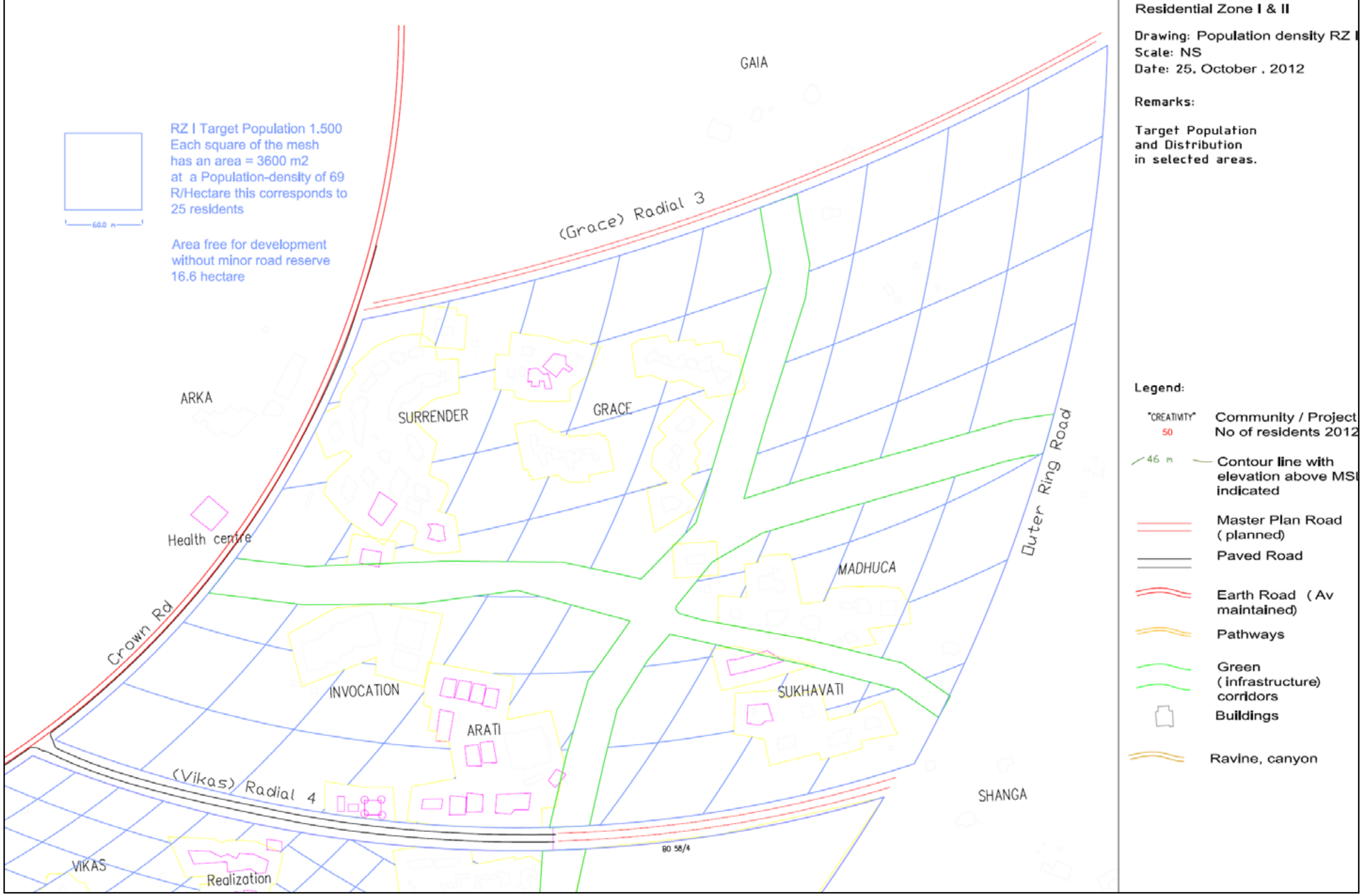
This leaves a population of 5000 – 920 = 4080 (10)
residents to be allocated on the remaining land and the mean population density for RZ I and RZ II is (10) / (8) = 4080/27.1 = 150 residents per hectare (11).

The table [4] below shows this calculation for RZ I and RZ II separately:

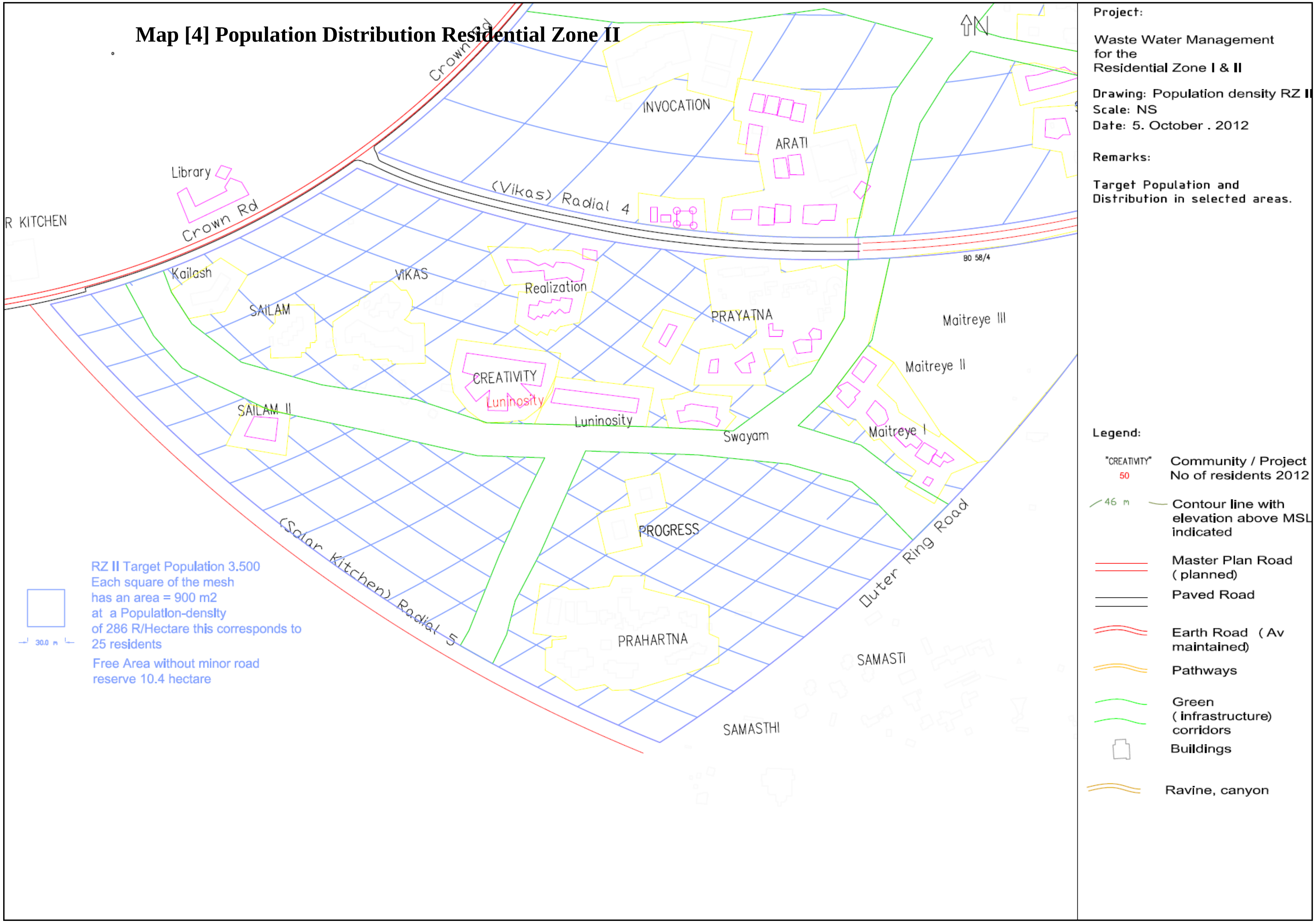
	Population distribution	RZ 1	% of total	RZ II	% of total	Thread	RZ I + II (people)
9	Existing population, including in approved projects	350	23%	570	16%		920
10	Planned final population	1500		3500			5000
11	Population to be allocated on remaining land	1150		2930		(10 -9)	4080
12	Mean population density for future projects (residents per hectare)	**69**		**280**		(11 / 8)	**151**
20	Current mean population density in existing projects (residents per hectare)	61		76			70

With a suitable grid size corresponding to 25 Residents, a raster is projected over the base map. The result is shown in the maps on the following page.

Map [3]Population Distribution Residential Zone I



Map [4] Population Distribution Residential Zone II



For example a plot in the RZ II with an area of approximately 5000 m2 is to be developed with infrastructure. The corresponding infrastructure requirements can be either calculated by using the density established in Table 4

$5000 * 286/10^4 = 135$ residents

or graphically by counting the number of raster elements which the plot covers. This would be the preferred method when the plot is irregularly formed

The same method may be used to determine other infrastructure requirements like water and power supply, number of telephone connections etc.

If during the next years planning goals would be refined or modified the above map method remains valid as long as the revised values for population density are applied to the map by adjusting the size of the raster elements.

Quality of waste water

In order to determine the quality of water, whether fresh water or treated and un-treated waste water numerous chemical, physical and biological parameters are defined.
Some parameters such as temperature or turbidity are easily established at site, chemical and biological impurities require a varying degree of sophistication of testing equipment. Also the required accuracy varies. For example the biological oxygen demand (BOD) of water is established in gram per liter or 100 ml and usually a measuring tolerance of 10 % would be unproblematic. Some heavy metals and organic and inorganic compounds are present only in small traces and measured in parts per million (ppm), which requires specialized testing laboratories.
The cost for taking a sample and analysis depends on the types of test to be performed.

The source of waste water in the study area is exclusively from residences. Heavy metals and other industrial pollutants as well as contamination with insecticides or other chemicals are presently of no concern.
The parameters of contaminants that are being tested for and compared are therefore restricted to those that are determined to play a defining role in the context.

Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are measured as indirect indicator for the amount of organic compounds in the water. In fresh domestic waste water the ratio of BOD to COD is usually about 0,6. This allows an approximate comparison of different samples if only one or the other value was tested. The test for COD is simpler and faster and often the preferred method. Typically, unpolluted surface water has BOD values of 2 mg/l or less.

Nitrate (NO3), Nitrite (NO2) often tested together as total Nitrates
and Phosphates are an indicator of nutrient content in the water

Coliforms as indicator for human or animal fecal contamination and possibility of pathogens

Potential of Hydrogen (PH) as indicator for the acidity/basicity of water ph = 7 being neutral, acid < ph = 7 < basic

Turbidity as indicated for suspended solids.

In polishing ponds the dissolved oxygen is of importance to indicate the capacity to absorb nutrients.

The widely accepted guide parameter for quantity and quality of waste water is the Person Equivalent (PE). This standardized value assumes that on average one person will produce a set amount of waste water of a fixed composition per day. The quality is defined by parameters that serve as indicator for the amount of organic and chemical pollution.

Other waste water, for example from industries, can be defined in terms of corresponding numbers of Person Equivalent. Hence the name.

The Indian Standards cite the following waste water characteristics per PE:

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 should be noted that the Indian Standard for BOD is over 3 days at 27° versus the international standard of 5 days at 20°. It was however demonstrated that the values differ only slightly[21].

Wastewater characteristics International Standards

Guide Values for Germany/Switzerland/Austria

For Population Equivalent (P.E.)

BOD5	300	mg/l
COD	600	mg/l
TOC	200	mg/l
TDS	300	mg/l
Total N	55	mg/l
Total P	12	mg/l

Metcalf and Eddy (1991) show the typical composition of untreated domestic wastewater in the US as follows. (Adapted).

Contaminants	**Unit**	**Concentration**
Solids, total (TS)	mg/l	720
Dissolved, total (TDS)	**mg/l**	**500**
Fixed	mg/l	300
Volatile	mg/l	200
Suspended solids (SS)	mg/l	220
Fixed	mg/l	55
Volatile	mg/l	165
BOD_5 at 20° C	**mg/l**	**220**
Total organic carbon (TOC)	mg/l	160
Chemical oxygen demand (COD)	**mg/l**	**500**
Nitrogen (total as N)	mg/l	40
Phosphorus (total as P)	mg/l	8
Grease	mg/l	100

Waste water sampling in Auroville at inlets of community treatment plants has been done.
The summarized results are shown in the table below.

Table [6]: Summary Test Results at the Inlet of Waste Water Treatment Plants in the Residential Zone
(Tested by Environmental Monitoring Service)

Parameters	Units	Creativity	Creativity	Invocation	Surrender	Vikas	Vikas	Arati
		7.4.2008	**13.3.2012**	**14/03/08**	**7.4.2008**	**7.4.2008**	**13.3.12**	**13.3.12**
pH (at 25º C)		7.2		7.1	7.5	6.9		
Total Dissolved Solids (at 103º C)	mg/l	690		860	589	778		
COD	mg/l	177	230	120	376	438	123	226
BOD_3 (at 27º C)	mg/l	107		55	189	179		
E. coli	N/100 ml	4.90E+06		4.10E+06	1.20E+07	7.80E+06		2.60E+05

Mean Parameters	Units	
pH (at 25º C)		7.2
Total Dissolved Solids (at 103º C)	mg/l	730
COD	mg/l	210
BOD_3 (at 27º C)	mg/l	130
E. coli	N/100 ml	7.27E+06

The tests were taken in single samples and may not be representative.
The sewage line between the source and the treatment plant is often very short and this leads to errors. The samples do not reflect the fact that over the period of one day there are hourly fluctuations in quantity and quality of waste water.

There is a wide variation in the samples and even within a sampled community the data is erratic. This can be seen on the two examples of Creativity and Vikas were sampling was done on two occasions.

Comparison the values for BOD and COD of the Auroville sample data with Indian and International standards shows that the waste water is "thinner" or diluted. This may however be attributed to the method of sampling (see point above).

Since the Indian and International standards are quite similar in their approach to the values for BOD and COD it is suggested to use the Indian reference values.

Use of recycled water

Several communities in the study area use recycled waste water for gardening. The survey shows that there is a large acceptance and appreciation for this within in the communities.
Recycled waste water can be an important resource because it replaces prime freshwater and the nutrient contents especially Phosphates and Nitrates are valuable as fertilizer for plants.
In some cases complaints were made in respect to odor and color of the recycled waste water and this raises doubt in regard to the hygiene of using the water from the present treatment systems.
Analysis of effluent of the existing treatment plants shows the presence of coliform bacteria in most cases and this could be cause of concern.

Depending on the method of waste water treatment 65-85% of the generated waste water is available as re-cycled water. The remaining 15-35% is lost due to leakage and evaporation.
Currently only "natural" treatment systems are in use in the study area and closed (underground) systems have a higher yield then open systems like planted filters and ponds. Planted filters on the other hand show a better treatment result in regard to COD and coli form than closed systems.

Poor results achieved by some of the treatment plants are not necessarily due to bad design, but rather the lack of maintenance. This is further elaborated on in the chapter "Performance of existing treatment plants".

Potential for recycled waste water

The average freshwater consumption per resident was estimated in Chapter 1 at 400 l with 205 l flowing into the households and 175 l discharged into the sewer systems. It can be assumed that the difference of 195 l is mostly used for gardening.

With a recycling yield of 75% the recycled waste water could potentially replace 65% of the water currently used for gardening and irrigation in the communities. Therefore this option should be further explored.

The major constraint in this application is that a secondary water distribution system within each community has to be built. Garden water taps have to be clearly marked to avoid accidental mix-up with fresh water supply, ingestion or contamination. Sociological factors may also play a role. While in communities currently using recycled wastewater for gardening the acceptance is high, this may be due to the fact that the residents are aware and involved with their own treatment plant, this could change if the recycled waste water would be provided from a centralized plant.

Another potential use for re-cycled waste water is irrigation of public green parks. The advantage in this application is that the distribution network is much simpler.

An other application for the use of recycled water could be in agriculture.

In all the above usages it has to be considered that the application would be seasonal and that during the rain season other means of disposal have to be found
The use of recycled waste water for applications such as toilet flushing has been tried in some projects with mixed results.
It is estimated that 30-45 liter per day and person are used in toilet flushing. Valuable fresh water is used as transport media for waste. If this were replaced with re-cycled waste water considerable savings could be achieved.
A secondary water distribution has to be installed within each residence and a higher degree of water quality/disinfection has to be achieved to avoid problems in the water storage when water is retained for extended time in flushing tanks.

Other medium level applications are laundry services, car wash, etc. which have been successfully tested in various countries but will be not further explored here.

Most applications to use recycled waste water are seasonal or otherwise irregular so that the discharge of waste water will in most cases not correspond to the demand of recycled waste water.
Storage and/or alternative means of disposal have to be provided.
If the treated water can not be otherwise reused it would have to be percolated into the ground either by soak pits or surface spreading. Eventually it will reach the aquifer. The benefit would be the recharge the ground water but safeguards against contamination have to be provided. The required quality of the discharged water depends on discharged volume per area, the type and depth of soil, distance to the nearest well and other factors.

Required treatment level of waste water for re-use or discharge.

In all cases the intended use of the recycled water would decide the degree of treatment that the waste water has to undergo.
The cost of treatment increases exponentially with the degree of purification.
It is therefore not desirable to plan for a higher degree of purification than required by the end-use.
Another consideration is that if waste water is to be used for irrigation then a residue of organic matter is appreciated and wanted as fertilizer. The organic matter is rich in nitrates and phosphates which otherwise has to be introduced by compost or artificial fertilize.
If waste water is released into an open water body, rivers or lakes, then the organic substances would draw on the oxygen reserve and cause eutrophication resulting in excessive algae blooms and be a problem for fish and other aquatic life.

Use of recycled waste water is clearly beneficial if adequate safety measures are applied.

Benefit	Safe guard
Reduce drinking water consumption	Protect humans and animals from disease
Fertilize the soil	Protect the ground water
Recharge the ground water	Protect the soil from accumulating harmful salts and other contaminants

Indian Standards

IS 11624:1986 - Guidelines for the quality of irrigation water.
The quality of irrigation water is evaluated in terms of degree of harmful effects on soil properties with respect to the soluble salts it contains, but has no further reference to human health concerns.

CPCB published the schedule VI , “Discharge of effluents into inland surface water bodies, public sewers, land for irrigation and marine coastal areas” . The guide values for irrigation water do not contain any limit for pathogens.

International Standards

WHO published in 2006 "*Guidelines for the safe use of wastewater, excreta and grey water*" [22] this 4 volume manual provides a detailed analysis of benefits and problems in the use of waste water for irrigation.
The safety of people who come into contact with the recycled waste water or the agricultural produce is being assessed. Of major concern is the presence of contaminants in the water used for irrigation.
Different requirements in regard to water quality have to be met depending of the method irrigation that is applied.
Irrigation through sprinkler systems causes aerosols that spread much further beyond the irrigated area and they can be inhaled
Flood irrigation and sub surface (drip) irrigation pose a much lesser problem in this regard.
Some irrigation systems are prone to blockages if water quality requirements are not met.

Of equal importance is what type of plants are being irrigated, whether they are crops for human consumption, low growing, high growing, to be cooked or eaten raw.

WHO distinguishes whether adults or children below 14 years have access to the irrigated site. Younger children are less likely to follow hygiene instructions (not to ingest the water, washing, shower after contact) and because their immune system is not yet fully developed they are more prone to contact disease.

Of concern are[S.12.Tabel 2.1 in 18]:

- Excreta-related bacteria like Escherichia coli, Vibrio, Cholerae, Salmonella etc.. states that although bacteria die off quite rapidly on crops they present a health risk and outbreak of typhoid and cholera have been associated with use of waste water on crops.

- Helmiths (intestinal worms, hookworms, Ascaris for example), because the eggs can survive in the environment a long time.

- Viruses (hepatitis A and E viruses, adenovirus, rotavirus, norovirus), because they are present in high numbers in wastewater and excreta, and some types can survive in the environment long enough to pose health risks.

- Vector-borne pathogens (dengue, encephalitis, filariasis)

The WHO study makes in [18 Table 2.9]: the following recommendations for waste water use in agriculture

Activity/exposure	Water quality monitoring parameters	
	E. coli per 100 ml	Helminth eggs
Agriculture		per liter
Unrestricted irrigation		
Root crops	$\leq 10^3$	≤ 0
Leaf crops	$\leq 10^4$	≤ 0
Drip irrigation, high-growing crops	$\leq 10^5$	≤ 0

The WHO guidelines are very thorough in their approach. However for Auroville, with limited resources and a small target population it would be complicated to distinguish between the different levels of irrigation. Hence it is proposed to apply a uniform value for reuse of water in irrigation.

US standards differ from State to State and are more stringent, but similar to the WHO standards they distinguish between the types of use for reclaimed water.
Main indicator is again the Coliform content. The table below gives a summary of all parameters of quality requirements for unrestricted use. Values for Coliform are given in addition for agricultural use for food crop and non-food crop.

Table: U.S. Environmental Protection Agency gives the following values for 7 US States

	Arizona	**California**	**Florida**	**Hawaii**	**Nevada**	**Texas**	**Washington**
Treatment	Secondary treatment, filtration, and disinfection	Oxidized, coagulated, filtered, and disinfected	Secondary treatment, filtration, and highlevel disinfection	Oxidized, filtered, and disinfected	Secondary treatment and disinfection	NS (1)	Oxidized, coagulated, filtered, and disinfected
BOD5	NS	NS	20 mg/l CBOD5	NS	30 mg/l	5 mg/l	30 mg/l
TSS	NS	NS	5.0 mg/l	NS	NS	NS	30 mg/l
Turbidity	2 NTU (Avg)	2 NTU (Avg)	NS	2 NTU (Max)	NS	3 NTU	2 NTU (Avg)
	5 NTU (Max)	5 NTU (Max)					5 NTU (Max)
Coliform	Fecal	Total	Fecal	Fecal	Fecal	Fecal	Total
	None detectable (Avg)	2.2/100 ml (Avg)	75% of samples below detection	2.2/100 ml (Avg)	2.2/100 ml (Avg)	20/100 ml (Avg)	2.2/100 ml (Avg)
Unrestricted Urban Reuse	23/100 ml (Max)	23/100 ml (Max in 30 days)	25/100 ml (Max)	23/100 ml (Max in 30 days)	23/100 ml (Max)	75/100 ml (Max)	23/100 ml (Max)
Agricultural Reuse - Food Crops	N one detectable (Av g)	2.2/100 m l (Av g)	75% of samples below detection	2.2/100 m l (Avg)	200/100 m l (Avg)	20/100 m l (Avg)	2.2/100 m l(Avg)
	23/100 m l (Max)	23/100 m l (M ax in 30 days)	25/100 m l (Max)	23/100 m l (Max in 30 day s)	400/100 m l (Max)	75/100 m l (Max)	23/100 m l(Max)
Agricultural Reuse - Non-Food Crops	200/100 m l (Avg)	23/100 m l (Avg)	200/100 m l (Avg)	2.2/100 m l (Avg)	200/100 m l (Avg)	20/100 m l (Avg)	23/100 m l (Avg)
	800/100 m l (Max)	240/100 m l (Max in 30 days)	800/100 m l (Max)	23/100 m l (Max)	400/100 m l (Max)	75/100 m l (Max)	240/100 m l(Max)

For the State of California the Titles 22 and 17 of the California Code of Regulations give detailed guide values and restrictions for the reuse of waste water.

The European Norm (76/160/EWG) on this subject was first published in 1975 and specifies that water quality for irrigation should follow the standard for bathing water quality.
The norm for bathing water quality was revised by Directive 2006/7/EC.
This norm is largely based on the WHO research. WHO proposed Intestinal Enterococci as the best indicator for microbiological contamination of coastal waters.
The EU Commission proposes in addition Escherichia Coli as an indicator for microbiological contamination of fresh water bathing areas [23].

Directive 2006/7/EC of the European Parliament for management of bathing water quality.

For inland waters

	A	B	C	D	E
	Parameter	**Excellent quality**	**Good quality**	**Sufficient**	**Reference methods of analysis**
1	Intestinal enterococci (cfu/100 ml)	200 [1]	400 [1]	330 [2]	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	500 [1]	**1000 [1]**	900 [2]	ISO 9308-3 or ISO 9308-1

For coastal waters and transitional waters

1	Intestinal enterococci (cfu/100 ml)	100 [3]	200 [3]	185 [4]	ISO 7899-1 or ISO 7899-2
2	Escherichia coli (cfu/100 ml)	250 [3]	500 [3]	500 [4]	ISO 9308-3 or ISO 9308-1

[1] Based upon a 95 ‐ percentile evaluation.
[2] Based upon a 90 ‐ percentile evaluation.
[3] Based upon a 95 ‐ percentile evaluation.
[4] Based upon a 90 ‐ percentile evaluation.

The prescribed evaluation method is interesting because it shows the statistical influence in sampling. 95% evaluation of samples with a rating “Good quality” show a higher number of e.coli than 90% evaluation of samples with the rating “sufficient”.

This demonstrates that the method of sampling in Auroville with typical one single sample reflects the actual quality of water only in a limited way.

Table [7]: Summary Test Results Outlet of five Waste Water Treatment Plants in the Residential Zone
(Tested by Environmental Monitoring Service)

Sl. No.	Parameters	Units	Creativity.	Invocation	Surrender	Vikas
			07/04/09	**14/03/09**	**7/04/09**	**7/04/09**
1.	pH (at 25º C)		7.2	6.6	7.1	7.7
2.	Total Dissolved Solids	mg/l	652	800	362	444
3.	COD	mg/l	77	36	44	61
4.	BOD_3 (at 27º C)	mg/l	23	14	12	25
5.	E. coli	N/100 ml	3.5E+04	2.0E+03	1.0E+02	4.2E+04

Sl. No.	Mean Parameters	Units	Results
1.	pH (at 25º C)		7.2
2.	Total Dissolved Solids	mg/l	601.6
3.	COD	mg/l	54.8
4.	BOD_3 (at 27º C)	mg/l	20.2
5.	E. coli	N/100 ml	3.E+04

Water sampling of outlets of waste water treatment plants in Auroville shows a high fluctuation. This may be due to the fact that some systems are lacking adequate maintenance (see following chapter).

Disposal of waste water by surface spreading

India Standards

The Manual on Artificial Recharge of Ground Water by the Central Groundwater Board stipulates that waste water can be used after primary sedimentation and secondary (biological) treatment and advantage can be taken of filtration and bio-degradation that occurs as the water passes through the upper soil layers and zone of aeration.

If deeper percolation pits are used for direct recharge, then secondary treatment should be done followed by chemical clarification and filtration, followed by tertiary treatment.(air tripping, granular activated carbon treatment, reverse osmosis and disinfection).

IS 10500 states the standards for discharge as follows:

Water Quality Standards (IS: 10500)
General Standards for Discharge of Effluents.

Sl	Parameter and Unit	Into surface water
4	pH (max) (min : 6.5)	5.5-9.0
5	BOD (3d, 27oC) (mg/L)	30
6	COD (mg/L)	250
7	TSS (mg/L)	100
8	TDS (mg/L)	2100
9	Oil and Grease (mg/L)	10

International Standards

US Environmental Protection Agency (EPA) formulate extensive quality requirements for treatment and reuse of waste water. These standards are more stringent than the others above mentioned.
In particular they require the waste water for re-use in unrestricted urban areas (irrigation, car wash toilet flushing etc.) to undergo secondary treatment, filtration and disinfection.

BOD 7 < 10 mg/l and no detectable fecal contamination.

US Department of Environmental Quality states that "..in case of infiltration of water into the ground the system has to be designed so that it will not impact existing groundwater beneficial uses such as water supply wells (i.e., exceed drinking-water standards in a domestic water supply well).."

EU standards specify

Requirements for discharges in sensitive areas

Parameters	**Concentration**	**Minimum reduction**
Total Phosphorus	2 mg/l P	80%
Total Nitrogen	15 mg/l N	70 – 80%
BOD5	25 mg/l O2	70 – 90%
COD	125 mg/l O2	75%
Total suspended solids	35 mg/l	90%

Discharge of recycled waste water into lakes

Looking at the quantities of waste water produced in the study area the possibility comes to mind to release the water into the planned lake at Matrimandir.
Depending on the size and built of the lake it would require a constant inflow to maintain the desired water level. Water is lost into the ground due to seepage and considerable amounts will be lost due to evaporation. There are certain advantages because the lake could potentially accommodate the entire amount of treated waste water as a single supply point. This would simplify the distribution network. The lake would then function as a polishing pond. The lake may not be able to accommodate the recycled water during the rainy season in addition to the large quantities of rain water.
Careful consideration has to be given to the question of eutrophication.
Rivers have a good self-purifying capacity because the water is mixed through the current. The waste water is diluted and oxygen from the surface is transported into the deeper areas. The water in the lake is stagnating. The treated waste water is not mixed with the remaining water, hence the cleaning capacity of the lake as a whole can not be taken into account. This could be improved with mechanical circulation device.
Additional aeration of the lake may be necessary during the hot summer month.
Since large quantities of water are lost due to evaporation, and there is no outflow of water from the lake, their will be a concentration of substances.
Therefore stringent guide lines and control for the release of treated waste water into the lake would have to be met.
The lake Bodensee in the border triangle Austria/Germany/Switzerland is the largest lake in West-Europe. Due to dense population along the shore of the lake and resulting pollution, special regulations were formulated in regard to quality standards for waste water released into the lake, shown in the table below:

Parameter	Size of Treatment Plant		
	50 - 1'000 Category I	>1'000 - 40'000 Category II	> 40'000 Category III
Biochemical Oxygen Demand (BOD5, with Nitrification catalysts	20 mg/l and 90% efficiency	15 mg/l and 93% efficiency	15 mg/l and 93% efficiency
Chemical Oxygen demand (COD)	90 mg/l	60 mg/l	60 mg/l
Dissolved organic carbons (DOC)3)	15 mg/l	10 mg/l	10 mg/l
Total Phosphor (P)	according to national norms	1 mg/l and 90% efficiency	0,3 mg/l) and 95% efficiency
Total Nitrates	according to national norms	according to national norms	according to national norms

Recommended standards for Auroville for new waste water treatment systems for different type of water reuse

In most cases children will have access to the gardens and parks to be irrigated. Occurrence of intestinal parasites is quite common in Auroville. Whether this is due to contaminated drinking water or food or contact with soil has not been researched, but it is recommended that if the waste water is to be used for irrigation it should meet the following standards:

E. coli < 10^3 count/100 ml (95% evaluation)

this corresponds to the WHO and EU standards for irrigation (unlimited use).
As per WHO standard

Helminth eggs count should be < 1 per liter.

In order to prevent unpleasant odors and sedimentation in the distribution system the following guide values should be met in addition:

BOD5 < 25 mg/l
COD < 125
TSS < 35.0 mg/l
Turbidity < 2 NTU

The same values are to be applied if the water is to be percolated into the ground by surface spreading, soak pits or shallow pipe systems (leach pipes)

If the water is be released into open water bodies (lakes).
The following additional parameters should be met

Total Phosphorus	2 mg/l P
Total Nitrogen	15 mg/l N

If the water is to be used for toilet flushing the water should additionally be disinfected with 1 mg/l Cl_2 (residual) or similar.

Developing a waste water quality management policy

Performance monitoring of the existing treatment plants shows that the above recommended values are only met in some cases.
A testing schedule should be formulated to ensure water quality management.
(See Part 3 of this study).
The testing schedule should be enforced so that all operators of waste water treatment plants in Auroville have to perform regular quality tests. The schedule should prescribe the method of sampling and testing and it should define how many of the annual water samples have to achieve the mandatory standard. There should be an emphasis on prompt management actions if the standards are not met.

Treatment and re-use or disposal of sludge

The sludge removed at various stages of domestic waste water treatment is a concentrate of the substances contained in the waste water. It contains mineral and biodegradable material as well as potentially pathogenic organisms (viruses, bacteria etc). The water content is usually above 90%. The sludge is rich in nutrients such as nitrogen and phosphorous and contains organic matter that is valuable a as fertilizer. Raw sludge emits a strong and unpleasant odor.

The sludge has to be processed in a suitable manner before it can be used as compost or fertilizer or disposed off.

Currently no standardized system for collection and treatment of sludge is in place.

The treatment involves removing excess water. The water separated from the sludge should be directed back into the waste water treatment plant.
Then the sludge should undergo a digestion process in which the organic substances, fats and proteins are reduced and pathogens die off.
The resulting compost should be safe to use for common gardening and in parks.

No (unpleasant) odor
Water content below 10%

European Norm 86/278/EEC deals with the maximum content of heavy metal and other chemical compounds. Since the waster water in the study area is purely of domestic nature this is not seen as an issue.
Of major concern are however the pathogens contained in the raw sludge.

The WHO Study (Volume 4 Table 3.5) presents

Die-off of selected pathogens in faces (expressed in T90 values)

Pathogen	**Die-off period in days,T90**
Salmonella	30
EHEC	20
Rotavirus	60
Hepatitis A	55
Giardia	27.5
Ascaris	125

It is found that in composting, turning and aeration of the compost accelerates the die-off.

It is proposed that processing of the sludge in digesters and subsequent composting and storage should be performed for 180 days before the sludge is brought onto the soil in parks or gardens.

The waste water treatment system and sludge processing should be designed in a manner that at no stage the staff on site or the public is exposed to health risks.

Bio gas

While the sludge is processed bio gas is produced. Handbook of Urban Drainage and Wastewater Disposal [24] describes the bio gas as composed of methane and carbon dioxide gas. The content of methane varies 65-80% depending on the type of digester used. The biogas has a calorific value of 7-8 kWh per m3.
The amount of gas produced is predicted at 13.5 liter per PE.
With an estimate population of 5000 PE the total biogas volume would be in the range of 67 m3/day. The gas can be used directly for cooking. If used in combustion engines the gas has to be cleaned sufficiently to meet the specifications of the engine.

Performance of existing treatment plants (with valuable input from Lars)

About 530 residents live in the study area in distributed over some 20 communities.
There is a variety of different types of treatment systems in use.
Generally the practice in Auroville is that after initial treatment in septic tanks (aerobic and/or anaerobic digesters), the waste water is passed either directly into “soak pits” or in some cases into planted filters. In some cases it then flows into an intermediate storage tank and is used for irrigation (during the summer months only).
Except for some cases were pumps are being used for aeration and irrigation, the systems are non-mechanical. The water flow is established by gravity.
Over the past years the performance of some of the systems has been monitored.
Extensive work was done by CSR, Tency, Gilles and others. For the purpose of this study Lars (CSR) did a lot of research. Extensive testing was done by Pierre Taillandier in 2009. Earth Institute published a study (Maud Perroud) in April 2012.
Laboratory analysis was done in most cases by Igor, Auroville Monitoring Service.

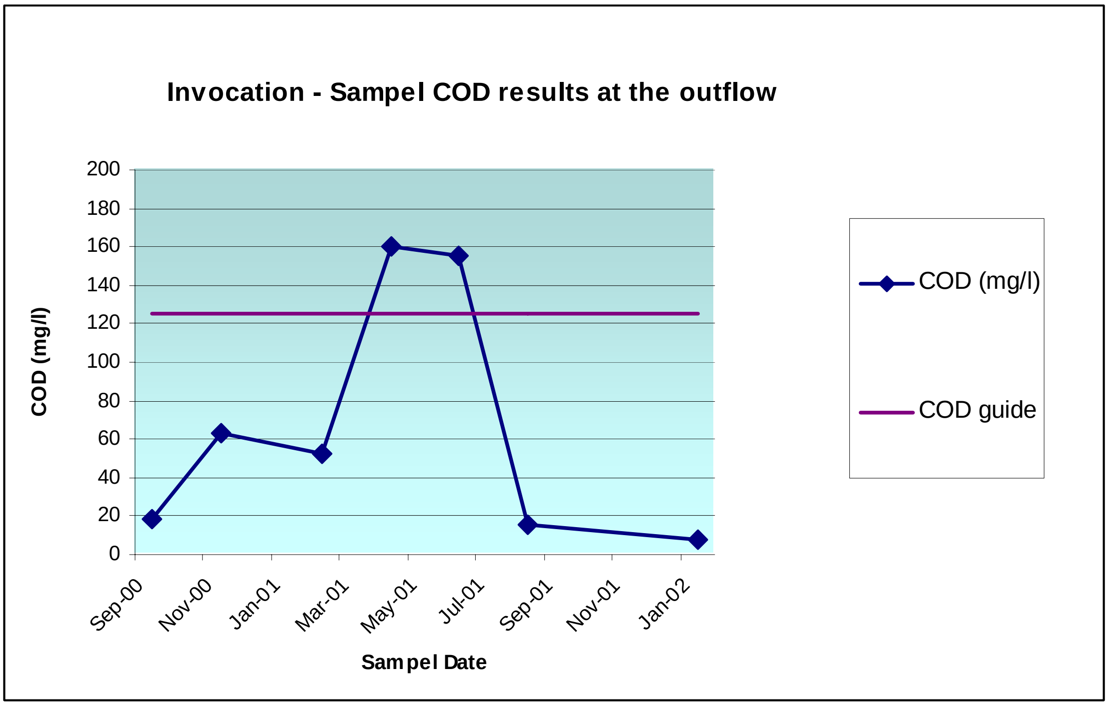
The following part of the study is mostly based on this data.

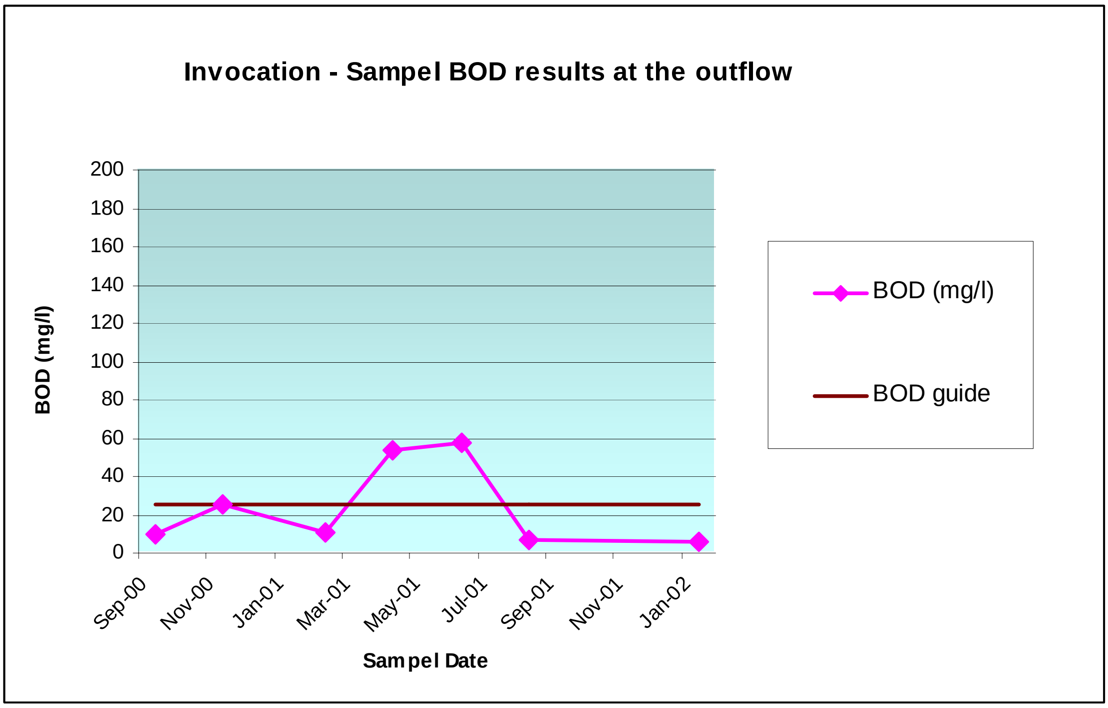
The European Norms for water quality control provide detailed description to the methodology of collecting samples, storage and transport, sampling frequency and analysis method in order to arrive at comparable results. Sampling in Auroville is for practical and costs reasons done in a much more simplified manner. This reflects on the accuracy of the test results.

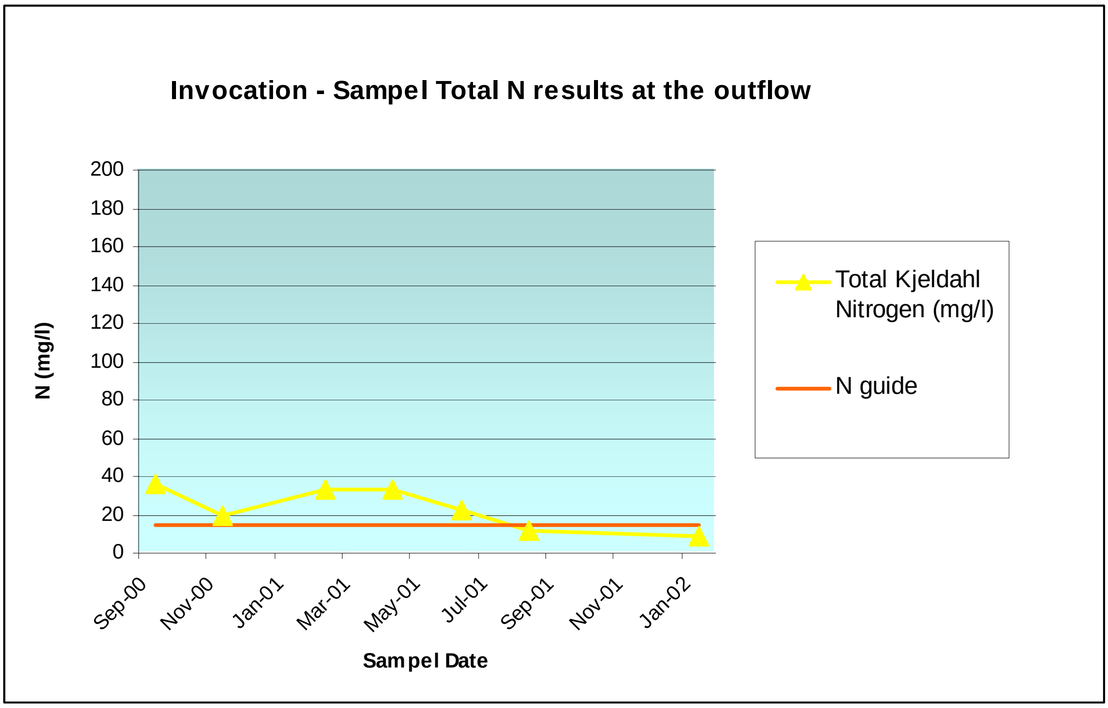
The performance of the treatment plants is graded based on several indicators

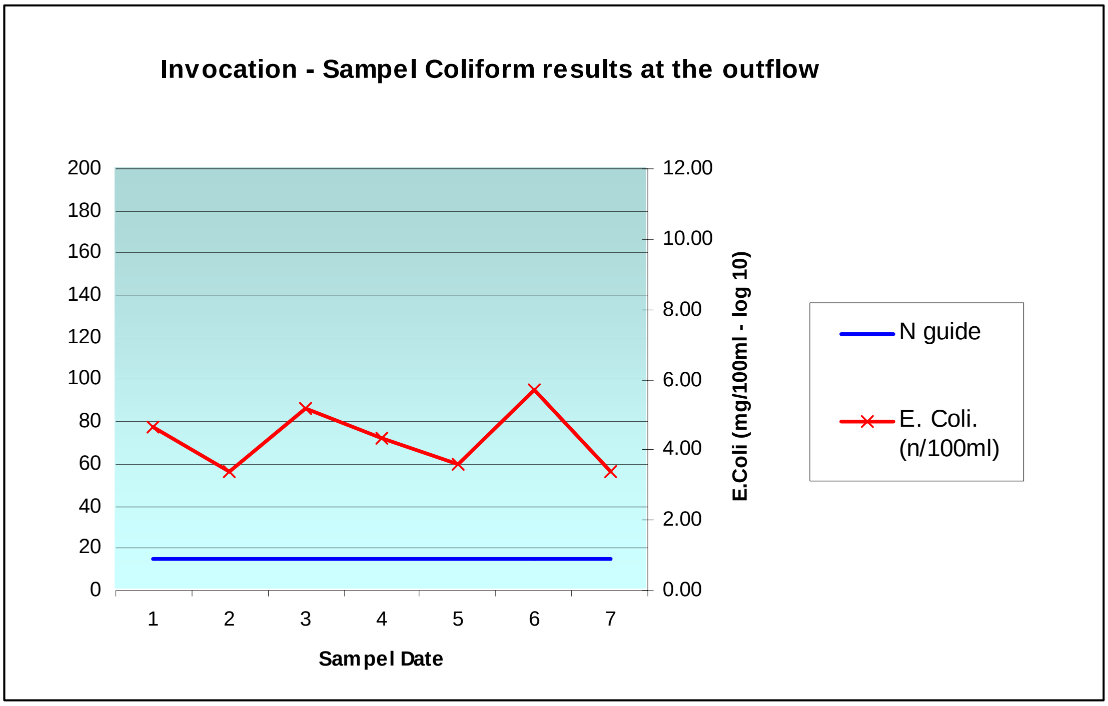
1- Reports of the residents
    a. Odor
    b. Color
    c. Re-use of recycled water
    d. Frequency of maintenance
2- General appearance of the visual parts (root zone treatment, polishing pond)
    a. No plants
    b. Excess plants
    c. Algae
3- Condition of the tanks (as far as accessible)
    a. Level of accumulated sludge
4- Chemical analysis
    a. Inlet
    b. outlet

Analysis of the effluent shows that most of the tested systems have a reasonable good performance in regard to BOD and COD.
Except in the case of Surrender, values for coliform are mostly higher than the proposed guide value of 10^3 n/l of Chapter 4.
However as mentioned above, single samples can only give an indication of the overall performance of a treatment plant.
In this context the sampeling of Invocation is more detailed. Here regular sampling was done over the period of 15 month from 2001-2002. The outlet parameters vary significantly over this time period. They are shown in the following 4 graphs, separately for COD, BOD, N (total) and Coliform (shown in log 10 scale). In each graph the suggested guide value from the previous chapter is indicated.

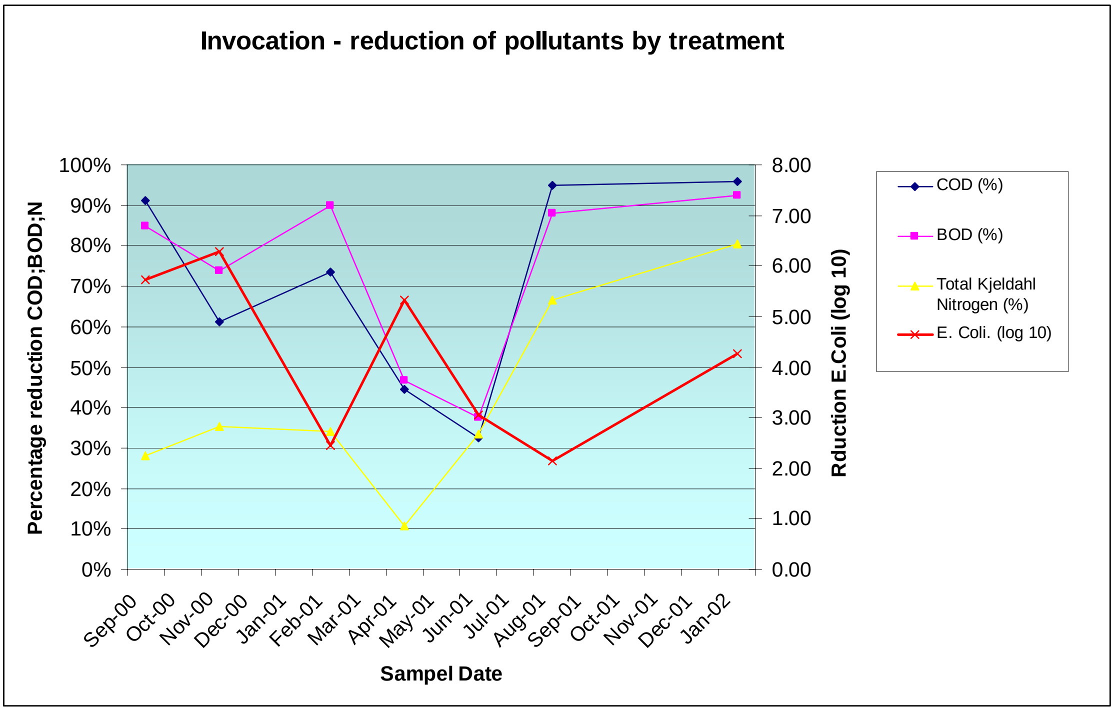



Invocation - Sampel BOD results at the outflow
BOD (mg/l)
200
180
160
140
120
100
80
60
40
20
0
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Sampel Date
BOD (mg/l)
BOD guide


Invocation - Sampel Total N results at the outflow
N (mg/l)
200
180
160
140
120
100
80
60
40
20
0
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Sampel Date
Total Kjeldahl Nitrogen (mg/l)
N guide



As was pointed out earlier, the inlet values of the raw sewage varies significantly. More informative in regard to the performance is the reduction of pollutants.
In the following graph the reduction in percentage of COD, BOD, N (total) and Coliform (in log 10 scale) is shown for the treatment plant of Surrender.



The graph shows that the system has an overall good performance. Hence it can be assumed that the system is well designed. The reason of the reduced performance during July/August is not known.

The table below shows an estimation of the required space for the treatment plants in use. The calculated requirements of this type of plant is approximately 20 m2 per PE :

Land use with current waste water treatment systems

Example "Invocation"		No of Residents	pre-treatment	Sludge removal	Root Zone	Pond	Total
Separate pre-treatment			m^2	-	m^2	m^2	m^2
joined Root Zone	Invocation	30	40	-	400	200	
	Surrender 1	35	40	-			
	Arati	24	40	-			
		89					
Including buffer space requirement of 2,0 m on underground structures and 5.,0 m on surface structures	(can be used for gardening, planting, non-resident buildings)		320		900	583	1803
					Area requirement per resident		**20**

Lars (CSR) has done extensive further work and organized 42 treatment plants in Auroville and the surrounding area according to their performance. Of these 7 major plants are in the study area shown in the table below.

No.	Name	date	users	capacity	% capacity.
1	Grace	23.08.12	50	35	142
2	Creativity	22.08.12	41	100	41
3	Luminosity	22.08.12	12	?	?
4	Prathna 1	23.08.12	45	55	122
5	Arati/Invo/Surre	24.08.12	113	150	75
6	Surrender 2	30.08.13	63	?	?
7	Maitreya	15.09.12	15	?	?

The rating is
green – fully functional yellow – partially functional red – not functioning

The reasons for partial functionality are given as follows

Grace	partly dysfunctional (de-sludging) Imhoff tank
Creativity	Planted falter water logged and sludgy, odors
Luminosity	Polishing pond with algae bloom, slight smell
Prathnna 1	Planted filter dead, effluent smells
Invocation/Arati /Surrender	working well, pond overloaded with water hyacinths
Surrender 2	status of ETP unknown, no odors
Maitreya	Activated, working well, monitoring ongoing

He estimates that in most cases bad performance is due to insufficient maintenance. Interesting is that several of the systems are functioning under capacity and this opens the possibility of connecting additional residences to these systems.

Lars suggests that a maintenance and service team, preferably from the Auroville Water Service should take up the required maintenance tasks, based on a yearly maintenance contract or similar. A user's manual should be provided by the manufacturer/designer of the ETP system.
Sampling and effluent quality analysis should be performed more regularly.

It is recommended that for existing treatment system standard guide values should be set. Due to the small size of the systems and limited number of residents, the values could be set higher than those for new treatment plants but then it should be ensured that the performance of all systems within these values is maintained.

Summary of recommended guide values for the design of waste water treatment plants in Auroville

Quantity of waste water per day

Per person Q^{ww}_{PE} = **175 l/d,**

For long-term planning

$Q^{ww}_{PE\ long\text{-}term}$ = **150 l/d**

Population benchmarks for phased infrastructure development for waste water treatment

	Population			**Comments**	**Waste water**	
	Total	**RZ I**	**RZ II**		**PE**	**Quantity**
Instances	(Res.)	(Res.)	(Res.)		(l/day)	(m^3/day)
November 2012	540	220	320	Existing population	175	93
Immediate requirements	1000	400	600	plus approved projects	175	175
Instance 1	1500			plus proposed projects	175	263
Instance 2	3000			Benchmark for the purpose of phased development of the waste water infrastructure. Sub-division into smaller increments is possible (i.e. 2000, 2500 etc)	175	525
Instance 3	5000	1500	3500	Population goal benchmark	150	750

Guide value (PE) for the characteristics of the waste water as per Indian Standards

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.

Mean population density for future projects (residents per hectare)

RZ I = 69 R/hectare and RZ II = 280 R/hectare

Effluent parameters for the design of new waste water treatment systems

Use: Irrigation (unlimited) or percolation into the ground:

E. coli < 10^3 count/100 ml (95% evaluation)
Helminth eggs < 1 per liter.

BOD5 < 25 mg/l
COD < 125
TSS < 35.0 mg/l
Turbidity < 2 NTU

Use: Release into open water bodies (lakes).

Total Phosphorus	2 mg/l P
Total Nitrogen	15 mg/l N

Use: Toilet flushing

Disinfection with 1 mg/l Cl_2 (residual) or similar.

Sludge handling

Processing in digesters and subsequent composting and storage for 180 days.

Bio gas

Cleaning by scrubber and safe storage.

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[23] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Developing a New Bathing Water Policy

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Guide lines

COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL

Directive 2006/7/EC of the European Parliament for management of bathing water quality

“Guidelines for the safe use of wastewater, excreta and grey water” WHO

Developing a New Bathing Water Policy, European commission