Potential sources for water supply for Auroville's population

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"There is enough water; the Aurovilians will have to use their ingenuity to collect it and make use of it."
The Mother, in conversation with Dr.Tim Rees

1 Introduction

For more than 10 years a lot of effort has been made from Auroville and friends from all over the world to understand the situation and behavior of water in our area and develop appropriate ways and means to use, reuse, protect, and improve this precious resource.

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

Still, other mile stones must be laid to address our growing needs for water, from a context where the only resource we use until today, groundwater, is heavily over exploited, depleting and threaten by seawater intrusion and pollution at a regional scale.

Considering that water resource management have a strong relationship and interdependency with planning and development issues, it is essential that the various sources potential, limits and possibilities, possible orientations and choices at hand as well as the implications of such choices are clearly understood. Auroville is still in a context where many possibilities are realistically feasible while further development, if not made in relation with our basic needs for water, can impair several of the possibilities and narrow down the choices.

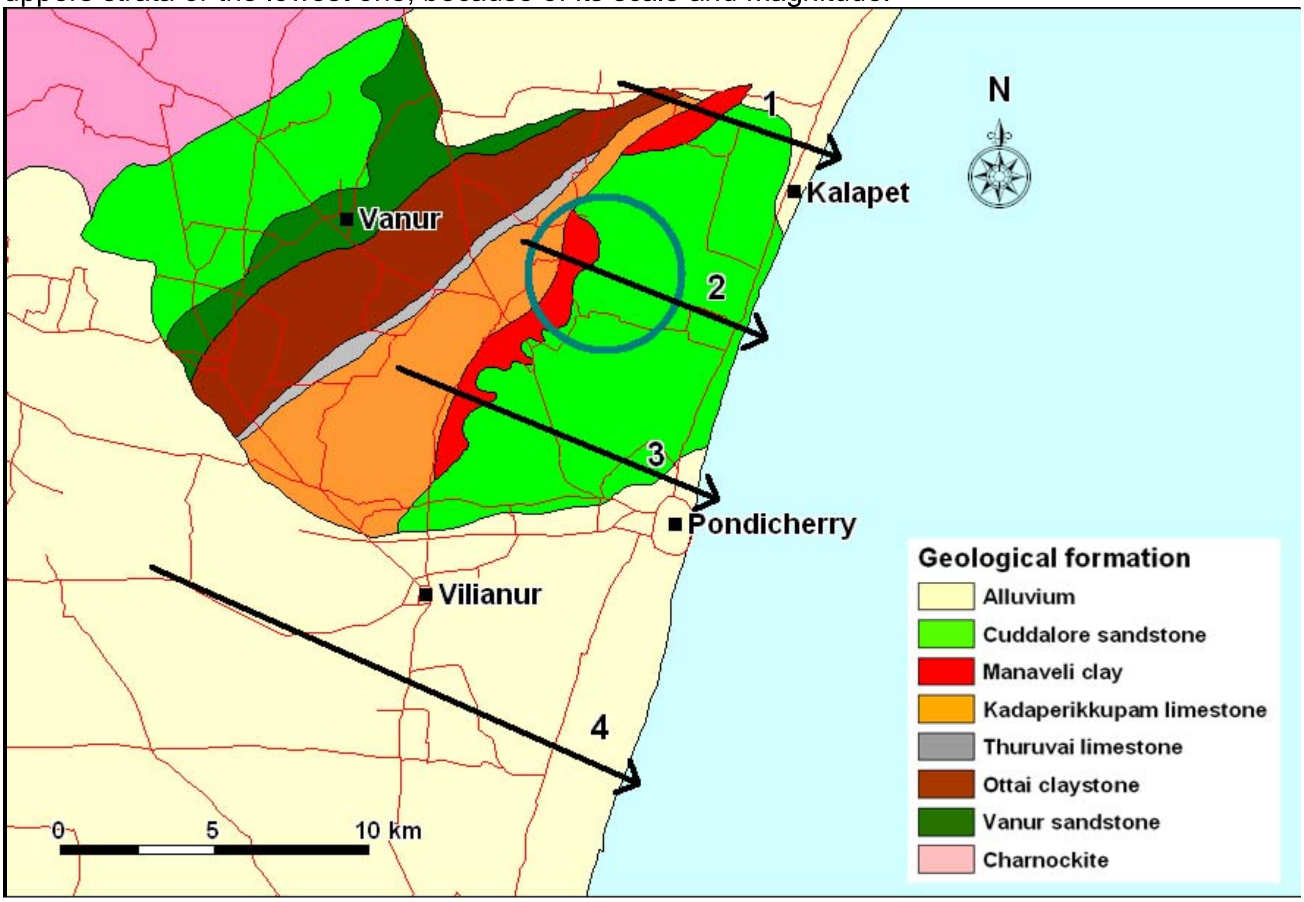
The present study proposes to screen the various options we have for today and for tomorrow in term of water resources in order to secure our demand in a sustainable way.

2 Context

2.1 Groundwater resource: is declining in Auroville.

Groundwater is the only water resource actually used for domestic and urban supply in Auroville and around. With the growth of the population the demand from groundwater for domestic and urban purpose will increase even further.

The large and effective effort Auroville is doing in surface water management and groundwater recharge is not sufficient to counteract the ongoing degradation of this resource, neither on the uppers strata or the lowest one, because of its scale and magnitude.

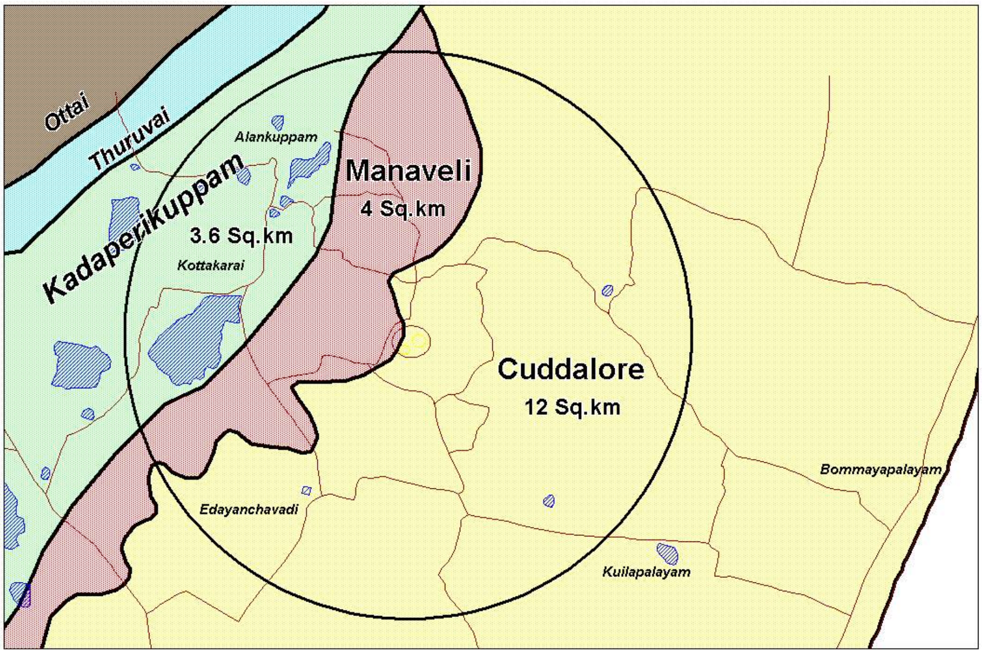


Picture 1: Surface geological formation in Auroville Area

Upper aquifers

Auroville is mainly build on Cuddalore sandstone and Manaveli clay outcropping formations.
The upper and most present aquifer on Auroville plateau, Cuddalore formation (relatively thin at this place), is under layered by a clayey layer (Manaveli clay) under which one find 2 other aquifers (Kadaperikuppam and Turuvai lime stones).

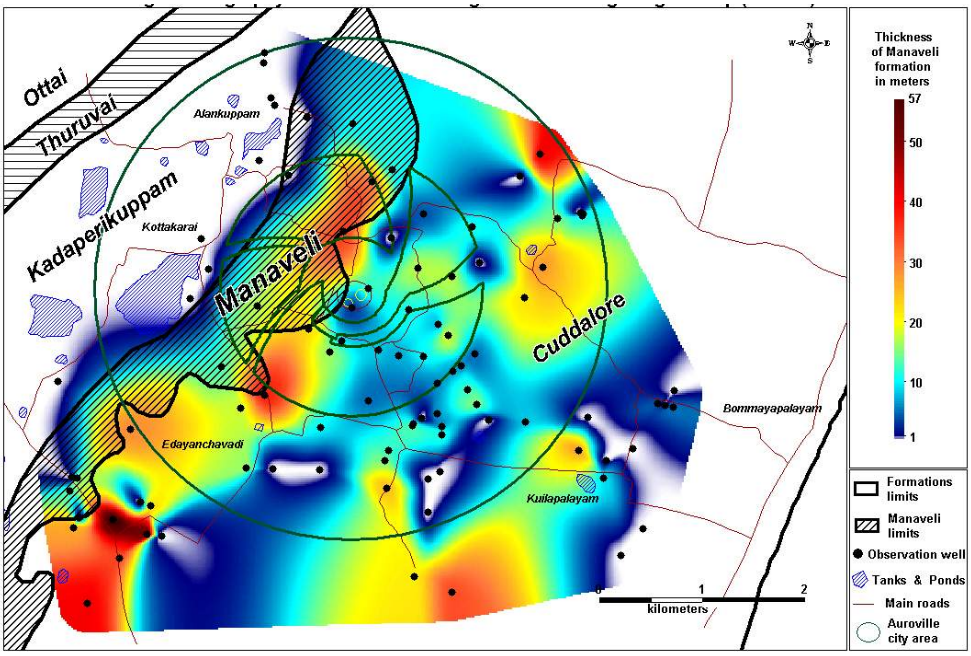
These 3 aquifers supply nearly all the wells of Auroville.



Picture 2Surface geological formation in Auroville

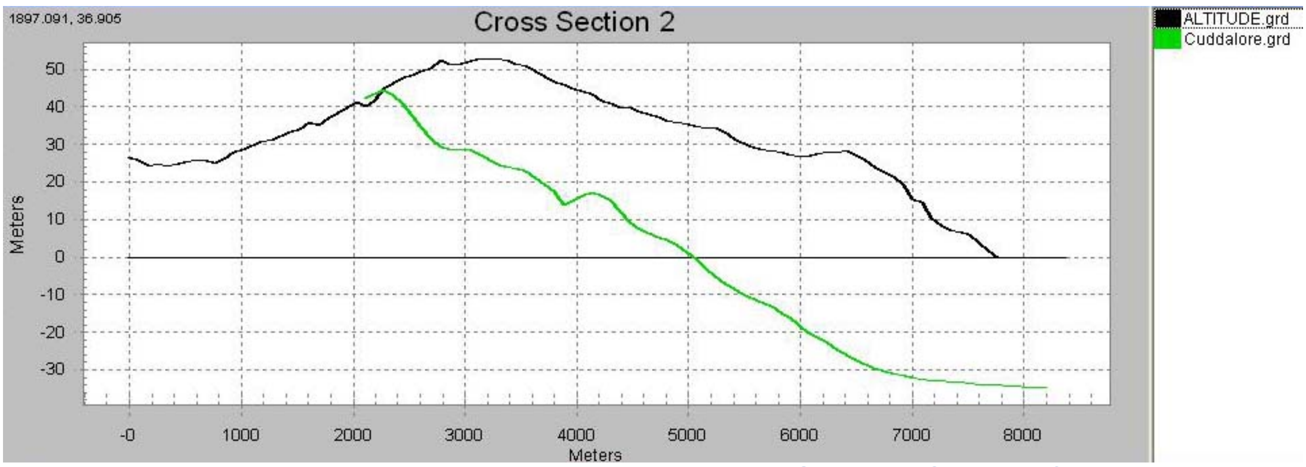
Because of the locally weak structure of Manaveli and because of numerous bore wells passing through, these 3 aquifers are locally interconnected while not acting as one single block.
In the present scenario of over extraction through the entire area, the 2 lowers mentioned aquifers are depleting and because of underneath loopholes and weaknesses in Manaveli clay, Cuddalore formation is leaking downward, getting regularly empty on Auroville's plateau during summer time. This is increasing the despondency on Kadaperikkupam and Turuvai formation, which offer good scope for extraction also 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 Redd, National Geophysical Research Institute HYDERABAD – 500 007 JUNE 1987
Ref: Page 119, para 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.

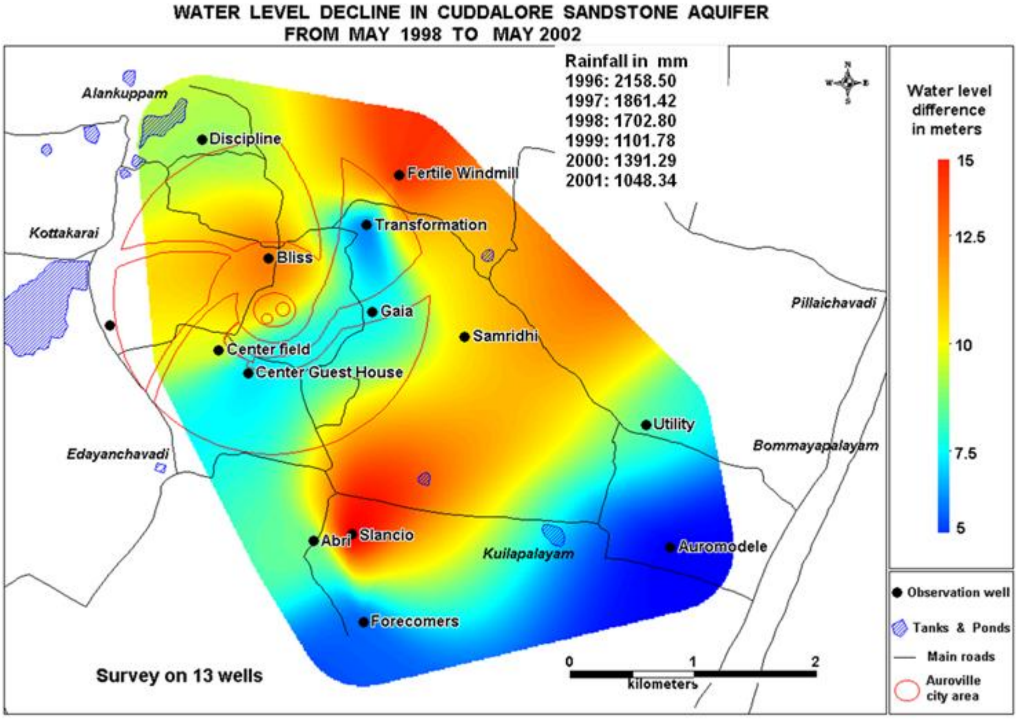


Picture 3Thickness of Manaveli formation in Auroville

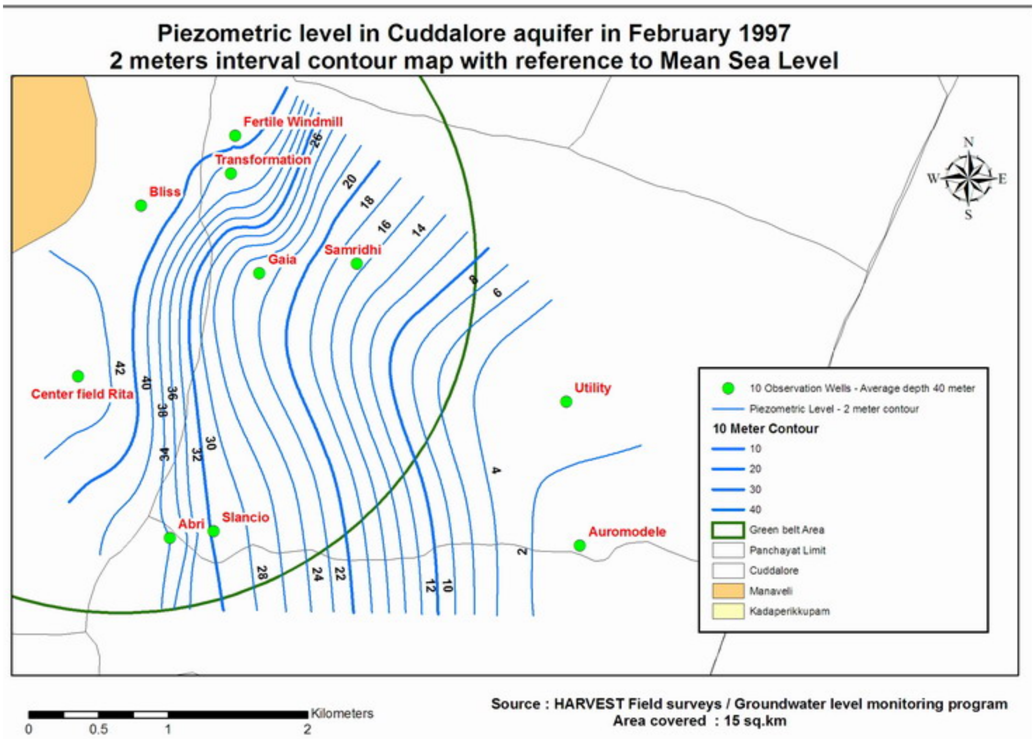
Closer to the coast (Auromodel area), while Cuddalore formation is thickening, one observe for the last 10 years that groundwater level is close or below main sea level. This phenomenon, observed at regional level and linked to over extraction of groundwater, is creating sea water intrusion in large patches along the coast and is extending further inland every year. Sea water intrusion is not yet observed in Auroville itself but may happen in course of time, anytime from now. One cannot predict at this stage and because of limited information how far can this affect the groundwater quality in Auroville's plateau.



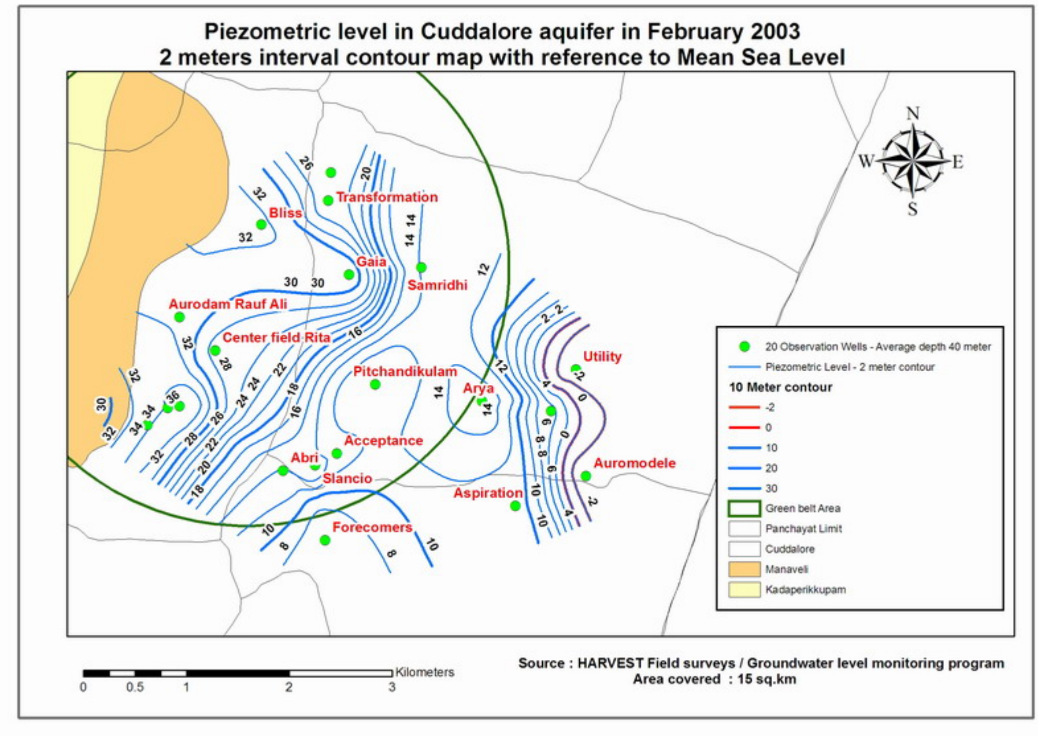
Picture 4: Section on Cuddalore formation in Auroville



Picture 5: Water level decline in Cuddalore formation in Auroville area



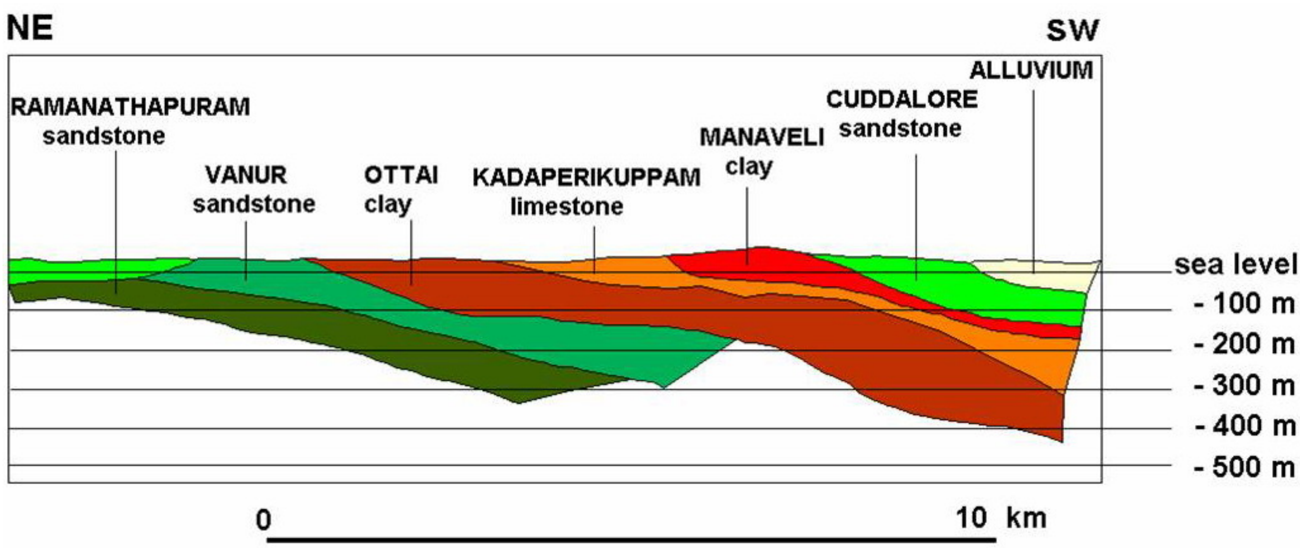
Picture 6: groundwater level in Cuddalore formation in feb 1997



Picture 7: Groundwater level in Cuddalore formation in feb 2003

Lowest aquifers

Deeper underground, and underneath a thick layer of clay, one can find a large aquifer, called Vanur formation (sandstone). This aquifer is heavily overexploited which results in fast depleting of groundwater. Salinity is also increasing, locally above acceptable limits for irrigation, but this salinity increase is so far not from direct sea water 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*), forecast that sea water will probably intrude massively this aquifer in a very short time (1 to 5 years from now) and invade the entire aquifer within 6 months, turning it improper for any direct usage.



Picture 8: Typical section on geological formation in Auroville area

Conclusion
Groundwater is still offering large scope for extraction but is not a secured resource on the long run because of the general trend of depletion and degradation. Remedial measures could address depletion but such complex solutions (reduction of groundwater usage for irrigation, large scale groundwater recharge…) require time to be realized.

One cannot base all the planning and development on groundwater resource because of this fragility.

2.2 Surface water: a large potential as a resource

Rainfall is the only natural, sustained and perennial source of fresh water in our area.
All other resources either originate from it (surface water, groundwater) or are artificially generated (desalinized water).

Considering the preciousness of water and problems rainfalls are generating when not properly integrated in planning issues (flood, erosion...) it is essential to foresee how rainwater may be used and the effects it will generate in Auroville's future.

Because of the large volume of rain falling during short periods, a good part of rain water is drained away if no proper measures are taken to slowdown, retain, store or infiltrate the generated runoff. Through time, Auroville has gained a very diversified, reach and successful experience in runoff control and groundwater recharge through contour bounding, infiltration systems, check dams and ponds together with appropriate plantation all over the plateau and downstream, but also at regional scale. This effort is showing remarkable effects by mitigating, if not fully controlling, surface water losses through runoff. As a large part of Auroville plateau is sloping toward the sea (east), the generated runoff from that part is simply lost if not stopped and stored on the way. The other part is slopping towards west where the chain of irrigation tanks of the area is located and usually stops and stores the runoff if not overloaded by large rains. If so, it ends also to the sea.

By developing further Auroville and hence creating very large impervious areas, the runoff will increase dramatically, overloading largely the existing water catchment systems. Moreover, changes in land use pattern will break the effects of contour bounding as it is today. Direct recharge to the aquifer will also be reduced because of limited area free from buildings.

Proper measures of rainwater harvesting, possibly combine with groundwater recharge, can transform these losses into usable resources and play a central role in supplying Auroville's water demand.

Both points lead logically toward multi sourcing as the most appropriate way to secure planning issues within a reasonable time frame.

3 Potential sources for sourcing

3.1 Groundwater: Infrastructure already existing

- Limited processing required
- Fragile because of general ongoing degradation
- Could be secured through large scale recharge and resource management program (require time)
- Can be integrated in planning and development in a stepwise approach.
- Time is a very serious constraint because of the risk of collapsing.
- Running cost and maintenance are easy and cheap (filtration)

3.2 Rainwater: yearly available in very large quantity but highly fluctuating.

- Can be collected using topographic conditions.
- Cheaper than other solutions.
- Become a multi-purpose solution: drainage, urban landscaping, water supply, awareness.
- Must be part of planning and development issues immediately.
- Not depending on any larger territory than Auroville
- A fully renewable resource
- The 4,9skm of the city area collect 6,4 Mm3 of rainfall per year on the average
- Running cost and maintenance are relatively complex and must be made steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro or ultra-filtration)

3.3 Wastewater: a percentage of the water consumption

- Depending on the population, behavior and process => must be augmented by other resources.
- High risk for cross contamination if not mitigated in large proportion with other resources.
- Can be integrated in planning and development in a stepwise approach
- Become a multipurpose solution: sanitation, supply, awareness induced
- Running cost and maintenance are relatively complex and must be made steadily (pressurized sand filter, activated carbon)

3.4 Seawater desalinization: unlimited resource

- Costly
- Social issues to address
- Highly centralized hence fragile.
- Can be integrated inn planning and development issues at any stage
- Unlimited resource
- Single purpose solution
- Running cost and maintenance are complex, costly and must be made very steadily (decantation, filtration, anti scaling, anti fouling, micro filtration, ultra-filtration, reverse osmosis)

3.5 Groundwater desalinization (once salinized): very large resource (as not used anymore by other users)

- Cheaper than Seawater
- Social issues not because of Auroville but because of general shortage of freshwater.
- Can be integrated inn planning and development issues at any stage
- Becomes a highly renewable resource once it becomes saline
- Single purpose solution
- Running cost and maintenance are relatively complex, rather costly and must be made steadily (filtration, micro filtration, ultra-filtration, reverse osmosis)

3.6 Evaluation table: 4 stars best, 1 star worth

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

GW: groundwater - RW: rainwater harvesting - WW: wastewater - SWD: Seawater desalinization - GWD: groundwater desalinization

*: Red color indicates that it is closed to disqualified solution

3.7 Conclusion

- All sources can be part of the sourcing system.
- Multi sourcing is a necessity
- Groundwater is already practiced but is very fragile. It need specific studies to evaluate its potential and limit as a resource (Cuddalore and the 2 underneath aquifers).
- Groundwater desalination seems a worthy solution if to compare to seawater desalination, and in case groundwater becomes saline of course!
- Rainwater harvesting solution offers best scores. It is hence studied further below. Moreover it must be integrated quickly from the planning point of view while the other solutions can be done through time.

4 Potential from rainwater and surface water

Looking at the topography and soil characteristics (infiltration rate) one can imagine several solutions to harvest this precious water either a systematic effort is made to develop and integrate recharge system through the city

4.1 Ground water recharge: GWR

- Very cost effective in east part of Auroville because of high infiltration rate, but limited scope on west part (clayey soil).
- Recharge potential will drop through development (impervious area)
- No evaporation losses
- Already largely practiced but with important scope for improvement and changes due to future development.
- Become then a groundwater resource and will help to maintain it but is vulnerable to points mentioned in paragraph 3.6.It is difficult to predict today how far it may compensate the ongoing depletion of the water table.

4.2 Roof rainwater harvesting: RWH

- Costly because of the rainfall pattern (large storage required to optimize collection)
- Connection to municipal supply or even neighborhood supply difficult
- Can be developed along the development process
- Single purpose solution
- No evaporation losses if water is stored in close system (underground tank…)
- Running cost and maintenance are complex and must be made steadily (decantation, filtration, pumps)

4.3 Catchment in existing Irumbai irrigation tank (ery): CIT

- Cheap
- Social issue, as it is a collective property of the village used for irrigation purpose and feeding the connected chain of tank.
- It is and must remain a source of irrigation in this part of the green belt which falls naturally in agricultural activities
- High losses by evaporation (shallow and very large water body) and limited storage capacity: water available for a short period of time
- Pollutant from agricultural activities difficult to avoid
- Exceeding water lost: drained out of Auroville area
- Necessity to pump up the water for further usage if used in Auroville
- Running cost and maintenance are relatively complex and must be made steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro or ultra-filtration, pumps to bring the water to the urban area)

4.4 Catchment in artificial ponds made in canyons: CAP

- Costly
- Large excavation required: no natural sites offer scope for storage
- Exceeding water mainly lost to the sea: topography, no down flow storage
- Limited evaporation losses is possible by deepening the ponds
- Running cost and maintenance are complex and must be made steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro or ultra-filtration, pumps to bring the water to the urban area)

4.5 Catchment in Matrimandir Lake: CML

- Cheap as only the drainage system is to be added
- Practical value generated for Matrimandir Lake
- Exceeding water could be recharged in groundwater table as the best possible location
- Social issues while minor cannot be neglected due to diversion of surface water from the irrigation tanks around Auroville to the lake.
- Becomes a multi-purpose solution: drainage, esthetical, symbolic, supply
- Important evaporation losses
- Running cost and maintenance are relatively complex and must be made steadily (decantation, filtration, then pressurized sand filter, activated carbon, micro or ultra-filtration)

4.6 Evaluation table: 4 stars best, 1 star worth

	Treatment required for supply	Fragility to external factor	Resource capacity for securing water supply	Sustainable and integrated solution	Rapidity of realization	Investment	Running cost and mainten-ance	Total
GWR	****	*	**	**	**	****	****	**19**
RWH	****	****	*	***	*	*	*	**15**
CIT	*	*	**	*	****	***	***	**15**
CAP	**	***	***	***	***	**	**	**18**
CML	**	***	****	****	**	****	****	**23**

GWR: Ground Water recharge – RWH: Rain Water Harvesting – CIT: Catchment in Irumbai Tank – CAP: Catchment in Artificial Ponds – CML: Catchment in Matrimandir Lake

CML : see paragraph 6

*: Red color indicates that it is closed to disqualified solution

4.7 Conclusion

- All solutions can be part of the sourcing system.
- The Catchment in Matrimandir Lake solution offers the best score. It is hence studied further below. Moreover it must be integrated quickly from the planning point of view while the other solutions can be done through time.
- Open storage system is generating important losses because of high evaporation rate.
  - Average rain fall: 1 280mm
  - Evaporation losses: 1 800mm
  - Balance: - 520mm

Note: Surface water as a resource imply a good control over pollution. While it cannot be totally avoided, main potential sources should be identified, circumvented and banned as much than possible. Today, the main risk comes from pesticide heavily sprayed on the privately owned lands. The development of a proper runoff water collection system, including along-the-way purification, must hence be developed in accordance with land acquisition to avoid concentration of dreadful substances in the storage and even more dangerous in the distribution system.

5 Definition of the limits for the study

In order to step further, it is necessary to define the criteria within which one can reasonably define a rainwater harvesting system as a resource for water supply.

Considering the large possibility and lack of clarity about the trend and future evolution, even in a short time period, it is proposed to define acceptable maximum and minimum criteria for each parameter as follow:

- Time frame
- Population
- Water consumption
- Runoff
- Limit of validity of a resource from the quantitative point of view

5.1 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 trend bring long term forecasting into a very hazy picture. To develop an infrastructure which will be used reasonably closed to its capacity only after a long time would lead to degradation.

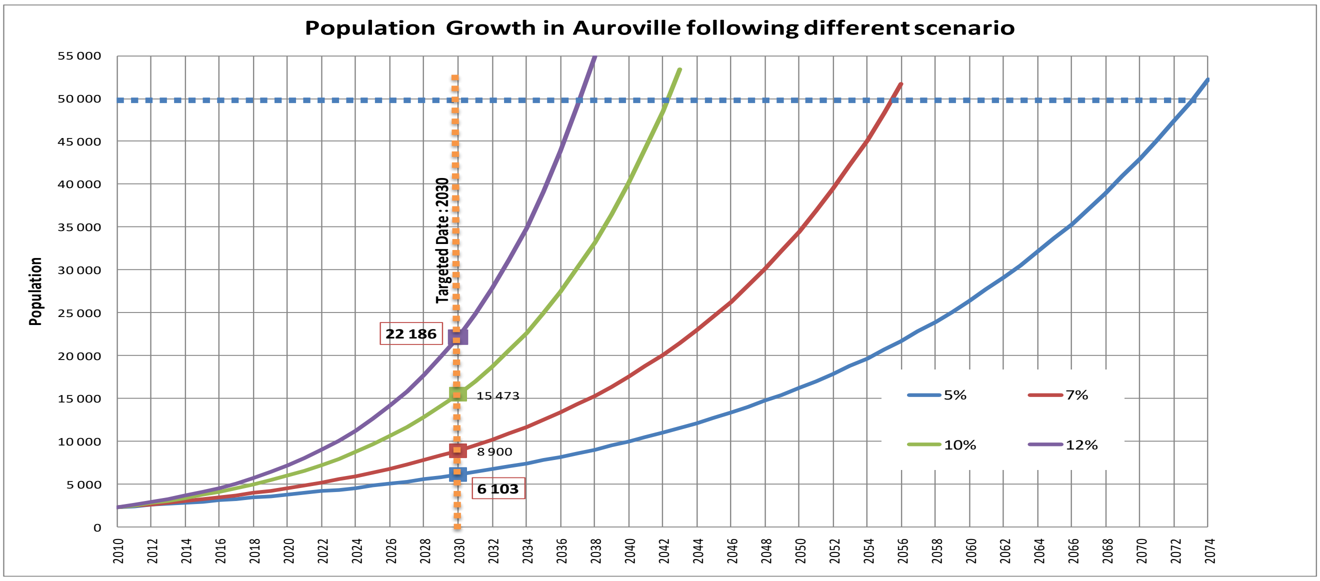
Hence, proposed solutions should fit with practicality in a reasonable time frame and be a sustained asset for the now as well as the long term.

Conclusion: By retrospectively looking at the past and learning from it, it seems very reasonable to **limit practical planning horizon to a 20 years time period** from now or the year 2030.

5.2 Population growth

The final population of Auroville is decided to be 50 000 inhabitant.
The growth of Auroville has been in the range of 5% for a long period.
By looking at various aspects, like housing accessibility for example, it seems clear that this is a low figure which could be much larger in the future. Other criteria, like social acceptability are limiting factors: a super fast growing population is explosive as the basic fabric of the society becomes unstable.

It is proposed to retain a fix range of 5% and 12% population growth as lower and limits to evaluate the effect on water demand.



Picture 9: Potential population growth in Auroville

Conclusion: **by 2030 Auroville's population will reach**

- **6100 people for a growth rate of 5%** and
- **22200 people for a growth rate of 12%**

Note: With a 5% population growth rate, Auroville will reach 50 000 people by 2074
With a 12% population growth rate, Auroville will reach 50 000 people by 2038

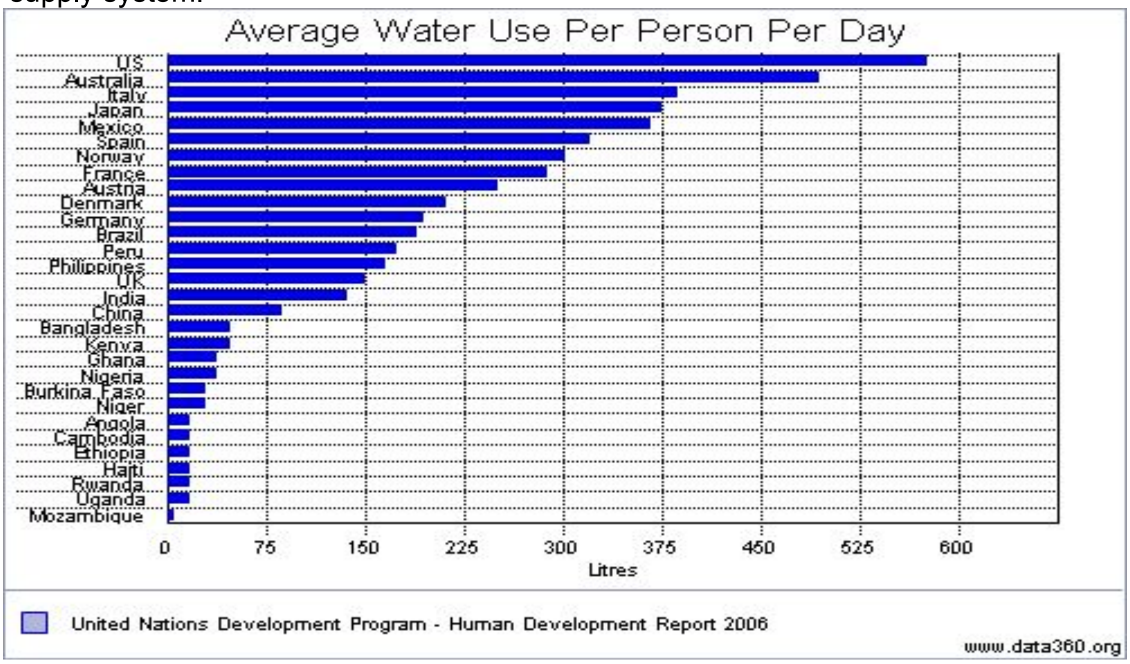
5.3 Water demand in urbanizing context

Is considered here only the urban population. Urban population refers to a population depending on a main collective system.

	Consumption as per literature (Indian values) lcd	Consumption low as per AV projection lcd	Consumption high as per AV projection lcd
Domestic use	135	100	135
Industrial use	50	30	40
Commercial use (factories, offices, hospitals, hostels, restaurants, schools)	20	20	20
Public use (gardening, park, road, public fountain)	10	0	0
Wastes	55	10	20
Average Municipal consumption	**270**	**160**	**215**

Note: Values for Auroville are based on:

- Domestic use is de facto lower than the given figures for Indian city as the volume made available is usually in the range of 90lcd and often much less. Scope for saving is very large on this part by appropriate fittings and metering, recycling of wastewater for toilet flushing, promotion of collective facilities (like collective kitchen and laundries) etc.
- Commercial use is limited because of the very nature of commercial activities in Auroville as planned
- No usage of freshwater for irrigation and roads must prevail but only treated wastewater.
- Limited wastes because of appropriate design, metering and choices of material for the supply system.



5.4 Runoff in a urbanizing context

By developing the city a larger surface will become impervious (buildings, roads, infrastructure…). The more impervious area, the more runoff is generated. The development of the city is in relation to the population growth, hence the proportion of impervious area grows more or less in parallel to the population grow.

As per various calculation, one come to the conclusion that a Roof Rainwater harvesting system will be able to harvest 80% of rainfall, the left over being splash effect, initial washing of surface (bird drops, leave…) collecting and processing devices. It is estimated that a surface runoff collection system will achieve the same results as initial loss by washing of surface etc is not required, while some losses will occur on the collection system itself.

	Minimum values	Maximum values
Population growth	5%	12%
Impervious area (80% runoff) in relation to population density	30%	60%
Natural area (15% runoff) in relation to population density	70%	40%
Average rainfall per year (m3/m2/y)	1,28	1,28
Resulting average runoff per year in relation to impervious area (m3/m2/y)	**0,44**	**0,69**
Runoff as a percentage of rain	*35%*	*54%*
Equivalent average runoff from Auroville (city's limits) (m3/y)	2 167 699	3 392 920

Note: scope for development within the green belt is not clear (villages, land ownership, large infrastructure…), hence the volume of runoff one can expect cannot be defined at this stage.

5.5 Limit of validity of a water resource from the quantitative point of view

The level of complexity and investment of a water resource system require that the volume potentially generated is large enough to justify such choice.

Generally speaking, an investment dedicated to a large infrastructure is justified either because it is acting on public safety or because it is fulfilling a function on the daily life of the targeted population. In the case of a lesser function, it must be evaluated vis-a-vis the global benefit, but also vis-a-vis the complexity of the running operation, or the problems long standby system may generate. Long standby systems have the tendency to be dysfunctional the day one need to restart it, or some of the equipment may need replacement. For example, in water purification system, that is the case of reverse osmosis membrane.

Hence, a water resource system must fulfill 2 criteria: to run for the longest possible period during the year and to run with the smallest possible interval between standby period.

It is fixed arbitrary that such a limit in the context of this study should be **to supply the targeted population for a minimum of half a year (180 days)**.

Below this value investment, maintenance and operation may become too costly to justify such choice.

5.6 Synthesis

	Minimum values	Maximum values	Units
Time frame	20	20	years
Population growth	5%	12%	
Resulting population by 2030	6 100	22 200	People
Fresh Water consumption per person	160	215	lcd
Consumption per day	974	4762	m3/d
Consumption per year	355 683	1 738 094	m3/y
Runoff proportion from rainfall in relation to population/ impervious area	**35%**	**54%**	%
Equivalent average runoff from Auroville (within city limits)	2 167 699	3 392 920	m3/y
Proportion on yearly water consumption	609%	195%	%

5.7 Conclusion

- A 20 years time frame is a reasonable limit for planning definition in Auroville's context.
- Even by using large fresh water consumption values, rainwater harvesting offers a very large scope as a source for supplying the population.
- Auroville as a developing city will offer larger scope for water harvesting through time.

6 Matrimandir Lake

6.1 Introduction

The Matrimandir Lake was decided by the Mother.

In the basic characteristic She gave, it was defined as a large water body acting as a reservoir to supply the City.
Through time, Roger developed several design for the lake. This study is based on the latest design he made.
As well, several technical or conceptual studies were conducted concerning the lake. H.Kraft (Pre-Feasibility Study on Water Supply, Storm water and Wastewater Management City of Auroville- 2003), then Jeen Kootstra & the Auroville Water Group (Auroville Water Management A pre-feasibility study- 2007), finally LGA developed the idea further and analyzed the way it could be integrated in Auroville's context, the role it can positively play in the entire water scenario, or the way it can be technically realized.

Nevertheless, such a large structure with its potential subsidiaries needs to be studied from a very practical point of view, means in relation to the ground reality and the way it can be integrated in the topographic context. It has potentially a very high impact on planning and development issues and must hence be talked in proper time, the earliest the best to avoid further major drawback or even impossibilities. This has never been done so far.

The lake has a symbolic and esthetical value, as a large piece of water surrounding Matrimandir and its gardens, the center of Auroville, which is representing its soul and connection to the Divine.

In our given context, such large water body would imply to compensate the yearly losses of water by evaporation (and leakage). The appropriate source of water must be found.

If one consider as well the lake as a reservoir, to identify the large water resources which one can tap to fill and replenish the lake becomes essential.

This part of the study is looking at the ways and potential for maintain the lake in its 3 functions: esthetical, symbolic and practical. It is not looking at the technical aspects of the realization of the lake itself but at the possibility to integrate it in the given and future context.

<u>The most appropriate and cost effective way to replenish the lake would be:</u>

- By collecting the runoff from an area large enough to generate the required volume, even in driest year
- By gravity to avoid large pumping systems and related mechanism

All other options will depend on resources already threaten or targeted for other purposes, or technically intense or very costly (like desalinized water) and hence most probably out of reach and inappropriate.

If the 2 criteria above are realistically achievable, then one can look at a third one and to turn the lake into a golden seal on our water resources:

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

If these 3 criteria can be achieved, then the lake becomes not only an extremely valuable asset but may become the heart of a living water system through the entire city.

<u>Note</u>: It is to worth mentioning that if it becomes possible to collect water harvesting through Matrimandir Lake, it does not represent a very large investment: the Lake and its maintenance are anyhow part of the Peace area's entire concept, and therefore costs which are not specifically related to runoff management does impair the Lake cost alone.
Moreover, as developed afterward, the lake needs a relatively large dedicated drainage area in order to replenish it through time without taping other resources: evaporation is larger than direct rainfall hence must be compensated.
Finally, a lake, in order to maintain its own ecological system, must have a minimum permanent depth, which is equally valid if the lake is a standalone system or a reservoir. Hence it must be replenished at time to avoid excessive depletion, hence the need for sourcing this water.

6.2 Basic

Because of its esthetical and symbolic aspects, Matrimandir lake is a necessity. A minimum size is required to fulfill these functions. Because of its requirement for regular refilling (evaporation lost, leakage) it is best to compensate losses through a drainage system. Hence the cost of the Matrimandir Lake and a part of the drainage system does not fall on the rainwater harvesting system for the city. On the opposite, Matrimandir Lake could be the central part of rainwater harvesting system.

6.2.1 As per Roger Anger's design:

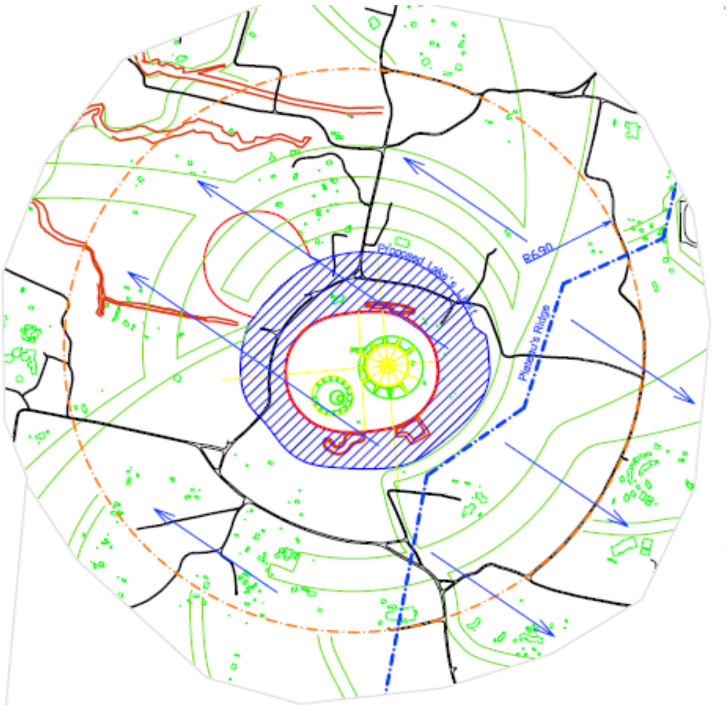
- The lake should cover an area of 162 000m2.
- The total depth is not defined
- The upper water level is fixed at 25cm below the Matrimandir oval path
- The oval path level is (and is in fact) fixed at an altitude of 50.90m
- The lower level is 75cm below upper water level (or one meter below the oval path level)
- The lake is designed as one single water body with one single level

6.2.2 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 53.00m (and up to 56.00m locally), so a minimum of 2.10m above the Matrimandir oval path level.

The separation of flow between east and west occurs along a line more or less oriented south-southwest, north-northwest and passing by Deepanam school area as shown on the map below.

Hence, Matrimandir Lake is fully on the west versant of Auroville's plateau and below the highest area. In this context, the possibility to collect surface water in the lake by gravity becomes worth looking at.



Picture 10: Dividing crest position for surface water reparation in Auroville' city area

<u>Conclusion</u>: It is possible to supply Matrimandir Lake by collecting surface water

6.2.3 Contour levels in and around Matrimandir Lake area

From Deepanam school area, the altitude goes lower in a more or less concentric mode elongated along the separation of flow line.

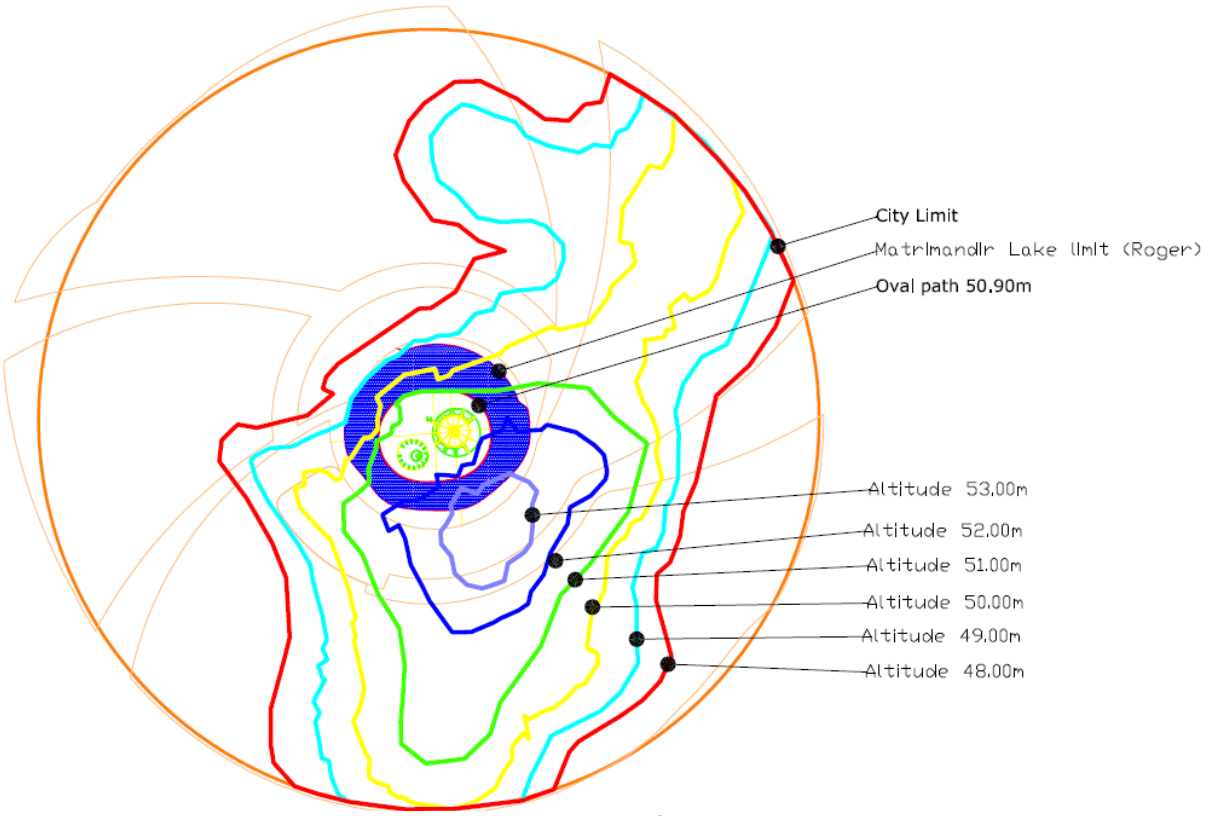
- Natural ground level is around 2m above lake level on the west part
- Natural ground level is around 2m meter below lake level on the east part
- Hence the lake is located on an area with 4m difference in level

<u>Personal note by Gilles B</u>: *while communicating topographic context around the lake to Roger Anger, in 2004 or earlier, it becomes clear that Roger was not aware of the ground reality. Hence the proposed design.*

In this given context, it is worthy to re-evaluate the various possibilities for the best possible lake's design in order to try to get the most valuable beauty to the city center together with best possible usage for this very large infrastructure.

For example, in the case the lake is made with one single level, equal to Matrimandir Oval path level, one as to consider that all the buildings situated on half of the lake's periphery will face a visual obstacle of 2 meters high minimum.

For example, the ground around Town Hall is about 2 meters below the lake border, situated about 30m away from the building (the border is materialize in its position by the light and low fence covered with blue creepers).



Picture 11: Contour lines showing altitude in Auroville 'city area

6.2.4 Conclusion

It becomes very clear that the integration of the lake with the surrounding area and the planed or existing buildings must be studied from a practical and esthetical point of view.

It is hence proposed to study 4 concepts for the lake

- To define the maximum lake size that it can be replenish by direct rain and collected drainage from Matrimandir Oval only, for yearly rainfall as low as 1m.
- To replenish the lake only (using Roger's design area) for yearly rainfall as low as 1m.
- To replenish the lake and supply the population from drainage area with one single water level (as per Roger's design for level and area)
- To replenish the lake and supply the population by using optimized drainage system (using Roger's design area).

6.3 Common retained design parameters

- The lake has an area of 162 000m2.
- Matrimandir oval is fixed and cover an area of 90 000m2, drained to the lake.
- The total depth is not defined (not critical for this study)
- The overflow (full) water level is fixed at 25cm below the Matrimandir oval path (altitude 50.90m, hence water level at 50.65m max)
- The lower water level is 100cm below full water level or 162 000m3 of usable storage
- An extra lowering of 10cm is accepted and fixes the lowest water level at 110cm below upper level.
- The lake's design will vary with the concepts

Note: f specific values prevail, it is mentioned for each system.
All following evaluations are based on 11 years daily rainfall data and day-by-day processing. Period 1995 to 2005, data from Auroville Water Harvest weather station.

A specific excel based software has been develop to compute the data as per multiple scenarios.

6.4 Minimum design: Self maintained lake (with Matrimandir Oval's runoff)

Trial and error method has been followed to determine the optimal value

Parameters:

- Replenished by direct rain on the lake and by collected runoff from Matrimandir Oval
- Tested values for the lake's area: as low than possible that the lake does not need replenishment from other sources for yearly rain as low than 1.00m.
- Excess runoff (higher than lake's storage capacity) will overflow.

Retained value for Lake's area			**73 500m2**
Equivalent volume down to lower level -1.00m			73 500m3
Equivalent volume down to lowest level -1.10m			-80350m3
Year	**Rainfall mm**	**Minimum stored water volume in the lake during the year - m3**	**Equivalent height of water - m**
1995	922	30 164	0,41
1996	2 159	4 826	0,07
1997	1 861	12 002	0,16
1998	1 703	8 249	0,11
1999	1 102	9 764	0,13
2000	1 391	23 358	0,32
2001	1 048	20 022	0,27
2002	1 012	9 065	0,12
2003	1 141	-7 403	**1,10**
2004	1 478	18 621	0,25
2005	1 668	-2 759	1,04

Note: Positive values on stored water volume indicate water level at or above -1.00 from overflow level.
Excess water will reach the lake, for example during the monsoon: the lake being of a fixed capacity, it will overflow. This excess water is to be handled properly, for further drainage or for recharge.

Conclusion:	the maximum area for a self maintained lake is 73 500m2 (lowest value during year 2003), or 45% of Roger's design.
Note:	Such lake will not fulfill esthetical parameters as it will drop lower than the acceptable limit during the dry period of the year (as low as -2.00 below full level). It must hence be compensated from other sources in order to maintain this minimum level.

6.5 Minimum function: to replenish the lake even with 1.00m rain

Trial and error method has been followed to determine the optimal value

Parameters:

- To Replenish the lake by: direct rain on the lake, collected runoff from Matrimandir Oval (90 000m2) and collected runoff from extended area **- to be defined**
- Tested values for the lake's area: as low than possible that the lake does not need replenishment from other sources for yearly rain as low than 1.00m.
- Excess runoff (higher than lake's storage capacity) will overflow.

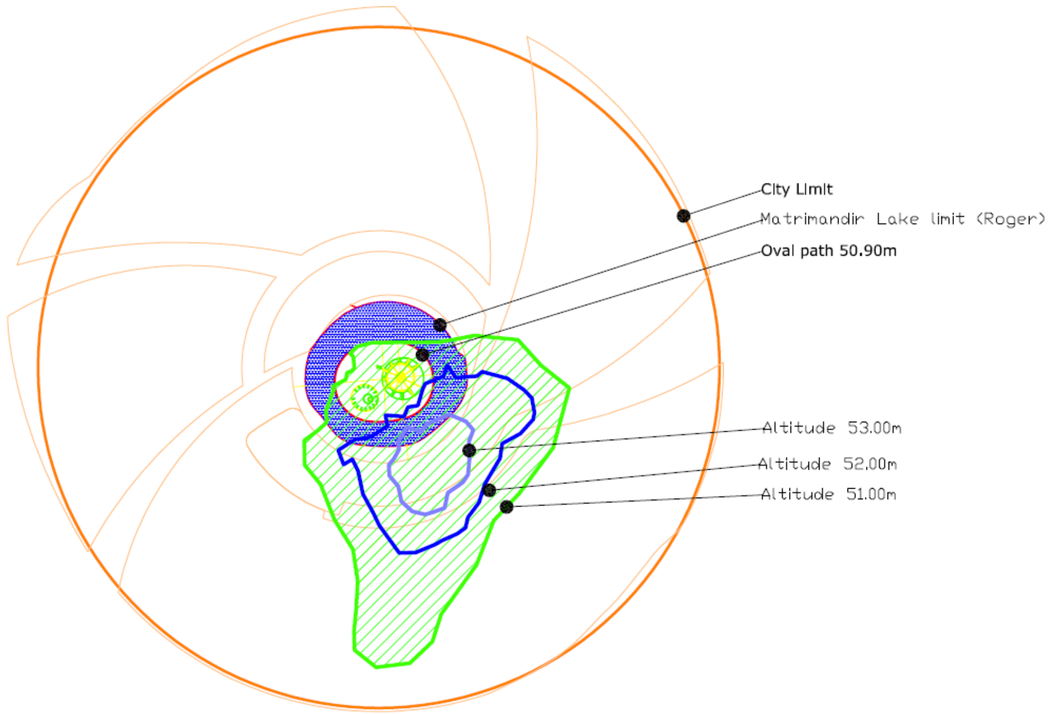
Tested drainage area		Minimum runoff value: 35% = > 350 000m2	Maximum runoff value: 54% = > 233 500m2
Year	Rainfall mm	Balance lake & Drainage area m3	
1995	922	32 162	-25 866
1996	2 159	465 235	329 443
1997	1 861	361 758	244 656
1998	1 703	306 083	198 960
1999	1 102	27 449	25 812
2000	1 391	108 242	108 418
2001	1 048	11 493	10 416
2002	**1 012**	**237**	**5**
2003	1 141	46 118	37 197
2004	1 478	141 362	133 254
2005	1 668	200 587	189 021

Conclusion : On top of Matrimandir Oval's runoff and direct rainfall on the lake, the area which must be drained toward the Matrimandir Lake in order to maintain it for a yearly rainfall as low than 1.00m (year 2002) is 143 500m2 for highest runoff values and 260 000m2 for lowest runoff values (see paragraph 0).
Larger yearly rainfall will generate runoff while lesser yearly rainfall will require replenishment from other sources.
Hence, part of the city must be studied and equipped with proper drainage system to fulfill this function.

Note: Such lake will not fulfill esthetical parameters as it will drop lower than the acceptable limit during the dry period of the year (as low as -2.00 below full level). It must hence be compensated from other..

6.6 Replenish the lake and supply the population from drainage area with one single water level (as per Roger's design)

- To replenish the lake by: direct rain, collected runoff from Matrimandir Oval (90 000m2) and collected runoff from area above the upper limit of the lake a per Roger's design - oval path at 50.90m altitude.
- Replenishment from other sources if level goes lower than -1.10m. The replenishment will bring back the water level to -1.00
- Runoff in relation to population and therefore build-up proportion is determined at 35% of rainfall (see paragraph 5.4).
- All other parameters as per paragraph 6.3: Common retained design parameters



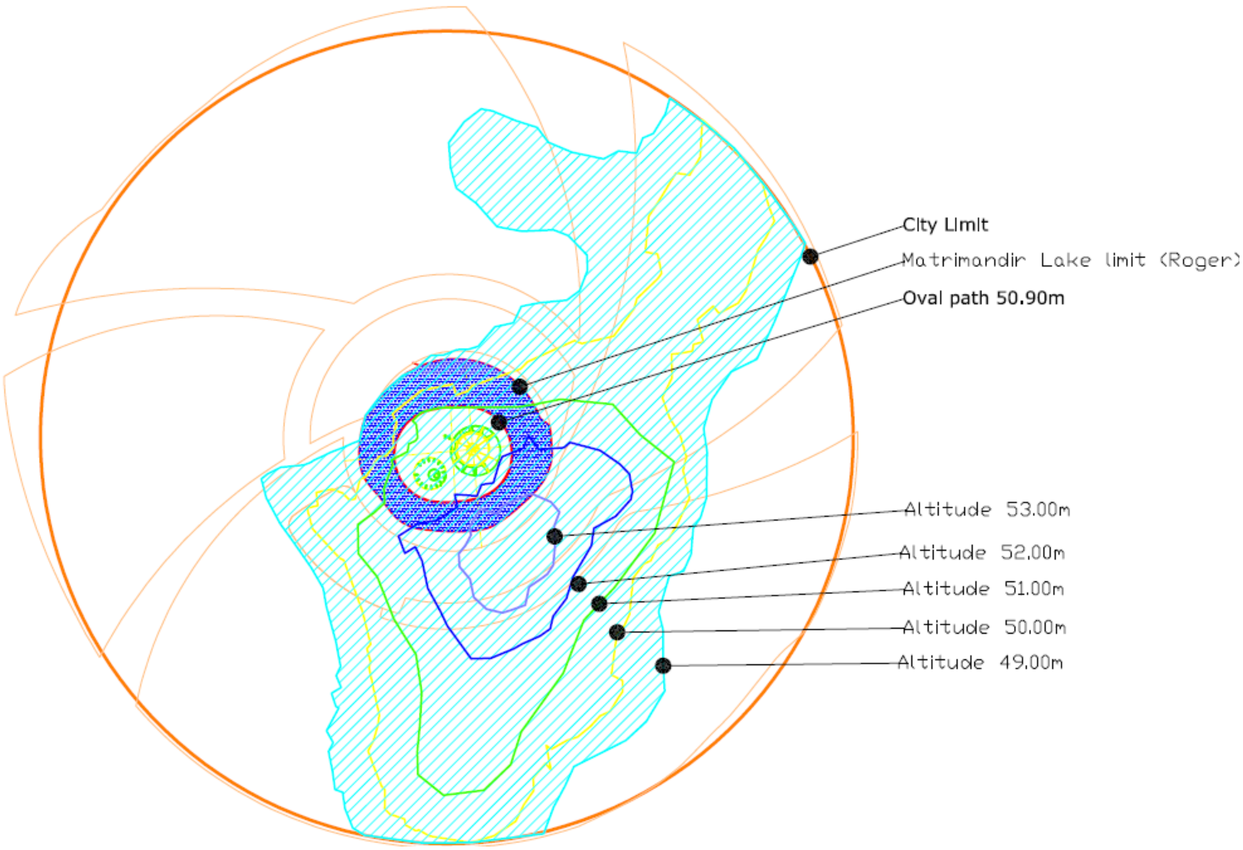
Picture 12: Contour lines showing ground level at and above oval path altitudes in Auroville's city area

	Minimum values	Maximum values	Units
Drainage area	**717 000**		m2
Runoff from drainage area			
Maximum	346 277		m3
Minimum	147 976		m3
Average	225 847		m3
Population in Auroville by 2030	**6 100**		People
Fresh Water consumption per person	160	215	lcd
Consumption per day	976	1 312	m3/d
Consumption per year	356 246	478 698	m3/y
Number of supplied days from lake			
Maximum	286	229	Days
Minimum	171	120	Days
Average	213	179	Days
Secondary results			
Extra volume required to maintain esthetical values			
Maximum	116 900	116 900	m3
Minimum	33 400	50 100	m3
Average	76 542	80 717	m3
Extra supplied days if to compare to non compensated lake (average)	59	55	Days
Overflow from lake			
Maximum	293 268	241 614	m3
Minimum	0	0	m3
Average	103 655	83 528	m3
Maximum runoff from drainage area in one day	69 199		m3

Conclusion :	In such condition, the lake can supply on the average 58% of the yearly demand for low water consumption values and 49% of the yearly demand for high water consumption values. Minimum values =0 from overflow indicates that the lake will not reach full level during certain years. Sources for extra water required to maintain the esthetical value of the lake are to be defined. Overflow values from the lake itself are anyhow usually superior to this requirement. Added water for esthetical reason plays an important role in increasing the number of supplied days.
Note :	Overflow is to be handled properly, for further drainage or for recharge for example. If not maintain to minimum esthetical level (-1.00), the lake will drop lower by respectively 45 and 52cm.

6.7 Replenish the lake and supply the population by optimizing drainage system and levels: a step lake

- To replenish the lake by: direct rain, collected runoff from Matrimandir Oval (90 000m2) and collected runoff from areas adjacent to lake: a step lake, related to the topography.
- Replenishment from other sources if level goes lower than -1.10m. The replenishment will bring back the water level to -1.00
- Runoff in relation to population and therefore build-up proportion is determined at 54% of rainfall (see paragraph 5.4).
- All other parameters as per paragraph 6.3: Common retained design parameters



Picture 13: Contour lines showing ground level fitting with lake's boundary in Auroville's city area

	Minimum values	Maximum values	Units
Drainage area	**2 074 000**		m2
Runoff from drainage area			
Maximum	2 123 705		m3
Minimum	907 531		m3
Average	1 385 109		m3
Population in Auroville by 2030	**22 200**		People
Fresh Water consumption per person	160	215	lcd
Consumption per day	3 552	4 773	m3/d
Consumption per year	1 296 480	1 742 145	m3/y
Number of supplied days from lake			
Maximum	233	203	Days
Minimum	171	158	Days
Average	202	179	Days
Secondary results			
Extra volume required to maintain esthetical values			
Maximum	100 200	116 900	m3
Minimum	33 400	50 100	m3
Average	73 758	82 108	m3
Extra supplied days if to compare to non Compensated lake (average)	15	14	Days
Overflow from lake			
Maximum	1 775 508	1 695 367	m3
Minimum	233 473	120 888	m3
Average	914 720	818 395	m3
Maximum runoff from drainage area in one day	267 222		m3

Note: comparatively, the drainage area as defined in the previous paragraph (717 000m2) will generate respectively 90 and 71 supplied days for this given population of 22 200 people.

Conclusion: In such condition, the lake can supply on the average 55% of the yearly demand for low water consumption values and 49% of the yearly demand for high water consumption values.
Minimum values >0 from overflow indicates that the lake will systematically reach full level every years.
Large volume of overflow generated will require appropriate measure to handle it and avoid flood.
Sources for extra water required to maintain the esthetical value of the lake are to be defined. Overflow values are anyhow usually superior to this requirement.
Added water for esthetical reason plays an interesting role in increasing the number of supplied days.
Note : Overflow is to be handled properly, for further drainage or for recharge for example.
If not maintain to minimum esthetical level (-1.00), the lake will drop lower by respectively 41 and 43cm.

6.8 Analytical Synthesis

The present analysis is bringing all the information in a single table format in order to get a synthetic overview for each case and between cases.

The code color included in the reference number is used in the following paragraph for easier understanding. Basically, yellow stand for a no supply of the population (ref 1), green for a supplied population of 6600 people (ref 2 to 5) and blue for a supplied population of 22000 people (ref 6 to 9).
On top of the analyses covered in the previous paragraph, is evaluated the impact of non replenishing of the lake to acceptable esthetical limits (from -1.10 to -1.00 below overflow level).
Because of the absence of interest for the initial evaluation: minimum self compensate lake, it is not include at this level.
The number of possible variation covered is therefore of nine.

Ref	Design	Advantage	Inconvenient	Constraints
1	Lake area 162000m2 (Roger's design)	Minimum drainage surface	Impossible to maintain the lake level within esthetical limits (-2,00)	To install a drainage system on 350 000m2
	No feeding of the population: not a reservoir			To take care of the overflow of the lake
	Level: 1	Collect by gravity		
	Minimum drainage area to replenishment the lake only		Difficulty to integrate existing and new buildings near the lake	
	Minimum level -1,00m below full level			
2	Lake area 162000m2 (Roger's design)	Feeding of the population for 154 days (average)	Impossible to maintain the lake level within esthetical limits (-1,45)	To install a drainage system on 717 000m2
	Feeding of the population - 6600 persons @160lcd		Difficulty to integrate existing and new buildings near the lake	To take care of the overflow of the lake
	Level: 1	Collect by gravity		
	Drainage area fitting with lake's level	Reduced excavation volume (~100 000 less if to compare to case 6 to 9)		
	No level compensation			
	Minimum level -1,00m below full level			

3	Lake area 162000m2 (Roger's design)	Feeding of the population for 213 days (average)	Extra resources to collect (storage?) and to bring to the Lake (pumps)	To install a drainage system on 717 000m2
	Feeding of the population - 6600 persons @160lcd		Difficulty to integrate existing and new buildings near the lake	To take care of the overflow of the lake
	Level: 1	Partial feeding by gravity		To locate and exploit extra resources in accordance with design
	Drainage area fitting with lake's level	Reduced excavation volume (~100 000 less if to compare to case 6 to 9)		
	Level compensation to minimum level			
	Minimum level -1,00m below full level	Respect of esthetical design		
4	Lake area 162000m2 (Roger's design)	Feeding of the population for 124 days (average)	Impossible to maintain the lake level within limits (-1,50)	To install a drainage system on 717 000m2
	Feeding of the population - 6600 persons @215lcd			To take care of the overflow of the lake
	Level: 1	Collect by gravity		
	Drainage area fitting with lake's level	Reduced excavation volume (~100 000 less if to compare to case 6 to 9)		
	No level compensation		Difficulty to integrate existing and new buildings near the lake	
	Minimum level -1,00m below full level			
5	Lake area 162000m2 (Roger's design)	Feeding of the population for 179 days (average)	Extra resources to collect (storage?) and to bring to the Lake (pumps)	To install a drainage system on 717 000m2
	Feeding of the population - 6600 persons @215lcd			To take care of the overflow of the lake
	Level: 1	Partial feeding by gravity	Difficulty to integrate existing and new buildings near the lake	To locate and exploit extra resources in accordance with design

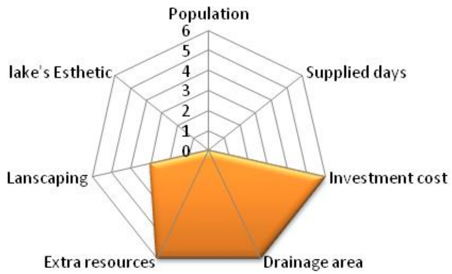
	Drainage area fitting with lake's level	Reduced excavation volume (~100 000 less if to compare to case 6 to 9)		
	Level compensation to minimum level			
	Minimum level -1,00m below full level	Respect of esthetical design		
6	Lake area 162000m2	Feeding of the population for 187 days (average)	Impossible to maintain the lake level within esthetical limits (-1,40)	To install a drainage system on 2 074 000m2
	Feeding of the population - 22 200 persons @160lcd			To take care of the overflow of the lake
	Level: multiple	Collect by gravity		
	Drainage area fitting with lake's extend	Easiness to integrate existing and new building around the lake	Increased excavation volume (~100 000 more if to compare to case 2 to 5)	
	No level compensation			
	Minimum level -1,00m below full level			
7	Lake area 162000m2	Feeding of the population for 202 days (average)	Extra resources to collect (storage?) and to bring to the Lake (pumps)	To install a drainage system on 2 074 000m2
	Feeding of the population - 22 200 persons @160lcd			To take care of the overflow of the lake
	Level: multiple	Partial feeding by gravity		To locate and exploit extra resources in accordance with design
	Drainage area fitting with lake's extend		Increased excavation volume (~100 000 more if to compare to case 2 to 5)	
	Level compensation to minimum level			
	Minimum level -1,00m below full level	Respect of esthetical design		
8	Lake area 162000m2	Feeding of the population for 165 days (average)	Impossible to maintain the lake level within limits (-1,45)	To install a drainage system on 2 074 000m2

	Feeding of the population - 22 200 persons @215lcd			To take care of the overflow of the lake
	Level: multiple	Collect by gravity		
	Drainage area fitting with lake's extend	Easiness to integrate existing and new building around the lake	Increased excavation volume (~100 000 more if to compare to case 2 to 5)	
	No level compensation			
	Minimum level -1,00m below full level			
9	Lake area 162000m2	Feeding of the population for 179 days (average)	Extra resources to collect (storage?) and to bring to the Lake (pumps)	To install a drainage system on 2 074 000m2
	Feeding of the population - 22 200 persons @215lcd			To take care of the overflow of the lake
	Level: multiple	Partial feeding by gravity		To locate and exploit extra resources in accordance with design
	Drainage area fitting with lake's extend	Easiness to integrate existing and new building around the lake	Increased excavation volume (~100 000 more if to compare to case 2 to 5)	
	Level compensation to minimum level			
	Minimum level -1,00m below full level	Respect of esthetical design		

6.9 Graphic representation of the results

The reference of the graphs refers to the table above. Numerically values used in the graphs come from the previous analysis transformed into identical values from 0 to 6, in order to harmonize the visual results.0 stand for worth and 6 for best.

1



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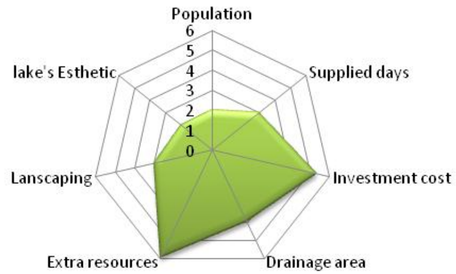

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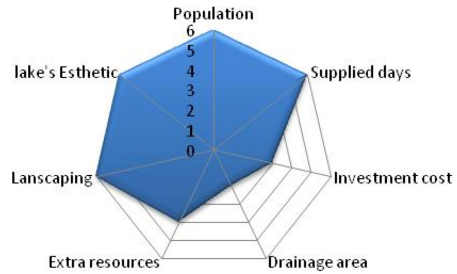

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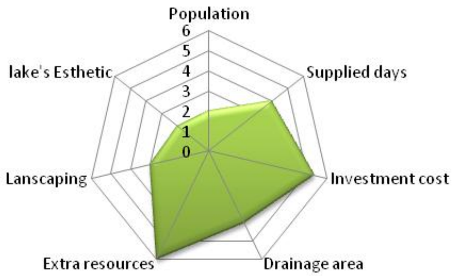

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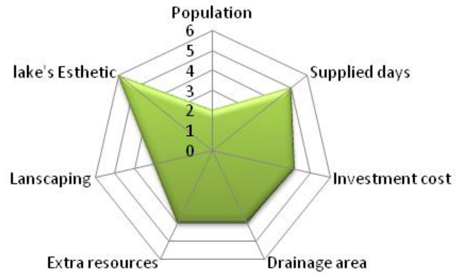

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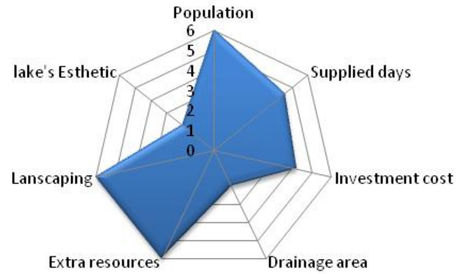

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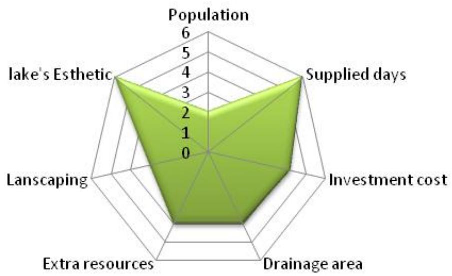

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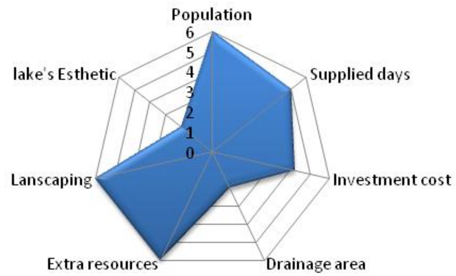

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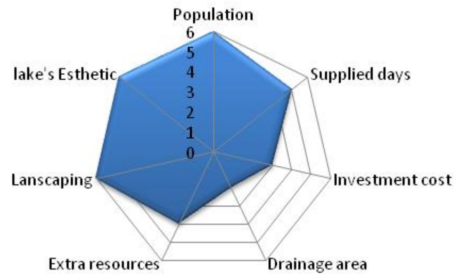

Term	Refer to
Population	Population supplied by the lake (values: 0, 6600, 22200)
Supplied days	Number of days the lake can supply the given population for a given daily consumption, as per results of the computation
Investment cost	Cost as per the complexity of the drainage system, the lake being a separate issue (see paragraph 6.1)
Drainage area	The smaller the drainage is the better the value as it becomes simpler to realize
Extra resources	Requirement if any to maintain the lake within esthetical limits
Landscaping	How the lake fit with the natural landscape (only 2 values)

Conclusion: The best scenario is given in the graph 7, while the graph 9 is only slightly inferior because of higher water consumption. Hence a large drainage system with a large population, combined or not with water consumption reduction, is the best solution.

6.10 General conclusion and recommendation

Matrimandir Lake can play a prime role in supplying the growing population of Auroville.

It is possible to supply water to a large part of Auroville's population from drained surface water to the lake. As such, it is a cost effective and simple concept.

A properly designed system developed in accordance with the topography will ensure the multiple functions (symbolic, esthetical and practical) it is proposed to have. But to reach its full potential and supply the largest possible population, the lake must be adapted to the topographical context, wish is anyhow crucial in regard to integration with the surrounding.

Nevertheless, if the esthetical aspect is to be respected, it requires getting water from other source.

Considering the overflow generated by the lake every year, it is largely enough in term of volume for this requirement. As well, areas non connected to the lake could be developed in order to collect the required water.

To step further, it is recommended:

- To study a step lake in regard to urban design and landscaping
- To study the way a proper drainage system could be developed in Auroville's urbanized context, including water ways, erosion control, sedimentation areas, biofiltre systems etc.
- To analyze the way the required extra water could be collected (surface water or else) to maintain esthetical minimum level.
- To envisage variable design scenario in regard to existing land feature (hillock, rockery, major trees...)
- To look particularly at the soil movement issue: such lake means to move a major volume of soil, to be disposed of somewhere...

Picture 14 & Picture 15: how a step lake (or a terrace lake) could look like

SECTION 2

Fil conducteur : comment le lac peut avoir une vrai fonction ?

Pourquoi un lac ?
Les indications de Mères : références bibliographiques
La fonction du lac : uniquement esthétique et symbolique ou aussi utilitaire ? Pour quels usages ? Comment ?

Historique des études existantes
Projet de Roger Anger
Autres études

Incidence du lac sur les projets d'aménagement d'Auroville ?
Alimentation en eau potable
Autres usages de l'eau
Recharge des nappes

Emplacement de bâtiments ou infrastructures existants
Emplacement des routes
Modifications topographiques ?

Incidence du lac sur l'environnement social et naturel autour d'Auroville ? Echelle des micro bassins versants adjacents concernés pour les eaux de surface ? Echelle des ressources souterraines concernées ?
Alimentation en eau potable ?
Recharge des nappes ?
Ruissellement ?
Remplissage des bassins d'irrigation (erys) ?

Quels sont les différents scénarios de construction du lac ? Avantages/ inconvénient
Lac dessiné par Roger Anger
Lac de même surface + même empreinte au sol mais à plusieurs niveaux (topographie)
Lac de même surface mais empreinte au sol différente et à plusieurs niveaux (topographie)
Surface différente
Pas de lac

Que faire avec les 500 000 m3 de terre excavés (soit un volume de terre à bouger de 600 000 m3 minimum) ? = 1km X 1 km X 600 m de hauts = un immeuble de 200 étages)

Aspects paysagers ?
Aspect de l'eau
Plantes aquatiques ou pas ?
Différents niveaux topographiques ?
Berges ?

Aspects d'Intégration du lac ?
avec les jardins du Matrimandir ?
avec le parc Matrimandir ?
avec la ville ?

Circulation autour/au dessus/ à travers le lac ?

Aspects environnementaux

Biologie du lac et fonctions épuratoires par rapport aux usages ciblés ?
Ecosystème (interface avec l'environnement faune et flore)

Interfaces du lac avec l'environnement social d'Auroville ? (villages alentours ?)

D'où vient l'eau ?
Qualité de l'eau du lac ?
Aspect de l'eau ?

Coûts directs et coûts induits des travaux ?

Fire Hydrant