CROWN ROAD

AUROVILLE

GENERAL TECHNICAL DESIGN STUDY

&

HYDRAULIC VERIFICATION

OF THE

ENTIRE CROWN ROAD

The following study was conducted by

Commissioned and financed by

FINAL REPORT

Auroville, September 2012

INDEX

1. Foreword

The Auroville Master Plan 2004 foresees the building of a circular Crown Road with an axis radius of 690 m. The reference for the centre is the banyan tree at the Matrimandir. In April 2012, TDC commissioned Aqua Engineers to carry out a study of the technical aspects of the entire Crown. The study has been presented to and accepted by TDC on Saturday, xx August.

2. Executive summary

The Right of Way (RoW = area where no building is allowed) of the Crown is supposed to be 18.0 m. A tolerance of 50 cm on each side has been agreed on by TDC.

The Crown surface and landscaping design with its final road width, cycle path, footpath and possibly a solar tram track is yet to be finalized. Different concepts have been discussed in the past, taking into consideration different mobility concepts and a solar powered public transport system, as well as a covered, shaded walking area. So far, there is no final layout available.

In 2007, TDC/L'Avenir team started to pave parts of the future road in phases, starting from Solar Kitchen/PTDC up to Kalabhumi. The road is not consistent because of land issues. The inner curb of this road was fixed at r = 687.25 m.

These existing stretches have different widths from 4.70 m up to 7.0 m with different transversal slopes of 1.5%, 2.5%, 3% and 3.5%. The subsurface structure or load carrying layers differ as well.

It is proposed, for the time being, to build the Crown Road with a maximum width of 4.70 m. This width is sufficient for the present traffic, and it will not harm any future possibilities for the development of the Crown and its public transport system.

The stormwater management plan for the Crown follows the principle of passive rainwater harvesting through infiltration. In general, the reduction of paved areas is essential. It saves costs and it allows permanent recharge through infiltration. Further, by infiltration of the road run-off through the topsoil level (living earth zone layer = Mutterboden), the potential impact of pollutants from vehicles is effectively managed.

So far, a detailed stormwater verification study was only carried out for the stretch from Kailash towards Solar Kitchen/PTDC, but the implementation of the relevant stormwater percolation channels and their related ponds is deficient.

The new planning of the longitudinal axis of the inner curb is based on a survey made by TDC, 18.07.2012.

The longitudinal profile shows differences in levels of 14 m in total. The high point is near Solar Kitchen, and the low point is in the Darkali canyon area. The integration and connection/junctions of the radials have been studied as well. Accordingly, conceptual layouts of the radial axis have been designed to determine the axis levels of the radials. In this regard, further details, e.g. the kind of radial, angle, width, surrounding area, etc. need to be discussed and integrated into the final design.

Technical details and the proposal for the transversal cross section, e.g. the carrying layer structure, water channels, ponds and pits have been designed on an implementation level. It is important that TDC ensure that these designs are implemented correctly for optimal performance.

The hydraulic verification of the necessary ponds' or infiltration pits' volume has been calculated according to the DWA Guideline, A 138 with a rainfall intensity of n = 0.1 or a 10 year heavy rainfall event.

Considering the entire Crown area, some places have clay formations. This means that the principal geotechnical requirements for percolation are not fulfilled. Those areas are found near Darkali, Aurodam and Centre Field. Here, the rainwater needs to be channelled to areas that have a good percolation possibility or to existing canyons.

The verification of the shear stress has shown that the channel layout can be simple. Accordingly, Aqua Engineers proposes one "uniform template" for the inner side and one for the outer side of the entire Crown Road zone. This design consists of layers of gravel and grass/creeper plants. A geo-textile might also be required in high slope areas.

Another important aspect is to install all required main infrastructure within the Right of Way of the Crown. TDC has approved the general infrastructural corridors, which follow a simple earth cut-and-fill principle. In this layout, app. 2 m width has been kept for the cable corridor, and 2 m for the water related infrastructure.

This corridor can be adjusted for each section, e.g. in the park areas, there might not be any need for a sewage piping system or a cable trench on both sides.

Looking at the social impact of the Crown implementation, Aqua Engineers and one member of TDC have had several meetings and dialogues with the present land stewards.

It became clear that the implementation process requires fresh concepts and ideas, e.g. to allow a solar public transport system and cycle path only, etc. given the present situation, which can only be done in collaboration with all concerned. It must be mentioned that, in principle, everyone was open for dialogue.

Concerning the environmental aspects, the circle crosses sensitive areas such as canyons, water recharge areas and the Bliss and Darkali forests. In some parts, special trees have been identified which need to be integrated into the design.

In the canyons, deeper studies and investigations, including an environmental impact study, are necessary, but they are not part of this study.

Dirk Nagelschmidt (M. Eng) 18.08.2012

3. Introduction

The study considers the following:

1. Basics, preparation and parameters
   - Base map (TDC)
   - Spot marking of km (TDC, Road Service)
   - Survey and levelling (TDC)

2. Planning
   - Design and drawings
   - Technical standards for roads and classification
   - Survey and levelling work in sections of 12 m
   - Longitudinal cross section
   - Transversal cross sections
   - Design of the first 25 m of each radial junction axis road level
   - Levels of the crossing radials

3. Stormwater management including hydraulics and volumes
   - Important stormwater data for a design rain which theoretically occurs every 10 years
   - Drainage system overview map
   - Hydraulic verification of existing channels as well as sizing of the road infiltration ditch
   - Dimensioning of the culverts and pipe ducts, main road
   - Detail drawings of entrance passages
   - Detail drawings of the ditch

4. Volume/Mass calculation
   - Preparing a basic spreadsheet for easy calculations of the cut-and-fill based road construction

The following report focuses on the technical aspects of the Crown.

4. Basics and technical standards

The basics for the water management concept are:

- Brief description of L'Avenir
- Survey and base map of L'Avenir, 18.07.2017
- Site visits and photos
- Data from the Indian Meteorological Department
- Data from Water Harvest
- RASt06, Guidelines for the design of city roads, December 2008
- RAStO, Guidelines for the surface and subsurface of roads, 2001
- RAS-Ew – Guidelines for road drainage, 2005
- RAS-Q – Guidelines for the design of transversal cross sections of roads
- Common DIN-EN norms and additional technical agreements
- DWA Guideline A 138, A 117

5. Climatic data

5.1. Rainfall data

The pre-monsoon rainfall is almost uniform throughout the Auroville region. The area gets most of its seasonal rainfall, app. 54%, from the north-east monsoon, from mid-October to mid-December. The balance of 36% comes with the south-west monsoon from mid-June to mid-August. The average annual rainfall is about 1266 mm. [w1]

PERIOD: 1951-1980

Month	Mean Temperature (°C)		Mean Total Rainfall (mm)	Mean Number of Rainy Days	Mean Number of days with			
	Daily Minimum	Daily Maximum			HAIL	THUNDER	FOG	SQUALL
Jan	20.6	28.4	16.2	1.0	0.0	0.0	0.2	0.0
Feb	21.2	29.9	3.7	0.3	0.0	0.0	0.2	0.0
Mar	23.1	31.9	3.0	0.2	0.0	0.2	0.1	0.0
Apr	25.9	33.6	13.6	0.7	0.0	0.9	0.0	0.0
May	27.6	36.4	48.9	1.6	0.0	1.6	0.0	0.1
Jun	27.2	36.6	53.7	4.1	0.0	3.3	0.0	0.2
Jul	25.9	34.7	97.8	7.3	0.0	3.2	0.0	0.0
Aug	25.3	33.9	149.7	8.5	0.0	4.4	0.0	0.0
Sep	25.3	33.5	109.1	6.6	0.0	4.5	0.0	0.0
Oct	24.3	31.4	282.7	10.2	0.0	5.1	0.1	0.0
Nov	22.8	29.2	350.3	10.1	0.0	2.2	0.0	0.0
Dec	21.6	28.1	138.2	5.5	0.0	0.5	0.1	0.0
Annual	24.2	32.3	1266.9	57.1	0.0	25.9	0.7	0.3

Image 1: Climatic data for Auroville region [3]

The highest annual rainfall recorded is 2570 mm in 2005.

5.2. Rainfall intensity [1]

The rainfall intensities are based on data collected over several decades. The conditions at the project are comparable to those in Auroville, so this data can be used for further calculations. The flood frequency of 10 years or n = 0.1 has been considered for further calculations.

Rainfall time according to intensity, D	Precipitation in mm for n=0.1	Precipitaion minus run-off loss	Precipitation factor $r_{m,n}$ in l/(s*ha)
15 min	20.0 mm	19.0 mm	211.1 l/(s*ha)
20 min	30.0 mm	29.0 mm	241.7 l/(s*ha)
30 min	50.0 mm	49.0 mm	272.2 l/(s*ha)
45 min	60.0 mm	59.0 mm	218.5 l/(s*ha)
60 min	70.0 mm	69.0 mm	191.7 l/(s*ha)
90 min	90.0 mm	89.0 mm	164.8 l/(s*ha)
120 min	110.0 mm	109.0 mm	151.4 l/(s*ha)
180 min	120.0 mm	119.0 mm	110.2 l/(s*ha)
240 min	125.0 mm	124.0 mm	86.1 l/(s*ha)

Image 2: Peak precipitation [1]

The important calculation figure is, according to Image 2, the 30 minute rainfall with a precipitation factor of $r_{30,n=0,1}$ = 272.2 l/(s*ha).

The factor was rounded to: **$r_{30,n=0,1}$ = 272 l/(s*ha).**

5.3. Temperature [w1]

The proposed area has a tropical climate, specifically a tropical wet and dry climate. The city lies on the thermal equator on the coast, which prevents extreme variation in seasonal temperature. The weather is hot and humid for most of the year. The hottest part of the year is late May to early June, known locally as *Agni Nakshatram* ("fire star") or *Kathiri Veyyil*, with average maximum temperatures between 38 and 42°C. The highest recorded temperature is 45°C.

The coolest part of the year is January, with minimum average temperatures between 18 and 20°C. The lowest temperature recorded is 15.8°C.

5.4. Wind [w1]

The two prevailing winds in Chennai are the south-westerly between May and September, and the north-easterly throughout the rest of the year. Cyclones in the Bay of Bengal sometimes hit the area. Wind speeds of more than 160 km/h have been recorded.

5.5. Evapotranspiration [1]

The Evapotranspiration consists of the total evaporation from water bodies, trees, roads, etc. The calculated Evapotranspiration for the study area, according to the *Thornthwaite-methode,* is 1750 mm/a. Monitoring of the open water bodies in the surrounding area has shown daily evaporation of 6 to 8 mm/d. If one considers 300 rain free days/a, the evaporation for a "single" water body would be between 1800 mm/a, and 2400 mm/a.

The average precipitation is rounded to app. 1300 mm/a. This means that the yearly evaporation, e.g. from a lake varies between (2400 – 1300) = 1100 mm/a, and (1800 – 1300) = 500 mm/a.

6. Geology and permeability of the earth surface [1]

The study area has different percolation areas which are classified in zones, see Image 3. In some areas, infiltration is not possible due to surface clay formations, whereas most parts of the future Crown have good infiltration possibilities.

6.1. Potential suitable soil types and their typical permeability coefficient k_f

Coarse gravel:	$k_f = 5 \times 10^{-3}$ to 10^{-1} m/s
Coarse sand:	$k_f = 10^{-4}$ to 5×10^{-3} m/s
Fine to medium gravel:	$k_f = 5 \times 10^{-4}$
Fine sand:	$k_f = 5 \times 10^{-5}$ to 5×10^{-3} m/s
Sand gravel:	$k_f = 10^{-4}$

6.2. Impermeable or less permeable soil types and their typical permeability coefficient k_f

Silt soil:	$k_f = 4 \times 10^{-3}$ to 5×10^{-7} m/s
Loam soil:	$k_f = 10^{-3}$ to 10^{-7} m/s
Clay soil:	$k_f = 10^{-8}$ to 10^{-10} m/s

The limit for infiltration is approximately: $k_f = 5 \times 10^{-6}$ m/s or 1.8 cm/h.

According to Images 3 and 4, the study area has six different kinds of soil permeability conditions.

Average Infiltration in m/s			
I	0 bis 1.5	I	$k_f = 2 \times 10^{-6}$ m/s
II	1.5 bis 5	II	$k_f = 7 \times 10^{-6}$ m/s
III	5 bis 10	III	$k_f = 2 \times 10^{-5}$ m/s
IV	10 bis 15	IV	$k_f = 3 \times 10^{-5}$ m/s
V	15 bis 25	V	$k_f = 6 \times 10^{-5}$ m/s
VI	über 25	VI	$kf = 8 \times 10^{-5}$ m/s

Image 3: Infiltration zones I to VI/soil permeability coefficient, Auroville

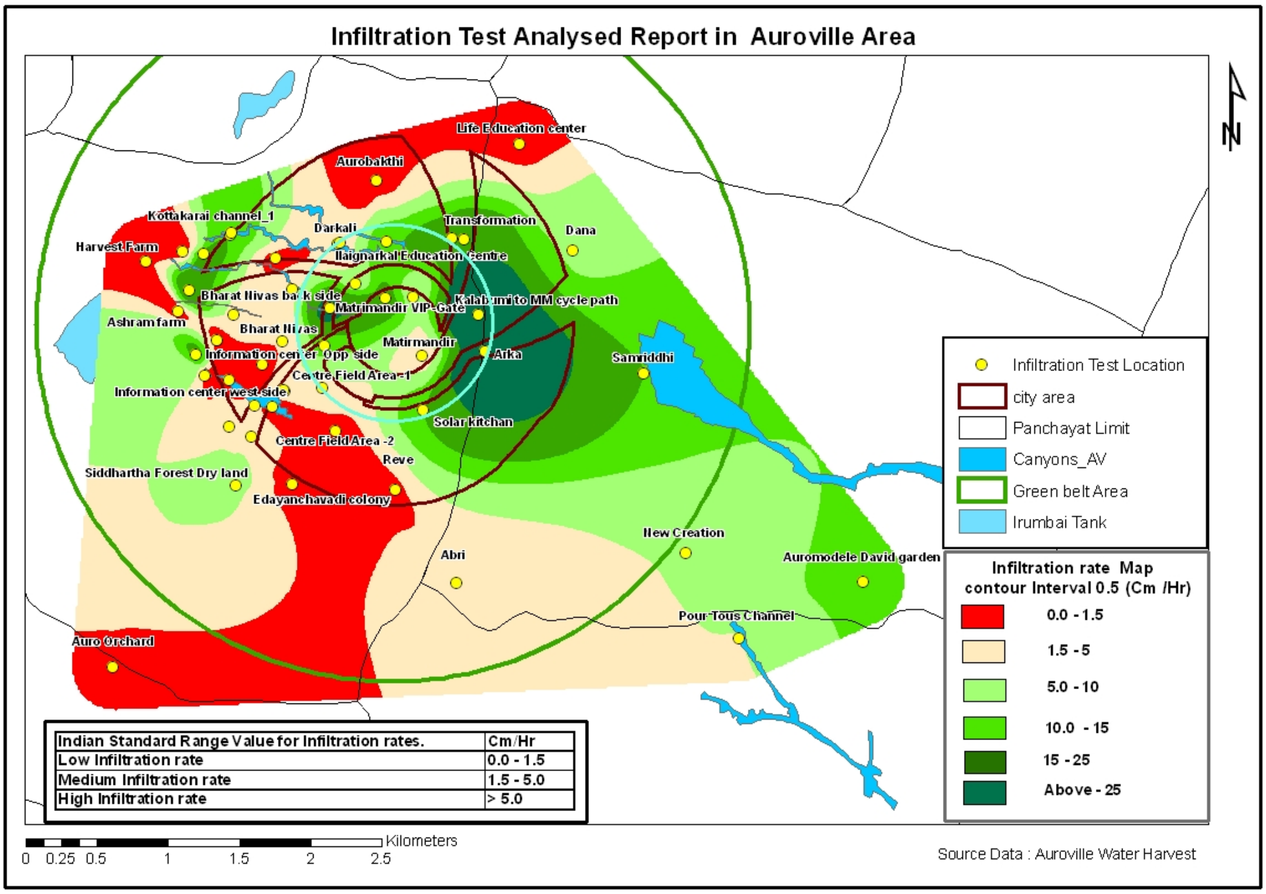


Image 4: Infiltration map, Auroville (Water Harvest) [1]

7. Technical study of the Crown Road and its parameters

7.1. Description of the alignment and the longitudinal profile and cross profiles

The alignment of the Crown has its centre at the Matrimandir banyan tree. The centre axis is at 690 m. The inner curb has a radius of 687.25 m.

The kilometrage starts with 0+00 near PTDC/Solar Kitchen, and ends at 0+4335.40. The profiles have been made at distances of 12.043 m. 0.043 m is the correction factor for the circle.

Image 5: km 0.00

In the study, the factor has been kept as the QA background figure, which means that the profiles start with 0+12, 0+24, 0+36… the correction comes into place, e.g. between km 0+157, followed by 0+169. In this case, the distance is 13 m.

The horizontal levelling of the ground reality has been based on a survey by TDC, 18.07.2012. The survey has been made at regular distances from the 690 m centre radius. Here, five points have been measured:

1) Centre -15.0
2) Centre -6.0
3) Centre point
4) Centre +6.0
5) Centre +15.0

The survey of the existing road pavers has been made with four points:

6) Centre -15.0
7) Inner curb
8) Outer curb
9) Centre +15.0

According to the survey, the longitudinal profile has been drawn, considering the existing ground level on the left and right sides, and the existing ground level at its centre.

The outcome of the profile has shown that there is a large difference of levels of app. 14.0 m between the highest and lowest areas of the Crown. The highest area is near Solar Kitchen with levels of app. 52.00 m AMSL (above mean sea level), and the lowest near the Darkali canyons with a level of app. 38.00 m AMSL.

Aqua Engineers has designed the new inner curb level considering the ground levels of the survey. For the final confirmation, field visits have been carried out, and indicators of 35 points of the planned levels have been marked by the survey team of TDC.

The longitudinal slope has been planned in the areas of the canyon so that it does not exceed 2.0%, which is an acceptable figure in terms of safety, and it is suitable for the eventual rail-based solar tram.

A field visit took place, together with Mr. Cristo of TDC and the TDC survey team, to observe and confirm how the planned levels look on the ground. The outcome was that some levels had to be adjusted and, in areas such as the canyons, further studies are necessary to define the best possible way for the Crown to be implemented.

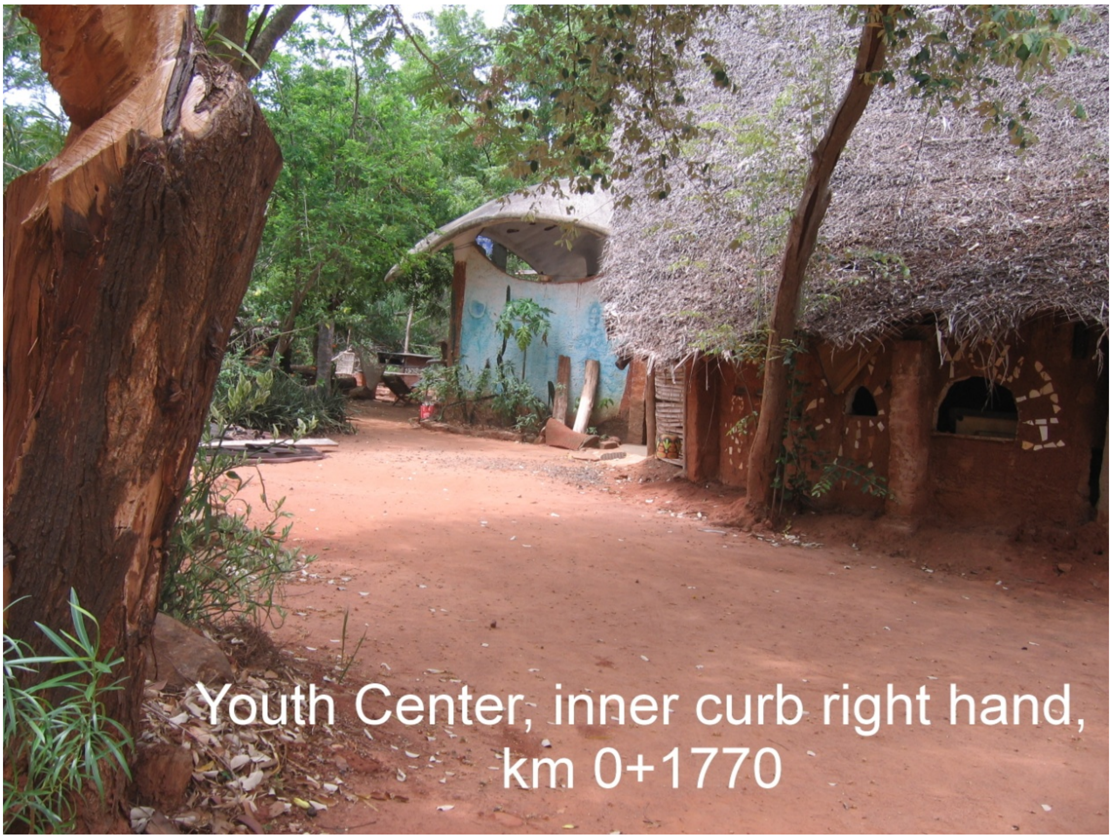
The following photos give a good impression of the site walk:

7.2. Present ground realities; a photo documentation


near AV Library, km 0+400


Crown near
Arka, km 600


near Kalabhumi, km 0+1360


Youth Center, inner curb right hand,
km 0+1770


Crown Michael Bonke land, left is inner
km 0+1999


Transition Radial Crossing, view towards
Darkali km 0+2095

After Transition Radial, view towards Darkali, km 0+2200

Darkali, Canyon crossing, view to outer curb
km 0+2650


View towards Darkali, inner curb right side,
Canyon crossing, km 0+2897


Cross of canyon from MM
Nursery, left is inner
km 0+3000


Crown near the Language Lab, view towards Aurodam
km 0+3035


Road Culvert between Savitri B. & the Language Lab
(road towards Kottakarai)
km 0+3131


Crown area near S. Bhavan, view towards
Darkali km 0+3347


Sri Aurobindo Statue
Savitri Bhavan
km 0+3432
Crown cross of MM / Visitor Center access


Near VC/ Aurodam km 0+3600


km 0+3926
In Centerfield, view towards SK

7.3. Classification of the Crown Road

In general, the most important factor for the technical planning of roads is to classify the road. Highway roads, for example, will have different standards from rural roads or city roads.

Usually, classification considers:

- Location
- Design speed
- Usage
- Purpose
- Traffic types
- Type of public transport
- Walk areas
- Cycle paths, etc.

The technical requirements are directly linked to the type of road, and they are formulated based on many years of experience. They are similar anywhere in the world.

Out of the spreadsheets for each class or type of road, one can read the main design parameters, e.g. the horizontal crest or value roundings/radius, the max. and min. longitudinal slope, transversal cross slope, its carrying layer structure and many other important factors.

The Auroville Crown Road is, according to the design and supposed function, comparable with a "main business road with low speed of traffic" and possible public transport. The radials function as "collection roads" between the Crown and the outer ring road. The outer ring road is the link or connection to the ECR (east) and the National Highway in the north.

According to Images 5 and 6, the following assumptions can be made:

Crown Road:	Main business road	ES	IV			
Radials:	Collection roads	ES	IV			
Outer Ring Road:	Connection road	HS	III	or	HS	IV

<u>Résumé:</u>

The Auroville Crown Road can be classified as a class IV type road.

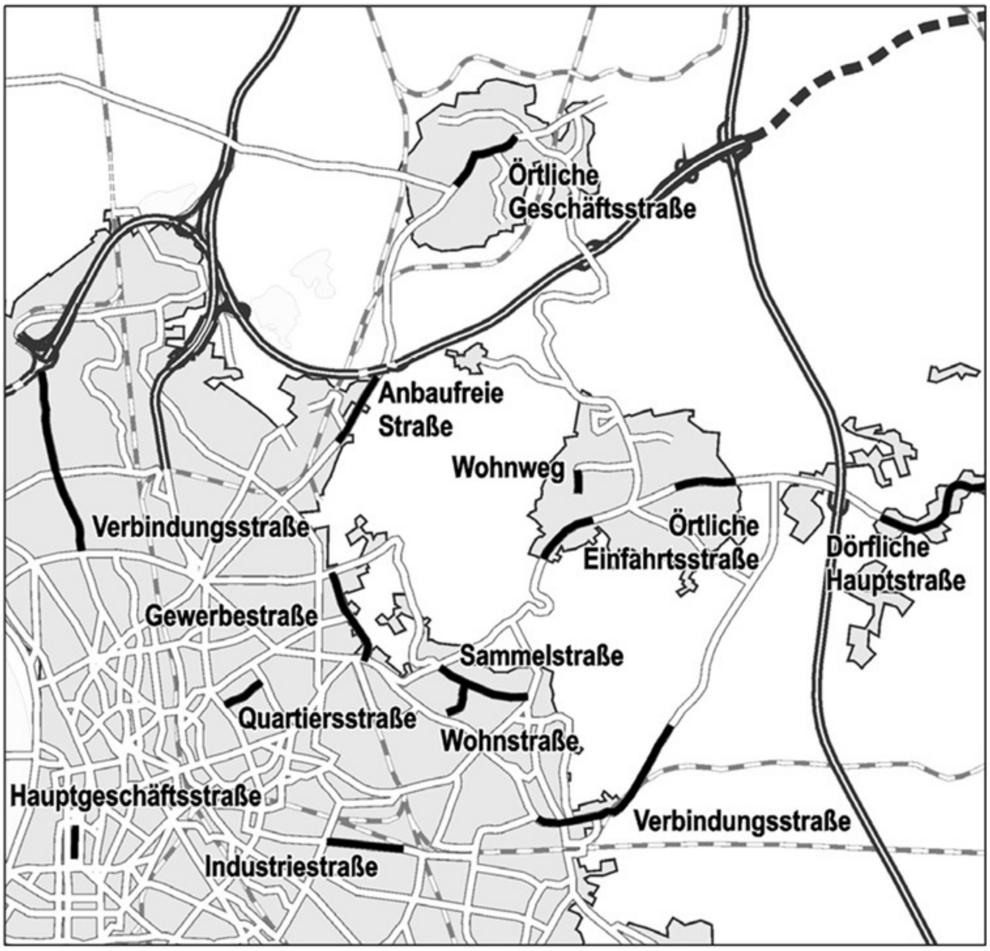


Image 6: Overview, road categories [4]

Design Criteria			Road Class
Residential pathway	or	Wohnweg	ES V
Residential road	or	Wohnstraße	ES V
Collection road	or	Sammelstraße	ES IV
Quarter road	or	Quartiersstraße	ES IV, HS IV
Rural village road	or	Dörfliche Hauptstraße	HS IV, ES IV
Local access road	or	Örtliche Einfahrtsstraße	HS III, HS IV
Local business road	or	Örtliche Geschäftsstraße	HS IV, ES IV
Main business road	or	Hauptgeschäftsstraße	HS IV, ES IV
Common trade road	or	Gewerbestraße	ES IV, ES V, (HS IV)
Industrial road	or	Industriestraße	ES IV, ES V, (HS IV)
Connection road	or	Verbindungsstraße	HS III, HS IV
Road without buildings	or	Anbaufreie Straße	VS II, VS III

Image 7: Road classification [4]

7.4. Design standards for the vertical alignment/longitudinal profile

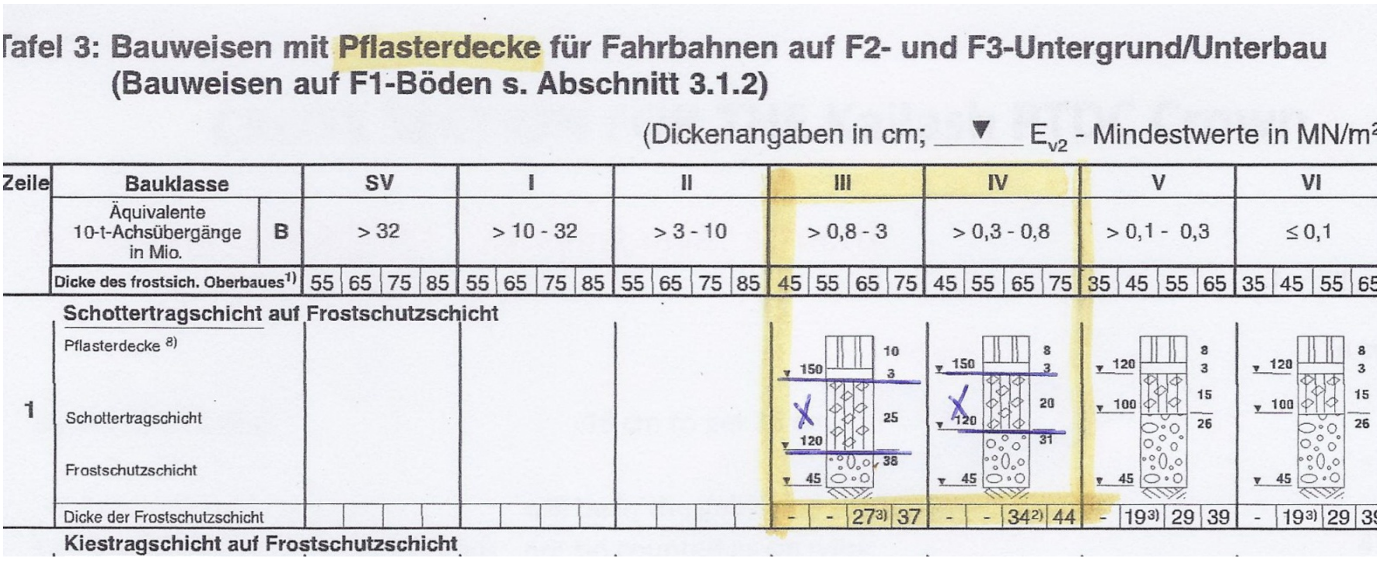
The requirements for ES/HS IV class roads on the vertical alignment of the axis specify that the max. slope should not exceed 8%. Since the speed is less than 50 km/h, the min. tangent intersection points of the vertical curves' crests and sags can be reduced to r = 50 m for a crest, and r = 20 m for a valley area.

The longitudinal profile has been designed based on the above criteria.

7.5. Design standards for the transversal slope and road carrying layer

The present existing roads show different types of transversal cross slopes of 1.5%, 2.5% 3% and 3.5%. For class ES/HS IV roads within city areas with low speed, the RAS-Q foresees a transversal slope of paved roads of > 2.5%. Aqua Engineers proposes to keep the minimum of 2.5% because of the level of the outer curb. The level of the outer curb will increase with the increase of the slope, which may lead to difficulties within the RoW area and the surrounding existing and non-existing buildings.

According to Image 8, (Tafel 3), the structural carrying layer of a paved road on a granite blue metal base must have a minimum thickness of (compacted) 20 cm.



Tafel 3: Bauweisen mit Pflasterdecke für Fahrbahnen auf F2- und F3-Untergrund/Unterbau
(Bauweisen auf F1-Böden s. Abschnitt 3.1.2)

(Dickenangaben in cm; ▼ E_{v2} - Mindestwerte in MN/m²

Zeile	Bauklasse		SV				I				II				III				IV				V				VI			
	Äquivalente 10-t-Achsübergänge in Mio.	B	> 32				> 10 - 32				> 3 - 10				> 0,8 - 3				> 0,3 - 0,8				> 0,1 - 0,3				≤ 0,1			
	Dicke des frostsich. Oberbaues[1]		55	65	75	85	55	65	75	85	55	65	75	85	45	55	65	75	45	55	65	75	35	45	55	65	35	45	55	65
	Schottertragschicht auf Frostschutzschicht																													
1	Pflasterdecke[8] / Schottertragschicht / Frostschutzschicht														▼150 10 3 25 ▼120 38 ▼45				▼150 8 3 20 ▼120 31 ▼45				▼120 8 3 15 ▼100 26 ▼45				▼120 8 3 15 ▼100 26 ▼45			
	Dicke der Frostschutzschicht														-	-	27[3]	37	-	-	34[2]	44	-	19[3]	29	39	-	19[3]	29	3
	Kiestragschicht auf Frostschutzschicht																													

Image 8: Recommendation of structural layers of paved roads as per RAStO

The existing parts of the Crown and radials have been built with a structural layer thickness of 25 to 30 cm blue metal. This is equivalent to a class III type of road.

The blue metal, jelly, granite chips and sand must be compacted in layers. The final strength of the structural layer is confirmed by a plate load-bearing test.

Image 9: Plate load-bearing test

Résumé:

Regarding the future sections of the Crown, considering the building and compacting techniques, the standard thickness should be kept at 25 cm total, see Image 10. It needs to be emphasized that Road Service MUST do these tests. This has to be imposed on them. It is not a matter of choice!

Structual Layout for the Crown				
				for filling gaps
		in cm		in cm
40 mm blue metal	17 cm to get 15 cm	15		-
				-
Granite powder/sand-mix to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		4
				-
20 mm blue jelly		7		-
Sand-mix-powder to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		1
6 mm baby jelly		3 to 4		-
Sand-mix-powder to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		1
	Total thickness of carrying layer:	25 to 26	Total thickness of filling:	6
Top layers				
Sand bedding for pavers	5 cm to get 3 to 4 cm	4		
Pavers	pre-fabricated	8		
	Total:	12		
	Total road thickness:	37 to 38		

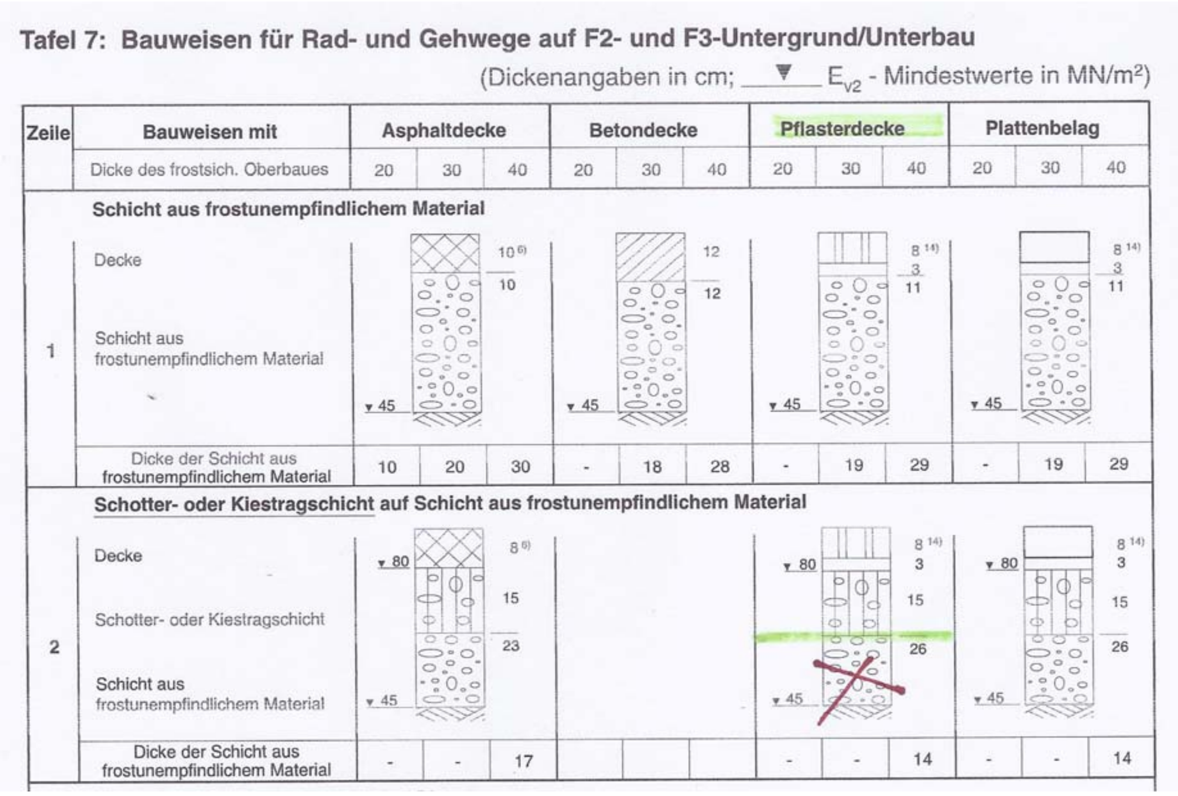
Image 10: Recommended structural layout for the Crown Road

7.6. Design standards for the walking and cycle paths

At present no walking pathways or cycle pathways have been build on a finishing level with pavers.

RAS-Q foresees a transversal slope of paved cycle pathways of > 2.5%. This slope corresponds with the recommended transversal slope of the roads. For the walkways, a min. transversal slope of 1.5% is sufficient.

According to Image 11, (Tafel 7), the structural carrying layer of a paved road on a granite blue metal base must have a minimum thickness of (compacted) 20 cm.



Tafel 7: Bauweisen für Rad- und Gehwege auf F2- und F3-Untergrund/Unterbau

(Dickenangaben in cm; ▼ E_{v2} - Mindestwerte in MN/m^2)

Zeile	Bauweisen mit	Asphaltdecke			Betondecke			Pflasterdecke			Plattenbelag		
	Dicke des frostsich. Oberbaues	20	30	40	20	30	40	20	30	40	20	30	40
1	**Schicht aus frostunempfindlichem Material** Decke Schicht aus frostunempfindlichem Material	▼ 45; 10 6); 10			▼ 45; 12; 12			▼ 45; 8 14); 3; 11			▼ 45; 8 14); 3; 11		
	Dicke der Schicht aus frostunempfindlichem Material	10	20	30	-	18	28	-	19	29	-	19	29
2	**Schotter- oder Kiestragschicht auf Schicht aus frostunempfindlichem Material** Decke Schotter- oder Kiestragschicht Schicht aus frostunempfindlichem Material	▼ 80; ▼ 45; 8 6); 15; 23						▼ 80; ▼ 45; 8 14); 3; 15; 26			▼ 80; ▼ 45; 8 14); 3; 15; 26		
	Dicke der Schicht aus frostunempfindlichem Material	-	-	17				-	-	14	-	-	14

Image 11: Recommendation of structural layers of walkways and cycle paths as per RAStO

Résumé:

The structural layer for the walkways and cycle paths should be built according to Image 12. Standard thickness should be kept at 25 cm total, see Image 10.

Structual Layout for Walkways and Cycle Paths				
				for filling gaps
		in cm		in cm
40 mm blue metal	8 cm to get 7 cm	7		-
				-
Granite powder/sand-mix to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		3
				-
20 mm blue jelly		5		-
Sand-mix-powder to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		1
6 mm baby jelly		3 to 4		-
Sand-mix-powder to fill in the gaps	will be in the gaps and shall not be counted as carrying layer	0		1
	Total thickness of carrying layer:	15 to 16	Total thickness of filling:	5
Top layers				
Sand bedding for pavers	5 cm to get 3 to 4 cm	4		
Pavers	pre-fabricated	8		
	Total:	12		
	Total thickness:	25 to 26		

Image 12: Recommended structural layout for the Crown walkways and cycle paths

Important:

In access areas to buildings/parking areas, the structural carrying layers of the walkways or cycle paths must be the same as that of the roads.

7.7. Bridges and dam structures for crossing canyons, further investigation needed!

In the areas of the canyons, bridges or dam structures must be built. These constructions require structural design, as well as detailed planning of the surroundings and the environmental impact on the canyons. It is important to discuss the social impact since the canyons are mainly on paramboke land.

The dam crossings can be used, for example, as check dams to create storage or infiltration ponds.

Image 13: Dam with road and overflow

7.8. Connection of the 12 radials

The planning of the junction points of the radials with the Crown has been studied. Unfortunately, there are many unknown factors, such as the design of the surrounding areas, e.g. is the radial open for traffic or just used as a cycle or walking passage? How does it look like under the Line of Force buildings? The answers to these questions were not satisfactory for the planning team.

Aqua Engineers has discussed this subject with TDC in a meeting on 01.08.2012, with the agreement that for the time being, the connection axis points of the radials should be defined at a length of 48 m.

This axis level will give an indication of the alignment, and as soon as a detailed layout of the junction points is made, the level of the road junctions can be calculated.

As the proposed width of the Crown is only 4.70 m in general, Aqua Engineers suggest that the width at the connection/junction points of the radials is enlarged to 6.0 m.

See in chapters 7.3, 7.4 and 7.5 discussed standards for the radial roads that have been adopted.

7.9. Infrastructure pipes and cables crossings

It is recommended to install empty ducts in the form of pipes below the road so that it is possible to cross the road, e.g. with a water pipe without breaking the road at a later date.

These ducts should be placed at regular intervals every 30 to 50 m. The use for each duct is:

As per corridor design, 26.03.2012 Top of the service line/cable/pipe	=> Inner curb minus	Required duct size	Bottom of the duct
Optical fibre	-0.40 m	3"	-0.45 m
Telephone	-0.50 m	3"	-0.55 m
LT cable	-0.70 m	4"	-0.75 m
HT cable	-1.00 m	5"	-1.10 m
Gas	-1.20 m	8"	-1.35 m
Water DW	-1.50 m	8"	-1.65 m
Water secondary	-1.70 m	8"	-1.85 m

Image 14: Provisional ducts and their required depth

It is important to keep the levels as defined in the general infrastructure corridor design of TDC, 18.03.2012. The depth of the duct pipes needs to be taken from the inner curb, see Image 12. The required Dia. of the duct shall be 3 x the Dia. of the service line proposed. Suitable material is HDPE or RCC or conduit plastic pipes by Georg Fischer or an equivalent company.

7.10. Technical equipment

So far, the technical equipment that is necessary to make the Crown and its road safe and comfortable for users has not been studied. Trials have been made with various types of technical equipment such as solar street lamps. Other technical equipment, such as speed breakers or road safety equipment such as reflectors or cat's eyes is in the trial process.

The paint marking of the existing road's edges or the middle line has not been tried yet.

Therefore, our recommendation is to request an expert study on the technical equipment for the Crown and radial roads. This should also include landscaping concepts such as green areas with chairs and tables, etc.

8. Stormwater management

8.1. Definition of stormwater: [w1]

Stormwater is a term used to describe water that originates during precipitation events. It may also apply to water that originates as snowmelt or run-off from over-watering that enters the stormwater system. Stormwater that does not soak into the ground becomes surface run-off, which either flows into surface waterways or is channelled into storm sewers.

Stormwater is a concern for two main reasons: one related to the volume and timing of run-off water (flood control and water supplies) and the other related to potential contaminants that the water is carrying, i.e. water pollution.

Image 15: Run-off flowing into a stormwater drain. Left: Crown at Solar Kitchen during construction

8.2. Stormwater run-off from roads and its impact

Two different aspects of road stormwater run-off need to be discussed and considered:

A. General technical possibilities, chap. 6.2.1
B. The biological impact, chap. 6.2.2

8.2.1. Possible technical solutions for stormwater drainage and erosion control

Stormwater can be collected and drained into open drainage systems/culverts/canals or in underground pipelines and channel systems.

Both systems require an outlet point for the water. This is usually a large river or the open sea (as can be seen in Pondicherry).

Alternatively, the stormwater can be collected on the surface and infiltrated into the soil if space and soil allow this. The following images give an idea of how the water can be drained or collected from the road.

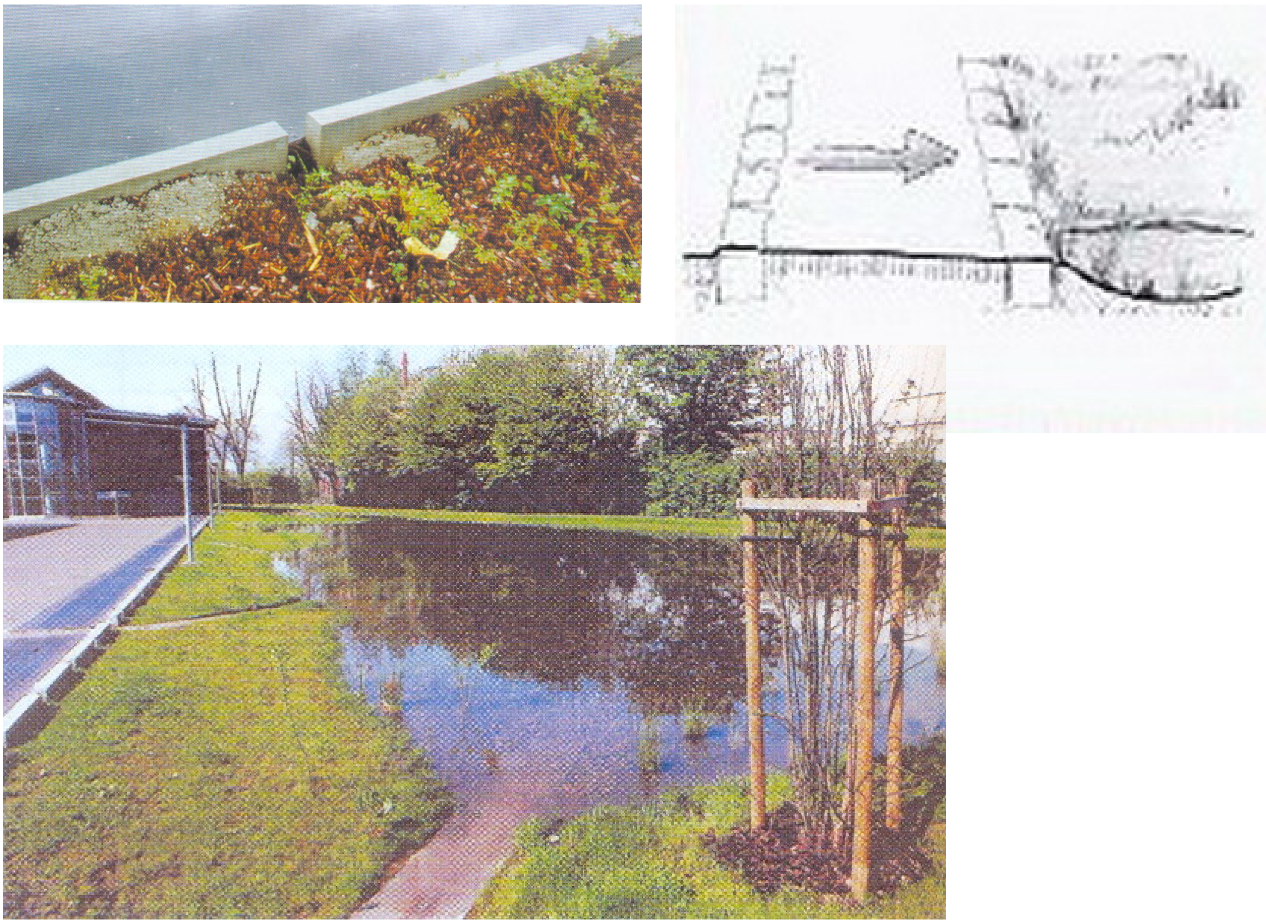


Image 16: Road drains, samples

To control erosion, or in slope areas, a dam needs to be built into the drainage collection system. Further, in some areas, e.g. canyons, gabions or culverts need to be placed, see Images 11,12,13,14.

Image 17: Cross dam, view in longitudinal direction in an infiltration ditch

Image 18: Infiltration ditch with cross dam; cross dam made with gravel

At some points of the future road, e.g. in the areas of the canyons, “stronger” solutions might be necessary. Image 13 shows the stabilization with a gabion system. During the study, we also found there is a need for culverts, Image 14.

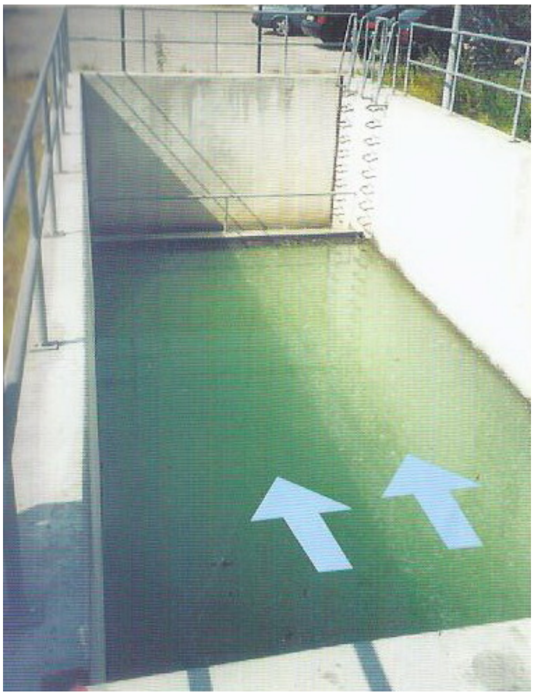
Image 19: Erosion control with gabions

Image 20: Road culvert during rain

8.2.2. Biological impact and its treatment

Large paved areas create heavy run-off during peak times. In most cases, the run-off water is polluted through abrasions from tyres, and oil and grease from vehicles. In Europe, water from roads needs to be treated before it is drained into an open water body or river. This requires large infrastructural systems, such as piping networks, inspection chambers, service personnel and cleaning facilities.

In a closed system, water is collected via the stormwater pipes and drained to a stormwater treatment system which collects the run-off water from the beginning of the rain up to the critical run-off of r_{crit} = 15 l/s. x ha, see Image 19. Excess flow is drained over a threshold into rivers, etc.



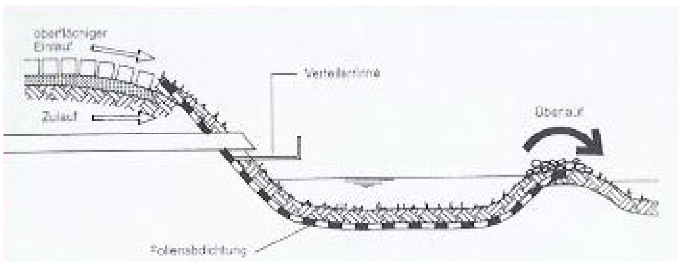
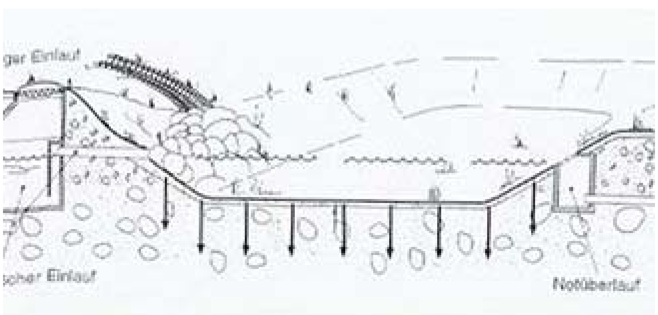


Image 21: Stormwater treatment basin. Right: concrete structure. Left: earth ditch/pit with overflow

Another cheaper solution is to treat the water with the help of an earth-bed filter before infiltration into the ground or drainage into a river or lake.



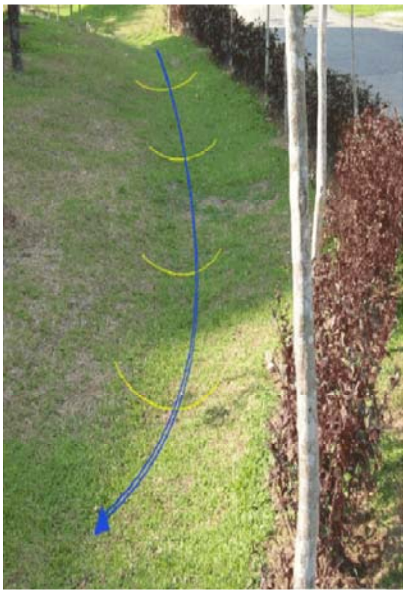


Image 22: Stormwater earth-bed treatment pond facility, ditch with grass vegetation

On roadsides, the best option is to develop an open stormwater infiltration ditch. This technique combines the technical and biological aspects.

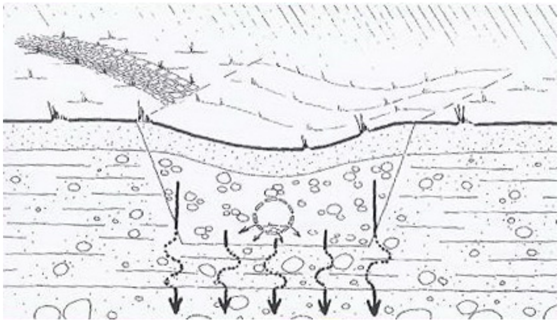


Image 23: Stormwater infiltration ditch

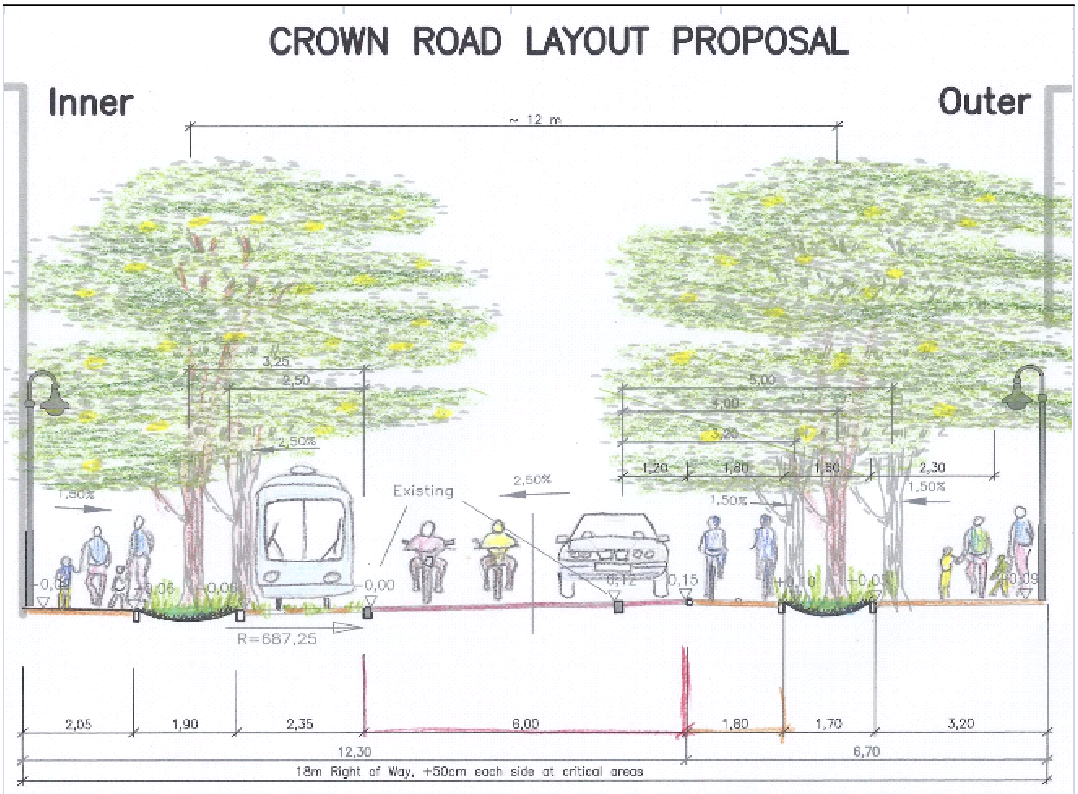
The choice of the technical and biological treatment facility depends on the permeability of the soil as well as the space availability. Considering the Auroville Master Plan, the available space and the geological possibilities for infiltration, our recommendation is to use stormwater infiltration ditches and retention ponds (swales) as tools for stormwater management of the future town. In areas where a clay/silt layer does not permit infiltration, the water can be channelled safely to the nearby canyons.

Résumé:

The reduction of paved areas is essential. It saves costs and it allows permanent recharge through infiltration. The area of the residential zone has sufficient potential to develop cost efficient stormwater systems. Further, by infiltration of the road run-off through the topsoil (living earth zone layer = Mutterboden), the potential impact of pollutants from vehicles is effectively managed.

9. Determination of the run-off area based on the proposed profile of the Crown Road

The Right of Way for the Crown is, according to the Auroville Master Plan, 18.00 m. This area is divided into:



Inner to Outer			
	width in m	transversal slope	run-off coefficient
walkway	2.05	1.5%	0.75
ditch + green	1.90	0.0%	0.10
tramway	2.35	2.5%	0.75
main road	6.00	2.5%	0.80
high point	12.30		
Considering Crown buildings, inner	5.00	-	0.90
	17.30	average:	0.74
cycles + pedestrains	1.80	1.5%	0.75
ditch + green	1.70	0.0%	0.10
walkway	3.20	1.50	0.75
low point	6.70		
Considering Crown buildings, outer	5.00	-	0.90
	11.70	average:	0.72
Right of way:	**19.00**	(incl. + 50 cm tolerrance each side!)	

Image 24: Cross section description for the Crown

As there is not a commonly agreed design available for the Crown so far, the above design concept has been chosen to determine the run-off area. The possible roof run-off from buildings has been included as a safety margin of up to 5 m on each side.

10. Hydraulic verification and dimensions of the road drains

10.1. Important aspects and assumptions for the calculations

For general stormwater calculations, so-called precipitation run-off models are prepared (NA Model). These models are based on a dynamic rainfall spread over a certain amount of time, e.g. 30 years. This method requires a well-selected, reliable database of rainfall measurement for the entire period, as well as accurate calibration of the input data.

Further, special simulation software is necessary e.g. LWA Flut, NASIM, MURISIM, etc.

Since these models are extremely time intensive and expensive, Aqua Engineers proposes to base the study on simple equations, considering the static rainfall formulae. This method will not give 100% accuracy, but will result in a reasonable safety factor. In a meeting on 27.07.2012, all parties of TDC agreed to the proposal.

The assumptions taken into account include catchment areas, rainfall intensity and run-off scenarios. The important factors for the hydraulic design of the stormwater facilities are:

1. **Dry season, ditches are dry => heavy rain occurs**
2. **During monsoon => ditches are wet and the surrounding area is flooded**

The dry situation occurs at the beginning of the heavy rains when the earth is hard and the first layers are dry. In this scenario, run-off occurs quickly and erosion can take place. With the continuation of the rain, the soil absorbs the water and allows percolation. This is similar to a sponge.

In this scenario, it is important that the shear stress limit is verified. In high, sloped areas, so-called cross dams need to be formed to create a storage volume capacity and to slow down the run-off, Images 12, 13, 14 15.

The dry season scenario is not important for the final dimensions of the necessary infiltration ditches or pits, because the soil is not completely saturated and it is still able to absorb water.

The second scenario occurs during heavy rains. Continuous heavy rain leads to saturated soil, which does not allow percolation, and this creates run-off. This is the most important parameter for the dimensioning of the ditch/drainage sizes and the final percolation ponds/pits.

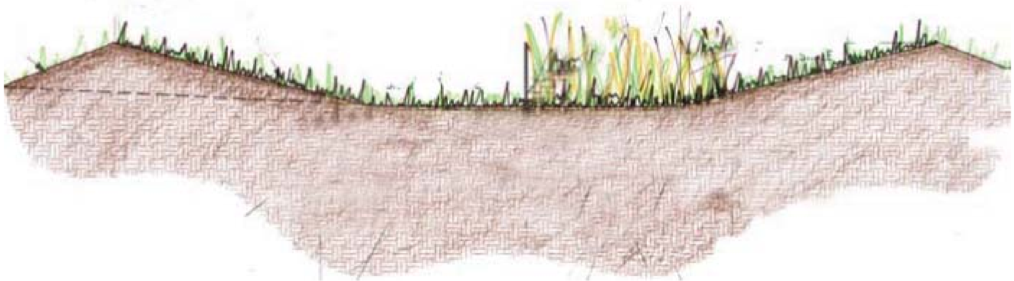


Image 25: Trapeze-bed-profile for drainage ditch

The following verification starts with the typical sizing of the drainage channel or ditch, according to the *Manning-Strickler formula,* for the run-off in the beginning, and at the peak time when the area is completely flooded, the soil cannot absorb any more water and the rain continues.

It is assumed that the form of the channel or ditch will be a trapeze-bed-profile. The difference from a parabolic channel is minor so the verification is considered accurate enough for the sizing. The asperity of the channel/ditch is taken care of by the Strickler coefficient or k_{st}. The value of k_{st} for a concrete channel is ~60 to 120 and for a grass ditch ~25 to 40 (depending on maintenance).

Another important factor is that the drainage ditch should not erode. This happens if the soil is wet and the run-off speed is too fast. The main negative effect is that loose sand flows into the percolation pits and creates a layer of silt, which in the worst scenario leads to a non-working infiltration ditch. Therefore, the author has included *shear stress limit verification* based on a grass-covered ditch in the calculations.

To keep the construction of the channels simple, Aqua Engineers proposed ONE standard ditch for the entire Crown on each side (inner and outer).

This ditch allows for the erosion risk in high slope areas as well as the siltation in low slope areas. The design includes a geotextile below to protect the shoulder, as well as gravel and grass or creeper plants at the bottom.

The second part of the verification is the final sizing of the percolation pit according to A 138. Here, the permeability coefficient k_f is taken into consideration. The calculation is based on DWA-A 138.

10.2. Stormwater hydraulic equations [2]:

The basic procedure [4] to calculate the water level for stationary asymmetric flow in non-prismatic channels is a progressive calculation from profile to profile of discrete water level heights. This serves the Bernoulli energy heights comparison between a section with already known and unknown water level height bases. Furthermore, flow change will be included using the **Extremal Principle**.

For variable compact sections, the critical velocity (Grenzgeschwindigkeit) is:

$$v_{gr} = \sqrt{g \cdot \frac{A_{gr}}{b_{Sp}}} \qquad (1)$$

and the maximum flow:

$$Q_{\max} = Q_{gr} = A_{gr} \cdot v_{gr} = \sqrt{g \cdot \frac{A_{gr}^3}{b_{Sp}}} \qquad (2)$$

The section-related energy gradient is determined by Manning-Strickler and Einstein. Medium flow rate can be predicted according to Manning-Strickler as follows:

$$v = k_{St} \cdot r_{hy}^{2/3} \cdot \sqrt{I_{So}} \qquad (3)$$

The energy gradient I_E for uniform motion flow is equal to the bed slope I_{So} of the culvert.

The hydraulic radius r_{hy} results from the quotient of flow section A and wetted perimeter $l_{U.}$

$$r_{hy} = \frac{A}{l_U} \qquad (4)$$

The outflow Q is determined according to the equation of continuity.

$$Q = v \cdot A \qquad (5)$$

The Manning-Strickler roughness coefficient k_{St} depends on different bed roughnesses (slopes and bed). The average k_{St}-*factor* is determined through the wetted perimeter $l_{U.}$ and the corresponding roughness coefficient k_{Sti} according to the Einstein equation:

$$\frac{l_{Uges}}{k_{St}^{3/2}} = \sum_i \frac{l_{Ui}}{k_{Sti}^{3/2}} \qquad (6)$$

For the calculation of the "particle movement" or **shear stress** τ_0 of the culvert bed, the following equation is valid:

$$\tau_0 = \sigma \cdot g \cdot r_{hy} \cdot I \qquad (7)$$

The shear stress limit is determined by:

$$\tau_{0,gr} = 0{,}047 \cdot g \cdot (\sigma_s - \sigma) \cdot d_m \qquad (8)$$

The peak outflow of the area, Q_{red} is determined by multiplying the "reduced area" A_{red} with the relevant design rain $r_{m,n}$.

$$Q_{Ared} = A_{red} \cdot r_{m,n} \qquad (9)$$

10.3. Stormwater hydraulic calculation

10.3.1. Hydraulic calculation of the necessary ditch size

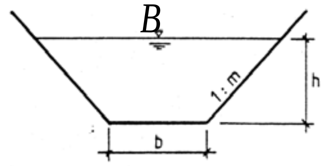
Simulation Trapeze bed profile						$\frac{b_{opt}}{h} = 2\left(\sqrt{1+m^2} - m\right)$							Shear Stress τ0 $\tau_0 = \sigma \cdot g \cdot r_{hy} \cdot I \quad (9)$			
		kst	I in ‰	h in m	m	b in m	B in m	A in m²	lu in m	rhy	v in m/s	Q_{max} in m³/s	σ	g in m/s²	rhy	τ_0 in N/m²
Min	Required Culvert size with design flow **Q_{red} = 0.050 m³/s**	25	**3.50**	0.25	2.00	0.50	1.50	0.25	1.62	0.15	0.43	**0.11**	1000	9.81	0.15	**5.31**
Max	Required Culvert size with design flow **Q_{red} = 0.050 m³/s**	25	**20.00**	0.25	2.00	0.50	1.50	0.25	1.62	0.15	1.02	**0.25**	1000	9.81	0.15	**30.31**

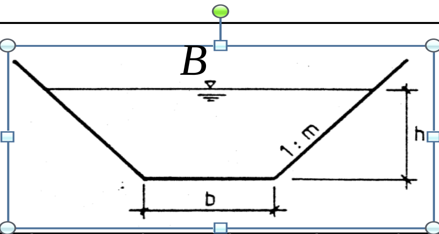
Image 26: Sizing of the channels for min. and max. slopes

The final ditch size must have the above measurements. See chapter 11.

10.3.2. <u>Hydraulic verification of the RCC crossing ducts</u>

Verification of the RCC channel on drive/walk over areas

Simulation Trapeze bed profile



$$\frac{l_{Uges}}{k_{St}^{3/2}} = \sum_i \frac{l_{Ui}}{k_{Sti}^{3/2}} \qquad (6)$$

$$\frac{b_{opt}}{h} = 2\left(\sqrt{1+m^2} - m\right)$$

		kst*	I in ‰	h in m	m	b in m	B in m	A in m²	lu in m	rhy	v in m/s	Q_{max} in m³/s
Min	Required Culvert size with design flow **Q_{red} = 0.050 m³/s**	100	**3.50**	0.25	0.00	0.20	0.20	0.05	0.70	0.07	1.02	**<u>0.05</u>**
Max	Required Culvert size with design flow **Q_{red} = 0.050 m³/s**	100	**20.00**	0.25	0.20	0.20	0.20	0.06	0.71	0.09	2.80	**<u>0.17</u>**
*** for RCC kst = 100**												

Image 27: Sizing of the entrance and crossing channels

The calculation of the max. flow of 0.05 m³/s and the min. slope of 3.50‰ and the max. slope of 20‰ has shown that the gutter size of 200 mm is sufficient.

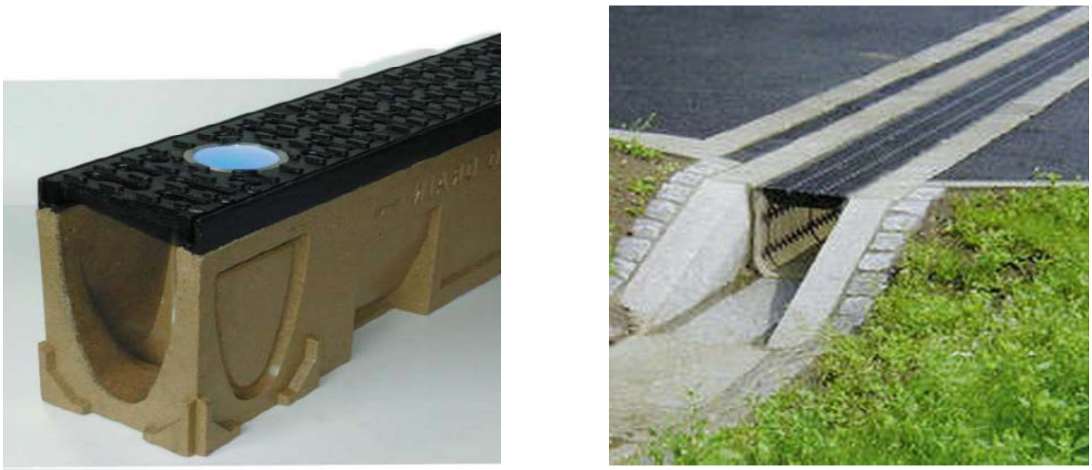


Image 28: Sample for entrance crossing gutters, left with LED light option, right smooth finishing of transition earth channel/RCC channel

10.3.3. Hydraulic verification of the shear stress of the channels

The shear stress calculation has shown that the culvert bed is not strong enough. τ0 > τ0,gr and that in case of large and heavy floods, the bed can be washed out. The solution is to stabilize the bed with suitable plants, e.g. grass or soil coverage creeper. Further, gravel should be mixed into the soil and a geo-textile may be applied in certain places. The choice of grass/creeper should be done in consultation with a botanical expert. There are certain questions to be answered relating to the cows and goats in the surrounding area.

Special attention needs to be given to the cross-areas of house entrances, dividing areas and outlets from the compound walls as well as in front of the road culverts.

Regular maintenance is necessary and should be done by, e.g. AV Road Service to ensure that the stormwater system is functioning properly.

ATTENTION: IN HIGH SLOPE AREAS, CROSS DAMS NEED TO BE BUILT!

Shear Stress τ0 $\tau_0 = \sigma \cdot g \cdot r_{hy} \cdot I \quad (9)$					Shear Stress limit τ0, gr $\tau_{0,gr} = 0{,}047 \cdot g \cdot (\sigma_s - \sigma) \cdot d_m \quad (8)$					
σ	g in m/s²	rhy	τ_0 in N/m²	Discription	σ_S in kg/m³ (Bed, Soil)	σ in kg/m³ (Water)	g in m/s²	d_m in m (soil corn size)	$\tau_{0,gr}$ in N/m²	
1000	9.81	0.15	**5.31**	*Existing soil, red sand*	2200	1000	9.81	0.008	**4.15**	☠💣
				Impprove with grass planting or creeper	2200	1000	9.81	0.020	**11.07**	ok!
1000	9.81	0.15	**30.31**	*Existing soil, clay/ sand peppels*	2200	1000	9.81	0.035	**19.36**	☠💣
				Improve with large gravels/ blue metal/ grass planting or creepers	2200	1000	9.81	0.065	**35.96**	ok!

Image 29: Dimensioning calculation and bed shear stress

10.3.4. Hydraulic verification of necessary percolation pits according to DWA A 138

The calculation of the necessary pond or pit volume has been calculated according to the DWA Guideline, A 138. The results are attached to the study.

Dimensioning of a percolation pit
according to the DWA-A 138 Guidline

Crown Road Auroville
Profil 44 to Profil 138
km 0+530 to 0+1662

Client:
TDC Auroville

Zone VI

Centerfield 1
km 0+530 to 0+1662, Outer

Eingabedaten: $V = [(A_u + A_S) * 10^{-7} * r_{D(n)} - A_S * k_f / 2] * D * 60 * f_Z$

Einzugsgebietsfläche	A_E	m^2	13,244
Abflussbeiwert gem. Tabelle 2 (DWA-A 138)	Ψ_m	-	0.72
undurchlässige Fläche	A_u	m^2	9,531
Versickerungsfläche	A_s	m^2	1400
Durchlässigkeitsbeiwert der gesättigten Zone	k_f	m/s	9.7E-05
gewählte Regenhäufigkeit	n	1/Jahr	10
Zuschlagsfaktor	f_Z	-	1.2

örtliche Regendaten:

D [min]	$r_{D(n)}$ [l/(s*ha)]
15	211.0
20	241.0
30	272.0
45	218.0
60	191.0
90	165.0
120	151.0
180	110.0
240	86.0

Berechnung:

V [m³]
175.6
281.4
495.2
551.6
608.0
727.8
838.2
676.4
448.5

Ergebnisse:

maßgebende Dauer des Bemessungsregens	D	min	120.0
maßgebende Regenspende	$r_{D(n)}$	l/(s*ha)	151.0
erforderliches Muldenspeichervolumen	**V**	**m^3**	**838.2**
gewähltes Muldenspeichervolumen	**V_{gew}**	**m^3**	**840**
Einstauhöhe in der Mulde	z_M	m	0.60
Entleerungszeit der Mulde	t_E	h	3.4

Image 30: Sizing of required filtration area, km 0+530 to 0+1662, inner

The required total percolation area is 2000 m² on the inner side of the road. The author recommends a percolation pond/pit no larger than 100 m². This is app. 10 m x 10 m. The min. depth must be 60 cm below the inlet.

The time until the water is fully absorbed by the earth after the rain has stopped is app. 3.5 hours.

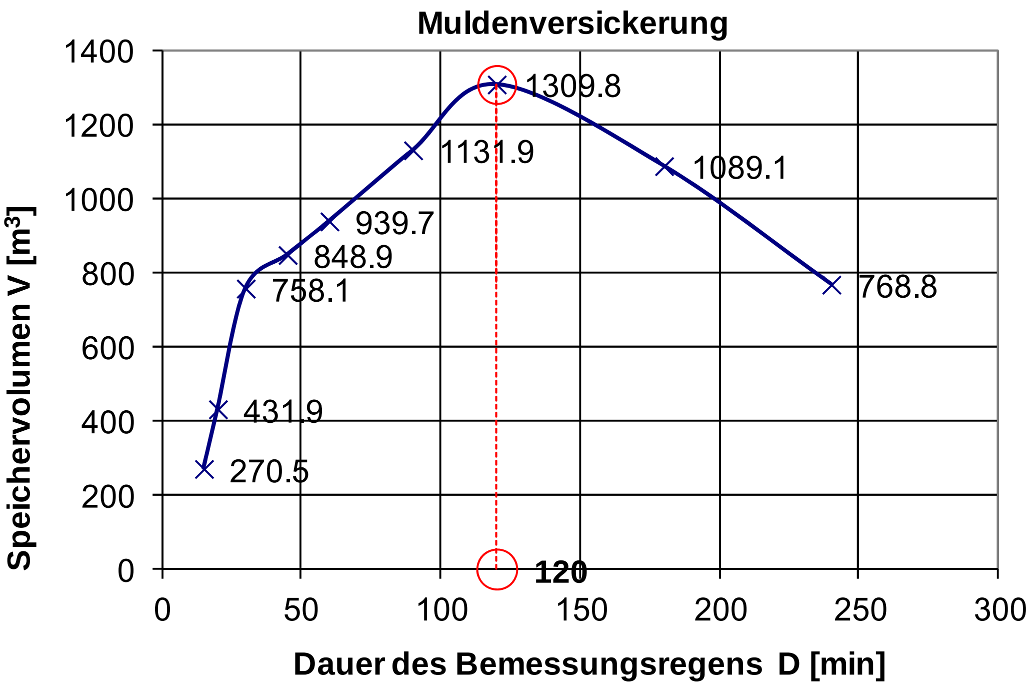


Image 31: Hydrograph of the percolation area, km

The hydrograph indicates that during a heavy rain, the water level increases constantly for the first 120 minutes. Afterwards, the infiltration is faster than the precipitation.

<u>Résumé:</u>

It is recommended that these areas are integrated into the landscaping concept and design of the Crown. It is understood that the location is flexible, and that the size and distance of the percolation ponds/pits can be chosen according to the landscaping design.

It is essential that the entire total size of percolation area for the given stretch of km 0+530 to 0+1662 and **its required min. depth below the inlet + 20 cm extra** does not change**.**

The correct depth reading would be: 60 cm + 20 cm extra for the above calculation, Image 28.

11. Remarks on the technical design of the stormwater channels

The technical design of the stormwater channels are shown in Map Nos. 22, 23, 24 and 25. The final location of the channels as well as the proposed percolation ponds depends very much on the progress of the work and the land availability. It might be necessary to build temp. systems until one can make the final ones. Hereby it is important that the temp. chosen solutions are following the technical standards as well as the given designs.

Nevertheless, in all cases the necessary steps require a collective approach by the people concerned.

12. Volume/Mass calculation

The volume/mass is an important factor to define any estimation. In the West, common PC based software is used to calculate the masses according to the 3D DGM (digital surface model). This requires special software, e.g. GEOGRAF and a trained operator. This option is not available in Auroville.

The proposed alternative is to calculate the volumes based on the actual cross sections at a distance of 24 m. Aqua Engineers has prepared an excel spreadsheet so that the masses between the profiles at any point can be calculated. The spreadsheet allows the user to adjust the width and depth accordingly.

To keep these calculations as simple as possible, they work with a constant road width of 4.80 m. The accuracy of this calculation leans towards the safe side with a tolerance level of +10%.

Still, the actual volumes may change because of varying ground situations. Therefore, the contractor or builder has to take the responsibility to check the volume. TDC may need to give the final approval and recheck the masses according to actual site measurements.

The canyon areas require separate formulae and methods because it is yet to be defined how the Crown will cross the difficult areas.

Auroville, 21.09.2012

Dirk Nagelschmidt (M. Eng.)

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14. Internet links

[w1] http://en.wikipedia.org

15. Attachments

15.1. Verification of the required percolation pit sizes according to DWA A 138