Surface Water as a Resource for Auroville City Area

A study exploring a multi-sourcing approach for Auroville with the integration of Matrimandir Lake.

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Surface Water Study for Auroville's City Area

1. Executive summary

"There is enough water; the Aurovilians will have to use their ingenuity to collect it and make use of it."

The Mother

Surface water as a resource for Auroville city area
A study exploring a multi-sourcing approach for Auroville with the integration of Matrimandir lake

Purpose of the study

The report explores the feasibility of capturing surface rainwater, storing the water resource on the Auroville plateau, and using it as a fresh water supply for Auroville city. Matrimandir lake is an integral part of the proposed multi-sourcing system.

Scope of the study

The study analyses essential parameters for designing and implementing a future secure water resources programme:

- a time-wise execution strategy with population growth predictions,
- land use,
- density,
- rainfall patterns,
- evaporation rates and run-off factors.

Several scenarios for realizing a surface water storage programme are investigated using different parameters and options to provide Auroville with fresh water supplied from captured surface water. The study concentrates exclusively on the city area and its estimated water demand.

Study outcomes

Auroville depends entirely on groundwater extraction for its drinking water consumption. Groundwater resources are continuously declining, with the threat of the used aquifers becoming saline.

Creating a reliable and secure Auroville water resources management programme will involve a multi-sourcing water strategy using rainwater, desalination and groundwater, combined with water saving and recycling practices, to optimize fresh water consumption within the city. A single resource will not be sufficient to meet the demand. Therefore a multi-sourcing strategy is essential.

Rainwater harvesting has huge potential as a water resource for supplying water to the emerging city. The strategy for capturing and storing rainwater needs to be planned and integrated within the city lay-out. Over time, more impervious areas will appear, resulting in a huge increase in run-off volume, which can be collected and stored. By developing appropriate drainage and sufficient storage capacity, surface water could match the demand for a population of 50,000.

Capturing surface rainwater for water consumption can be achieved provided that:

- The drainage from rainwater capturing zones is properly integrated within the urban design,
- The topographic features are an integral part of the landscape development,
- The rainwater is purified, preferably by natural means, before entering the storage facility,
- Storm water control and safety measures are taken into account,
- Possible pollution risks, or unforeseen events, are minimized by creating several water storage bodies and drainage systems,
- The conditions for managing and maintaining fresh water reserves are acknowledged and practised,
- The implementation of wastewater recycling is a basic element of water saving practices,
- Other sources are identified and protected to ensure adequate supply during extreme years.

The potential sources for supply, other than surface water, are groundwater from protected areas, desalinated seawater and desalinated brackish groundwater. An initial techno-economic evaluation (investment and running costs) shows that fresh groundwater is the cheapest source, followed by surface water, then desalinated brackish groundwater, while the most expensive is desalinated seawater.

It is wise to plan, invest and implement infrastructure in relation to demand and population growth. The study adopts a 20 year timeframe for infrastructure planning, with a maximum population of 15,000 and the corresponding drainage and demand requirements.

Based on a 15,000 population model, which is the maximum growth prediction for 20 years, a combination of resources is examined to ensure water security for Auroville. Taking into account the investment and running costs for a 20 year period, a combination of surface water harvesting, brackish water desalination and a back-up of groundwater extraction is the most feasible method. Economic, environmental, technical and social aspects need to be incorporated in order to achieve water security for Auroville.

The study finds that a 300,000 m³ (60,000 m²/5 m deep) storage tank supplied by an appropriate drainage system is sufficient to ensure the surface water requirement for the overall system. This type of system would be able to supply 95% of the annual water demand for a population of 15,000.

The inclusion of a water body around the Matrimandir, situated on one of the highest elevations of the plateau, will require an integrated approach, combining planning, engineering, design and topographical features, as well as environmental, ecological, financial and social elements.

The building of such a large water body, under tropical conditions, will involve integration of the surrounding landscape and trees, appropriate shore and lake bed shapes, the need for shaded areas, appropriate inflow systems, a functional depth and variable water level fluctuations. The presence of animal life within and around the water body will need to be managed properly.

There is an effective drainage area of 1,446,000 m² (356 acres) bordering Matrimandir, from which surface water can be captured and harvested to form the lake, if properly designed and fulfill a real function. The only option to achieve this purpose is to consider a terrace lake.

Since the fluctuation of the water level of the Matrimandir lake will be limited in order to respect its aesthetic functions, it will generate a very large overflow. The overflow water needs to be stored in a secondary tank to ensure overall water security.

It is accepted that the water level of such a large storage body cannot fluctuate more than 2 metres throughout the year; as such, it is desirable that the maximum depth is 4 metres. This depth would have the advantage that it would be relatively easily replenished on a yearly basis, ensuring a regular fresh water supply.

A deeper lake raises serious concerns for the ecological and aesthetic considerations. A 10 m deep water body will require huge investments and running costs, will have higher seepage losses and will be more difficult to maintain. It will not provide extra water security as the acceptable fluctuation levels and therefore usable water volume remain the same regardless of the depth.

Around Matrimandir, soil movement and displacement should be minimized by incorporating the topographical features of the area.

By collecting the overflow of the lake into a secondary storage tank of 150,000 m³ (30,000 m²/5 m deep), a population of 15,000 can be supplied from the captured and stored water.

In case, after 20 years, Auroville's population is the lowest envisaged (4000 people), one third of the proposed lake surface area, fed by one third of the proposed drainage area, can supply the population. Thus, modularity is possible and recommended.

At later development stages, other parts of the city and green belt can be drained to separate water bodies outside the city area, ensuring water supply for the eventual 50,000 people.

The study underlines that it is essential that the changes occurring over time, demographic, technical and others, are understood and incorporated in future water resource scenarios.

Study recommendations

The challenge of implementing the Matrimandir lake will follow the traditional methods of rainwater harvesting, while new knowledge and innovations will introduce water security for Auroville's future in a sustainable way.

It is taken for granted that Matrimandir lake will contribute towards the water security of Auroville. Such a large water storage body can only be an asset. It is evident that the water source for filling the lake will come primarily from captured surface water from the surrounding drainage areas.

The study recommends limiting the usage of the Matrimandir lake and its dedicated secondary storage tank and drainage to an equivalent population of 15,000.

Future steps

- To study the potential for design variation, in order to optimize the potential drainage area, with integration of natural features and existing buildings.
- To study a proper drainage system integrated in Auroville's urban plan, including waterways, erosion control, sedimentation areas, bio-filter systems, etc.
- To envisage variable design scenarios with regard to existing land features (level differences, hillocks, major trees...).
- To study the soil movement issue, since storage and drainage on this scale require moving major volumes of soil, which needs to be disposed of and used in an appropriate way.
- To study various lake and storage designs in regard to urban design, landscaping and ecology.

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2. Introduction

For more than ten years, considerable efforts have been made by Auroville and scientists from all over the world to understand the situation and behaviour of water in our area and develop appropriate methods to use, reuse, protect and improve this precious resource.

Fundamental steps have been made in our understanding as well as in the way we share this knowledge with the scientific world and the Indian authorities.

The only resource we use today, groundwater, is depleting due to overuse and is threatened by seawater intrusion and pollution on a regional scale. Hence, all available resources must be explored to address our growing needs and create long-term water security.

Considering that water resource management has a strong relationship and interdependency with planning and development issues, it is essential to determine the various potential sources, their limits and possibilities, and the viable orientations and options available. The implications of these choices, or lack of choices, should be clearly understood by the community at large.

Auroville is still at a phase where many solutions are feasible, while further development, if not made in relation to our basic water needs, can limit several of the possibilities and restrict choices to the most unsuitable ones, with serious consequences for the future.

The present study proposes to screen the various options we have at present and in the future, in terms of water resources, in order to secure our demand in a sustainable way. It investigates the potential of surface water and looks at the ways it could be part of a multi-sourcing strategy. The study explores the potential and limitations of the Matrimandir lake as part of the overall water management approach, while examining the possibility that the Matrimandir lake could be integrated into the overall water resource management and water supply approach, ensuring that the lake is an asset rather than a liability.

Considering the scope of the study, the time frame and the resources allocated for it, while a step by step analytical process is followed, the aim is to define workable options from actual consolidated data, rather than to deliver a detailed technical report. Additionally, the study is assessing constraints and conditions which are decisive factors in the design of Matrimandir lake.

The present document is a detailed evaluation of the prevailing ground realities and a starting point for the decision-making process.

The second part of the present study will look at the integration potential of surface water infrastructure in regard to the Master Plan.

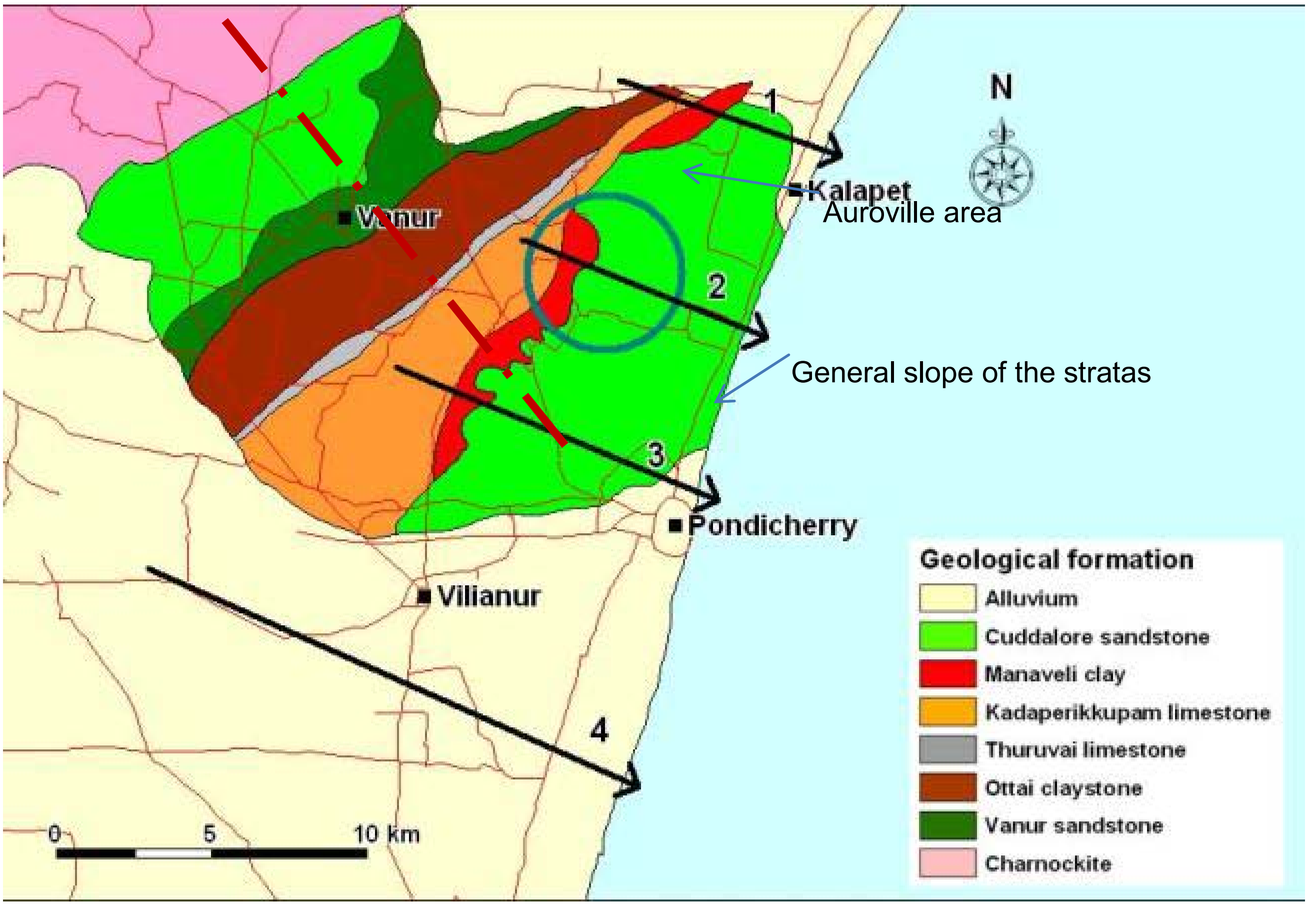
3. Context

3.1 Groundwater resources: declining in Auroville

Groundwater is the only water resource currently used for domestic and urban supply in Auroville and the surrounding area. With the growth of the population, the demand for groundwater for domestic and urban purposes will increase still further.

The large and effective effort Auroville is making in surface water management and groundwater recharge is not sufficient to counteract the ongoing deterioration of this resource, neither on the upper strata nor the lowest one, because of the scale and magnitude of overexploitation in the region and the direct connection of local groundwater resources to the surroundings.

The map below shows the outcropping location of each geological formation.



Picture 1: Surface geological formation in Auroville bioregion

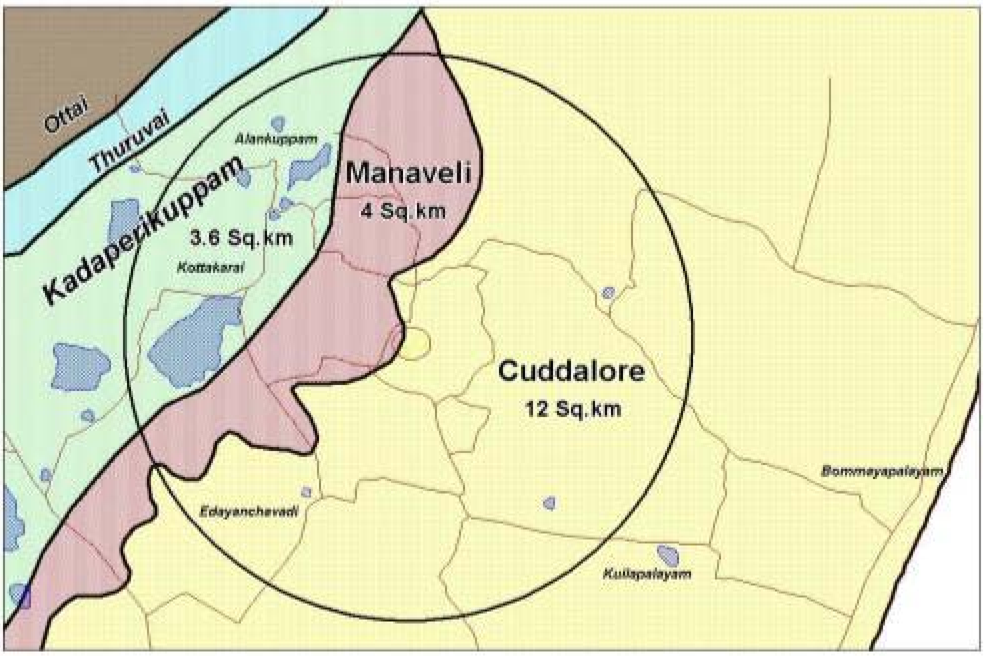
3.1.1 Upper aquifers

Auroville city area is mainly built on Cuddalore sandstone and Manaveli clay outcropping formations.

The upper and most present aquifer on the Auroville plateau, Cuddalore formation (relatively thin in Auroville, becoming thicker towards the coast and the South), is under-layered by a clayey layer (Manaveli clay), below which are two other aquifers (Kadapperikuppam and Thuruvai limestones).

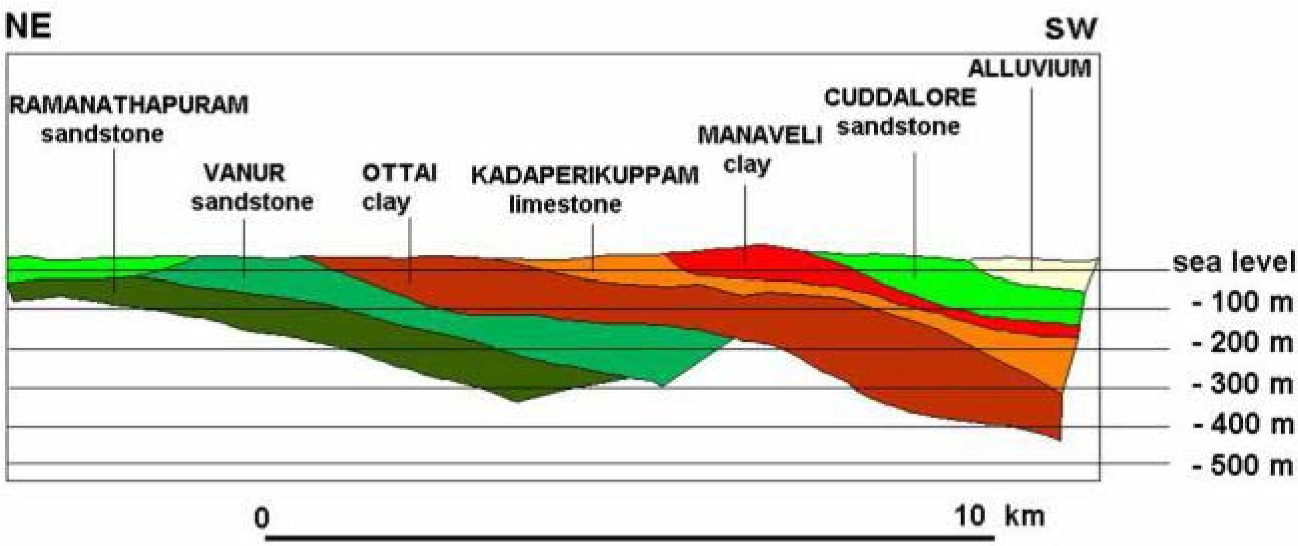
These three aquifers provide, through the existing bore wells, a significant part of the water supply to Auroville.

The map below shows the outcropping location for each geological formation in Auroville.



Picture 2: Surface geological formation in Auroville

The section below shows a typical profile of overlapping geological formations in the Auroville area.



Picture 3: Typical section on geological formation in the Auroville area

Due to the weak structure of Manaveli, and because of numerous bore wells passing through this clayey layer, these three aquifers are locally interconnected but they do not act as a single block.

In the present scenario of over-extraction throughout the area, the two lower aquifers are depleting, and because of structural gaps and weaknesses in Manaveli clay, the Cuddalore formation is leaking downwards, which means that on the Auroville plateau, Cuddalore formation is regularly empty during the summer months. This is increasing the dependency on Kadapperikuppam and Thuruvai formations, which offer good scope for extraction but cannot be controlled by groundwater recharge measures in Auroville alone.

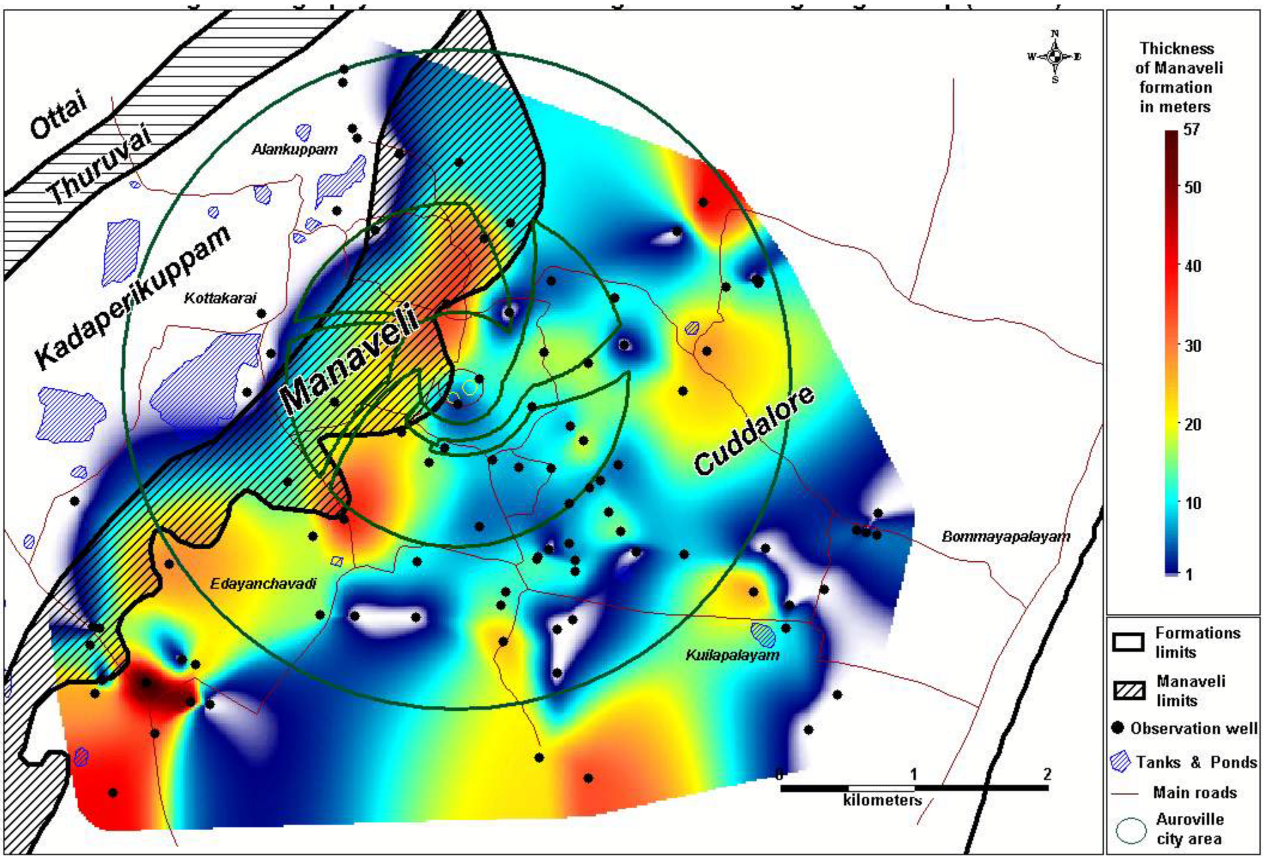
"STUDY OF GROUNDWATER RESOURCES OF PONDICHERRY AND ITS ENVIRONS", B.S. Sukhija, D.V. Reddy & I. Vasanthakumar Reddy, National Geophysical Research Institute HYDERABAD – 500 007 JUNE 1987

Ref: Page 119, § 4.2.1. Piezometric studies

Interconnections between important aquifers have been studied by installing piezometers in individual formations at the same location…

Cuddalore and Kadapperikuppam aquifers: a pair of piezometers are installed at the slopes of eastern uplands (at K.V.K) tapping Cuddalore and Kadapperikuppam aquifers. In between these two aquifers one more aquifer called Manaveli (relatively thinner) also exists. It can be seen from the figure 38 that the potentiometric surface of both the wells show equal response to the recharge and discharge. Thus, despite the geological variation in strata these two aquifers seem to have very good communication with each other.

The map below shows the thickness of the Manaveli clay formation below Auroville using interpolation techniques.



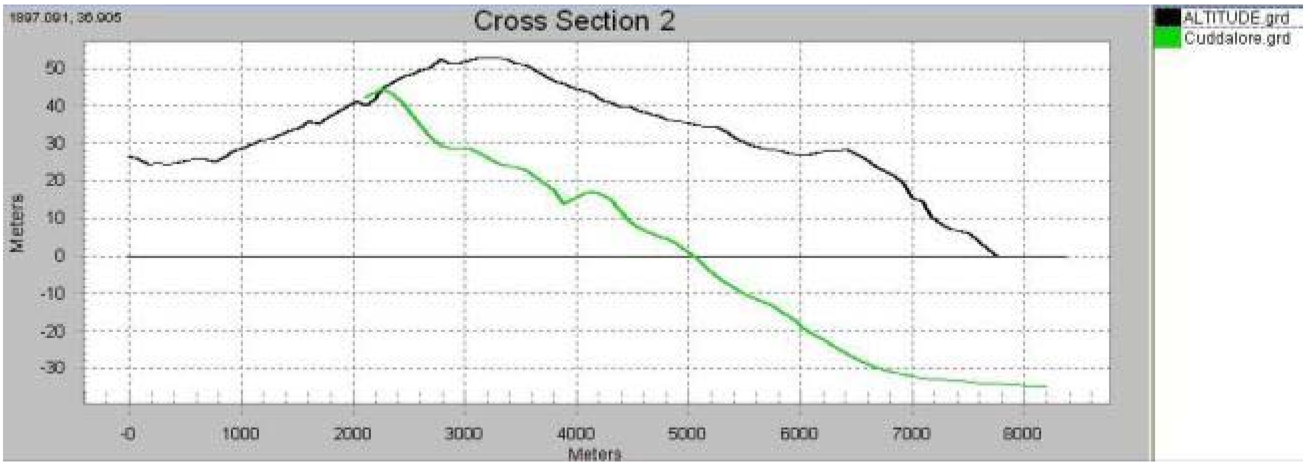
Picture 4: Thickness of Manaveli formation in Auroville

Closer to the coast (Auromodele area), the Cuddalore formation is thicker, but over the past ten years it has been observed that the groundwater level is close to, or below, mean sea level.

This phenomenon, observed on a regional scale and directly linked to over-extraction of groundwater, is causing seawater intrusion in large areas along the coast, and it is extending further inland every year.

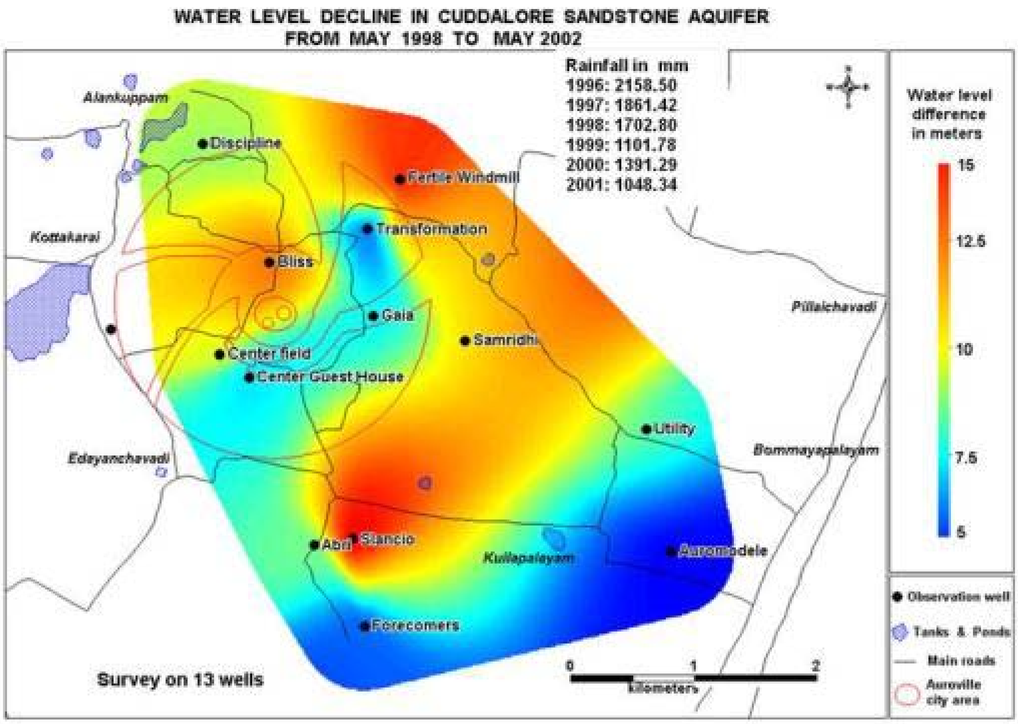
To date, seawater intrusion has not been observed in Auroville's bore wells but it is likely to happen within a short period of time. One cannot predict at this stage, due to limited information, how seriously this can affect the groundwater quality on Auroville's plateau.

The section below shows the shape of the surface and the bottom of the Cuddalore formation, in relation to sea level. The section is passing by the Matrimandir area.



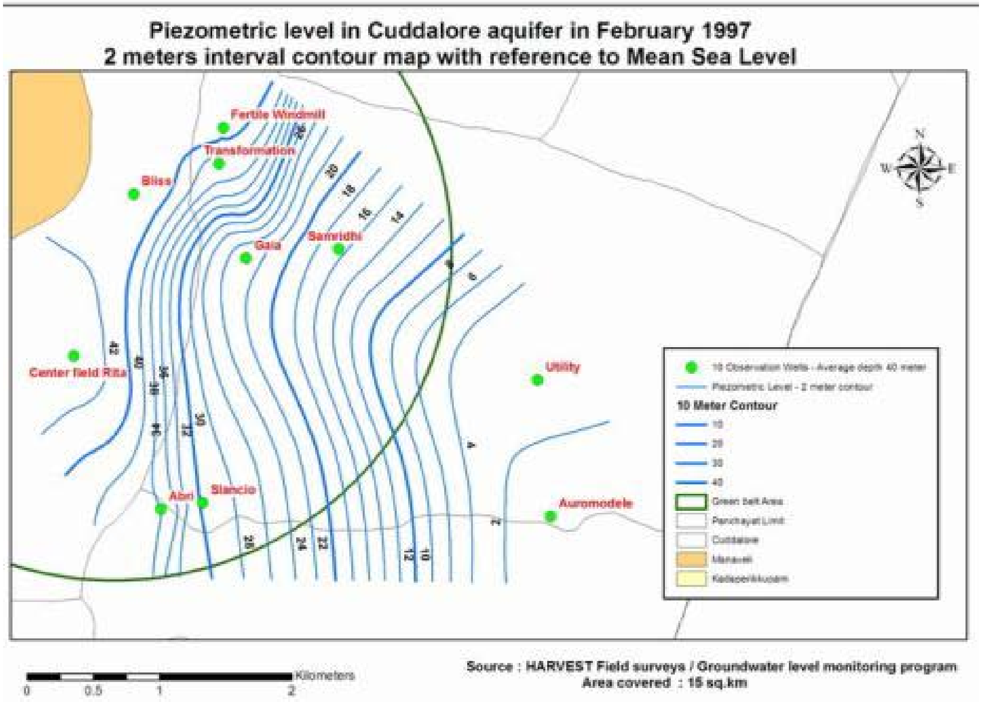
Picture 5: Section of Cuddalore formation in Auroville

The map below shows the water level decline in the Cuddalore aquifer from May 1998 to May 2002.

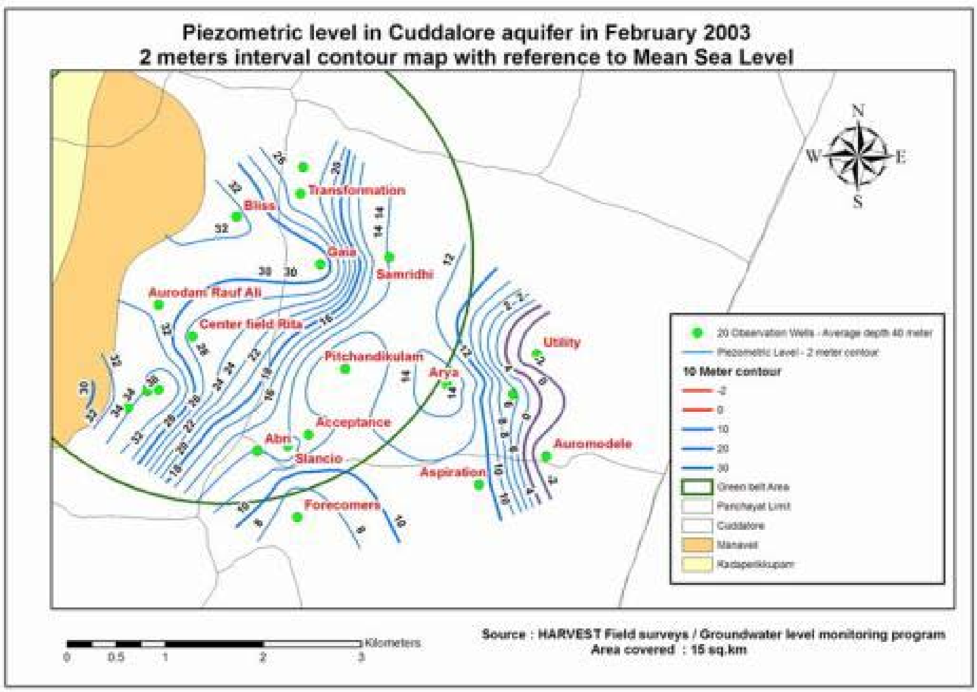


Picture 6: Water level decline in Cuddalore formation in the Auroville area

The two maps below indicate the groundwater level in comparison to the seawater level for February 1997 and February 2003.



Picture 7: Groundwater level in Cuddalore formation in Feb 1997



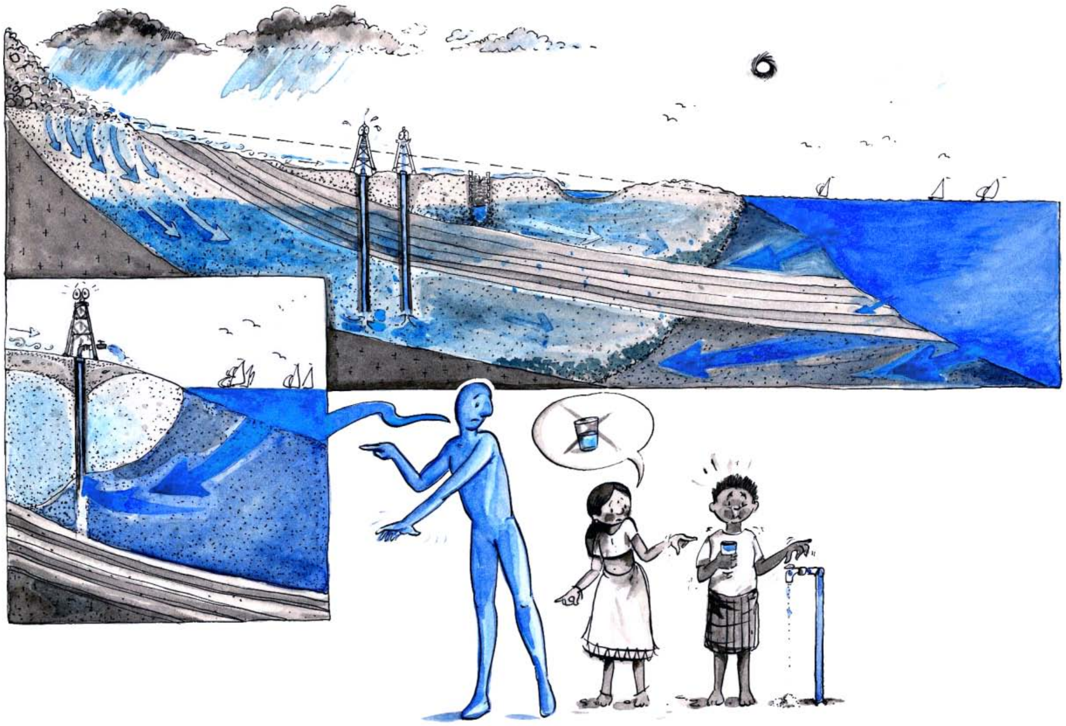
Picture 8: Groundwater level in Cuddalore formation in Feb 2003

On the southern border of Auroville, there is another serious threat to the groundwater. For 30 years unprocessed wastewater, and for 10 years solid waste, have been 'illegally' dumped in this area from Pondicherry. The soil here shows a remarkable permeability, which then leads to direct leaching of pollutants into the water table.

A study conducted on this particular area shows that the canyon located along the southern boundary of Auroville seems to be bordered by a sticky clay layer, which probably acts as a physical barrier from south to north. In addition, the general groundwater flow is away from Auroville in a south-west direction. In this context, it seems to indicate that while one must continue to observe the changes to the groundwater in this area, there is no immediate contamination in Auroville.

3.1.2 The Lowest aquifers

Deeper underground, and underneath a thick layer of clay (Ottai), there is a large aquifer called Vanur formation (sandstone). This aquifer is heavily overexploited which results in the fast depletion of groundwater. Locally, salinity is also increasing and it is above acceptable limits for irrigation, but to date this increase in salinity is not from direct seawater intrusion. An in-depth hydro-geological study (*Etude hydrologique et hydrogéologique du bassin sédimentaire côtier de Kaluvelli-Pondichéry, Tamil Nadu, Inde – Docteur Aude VINCENT - 2007*), forecasts that seawater will probably intrude into this aquifer very soon (1 to 5 years from now) and invade the entire aquifer within six months, making it unsuitable for any direct usage.



3.1.3 Conclusion on groundwater resources

Auroville is tapping almost all its water from five overlapping geological formations: chiefly Cuddalore, Kadapperikuppam and Thuruvai, but also Ottai and to a lesser extent Manaveli, while these two formations are not defined as aquifers.

A few wells tap water from the deepest Vanur formation, were the water is known to be poor quality.

Bore well set-ups in Auroville are systematically tapping multiple aquifers, creating inter-connectivity from layer to layer, and are consequently dependent on and connected with neighbourhood practices.

Groundwater still has a large capacity for extraction, but it is not a secure long-term resource because of the general trend of depletion and deterioration. Corrective measures could address depletion and seawater intrusion if conducted on a massive (regional) scale and launched immediately. But these solutions (massive reduction of groundwater usage for irrigation, large-scale groundwater recharge, a systematic approach to pollution control, beach erosion protection…) can only be implemented by the government with systematic public participation. Action on this scale has not occurred, and therefore, it is essential that Auroville develops local solutions in order to secure its future and help the surrounding population and environment.

However, locally, the groundwater is not threatened by saline intrusion. Therefore it is important to identify and protect these areas, and eventually increase the recharge as this local resource may provide a substantial buffer as part of a future multi-sourcing strategy for Auroville.

Considering, the drastic change in land use patterns in the Auroville bioregion, and the changes it has produced in the local groundwater conditions, it remains very difficult to predict the evolution of groundwater systems in the future.

One cannot base the planning and development of Auroville on groundwater resources because of their fragile nature. It could still play an important role, either through appropriate management of naturally protected areas or by processing brackish water for further usage.

3.2 Surface water: large potential as a resource

Rainfall is the only natural, sustained and perennial source of fresh water in Auroville's area.

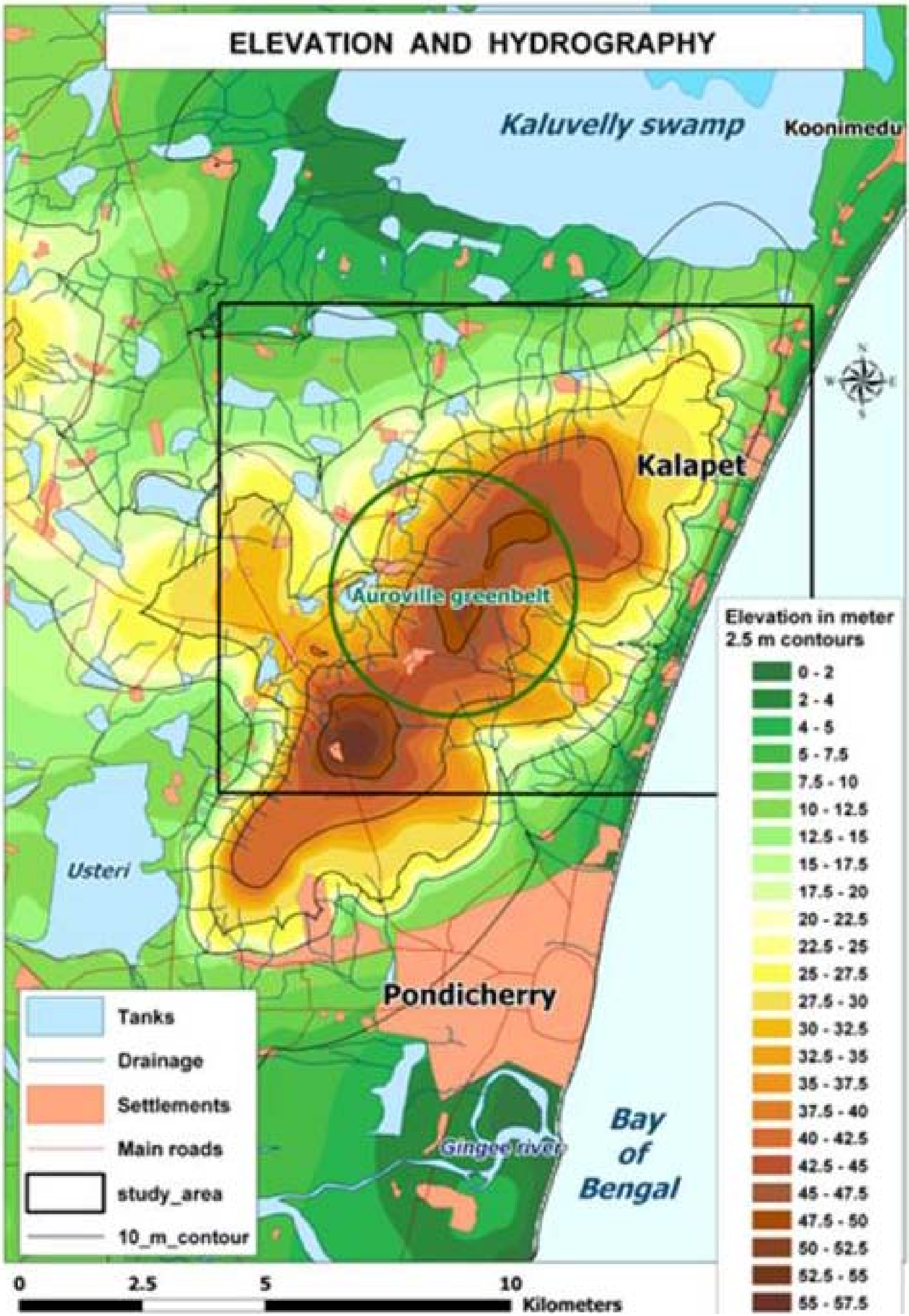
All other resources either originate from it (surface water, groundwater) or have to be artificially generated (desalinated water, recycled water).

Considering the value of water and the problems that rainfalls generate when they are not incorporated in planning issues (flood, erosion...), it is essential to anticipate how rainwater may be used, while considering the effects it will have on Auroville in the future.

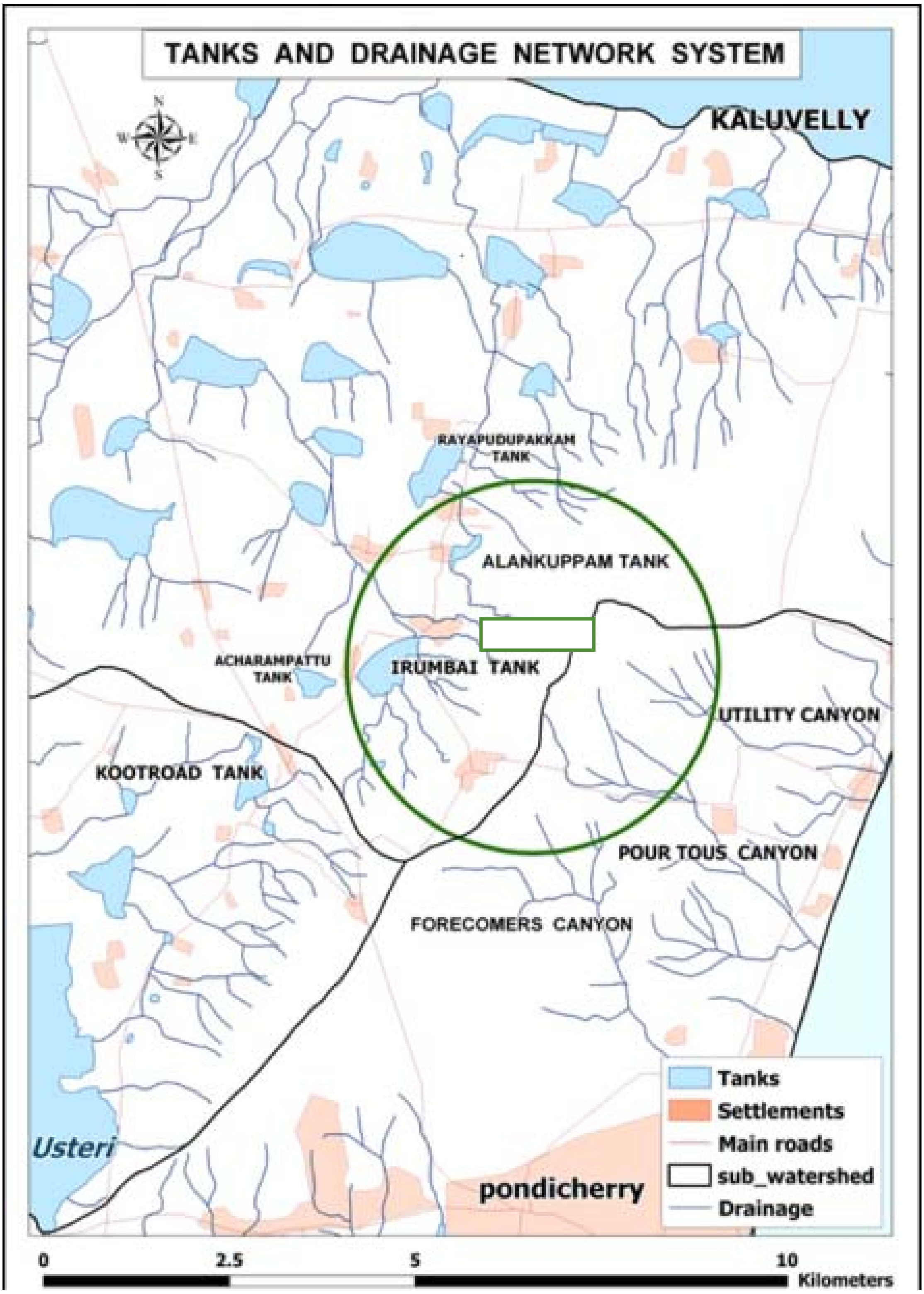
Because of the large volume of rain falling during short periods, a sizeable quantity of rainwater is drained away if appropriate measures are not taken to slow down, retain, store or facilitate the infiltration of the resulting run-off.

The common approach worldwide is to swiftly evacuate run-off from urban areas, as it is chiefly considered a nuisance, not a potential resource, while paradoxically gigantic efforts are undertaken to transport water, over large distances and at great expense, to the same urban areas. This method causes major disturbances in the tapped regions. A natural and healthy balance is not respected in modern urbanization approaches, and so city development has an impact on a much larger area. The same phenomena can be observed for human movement, energy, transport, goods, waste, etc. Over time, Auroville has gained diverse, rich and successful experience in run-off control and groundwater recharge through contour bunding, infiltration systems, check dams and ponds, together with appropriate planting on the plateau and downstream. Major efforts have been made on the regional scale, including socio-economic efforts, which demonstrate remarkable results by alleviating, if not fully controlling, surface water losses through run-off.

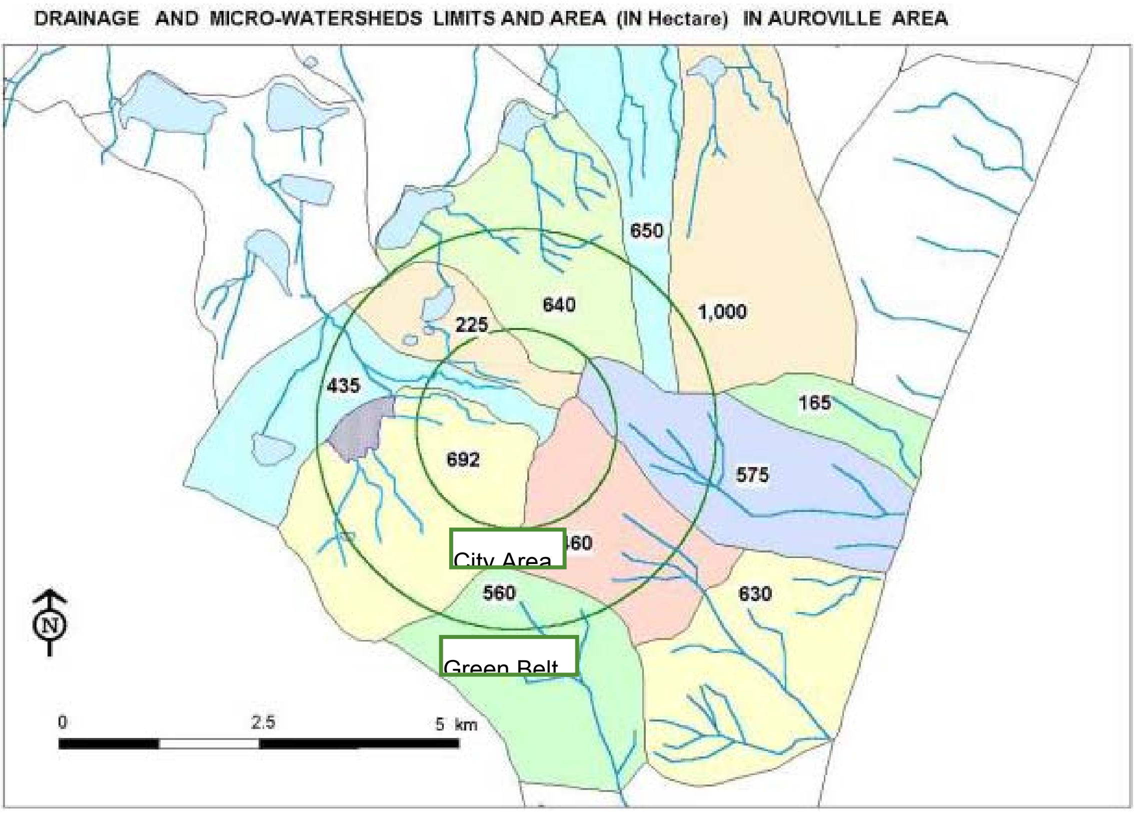
A large part of the Auroville plateau is sloping towards the sea (east), and the generated run-off from that area is lost if it is not stopped and recharged or stored along the way. The other part is sloping towards the west, where a series of irrigation tanks are located which store the run-off, and eventually channel the water to the sea (see the drainage network and watershed divisions below).



Picture 9: Topography in Auroville

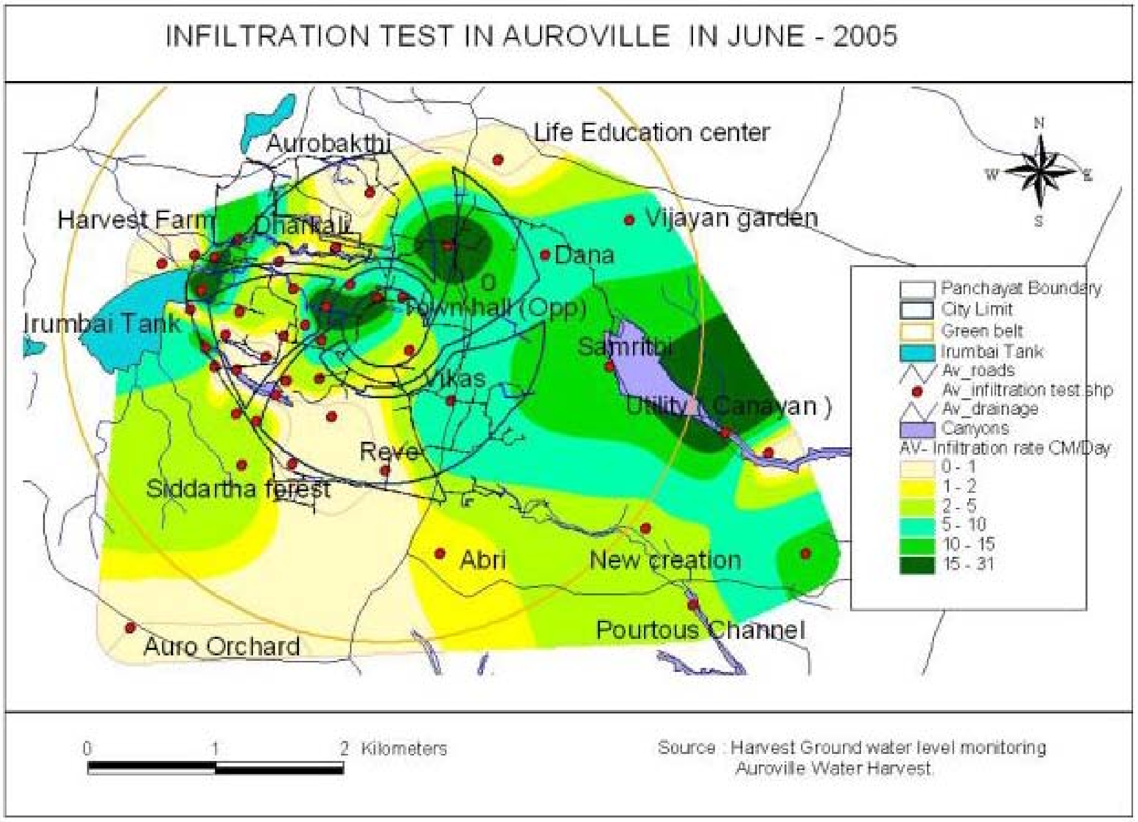


Picture 10: Drainage and sub-watershed in Auroville's area



Picture 11: Micro-watershed limits in Auroville

The following figure presents the infiltration rates measured at different locations in the Auroville area. It is of interest to conduct further investigations to consolidate the findings locally.

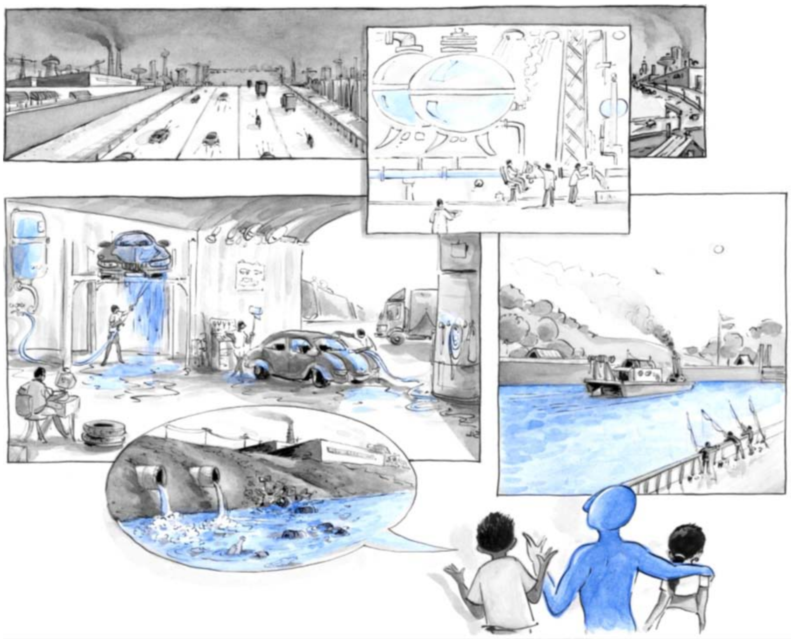


Picture 12: Infiltration rate in Auroville

By further developing Auroville and creating very large impervious areas, the run-off will increase dramatically, overloading the existing water catchment systems and recharge structures. Moreover, changes in land use, new development and infrastructure will decrease the efficiency of the existing contour bunding. Due to the increase in built-up areas, natural recharge to the aquifers will also be reduced.

Appropriate measures of rainwater harvesting can transform these huge losses into usable resources and play a central role in supplying Auroville's water demand.

It should be noted that run-off water in an urban context also acts as the main mechanism for city cleaning. While appropriate solid and liquid waste management can address littering, and therefore avoid turning run-off into sewage flow, the disposal of uncontrolled substances is a greater challenge. Many toxic or harmful agents are generated through human activities which end up in air, soil and water. The rain then washes the sky, the ground and the built-up areas, and the pollutants are carried away by the run-off. Since it is difficult to avoid polluting activities, like driving petrol based vehicles, one should include measures to decrease pollution.



Auroville's area shows a remarkably high infiltration rate on the east side; it is much less on the west side.

One approach could be to develop the urban area so that recharge is systematically favoured at very local levels by controlling storm water and allowing for groundwater recharge at the same time. This water would be available from the aquifer, when and where necessary, at very little cost. That is the core approach H. Kraft took in his study in 2001. As described in the previous chapter, this cannot be considered an ideal solution: a large part of the city area is not situated on high permeable ground, the upper (Cuddalore) aquifer is generally connected to the aquifer below, and seawater intrusion is directly affecting this layer. To recharge all the run-off water to the aquifer will lead to a direct loss in both quantity and quality, and add considerable additional costs. Some areas are naturally impervious and protected from seawater intrusion, and could act as a back-up system when and if required.

Roof rainwater harvesting and local storage have been envisaged as possible solutions in this regard. While they could play a role in water sourcing, they have serious limitations due to the level of investment required for individual or local development. The prohibitive cost is the main hurdle and it is due to the large storage capacity required to store water for the many dry months. Another drawback is the quasi-impossibility of using such a huge number of small systems in a city network; the intricacy of the operation is extremely complex.

The other possibility is to develop an appropriate drainage and storage system throughout the city. This would be more cost-effective due to its scale factor, and because the dynamism of the entire system allows for the development of open storage, as opposed to closed systems. While a significant volume would be lost by evaporation in such a scenario, the direct and indirect benefits of this type of system can outweigh the negative aspects.

Surface water has huge potential as a resource and can play a major role in Auroville's water supply approach. Nevertheless, it is sensitive to pollution and there are large and unpredictable variations in its volume and distribution.

3.3 Ownership, legal and social aspects

Legal and social aspects, while not in the scope of this study, must be investigated further.

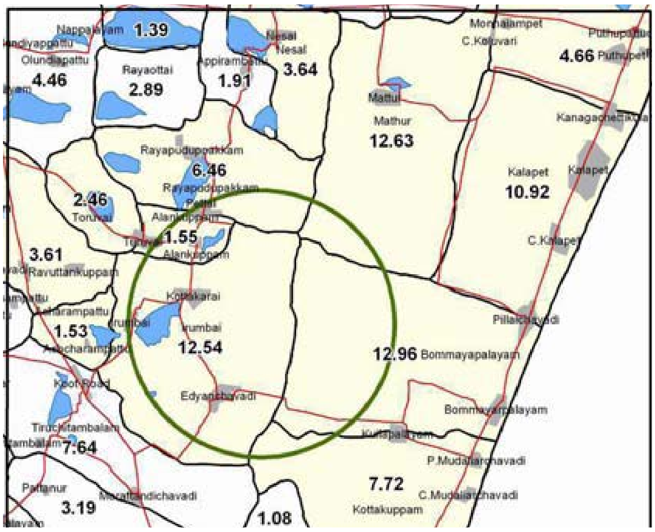
The law of India defines that water is generally the property of the states, which explains the tension between Kerala and Tamil Nadu over the Cauvery river issue, since no central authority is fully entitled to decide how this resource is shared. Concerning rainwater, the basic approach is that it belongs to the place where it falls, while the generated run-off has been a common and shared resource since ancient times in India.

The history of Auroville is full of events regarding the impact of all the water recharge and storage structures developed over the years on the surrounding population: often, check dams or other set-ups have been destroyed because of the perception people have of their impact on the accessibility of water. On a larger scale, the efforts conducted by Auroville to maintain the aquifer are basically unrecognized, while frequent tensions occur during dry years concerning the usefulness of irrigation structures and their connecting channels in relation to encroachment pressures.

By developing Auroville further, which will lead to a greater urban impact, it becomes necessary to address these issues. In Auroville's regional context of water scarcity and salinity increase, one should integrate the appropriate development of major water infrastructure.

The concerned authorities are:

- Central Ground Water Board, Public Works Department Tamil Nadu, Tamil Nadu Water Supply & Drainage Board, Collector, Tasildar, TWAD Pondicherry, PWD Pondicherry, Groundwater Department Pondicherry, Agricultural Department Pondicherry.
- Other central or local authorities related to town planning, waterways and coastal issues, etc.
- Panchayats from Kottakuppam, Bommayarpalayam, Irumbai, Mattura and Rayapudupakkam in Tamil Nadu State, and Alankuppam in Pondicherry territory.



Picture 13: Panchayat administrative boundaries and areas in km²

It is assemble the required task force to initiate this work immediately. (*Ref: A Water Organization for the Auroville area, Luxury or necessity - Eri Salomé (Vitens Flevoland and support from Jeen Kootstra, Israel Gev and Gilles Boulicot.)*

3.4 Conclusion on context

The strengths and weaknesses of groundwater and surface water logically lead to a combined approach, using various sources. Multi-sourcing is the most appropriate way to secure development and planning issues within a reasonable time frame.

The social aspects and legal issues, while not in the scope of this study, are of critical importance in order to make appropriate choices, and they must be fully investigated for each resource and the potential combinations.

4. Potential sources

The following points outline the pros and cons for the use of the different water sources in the Auroville context in order to compare them.

4.1 Groundwater: Existing infrastructure

+ Limited processing required
+ Running costs and maintenance are cost-efficient and easy
+ Can be integrated in planning and development in a step by step approach
+ Could be (only partially) secured locally through appropriate recharge programmes
– Aquifers extend far beyond Auroville's boundary and therefore cannot be controlled by Auroville
– Time is a very serious constraint because of the risk of the aquifers collapsing
– Fragile because of general ongoing deterioration

4.2 Rainwater: Available on a yearly basis in large quantities but highly fluctuating

+ Can be collected using topographic conditions
+ More cost-efficient than other solutions
+ Part of a multi-purpose solution: drainage, urban landscaping, beautification, water supply, awareness
+ Not dependent on usage outside of Auroville
+ A completely renewable resource
– Must be integrated in planning and development activities immediately
– Running costs and maintenance are relatively complex (decantation, filtration, then pressurized sand filter, activated carbon, micro- or ultrafiltration)

4.3 Wastewater: A sub-product of water consumption

+ Can be integrated in planning and development in a step by step approach
+ Part of a multi-purpose solution: sanitation, supply, awareness
– Depending on the population, behaviour and process => must be augmented by other resources
– High risk for cross contamination if not supported by other resources or recycled in a suitable way
– Hazardous for all usage because of health issues; recommended for secondary usage only (municipal use, irrigation, toilet flushing...)
– Running costs and maintenance are relatively complex (pressurized sand filter, activated carbon, UV or chlorination process)

4.4 Seawater desalination: Unlimited resource

+ Can be integrated in planning and development issues at any stage
+ Unlimited resource
– Expensive
– Social issues need to be addressed
– Highly centralized, hence fragile
– Single purpose solution
– Running costs and maintenance are complex and expensive (decantation, filtration, anti-scaling, anti-fouling, microfiltration, ultrafiltration, reverse osmosis)

4.5 Groundwater desalination (once it has turned brackish): Very large resource (no longer utilized by other users)

+ More cost-efficient than seawater desalination
+ Can be integrated in planning and development issues at any stage in a flexible way
+ Becomes a highly sustainable resource once it is brackish
– Social issues (because of general shortage of potable water)
– Single purpose solution
– Running costs and maintenance are relatively complex and rather expensive (filtration, microfiltration, ultrafiltration, reverse osmosis)

4.6 Source evaluation table: 4 stars best, 1 star worst

	Treatment required for high quality supply	Fragility to external factors	Resource capacity for securing water supply	Sustainable and integrated solution	Rapidity of realization	Investment	Running costs and maintenance	Total
GW	****	*	**	**	****	****	****	21
RW	***	****	**	****	*	***	***	20
WW	**	***	*	***	**	**	**	15
SWD	*	*	****	*	***	*	*	12
GWD	**	***	****	*	***	**	***	18

Table 1: Evaluation of sources

GW: groundwater, RW: rainwater harvesting, WW: wastewater, SWD: Seawater desalination, GWD: groundwater desalination

Comments: A single red star brings strong reservations the concerned resource. Black stars indicate the positive scoring of each resource.

4.7 Conclusion on the potential sources

- **Multi-sourcing is essential!**
- All sources can be part of the sourcing system.
- Groundwater is already used but it is very fragile. Specific studies are needed to evaluate its potential and limitations as a resource, where it is located, and how it can be maintained and protected (Cuddalore locally, the two lower aquifers and chiefly Manaveli).
- Groundwater desalination seems a feasible solution when compared to seawater desalination, but only if the groundwater becomes saline.
- Wastewater recycling must be part of the planning and development in a step by step approach.
- Rainwater harvesting achieves the highest and safest scores. Hence, it is studied further below. Moreover, it must be integrated into the planning at an early stage, while the other solutions can be incorporated over time.

4.8 Comparison of surface water management possibilities

Looking at the topography and soil characteristics (infiltration rate), it is possible to envision several ways to harvest surface water, if a systematic effort is made to develop and integrate recharge systems throughout the city.

4.8.1 Groundwater recharge: GWR

+ No evaporation losses
+ Already practised extensively, but with room for improvement and changes due to future development
+ Very cost-effective in the eastern part of Auroville because of the high infiltration rate
– Limited potential in the western part (clayey soil).
+ Becomes a groundwater resource and will help to sustain it
– Is vulnerable to points mentioned in 3.6. It is difficult to predict today to what extent it may compensate the depletion of the water table
– Recharge potential will drop through development (impervious area) if not compensated

4.8.2 Roof rainwater harvesting: RWH

+ Can be implemented alongside the development process
+ No evaporation losses if water is stored in closed systems (underground tanks…)
– Expensive because of the rainfall pattern (large storage required to optimize collection)
– Difficult to connect to municipal supply or even to neighbourhood supply
– Single purpose solution
– Running costs and maintenance are complex and must be managed steadily (decantation, filtration, pumps)

4.8.3 Catchment in existing Irumbai irrigation tank (Tamil - *ery*): CIT

+ Cost-effective
+ Could be turned into a reservoir for city supply if modified for this purpose
– Social issue, as it is collective property of the village used for irrigation purposes and feeding the connected series of tanks
– Under PWD responsibility
– It is and should remain a source for irrigation in this part of the green belt which naturally falls under agricultural activities
– High losses through evaporation (shallow and extensive water body) and limited storage capacity: water available for a short period of time
– Difficult to avoid pollutants from agricultural activities
– Excess water lost: drained out of Auroville area
– Necessary to pump the water out for further usage in Auroville
– Running costs and maintenance are relatively complex and must be managed steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro- or ultrafiltration, pumps to bring the water to the urban area)

4.8.4 Catchment in artificial ponds made in canyons or other suitable areas: CAP

+ Limited evaporation losses are possible by excavating the ponds or canyons locally
+ Can be carried out in a modular way in relation to the demand
+ Can incorporate the needs of the surrounding villages
– Large excavation required: natural sites do not offer any easy possibilities for storage
– Excess water mainly lost to the sea: topography, no down flow storage
– Running costs and maintenance are relatively complex and must be managed steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro- or ultrafiltration, pumps to bring the water to the urban area)

4.8.5 Catchment in Matrimandir lake: CML

+ Relatively cost-efficient as only the drainage system needs to be added

+ Matrimandir lake has a real function in the overall water management
+ Overflow could be
    - Collected in a secondary storage system and then used
    - Recharged in groundwater table as the best possible location for further extraction
+ Becomes a multi-purpose solution: drainage, aesthetic, symbolic, supply
– Social issues cannot be neglected due to the diversion of surface water from Auroville to the lake
– Important evaporation losses
– Running costs and maintenance are relatively complex (decantation, filtration, then pressurized sand filter, activated carbon, micro- or ultrafiltration)

4.8.6 Rainwater harvesting evaluation table: 4 stars best, 1 star worst

	Treatment required for supply	Fragility to external factors	Resource capacity for securing water supply	Sustainable and integrated solution	Rapidity of realization	Investment	Running cost and maintenance	Total
GWR	****	*	****	**	**	****	****	**21**
RWH	***	****	*	***	*	*	*	**14**
CIT	*	**	**	***	****	****	***	**18**
CAP	**	***	****	****	***	**	**	**20**
CML	**	***	***	****	**	***	**	**19**

Table 2: Evaluation for RWH & surface water catchment system

GWR: Groundwater Recharge, RWH: Roof Rainwater Harvesting, CIT: Catchment in Irumbai Tank, CAP: Catchment in Artificial Ponds, CML: Catchment in Matrimandir Lake

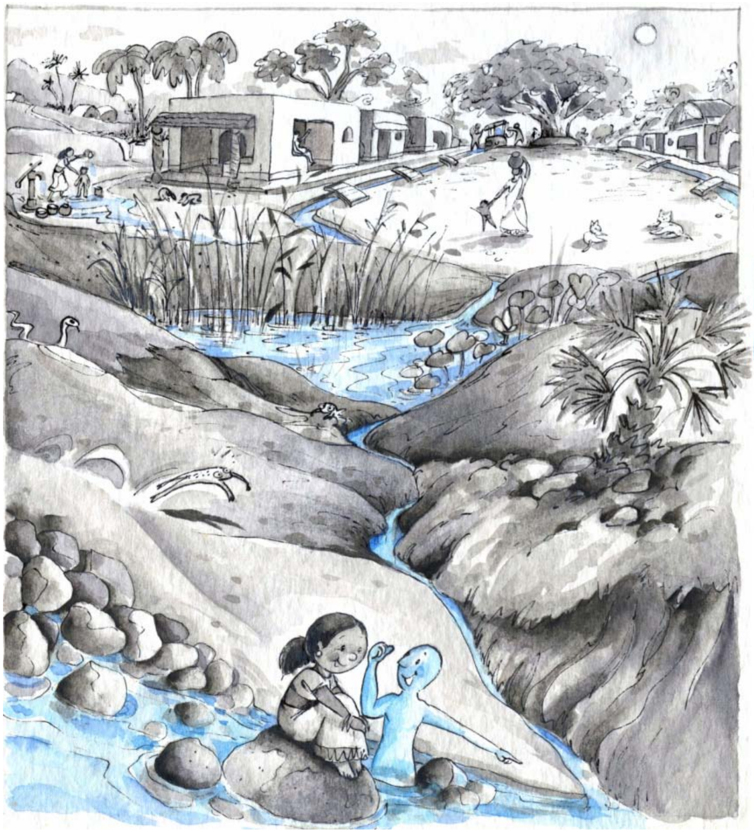
Comments: A single red star brings strong reservations on the concerned resource. Black stars indicate the positive scoring of each resource.

4.8.7 Conclusion

- All solutions can have a role in the surface water management system.
- Groundwater recharge has the best score but is strongly fragile, hence not investigated further in details
- The catchment in artificial ponds and Matrimandir lake solutions have the second best scores at this preliminary stage. It is studied further below. Moreover, they must be integrated into the planning at an early stage, while the other solutions can be implemented over time.
- An open storage system will generate significant losses because of high evaporation rates.
    - Average rainfall: 1299 mm
    - Evaporation losses: 2034 mm
    - Balance: - 735 mm

Surface water as a resource implies good control over pollution. While it cannot be totally avoided, key potential sources of pollution should be identified, avoided and banned as much as possible. Today, the main contaminants are pesticides that are heavily sprayed on privately owned land, and oil and diesel from the increasing number of vehicles.

5. Surface water sourcing study for Auroville's city area: A step by step approach



Since 1966, the possibility of using surface water to maintain Matrimandir lake has been envisaged. At that time, it was already defined that the lake must be part of the water supply system.

In 2001 this subject re-emerged when Matrimandir was completed and it became imperative to go on with the next steps of the city's development. Kraft Engineering from Berlin conducted a pre-feasibility study for the water management of Auroville in 2001. The scheme consisted of a ring of wells, positioned on the eastern side of Auroville, pumping water to an underground storage tank. From the underground tanks, booster pumps keep the city's network under pressure, aided by small balancing tanks. Parallel to the drinking water supply network, the study proposed an irrigation water supply network, which is fed from the effluent of three wastewater treatment plants.

Rainwater is collected at the household level and reused for low-grade applications (toilets and laundry). The excess rainwater is infiltrated underground. The run-off from pavements, roads, public areas and parks is collected in large, open reservoirs (tanks and lakes), filtered and infiltrated underground. The storm water is treated in several stages, passing through sand filters, watercourses and water bodies in the parks, and is eventually pumped into the Matrimandir lake. From infiltration gullies in the centre of the lake in the gardens around the Matrimandir (referred to as the oval), the water is infiltrated underground. Kraft assumes a drinking water demand of 1,834,000 m^3/yr, whereas the irrigation demand has been estimated at 4,505,000 m^3/yr for an average year. The total water demand is 6,340,000 m^3/yr, which is rounded to 6.34 million cubic metres/yr (MCM/yr), and 17,370 m^3/day or 200 l/sec.

The concept is invalid as it is based on the presumption that the first aquifer is a safe and closed reservoir, which is clearly not the case (see 3.1.1).

Considering the inappropriateness of Kraft's study and the total absence of a comparative approach between various solutions, essential at this stage of planning, Kootstra and Co. were required to conduct a new pre-feasibility study, delivered in 2007.

The aim of this study was not to present a ready-made solution, but to integrate and analyse all the available knowledge pertaining to the water situation, its foreseeable evolution and the feasible technical solutions in this context, while developing a tool for a decision-making process for the community, strongly recommending a participatory approach.

From the above table it is clear that decentralized schemes and certain hybrid schemes score better. Best score is from the decentralized system that combines all sources. A brief sensitivity analysis of the results (details can be found in Annex I) shows that invariably, the decentralized scheme using all sources comes out best.(Jeen Kootstra, Auroville Water Management, A pre-feasibility study, July 2007, Final Report)

The water situation has degraded since then, in line with the predictions emerging from scientific studies conducted between 2000 and 2007 on Auroville's regional context. At the same time, Auroville's development is reaching a stage where it is urgent to integrate a sustainable approach. Considering the significant impact of surface water on urban planning, particularly in regard to the Matrimandir lake because of its magnitude, the need to find appropriate solutions is of immediate importance.

5.1 Basic data range and their validity

It is necessary to identify the criteria within which one can reasonably define a rainwater harvesting system as a resource for water supply.

Only the city area is of concern at this stage, due to the lack of clarity regarding development and ownership in the green belt.

Considering the range of possibilities and the difficulty in predicting the trends and future changes, even for a short time period, it is proposed to define acceptable maximum and minimum criteria for the following parameters:

- Time frame
- Population
- Water consumption
- Land use
- Rainfall
- Potential evapo-transpiration
- Run-off coefficient
- Run-off
- Water balance

5.1.1 Time frame

Urban planning is related to the capacity to forecast issues pertaining to development. While long-term targets must be kept in mind to frame planning issues, multiple and interdependent local and global issues, together with emerging solutions and trends, make long-term forecasting difficult. To develop infrastructure which will be usable when all parameters have been achieved, leads to wasteful and dysfunctional systems. The proposed solutions should fit within a reasonable time frame and be a sustained asset for the present as well as in the long term.

Conclusion: By looking at the past and learning from it, it seems reasonable to **limit the practical planning time frame to a 20 year period**, i.e. until 2032.

5.1.2 Population growth

It is agreed that the final population of Auroville will be 50,000 inhabitants. However, it is unlikely that this figure will be reached in 20 years.

The Auroville population data from 1972 to 2012 has been collected and extrapolated in order to define a range of reasonable possibilities for the population in 2032.

Since there was a sudden drop in the population in 1981, the tendency in the population growth is more accurately determined using the data from then onwards.

The following charts show the growth of Auroville's population for the period from 1981 to 2012, during which the population grew from 447 to 2255 inhabitants (Aurovilians + Newcomers). If the growth appears quite steady (*Picture 16*), the growth rate has in fact decreased from 8% in the early 1980s to 3% today (*Picture 17*).

Until 2000 the population was expanding with a 7% growth curve. The effect of several breaks in the entry process (first in 1999, and three or four times since then) has not only slowed the growth but even halted it, until it becomes linear (~55 residents added yearly for the last 12 years).

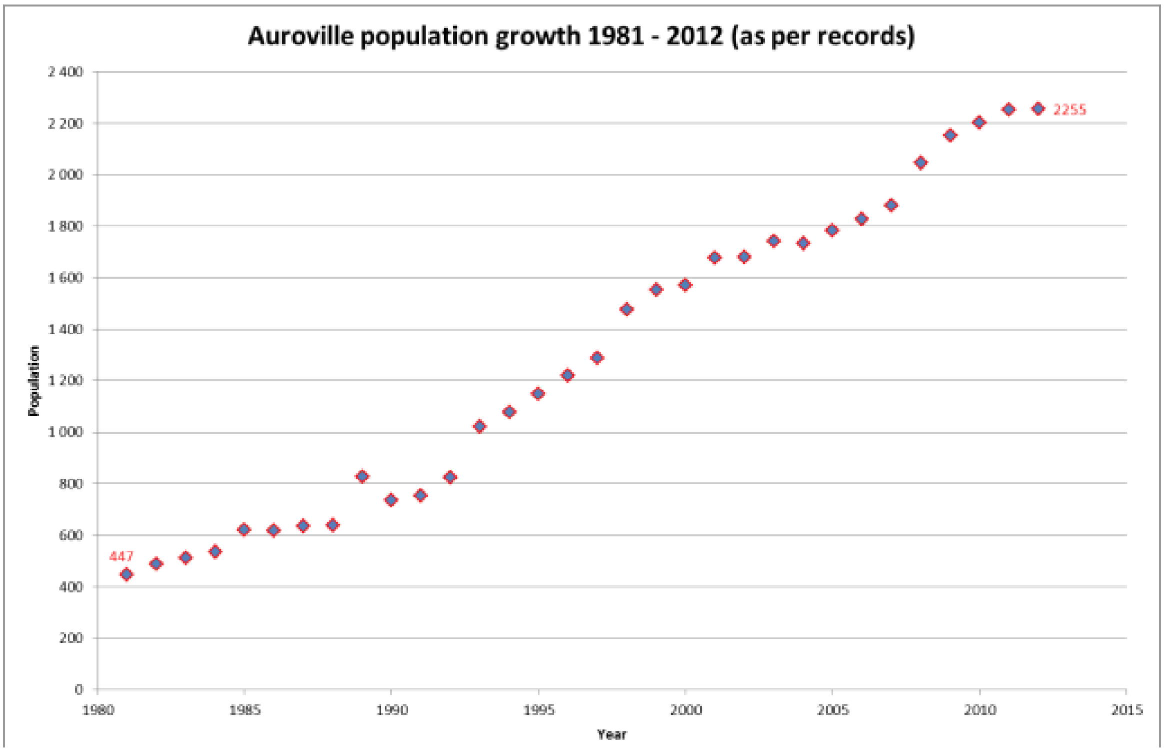
By looking at various aspects, like planning issues for example, it seems clear that this is a low figure which could increase in the future. Other criteria, like social acceptability are limiting factors: a population that grows too quickly is explosive as the basic fabric of the society becomes unstable.

It is proposed to retain a fixed range of 3% to 10% population growth as lower and higher limits to evaluate the impact on water demand (*Picture 18*).

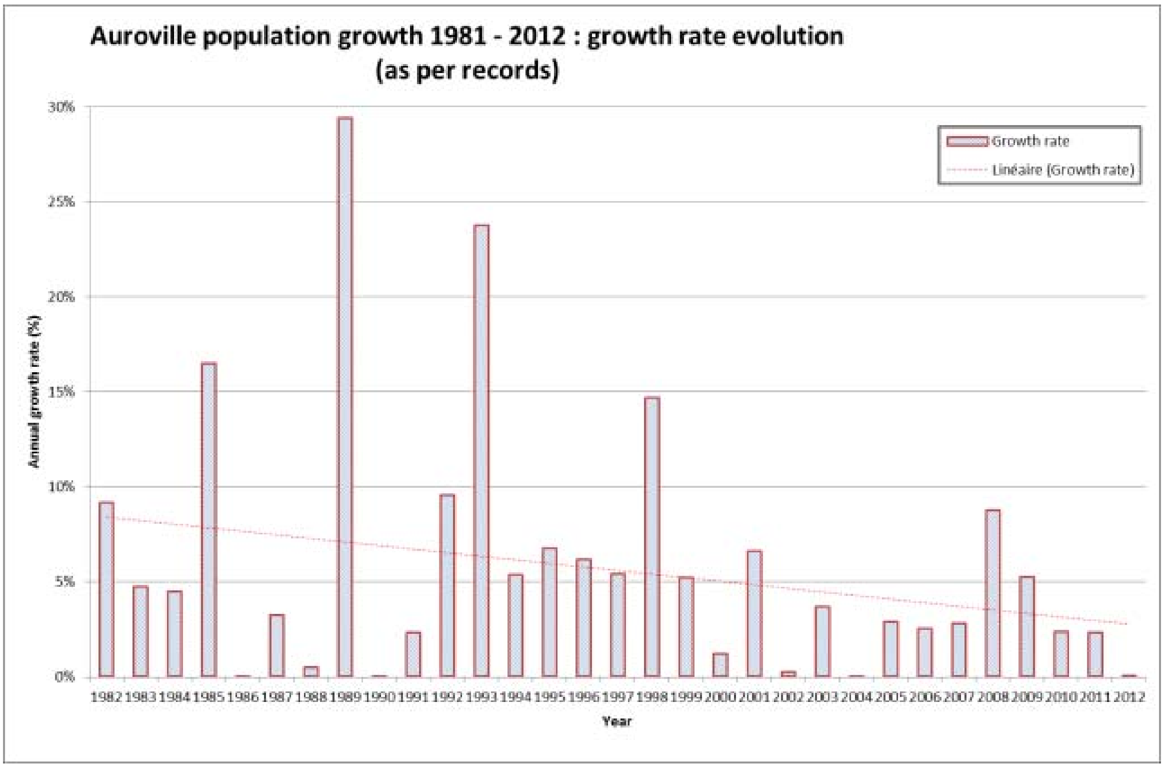
Conclusion: by 2032 Auroville's population would reach

- **4073 people with a growth rate of 3%** and
- **15,171 people with a growth rate of 10%**

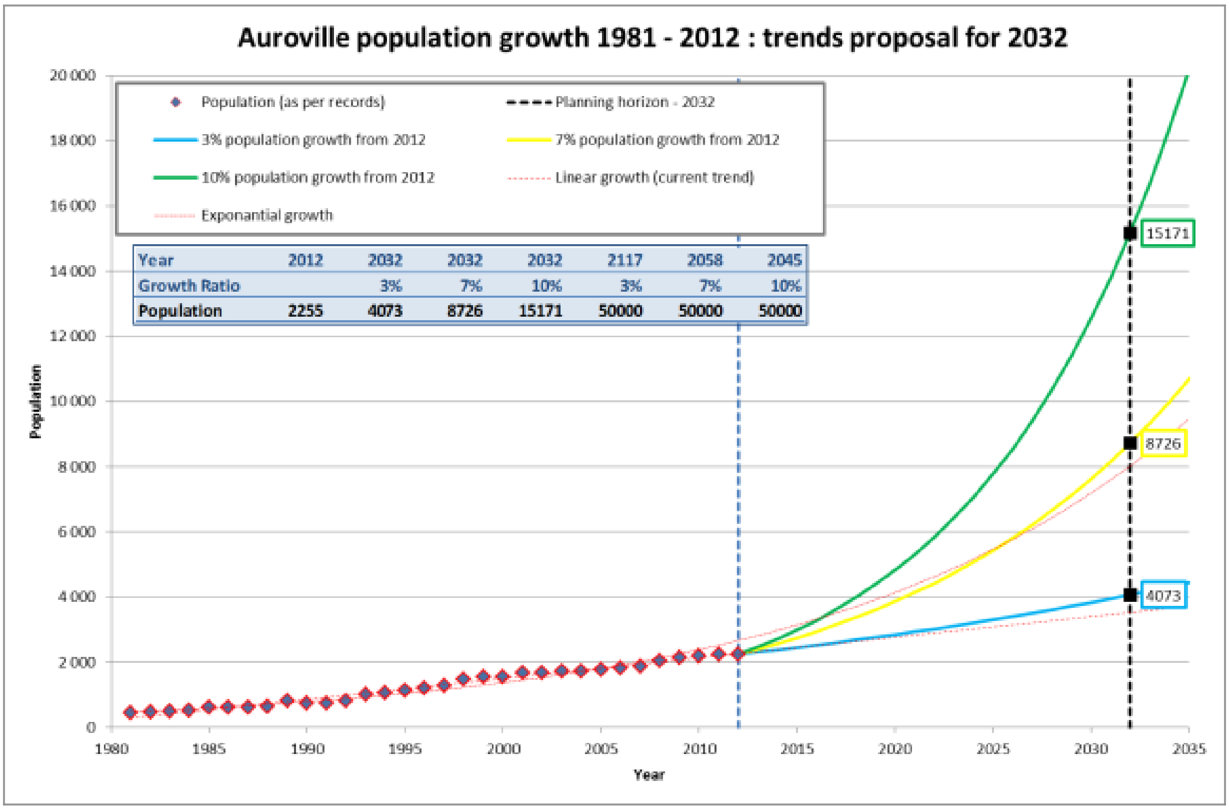
Note: With a 3% population growth rate, 50,000 inhabitants will live in Auroville by 2117
With a 10% population growth rate, 50,000 inhabitants will live in Auroville by 2045



Graph 1: Auroville population growth over the years



Graph 2: Auroville population growth rate evolution over the years



Graph 3: Population growth trends proposal for the next 20 years

NB The data predicted by the Master Plan for 2025, the Kraft study and the Kootstra feasibility study are obviously no longer valid since a population of 50,000 was expected by 2025.

In 2012, L'Avenir d'Auroville redefined the highest population growth value as 7.75%. Considering that the range used in the present study includes this value, the authors have chosen to keep the proposed range, while additional specific data include L'Avenir's figures.

Water demand in an urban context

Urban population refers to a population depending on a main collective system. In fact, Auroville currently (2012) employs about 5000 people and has a large flow of guests and visitors. The resident population fluctuates dramatically throughout the year (summer time), as does the number of guests. In the future, it is likely that the resident population will represent a much greater proportion in comparison to the daily workers, while the visitors' and guests' proportion is difficult to predict.

The water consumption evaluation for Auroville is derived from the National Building Code, and it is assumed that the seasonal variation will be proportionally less than today. The water consumption is therefore defined as constant throughout the year at this stage.

Based on the Indian National Building Code for water consumption in an urban context (NBC 2005) in litres per day per capita (**lcd**), a high consumption value has been defined for Auroville, adjusting the commercial and industrial consumption according to the planned orientation for the development of these activities (non-water based industries and large educational facilities).

From this high consumption value, a low consumption scenario has been established following the Green Rating for Integrated Habitat Assessment (GRIHA).

Eventually, a consumption scenario has been defined using wastewater recycling for flushing and similar uses in order to optimize the potable water use and hence validate the available water and reduce the pressure on natural resources. The figures used here are based on GRIHA-derived guidelines.

	Consumption as per literature (NBC) lcd	Consump-tion as per AV projection lcd	Consump-tion as per GRIHA guidelines lcd	*Recyc-lable part lcd*	*Potentially recycled lcd*	Potable water demand per capita lcd (to the network)
Domestic use	135	135	101	*77*	*31*	70
Industrial use	50	30	21	*16*	*7*	14
Commercial use (factories, offices, hospitals, hostels, restaurants, schools)	20	25	19	*14*	*6*	13
Public use (gardens, parks, roads, public fountains)	10	10	10	*0*	*10*	0
Waste/leaks	55	51	15	*0*	*5*	10
Average municipal consumption	**270**	**251**	**166**	***107***	***59***	**107**

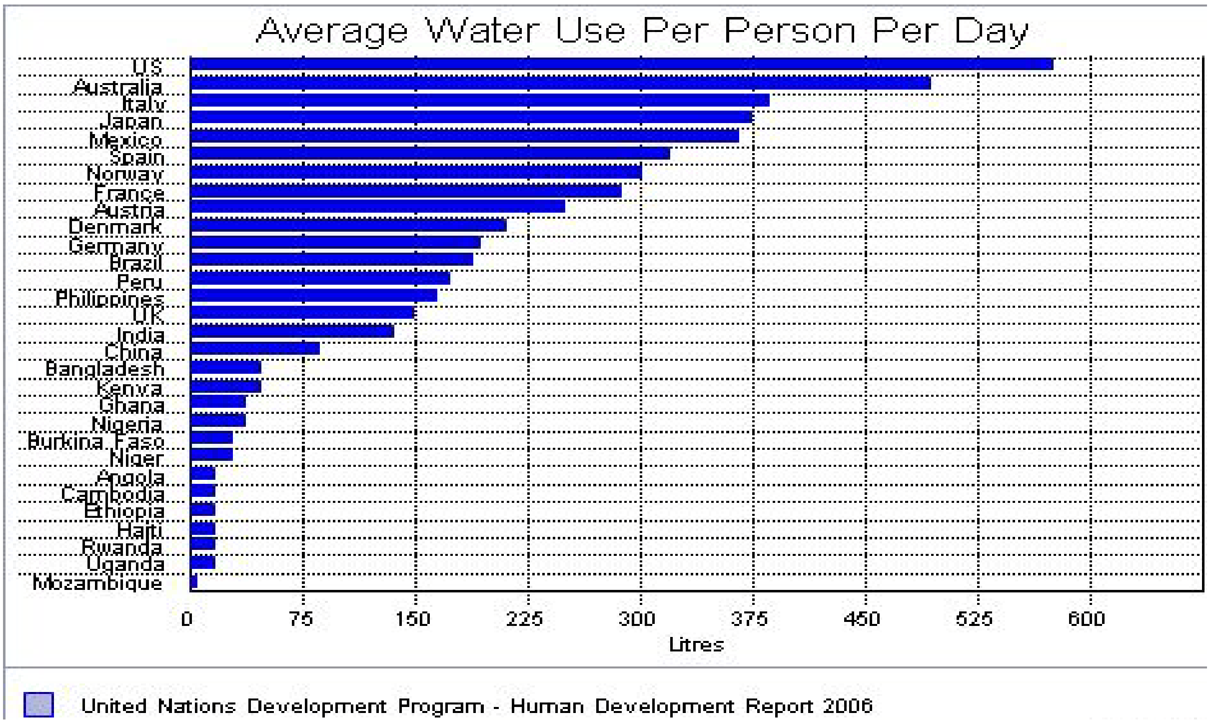
Table 3: Potential evolution of water consumption for Auroville

- The **water consumption as per literature** is based on the Indian National Building Code: **270 lcd**.
- The **consumption as per AV projection** is derived from the former, with a lower value for industrial use because of the absence of large industries in Auroville's plan, and a higher value for commercial use because of greater usage for schools and facilities: **251 lcd**.
- The **water consumption as per GRIHA guidelines** is based on the Green Rating for Integrated Habitat Assessment (GRIHA) recommendations, jointly developed by TERI and the Ministry of New and Renewable Energy, Government of India: **166 lcd**.
- The **water consumption**, taking recycling into account, according to GRIHA guidelines: **107 lcd**.
- The **recyclable part** defines the volume of potable water that could be recycled from the overall consumption.
- The **potentially recycled part** is the amount of recyclable wastewater which could be reused in the overall water demand scenario. It indicates that a large volume of processed wastewater remains untapped and can be used for groundwater recharge or irrigation purposes within and beyond the city: **59 lcd**
- **Potable water demand** is the retained value to be supplied to the population if wastewater recycling for secondary use is systematically applied: **107 lcd**

The recycling calculation has been determined considering the use of excess domestic, industrial or commercial wastewater for public use.

All the recyclable water is not reused, which means an additional 48 lcd is available. This water, which accounts for 29% of the daily demand, could be used for groundwater recharge or irrigation in the green belt.

As a comparison, here are the figures of average water consumption per person per day in different countries.



Graph 4: Water consumption in different countries

5.1.3 Land use

Auroville plans that in the future, the city will consist of 50% built areas and 50% green areas. The built areas don't include the secondary buildings and other infrastructure.

It is therefore assumed here that the **maximum ratio for impervious areas will cover 60% of the city area, while 40% will remain green.** This land occupation ratio will be the maximum value retained for this study and will be used to determine the associated maximum run-off.

Currently, the ratio is about 5-10% built areas to 90-95% green areas.

In 20 years, even with low population growth, a lot of infrastructure will have been developed, and because of the planned development in certain sectors, most of the population and infrastructure will initially be concentrated in sectors 1 and 2 of the residential zone. It is likely that it will then progress in a concentrated pattern from the centre to the outside.

Hence, **a minimum ratio of 30% impervious areas and 70% green areas is retained.** This ratio will be used for the low run-off value calculation.

5.1.4 Rainfall

Synthesis and validation of the existing rainfall and potential evapo-transpiration statistics have been carried out in order to submit a reliable and relevant set of data (Appendix 1).

The present study is based on daily rainfall data from 1969 to 2008, covering a 40 year period. The first part of the data is from the Pondicherry meteorological station (1969 – 1999), while the latter data is from the Auroville Harvest station (2000 – 2008). Data for the period from 2009 – 2011 have not been located.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Mean rainfall (mm)	20	24	20	12	42	46	70	114	131	267	357	195	**1299**

Table 4: Average monthly rainfall in Auroville

5.1.5 Potential evapo-transpiration

Potential evapo-transpiration (PET) data are available in the Ph.D. report of Dr Aude Vincent. Calculations using the Thornthwaite method have been carried out using the Certitude meteorological station data for the period from 1972 to 1981. Similar calculations have also been done for the data from the Pondicherry and Vanur meteorological stations for the period from 2001 – 2005.

This results in monthly mean values as shown in the following table.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Mean PET (mm)	80	90	138	202	267	273	244	217	179	152	108	84	**2034**

Table 5: Potential evapo-transpiration in Auroville

NB The standard formula to determine losses by evaporation for large areas is the Penman, which then determines the so-called Consumptive Use. It deviates from the Thornthwaite method by integrating a specific factor related to the nature of the surface (cultivated field, forest, large water body...) Considering the relatively large range of values obtained from the available years and in comparison to field measurements available *(ref CGWB 1984 report for Cuddalore meteorological data, year 1981 to 1983)*, the retained value according to the Thornthwaite method corresponds with reality.

5.1.6 Run-off coefficient

Regarding land occupation as described above in the city area, run-off coefficients have been attributed to types of land use, applying typical values to green and impervious cover as per usual practices (soil, topography and land use are some of the parameters used to determine run-off coefficient, together with on-site investigations).

Soil occupation	Green	Impervious
Run-off coefficient	10%	80%

Table 6: Retained run-off coefficients in Auroville

These coefficients, together with various development density patterns (see 5.1.3), lead to low and high boundary conditions for the global run-off coefficient.

Run-off coefficient	Low	High
Land occupation	70% Green – 30% Impervious	40% Green – 60% Impervious
Value	**31%**	**52%**

Table 7: Run-off coefficient applied to various development density patterns for Auroville

NB Scope for development within the green belt is not clear (villages, land ownership, large infrastructure…), hence the potential volume of run-off cannot be defined at this stage.

5.1.7 Run-off

The run-off coefficients determined above are appropriate for medium to high rainfalls, but during small rain events, no run-off occurs. It is therefore necessary to process the daily rainfall data in order to filter out rains below a defined value.

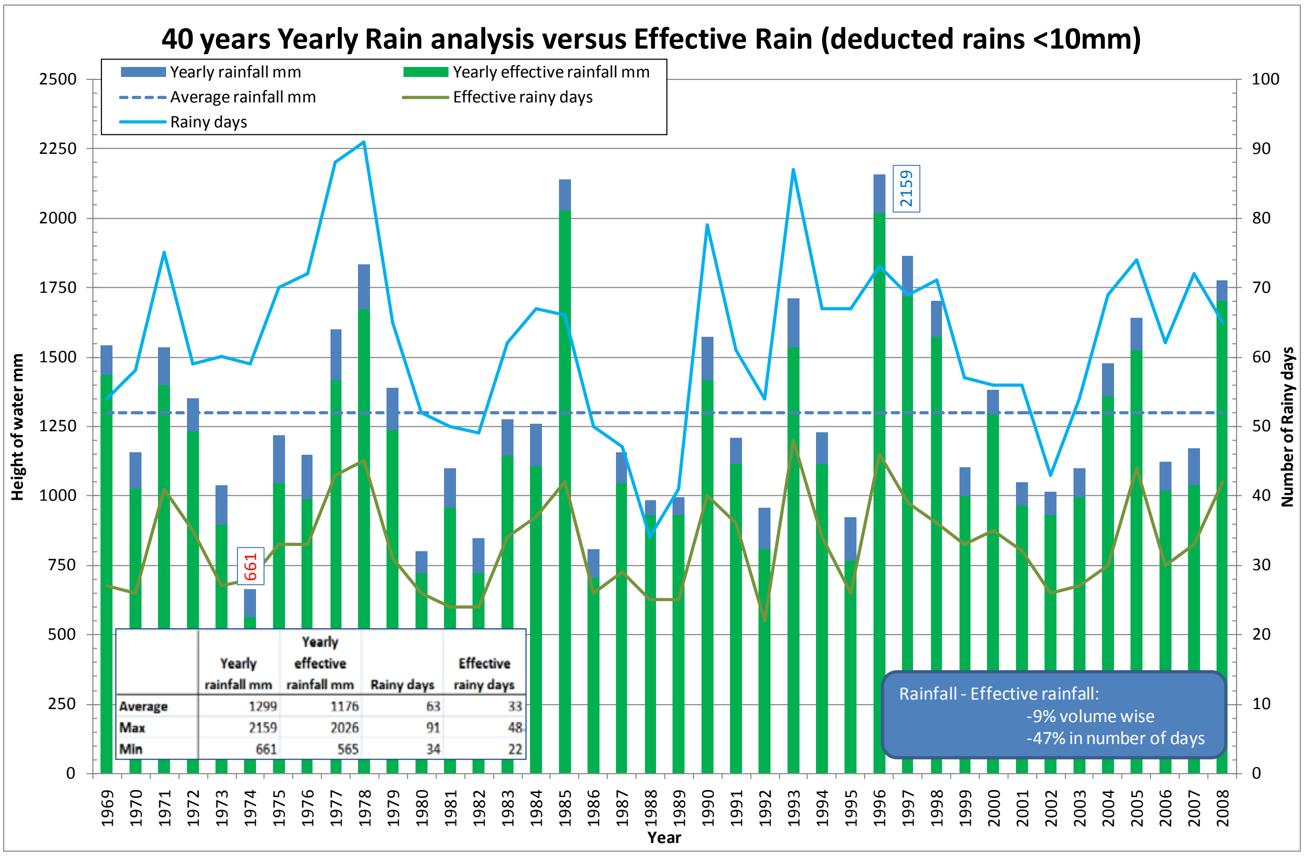
Taking the small rainfall event distribution over the years, it is chosen to consider rainfalls inferior to 10 mm as ineffective, i.e. without run-off production.

Rainfalls that are greater than 10 mm are called “effective rain”. The study used data covering 40 years of daily rainfalls, and removed any rainfall events that were below 10 mm.

The table and the chart below compare the effective rain with the gross rain over the years on the basis of the volume and the number of days of occurrence.

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Mean rainfall (mm)	20	24	20	12	42	46	70	114	131	267	357	195	**1299**
Effective rainfall	16	22	18	10	37	38	57	97	116	246	335	183	**1176**

Table 8: Monthly average effective rainfall in Auroville



Graph 5: Comparison of rainfall with effective rainfall

The mean annual effective rainfall represents 91% of the mean rainfall in volume. However, the 9% of rainfall removed accounts for 47% of the number of events.

It is interesting to note that even if the fluctuation of the rainfalls varies over the years (661 to 2159 mm/year), the ratio $\frac{effective\ rain}{rain}$ is quite constant.

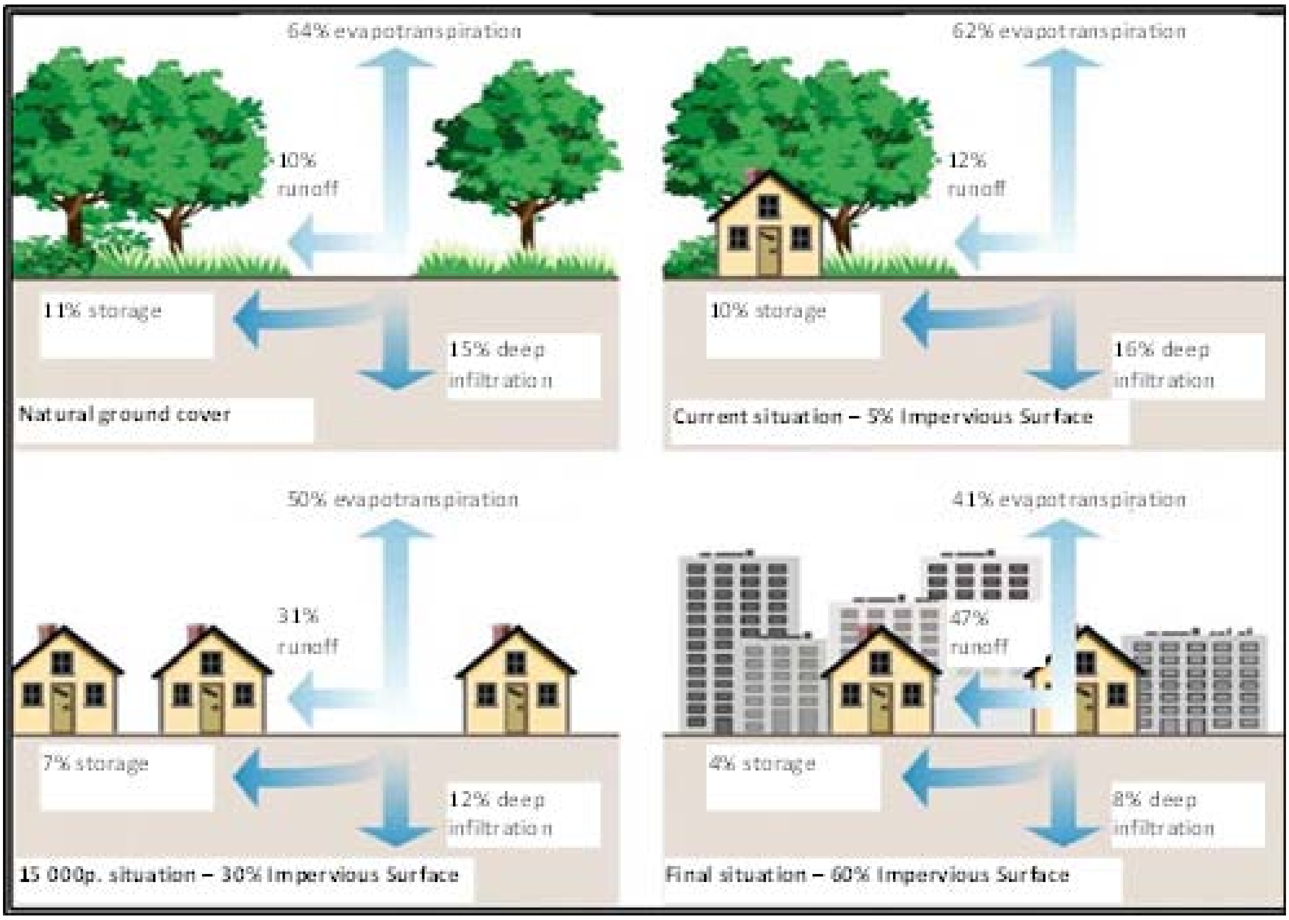
5.1.8 Water balance

According to the figures determined earlier in this study, the water balance has been estimated for the different stages of Auroville's development. These figures must be taken as orders of magnitude only as they cannot be refined further at this stage of planning for the city.

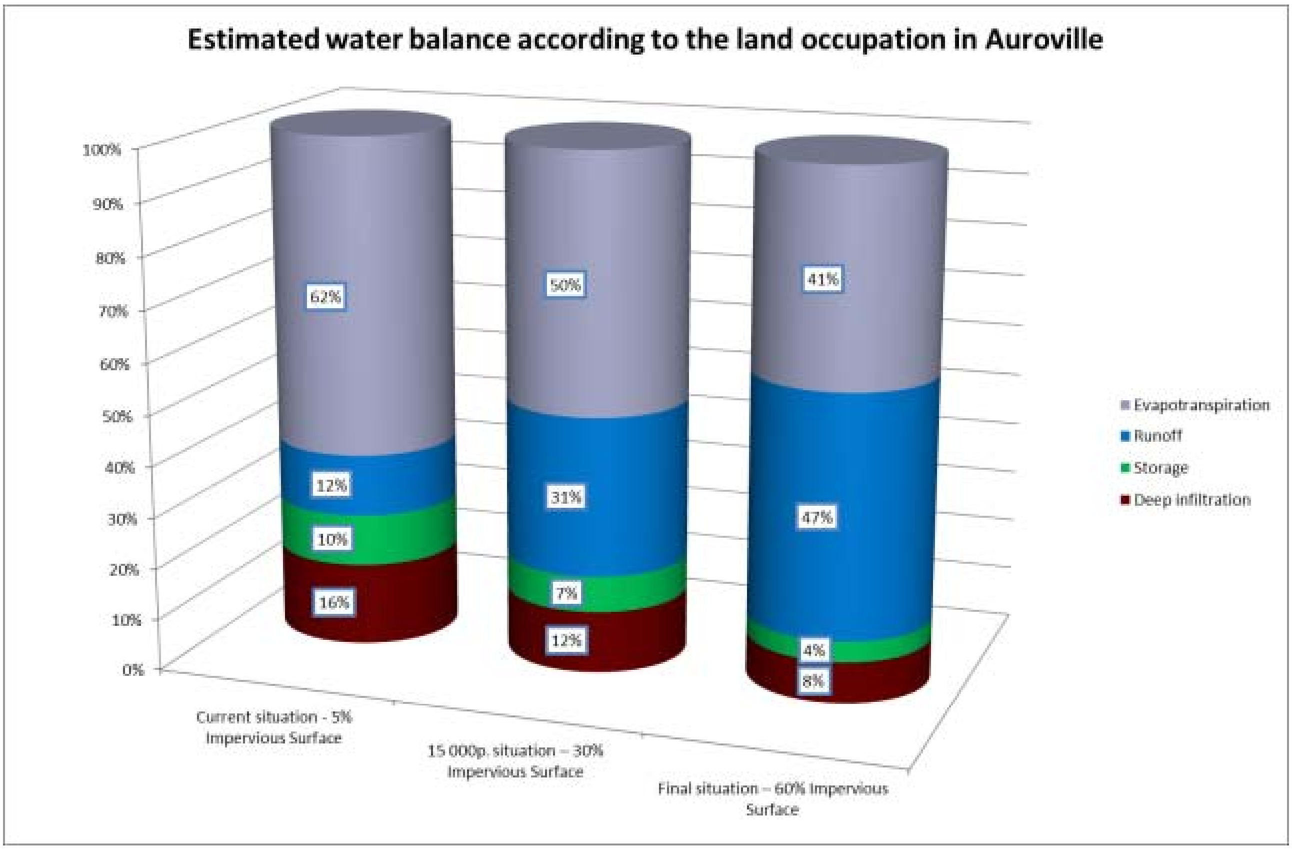
The scheme and chart below illustrate these balances.

NB The infiltration is 16% $\pm$ 2% in the Cuddalore aquifer.

Ref: Study of groundwater resources of Pondicherry and its environs, B.S. Sukhija, D.V. Reddy & I. Vasanthakumar Reddy, National Geophysical Research Institute HYDERABAD – 500 007 JUNE 1987.



Picture 14: Evolution of water balance through urban development



Graph 6: Water balance evolution in the Auroville context

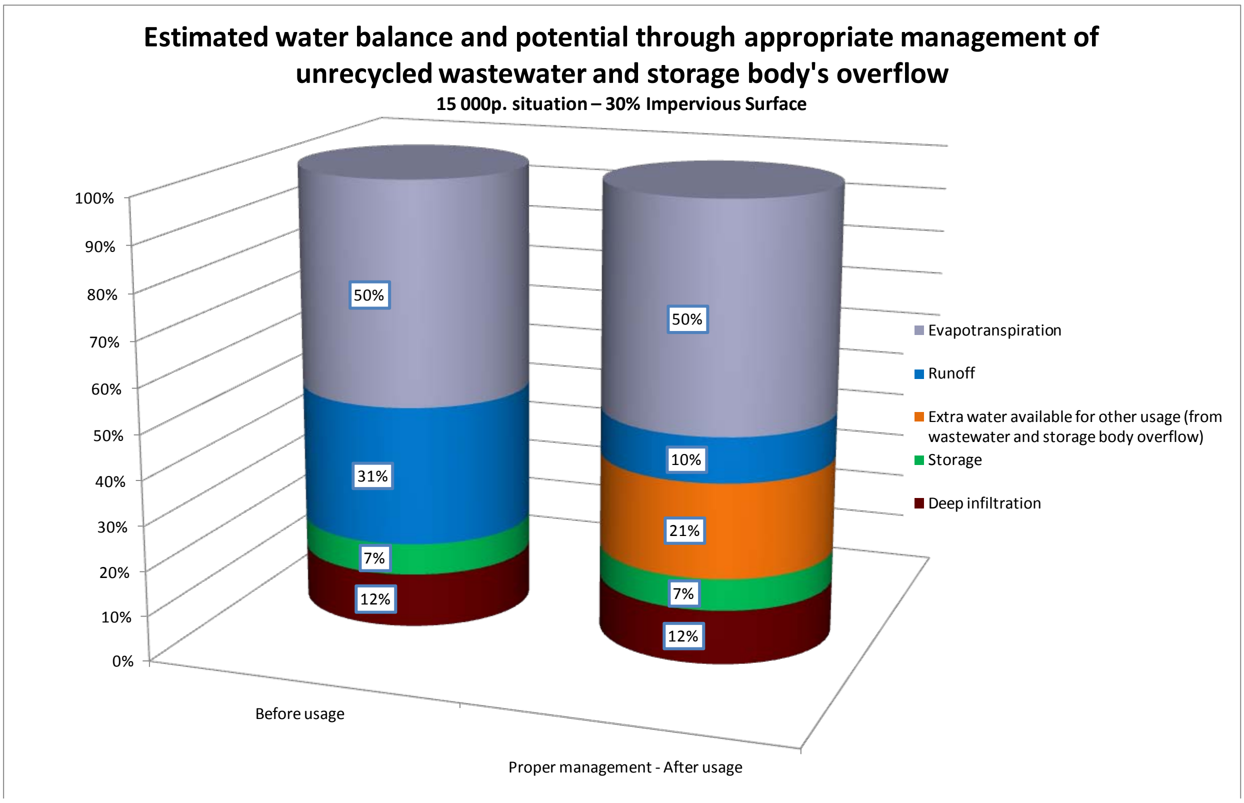
The general trend with the development of a city is a massive increase in run-off at the expense of other elements of the water balance (evaporation, storage and infiltration). Fewer green areas and more built-up areas lead to less evaporation losses and less recharge into the ground, while the run-off increases proportionally. Such a significant volume of run-off becomes a major problem; usually run-off is not considered a resource.

Since groundwater is overexploited on a regional scale, the positive impact of local recharge is negligible and does not prevent the depletion of the aquifer or stop the ongoing seawater intrusion along the coast.

Additionally, as shown in the water demand section of this report, 48 lcd of the recyclable water is not recycled and hence could be available as an additional water source if well managed. Moreover, the seasonal overflow of any storage body would also provide extra water. The water derived from run-off is potentially available for secondary usage such as agriculture or groundwater infiltration.

If the excess run-off and non-recycled water is used for groundwater recharge, the infiltration levels would be much higher in the future.

The following chart shows the potential projected water balance with proper water management.



Graph 7: Effect of appropriate management of resources on the water balance

An integrated approach would therefore create a multiple positive impact, by allowing for safe supply to the population and benefiting the larger area as well.

5.1.9 Conclusion on data range and their validity

Determined ranges of validity for the main variables applicable.

Variable	Range
Time frame	20 years
Population	3% 4073 – 10% 15,171
Water consumption	High value (National Building Code): 270 lcd Low value (GRIHA guidelines): 166 lcd Low value with recycling (GRIHA guidelines): 107 lcd
Rainfall	1299 mm/y on average
Effective rainfall	1176 mm/y on average
Evaporation	2034 mm/y on average
Land occupation	High ratio: 60% impervious – 40% green Low ratio: 30% impervious – 70% green
Run-off coefficient	High: 52% Low: 31%

Table 9: Recapitulation on retained parameters range

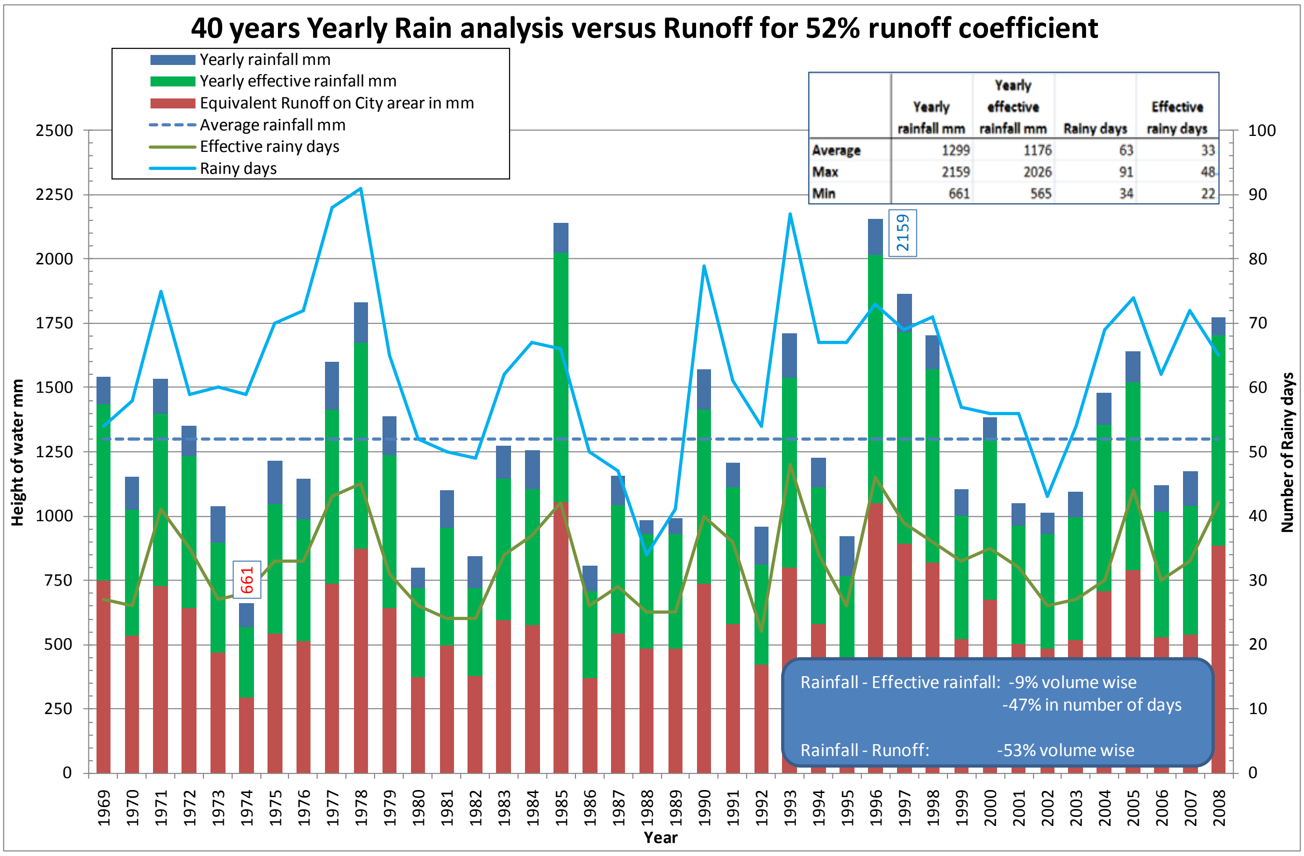
Taking the above parameters, an adaptable system can be designed which would be most suitable for all these values.

5.2 First quantitative assessment

Now that the range of validity of the main data has been established, the rainwater harvesting system capacity can be evaluated according to the scale of the city.

5.2.1 Rainfall versus run-off

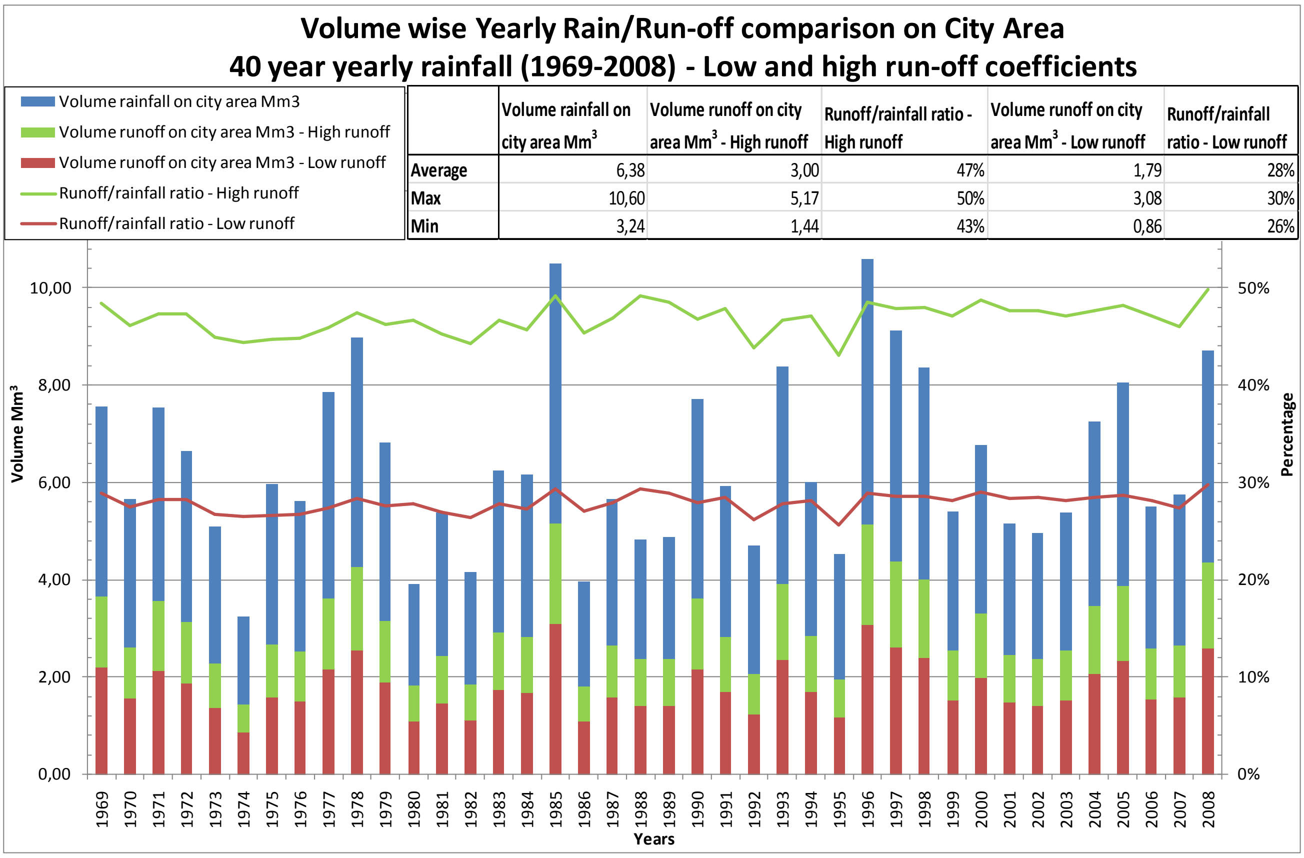
The high run-off coefficient on the effective rain over the city area has been applied on a yearly basis, see figure below.



Graph 8: Comparison of rainfall with run-off

This chart indicates how much rainwater is lost through natural processes as only 47% of the rain eventually ends up as run-off.

The following chart compares the influence of the run-off coefficient value on the run-off generated, and shows the development of the ratio $\frac{run-off}{rainfall}$ over the years, both for the low and high run-off coefficient.



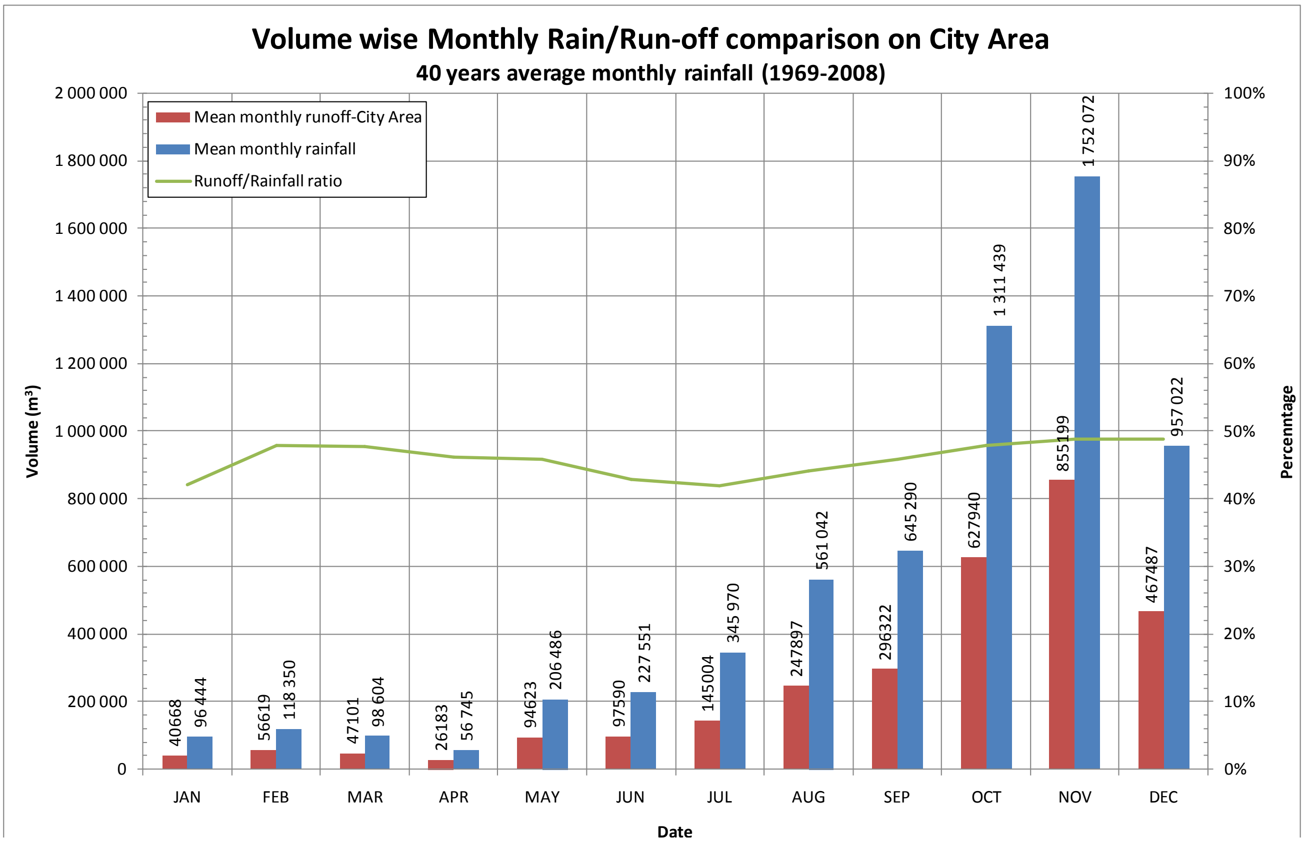
	Volume rainfall on city area Mm^3	Volume runoff on city area Mm^3 - High runoff	Runoff/rainfall ratio - High runoff	Volume runoff on city area Mm^3 - Low runoff	Runoff/rainfall ratio - Low runoff
Average	6,38	3,00	47%	1,79	28%
Max	10,60	5,17	50%	3,08	30%
Min	3,24	1,44	43%	0,86	26%

Graph 9: Comparison of volumes between yearly rainfalls and run-off

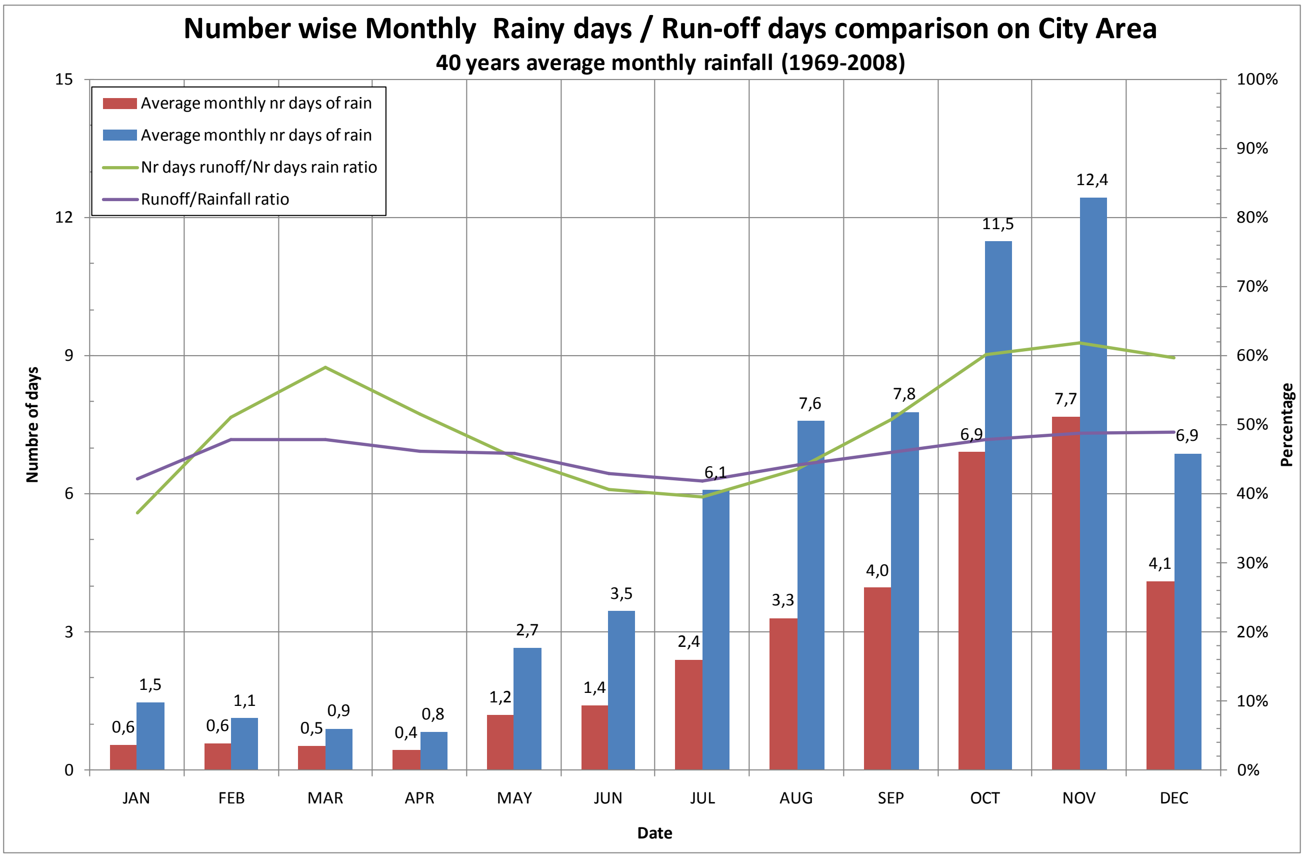
The ratios $\frac{run-off}{rainfall}$ are quite constant over the years, and their mean values are 28% for the low run-off coefficient and 47% for the high one.

The run-off coefficient has considerable influence on the quantity of water available from the rainfalls. This point is relevant as it implies that the quantity of water available would increase as Auroville develops, i.e. with the general water demand.

The two charts below compare the run-off with the rainfalls in the city area for a high run-off coefficient on a monthly basis. First, the volumes are presented, followed by the number of days on which they occur.



Graph 10: Comparison of the volumes of monthly rainfall versus run-off



Graph 11: Comparison of monthly no. of rainy days with run-off

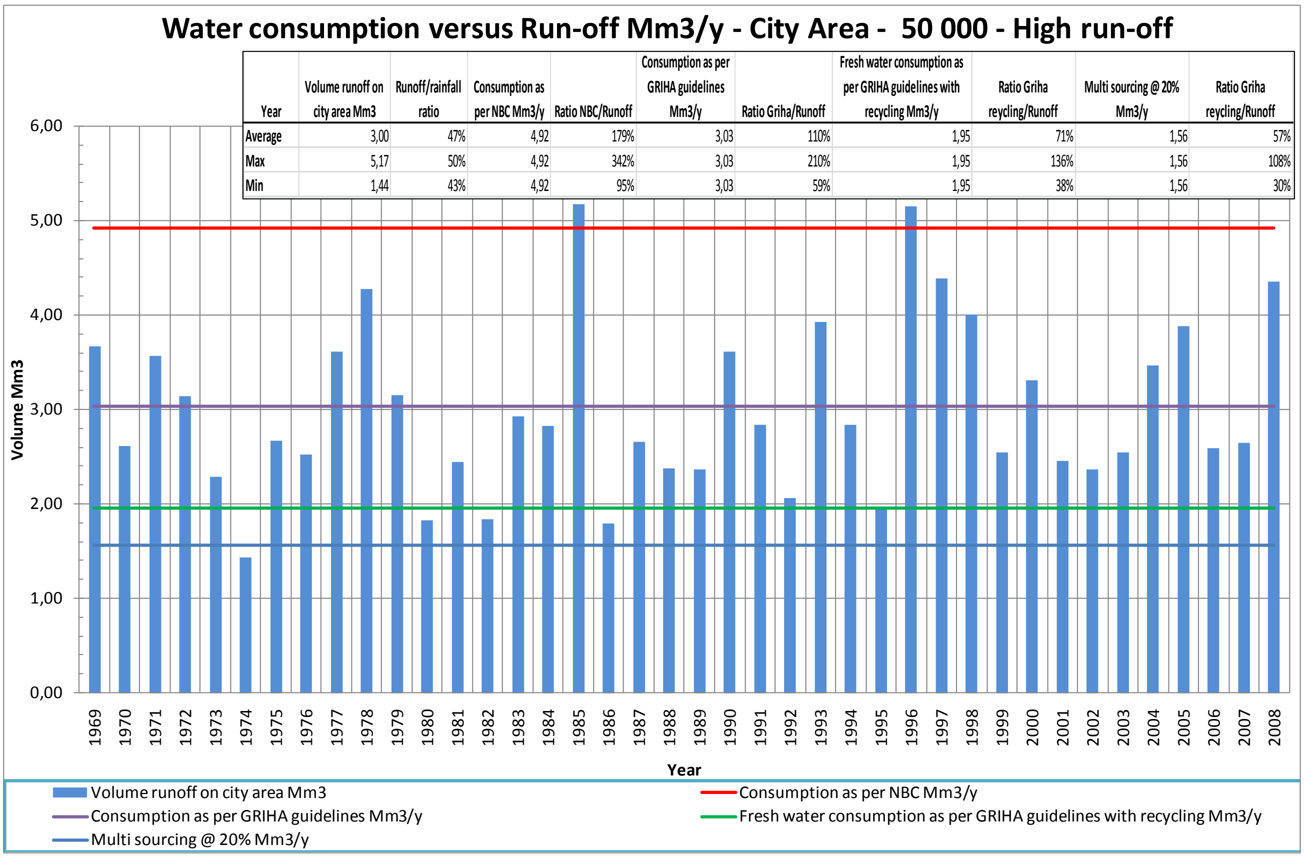
The ratio $\frac{run - off}{rainfall}$ is more constant for the volume than for the number of occurrences throughout the year. This is more advantageous to a rainwater harvesting system which primarily works with the volumes. It indicates that no negative phenomena that could limit the rainwater harvesting capacity are observed.

NB The number of days of effective rainfall is the same as the number of days of run-off.

5.2.2 Run-off versus consumption

The following chart presents the yearly volume of run-off in the city area for the high run-off coefficient and compares it with the expected consumption for 50,000 people for the three values of daily consumption used for the study: high (NBC), low (GRIHA) and recycled (GRIHA). A combined sourcing system has been added to the chart allowing for 20% of the daily supply coming from a secondary resource. This comparison aims to estimate the potential of rainwater harvesting with the goal of supplying the population with potable water.

NB A population of 50,000 people is used here to highlight the limits of this system.



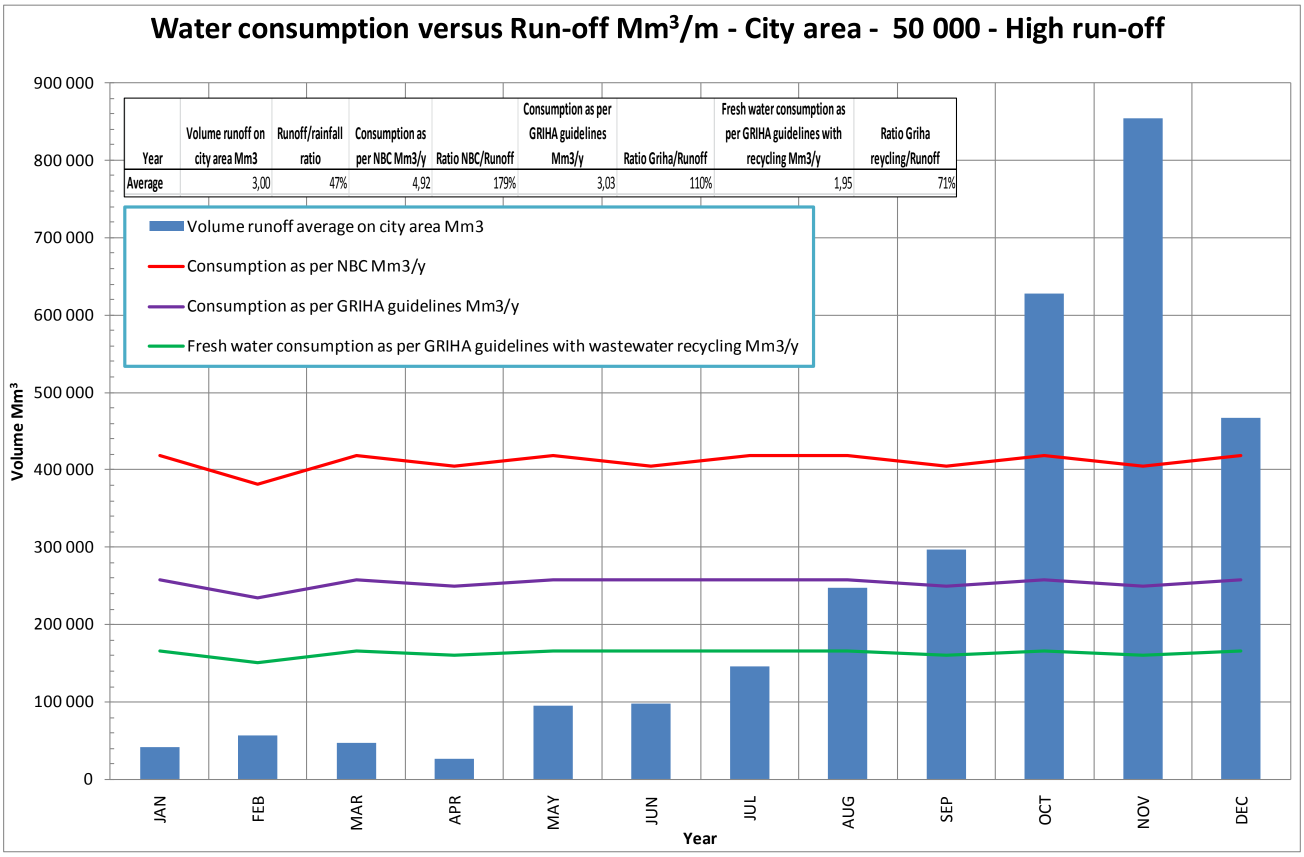
Year	Volume runoff on city area Mm3	Runoff/rainfall ratio	Consumption as per NBC Mm3/y	Ratio NBC/Runoff	Consumption as per GRIHA guidelines Mm3/y	Ratio Griha/Runoff	Fresh water consumption as per GRIHA guidelines with recycling Mm3/y	Ratio Griha reycling/Runoff	Multi sourcing @ 20% Mm3/y	Ratio Griha reycling/Runoff
Average	3,00	47%	4,92	179%	3,03	110%	1,95	71%	1,56	57%
Max	5,17	50%	4,92	342%	3,03	210%	1,95	136%	1,56	108%
Min	1,44	43%	4,92	95%	3,03	59%	1,95	38%	1,56	30%

Graph 12: Comparison of yearly run-off with consumption for 50,000 people

This comparison highlights the influence of the population consumption, the need for an adequate and functioning distribution system, and the need to adapt building design criteria following GRIHA guidelines.

It would be possible **in average conditions** to supply the final 50,000 people with the implementation of wastewater recycling incorporated in the water supply cycle.

The chart below presents the monthly volume of run-off in the city area for the high run-off coefficient and compares it with the expected consumption for 50,000 people for the three values of daily consumption retained for the study: high (NBC), low (GRIHA) and recycled.



Year	Volume runoff on city area Mm3	Runoff/rainfall ratio	Consumption as per NBC Mm3/y	Ratio NBC/Runoff	Consumption as per GRIHA guidelines Mm3/y	Ratio Griha/Runoff	Fresh water consumption as per GRIHA guidelines with recycling Mm3/y	Ratio Griha reycling/Runoff
Average	3,00	47%	4,92	179%	3,03	110%	1,95	71%

Graph 13: Comparison of monthly run-off with consumption for 50,000 people

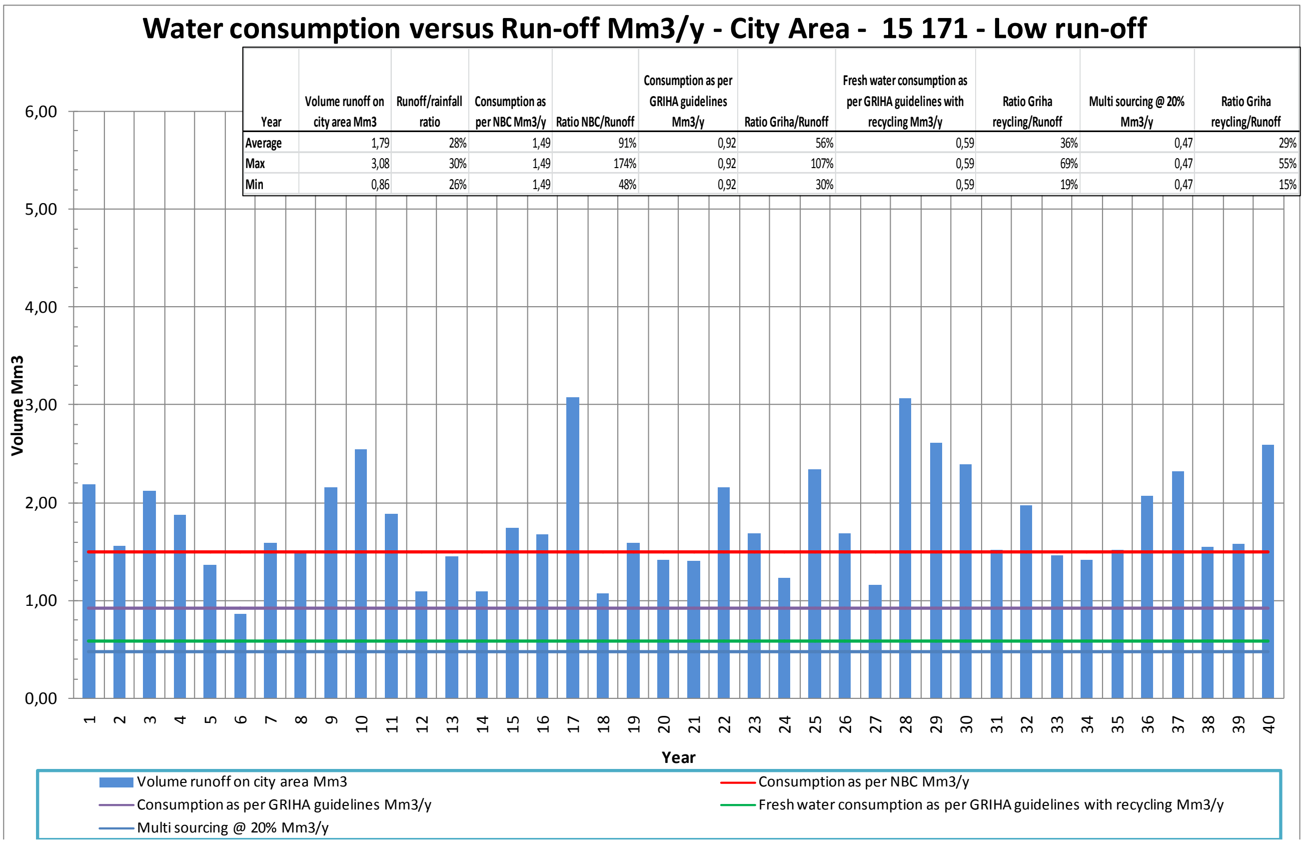
While previous observations are further highlighted, the seasonal fluctuation in the available water is extremely marked and this demonstrates the necessity of installing an adequate storage system.

Up to this point of the study, it is not possible to evaluate the required storage volume to supply the population throughout the year. Indeed, the yearly and monthly meteorological fluctuations mean an extremely big storage system would be required to supply the entire population in every instance.

Is it economically and technically worthwhile to design such a large tank or is it more feasible to make it smaller and to supply the missing days with a complementary resource?

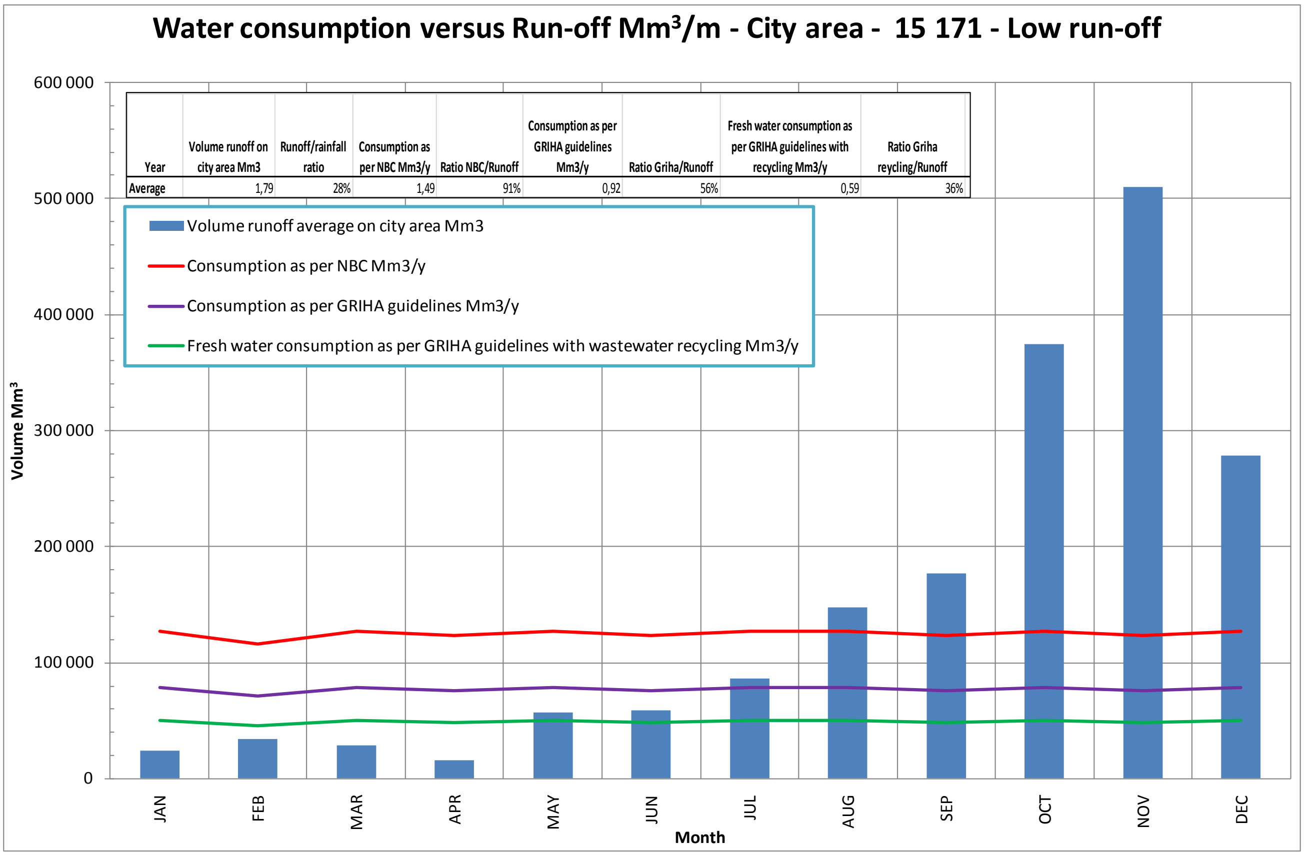
Moreover, criteria such as the effects of potential evapo-transpiration or infiltration on the storage system have not been taken into account, as well as the overflow of the system during substantial rainfalls.

The two graphs below are based on the maximum envisaged population of 15,171 people in 20 years, for a low run-off coefficient.



Year	Volume runoff on city area Mm3	Runoff/rainfall ratio	Consumption as per NBC Mm3/y	Ratio NBC/Runoff	Consumption as per GRIHA guidelines Mm3/y	Ratio Griha/Runoff	Fresh water consumption as per GRIHA guidelines with recycling Mm3/y	Ratio Griha reycling/Runoff	Multi sourcing @ 20% Mm3/y	Ratio Griha reycling/Runoff
Average	1,79	28%	1,49	91%	0,92	56%	0,59	36%	0,47	29%
Max	3,08	30%	1,49	174%	0,92	107%	0,59	69%	0,47	55%
Min	0,86	26%	1,49	48%	0,92	30%	0,59	19%	0,47	15%

Graph 14: Comparison of yearly run-off with consumption for 15,171 people



Year	Volume runoff on city area Mm3	Runoff/rainfall ratio	Consumption as per NBC Mm3/y	Ratio NBC/Runoff	Consumption as per GRIHA guidelines Mm3/y	Ratio Griha/Runoff	Fresh water consumption as per GRIHA guidelines with recycling Mm3/y	Ratio Griha reycling/Runoff
Average	1,79	28%	1,49	91%	0,92	56%	0,59	36%

Graph 15: Comparison of monthly run-off with consumption for 15,171 people

5.3 aims to define an optimal storage system, and evaluate its capacity to deal with the yearly and monthly fluctuations in the rainfalls.

5.3 Overall surface water system definition

5.3.1 Overall considerations

To use surface water as a resource implies that pollution is well controlled. While it cannot be totally avoided, the main potential pollution sources should be identified, avoided or banned as much as possible. Today, the main risk comes from pesticide which is heavily sprayed on privately owned land, and oil and petrol products from the increasing number of vehicles.

The development of a suitable run-off water collection system must include purification along the way; hence it must be synchronized with land acquisition to avoid the concentration of polluting substances in the drainage system, the storage tanks, and particularly the distribution system.

A suitable drainage and storage system needs to follow an appropriate design approach from the hydraulic and physical points of view, but also with regard to aesthetics, operation and maintenance. But the most important consideration for a large, open storage system is related to the complex ecology of a water body in tropical conditions. In addition to pollution aspects, which are certainly critical, the specific life and evolution of a water body follows the same principle as any ecological set-up: environmental and climatic constraints are prominent, together with the large inflow fluctuation and the physical dynamic of the water body through evaporation, infiltration and extraction, if any. It is better to let Nature take its course through diverse solutions, rather than to attempt to implement a purely technical approach.

Nature's design works in a holistic way, integrating all the different factors and their specific variations, as well as the interactions affecting it; elements are not eliminated but regulated by the flexibility created in a system.

An "industrial" design, following strict lines and trying to eliminate undesired elements, cannot guarantee comparable levels of endurance or resilience.

It is highly recommended that the design of such a system, in its different components and as a whole, respects the fundamental laws of Nature and their inbuilt flexibility.

Note that the following chapters only apply to the city area. The green belt is not included due to lack of planning precision, the impact of uncontrolled development, actual and future land use and the proposed time frame for implementation.

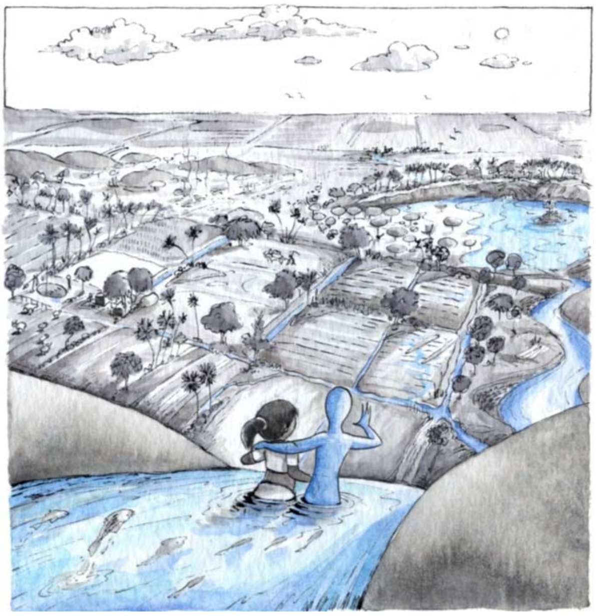
It has been demonstrated that a storage system is required in order to supply the population on an annual and long-term basis because of the substantial rainfall fluctuations. Furthermore, a drainage system is an added necessity.

The overall system not only has to manage the volume of water, but also has to include water quality management, as any surface water system is vulnerable to accidental pollution.

The main technical elements of the integral system are described below.

5.3.2 Drainage system

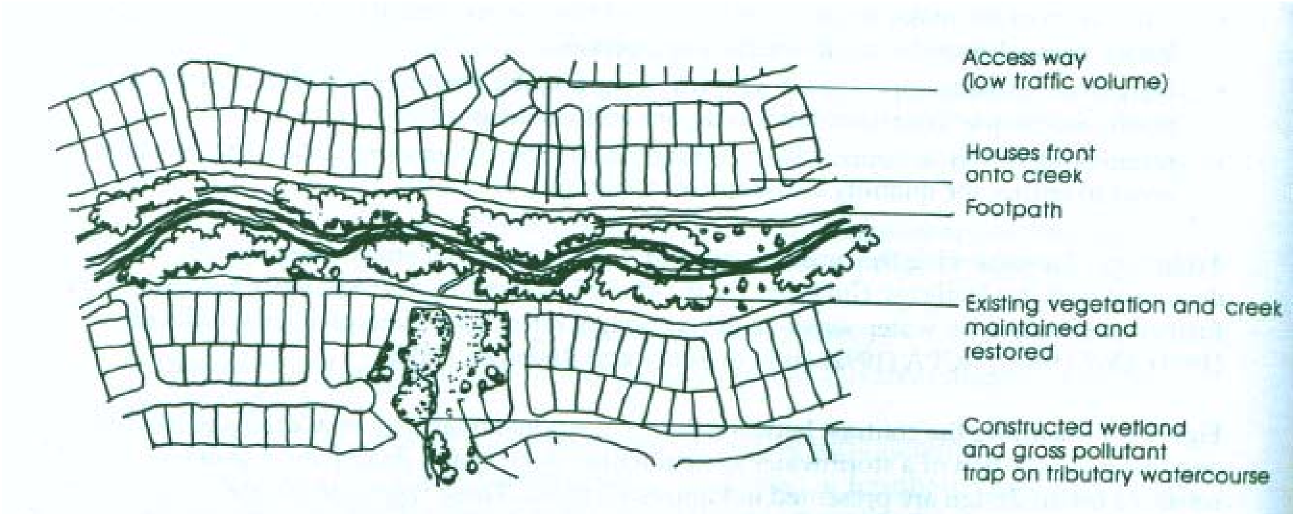
As shown previously, an independent open storage tank is not sustainable and requires a drainage area to feed it. In order to supply the city with harvested rainwater, the widest possible area has to be drained.



It is assumed that the entire city area can be drained to feed the storage tank.

Furthermore, the drainage system should:

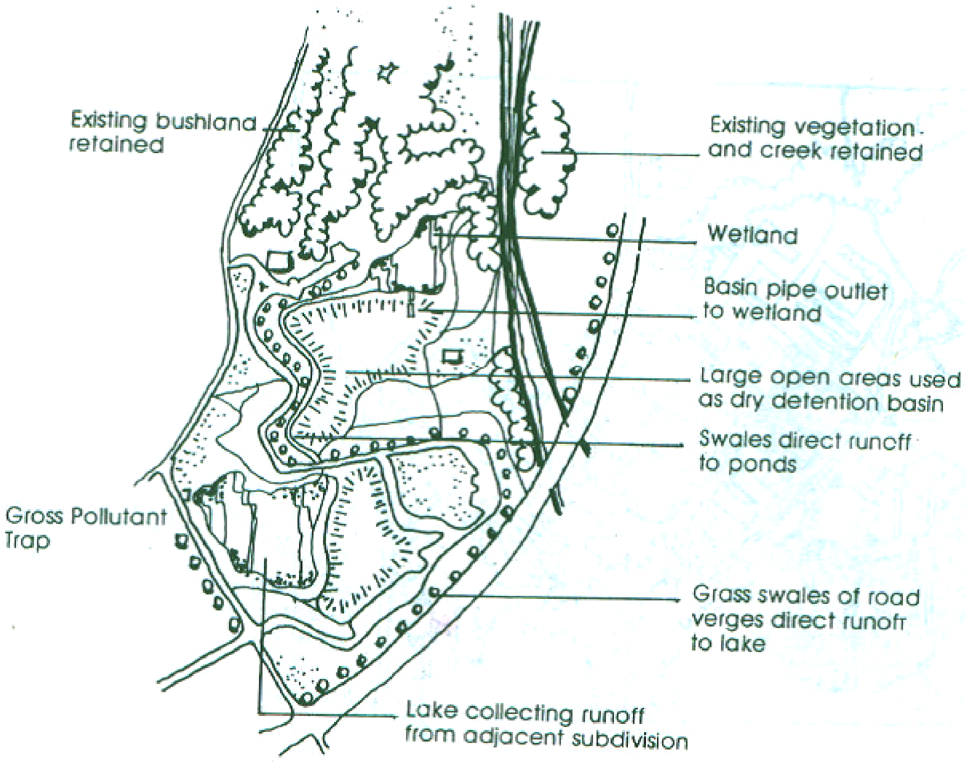
- Feed the surface water supply system
- Improve the general water quality of the storage tank inflow
- Control erosion of the drainage area
- Control floods
- Enhance the hydrological balance of the area
- Be beautifully integrated
- Be able to manage any accidental pollution



Picture 15: Swale integrated in an urban area

In order to comply with these recommendations:

- The major drains will be designed following contour lines
- A secondary drainage system will convey the water from the different areas to the major drains. Locations will be chosen according to local land use occupations
- Drains will generally have a trapezoidal shape, if possible
- Drains will be covered with grass
- A central ditch with a better flow capacity can be added in order to improve the flow for the smaller rain events and assist with the general maintenance of the drains
- Sedimentation ponds will be added along the way to minimize the debris and silt
- Drains and ponds will be beautifully designed and integrated into the landscape, creating a feeling of flowing water throughout the city, even during dry periods



Picture 16: Several elements of a storm water management system in an urban park

5.3.2.1 Definition of maximum rainfall intensity

This parameter is determined in order to design the drainage system.

The general equation correlating the intensity-duration-return period is given as:

$$I = \frac{K \times T^a}{(t_c + b)^n}$$

Where I is the intensity of rainfall, T the return period, t_c the concentration time of the watershed; K, ^{a}, b and ^{n} are constants.

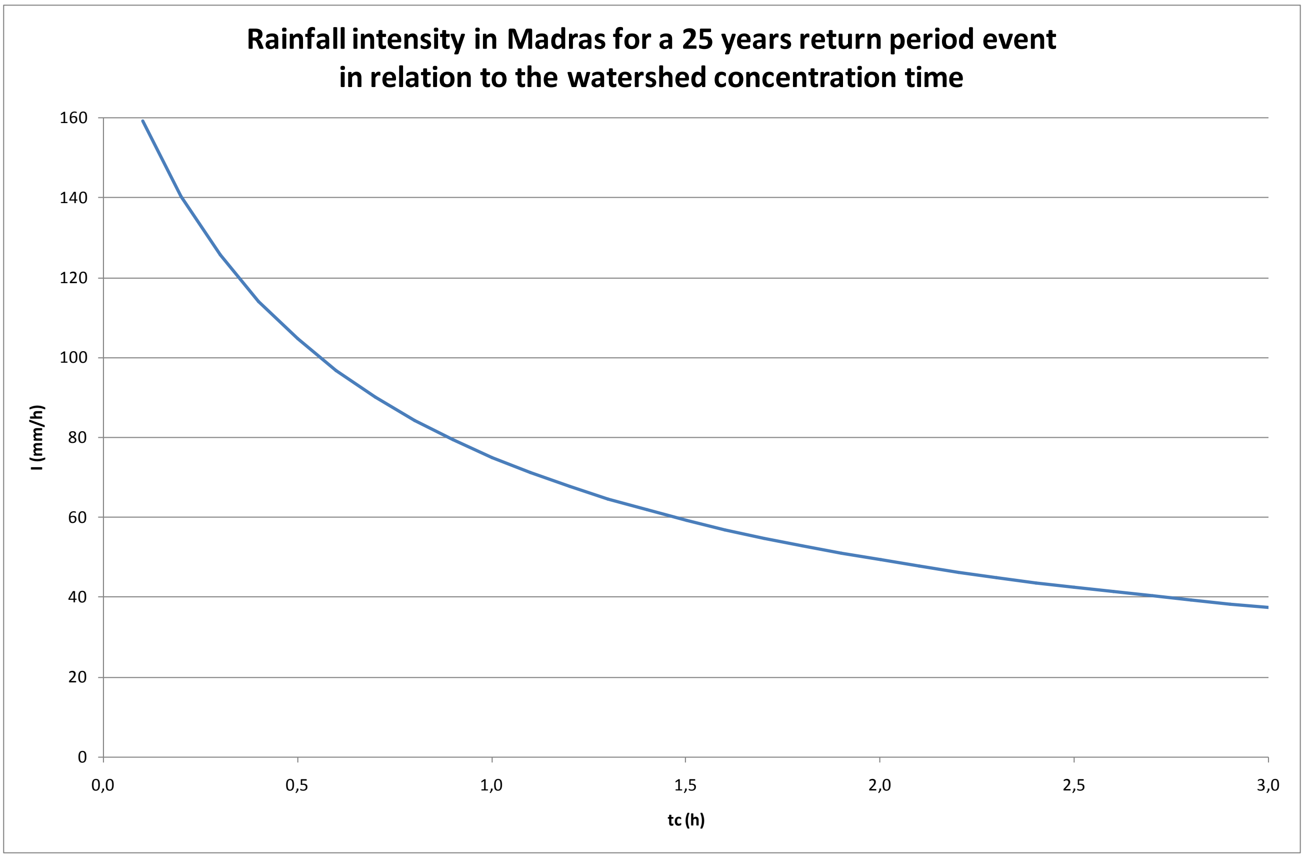
Chennai's constant values are:

K = 6126; ^{a} = 0.1664; b = 0.5; ^{n} = 0.8207.

Source: Hydrology and Water Resources Engineering Second edition, K.C. Patra

In urban areas, flood control structures are generally based on a 25 year return period.

The following chart shows the variation of the rainfall intensity with the concentration time of the watershed for a 25 year return period.



Graph 16: Definition of max. rainfall intensity for Chennai area

According to the watershed size, the 25 year rainfall intensity will vary. Indeed, for a given return period event, the larger the catchment area, the higher the concentration time, and therefore the lower the rainfall intensity.

5.3.2.2 Hydraulic design principles

For a given watershed, a one-time rainfall intensity is deducted from the previous graph and then used for the drains' design. The maximum flow the drain can absorb is calculated with the rational formula using a run-off coefficient of 0.59 (*relation de Schaake, Geyer et Knapp [1967]*).

Then, according to the physical parameters such as the available height or the land use, the drains are designed using the Manning-Strickler formula. For cost effectiveness, the retained drain shape is trapezoidal with banks slopes ratio of 0.5. The mean velocity of the water is kept below 1.5 m/s in order to limit erosion and a subcritical flow regime is also maintained.

The drains are covered with short grass, providing both aesthetic and technical solutions (low roughness).

In order to improve the system's yield during low rainfall events and ensure the filling of the storage body, it is advised to add a ditch with an improved roughness in the middle of the drain. This central ditch will also facilitate the drain's self-cleaning.

NB Increasing the number of drains not only limits the size of the equipment but also helps to manage accidental pollution (chemical truck spillage, factory accident, etc.) by allowing isolation of branches of the drainage system.

It is planned to integrate settling tanks in order to reduce the silt and other matter entering the storage tank. It must be understood that such devices will lead to water losses, especially for small and isolated rain events.

5.3.3 Storage body

5.3.3.1 Losses

Any storage system presents some losses through infiltration/seepage. The losses depend on three main parameters:

- The hydraulic head in the tank or the water level above the base of the tank
- The permeability of the tank base (hydraulic conductivity and thickness)
- The tank surface

They can be estimated with the Darcy formula:

$$Q = K \times S \times \frac{H + h}{h}$$

Where:

- Q is the flow rate of infiltration through the base of the tank in m^3/s
- K is the hydraulic conductivity of the base of the tank in m/s
- S is the tank surface in m^2
- H is the water level above the tank base in m
- h is the thickness of the waterproofing layer in m, which is characterized by K (hydraulic conductivity)

Depending on the applied technologies, the hydraulic conductivity can vary from 10^{-11} m/s to 10^{-9} m/s.

Given the technologies that already exist in Auroville, and bearing in mind the complexity of applying highly specialized technologies, it has been chosen as trustworthy enough for this study to consider the hydraulic conductivity equal to 10^{-9} m/s for a 50 cm waterproofing layer. The hydraulic conductivity corresponds to a clay layer.

One can approximately estimate the infiltration rate independent of the tank surface for a given tank volume, unlike the losses through evapo-transpiration which increase with the tank surface area.

The following table displays the yearly losses through evapo-transpiration and infiltration in a 5 m deep tank with surfaces varying from 10,000 m² to 300,000 m².

	5m deep lake					
Lake surface (m^2)	10 000	20 000	50 000	100 000	162 000	300 000
Lake volume (m^3)	50 000	100 000	250 000	500 000	810 000	1 500 000
Yearly infiltration (m^3)	3 469	6 938	17 345	34 690	56 197	104 069
Yearly evaporation (m^3)	20 340	40 680	101 700	203 400	329 508	610 200

Table 10: Losses in an open water storage tank of various capacities

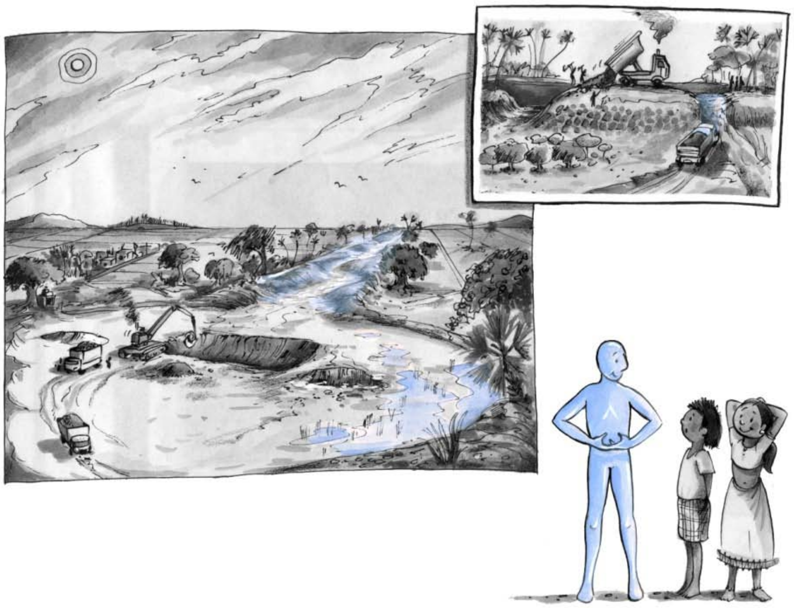
NB The evaporation values are roughly 6 times the infiltration value .

5.3.3.2 Other considerations

The conclusion is the greater the storage tank, the more autonomous the supply system becomes. However, it has been shown that the losses through evapo-transpiration increase in relation to the tank surface, hence either the $\frac{\text{Tank Surface}}{\text{Tank Volume}}$ ratio must be decreased, or the storage tank has to be closed.

Even if the underground detention tanks prevent the potential evapo-transpiration (PET) losses, their prohibitive cost disqualifies this option. The study only focused on open storage tank systems.

Furthermore, regarding the water quality in the tank, a limited volume of stored water allows for better replenishment of the lake and hence better water quality. If the tank is regularly replenished, this will prevent the accumulation of pollutants.



5.3.4 Secondary equipment

Several secondary devices are part of the system. In general, the system will be as simple as possible with minimal equipment required.

It is not in the scope of this study to design these devices. However, here are a few examples of the kind of equipment required:

- Settling tanks before the main storage body to remove up to 80% of the water pollution
- Overflow structures
- Control gates to control accidental pollution
- Culverts, etc. These devices are included in the financial analysis (below), adding a given percentage to the general cost of the drainage system and the storage body.

5.4 "Ideal/theoretical" system definition

5.4.1 "Ideal/theoretical" storage calculation

The main criterion, for what is referred to as an *Ideal Storage tank*, is in relation to cost effectiveness. A concrete structure of an appropriate size would be extremely expensive, and a covered one even more so. The selected depth of 5 m is related to the fact that deeper digging is more expensive. The chosen water sealant conductivity is the most cost-effective yet efficient one. It is clear that other alternatives should be studied in accordance to funding capacity.

This is an attempt to determine the parameters of an *ideal storage tank*.

The "ideal/theoretical" storage design is based on the defined set of reference hypotheses above:

- **15,171 people (maximum growth rate over 20 years: 10%)**
- **107 lcd (low water consumption rate with recycling - GRIHA guidelines)**
- **City area as drainage surface**
- **31% as run-off coefficient, considered appropriate at this stage of development (low hypothesis for the city area)**
- **50 cm of water sealant with 10^{-9} m/s hydraulic conductivity**
- **A usable depth of 5 m**

The calculation is provided on a daily basis for the period from 1969 to 2008, using specific excel-based software that has been developed to compute the data. A description of the system is given in the Appendix.

The following parameters are taken into account:

- The daily rainfall over the area
- The daily PET from the tank
- The daily infiltration in the tank
- The run-off from the different areas
- The overflow of the storage tank
- The daily consumption by the population
- The water availability

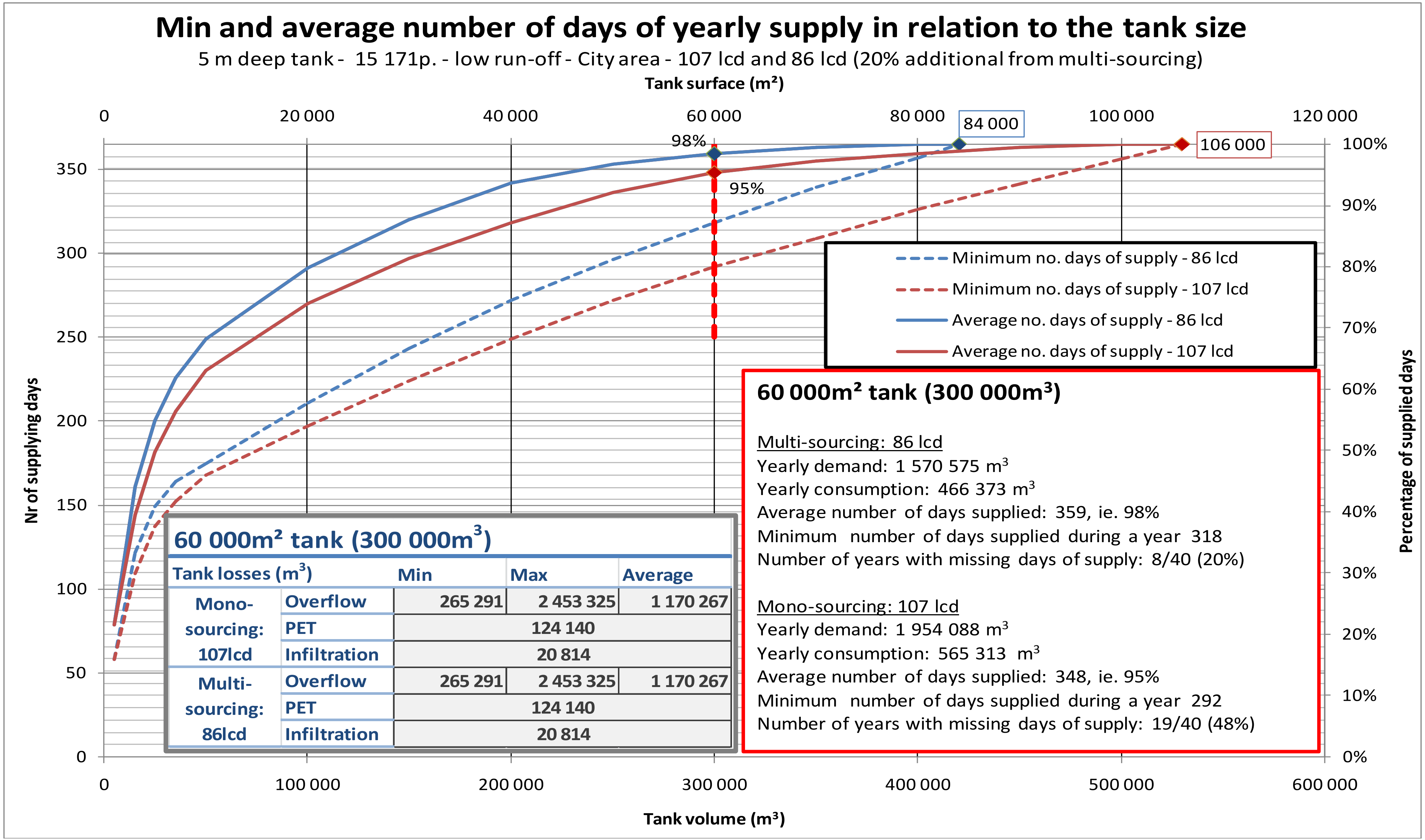
In order to minimize evaporation losses, the tank is designed with what is thought to be an **optimal depth: 5 m**.

This optimal depth is justified by:

- The poor water quality observed in deeper tanks (lack of light and oxygen penetration)
- The presence of massive blocks of limestone below this depth in some areas of Auroville, which implies extra work and additional expense to dig out the storage tank
- The need to increase the water replenishment in order to maintain high water quality in the tank

A set of lake surfaces have been used. The results are compared according to the average number of days of supply provided by the system over the 40 years of data, as well as the minimum number of days of supply in a year.

The following chart presents the results of these theoretical tests, first for the 107 lcd consumption, and then for multi-sourcing based on a consumption rate of 86 lcd. The latter rate presumes that 20% of the daily supply is provided by a secondary source.



60 000m² tank (300 000m³)

Tank losses (m³)		Min	Max	Average
Mono-sourcing: 107lcd	Overflow	265 291	2 453 325	1 170 267
	PET	124 140		
	Infiltration	20 814		
Multi-sourcing: 86lcd	Overflow	265 291	2 453 325	1 170 267
	PET	124 140		
	Infiltration	20 814		

60 000m² tank (300 000m³)

Multi-sourcing: 86 lcd
Yearly demand: 1 570 575 m³
Yearly consumption: 466 373 m³
Average number of days supplied: 359, ie. 98%
Minimum number of days supplied during a year 318
Number of years with missing days of supply: 8/40 (20%)

Mono-sourcing: 107 lcd
Yearly demand: 1 954 088 m³
Yearly consumption: 565 313 m³
Average number of days supplied: 348, ie. 95%
Minimum number of days supplied during a year 292
Number of years with missing days of supply: 19/40 (48%)

Graph 17: Rationale for sizing for an "ideal/theoretical" storage tank

The results obtained show a horizontal asymptote for the number of days of supply in relation to the tank surface. These curves lead to two major conclusions:

- It is possible to supply the whole population each day of every year with a 106,000 m² tank,
- The last percentages of supplied days are becoming increasingly expensive.

As an example, the results provided by a 60,000 m² tank are detailed. This system would supply the population for 95% (348 d/y) of the days on average with a minimum of 292 days per year.

The use of a secondary source (see later in this report) to supply 20% of the daily demand would improve the results to 98% (359 d/y) of the days supplied on average with a minimum of 318 days per year.

5.4.2 Conclusions on an "ideal/theoretical" storage system and study directions

Conclusions can be derived from these assumptions. Many questions still need to be answered.

What is the most cost-effective solution?

- A sufficiently large storage tank which is adapted to the prevailing climatic conditions and able to provide the entire population with drinking water supply in all circumstances.
- A smaller tank complemented by a secondary resource contributing a constant proportion of the daily supply, and able to supply the entire population under any circumstances.
- A more reasonable tank supported by a back-up secondary source that can supply the entire population for a few days per year.
- A more reasonable tank supported by a daily secondary source and a back-up source.
- To supply water from several sources in order to be able to withstand any malfunction.

NB It is also appropriate to consider decreasing the daily supply during periods of shortage which is done in many countries. This is related to regulatory mechanisms and is not pursued further in the present study.

There are various ways to supply the entire population. According to the first results presented above (calculation based on the 40 year daily rainfall data), it is possible to highlight examples of these different solutions as presented in the following table.

Category	1	2	3	4
Tank volume	106,000	84,000	60,000	60,000
Daily secondary resource	-	20% daily	-	20% daily
Supply	100%	100%	95%	98%
Back-up resource requirement	-	-	17 days on average 73 days maximum	6 days on average 47 days maximum
Pros	- limit the amount of equipment - do not require daily secondary source - do not require back-up source	- do not require back-up source - do not rely on a single source	- do not require daily secondary source - do not rely on a single source	- do not rely on a single source
Cons	- rely on a single resource - require a relatively large tank	- require a relatively large tank - require more equipment	- require more equipment	- require more equipment

Table 11: Synthesis of ideal storage system

If this table gives an indication of the most technically appropriate system, the economic aspects will be crucial in the selection of a solution.

The study will aim to:

- Define the set of technical solutions that meet the system requirements, through a large set of parameters (tank size, daily secondary source contribution, back-up source contribution, daily supply regulation during times of scarcity, etc.)
- Define the sources that fit with the requirements of the daily secondary source and back-up source
- Define the service cost for each source (main, daily secondary and back-up)

The assumptions should indicate the most cost-effective system.

5.4.3 "Ideal/theoretical" integral system

In the previous part of the report, it has been attempted to define an ideal storage system. It has resulted in a key question:

What is the most cost-effective combination of water sources in order to supply the projected population for a 20 year period?

The following section aims to identify an optimum combination and proportion of sources by:

- Roughly identifying the potential of the secondary sources
- Comparing the costs of each of these sources

5.4.3.1 Prospects for secondary resources

As highlighted in §4, the proposed secondary sources are:

- Seawater desalination
- Groundwater/brackish water desalination
- Wastewater
- Storage tank overflow
- Groundwater

It is attempted here to define the characteristics and usage prospects of each of these resources.

There are two types of secondary resources:

- Daily secondary resource: supplies a fixed volume of water every day of the year
- Back-up resource: supplies the population when the rainwater storage system is empty. Hence, the back-up resource provides the same volume of water as the rainwater system, but only for a few days of the year.

5.4.3.1.1 Seawater desalination

Seawater is an unlimited resource which can be used continuously throughout the year. It is therefore a suitable daily secondary supply.

However, reverse osmosis technology needs to operate continuously in order to maintain the running condition of the membranes. If this procedure is not followed, it leads to rapid deterioration and extra running costs. Since water production is relatively expensive through this process, and the water has to be transported uphill, it is judicious to limit the use of this secondary source.

The economic aspect, as well as other limitations, will determine the contribution of desalinated seawater to the supply system.

5.4.3.1.2 Brackish water desalination

Desalinated brackish water has approximately the same characteristics as desalinated seawater, but it is more cost-effective because of its lower salinity and the natural filtration occurring in the ground. Single point sourcing is not necessary and it can be apportioned over several wells. In principle, the desalination of brackish water is an appropriate daily secondary resource.

5.4.3.1.3 Wastewater

It has been explained earlier that wastewater should be recycled and therefore it should already be included in the daily demand. A significant part of the generated wastewater will not be recycled: 48 lcd. Indeed, there are not enough uses for this water in the city area. The available water volume can be used for groundwater recharge, irrigation for agriculture, etc.

NB It is noted that the treatment of this resource in order to integrate it directly in the distribution network is ruled out since:

- The risk of contamination is high and prevention is expensive
- There is an important psychological barrier

5.4.3.1.4 Storage tank's overflow

The assumptions demonstrate an average yearly overflow of 991,416 m^3/y (corresponding to a 106,000 m^3 tank: 100% of the supply from rainwater) for the given drainage area. This volume of water could potentially be recharged to one of the aquifers or used in another appropriate way.

5.4.3.1.5 Groundwater

Groundwater is threatened and at this stage it cannot be considered a reliable resource for Auroville in the future.

However, it is also known that isolated pockets of the aquifers are protected and they could be utilized in a future context.

Furthermore, groundwater would be an ideal back-up resource since it is easy to switch the supply on and off on a daily basis, which is not the case with the other resources. Depending on the demand, the required treatment is fairly straightforward (strainer).

To what extent is it possible to use appropriate areas and associated aquifers to supply the population as a back-up resource?

The assumptions show an average yearly overflow of 991,416 m^3/y with a minimum value of 83,716 m^3/y (corresponding to a 106,000 m^3 tank: 100% of the supply from rainwater). This volume of water could potentially be recharged to an appropriate part of the aquifer, and extracted later as needed.

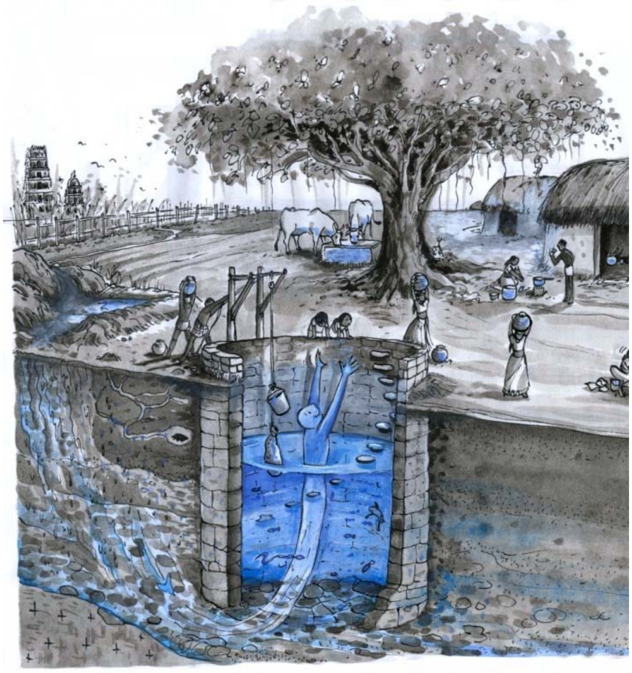
As a comparison, using groundwater as a back-up resource, in order to supply up to 10% of the days, requires that 59,290 m^3/y and 1623 m^3/d (100% of the daily demand) is made available for a population of 15,171.

It is possible, as far as volume is concerned, to use the overflow of the main storage tank to recharge specific areas and then reuse this water as a back-up resource to supply up to 10% of the days (37 d/y).

Two aspects have to be clarified:

- Are there parts of the aquifer that are able to provide a safe and large enough storage area?
- Is it possible to extract 1623 m^3/d from these secured portions of the aquifer?

Possibility to use the Manaveli formation to collect the water storage tank's overflow:



The Manaveli clay outcropping has the advantage that it is entirely situated on Auroville land, and hence it can potentially be protected from sources of pollution. Moreover, it is possible to feed it through infiltration ponds, and the outcropping of the aquifer is at an altitude that is not threatened by seawater intrusion.

According to the study – POTENTIAL OF SUSTAINABLE WATER RESOURCE MANAGEMENT FOR THE INTERNATIONAL ZONE OF AUROVILLE by Auroville Water Harvest, 2006 – the Manaveli clay formation seems to be a continuous layer in the international zone, where the average depth of the Manaveli formation is 20 m. Its porosity is 5% and its outcropping area is 1.1 km^2 in the Auroville area (international and industrial zones). Calculations lead to an approximate storage volume of: 1.1 Mm^3.

This storage capacity is sufficient for the 10% back-up in the multi-sourcing strategy.

NB: As explained earlier in this study, Manaveli clay formation is not an impermeable barrier; the formation is leaking into the lower aquifer.

- While clay does not offer a good extraction rate and storage capacity, the existing wells in the international zone demonstrate that a significant volume of water can be extracted through appropriate installations (open wells and jacked horizontal wells).

- The efforts to develop recharge ponds in the international area are ongoing.

- In case of excess water feeding into the Manaveli aquifer, the water could be channelled towards the Irumbai tank downstream.

The figures given above are orders of magnitude; further studies have to be done to understand the following issues:

- How important are the seepages from the Manaveli aquifer on this specific area?
- What are the horizontal flow losses?
- How protected is this area?
- What is the capacity of the existing wells and how many extra wells are required to supply the required 1623 m^3/d?

- Is there an agreement on planning to implement appropriate recharge and extraction structures?

There should be detailed investigations (on Manaveli and other formations) in order to identify areas with the potential to provide the back-up resource, together with recommendations of protective measures for the areas.

5.4.4 Integral system definition

A range of resource combinations are screened for technical and economic comparison.

All these figures are applied for a population of 15,171, which is the most critical assumption, with a daily consumption rate of 107 lcd. A depth of 5 m is used for the storage tank.

Solution	Rainwater (% of daily volume supplied)	Daily secondary resource (% of daily volume supplied)	Back-up resource (% of supplied days) for the most critical year
1	100%	0%	0%
2	80%	20%	0%
3	100%	0%	10%
4	80%	20%	10%
5	60%	40%	10%
6	90%	10%	10%

Table 12: Various scenarios for global system definition

On a normal day, only the figures in the two left-hand columns contribute to the supply. The right-hand column refers to the back-up supply that intervenes when the rainwater system is incapable of providing water. Thus, on a normal day, the rainwater resource and the daily secondary resource provide the water, and on unusual days, the back-up resource and the daily secondary resource provide the water.

The percentage of days supplied by the back-up resource corresponds to the maximum percentage of days that the system (rainwater + daily secondary resource) is not able to supply in the entire 40 year period.

In fact, for safety reasons, it is necessary that the back-up resource is able to supply the population in every instance, particularly in the most critical cases.

Below is a concise technical description of these solutions with a grading.

Solution	Rainwater (% of daily volume supplied)	Daily secondary resource (% of daily volume supplied)	Back-up resource (% of supplied days) for the most critical year	Tank area requirement (m²)	Average no. of back-up days required	Average volume overflow (m^3/y)	Commentary	Technical grade
1	100%	0%	0% (0 days)	106,000	0	991,416	Exposed to technical incidents on the main resource + at risk in case of an extremely critical year	0
2	80%	20%	0% (0 days)	84,000	0	1,133,624	At risk in case of an extremely critical year	0
3	100%	0%	10% (37 days)	82,000	5	1,027,986	Exposed to technical incidents on the main resource	1
4	80%	20%	10% (37 days)	65,000	4	1,161,344	Sturdy	3
5	60%	40%	10% (37 days)	49,000	3	1,293,867	Very sturdy	5
6	90%	10%	10% (37 days)	74,000	4	1,093,601	Still vulnerable	2

Table 13: Grading for selected scenarios

NB The technical grading calculation is based on the following formula:

(1 *with back-up* OR 0 *without*) *(1+% of secondary resource/10)

In every instance, the minimum access to water must be assured, even in extreme conditions.

5.4.5 Conclusion on integrated system definition

- Solutions 1 and 2 do not have a back-up resource, which increases the risk factor above acceptable levels in case of an exceptionally dry year (more critical than the 40 years data used for the system design). In that situation, the systems would not be able to provide any water for one or more days, which is unacceptable.
  In general, **the back-up resource is vital**.
- Solutions 3 to 6 have a back-up resource which is able to meet the demand for up to 10% of the days in a year.
- Solution 3 has no daily secondary resource which means it is exposed to any technical incident occurring on the main resource (pollution, mechanical issue, etc.). This type of situation is obviously uncomfortable but could be counterbalanced by the back-up resource to a certain extent.
- Solutions 4 to 6 differ in their contribution to the daily secondary resource. Understandably, the more the distribution is balanced between the main resource and the daily secondary resource, the sturdier the system is. In case of any technical incident occurring on the main resource, combined with a critical year exhausting the back-up resource, 10% to 40% of the daily supply would still be distributed to the population depending on the solution.
- Furthermore, various sources take 20 lcd as a minimum limit of water supply. Since 10% of the daily supply represents approximately 10 lcd, **20% of daily secondary resources appears to be a minimum acceptable value**. This consideration makes solution 6 less relevant.

5.4.6 Financial analysis

The aim of this part of the study is to approximately evaluate the price of each m^3 of water depending on its production source. It is not a precise calculation, but aims to give an order of magnitude. This estimate is meant to help in targeting the most cost-effective sourcing system. The table below is an indicative financial analysis, comparing various sources of water of similar capacities (mere hypothesis aimed at allowing a comparison). It is followed by the calculation hypothesis description.

	Sea water desalination plant		Brackish water desalination plant		Rainwater system 106,000 m^2/5 m		Groundwater	
INVESTMENT COST			To fit with 20 year demand 2000 m^3/d production capacity				1623 m^3/d	
Desalination plant	140,000,000	Rs	56,000,000	Rs				
Pipe to city	63,000,000	Rs						
Storage tank of 106,000 m^2/5 m deep					117,600,000	Rs		
Ultrafiltration					33,000,000	Rs		
Infrastructure	40,000,000	Rs	26,666,667	Rs	10,542,000	Rs	910,000	Rs
Bore wells			9,100,000	Rs			9,100,000	Rs
Drainage system			21,000,000	Rs	64,500,000	Rs		
Genset	61,600,000	Rs	24,640,000	Rs	12,320,000	Rs	10,472,000	Rs
TOTAL investment	**304,600,000**	**Rs**	**137,406,667**	**Rs**	**237,962,000**	**Rs**	**20,482,000**	**Rs**
RUNNING COST								
Maintenance cost including manpower	4,332,000	Rs/y	1,912,800	Rs/y	1,794,400	Rs/y	889,940	Rs/y
Power consumption	1,244,882	kWh/y	497,953	kWh/y	248,976	kWh/y	213,408	kWh/y
Generator (100%)	24,544,800	Rs/y	8,963,147	Rs/y	4,481,574	Rs/y	3,841,349	Rs/y
Grid high tension consumption	10,124,730	Rs/y	3,286,487	Rs/y	1,643,244	Rs/y	1,408,495	Rs/y
At 80% grid supply and 20% generator	13,622,364	Rs/y	4,421,819	Rs/y	2,210,910	Rs/y	1,895,065	Rs/y
TOTAL yearly running cost	**17,954,364**	**Rs/y**	**6,334,619**	**Rs/y**	**4,005,310**	**Rs/y**	**2,785,005**	**Rs/y**

Table 14: Financial analysis

Hypothesis

Capacity for all sources: **2000 m³/d**

Production capacity for all sources: **1623 m³/d**

Source	Investment	Running cost
Seawater desalination	• Reverse osmosis desalination plant - based on Michael Bonke's proposal for a 1000 m^3 plant at 1000 €/m^3 production capacity. The investment values are multiplied by 2 to fit with the 2000 m^3 requirement • Including infrastructure and pipe from beach to city and genset for power back-up	• Maintenance: including 2% of desalination plant cost + one technically qualified person at 25,000 Rs/month • Power consumption at 2.1 kWh/m^3 of produced water • Power cost: mixed supply at 80% grid and 20% generator at 6.6 Rs/kWh for grid supply and 16 Rs/kWh for generator supply
Brackish water (ground) desalination	• Reverse osmosis desalination plant based on 40% of the cost of seawater desalination as per available commercial figures • Infrastructure, bore wells and drainage pipe to the sea for brine discharge included. The feeding pipe to the city is not part of the system as it can easily be located within the city limits or close by, and genset for power back-up NB The existing wells could be used to feed the system which would reduce the investment proportionally	• Maintenance: including 2% of desalination plant cost + one technically qualified person at 25,000 Rs/month • Power consumption at 0.7 kWh/m^3 of produced water as per available commercial figures • Power cost: mixed supply at 80% grid and 20% generator at 6.6 Rs/kWh for grid supply and 16 Rs/kWh for generator supply
Surface water	• Storage tank of 106,000 m^2 and 5 m deep, with suitable water sealant, including 20% extra cost for specific investments and infrastructure (overflow, etc.) • Ultrafiltration based on 300 US$/$m^3$ as per available commercial figures • Including infrastructure and drainage system throughout the city (215,000 m^3 of soil to excavate) and genset for power back-up	• Maintenance: including 2% ultrafiltration plant cost + 0.5% for maintenance of the storage tank + one technically qualified person at 25,000 Rs/month • Power consumption at 0.42 kWh/m^3 of produced water (on the high side) • Power cost: mixed supply at 80% grid and 20% generator at 6.6 Rs/kWh for grid supply and 16 Rs/kWh for generator supply
Groundwater (for comparison purposes)	• Bore wells of sufficient capacity • Including infrastructure and genset for power back-up	• Maintenance: including 5% wells and infrastructure cost (very high) + one technically qualified person at 15,000 Rs/month • Power consumption at 0.375 kWh/m^3 of produced water (on the high side). Power cost: mixed supply at 80% grid and 20% generator at 6.6 Rs/kWh for grid supply and 16 Rs/kWh for generator supply

Table 15: Hypothesis used for the financial analysis

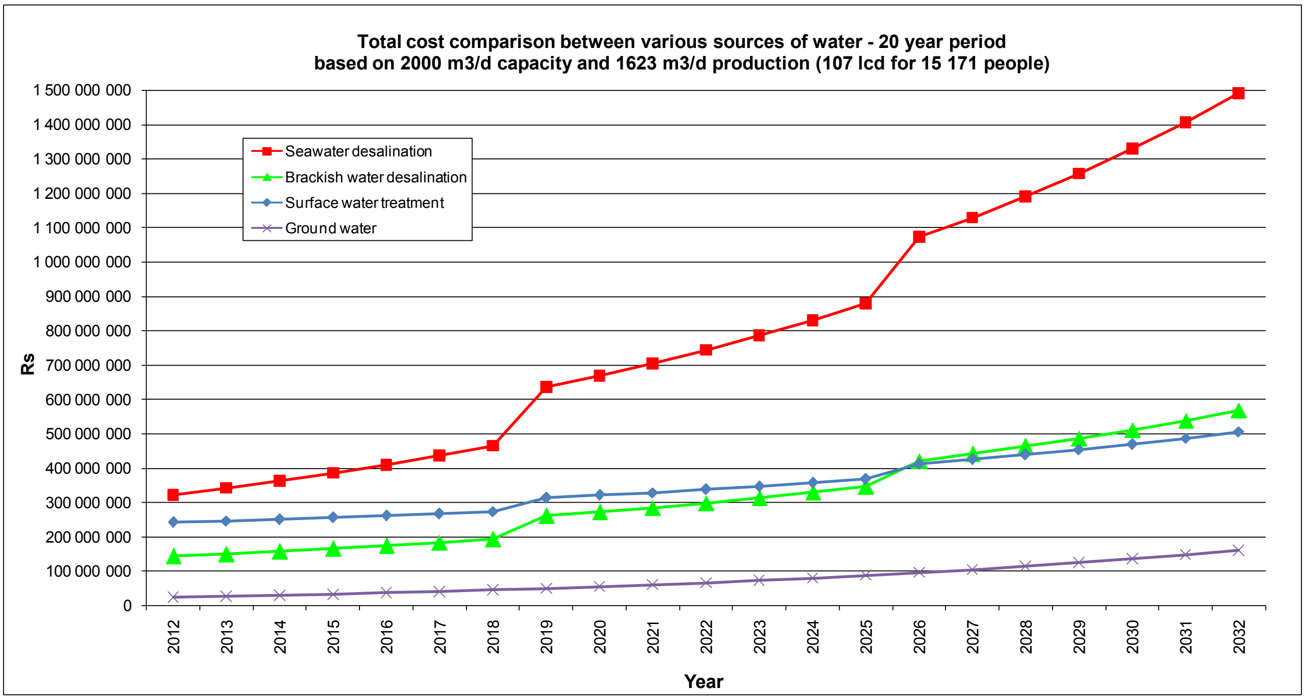
NB This is for sourcing only and does not include the distribution system, which is not in the scope of this study.

NB The production capacity is higher than the consumption rate because a buffer is necessary and technical processes like RO are available according to the range of their production capacity. In order to have a common base for all devices, ranges of 500 m^3/d capacity are retained.

NB It has been mentioned that through wheeling of energy from wind generators, power could be billed at 4 Rs/kWh. Taking into account that energy considerations are not part of the study's scope, this figure is not used in this financial analysis.

A conveyor belt option has been proposed for the soil movement required for the excavation. In the absence of details, this option is not part of the financial analysis.

The actual cost has been calculated from the investment and running costs for each technology over a 20 year period, taking into account an inflation rate of 8%.



Graph 18: Expenses for various single sourcing systems in relation to time

The graph points out:

- The universal low cost of a groundwater supply system in comparison with the other technologies
- The significant cost of a seawater desalination plant in comparison with the other technologies (investment cost, running cost and replacement costs)
- The relatively similar costs of the brackish water desalination and the surface water supply, even if in the long run surface water becomes less expensive

Considering the similarity between seawater desalination and brackish water desalination, it is proposed to only work with brackish water desalination as a daily secondary resource.

According to the six resource combinations described previously, the production cost of 1 m^3 of water has been calculated over a 20 year period.

Solution	Rainwater (% of daily volume supplied)	Brackish water desalination daily secondary resource (% of daily volume supplied)	Groundwater back-up resource (% of supplied days) for the most critical year	Production cost of 1 m^3 of water
1	100%	0%	0%	42.7
2	80%	20%	0%	48.7
3	100%	0%	10%	41.4
4	80%	20%	10%	47.1
5	60%	40%	10%	49.7
6	90%	10%	10%	47.2

Table 16: Production cost for 1 m^3 of water for each scenario

The following analysis of the solutions points out:

- The least expensive solution is no. 3 which provides daily potable water from rainwater and uses groundwater as a back-up resource. This result is understandable since groundwater is the least expensive resource, and using only one resource to supply the daily demand limits the investment costs (fixed portion + variable portion).
- It is noted that the cost per m^3 of water increases with the proportion of the daily secondary resource (brackish water), and that the investment and running costs are not linear with the production. Indeed, there are some stages related to the treatment capacity of the treatment units (500 m^3) where the increase in cost is not linear. Therefore, once a resource combination is selected, it is possible to find an optimal arrangement taking these steps into account. Such considerations are beyond the scope of the present study.

NB100% production from brackish water would cost Rs 48/m^3 of water. This is expensive and has the disadvantage of being a single resource (vulnerability).

5.4.7 Conclusion on techno-financial analyses

The aim is to cross-check the technical and economic results from the six solutions studied in order to select the most cost-effective resource combination.

The following table summarizes the technical and economic features of each solution.

Solution	Rainwater (% of daily volume supplied)	Brackish water desalination Daily secondary resource (% of daily volume supplied)	Groundwater back-up resource (% of supplied days) for the most critical year	Technical grade	Production cost of 1 m^3 of water in Rs
1	100%	0%	0%	0	42.7
2	80%	20%	0%	0	48.7
3	100%	0%	10%	1	41.4
4	80%	20%	10%	3	47.1
5	60%	40%	10%	5	49.7
6	90%	10%	10%	2	47.2

Table 17: Synthesis for techno-financial analysis

The table leads to the following conclusions:

- Solutions 1 and 2 which do not include a back-up resource are disqualified for technical reasons.
- Solution 3 which does not have any daily secondary resource is the most cost-effective system and is technically sound. Solution 3 appears to be extremely cost-effective but shows deficiencies: This resource is vulnerable to accidental pollution hazards. The back-up resource capacity must be confirmed by a complementary study, allowing for the supply of at least 20% (10% + a large margin) of the number of supplied days.
- Solutions 4 and 5 are technically the most favourable, and the higher the daily secondary resource is, the better, but the cost is greater. Scenario 4 is the more cost-effective of these two scenarios.
- Solution 6 is similar to solutions 4 and 5 but has the disadvantage that the daily secondary resource does not produce enough water to supply the population with its minimum needs in times of crisis: 20 lcd.

It would be better to opt for solution 4 which ensures a minimum supply of potable water for the population at all times.

Since, the choice between solutions 3 and 4 is beyond the scope of this study, it is chosen to work with solution 3 for the remainder of the study. Any possible design for 100% of the surface water would also work with a combination of 80% surface water and 20% other sources.

Note that it is possible to initially implement the surface water supply system, and at a later phase set up a daily secondary resource to decrease the vulnerability of the resource, and/or to deal with a higher water demand if the population goes over 15,171.

NB If there are areas that are difficult to drain or channel towards the water storage body, it would be possible to increase the storage volume or to increase the daily secondary resource contribution in the overall supply.

It is an option to limit the daily supply in case of critical water storage in order to improve the dependability of the system.

6. Further considerations on large water bodies

The conclusion is that surface water provides an answer for water sourcing as part of a multi-sourcing strategy. This solution requires a drainage network design, including natural waterways to supply water to the reservoir (or reservoirs) of appropriate capacity.

It is essential to integrate some crucial features of surface water bodies, including physical, ecological and biochemical factors.

To create an everlasting, lagoon-type, perfectly transparent water body is unrealistic. Even if the water body is filled with crystal clear water, wind, foliage, animals, water plants, etc. will bring organic matter, leaves, dust, and so on into it. Additionally, if the filling and refilling of the water body is to be done with surface water, turbidity is unavoidable. It is essential to develop a model which integrates Nature's processes in the design, and accept that forced artificial conditions will not work in the long term.

In order to adjust to ever-changing conditions (rain, temperature, evaporation, seepage, overflow, extraction, etc.) it is recommended to integrate the following elements in the design of a large water body:

1. Allow for the regular renewal of the stored water; this is in order to ensure that pollutants will not accumulate beyond a manageable level.
2. Split the system into several parts to ensure safety in case of unpredictable pollution.
3. Maintain a minimum depth over time so that the ecological principles of the system are sustained.
4. Design the inflow and overflow systems so that when refilling and overflow occur, they do not destabilize the lower layers or create a destructive wave effect. If this happened, it would move the sediments and minerals that naturally accumulate in the lower layers excessively, and create unwanted aesthetic conditions, or even destroy the ecology and structure of the lake.
5. Reduce the light intensity on the water body as much as possible by introducing shade elements like trees and reeds. This will reduce the evaporation losses and allow for better movement of the water through the variable thermal conditions in the water body by avoiding stagnant and potential dead zones.

6. If possible keep the water shaded in the earlier stage of the inflow area to prevent warm or stagnant shallow water.
7. Design features with different depths and shapes within the water body to allow for temperature gradients and a natural mix of different water strata during the night/day cycles. Islands can play a major role in this. It is better to avoid uniform depth and design.
8. Use water plants and reeds (along the northern and southern shores) in order to generate competition for nutrients within the habitat like water hyacinths, water lilies and water lettuce. A large water body will automatically attract a large variety of living organisms. Single vegetation species (algae or water plants) are fragile and will create problems that may lead to the collapse of the whole system.
9. Identify the type or family of algae that is dominant. Check if the algae can regulate its buoyancy or not.
10. Work with nature as it is not realistic to overcome it: animal life will proliferate in such a water body, and water birds and other aquatic life must be part of the environment of an appropriate lake's design.

The next step is to evaluate how to strategically integrate the most feasible water body for Auroville.
Matrimandir lake is part of the overall city concept, and while the actual design may evolve according to the conditions, scope and constraints, this feature is a component of the overall water system for Auroville.

The next chapters of this study will investigate in detail the possibility of integrating the lake in the proposed surface water system.

7. The Matrimandir lake potential

7.1 Introduction

Matrimandir lake was seen by the Mother as an essential feature of the city centre.

Describing its basic characteristics, she said that it was a large water body which would act as a reservoir to supply the city.

Over time, Roger Anger, chief architect of Auroville, has developed several designs for the lake. This study is based on the latest design he made.

Additionally, several technical conceptual studies were conducted concerning the lake. H. Kraft *(Pre-Feasibility Study on Water Supply, Storm water and Wastewater Management - City of Auroville - 2003)*, Jeen Kootstra & the Auroville Water Group *(Auroville Water Management - A pre-feasibility study - 2007)*, and finally, LGA developed the idea further and analysed how it could be integrated in the context of Auroville, the positive role it could play in the entire water scenario, and the way it could be technically realized.

Such a large structure, with its potential side effects, needs to be studied from several points of view in relation to the ground reality and the way it can be integrated in the topographic context. It has a high impact on planning and development issues, and this should be taken into account at the earliest in order to avoid long-term disasters.

We note that the following points have not been seriously considered so far.

The lake has a symbolic and aesthetic value, as a large water body surrounding Matrimandir and its gardens, the centre of Auroville, representing its soul and relation to the Divine.

In the given context, such a large water body implies the identification and connection to a source that will compensate the yearly losses of water through evaporation and seepage. The appropriate source of water must be found to allow for this compensation, taking into account technical practicality and affordability.

If one considers that the lake will serve as a reservoir, identifying the huge water resources for filling, using and replenishing it becomes essential.

This part of the study is looking at the methods and the potential to sustain the lake in its three functions: aesthetic, symbolic and practical. It does not consider the technical aspects of the realization of the lake itself, but looks at the possibility of integrating it in the given and future context.

It is possible to harvest, store and supply water through the Matrimandir lake. Considering that the lake is an integral part of the Peace area's entire concept and must therefore be financed, the extra investment linked to harvesting and storage for supply purposes is proportionally not very large.

The lake needs a relatively large dedicated drainage area in order to replenish it without tapping other resources: in fact evaporation is greater than direct rainfall and must be compensated.

Finally, in order to sustain its own ecological system, a lake must have a minimum permanent depth, which is equally valid if the lake is a separate system or a reservoir. It must be replenished to avoid excessive reduction or fluctuation of the water level. Therefore a large input of water is required.

In this context, it is noted that Matrimandir lake does not correspond to the *ideal storage tank* as defined above: the usable depth is limited for aesthetic reasons, which leads to limited storage capacity and consequently relatively high evaporation losses.

The limited storage capacity implies that a large volume of water is available to maintain its aesthetic value, and a significant overflow will be generated from the lake.

This leads to the conclusion that an appropriate dedicated drainage area is needed to maintain the water level in the lake. By developing a drainage system to feed the lake and connect the lake overflow to a secondary storage system which can be used to refill the lake as required, the integration of the lake into the entire water management approach becomes a reality, and the lake becomes a valuable asset, rather than a liability.

The most appropriate and cost-effective way to replenish the lake would be:

- To collect the run-off from an area large enough to generate the required volume, even during the driest years;
- To use gravity to avoid large pumping systems, related equipment and maintenance expenses.

All other options depend on resources that are either threatened or targeted for other purposes, or they are expensive high tech options (like desalinated water).

If the two criteria above are achievable, one can integrate a third aspect:

- To supply a substantial part of the water demand to Auroville's population.

If these three criteria can be achieved, Matrimandir lake, as an isolated system or in connection with a secondary system, becomes a valuable asset, supplying water to the entire city.

The following part of the study will look at the context and implications of the lake as proposed today, and the ways that it can be turned into a water resource asset.

7.2 Basic considerations

Because of its aesthetic and symbolic aspects, Matrimandir lake is considered an essential part of the city. A minimum size is required to fulfil these functions. Given its requirement for regular refilling (evaporation losses, leakage), losses can be compensated through the drainage system as this is the most evident and cost-effective option. As mentioned, the cost of the Matrimandir lake and part of the drainage system does not pertain to the rainwater harvesting system. On the contrary, the Matrimandir lake could be a central part of the rainwater harvesting system.

7.2.1 Roger Anger's lake design specifications

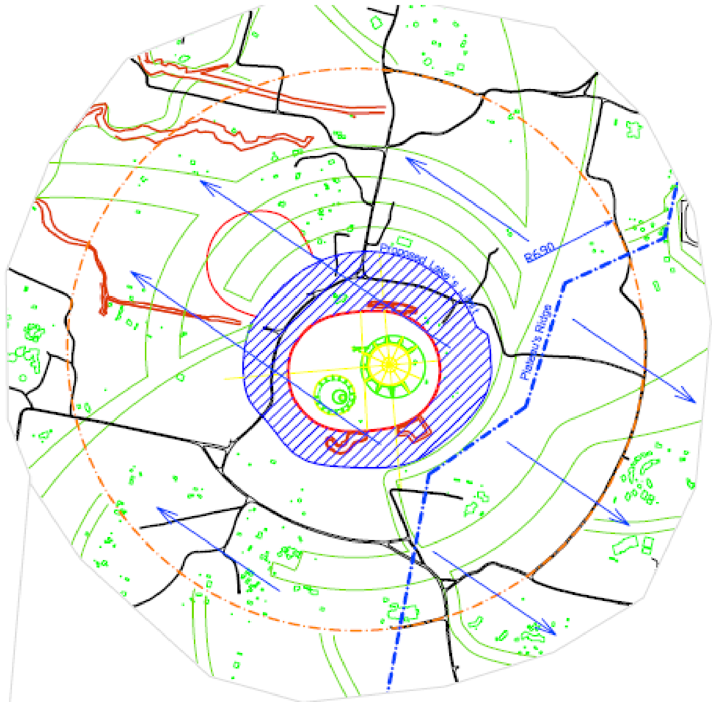
- The lake should cover an area of 162,000 m^2
- The total depth is not defined
- The maximum water level is fixed at 25 cm below the Matrimandir oval path (limit of the garden surrounding Matrimandir and the amphitheatre)
- The oval path level is fixed at an altitude of 50.90 m
- The lower level is 75 cm below the maximum water level (or one metre below the oval path level)
- The lake is designed as a single water body with one level

7.2.2 Context: the topography

The highest area of Auroville is situated around Deepanam School, on the south-western part of the lake, at an altitude of 53.00 m (up to 56.00 m locally), which is a minimum of 2.10 m above the Matrimandir oval path level.

The separation of flow between east and west occurs along a line which is more or less oriented south-southwest, north-northeast, and passes by Deepanam School area as shown on the map below.

Hence, Matrimandir lake is on the western side of Auroville's plateau and below the highest area. In this context, the possibility of collecting surface water in the lake by gravity becomes feasible.



Picture 17: Ridge position for surface water partition in Auroville city centre

Conclusion: It is feasible to supply Matrimandir lake by collecting surface rainwater.

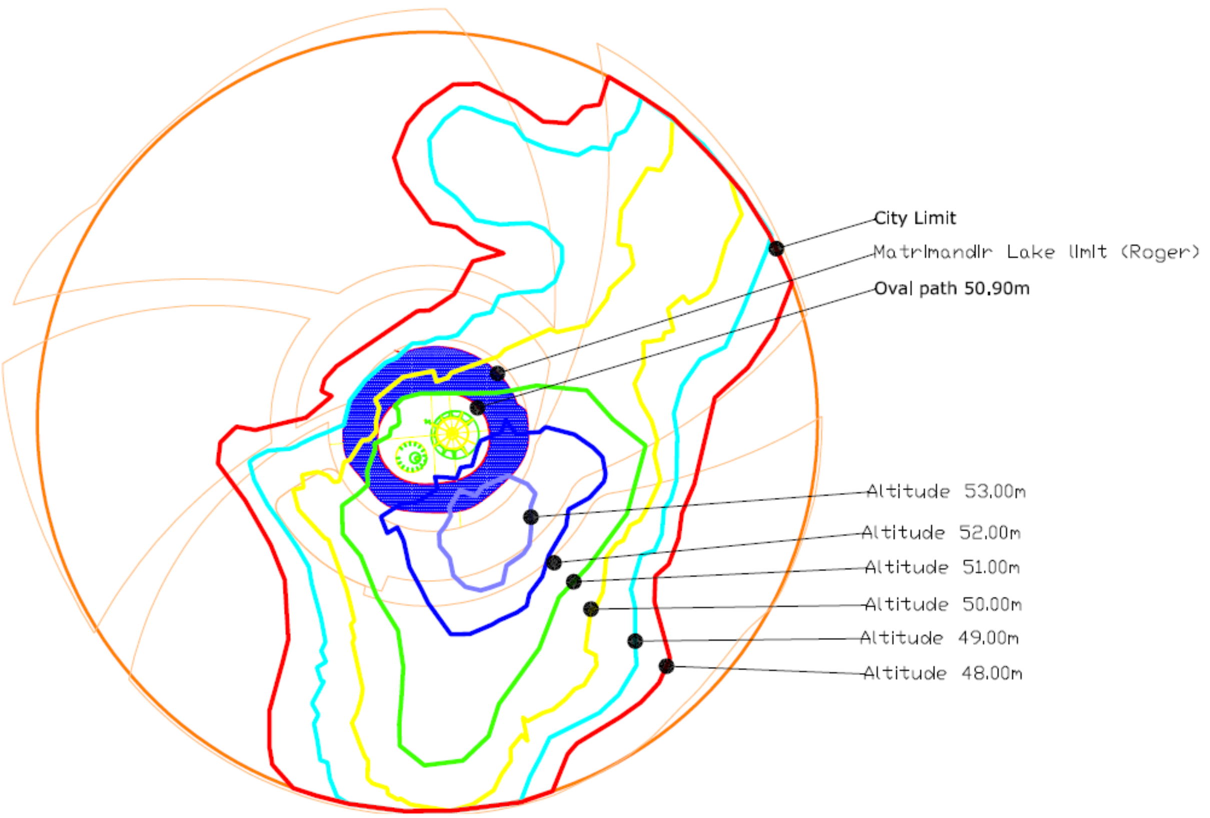
7.2.3 Contour levels in and around Matrimandir lake area

From Deepanam School area, the altitude drops, more or less concentrically, and is elongated along the ridge (see figure below).

- Natural ground level is around 2 m above the level of the oval path as fixed on-site on the eastern side
- Natural ground level is around 2 m below the level of Matrimandir's oval path on the western side
- Hence the lake is located in an area with a 4 m difference in level

In this context, it is worth re-evaluating the various possibilities for the optimum lake design in order to find the most valuable aesthetic solution as well as the best possible usage for this large infrastructure.

If the lake is constructed using a single level, equal to Matrimandir's oval path, one has to acknowledge that all the buildings situated on half of the lake's periphery will face a 2 metre high visual obstacle. On the eastern side, the buildings will be located 2 metres above the edge of the lake's border. The site of Auroville's Town Hall is more than 2 metres below the lake border, which is situated about 30 m away from the building (the border is positioned at the fence covered with blue creepers).



Picture 18: Contour lines showing altitude in Auroville city area

The following table gives the different areas defined by the contour lines, excluding the lake and the oval path.

Level	Area (m^2)
>52 m	225,000
51 m - 52 m	335,000
50 m - 51 m	788,000
49 m - 50 m	1,033,590

Table 18: Areas in relation to levels

7.2.4 Conclusion on basic considerations

It becomes apparent that the integration of the lake with the surrounding area and the planned or existing buildings must be studied from practical, ecological and aesthetic angles.

The following points should be considered

- To define a self-sustaining lake, explaining its filling requirements.
- To study the lake potential as per Roger Anger's design, considering the recognized drainage area.
- To study the potential for design variation in order to optimize the potential drainage area.
- To take care of the overflow generated by the lake and the potential it could have for further supply.

7.3 Common retained design parameters

- The lake has an area of 162,000 m^2
- Matrimandir oval path is fixed and covers an area of 90,000 m^2, which would drain into the lake
- The overflow (full) water level is fixed at 25 cm below the Matrimandir oval path (altitude 50.90 m, hence water level of 50.65 m max.)
- The lower water level is 100 cm below full water level (49.65 m) which amounts to 162,000 m^3 of usable storage. Alternatively, 200 cm below full water level (48.65 m) which amounts to 324,000 m^3
- The lake's design will vary according to the concepts: whether it is a single-level or step lake; variations in usable water

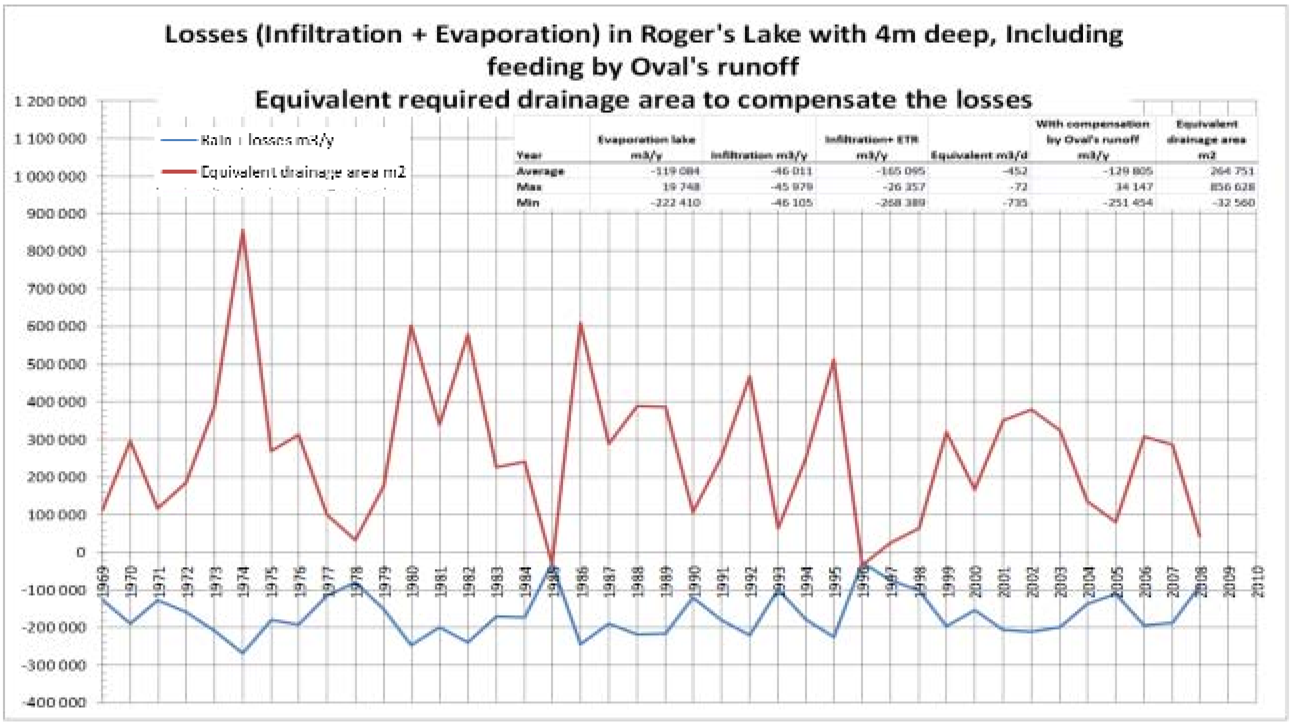
NB If specific values prevail, they are mentioned for each system.

7.4 Evaluation for a self-sustained lake

The aim of the following calculation is to determine the losses of the Matrimandir lake for a 4 m deep and a 10 m deep lake, as well as the drainage area needed to sustain the lake throughout the year

7.4.1 4 m deep lake

The chart below shows the yearly losses and the extra drainage surface required to prevent the lake from emptying.



Graph 19: Losses in RA design for Matrimandir lake (4 m deep)

The following table shows the result of the average monthly calculation for a 4 m deep lake, considering the drainage area with a high run-off coefficient: 0.52.

Matrimandir Lake 162 000m2 with 4m depth													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Average rainfall (mm)	20	24	20	12	42	46	70	114	131	267	357	195	1 299
Equivalent rain on Lake (m3)	3 183	3 906	3 254	1 873	6 815	7 510	11 418	18 516	21 296	43 281	57 823	31 584	210 457
PET (mm)	80	90	138	202	267	273	244	217	179	152	108	84	2 069
Equivalent Evaporation for Lake 162 000m2 (m3)	12 895	14 623	22 367	32 735	43 232	44 302	39 463	35 230	28 998	24 581	17 539	13 576	329 540
Infiltration lake (m3)	3 905	3 527	3 905	3 779	3 905	3 779	3 905	3 905	3 779	3 905	3 779	3 905	45 979
Losses lake m3	16 800	18 150	26 272	36 514	47 138	48 081	43 368	39 135	32 777	28 486	21 318	17 481	375 520
Equivalent monthly balance lake (m3)	**-13 617**	**-14 245**	**-23 018**	**-34 641**	**-40 323**	**-40 571**	**-31 950**	**-20 619**	**-11 481**	**14 795**	**36 504**	**14 103**	**-165 063**
Equivalent daily volume (m3)	-439	-509	-743	-1 155	-1 301	-1 352	-1 031	-665	-383	477	1 217	455	
Oval's runoff													
Average effective rainfall (mm)	16	22	18	10	37	38	57	97	116	246	335	183	1 176
Runoff oval (m3)	478	665	554	308	1 112	1 147	1 704	2 914	3 483	7 380	10 051	5 494	35 290
Net lake balance with refilling by Oval's runoff (m3)	**-13 139**	**-13 579**	**-22 464**	**-34 333**	**-39 211**	**-39 424**	**-30 246**	**-17 705**	**-7 998**	**22 175**	**46 555**	**19 598**	**-129 773**
Average daily Runoff oval	15	24	18	10	36	38	55	94	116	238	335	177	
Equivalent daily volume (m3)	-424	-485	-725	-1 144	-1 265	-1 314	-976	-571	-267	715	1 552	632	
Extra drainage area required to maintain the lake (m2)													**212 155**

Table 19: Monthly water balance for a 4 m deep lake

The calculation highlights a deficit for the lake: 129,773 m^3/y on average, and the need for a 212,155 m^2 connected drainage area to compensate the losses.

7.4.2 10 m deep lake

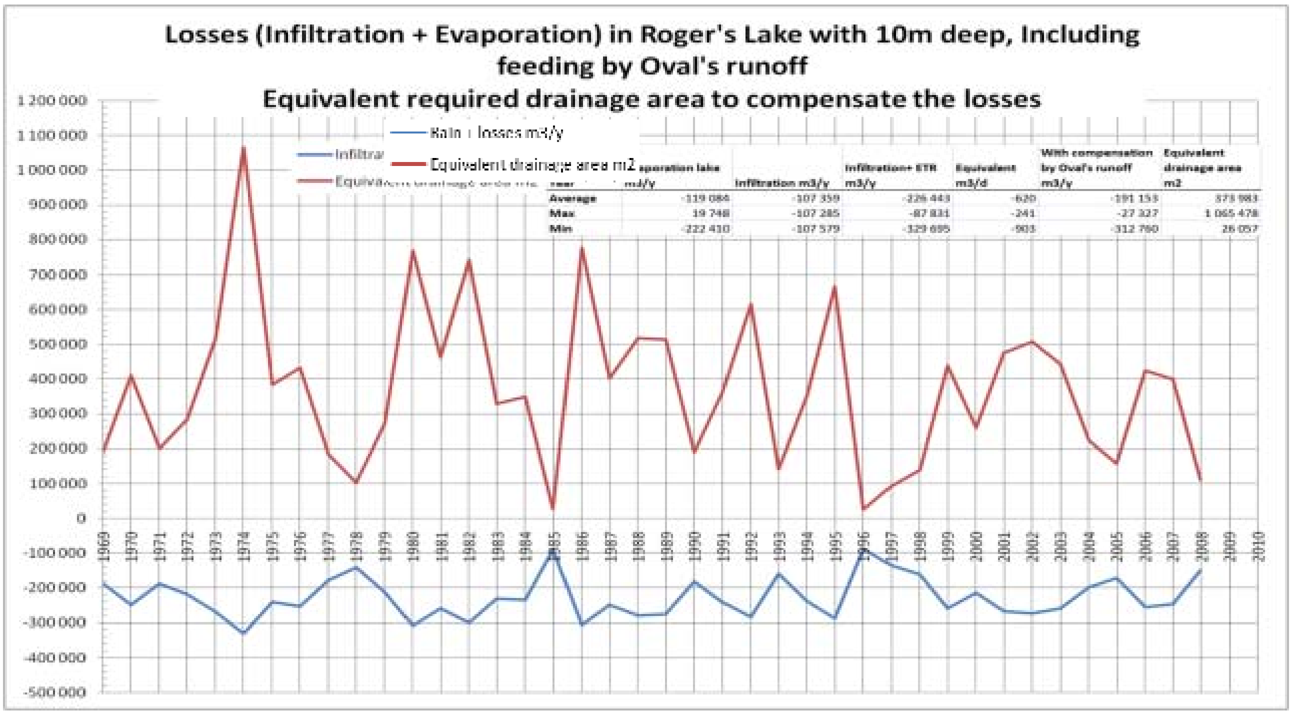
The following table shows the result of the monthly calculation for a 10 m deep lake, considering the drainage area with a high run-off coefficient: 0.52.

Matrimandir Lake 162 000m2 with 10m depth													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Average rainfall (mm)	20	24	20	12	42	46	70	114	131	267	357	195	1 299
Equivalent rain on Lake (m3)	3 183	3 906	3 254	1 873	6 815	7 510	11 418	18 516	21 296	43 281	57 823	31 584	210 457
PET (mm)	80	90	138	202	267	273	244	217	179	152	108	84	2 069
Equivalent Evaporation for Lake 162 000m2 (m3)	12 895	14 623	22 367	32 735	43 232	44 302	39 463	35 230	28 998	24 581	17 539	13 576	329 540
Infiltration lake (m3)	9 112	8 230	9 112	8 818	9 112	8 818	9 112	9 112	8 818	9 112	8 818	9 112	107 285
Losses lake m3	22 007	22 853	31 479	41 553	52 344	53 120	48 575	44 342	37 816	33 693	26 357	22 688	436 826
Equivalent monthly balance lake (m3)	**-18 824**	**-18 947**	**-28 225**	**-39 680**	**-45 530**	**-45 610**	**-37 157**	**-25 826**	**-16 520**	**9 588**	**31 465**	**8 896**	**-226 369**
Equivalent daily volume (m3)	-607	-677	-910	-1 323	-1 469	-1 520	-1 199	-833	-551	309	1 049	287	
Oval's runoff													
Average effective rainfall (mm)	16	22	18	10	37	38	57	97	116	246	335	183	1 176
Runoff oval (m3)	478	665	554	308	1 112	1 147	1 704	2 914	3 483	7 380	10 051	5 494	35 290
Net lake balance with refilling by Oval's runoff (m3)	**-18 346**	**-18 282**	**-27 671**	**-39 372**	**-44 418**	**-44 463**	**-35 453**	**-22 912**	**-13 037**	**16 968**	**41 516**	**14 391**	**-191 079**
Equivalent daily volume (m3)	-592	-653	-893	-1 312	-1 433	-1 482	-1 144	-739	-435	547	1 384	464	
Extra drainage area required to maintain the lake (m2)													**312 379**

Table 20: Monthly water balance for a 10 m deep lake

The calculation highlights a deficit for the lake: 191,079 m^3/y, and the need for a 312,379 m^2 drainage area to compensate the losses.

The chart below shows the yearly losses and the extra drainage surface required to prevent a 10 m lake becoming empty/dry.



Graph 20: Losses in RA design Matrimandir lake (10 m deep)

7.4.3 Detailed calculation

In order to obtain precise results about the sustainability of the Matrimandir lake, the daily calculation on the 40 year daily rainfall data has been applied to the following systems:

- 4 m deep lake with 1 m maximum fluctuation
- 4 m deep lake with 2 m maximum fluctuation
- 10 m deep lake with 1 m maximum fluctuation
- 10 m deep lake with 1 m maximum fluctuation

The drainage areas required to compensate the system's general losses have been calculated for a maximum run-off coefficient of 0.52.

The table below summarizes the results of the different conditions:

Scenario	Yearly hydrological balance	Drainage surface required	Max. no. of days with level < level min.
4 m deep/ 1 m variation	-129,805	6,000,000	52
4 m deep/ 2 m variation	-129,805	500,000	0
10 m deep/ 1 m variation	-191,153	9,000,000	69
10 m deep/ 2 m variation	-191,153	800,000	0

Table 21: Drainage area requirement for various lake depths

The results show that if only run-off is used to compensate the lake's losses, it is impossible, whatever the drainage area, to keep the water level within a 1 m fluctuation level as per Roger Anger's design.

With a 2 m fluctuation level, it would allow the lake to be sustained with a drainage area of 500,000 m² for a 4 m deep lake, and 800,000 m² for a 10 m deep lake.

The hydrological balance is the water that enters the system. It includes:

- Direct rainfall on the lake
- Effective rainfall on the oval
- Evaporation on the lake
- Seepage from the lake

7.4.4 Conclusion on the self-maintained lake principle

- The Matrimandir lake as per Roger Anger's design cannot be self-sustained, even by draining the entire oval's run-off towards it
- The lake has a large deficit of 130,000 m^3/y (4 m) and 191,000 m^3/y (10 m) in average years, and 251,000 m^3/y (4 m) and 313,000 m^3/y (10 m) in extreme conditions
- It is impossible to maintain a 1 m fluctuation level for the lake, whatever the drainage area
- The required drainage areas to maintain a lake with a 2 m fluctuation level are 500,000 m^2 (4 m) and 800,000 m^2 (10 m)

NB Water supply is not considered at this stage.

It is essential:

=> To develop a large drainage system to sustain the lake, even without water usage

=> To consider alternative designs with a larger water fluctuation level than 1 m

= > To consider the appropriateness of a secondary storage system to capture the overflow of the lake for further refilling

There are no advantages to deepening the lake to 10 m.

On the contrary, with a depth of 4 m, the volume of water in the lake could be renewed every year with a suitable drainage system, which then will limit the accumulation of pollutants in the lake. This is generally not possible for a 10 m deep lake.

A 4 m deep lake will represent an excavation of approx. 742,000 m^3 and soil movement of approx. 1,000,000 m^3.

Using 4 excavators with a capacity of 1 m^3, working 14 h/d and based on the usual levels of efficiency, for a trip of 2 km will require 27 tipper trucks with a capacity of 10 m^3, with one truck passage every 21 seconds for a minimum period of 6 months, just for the excavation work.

A 10 m deep lake will represent an excavation of approx. 1,731,000 m^3 and soil movement of approx. 2,337,000 m^3.

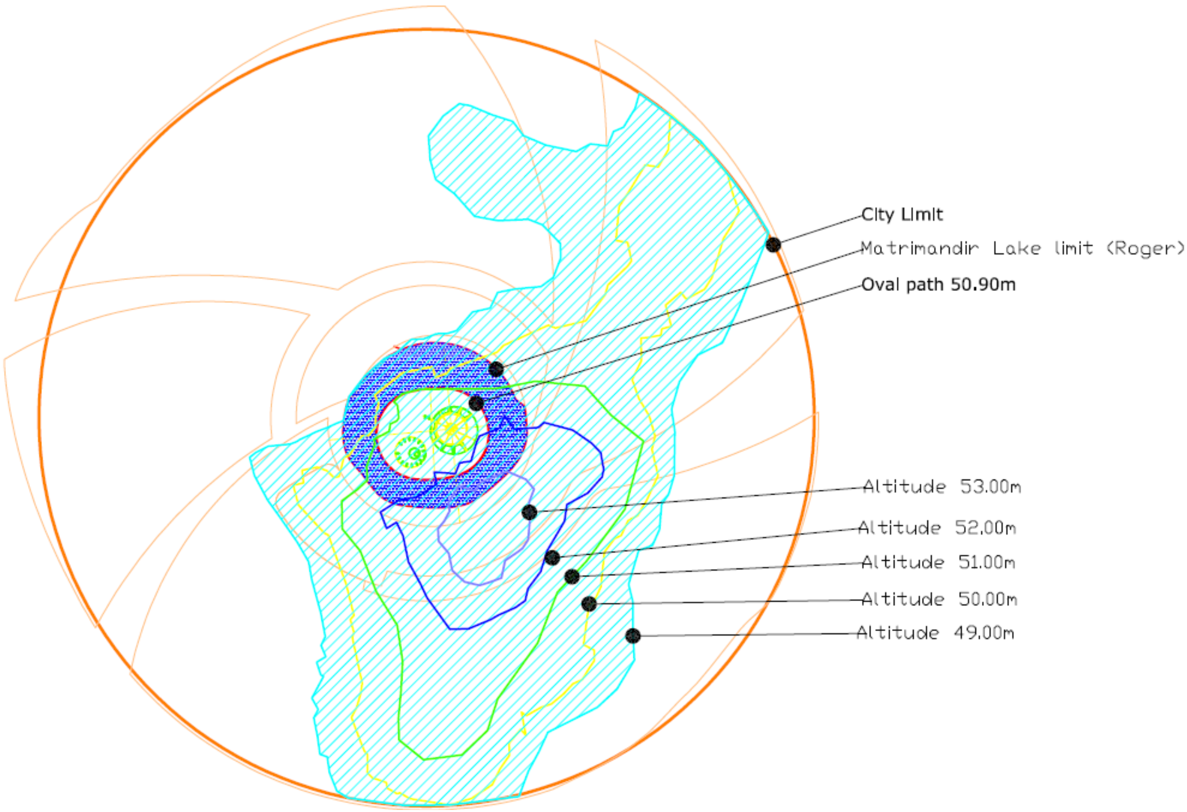
Using 4 excavators with a capacity of 1 m^3, working 14 h/d and based on the usual levels of efficiency, a trip of 2 km will require 27 tipper trucks with a capacity of 10 m^3, with one truck passage every 21 seconds for a minimum period of one year, just for the excavation work.

7.5 Matrimandir lake physical analysis

7.5.1 Drainage area

By using topographical contours, one can view the drainage area associated with the Matrimandir lake's footprint. The figure below displays the contours in 1 metre intervals around the Matrimandir lake.

The total area which could be drained into the lake, considering the slope requirement for the drains, is 1,446,000 m^2.



Picture 19: Contour lines showing ground levels fitting with the lake's boundary

Three different drainage areas can be identified to potentially feed the lake as per the lake's footprint. They are analysed in the table below following Roger Anger's lake layout (oval path level 50.9 m).

NB The drainage area subdivision in approximately equal areas aims to optimize the required drain sizes and the volume of water entering the lake from each area.

Level/Area	Description
Above 51.2 m	• Provides approx. a 500,000 m² drainage area – sustained lake requirement (4 m/2 m). Exact area: 476,800 m² (oval and lake excluded) • 0.3 m above the lake level (50.9 m)
From 50.2 m to 51.2 m	• Drainage area: 488,600 m² (oval and lake excluded)
From 49.5 m to 50.2 m	• Ground level of the lake layout (49 m) with an extra 0.5 m to provide a general slope for the drains • Similar drainage area: 480,600 m² (oval and lake excluded)

Table 22: Drainage area in relation to various levels around Matrimandir lake

7.5.2 Drainage system

In order to design the drains associated with these contour lines, and according to the general methodology applied in the report, the concentration time is fixed at 1.5 h which is quite a representative value regarding the drainage areas and general slopes. It leads, according to the previously described calculation method, to a rainfall intensity of 59.3 mm/h for a 25 year return period, which is a typical retained value for flood management in urban areas.

NB The constant values used correspond to Chennai. *Source: Hydrology and Water Resources Engineering Second edition, K.C. Patra*

Project rainfall intensity	
T (Return period)	25 years
K (Madras)	6,126
a	0,1664
b	0,5
n	0,8207
tc	1,5 h
I	59,3 mm/h

$$I = \frac{K \times T^a}{(t_c + b)^n}$$

Applying the rational formula and the Manning-Strickler formula, the drain dimensions are determined. The calculation is achieved assuming an available height of 0.5 m to provide a general slope in the drains, except for the highest area where only 0.3 m are available.

The table below recaps the resulting values.

Levels (m)	Collection point level (m)	Drainage area (m²)	Drain length (m)	Pick flow (m^3/s)	Drain max. cross sectional area (m²)	Drain average cross sectional area (m²)	General drain slope
Above 51.2 m	50.9	476,800	3024	2.3	7.4	4.9	0.02%
From 50.2 m to 51.2 m	49.7	488,600	5329	2.4	7.7	5.1	0.02%
From 49.5 m to 50.2 m	49.0	480,600	8090	2.3	8.7	5.8	0.01%

Table 23: Drainage sizing in relation to various levels around Matrimandir lake

NB The flow input along a drain is quite homogeneous, therefore the upstream drain cross section does not need to be as large as it is downstream. It indicates the maximal drain cross section as well as the average drain cross section. In order to calculate the average cross section, a 2/3 ratio has been applied from the former to the latter, since a ½ ratio is impractical and complicated to set up.

According to the previous calculation, it is feasible to sustain the Matrimandir lake with a depth of 4 m with 2 m fluctuation and a gravity drainage system. Even in this case, it is not possible to supply water to the population from the lake.

NB For the first drainage area (>51.2 m), the concentration time is equal to 1.3 h, in line with the 1.5 h value as a basic hypothesis. For the two other drainage areas, the values are above 1.5 h and results in rainfall of half the projected intensity (59.3 mm/h) providing a large design margin. This needs to be explored in a follow-up study.

7.6 Matrimandir lake as part of a supply system

Matrimandir lake, apart from fulfilling symbolic and aesthetic functions, should also be able to supply water to Auroville's population.

Three drainage areas have been highlighted according to the Matrimandir lake's layout. In order to use these drainage areas through gravitational flow, it is proposed to adapt the lake design, creating a **step lake or terrace lake**.

As summarized in the table below, the lake would have three steps related to three drainage areas.

Levels (m)	Drainage area (m^2)	Drain length (m)	Lake step level (m)	Lake step corresponding area (m^2)
Above 51.2 m	476,800	3024	50.9	53,417
From 50.2 m to 51.2 m	488,600	5329	49.7	54,739
From 49.5 m to 50.2 m	480,600	8090	49.0	53,843
Total	**1,446,000**			**162,000**

Table 24: Basic drainage sizing as per contour levels around Matrimandir

The lake areas are chosen in proportion to the corresponding drainage areas and will give simultaneous fluctuations in the different segments of the lake.

These divisions in the drainage areas have the advantage of having three areas of similar size, and the upper one is able to feed the Matrimandir lake so that it is self-sustaining in the case of no water supply to the population.

It is clearly possible to subdivide the lake into more than three parts or steps.

A step lake can be developed in a phased manner, which allows for flexibility in execution and reduced disturbance to the surroundings. Additionally, the lake's development can adapt to population growth.

The aesthetic integration of the lake could include waterfalls, islands and flowing water.

The design could integrate the mature trees that are already around the Matrimandir, and islands and shape variations become feasible.

7.7 Matrimandir lake's potential calculation

It has been calculated that solution 3 is able to supply a population of 15,171 using the city area as the drainage area and a storage body of 82,000 m² and 5 m deep.

This includes a resource combination of 100% rainwater and 10% groundwater/back-up resource. One can estimate the Matrimandir lake potential over 20 years in the context of the city supplied by a rainwater harvesting system with the following basic parameters:

- Population: 15,171 inhabitants (10% growth until 2032)
- Drainage area: 1,446,000 m² (maximum drainage area by gravity)
- Run-off coefficient: max. => 52%
- Consumption per inhabitant per day: 107 l (100% potable water demand)
- Storage area characteristics: 162,000 m², 4 m deep, 1 m or 2 m of admitted fluctuation level

The calculations are done on a daily basis over a 40 year period with 1 m and 2 m of admitted lake level fluctuation.

The tables below present the outcome of this assumption.

NB The retained run-off coefficient is the maximum figure for this part of the study, as the area concerned is earmarked for development, and will generate the maximum run-off coefficient faster than the entire city area.

The values are not directly related to each other. Indeed, the minimum figure in one category can refer to a certain year, and the minimum figure in another category can refer to a different year in the 40 year test period.

The hydrological balance is the water that enters the system. It includes:

- Direct rainfall on the lake
- Effective rainfall on the oval and the drainage area applying corresponding run-off coefficients
- Evaporation on the lake
- Seepage from the lake

With 1 m admitted fluctuation:

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year	Percentage of volume supplied	Annual minimum storage	No. of days under minimum level	Yearly overflow volume	Yearly hydrologic -al balance	Yearly balance minus yearly supply (m^3)	Comments
MAX.	261		423,681	71%	-7152	37	1,150,267	1,575,065	982,155	Large amount of excess water available. Storage below minimum level sometimes.
MIN.	110	**592,909**	178,563	30%	-72,534	7	89,531	352,107	-240,802	Large water deficit. Storage below minimum level sometimes
AVERAGE	176		286,431	48%	-36,871	19	544,225	865,130	272,221	Excess water available. Storage below minimum level sometimes

Table 25: Water balance and supply potential from Matrimandir lake with 1 m fluctuation level

With 2 m admitted fluctuation:

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year	Percentage of volume supplied	Annual minimum storage	No. of days under minimum level	Yearly overflow volume	Yearly hydrologic -al balance	Yearly balance minus yearly supply (m^3)	Comments
MAX.	323		524,325	88%	-4395	37	1,079,865	1,575,065	982,155	Large amount of excess water available. Storage below minimum sometimes.
MIN.	143	**592,909**	232,131	39%	-70,480	4	34,339	352,107	-240,802	Large water deficit.
AVERAGE	215		348,684	59%	-32,780	16	481,971	865,130	272,221	Excess water available. Storage below minimum level sometimes.

Table 26: Water balance and supply potential from Matrimandir lake with 2 m fluctuation level

NB The negative values of “Annual minimum storage” refer to the number of cubic metres below the minimum admitted water level in the lake. The equivalent height is also indicated in metres.

The Matrimandir step lake and its connected gravity drainage area do not meet the demand of the projected population (for 20 years) of 15,171 inhabitants. Only 48% of the days for a 1 m fluctuation level and 59% for a 2 m fluctuation level can be supplied on average.

The average yearly hydrological balance is inferior to the yearly demand of the population. This means that even with a larger storage system, it would be impossible to supply the entire population from this drainage area.

7.8 Conclusion on the Matrimandir lake

From the analysis, one can deduct:

- **The Matrimandir lake with a depth of 4 m:**
  - Can only work if it is filled by pumping with a resource to be defined
  - Can be sustained by a drainage system if:
    - 2 m of water level fluctuation are admitted
    - The drainage area is 500,000 m²
  - Does not contribute to the supply
- **The Matrimandir lake with a depth of 10 m:**
  - No advantages emerge from increasing the depth of the lake to 10 m
  - With a depth of 4 m, the volume of water in the lake could be renewed entirely every year with a proper drainage system, which then will limit the accumulation of pollutants in the lake. This is not possible for a 10 m deep lake
- **The Matrimandir lake as a step lake adapted to the topography:**
  - Can only work within defined criteria if it is sometimes refilled through pumping from another source to be defined
  - Can be sustained by a drainage system
  - Can contribute towards supply, but not sufficient to sustain the targeted population
  - Has a significant overflow which could be stored for further replenishment of the lake
  - The step design allows for partition of the entire water volume and dedicated drainage systems, which will reinforce the overall safety factor (control on pollution risks)

NB a large volume of overflow will be generated from the lake every year because of its limited usable storage capacity. It is feasible to collect this water and pump it back to the lake when required in order to maintain its aesthetic and functional use.

For Matrimandir lake to function as an integrated supply body:

- One has to pump the volume of water required to supply the population to the lake from sources to be identified, which implies high running costs.
- One can improve the lake drainage capacity by turning the lake into a step lake.
- One can integrate a secondary storage system to capture the overflow for further refilling and supply.
- A dedicated drainage system can be linked to the secondary storage system to consolidate its capacity.
- In all cases, an in-depth study is to be conducted regarding the excavation, soil movement and soil compacting in case of large-scale dumping and related erosion control with cost analyses and identification of further usage.

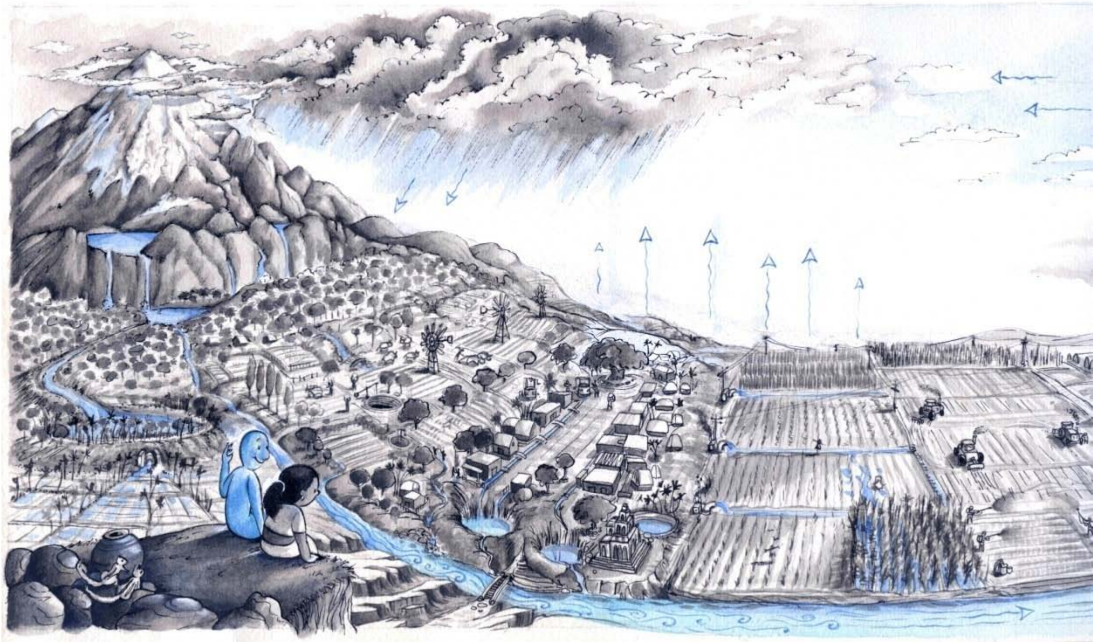
Matrimandir lake should be integrated in a comprehensive system in order to fit with the following basic assumptions:

- The Matrimandir lake should be sustained without huge yearly expenses;
- The overall system, including the lake, should be able to supply the projected population (for 20 years) of 15,171 with a daily demand of 107 lcd.

It remains of prime importance to integrate the ecological aspects in the overall surface water devices, including the lake, and other storage and drainage systems.

An integrated solution is proposed in the following chapter.

8. An integrated solution



8.1 Evaluated system description

It is necessary to integrate the Matrimandir lake in a comprehensive system so that it becomes an asset, not a liability. The lake should supply the projected 20 year population of 15,171 with a daily demand of 107 lcd. The following calculation is made in order to give initial indications, while final choices will have to be made in accordance with site integration and safety issues.

Basic parameters

- General
  - Population: 15,171 inhabitants (10% growth until 2032)
  - Consumption per inhabitant per day: 107 lcd (100% of the potable water demand), 86 lcd (80%) from the lake, 20% from other sources
- Matrimandir lake
  - Lake characteristics: 162,000 m², 4 m deep, 2 m admitted level fluctuation => storage available = 324,000 m^3
  - Drainage area to lake: 1,446,000 m² (maximum drainage area => step lake)
  - Run-off coefficient for the drainage area of the lake: max. => 52%
  - 50 cm water sealant with 10^{-9} m/s hydraulic conductivity
- Secondary storage
  - Secondary storage characteristics: 30,000 m², 5 m deep, full depth available => storage capacity available = 150,000 m^3
  - Collecting overflow from Matrimandir lake
  - Drainage area to secondary tank: 1,000,000 m²
  - Run-off coefficient for drainage area on secondary tank: max. => 31%
  - 50 cm water sealant with 10^{-9} m/s hydraulic conductivity

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year (m^3)	Percentage of volume supplied	Annual minimum storage (m^3)	No. of days under minimum level	Yearly overflow volume (m^3)	Yearly hydrological balance (m^3)	Comments
MAX.	366	**474,327**	475,301	100%	81,078	135	1,038,298	1,555,271	100% supply
MIN.	227		294,791	62%	-102,711	0	0	173,004	Groundwater back-up is necessary up to 80%. Extension of secondary drainage and/or groundwater back-up. Strict regulation for exceptional cases.
AVERAGE	343		445,595	94%	-6407	20	366,385	754,700	Groundwater back-up is necessary up to 10%.

Table 27: Testing water balance and supply potential for an integrated system

Note: in this scenario, 3 years out of the 40 years used for the calculation could supply less than 80% of the water demand. Hence, a back-up system that can supply 20% of the capacity (based on number of days) will be sufficient in nearly all cases, while in an exceptionally dry year it is necessary to have regulations to limit usage.

The secondary storage could be extended as well.

8.2 Conclusions and limitations of the system

At this stage, one can conclude that:

- There needs to be systematic wastewater recycling
- A potable water supply consisting of multi-sourcing with 80% rainfall and 20% other sources is required
- A step lake at Matrimandir, fed by a suitable drainage system, is a viable solution. Regarding the lake:
  - Its overflow needs to be collected in a secondary storage
  - It should be fed by a dedicated drainage system

- The water collected from the secondary storage tank should be pumped back into the lake
- A back-up system providing 20% buffer and water security is needed

- ➢ The maximum population of 15,171 (in 20 years) can be supplied
- ➢ Regulations need to be introduced in case of exceptionally dry years to reduce consumption

In the proposed scenario, part of the city area is drained to the storage structures. Out of the 4,656,739 m^2 of the city area, only 2,446,000 m^2 are drained for further usage (52%). Additionally, the retained run-off coefficient for the secondary storage system is lower because of the expected imperviousness at this stage of Auroville's development. Later, this run-off coefficient will increase, allowing for larger run-off generation and collection.

The green belt is not considered in the present study; it could be integrated at a later stage.

For safety and aesthetic reasons, the present system is based on a single secondary storage system. It is of prime importance to consider how to address unpredictable pollution in the overall set-up. This is of concern for any centralized approach and should be considered by the planning agency in order to integrate the development of the main infrastructure for water supply.

From this point of view, it is better to develop several drainage and storage systems with several treatment systems. The Matrimandir lake will benefit if it is split in several parts and supplied through several drainage systems. The step lake described earlier fits with these concerns.

One can conclude that it is better to develop multiple systems, but it will add extra costs due to the increase in related infrastructure, mainly for treatment. An integrated design system is optimal and cost-effective.

This particular aspect is beyond the scope of the study, as many issues related to planning and general city design are not defined at this stage.

The strategy for water supply is to be determined in regard to resources.

From the practical point of view, it is known that it is very difficult to maintain high water quality in a supply system in tropical conditions. In this regard, it is wise to target high standards, bearing in mind that potable water needs to be supplied from dedicated systems. The technical choices for these systems (neighbourhood purification units, household purification systems) are beyond the scope of this study, but strategic decisions are required in this regard.

8.3 A phased lake development?

Considering the massive implementation work that the Matrimandir lake represents, particularly in regard to excavation and soil movement, it is relevant to look at how it could be created in a phased manner. In this case, it is simpler to start with the proposed step lake, as basic criteria for related drainage are already defined.

Basic parameters

- General
  - Population: 4073 inhabitants (3% growth until 2032)
  - Consumption per inhabitant per day: 107 lcd (100% of potable water demand), 86 lcd (80%) from the lake, 20% from other sources
- Matrimandir lake
  - Lake characteristics: 54,000 m^2 (1/3 of final area), 4 m deep, 2 m admitted level fluctuation => storage available = 108,000 m^3
  - Drainage area to lake: 488,667 m^2 (1/3 of maximum drainage area => step lake)
  - Run-off coefficient for drainage area to the lake: max. => 31% (low density)
  - 50 cm water sealant with 10^{-9} m/s hydraulic conductivity
- Secondary storage
  - Secondary storage characteristics: 15,000 m², 5 m deep, full depth available => storage available = 75,000 m^3
  - Collecting overflow from Matrimandir lake
  - Drainage area to secondary tank: 200,000 m²
  - Run-off coefficient for drainage area on secondary tank: max. => 31%
  - 50 cm water sealant with 10^{-9} m/s hydraulic conductivity

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year (m^3)	Percentage of volume supplied	Annual minimum storage (m^3)	No. of days under minimum level	Yearly overflow volume (m^3)	Yearly hydrological balance (m^3)	Comments
MAX.	366	**127,344**	127,605	100%	16,814	256	148,541	358,075	100% supply
MIN.	103		35,911	28%	-58,236	0	0	12,986	Groundwater back-up is necessary. Extension of secondary drainage. Strict regulation for exceptional cases.
AVERAGE	291		101,370	80%	-13,241	71	37,548	158,456	Groundwater back-up is necessary up to 20%.

Table 28: A phased lake

8.4 Final population and system modularity

For a future perspective, it is relevant to check the performance of the system for the final population of 50,000 inhabitants. The run-off coefficient is then taken as 0.52.

In order to reach a conclusive statement on the pro and cons of the ideal storage system and the integration of Matrimandir lake in the overall scenario, the following table shows the results for both cases.

8.4.1 Ideal drainage and storage tank

The retained capacity for the storage tank is 106,000 m^2 for 5 m depth as previously defined, while the drainage area is the entire city area.

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year (m^3)	Percentage of volume supplied	Annual minimum storage (m^3)	No. of days under minimum level	Yearly overflow volume (m^3)	Yearly hydrological balance (m^3)	Comments
MAX.	366	**1,563,270**	1,566,480	100%	164,891	0	3,505,503	4,940,764	100% supply
MIN.	246		1,052,880	67%	0	0	36,999	1,201,576	Groundwater back-up is necessary up to 30%. Extension of secondary drainage and/or groundwater back-up. Strict regulation for exceptional cases.
AVERAGE	300		1,284,214	82%	7834	0	1,502,505	2,769,060	Groundwater back-up is necessary up to 20%.

Table 29: Ideal drainage and storage tank

8.4.2 Matrimandir lake and secondary storage tank

The selected design for the Matrimandir lake is a step lake with maximum potential drainage area, while the secondary storage tank is 106,000 m^2 with a depth of 5 m, and the drainage area is the entire city area minus the part already drained to the lake.

	Supplying days per year	Yearly demand (m^3)	Volume supplied per year (m^3)	Percentage of volume supplied	Annual minimum storage (m^3)	No. of days under minimum level	Yearly overflow volume (m^3)	Yearly hydrological balance (m^3)	Comments
MAX.	319		1,365,320	87%	-12,092	0	575,738	1,576,339	Groundwater back-up is necessary.
MIN.	101	**1,563,270**	432,280	28%	-175,212	0	0	178,875	Not appropriate.
AVERAGE	221		944,382	60%	-83,381	0	159,162	766,934	Extra resources are required. The lake's minimum depth is not respected, hence it cannot be used as intensively.

Table 30: Matrimandir lake and secondary storage tank

8.4.3 Conclusion

The "ideal/theoretical" system (optimized drainage and storage) is the most efficient. The Matrimandir lake is less efficient due to greater losses from evaporation.

It is advisable to limit the usage of the Matrimandir lake and its dedicated secondary storage tank and drainage to the equivalent population of 15,000 people as described above in 8.1.

The city area that is not drained to the Matrimandir lake (secondary storage and drainage system) can be drained to another collection system. In this case, a 100,000 m²/5 m deep storage system could supply 35,000 people for 300 days a year on average. These drainage and storage systems could be integrated throughout the city, which will increase the safety factor (minimizing pollution risks).

9. General conclusions and recommendations

Since the inception of Auroville, the supply of its population is solely from the groundwater resource. Over time, this initially well-secured resource has been heavily over-exploited on a regional scale, which has led to the depletion of the water table and seawater intrusion. Seawater intrusion is occurring on large stretches along the coast in the Cuddalore aquifer, a very large aquifer of coastal Tamil Nadu. A more locally critical aquifer, Vanur formation, may be exposed to seawater intrusion at any time. This regional phenomenon emphasizes the interdependency Auroville has with its surroundings. While Auroville has developed groundwater recharge through its entire command area, and while the overall water consumption of Aurovilians is less than the recharge generated locally, the huge volume of groundwater extracted from the surroundings, chiefly for irrigation purposes, counteracts any benefits.

Despite the fact that many efforts have been made on a regional level to reduce groundwater extraction by reviving the surface water harvesting structures, which allows for larger irrigation from this resource, groundwater depletion and consequent seawater intrusion continue at a disturbing pace. The trend for the future is difficult to predict because of the substantial changes in land use, the transfer of the population's activities from primary to secondary and tertiary sectors, and the unplanned urbanization in the area. When the groundwater turns saline, less potable water will be accessible, leading to a reduction in agricultural activities, and groundwater extraction. If urbanization is not implemented consistently, and resources are not protected, it will lead to large losses of rainwater to the sea through run-off escalation.

These two opposite trends will lead to continuous changes for the decades to come. A total collapse of the water system is one of the possible outcomes along the way, and it may happen in the near future. Once groundwater turns saline, it is very difficult to restore it, and in some cases, like seawater intrusion into the Vanur formation, reversal is beyond predictable time. One can imagine that to supply water to a city is possible by technical means like seawater desalination, but what about the hundreds of villages and hamlets in the surrounding area? What about the agricultural activities, services and industries in the entire region?

In this context, one should look for other water resources to supply Auroville.

Amongst accessible water resources, one can identify desalinated water, wastewater and rainwater. One should bear in mind that groundwater, when it becomes brackish, can be desalinated. An initial evaluation shows that only multiple-sourcing can guarantee reliable and cost-effective access to water. Water saving procedures must be part of a sound code of practices for planning, development and building. Wastewater must be recycled in order to reduce the pressure on potable water resources. Brackish water desalination is more feasible than seawater desalination due to cost-effectiveness and social issues. Groundwater, while endangered, is not usually at risk locally from seawater intrusion and can remain part of the targeted resources once it has been thoroughly evaluated. Rainwater harvesting requires detailed investigation. Focusing solely on the suitability of rainwater harvesting techniques to supply Auroville would mean that large surface storage systems are required, with options for multiple storage tanks and the Matrimandir lake. A combination of different solutions is advisable. The city must be equipped to harvest rainwater and deal with flood control, so that the population can be at least partially supplied from this resource.

Desalination processes from groundwater or seawater, as well as wastewater treatment and recycling, are mainly strategic and technical, whereas rainwater harvesting is a more complex issue because of its high variability, the intricate land use pattern, pollution risks and the need to integrate Matrimandir lake in the overall water scenario. Since development of infrastructure and construction is ongoing, it becomes essential to look at the ways these resources could be harvested and how the harvesting structure could be integrated in the overall planning and development exercise in an appropriate time frame and in relation to the potential population growth.

At this stage, it is essential to define the various scenarios and related parameters which need to be integrated in order to define the way to proceed. Only the city area is considered for the study, and the final population will be 50,000 people. The first parameter is the time frame and related population growth. While the final size of the city needs to be taken into consideration, infrastructure appropriateness is defined by its suitability in terms of investment and planned use. To invest in infrastructure which will be used once the final population is reached is not viable, as investment and running costs, as well as suitability, will become a liability. A targeted 20 year period is used for the time frame, with a resulting range of population between 4000 for 3% growth and 15,000 for 10% growth for the given period.

Water demand is the second parameter. The basic figures are from the National Building Code for urban water demand - 270 lcd, which includes domestic, commercial (including schools and hosting services) industrial and public use as well as waste. A secondary figure is generated out of the first because of the specific features that apply to Auroville, including the absence of large industries or water based industries and the presence of large educational and hosting facilities, which increase the urban water demand to 251 lcd. Considering that all aspects of Green Practices and sustainability approaches are incorporated in the plan, the GRIHA standard applies, which represents a large reduction in the overall water demand - 166 lcd (-34%).

This figure is realistic, provided the water resource management and supply water systems are well maintained. Further, wastewater recycling must be integrated. Out of the 166 lcd water demand for global urban activities, 107 lcd can be processed and could be recycled. As per common and successful practices in many development projects in the country, 59 lcd out of 107 lcd of treated wastewater can be recycled for low risk demand like public use (garden and parks), domestic, industrial and commercial demand where hygiene is not essential (toilet flushing, etc.). It is important to note that 48 lcd of processed wastewater will not be used for urban demand, and hence can benefit the larger area, for example, for groundwater recharge or irrigation purposes. This determines the drinking water demand, and therefore the adequate volume of potable water to be supplied. It comes to 107 lcd with all needs included. Scrutinizing practices worldwide, it is observed that the scenario for water demand evolves, with growing density and the integration of appropriate practices, towards less demand per capita than today. For example, the irrigation for the Matrimandir gardens is currently an important aspect of the entire water consumption of Auroville, while in the future this demand will not increase as the population increases, hence it will become proportionally much less than today. Additionally, irrigation for these gardens can be ensured by processed wastewater, so that the potable water demand for such purposes is nil.

Human or planned impact, along with natural considerations, is the next essential criteria to be determined. Land use is to be defined in order to determine the impact on surface water. In the Auroville Master Plan, 50% of the city area will be built up, while 50% will remain green. Considering that some infrastructure, paths and secondary building will come into the green area, the retained figures for the final development stage or selected development areas are 60% impervious (buildings, sheds, roads) etc. or semi-pervious area (green parking lots, etc.), and 40% green area. The intermediate values for a time frame of 20 years are 30% impervious and 70% green areas. From these values and the local conditions (soil, slopes, local conditions, etc.), one can determine that the run-off coefficient will be 80% from impervious and semi-pervious areas, while it is 10% from green areas as per site measurement. The run-off coefficient figures combined with the land use pattern defined above, result in an average value of 52% for the run-off coefficient for fully developed areas and 31% at an intermediate stage of development. This means that from the current 10 to 12% run-off coefficient, in the future (due to development) there will be a significant increase in surface water, but correspondingly, there will be a large-scale reduction of losses by the vegetation, which will be less present than it is today, and less natural groundwater recharge as less area will be left undeveloped for this phenomenon to occur. The water balance will go through major changes in all aspects, and the ensuing consequences must be understood and taken care of.

The last essential parameter to be determined is the rainfall, from which run-off volume can be ascertained. The average yearly rainfall in Auroville, based on 40 years of consolidated daily data, is 1299 mm/y. Since rainfall events below 10 mm do not generate run-off, these daily values are systematically screened out, which leaves 'effective rainfall', with an average yearly value of 1176 mm/y. The potential evapo-transpiration, which will determine the losses for any large open water storage structure, is established at 2034 mm/y on average as per previous scientific studies.

At this stage, a first quantitative assessment of the potential of surface water to supply the population is done. If appropriate water practices and recycling are systematically applied, surface water becomes a very promising resource, as it could ensure the demand for nearly every given year, even for 50,000 people. A monthly evaluation highlights the necessity to develop a large storage system, because in many months of the year, rainfalls are scattered and small. One can determine the overall surface water system definition. The drainage system must be integrated in the urban landscape, respect contour lines and be made in such a way that it acts not only as a technical facility, but allows for dust to be intercepted and cleaning along the way. Combined with the need for aesthetic integration in the urban tissue, this leads to a channel-like design. All parameters relating to storm water control and safety measures are part of this system. The storage system is considered for its storage efficiency, cost effectiveness, and all technical parameters related to this type of device, like inflow and overflow structures, hydraulic characteristics and so on. For financial and practical reasons, the depth of the planned storage system is retained at 5 m, while the hydraulic conductivity is equal to 10^{-9} m/s for a 50 cm waterproofing layer. The hydraulic conductivity corresponds to a clay layer or mixed red soil and bentonite. It is worth mentioning that the losses by evaporation for this type of storage system are about six times the losses occurring through seepage.

Taking into consideration all the primary parameters defined above, the evaluation indicates that surface water from the entire city area, collected through a suitable drainage system and stored in a storage tank of 300,000 m^3 (60,000 m^2/5 m), would be able to supply 95% of the yearly water demand for 15,000 people (the higher population prediction for 20 years). For sufficient water supply, it becomes clear that multi-sourcing is essential. An appropriate proportion for daily supply is the range of 80% surface water and 20% other sources, with an additional possible safety margin of 10% for days where stored surface water is not available (exceptional dry years), which may come from groundwater stored in protected pockets, like Manaveli formation. It is to be noted that this type of system will generate large overflows, which can be integrated as part of a larger supply system in the future.

A technical, financial comparative evaluation determines the production cost of water (investment and running costs over a 20 year period, including power back-up) for each source, and the best combination of sources to ensure water accessibility. At this stage, the cheapest solution is groundwater extraction, but as stated above, it cannot single-handedly ensure the supply of the population in the long run. The next best solution is surface water, followed by brackish water desalination, while seawater desalination is the most expensive solution, with a range from 1 to 15 for the investment costs and 1 to 6 for yearly running costs. All points considered, it emerges that an apt combination could be surface water harvesting combined with brackish water desalination and a back-up of groundwater from protected areas. Through analysing various scenarios, the indicative production costs (we are not speaking of supply at this stage) are in the range of 41 Rs/m^3 to 49.7 Rs/m^3, with the highest technical and sustainable score given to a solution where water cost is 47 Rs/m^3. An intermediate solution at 41 Rs/m^3 is possible but will need improvement for future developments.

An overview of the potential for each resource and the role they may play in an overall water scenario needs to take into account the implementation of ecologically sound drainage systems and water bodies. It is doubtful if a technical design will be able to accommodate the complex aspects of sustaining such large water bodies. It is imperative to integrate technical, aesthetic, symbolic, practical and ecological aspects in the designs and the execution. The combination of resources is essential to ensure water accessibility and future growth. It is necessary to create several systems to build resilience to pollution risks and other unpredictable factors. The GIS integration and landscape study supplementing the present study will establish appropriate design and implementation features.

Matrimandir, due to its location, does not offer the most ideal storage system. It is understood as per the Mother's statement that it must be part of the overall water supply system. If the large water body is not included in overall water resource management, it will be a liability for the community, and will be a model of inappropriateness, definitely not in line with "The City the Earth needs" from environmental, practical and financial standpoints. This feature should be a living symbol, integrating beauty and functionality. The location of Matrimandir, close to the ridge of the Auroville plateau, is challenging, and highlights the necessity to integrate the topographic features into the lake design. The lake, as designed, is situated in such a way that the bordering lands on the eastern side are about 2 m above the oval path, which forms the island where the Matrimandir and its gardens are located, while the western side is 2 m below. The integration of these constraints is not yet considered in any of the proposed designs for the city centre.

Further, the question remains: how will the lake be filled? Such a large water body, 162,000 m^2, shows high losses by both evaporation and seepage (average 165,000 m^3 per year for a depth of 4 m), which must be compensated regularly to ensure that minimum aesthetic values are respected. The findings are that by draining the potential area to the lake, including the entire oval area, it is impossible to maintain a 1 m maximum level variation in the lake. With a 2 m water level variation, a drainage area of 500,000 m² for a 4 m deep lake and 800,000 m² for a 10 m deep lake will be required. These figures do not include any water usage at all at this stage.

The choice is to compensate for the losses with other sources which need to be identified, or to come up with an appropriate design that avoids the lake becoming a liability (not in tune with the practical, economic and social parameters of sustainability). It is worth mentioning that increasing the depth of the lake more than 4 m has no advantage or positive impact as far as the water supply is concerned.

One can observe that a fairly large potential drainage area borders the Matrimandir lake, as far as footprint is concerned. Considering the slope requirement for the drains and other parameters, 1,446,000 m^2 could potentially be drained to the lake. If the run-off generated from this drainage area is to be collected in the lake, it implies a major change in the way the lake is to be designed. Respecting the topographic conditions and optimizing the functionality of the lake, for 15,000 people (592,900 m^3/y) on average, 48% of the yearly demand could be ensured by the lake with 1 m level variation, and 59% with 2 m variation. A large overflow (544,000 m^3 for 1 m and 482,000 m^3 for 2 m) would be produced by this system, which could easily be collected. It is worth mentioning that raised elevations and partitioning of the lake could minimize pollution transfer.

Finally, one can reach a conclusion regarding the most promising direction to take. The study indicates that the most effective regular water sourcing could be 80% surface water, 20% other sources (with the most cost-effective and adaptable secondary source being desalinated brackish water) and an extra safety of up to 10% of the yearly surface water capacity from groundwater extracted from protected areas. Wastewater is recycled for irrigation and secondary usage in houses and services systematically.

A possible design for surface water could be a step lake of 162,000 m^2 with a depth of 4 m, collecting water from the topographically connected drainage area (1,446,000 m^2), which will overflow into a secondary storage system. This storage system, if made with an area of 30,000 m^2 and 5 m deep (150,000 m^3 capacity), and fed by a connected drainage system of 1,000,000 m^2, can supply the lake or feed the supply lines directly. This system can ensure 94% of the yearly demand for 15,000 people in an average year, with a 10% safety from groundwater. With a total city area of

4,656,739 m², this system leaves 2,210,739 m² untapped, which then could be included in the overall system at later stages in relation to the population growth and yield even better results as the run-off will increase over time.

It is possible to supply water to Auroville's growing population from combined sources, primarily from captured surface water. With this approach, Matrimandir lake can be an integral part of a secure water management programme to supply the population of Auroville.

A well-designed system developed in accordance with the topography will support the multiple functions (symbolic, aesthetic and practical) which are required. But to reach its full potential and supply the highest possible population, the lake should be integrated within the topographical context, and meet crucial fundamental criteria in regard to the surrounding city landscape.

The overflow generated by the lake every year is large enough in volume for these requirements. Additionally, areas that are not connected to the lake could be captured in order to collect larger volumes of water and extend the potential for supply.

Future steps:

- To study how appropriate drainage systems could be developed in Auroville's urbanized context, including waterways, erosion control, sedimentation areas, bio-filter systems, etc.
- To analyse the way the required extra water could be collected (surface water or other sources) to meet the aesthetic and level fluctuations criteria.
- To envisage variable design scenarios in regard to existing land features (hillocks, rockeries, major trees etc.).
- To focus on the soil movement issue: the envisaged storage and drainage involves the movement of a major volume of soil, which needs to be disposed of and used in an appropriate way.
- To study various lake and storage designs in regard to urban design and landscaping.

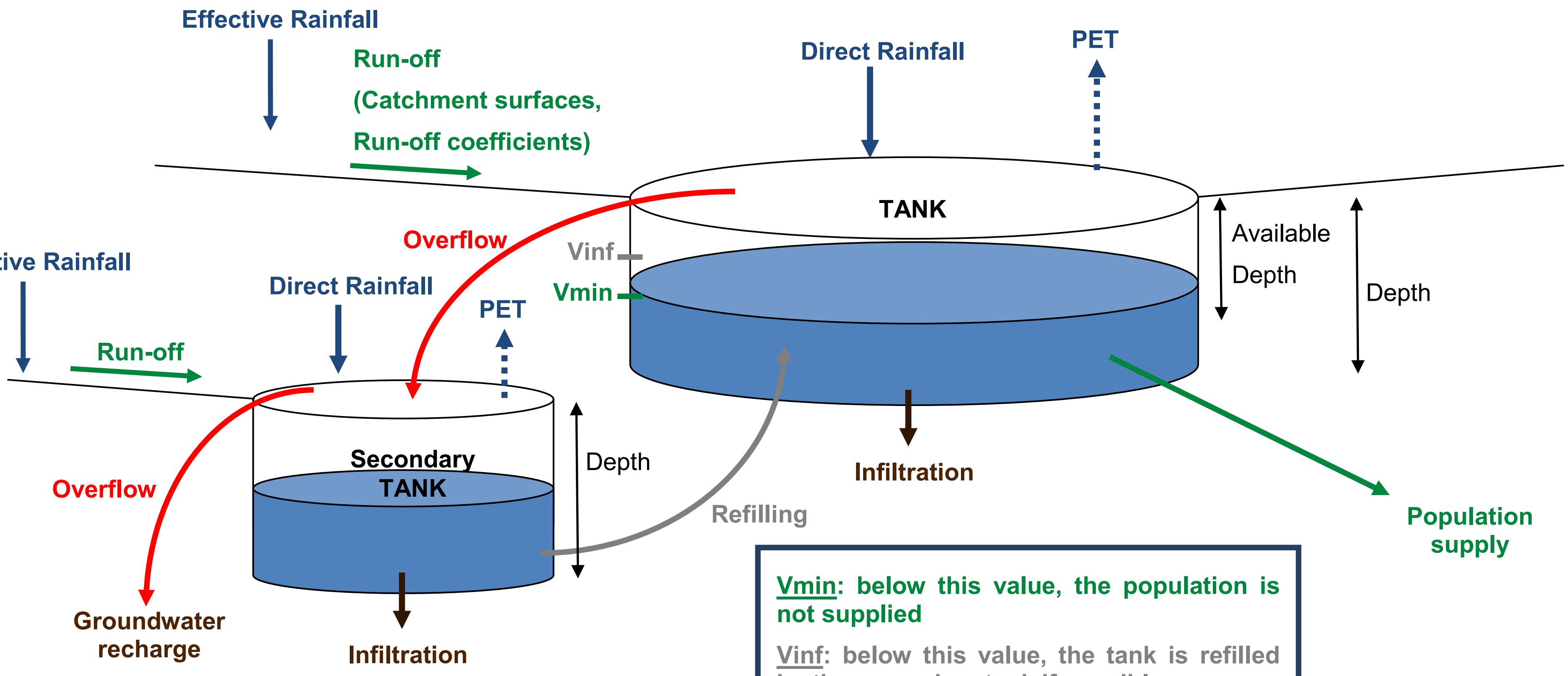
Appendix 1: Hydrological data treatment

Rainfalls and Potential Evapo-transpiration

Type of Data	Place	Period	Source	Commentary
Daily Rainfalls	Pondicherry	April 1968 - 1999	M.Phil _Pondy_rainfall_data	Selected data
Daily Rainfalls	Auroville Harvest	1998 - 2009	Harvest Rainfall	Selected data
Daily Rainfalls	Auroville Harvest	1998 - 2006	Aude Vincent Ph.D.	Identical to selected data
Daily Rainfalls	Auroville Harvest	Jan - June 2010	Daily Rainfall data file	Time frame too short
Daily Rainfalls	Auroville Harvest	Jan 2006 - June 2007	Harvest_meteo Temperature and Humidity	Time frame too short
Daily Rainfalls	Aurogreen	April 1989 - 2003	Aurogreen Rainfall Data	Used to validate the selected data
Daily Rainfalls	Pondicherry	Oct - Dec 2004 then Jul - Aug 2005	Aude Vincent Ph.D.	Time frame too short
Daily Rainfalls	Cuddalore	Oct - Dec 2004 then Jul - Aug 2005	Aude Vincent Ph.D.	Time frame too short
Daily Rainfalls	Chennai	Oct - Dec 2004	Aude Vincent Ph.D.	Time frame too short
Monthly Rainfalls	Vanur	1960 - 2007	Vanur Rainfall	Too large time intervals - used to validate the selected data
Monthly Rainfalls	Pondicherry-Auroville Harvest	1911 - 2000	Auroville Rainfall 1968 - 2004	Too large time intervals - used to validate the selected data
Monthly Rainfalls	Local villages	2006 - 2008	*Foundation Ensemble* project rainfalls	Time frame too short
Monthly PET	Certitude	1972 - 1981	Aude Vincent Ph.D.	Selected data - Thornthwaite method
Monthly PET	Pondicherry and Vanur	2001 - 2005	Aude Vincent Ph.D.	Selected data - Thornthwaite method
Daily Evaporation rate	Auroville Harvest	Jan 2006 - June 2007	Harvest_meteo Temperature and Humidity	Unusable data
Monthly PET	Pondicherry	1911 - 2001	ETP calculated Combined over 90 years	Used to validate the selected data

NB It is commonly accepted that it is more appropriate to use the Penman formula to calculate the PET, rather than the Thornthwaite formula. This formula results in a 16% extra PET for the selected period (1972 - 1981 then 2001 - 2005). Since the 1972 - 1981 period seems to have especially high PET values, it is chosen to retain the values calculated with the Thornthwaite formula in order to get mean monthly values that are more accurate.

Appendix 2: Storage tank calculation software description



Software calculation process description

The software executes the calculation using a 40 year (1969 - 2008) daily database on rainfall and potential evapo-transpiration (ETP).

It is possible to implement one or two tanks in the system, the first one overflowing into the second.

The main tank:

- Receives direct rainfall
- Receives run-off from a catchment area with a given run-off coefficient
- Releases water in the atmosphere through direct evaporation
- Loses water through seepage at the base of the tank
- Overflows when full
- Supplies the city population
- Can be refilled by the secondary tank when needed and possible
- Has an overall depth and an available depth which is the water level fluctuation allowed in the tank for aesthetic reasons
- Has a minimum volume of available water below which the population is not supplied any more in order to respect the permitted level fluctuations. This volume is calculated daily and takes into account the overall needs of the day (population needs, evaporation, infiltration)
- Has a volume cut-off below which the tank is refilled with water from the secondary tank (if available) (Vinf = 10% of lake area multiplied by 1 m)

The secondary tank:

- Receives direct rainfall
- Receives the main tank overflow
- Receives run-off from a catchment area with a given run-off coefficient
- Can be open (or not), thus releases (or not) water in the atmosphere through direct evaporation
- Loses water through seepage from the base of the tank
- Overflows when full (towards groundwater recharge pits for instance)
- Supplies the main tank when required if is not empty

Commentaries:

- The main tank and the secondary tank are considered full at the beginning of the simulation.

NB It can happen that the PET and seepage empties the tanks at some point, and then the levels cannot drop any more.

Appendix 3: Water Quality Standards - Guideline Values CPCB - Classification of Inland Surface Water

S. No.	Characteristics	A	B	C	D	E
1	Dissolved Oxygen, mg/l, Min.	6	5	4	4	-
2	Biochemical Oxygen Demand, mg/l, Max.	2	3	3	-	-
3	Total Coliform Organisms* MPN/100 ml, Max.	50	500	5000	-	-
4	Total Dissolved Solids mg/l, Max.	500	-	1500	-	2100
5	Chlorides (as CL), mg/l, Max.	250	-	600	-	600
6	Colour, Hazen Units, Max.	10	300	300	-	-
7	Sodium Absorption Ratio, Max.	-	-	-	-	26
8	Boron (as B), mg/l, Max.	-	-	-	-	2
9	Sulphates (as SO4), mg/l, Max.	400	-	400	-	1000
10	Nitrates (as NO3), mg/l, Max.	20	-	50	-	-
11	Free Ammonia (as N), mg/l, Max.	-	-	-	1.2	-
12	Conductivity at 25°C, micromhos/cm, Max.	-	-	-	1000	2250
13	pH value	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
14	Arsenic (as As), mg/l, Max.	0.05	0.2	0.2	-	-
15	Iron (as Fe), mg/l, Max.	0.3	-	50	-	-
16	Fluorides (as F), mg/l, Max.	1.5	1.5	1.5	-	-
17	Lead (as Pb), mg/l, Max.	0.1	-	0.1	-	-
18	Copper (as Cu), mg/l, Max.	1.5	-	1.5	-	-
19	Zinc (as Zn), mg/l, Max.	15	-	15	-	-

* If the coliform is found to be more than the prescribed tolerance limits, the criteria for coliform shall be satisfied if not more than 20 percent of samples show more than the tolerance limit specified, and not more than 5 percent of samples show values more than 4 times the tolerance limits. Further, the faecal coliform should not be more than 20 percent of the coliform. Source: Indian Standard (IS: 2296 – 1982).

A - Drinking water surface without conventional treatment but after disinfection
B - Outdoor bathing (organized)
C - Drinking water source with conventional treatment followed by disinfection
D- Propagation of wildlife, fisheries
E - Irrigation, industrial, cooling, controlled waste disposal

Appendix 4: Study Brief

Study proposal by Auroville Centre for Scientific Research- 19 July 2012
Surface Water Sourcing Study for Auroville city area
Context

A fast track study to evaluate the feasibility and appropriateness of collecting, storing, cleaning and using surface water to supply water as part of the multi-sourcing strategy envisaged for Auroville.

The multi-sourcing strategy envisages integrating surface water, ground water, recycled wastewater and desalinated water (brackish groundwater/seawater).

Such an approach has consequences on multiple aspects for urban integration: concept, strategy, environmental impact, social issues, resource reliability, techno-economic feasibility, sustainable issues.

The only used water resource until now has been groundwater. Giving the fact that ground water resource is under heavy pressure, declining in quantity and under seawater intrusion treat; it is imperative that other resources must be explored, integrated in our water policy.

Rainwater is abundant while fluctuating in quantity, but qualifies to have a promising potential in the multi-sourcing concept.

Considering the early state of urban development, it is the right moment to proceed with the planning and execution of proper implementation practices of surface water management, chiefly drainage and storage practices.

Postponing any longer the execution of such programs will miss the opportunity of implementation and jeopardize the utilization of surface water resource.

Study scope

- The study will focus on the city area
- The Matrimandir lake will be part of the entire system, looking at the possibility of using it as a storage reservoir
- Secondary reservoirs will be explored for overflow and storage purpose
- Existing topographic features need to be taken care of
- Gravity flow towards the identified storage areas are the preferred feature inputs
- Identifying the basic design criteria for the system components
- Identification of risk factors (pollution, drought, floods)
- Identification of overlap/conflicting zones with Auroville site plan
- Identification of different data required for detailed study
- The proposed system design should include minimum external inputs for its functioning and aim towards low energy demands, reduced heavy infrastructure works, positive environmental impact, easy maintenance practices, self cleaning mechanisms, long term reliable functioning, integrated aesthetical design
- System reliability during periods of environmental stress

Outcome/deliverables

- Potential surface water capturing/production capacity and system dynamic: losses evaluation and evolution through density/population growth
- Pre-dimensioning of the required drainage and storage systems
- Possibilities for scalability
- Estimated costing and timeline implementation

The outcome of this preliminary study should be able to help to determine the most appropriate sourcing mix (surface water, ground water, recycled water and desalinated water) strategy to be put in practice.

Appendix 5: Lexicon

Source: Desalination and Water Purification Technology Roadmap - A Report of the Executive Committee U.S. Bureau of Reclamation - Sandia National Laboratories - January 2003

Conventional water treatment technologies

Typical conventional water treatment consists of six basic steps: screening; coagulation to combine solids so that they settle; sedimentation to settle suspended solids; filtration; disinfection; and storage. Sometimes all of these five steps are not needed, and sometimes, additional steps are required to meet water quality standards. Dissolved ionic species and hydrocarbons in source waters require treatment using chemical additions, soda ash or weak acids, or by filtration with activated carbon or calcite filters. Conventional water treatment processes have been employed for more than 100 years.

Aquifer A subsurface feature comprised of permeable soil and rock that contains water.

Brackish water Brackish water is defined by containing higher TDS levels than potable water, but lower TDS levels than seawater (in the range of 1,000 mg/l TDS to 25,000 mg/l TDS). Brackish waters can be found in coastal areas (bays and estuaries, where fresh water mixes with salt water), in aquifers (where it is usually referred to as saline water), and in surface waters (salt marshes, for instance, contain brackish water).

Concentrate: Concentrate is the byproduct from desalination. This byproduct contains the contaminants removed from impaired waters during desalination and water purification processes. Concentrates are generally liquid substances that may contain up to 20% of the water that is treated (i.e., for every 100 gallons of impaired waters that are treated, up to 20 gallons of that water is commingled with the removed contaminants).

Conjunctive use The coordinated and integrated management of surface water and groundwater resources.

Fouling The reduction in performance of process equipment that occurs as a result of scale buildup, biological growth, or the deposition of materials.

Groundwater Water normally found underground and obtained from wells. Not to be confused with surface water such as rivers, ponds, lakes, or waters above the water table

Membrane A semi-permeable film. Membranes used in electrodialysis are permeable to ions of either positive or negative charge. Reverse osmosis membranes ideally allow the passage of pure water and block the passage of salts.

Saline water Water with dissolved solids exceeding the limits of potable water. Saline water may include seawater, brackish water, mineralized ground and surface water and irrigation return flows.

Salinity Salinity is a term used to describe the amount of salt in a given water sample. Salinity is usually referred to in terms of total dissolved solids (TDS), and is measured in milligrams of solids per litre (mg/l). Seawater has a worldwide average of 35,000 mg/l TDS. Brackish waters contain between 1,000 mg/l and 25,000 mg/l TDS. Drinking water contains between 400 and 800 mg/l TDS.

Salt Salt, as referred to in this document, is a catch-all term that incorporates a variety of substances found in source waters, including: calcium, sodium, magnesium, carbonate, bicarbonate, sulfate, chloride. Salts may also include lesser amounts of potassium, selenium, boron, manganese, fluoride, nitrate, iron, and arsenic. It is important to note that the salts referred to in this document are not the same as table salts (NaCl).

Seawater Seawater is water found in the oceans. Seawater has a worldwide average concentration of 35,000 mg/l TDS, 3/4 of which is NaCl.

Surface water Surface waters are those waters contained in flowing sources (rivers, streams, etc.) and in still sources (oceans, seas, lakes, man-made reservoirs, etc.)

High pressure pump

The pump supplies the pressure needed to push water through the membrane, even as the membrane rejects the passage of salt through it. Typical pressures for brackish water range from 225 to 375 psi (15.5 to 26 bar, or 1.6 to 2.6 MPa). In the case of seawater, they range from 800 to 1,180 psi (55 to 81.5 bar or 6 to 8 MPa). This requires a large amount of energy.

Appendix 6: Basic on Desalination of Seawater and Brackish Water

Source: http://www.wwdmag.com/desalination/desalination-seawater-and-brackish-water, Wil Pergande and Barry Abolmaali
December 28, 2000

For more than 30 years there has been remarkable growth in the need for high quality water purification by all categories of users including municipal, industrial, institutional, medical, commercial and residential. The increasingly broad range of requirements for water quality has motivated the water treatment industry to refine existing techniques, combine methods and explore new water purification technologies.

Membrane Technology

Reverse osmosis (RO). The first method for desalination is membrane separation technology such as RO, which was invented in 1959 and commercially produced in the mid-'60s. RO is a process in which both dissolved organics* and salts are removed using a mechanism different from distillation, ion exchange or activated carbon. The pressurized feedwater flows across a membrane surface with a portion of the feed permeating the membrane. The balance of feed sweeps parallel to the surface of the membrane to exit it without being filtered. This type of system is called crossflow filtration.

The basic process of RO simply requires a pump, membrane pressure housing, membrane element(s) and plumbing connections. The number of membrane elements used in each desalination system is related to the quantity of water produced by the system. There are many types of membranes, each characterized by a particular salt rejection. The pump is used to pressurize the feed water to create the RO effect and distribute the fresh water to storage.

Seawater RO has a conversion rate of 35 percent to 40 percent, which means 35 percent to 40 percent of the feedwater is permeated and the remainder is concentrated to be returned to the water source(s). **The conversion rate of brackish RO could be more than 90 percent**.

RO, using the first crossflow membrane separation, was the first to be widely commercialized. An advantage of crossflow filtration is that the impurities concentrated on the membrane surface are constantly swept away by the concentrate stream, thus continually cleaning the membrane surface. This prolongs its life, reduces fouling of the membrane surface and reduces maintenance costs. Another advantage of the RO process is that it removes most organic compounds and up to 99.5 percent of all ions. In contrast, conventional filters accumulate the captured, non-dissolved impurities on the filter medium and must be periodically cleansed and/or replaced.

Nanofiltration (NF). Often, NF is wrongly categorized as a "loose RO" membrane. The differences are subtle, yet distinct. Most notable is NF's ability to reject only ions with more than one negative charge such as sulfate or phosphate while passing single-charged ions. Another significant feature is its ability to reject uncharged, dissolved materials and positively charged ions according to the size and shape of the molecule in question. This effect is desirable for a number of applications where moderate salt removal is acceptable since operating pressures and power consumption are significantly lowered. So, in exchange for less than complete salt removal, costs are reduced. NF is currently being applied in many industrial settings, municipal water treatment (known as softening plants) and the sugar, dairy and textile industries.

Other crossflow filtration methods. In addition to **RO**, (depending on the size of the pores engineered into a membrane) and **NF**, **ultrafiltration (UF)** and the most recent, **microfiltration (MF)**, also are effective filtration methods. However, only RO and NF have the capability of removing dissolved salts from water. While RO and NF are capable of separating substances as small as ions from feed stream, UF and MF typically separate larger, non-dissolved material, and their systems are typically used as pretreatment prior to RO or NF.

Membrane Technology Advances

Major improvements have been made in membrane technology over the past several years. Thanks to innovative strategy and design mechanisms, performance can now exceed a 99 percent rejection rate. With new, smoother, foul-resistant membranes and improvements designed to lower energy and pumping costs, desalination is becoming a viable option for more markets.

NF/RO. The pioneering process of integrating the NF membrane with RO or one of the conventional desalination processes has been under the development at the Saline Water Conversion Corp. / R & D Center in Saudi Arabia. This process, known as NF/RO, is considered a high-tech pretreatment method to protect the more sensitive RO membranes. Using NF reduces the need for pretreatment with cruder methods such as sand-media filters and clarifiers.

NF pretreatment reduces the RO membrane fouling (plugging) by the removal of turbidity and bacteria; prevents plant scaling (both RO and multistage flash distillation) by removal of scale forming hardness and sulfate ions; and lowers required pressure to operate an RO plant by reducing total dissolved solids (TDS) of seawater feed by more than 25 percent.

The NF/RO process produces a very clean, partially desalinated seawater product. Permeate recovery of NF/RO is approximately 50 percent to 80 percent, which is favorable when compared to the 35 percent to 40 percent produced by the standard RO process. And, as mentioned before, NF pretreatment requires less pumping pressure by reducing the TDS of seawater feed.

To summarize, NF helps RO last longer, which results in a lower cost for operators. The financial and production benefits of NF pretreatment (i.e., the fine quality of the product and reduced cost for operators) make this application particularly attractive to companies wanting to expand their existing plants. Even though capital costs are higher to invest in the extra NF unit, the operations and maintenance costs will be 25 percent lower, which will result in higher conversion and higher output.

RO/RO. RO/RO, a two-pass treatment process, is considered a high-flow seawater RO/low-energy RO process. Although it is an established technology, it can be manipulated to produce very high quality when required.

Single-pass RO normally takes 45,000 TDS water down to 500 parts per million (ppm). (These statistics do not meet the standards required for industrial ultrapure water applications.) Using RO/RO, the first pass high-flow seawater RO takes up to 48,000 ppm, down to 500 ppm. The second pass then takes the 500 ppm water and, using low energy RO, brings it below 50 ppm, which is extremely high quality water (better than drinking water). The conversion rate of this process is 30 percent to 35 percent.

Energy costs of the RO/RO process are more than traditional, single-pass seawater RO systems. However, the extra housing and membrane costs for the RO/RO will add expense to the project, therefore an "economical vs. quality permeate" analysis is recommended to decide if RO/RO will be cost effective.

Applications of Membrane Technology

Seawater desalination systems are serving as resourceful solutions for freshwater scarcity in many markets. Take for example, the sea vessel market. From small boats to cruise and military ships, desalination has become a standard aboard certain vessels. Rather than carrying fresh water, many choose to have a seawater desalination system aboard to save room and avoid the possibility of a water shortage. These systems, varying in size, produce permeate ranging from 20 to several hundred thousand gallons of water per day.

Coastal golf courses and hotels are starting to use desalination plants as a means of irrigation. More resorts are relying on high-efficiency seawater osmosis for potable and irrigation water when before, pure water had to be purchased from local aqueducts because of high domestic water demands.

Cost. To apply cost to the desalination technology, one can use a rough formula. Calculate the estimated cost of a brackish water desalination system by simply taking the cost of the membrane times four. For a seawater desalination system, the total cost is 15 times the membrane expense. (Remember, if employing the NF/RO process, capital costs will rise because of pretreatment.) Similar increases in capital costs apply to the RO/RO process because of the second path, but because this process is effective with lower pressure, lower energy will result.

According to findings in the McIlvaine Report, the total capital cost of RO desalination plants is currently just under $1 billion per year. This does not include RO pretreatment costs. Using an average of $4 per gallon per day (based on total plant cost of previous jobs), the total capital cost of RO desalination plants including both the RO system, piping and other system costs is currently $868 annually. The total cost of owning and operating a plant (based on a $4 per 1,000 gallons of purified water) is $3.2 billion per year. If you consider future plants will be built at an average rate of $3.30 per 1,000 gallons, the implication is that the rate of dollar increase could be affected in a negative fashion. However this rate will be offset by the greater number of plants being built than closed, providing a continuing rise in installed capacity.

By illustrating these advances in membrane technology, one can project that the new millennium will bring remarkable growth to the desalination industry. Four trends are occurring throughout the world that predict increased applications for water desalination in the 21st century. The first is deterioration of water supplies from increased use and disposal of chemicals. Second is the development of increasingly sensitive instruments capable of detecting water contaminants in the parts per billion and even parts per trillion range. Third is the growing sophistication of the general public's knowledge of water quality, demand for contaminant-free water and the regulating authority response in mandating high standards. Fourth is the development of new or refined high-technology products and biotechnology products that require ultrapure water as part of their manufacturing process. Water treatment techniques will require even greater sophistication in years ahead.