Calculations

1. BASIS OF CALCULATIONS

1.1. PRECIPITATION:**

	Auroville's period	Since 1911
Average	1.279 mm	1.290 mm
Minimum	731 mm	626 mm
Maximum	1.910 mm	2.604 mm

NOTE: the data on Auroville's period has been taken for the following calculation

1.2. EVAPORATION: (CLASS A PAN CUDDALORE)*

Winter:	237 mm
Summer:	498 mm
South-west Monsoon:	694 mm
North-east Monsoon:	301 mm
Average:	1.600 mm

1.3. POTENTIAL EVAPOTRANSPIRATION:

POTENTIAL EVAPOTRANSPIRATION AT AUROVILLE STATION
As per Several Calculation Methods (mm)

Method	Total
PET as per THORNTHWAITE's Method	1682
PET as per TURC's method	1753
Referencial ET as per HARGREAVE's method	1679
PET in CGWB 1984 report using Thornthwaite's Method	1732
Calibration of Penman PET using Thornthwaite PET (*)	*1880*

(*) The Thornthwaite method is known to systematically underestimate PET in more arid regions and seasons. Thus the UEA/CRU provided an empirical adjustment factor using detailed data sets for Europe and Sudan, where Penman estimates were

PET(P) = 1.3 * PET(T) - 0.428 * PRECIP + 246

While Penman and Thornthwaite PETs remain comparable in humid areas, the above formula allows for greater adjustments in dry and semi-arid regions where the underestimation of Thornthwaite PET is highest.

PET: 1.880 mm/yr.

NOTE: The process of assessing Potential Evapotranspiration in Auroville by using Penman's equation and satellite image is ongoing and will allow giving much accurate estimate soon.

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* Sources: Regional Weather Station Pondicherry, Auroville Station-Certitude, PWD Pondicherry, Auroville Station-Harvest

COMMENT ON DRAFT REPORT OF HARALD KRAFT FROM AUROVILLE WATER SERVICE – HARVEST

1.4. TEMPERATURE:*

Maximum:	43,8°C in May 1976
Minimum:	14,9 °C in February 1974
Winter:	Average 23,5 – 25,4°C
March - May:	Average 26,9 – 31,1°C
SW Monsoon:	Average 31,5 – 38,5°C
NE Monsoon:	Average 27,6 – 23,8°C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temperature'C'	23.5	24.9	26.9	29.3	31.1	31.4	30.4	29.5	28.5	27.6	25.6	23.8

The yearly mean temperature fluctuation is of 7.9ºC.

1.5. RELATIVE HUMIDITY:*

	8.00 a.m.	4.00 p.m.
Winter:	81 %	71 %
SW Monsoon:	66 – 81 %	64 – 79 %
NO Monsoon:	87 %	80 %

1.6. AREA

Area		
City Ac		
Impervious area	**45%**	**2.21 km²**
Rooftops	50%	1.10 km²
Streets, Sidewalks and Public Squares	50%	1.10 km²
Open area	**55%**	**2.70 km²**
Garden area	10%	0.27 km²
Parks, Green Corridors	90%	2.43 km²
Greenbelt		
Agricultural area	50%	7.36 km²
Wooded area	50%	7.36 km²
City (Ø 2,5 km)	Ac =	4.91 km²
Greenbelt (Ø 5,0 km)	AGB =	14.73 km²
Total	**Atot =**	**19.63 km²**

1.7. POPULATION

Final Population: 50.000 inhabitants

2. SAFE WATER YIELD FROM PRECIPITATION

2.1 PRECIPITATION

Area	Rainwater Yield		
	Average M m³	Minimum M m³	Maximum M m³
City			
Impervious area	**2.83**	**1.61**	**4.22**
Rooftops	1.41	0.81	2.11
Streets, Sidewalks and Public Squares	1.41	0.81	2.11
Open area	**3.45**	**1.97**	**5.16**
Garden area	0.35	0.20	0.52
Parks, Green Corridors	3.11	1.77	4.64
Greenbelt			
Agricultural area	9.42	5.38	14.07
Wooded area	9.42	5.38	14.07
City (Ø 2,5 km)	6.28	3.59	9.38
Greenbelt (Ø 5,0 km)	18.84	10.76	28.13
Total	**25.12**	**14.34**	**37.51**

2.2 RUNOFF

The general approach about rainwater catchments in Auroville has been a zero runoff approach.
Considering the very promising result so far, it seems obvious that it is possible to improve the actual situation further, especially in view of the impervious area.

- Runoff is actually safely observed in Auroville above 120mm of rainfall per day. it generates an average runoff of 0.885Mm3 per year, with a minimum of 0Mm3/y and a maximum of 4.634Mm3/y.
- Considering the ground reality (poor landscaped areas, private lands) we can very safely assume that it will rise at least to 150mm of rainfall per day.
- Frequency of Runoff as per actual conditions: 3 days every 2 years.
- As per future expected conditions: 1day every 2 years (for unpaved area).
- Frequency of heavy runoff (above 200mm of daily rainfall): 1 day every 6 years.
- Maximum observed daily rainfall: 324mm
- Average rainy days per year: 62
- Average runoff per year as per expected conditions on unpaved area: 23mm (2% of average yearly rainfall).
- Maximum yearly runoff as per expected conditions on unpaved area: 174 mm (13% of average yearly rainfall).
- Safe minimum daily rainfall to get runoff on cultivated lands: 100mm
- Safe Minimum daily rainfall to get runoff from roof top with appropriate infiltration structures: 100mm
- Minimum daily rainfall to get runoff on streets: 30mm

The following tables show a progression linked to appropriate surface water management devices.

2.2.1 Yearly runoff as per combined daily rainfall data (1968-2002) and improved facilities

Unpaved area:

- Garden, parks and wooded area: runoff start above 150mm of rainfall per day (the difference is infiltrated)
- Agriculture area: runoff start above 100mm of rainfall per day (the difference is infiltrated).

Runoff on open area in meters per year			
	Average	Minimum	Maximum
Green area	0.023	0.000	0.174
Agriculture area	0.067	0.000	0.316

Impervious area:

- Rooftop: properly collected and infiltrated runoff start above 100mm of rainfall per day (the difference is infiltrated)
- Streets: runoff start above 20mm of rainfall per day.

Runoff on paved area in meters per year			
	Average	Minimum	Maximum
Streets	0.743	0.172	1.547
Rooftop collected	0.023	0.000	0.174

Note:

- The runoff as been calculated with rainfall above the starting limit for the streets (20mm/d), and with the potential runoff (means the part of the rainfall above the runoff limit) for the other areas.
- As per practical experiments in Auroville, it is simple and cheap to limit to a very large extend the runoff from the paved area (a part of the streets, parking and other areas used by petrol engine because of pollution). Hence it is possible to reduce the runoff from the city and adjust the drainage and storage facilities accordingly.
- As per practical experiments in Auroville, it is simple and cheap to limit to a very large extend the runoff from the paved area (a part of the streets, parking and other areas used by petrol engine because of pollution). Hence, it is possible to reduce the runoff from the city and adjust the drainage and storage facilities accordingly. In that view, it is expected to catch rainfall up to 100mm per day. For the Roof top area.

2.2.4 Resulting Runoff

Area	Runoff Final			
	Runoff Coefficient %	Average M m³	Minimum M m³	Maximum M m³
City				
Impervious area		**0.85**	**0.19**	**1.92**
Rooftops	5%	0.03	0.00	0.19
Streets, Sidewalks and Public Squares	32%	0.82	0.19	1.73
Open area		**0.06**	**0.00**	**0.47**
Garden area	2%	0.01	0.00	0.05
Parks, Green Corridors	2%	0.06	0.00	0.42
Greenbelt				
Agricultural area	5%	0.50	0.00	2.33
Wooded area	2%	0.17	0.00	1.28
City (Ø 2,5 km)		0.91	0.19	2.39
Greenbelt (Ø 5,0 km)		0.67	0.00	3.61
Total		**1.58**	**0.19**	**6.00**

2.3 SEWAGE FLOW

Day	50.000 P x 159 L/P	=	7,950 m³/d	= 0.008 M m³
Month	7.950 m³ x 30 d/month	=	238,500 m³/month	= 0.238 M m³
Year	7.950 m³ x 365 d/a	=	**2,901,750 m³/year**	**= 2.900 M m³**

2.4 WATER DEMAND

2.4.1 Water Demand for Municipal Supplies in India

	Consumption lcd	*Reusable part %*	*Reusable part lcd*
Domestic use	135	80	108
Industrial use	50	70	35
Commercial use (factories, offices, hospitals, hostels, restaurants, schools)	20	80	16
Public use (gardening, park, road, public fontain)	10	0	0
Wastes	55	0	0
Average Municipal consumption	**270**		**159**

2.4.3 Equivalence for Auroville Population

	Equivalent Water Demand for Auroville City	
	Consumption M m3/y	***Reusable part M m3/y***
Domestic use	2.46	1.97
Industrial use	0.91	0.64
Commercial use (factories, offices, hospitals, hostels, restaurants, schools)	0.37	0.29
Public use (gardening, park, road, public fontain)	0.18	0.00
Wastes	1.00	0.00
Average Municipal consumption	**4.92**	**2.90**

2.4.4 Estimated Actual Water Demand in Auroville

	Consumption lcd
Domestic use	185
Industrial & Commercial use	31
Public use (gardening, park, road, public fontain)	600
Wastes (10%)	82
Average Municipal consumption	**898**

2.4.5 Irrigation Demand

The water demand from the vegetation in the parks and the greenbelt is equivalent to the precipitation minus the runoff.

No other additional irrigation is planned.

Note: While being suitable for the Greenbelt's forest area and part of the park in the city area, does it fit with all Parks and Gardens of the City Area as well as the agricultural part? If not, then the water consumption must be assessed.

The water demand for gardens and agricultural areas is equivalent to the potential evapotranspiration.

COMMENT ON DRAFT REPORT OF HARALD KRAFT FROM AUROVILLE WATER SERVICE – HARVEST

NOTE:

- The water requirement for paddy is of 120cm when groundnut need 45cm, gram 30cm and vegetables about 60cm, this for one culture only. To optimise the land use means to utilize the land for several cultures per year: usually three to four (ex: rice, groundnut, gram, green manure). Hence, the irrigation demand would be about 200cm per year.
- The PET value is from Thornthwaite corrected formula. By looking to Penman's equation, more accurate, we obtain a PET value of 2016mm for closed grain crops, which generate a water deficit even more important. To simplify the comparison, the table below is as per Harald Kraft calculation.

		As per Daily Rainfall		
Water Balance		Average	Minimum	Maximum
Potential Evapotranspiration	m	1.88	1.88	1.88
PRECIPITATION mm	m	1.28	0.73	1.91
RUNOFF mm	m	0.07	0.00	0.31
Water Deficit	**m**	**0.67**	**1.15**	**0.28**
Irrigation Demand				
Garden Area	M m³	0.18	0.31	0.08
Agricultural Areas	M m³	4.91	8.46	2.07
Total Irrigation Demand	**M m³**	**5.09**	**8.77**	**2.14**

3. WATER BALANCE

	As per Optimized situation		
Water Demand	For Average Rainfall M m³/a	For Minimum Rainfall M m³/a	For Maximum Rainfall M m³/a
Municipal Consumption	4.92	4.92	4.92
Irrigation	5.09	8.77	2.14
Total Water Demand	**10.01**	**13.70**	**7.07**
Safe Water Yield			
Rooftops	0.03	0.00	0.19
Surface	1.55	0.19	5.81
Sewage	2.90	2.90	2.90
Total Safe Yield	**4.48**	**3.09**	**8.90**
Water Balance	**-5.53**	**-10.61**	**1.83**

3.1 DRINKING WATER SUPPLY

The precipitation distribution in the rainy season is as follows:

		Average	Minimum	Maximum
SW Monsoon	31 %	406 mm	88 mm	1071mm
NE Monsoon	62 %	809 mm	214 mm	1869 mm

	As per Optimized situation		
Safe Water Yield	**Average M m³/a**	**Minimum M m³/a**	**Maximum M m³/a**
Municipal Water Demand	**4.92**	**4.92**	**4.92**
Rainwater from the Rooftops	0.03	0.00	0.19
Rainwater from the Streets	0.82	0.19	1.73
Rainwater from the Open Areas	0.06	0.00	0.47
Green Belt Agricultural areas	0.50	0.00	2.33
Green Belt Wooded areas	0.17	0.00	1.28
Total Rainwater Runoff	**1.58**	**0.19**	**6.00**
Water Balance	**-3.35**	**-4.73**	**1.08**
	-68%	**-96%**	**22%**

The precipitation distribution in the rainy season is as follow:

		Average	Minimum	Maximum
SW Monsoon	31 %	385mm	158 mm	659 mm
NE Monsoon	61 %	771mm	298mm	1386 mm

Maximum precipitation of 1.654 mm in 4 months
Maximum monthly precipitation of 748 mm
Maximum runoff per month:
From roof top of 549mm, 466 for streets, 255mm on cultivated land and 174mm on forest and other lands
Maximum runoff during NE Monsoon:
From roof top of 919mm, 786mm for streets,316mm on cultivated land and 174mm on forest and other lands.

		As per Optimized Situation			
Catchment Area	Area km²	Runoff Coeff. %	Ared km²	Runoff max. Month M m³	Runoff max NE-Monsoon M m³
Rooftops	1.10	5%	0.06	0.03	0.08
Streets	1.10	32%	0.36	0.15	0.46
Open Areas	2.70	2%	0.05	0.02	0.06
Agricultural areas	7.36	5%	0.39	0.17	0.50
Wooded areas	7.36	2%	0.13	0.06	0.17
Total	**19.63**		**0.99**	**0.43**	**1.28**

4. REQUIRED STORAGE VOLUME IN THE GREENBELT

As per Indian Meteorological Department, the Probable Maximum Precipitation for our area is of 60cm in 2 days and 70cm in 3 days.
Anyhow, it odes not make sense to try to catch any imaginable quantity of rainfall.
Much more realistic is to try to define suitable size of storage facilities as per available data.
According to monthly rainfall data, we get the following information:

- During one month, rainfalls above 600mm happen only four times in 35 years. Hence, we may safely consider that 600mm is a suitable maximum figure.

		As per Optimized Situation			
Catchment Area	Area	Runoff Coeff.	Ared	Runoff max. Month	Runoff max NE-Monsoon
	km²	%	km²	M m³	M m³
Rooftops	1.10	5%	0.06	0.15	0.15
Streets	1.10	32%	0.36	0.64	1.03
Open Areas	2.70	6%	0.17	0.30	0.32
Agricultural areas	7.36	5%	0.39	1.03	1.03
Wooded areas	7.36	2%	0.13	0.81	0.88
Total	**19.63**		**1.11**	**2.93**	**3.42**

- During NE Monsoon, rainfalls above 1300mm happen only three times in 35 years. Hence, we may safely consider that 1300mm is a suitable maximum figure.
- For a 4 months period, rainfalls above 1350mm happen only three times in 35 years. Hence, we may safely consider that 1350mm is a suitable maximum figure.

By using the Corrected data from daily rainfall minimized at an acceptable level (4 runoffs not included for 35 years), we obtain the following result:

Maximum Precipitation – NE Monsoon: 1,300 mm

Average Max Monthly Precipitation NE Monsoon: 433 mm

Required Maximum Capacity for Infiltration Trenches:

Q_{inf} = 14,239 m³/d

Required Storage Volume in the Greenbelt:

min $V_{GB} = A_{red} \times 433$ — 0.427 M m³

max $V_{GB} = A_{red} \times 1{,}300$ mm — 1.281 M m³

	Max runoff per month m	Max runoff NE Monsoon m
Rooftop collected	0.140	0.140
Streets	0.580	0.930
Green area	0.110	0.120

To collect the entire runoff of Auroville the storage facilities in the Green Belt should be sized between 2.90Mm3 and 3.5Mm3

5. REQUIRED STORAGE VOLUME FOR THE CENTRAL LAKE AROUND THE MATRIMANDIR

Equivalent volume of lake for 40 days retention time — 569,545 m3

Chosen characteristics for the central lake at the Matrimandir

Surface area	A_{tot}	= 181.100 m²
Inner Embankment	A_i	= 36.377 m²
Outer Embankment	A_o	= 55.253 m²
Area of lake bottom	A_b	= 94.173 m²
Slope of Embankment	1:n	= 1:3
Maximum depth	t	= 10 m
Average depth	t_m	= 7,60 m
Volume	V_n	= 1.376.369 m³
Minimum retention time	t_r	= 40 days

Inlet Filter

Inflow	max Q_d = 34.400 m³/d
Filter velocity	V_F = 0,2 m/h = 4,8 m/d
Minimum filter size	A_F = 34.400 m³/d / 4,8 m/d = 7.167 m²
Chosen	72 m x 100 m = 7.200 m²
Alternative	Ø 96

Outlet Filter

Filter velocity	10 m/h = 240 m/d
Minimum filter size	A_F = 34.400 m³/d/240 = 143 m²
Chosen	10 m x 15 m

6. INFILTRATION AND EVAPORATION LOSSES IN THE LAKE

1.8. 6.1 INFILTRATION LOSSES IN THE CENTRAL LAKE

Losses through infiltration with a sealant made of 1.000 mm vacuum-sealed natural clay:

Embankments

$Q_B = A_{tot} \times k_f \times H / L = 3{,}5 * 10^{-11}$ m/s x 91.630 m² x 5 m / 0,1 m

Q_B = 0,0002 m³/s = 13,85 m³/d = 5.057 m³/yr.

Bottom of Lake

Q_S = 94.173 m² x 3,5 x 10^{-11} m/s x 10 m / 0,1 m = 0,0003 m³/s

Q_S = 28,47 m³/d = 10.394 m³/a

Q_{INF} = 15.450 m³/yr.

Evaporation Losses

Precipitation:	P_{ave} =	1.300 mm
Evaporation:	E_{ave} =	1.600 mm
Deficit:	D =	300 mm
Surface area:	=	181.000 m²
Evaporation Loss:	Q_V = A x D =	181.000 m² x 0,3 m
	Q_V =	54.300 m³/yr.

Total Losses in Lake through Infiltration and Evaporation

Q_{EI} = 69.750 m³/yr. ≅ 0,07 M m³/yr.
This corresponds to about 5 % of the storage volume and a sinking of the water level of around 38,5 cm, or about 3,2 cm on the average each month throughout the year.

Estimation of the Losses in Storage in the Greenbelt

Storage Volume
min V_{GB} = 1,033 M m³
max V_{GB} = 3,983 M m³
Average Depth = 5,0 m
Surface Area
min A_{GB} = 206.600 m²
max A_{GB} = 796.600 m²
Evaporation Losses
max Q_E = 0,239 M m³
min Q_E = 0,062 M m³
Infiltration losses when sealing with 10 mm vacuum.sealed natural clay

min Q_{INF} = 1,75 x 10^{-9} m/s x 206.600 m² x 3.600 s x 24 h = 31 m³/d = 11.315 m³/yr.
max Q_{INF} = 1,75 x 10^{-9} m/s x 796.600 m² x 3.600 s x 24 h = 120 m³/d = 43.963 m³/yr.
Total Losses to Storage in the Greenbelt
min Q_{EI} = 0,073 M m³
max Q_{EI} = 0,283 M m³

Total Storage Losses

min Q_{tEI} = 0,073 + 0,07 = 0,143 M m³/yr.
= 3,7 % of average annual discharge (3,845 M m³/yr.)
max Q_{tEI} = 0,283 + 0,07 = 0,353 M m³/yr.
= 9,2 % of average annual discharge (3,845 M m³/yr.)

7. FACILITIES FOR THE CONVEYANCE OF SURFACE WATER

1.9. 7.1 ANNUAL OUTPUT

Q_{fl} = 2,07 – 5,6 M m³/yr.
Q_{max} = 33.600 m³/d = 388,9 l/s
The maximum capacity required for the pumps is calculated from the output at maximum water level in the lake and the corresponding vertical rise according to the following equation:

$$P_P = \frac{\rho\, g\, Q_{P\max} H}{1.000\, \eta} \quad (7-1)$$

ρ = 1.000 kg/m³
H = 25 m
Q_{pmax} = 400 l/s = 1.440 m³/h = 34.560 m³/d
H = 0,61

$$P_P = \frac{1\, kg/l \cdot 9{,}81\, m/s^2 \cdot 400\, l/s \cdot 25\, m}{1.000 \cdot 0{,}61} = 160{,}83$$

According to manufacturer's instructions, an increase of about 20 % above the required pump capicity, P_P, is necessary as a safety measure for the estimation of the minimum required motor capacity, P_M:

P_M = 1,2 P_P = 192,99 kW