Pervious Hydraulic Design Tool

What are the main problems addressed by the Tool ?

1. **Effects of Soil Characteristics on Intrinsic Water Permeability**
   - ✓ Provides natural limit of permeability without external drainage

2. **Effect of Load requirements on the thickness of Pervious Pavement and Gravel layer considering hydraulogical characteristics**
   - ✓ Allows optmimal design thus reducing cost of cosntruction

3. **Effects of Water Charging Profile (Rain & Other sources) on Pavement design**
   - ✓ Statistical considerations needed to incorporate in the Optimal design

Pervious Hydraulic Design Tool

What are the main problems addressed by the Tool ?

1. **Effects of Soil Characteristics on the road/parking section design**
   - ✓ Allow easy understanding of the hydraulic method of work of the PRV pavement (reservoir or simple drainage)
   - ✓ Provides natural limit of permeability without external drainage
   - ✓ Provides clear indication of the suitable type of soil for PRV pavement

2. **Effects of hydrological parameters on the road/parking section design**
   - ✓ Allows optmimal design thus reducing cost of construction
   - ✓ Statistical analysis of water profile inside the road/parking section for the all length of the design rain
   - ✓ Allows both numerical definition and modellized version of the design ietrograph, in order to better fit with all the possible climate types

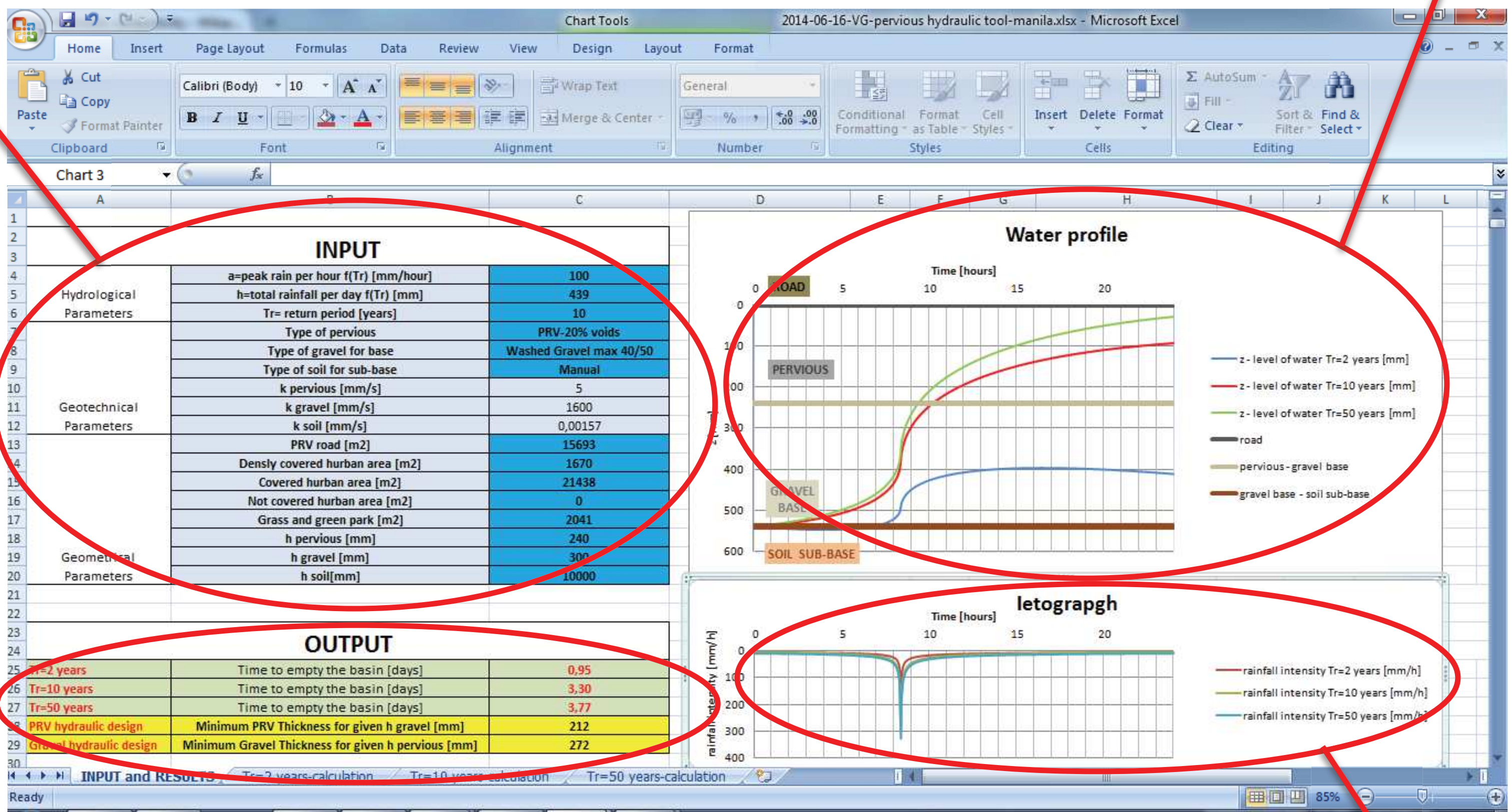
Pervious Hydraulic Design Tool

INPUT

1-**Hydrologic parameters** (total rain, peak hour rain,...)
2-**Geotecnical parameters** (types of PRV/gravel/soil and hydraulic conductivity)
3-**Geometrical parameters** (run-off areas, thicknesses)

WATER PROFILE

$$Q_{c,T} = \psi \; i_{r,T} \; (t_c) \; A_b = i_{nr,T} \; (t_c) \; A_b$$



OUTPUT

1-**Times for emptying the basin** (for different returning period)
2-**Minimum PRV thickness for given gravel thickness**
3-**Minimum gravel thickness for given PRV thickness** (extremely important when the PRV thickness is the result of the structural design)

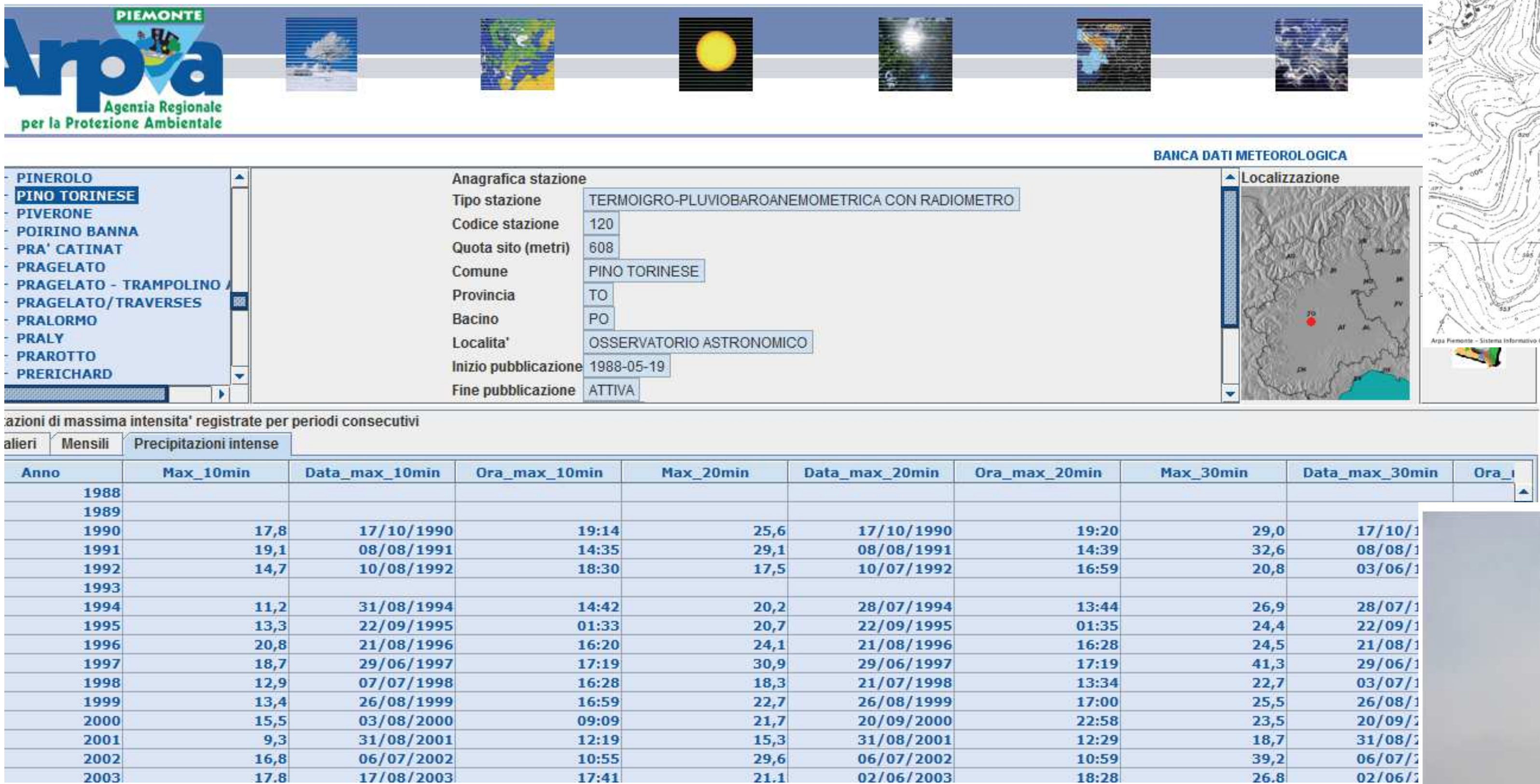
IETOGRAPH

1-Graph of the ietographs used in the design (for T=2,10,50)
2-Any ietograph type can be implemented in the sw, since the calculation is done in a step-by-step integration numerical

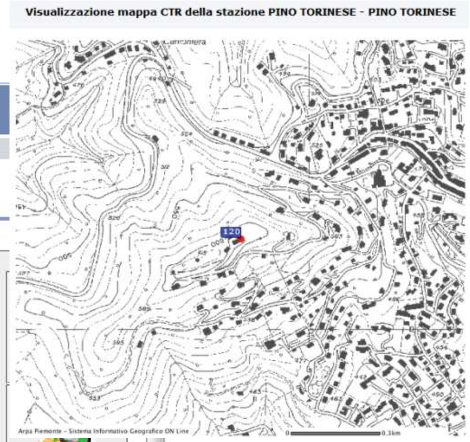
Pervious Hydraulic Design Tool

Rain extimation – Hydrological data from the local autorities

(distribution of rainfall over time)



Anno	Max_10min	Data_max_10min	Ora_max_10min	Max_20min	Data_max_20min	Ora_max_20min	Max_30min	Data_max_30min	Ora_
1988									
1989									
1990	17,8	17/10/1990	19:14	25,6	17/10/1990	19:20	29,0	17/10/1	
1991	19,1	08/08/1991	14:35	29,1	08/08/1991	14:39	32,6	08/08/1	
1992	14,7	10/08/1992	18:30	17,5	10/07/1992	16:59	20,8	03/06/1	
1993									
1994	11,2	31/08/1994	14:42	20,2	28/07/1994	13:44	26,9	28/07/1	
1995	13,3	22/09/1995	01:33	20,7	22/09/1995	01:35	24,4	22/09/1	
1996	20,8	21/08/1996	16:20	24,1	21/08/1996	16:28	24,5	21/08/1	
1997	18,7	29/06/1997	17:19	30,9	29/06/1997	17:19	41,3	29/06/1	
1998	12,9	07/07/1998	16:28	18,3	21/07/1998	13:34	22,7	03/07/1	
1999	13,4	26/08/1999	16:59	22,7	26/08/1999	17:00	25,5	26/08/1	
2000	15,5	03/08/2000	09:09	21,7	20/09/2000	22:58	23,5	20/09/2	
2001	9,3	31/08/2001	12:19	15,3	31/08/2001	12:29	18,7	31/08/2	
2002	16,8	06/07/2002	10:55	29,6	06/07/2002	10:59	39,2	06/07/2	
2003	17.8	17/08/2003	17:41	21.1	02/06/2003	18:28	26.8	02/06/2	



DATA PROVIDED:

- Location, Altitude, type of sensor installed and picture of the weather station
- Max rain for 10,20,30 min, 1,3,6,12 hours and 1,2,3,4,5 days; for each year since 1990 to 2009
- Date of the max rain for any duration considered
- Time of the max rain for any duration considered (average time at the middle of the interval)

Pervious Hydraulic Design Tool

Run-off coefficient for the rational method

(from Chow et al.)

Overall run-off coefficient (>1 always)

$$\psi = \sum \frac{\psi_i A_i}{A_b}$$

Weigthed sum of the Area hydrographically dependant ond the Pervious Area (with run-off coefficients)

Pervious Area

Run-off areas

1-Pervious road/parking
ψ_1=0,8/1

2-Densily covered urban area
ψ_2=0,7/0,8

3-Covered urban area
ψ_3=0,3/0,7

4-Not covered urban area
ψ_4=0,1/0,3

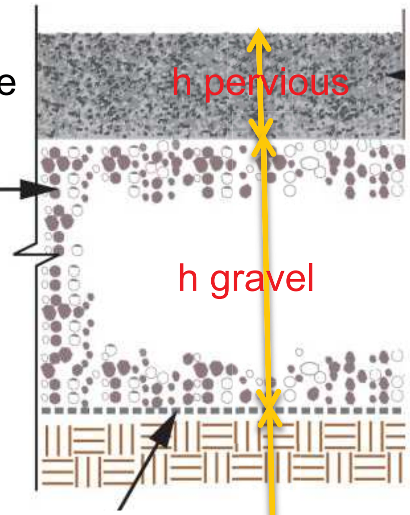
5-Grass and green park
ψ_5=0/0,2

Pervious Hydraulic Design Tool

Geotechnical/Hydraulic parameters

K (hydraulic conductivity)
(from Darcy's law)

$$U = -K\frac{dh}{dz}$$



K (cm/s)	10^2	10^1	$10^0=1$	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
K (ft/day)	10^5	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}
Relative Permeability	Pervious				Semi-Pervious				Impervious				
Aquifer	Good					Poor				None			
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Fat / Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	

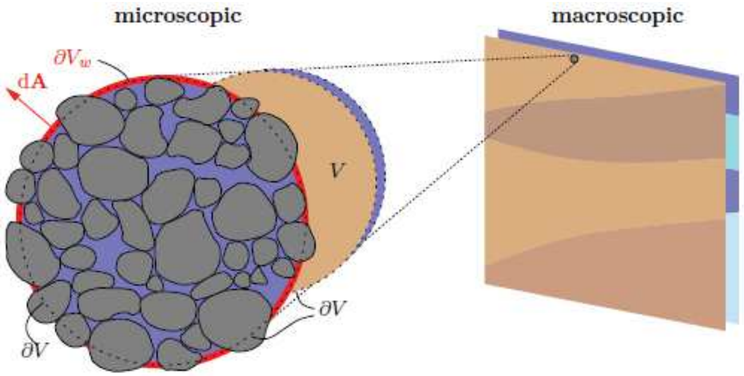
K estimation for gravel
(from Hazen's law)

$$K = C(D_{10})^2$$

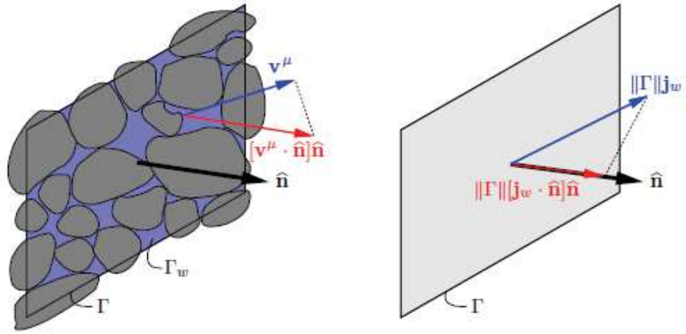
K – field measurements
1 – cylindrical infiltrometer
2 – multi-cylindrical infiltrometer
3 – Guelph's permeameter

Fluido-dynamic of porous media

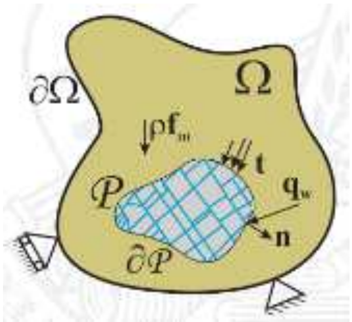
Size effect modelling

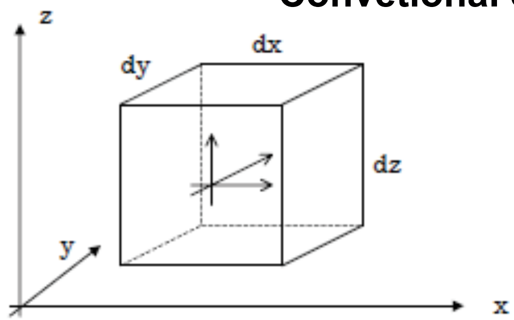


Effect of capillar adehesion



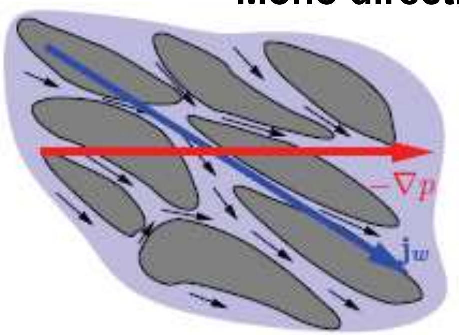
Convetional 3D flow model





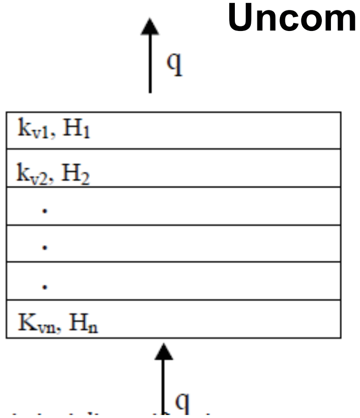
$$\left(k_x \cdot \frac{\partial^2 h}{\partial x^2} + k_y \cdot \frac{\partial^2 h}{\partial y^2} + k_z \cdot \frac{\partial^2 h}{\partial z^2}\right) = \frac{1}{1+e} \cdot \left(e \cdot \frac{\partial S_r}{\partial t} + S_r \cdot \frac{\partial e}{\partial t}\right)$$

Mono directional flow model



$$j_w = -\theta_w \frac{1}{\mu} \langle \kappa \nabla p^\mu \rangle_w$$

Uncompressible multilayer flow



$$j_i = -K_i(\theta_i)\nabla\psi_i \ ,$$

CEMEX

Pervious Hydraulic Design Tool

Output provided by the software

OUTPUT	WHAT'S FOR?	CONSEGUENCES
Time to empty the "basin" (draw-back effect caused by lack of conductivity of the soil) for different return periods (Tr=2,10,50 years)	Because of biological degradation of water (bad smelling, proliferation of insects, ...) it's usually recommended to have emptying time of max 7 days for 50 return period	Soil with low permeability are not recommended for PRV pavements. Foe example: Silt, Clay, Sandstone, Basalt, Granite, Dolomite, Slate,...
Minimum gravel thickness for a given PRV thickness	Usually, the PRV is given by the structural design, so in this case the adaptation of the gravel thickness will be done according to hydraulical reasons. Very important for road and high-load capacity demanding structures	Better cost optimization of the total construction
Minimum PRV thickness for a given gravel thickness	Usefull once the PRV is not structural (walking paths, roads for bikes, eastetic pavements....) where the only the hydraulic issue is relevant to the solution	Better cost optimization of the total construction
Graph of the water profile, inside the designed construction in fuction of the time (max 24 h) and the return periods (Tr=2,10,50 years)	To visually control the design process (avoid error), understand fastly the design bottle neck	Better control of the design, optimization of the design in case of very hydraulically-demanding construction, optimization of the thickness requirements for different retorun periods
Ietographs used for the different return periods studied (Tr=2,10,50 years)	To visually control the design process (avoid errors), avoiding divergences of the numerical interaction process	Understanding and "allowing" local overflow in case of very localized storm areas (trophical, South-European,...)

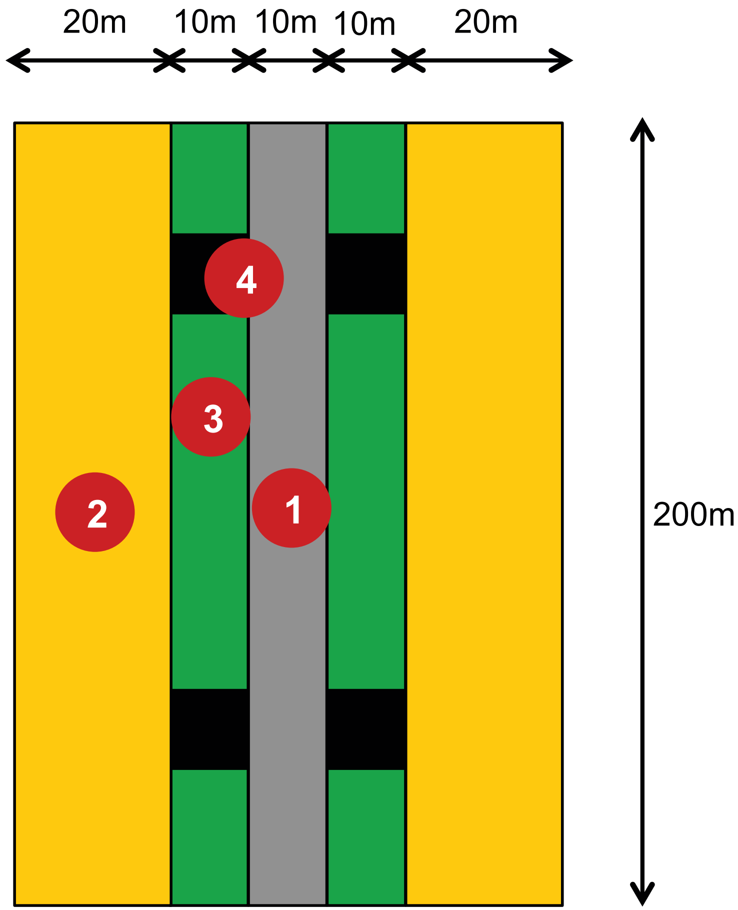
Pervious Hydraulic Design Tool – Numerical example

Geometrical data

Zone	Area [m2]
PRV road	2000
Buildings	8000
Grass	3600
Access roads to the buildings	400

Zone	ψ (Tr=2 years)	ψ (Tr=10 years)	ψ (Tr=50 years)
PRV road	0,5	0,9	0,98
Buildings	0,27	0,5	0,54
Grass	0,05	0,1	0,11
Access roads to the buildings	0,11	0,2	0,22

Zone	Aeq (Tr=2 years) [m2]	Aeq (Tr=10 years) [m2]	Aeq (Tr=50 years) [m2]
PRV road	1000	1800	1960
Buildings	2160	4000	4320
Grass	180	360	396
Access roads to the buildings	44	80	88
TOTAL	3384	6240	6764
ψeq	**1,692**	**3,12**	**3,382**



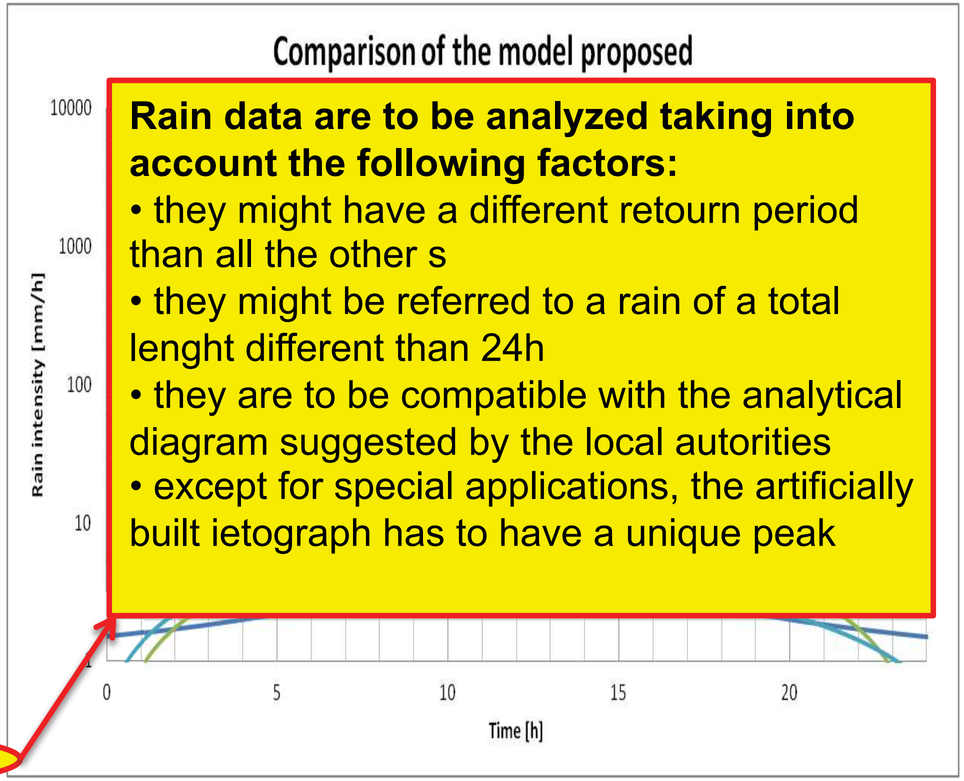
1 – PRV road
2 – Buildings
3 – Grass
4 – Access roads to the buildings

Pervious Hydraulic Design Tool – Numerical Example

Rain analysis from database

(distribution of rainfall over time)

Year	Max_10 min	Max_20 min	Max_30 min	Max_1h	Max_3h	Max_6h	Max_12h	Max_24h
1990	17,8	25,6	29	29,8	30	41	49	61,8
1991	19,1	29,1	32,6	37,8	52	73,8	75,9	82,9
1992	14,7	17,5	20,8	28,6	41,5	41,7	52,8	74,5
1993								
1994	11,2	20,2	26,9	30	36,6	57	92,7	124,8
1995	13,3	20,7	24,4	28,4	32,8	32,8	44,1	45,9
1996	20,8	24,1	24,5	34,3	39,5	46,9	47,7	50,7
1997	18,7	30,9	41,3	49,6	57,1	57,1	61,5	66,7
1998	12,9	18,3	22,7	28,6	28,6	28,6	28,6	51,9
1999	13,4	22,7	25,5	25,8	41,2	41,6	41,6	46,8
2000	15,5	21,7	23,5	24	41,4	63,2	82,4	97,1
2001	9,3	15,3	18,7	21,2	24,6	26,1	26,9	28,1
2002	16,8	29,6	39,2	46,7	59,3	66,7	66,7	66,7
2003	17,8	21,1	26,8	30,4	34,6	36	36	39,8
2004	20,5	32,7	33,7	33,9	54,8	57,4	57,4	57,4
2005	15,7	21,3	31,7	39,8	40,2	43,6	44,2	49
2006	10,3	12,3	13,1	15,5	24,7	38,3	54,2	90,8
2007	[illegible]	[illegible]	22,5	26,1	26,7	31,2	33,2	43,1
2008	13,5	18,4	19	22,9	27,3	34,3	39,5	59,3
2009	16,4	28,4	41,9	**62,2**	**88,2**	**88,2**	**88,2**	**88,2**



Rain data are to be analyzed taking into account the following factors:
- they might have a different retourn period than all the other s
- they might be referred to a rain of a total lenght different than 24h
- they are to be compatible with the analytical diagram suggested by the local autorities
- except for special applications, the artificially built ietograph has to have a unique peak

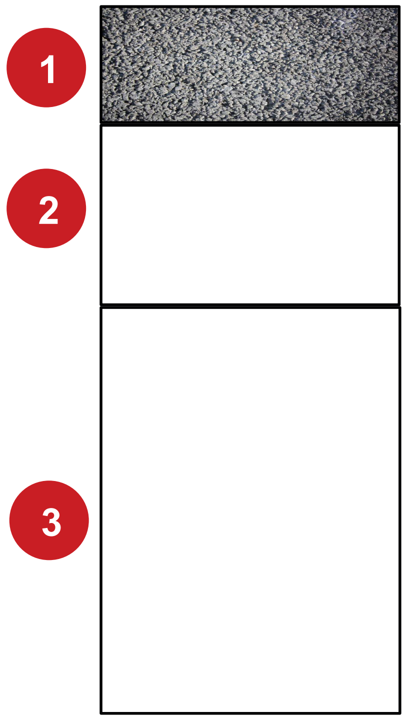
ASSUMPTIONS:

- For safety reasons, we assume the **return period to be the total age of the database** (even if can happen that a higher-return period event was measured inside it)
- For safety reasons, we assume the **max precipitations for any interval from any year**, even if they are coming from different years and rain sessions
- We assume **the peak of the rain to be at mid-day** for make an easier calculation. Conventional the peak is situated at 35% of the total lenght of rain considered (at 8h 25min)

Pervious Hydraulic Design Tool – Numerical example

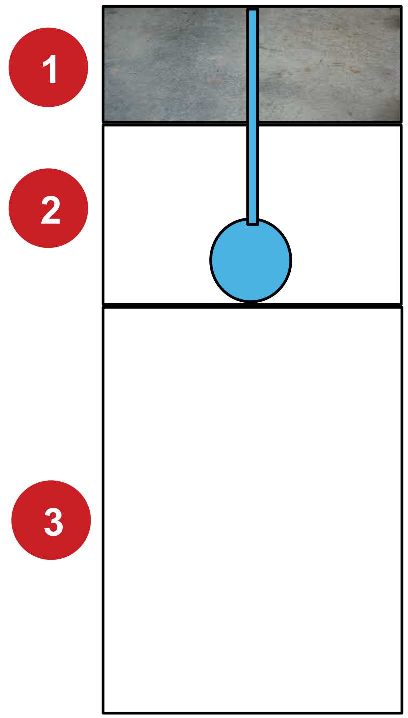
Geological/hydraulic data

CASE 1



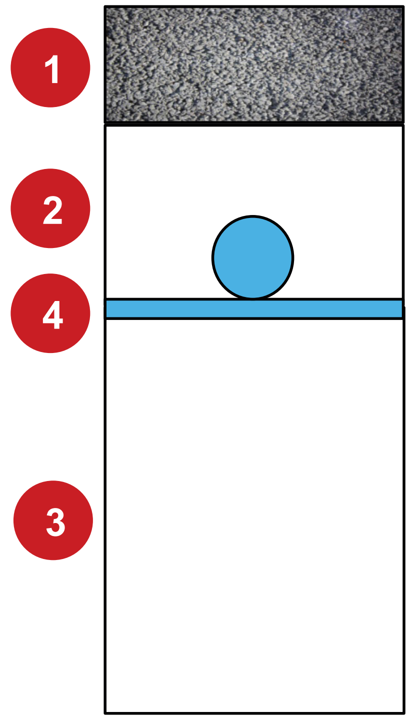
Layer	Material	water conductivity k [mm/s]
1	Structural pervious concrete	5
2	Washed gravel 30/50	1600
3	Peat	0,0007

CASE 2



Layer	Material	water conductivity k [mm/s]
1	Concrete/asphalt	1e-18
2	Washed gravel 30/50	1600
3	Peat	0,0007

CASE 3

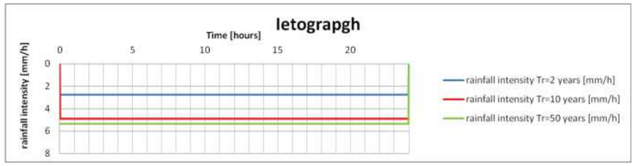


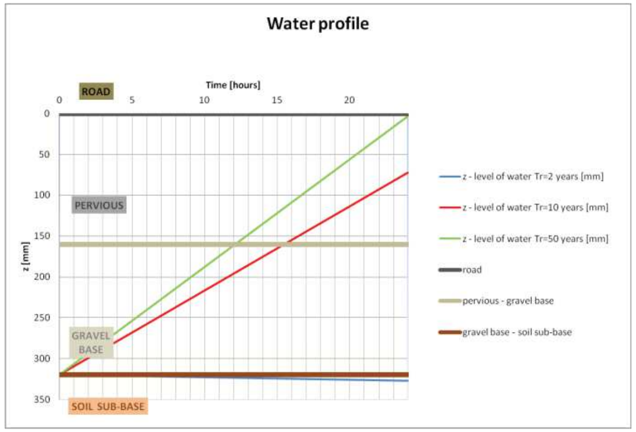
Layer	Material	water conductivity k [mm/s]
1	Structural pervious concrete	5
2	Washed gravel 30/50	1600
3	Peat	0,0007
4	Plastic foil	1e-18

Pervious Hydraulic Design Tool – Numerical example

Case 1 – PRV drainage

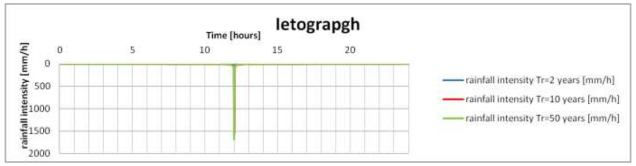
CONSTANT IETOGRAPH

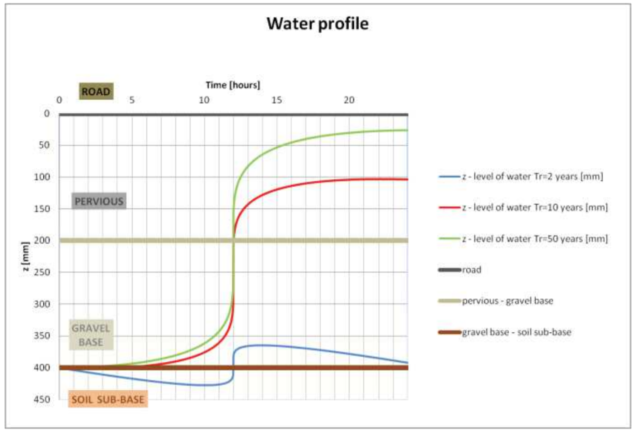




h PRV [mm]	160
h gravel [mm]	160
pipe diameter [mm]	-

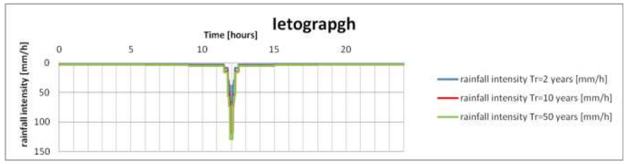
CHICAGO IETOGRAPH

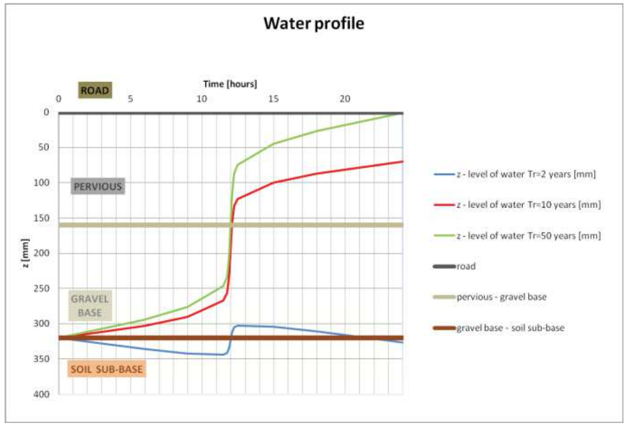




h PRV [mm]	200
h gravel [mm]	200
pipe diameter [mm]	-

NUMERICAL INTEGRATION



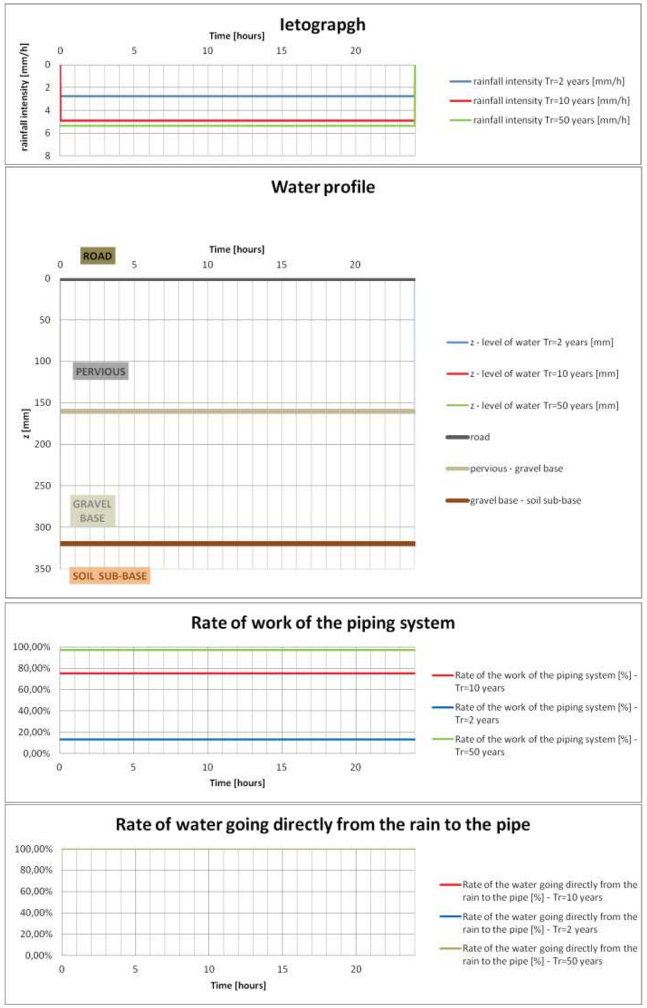


h PRV [mm]	160
h gravel [mm]	160
pipe diameter [mm]	-

Pervious Hydraulic Design Tool – Numerical example

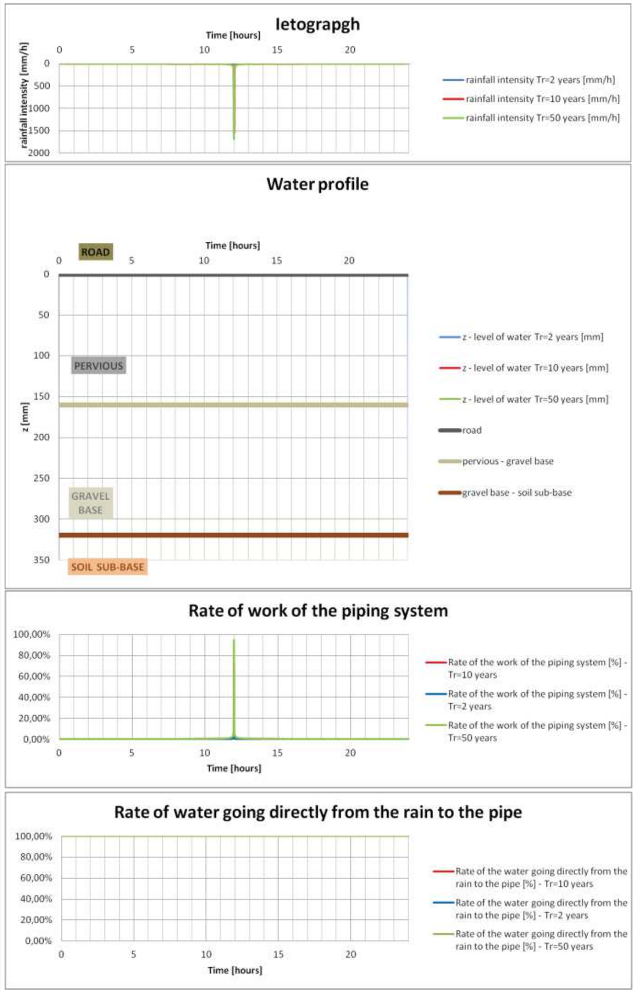
Case 2 – Conventional drainage

CONSTANT IETOGRAPH



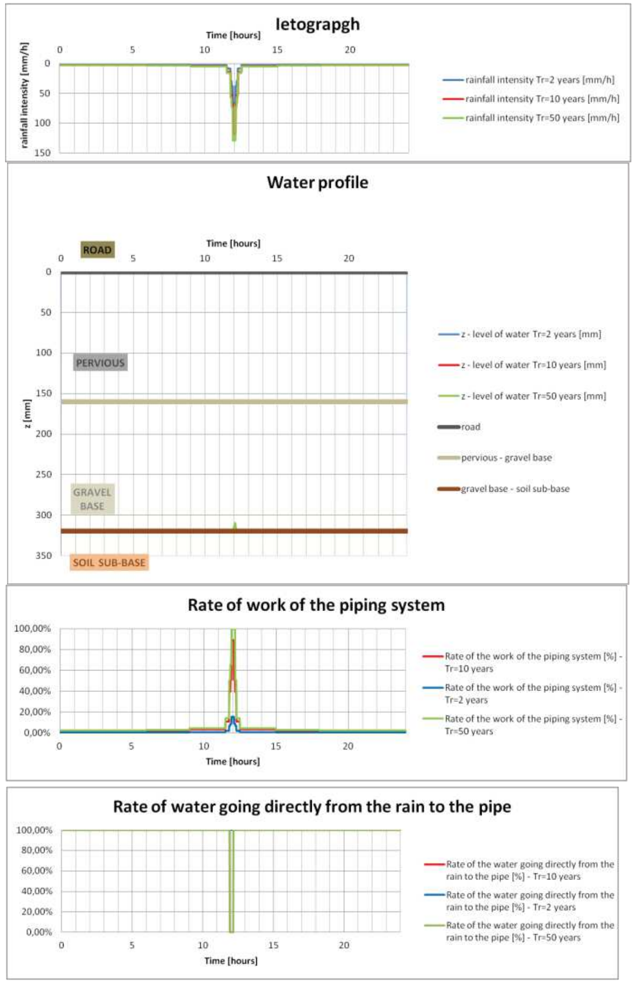
h PRV [mm]	-
h gravel [mm]	-
pipe diameter [mm]	700

CHICAGO IETOGRAPH



h PRV [mm]	-
h gravel [mm]	-
pipe diameter [mm]	6300

NUMERICAL INTEGRATION

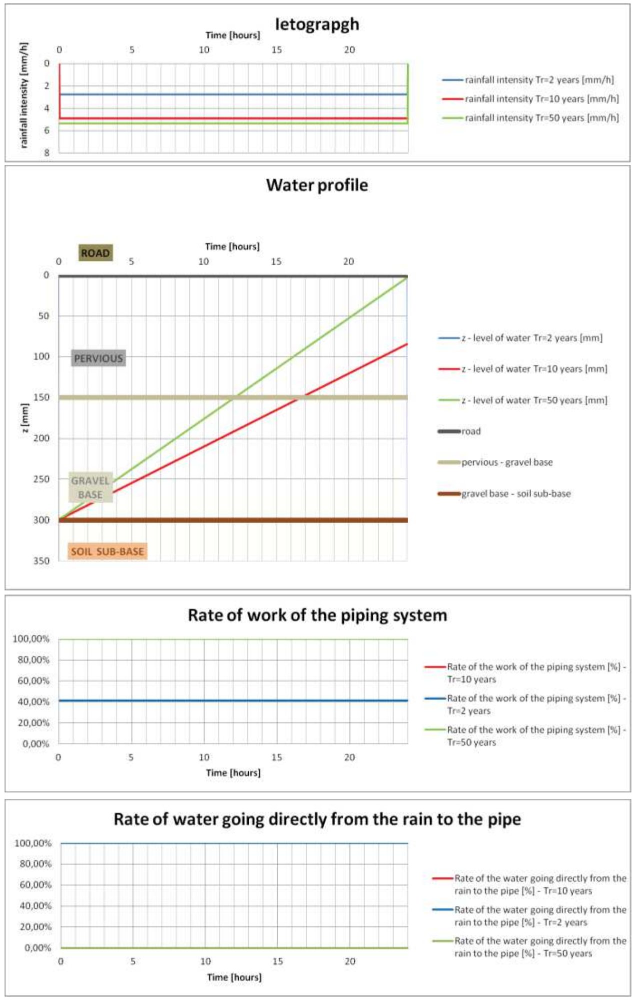


h PRV [mm]	-
h gravel [mm]	-
pipe diameter [mm]	2200

Pervious Hydraulic Design Tool – Numerical example

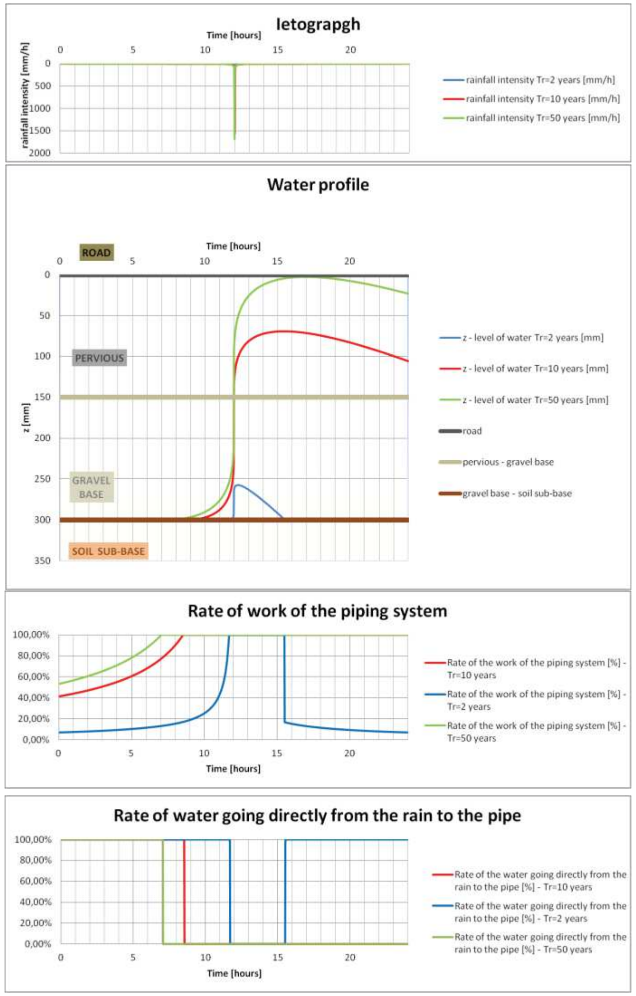
Case 3 – Hybrid PRV/convetional drainage

CONSTANT IETOGRAPH



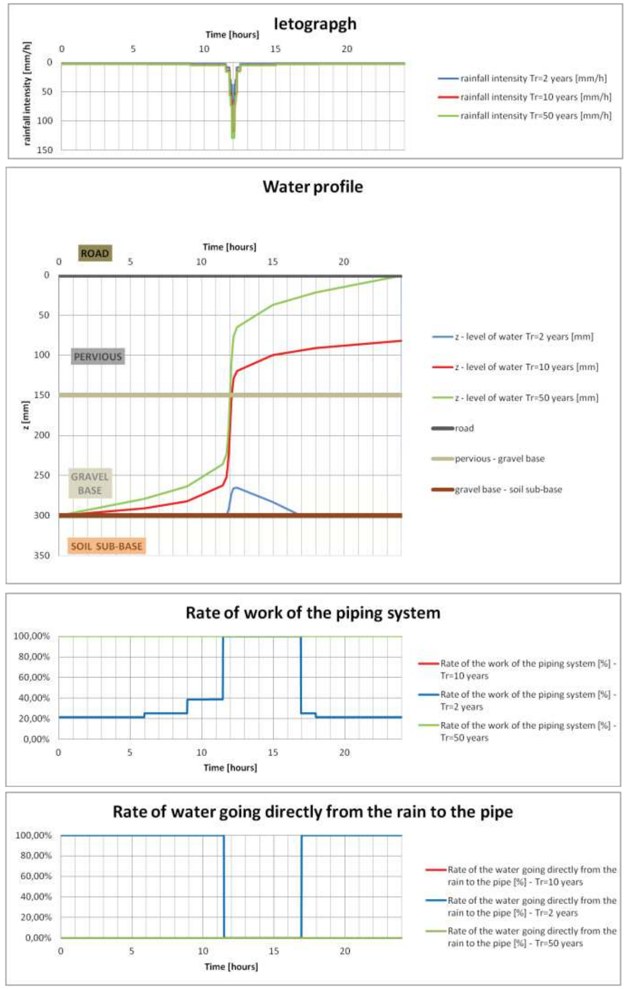
h PRV [mm]	150
h gravel [mm]	150
pipe diameter [mm]	450

CHICAGO IETOGRAPH



h PRV [mm]	150
h gravel [mm]	150
pipe diameter [mm]	550

NUMERICAL INTEGRATION



h PRV [mm]	150
h gravel [mm]	150
pipe diameter [mm]	450

Pervious Hydraulic Design Tool – Numerical example

Comparison of the results

Geometrical results						
	Constant ietograph		Chicago ietograph		Numerical ietograph	
PRV drainage	h PRV [mm]	160	h PRV [mm]	200	h PRV [mm]	160
	h gravel [mm]	160	h gravel [mm]	200	h gravel [mm]	160
	pipe diameter [mm]	-	pipe diameter [mm]	-	pipe diameter [mm]	-
Conventional drainage	h PRV [mm]	-	h PRV [mm]	-	h PRV [mm]	-
	h gravel [mm]	-	h gravel [mm]	-	h gravel [mm]	-
	pipe diameter [mm]	700	pipe diameter [mm]	6300	pipe diameter [mm]	2200
Hybrid PRV/ convetional drainage	h PRV [mm]	150	h PRV [mm]	150	h PRV [mm]	150
	h gravel [mm]	150	h gravel [mm]	150	h gravel [mm]	150
	pipe diameter [mm]	450	pipe diameter [mm]	550	pipe diameter [mm]	450

Time to empty the basin [days]						
	Constant ietograph		Chicago ietograph		Numerical ietograph	
PRV drainage	Tr=2 years	0	Tr=2 years	0,13	Tr=2 years	0
	Tr=5 years	4,1	Tr=5 years	4,91	Tr=5 years	4,14
	Tr=10 years	5,23	Tr=10 years	6,19	Tr=10 years	5,27
Conventional drainage	Tr=2 years	0	Tr=2 years	0	Tr=2 years	0
	Tr=5 years	0	Tr=5 years	0	Tr=5 years	0
	Tr=10 years	0	Tr=10 years	0	Tr=10 years	0
Hybrid PRV/ convetional drainage	Tr=2 years	0	Tr=2 years	0	Tr=2 years	0
	Tr=5 years	1,41	Tr=5 years	0,75	Tr=5 years	1,41
	Tr=10 years	2,1	Tr=10 years	1,16	Tr=10 years	2,13

Pervious Hydraulic Design Tool – Numerical example

Conclusions

• PRV drainage solution can adapted to any of the the theoretical ietograph studied (constant, Chicago, Numerically defined according to the real data coming from the metereological stations. In case of high rain zone (e.g. Equatorial Zone) can lead to very high pavement thicknesses if the soil is not enough permeable.

• Convetional drainage system (localized empty points on the surface and main pipe) is suitable once the rain distribution is very constant (e.g. London....). For climate area where the rain are concetrated (e.g. Mediterranean Zone, Central Europe, Equatorial Zone, ...) convetional system will lead to an huge overestimation of th pipe's dimension, once we want to ensure no water laying on the road surface.

• Hybrid system with a plastic foil on the soil layer (system n.3) brings the good characteristics of the two original systems: minimum pavement thicknesses and reduced pipe's diameter (around 5-10) in case of localized (in the time domain) rains

• Plastic foil to be placed under the gravel layer is to be thick enough to sustain the load given by the working equipments (usually very heavy, 10-40 tonnes) used for the placing and for the compaction of the gravel and pervious layer

• In case of low permeability soil (clay, rocks, ...) the hybrid system might be used without the plastic foil.

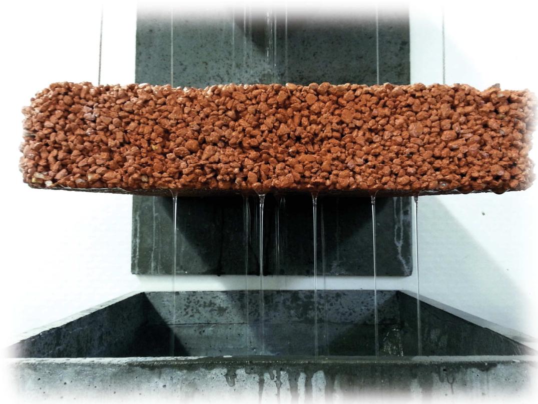
• In case of medium permeability soil (silt, peat, fine sand,...) the hybrid system without plastic foil would be the and advatage from the hydraulic point of view

ZOO ST. THIBERY
Report of structural Pervious and Hydraulical design

PRODUCT DEVELOPMENT & CONSTRUCTION TRENDS

Product Development & Industrialization

28/01/2015



Current situation and motivation

The alleys were built from an impemeble asphalt layer (ca. 1 cm thick) on a “tout-venant” base (0/20 – ca. 20 cm thick). A thin layer of exposed aggregates was used for aesthetic reasons.

Their width is constant and ca. 3.5m on the entire Zoo, and surronded by soil.

⇒ Due to the impermeable nature of the alleys and the natural slope on the site, storm water is is generally accumulated in the main entrance, incl. the handicap parking, and in front of the arena.

Objectives

✓ Ensure a complete management of the storm water: no flooding of the alleys or into the bassins of animals, and in the main entrance/handicap parking area.

✓ In order to respect the continuity for handicap people, a similar pavement on the handicap parking area than in the Zoo will be used.

✓ The proposed design should ultimately integrate the existing drainage already in place.

INTRODUCTION – Profile of the job site

Meteorological Profile

PERVIA – Permeable Concrete for Cost Effective Water Management

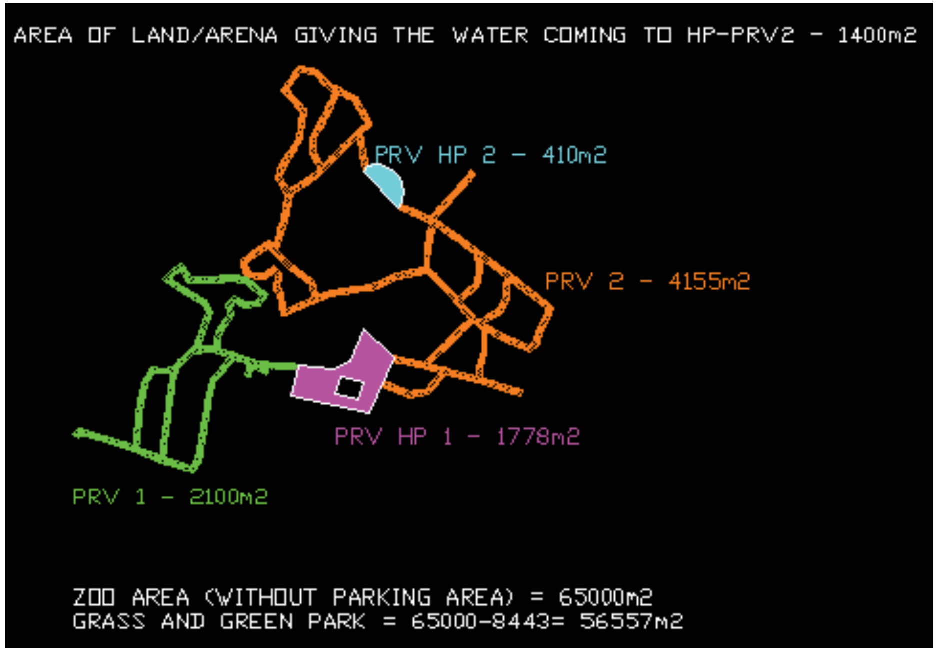
Pervia
Permeable by design

Challenge	Key Benefits	Technical Advantage
Low-volume, heavy load pavements	• Easy placement • High Strength	**Permeability** **High flexural strength** More than 3.5 MPa
Water management	• Reduction of storm water • Reservoir effect	
Green label	• Fulfill 2 points of the LEED certification	

CEMEX

OUR PROPOSAL – Definition of 4 different zones

Drawn map of Zoo



AutoCAD representation of the pathway of the Zoo

Due to the natural slope, we propose to drain and direct all the water flow from the alleys to the main entrance area, where a specific drainage will be design.

⇒The main alleys (PRV1 and PRV2) will be built with a single layer of 15 cm of Decorative Pervia Concrete on top of the existing pavement. Edges will be covered by geotextile and soil.

⇒The area of the entrance and the handicap parking (PRV HP1), where the water is directed, will be a combination of a High Performance Pervia Concrete (15 cm) and a specific Sub-base

⇒In the case of the area in front of the Arena (PRV HP2) the pavement will be designed to ensure a complete drainage using High Performance Pervia Concrete (15 cm) and also a permable sub-base

Calculated volume

Decorative

PRV1 : 2100 m^2

PRV2 : 4155 m^2

→ **6255m^2 - 938 m^3**

High Performance

PRVHP1 : 1778 m^2

PRVHP2 : 410 m^2

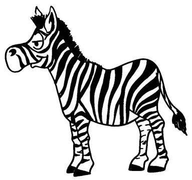
→ **2188m^2 - 328 m^3**

** Details slide 7*

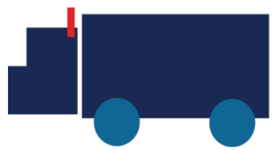
STRUCTURAL DESIGN – Decorative and High Performance

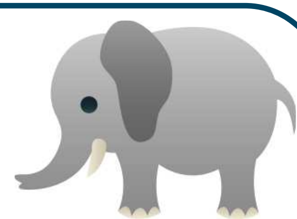
- PRV 1 - Decorative
- PRV 2 - Decorative
- HP PRV 1 – High Performance
- HP PRV 2 – High Perfiormance

Structural Design



Decorative
Up to 3.5t vehicules
Drainage using Asphalt
Aesthetic finish





High Performance
Up to 12t vehicules
Optimised Pervia Sub-base
High structural resistance

COST — *€*

STRUCTURAL — *Tonnes*

PERMEABILITY — *Liters*

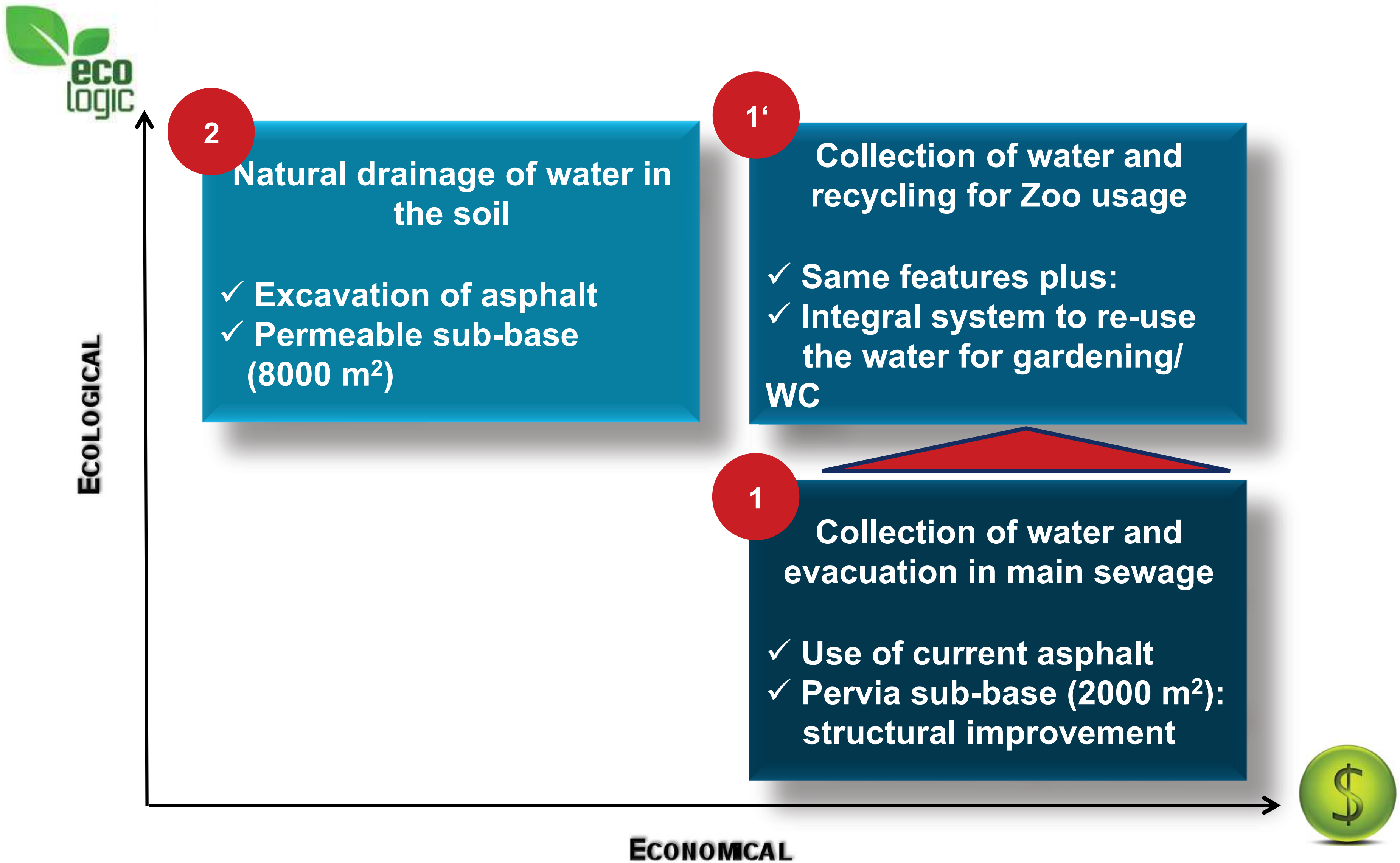
COST — *€*

STRUCTURAL — *Tonnes*

PERMEABILITY — *Liters*

DIFFERENT APPROACHES – Economical or Ecological

From the initial proposal, two main approaches can be envisaged depending if focus is given to economical aspects or to ecological considerations. The economical solution is an evolutive proposal, where green recycling of water can be implemented.



CEMEX

The Option 1 is to our opinion the best approach, making use of the current asphalt pavement that can be re-used as sub-base. The excavation would be extremely reduced and the re-opening of the alleys would be faster.

eco logic

ECOLOGICAL

2 – Natural drainage of water in the soil

- ✓ Excavation of asphalt
- ✓ Permeable sub-base (8000 m²)

1' – Collection of water and recycling for Zoo usage

- ✓ Same features plus:
- ✓ Integral system to re-use the water for gardening/ WC

1 – Collection of water and evacuation in main sewage

- ✓ Use of current asphalt
- ✓ Pervia sub-base (2000 m²): structural improvement

- ✓ Fastest re-opening of alleys
- ✓ Reduced needs for excavation
- ✓ Optimized structural design
- ✓ Evolutive solution

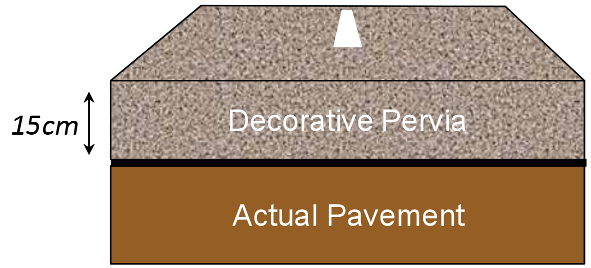
ECONOMICAL

ECONOMICAL PROPOSAL – Schematic Sections

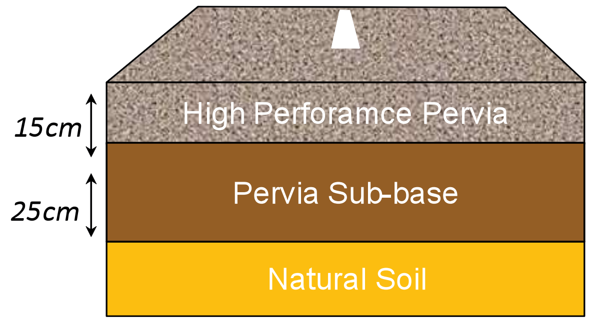
Zones	Base (thickness)	Pervia (thickness)	Hydrological Design
PRV1/2	Actual(1)	Decorative (15 cm)	
HP PRV 1	Pervia Sub-base (25 cm)	High Performance (15 cm)	
HP PRV2	Gravel (35 cm)	High Performance (15 cm)	

↳ **Material needed....................**

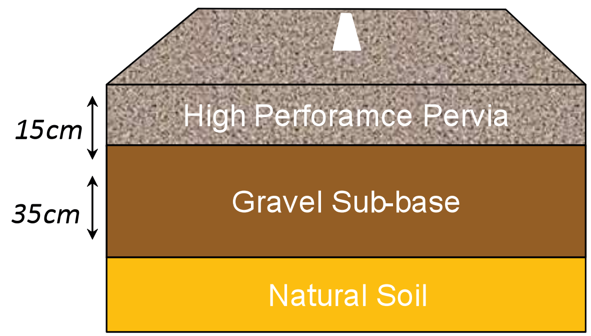
- PRV 1 - Decorative
- PRV 2 - Decorative
- HP PRV 1 – High Performance
- HP PRV 2 – High Performance



PRV1 and PRV2

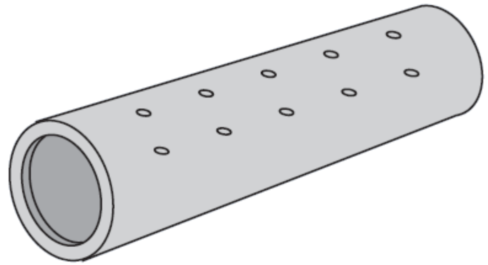


HP PRV 1

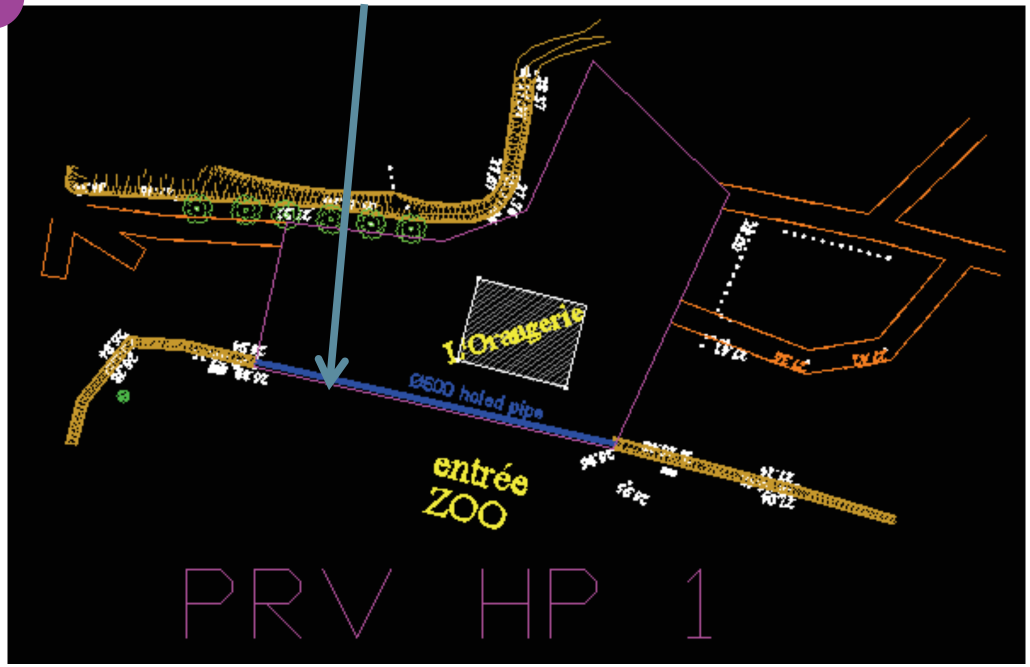


HP PRV 2

DRAINAGE SYSTEM – Using the existing sewage



A D=600mm – 60 m length holed pipes (only on top half circle) will be placed in the lowest part of the HP PRV 1 zone and covered by mean of geotextile in order to prevent clogging of the holes.

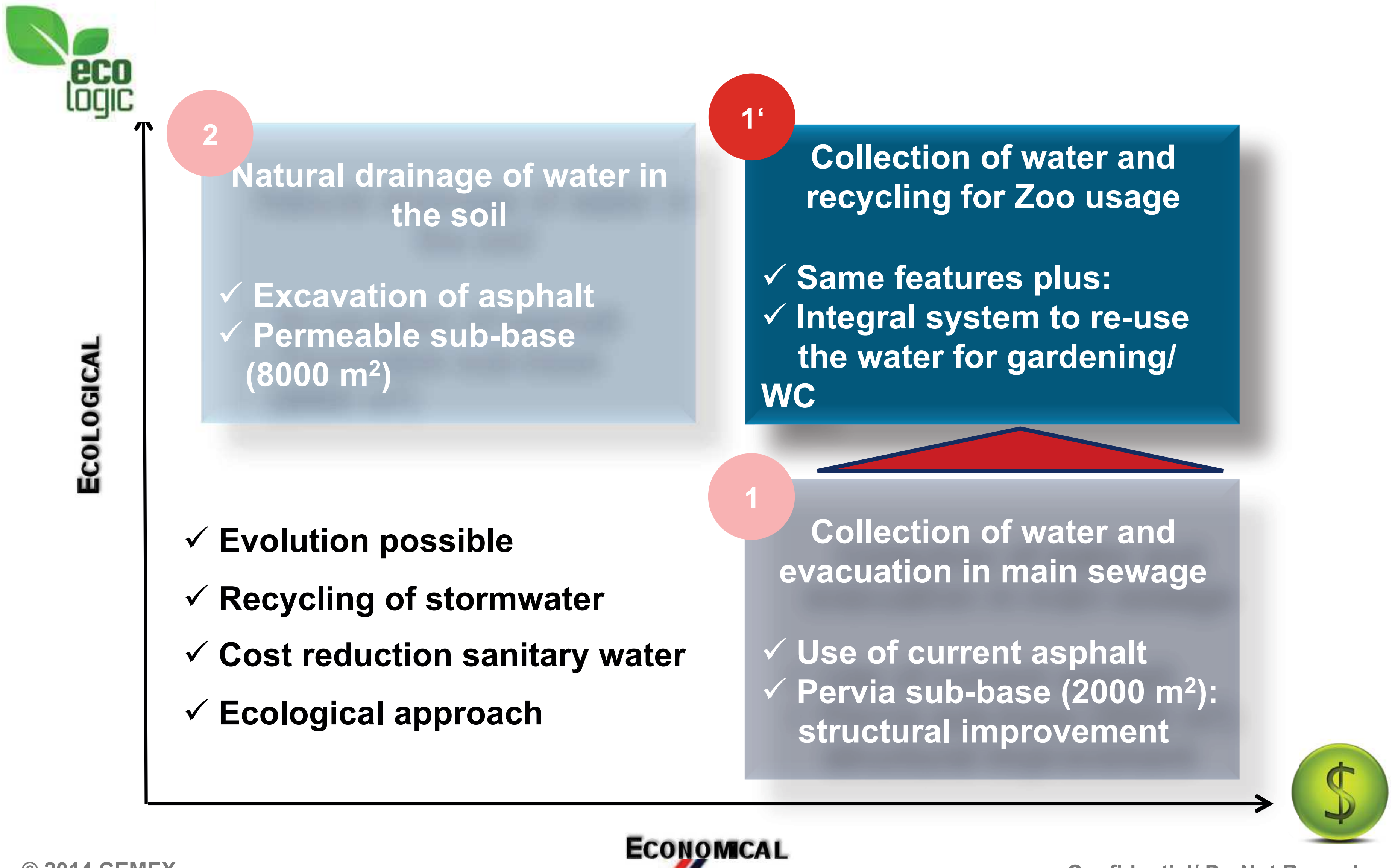


Main Entrance
Water is drained entirely to the Main Entrance
Area where a pipe will ensure the evacuation
To the existing sewage.

CEMEX

EVOLUTION OF OPTION 1 – Recycling of stormwater

The storwater collected at the main entrance by the pipe system can be stored and re-used after adequate treatment for gardening and non-sanitary usages.



WATER CITERN – Soft containers to store and reuse water

High volume (ca. 5000 m^3) container can be easily found and can be installer to store water during rainy season. The recycled water can then be used during the dry season.

ECOLOGICAL APPROACH – Natural Drainage

The second would consist in a complete excavation of the asphalt pavement, and to design the alleys and pavements to allow a natural drainage of the stormwater in the soil. Although this option is attractive, it would generates more waste materials and would necessitate higher concrete volumes.

ECOLOGICAL

2 – Natural drainage of water in the soil

- ✓ Excavation of asphalt
- ✓ Permeable sub-base (8000 m²)

1' – Collection of water and recycling for Zoo usage

- ✓ Same features plus:
- ✓ Integral system to re-use the water for gardening/ WC

1 – Collection of water and evacuation in main sewage

- ✓ Use of current asphalt
- ✓ Pervia sub-base (2000 m²): structural improvement

- ✓ Natural drainage of water
- ✓ Optimized sub-base design
- ✓ No need to level borders

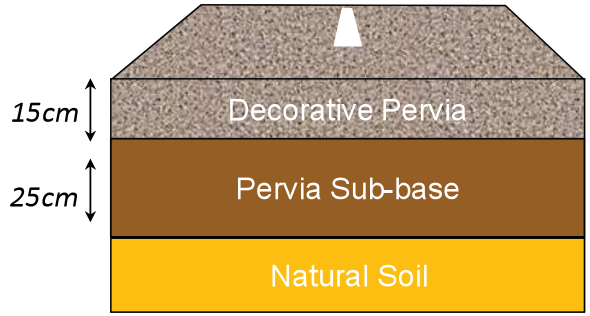
ECONOMICAL

ECOLOGICAL PROPOSAL – Schematic Sections

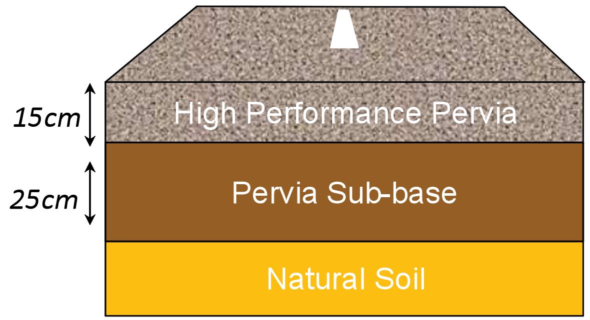
Zones	Base (thickness)	Pervia (thickness)
PRV1/2	**Pervia Sub-base** (25 cm)	**Decorative** (15 cm)
PRV HP1	**Pervia Sub-base** (25 cm)	**High Performance** (15 cm)
PRV HP2	**Gravel (granulometry TBD)** (35 cm)	**High Performance** (15 cm)

↳ **Material needed……………..**

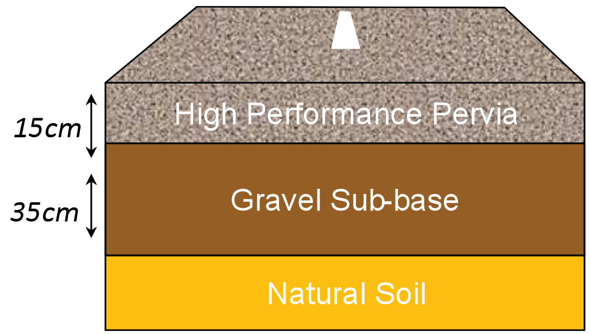
- PRV 1 - Decorative
- PRV 2 - Decorative
- HP PRV 1 – High Performance
- HP PRV 2 – High Performance



PRV1 and PRV2



HP PRV 1

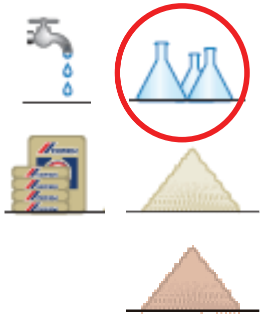


HP PRV 2

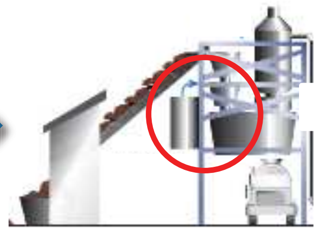
Pervious Concrete vs. Asphalt

Value Chain

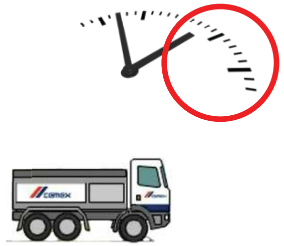
1 Raw materials



2 Production



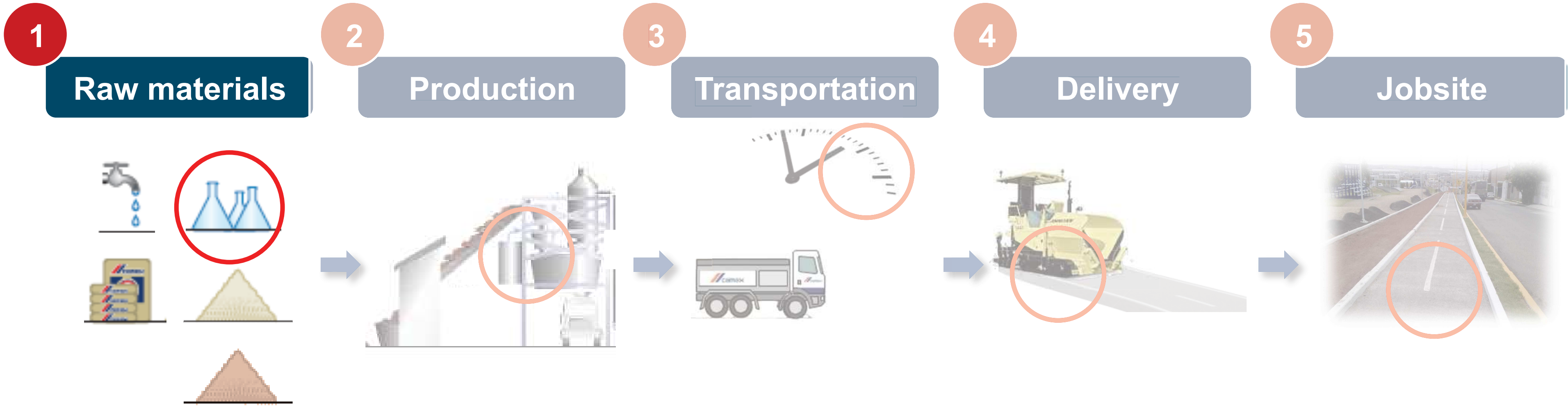
3 Transportation



4 Placing

5 Jobsite

Pervious Concrete vs. Asphalt
Value Chain



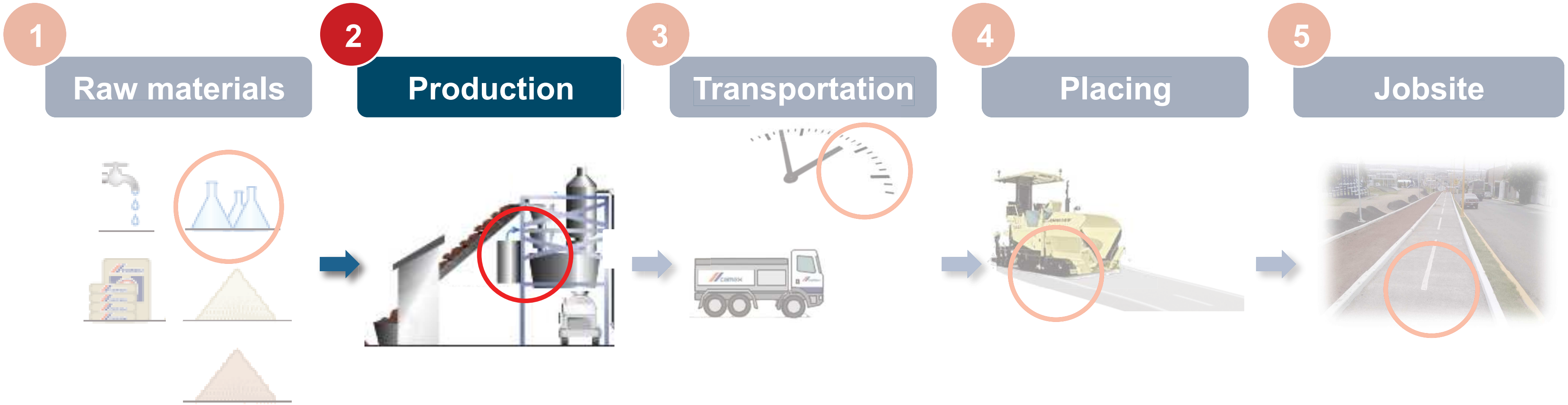
Gravel / Sand	- Selection of local source of aggregates
	  - Easy to produce and eventually reproduce in the future
	  - Choice of granulometry possible to change texture

Admixtures	- In house technology to manage range of performance
	  - Decorative
	  - High performance

Colorant	- Final aspect and color can be tailor design to the wishes of the customer

Pervious Concrete vs. Asphalt

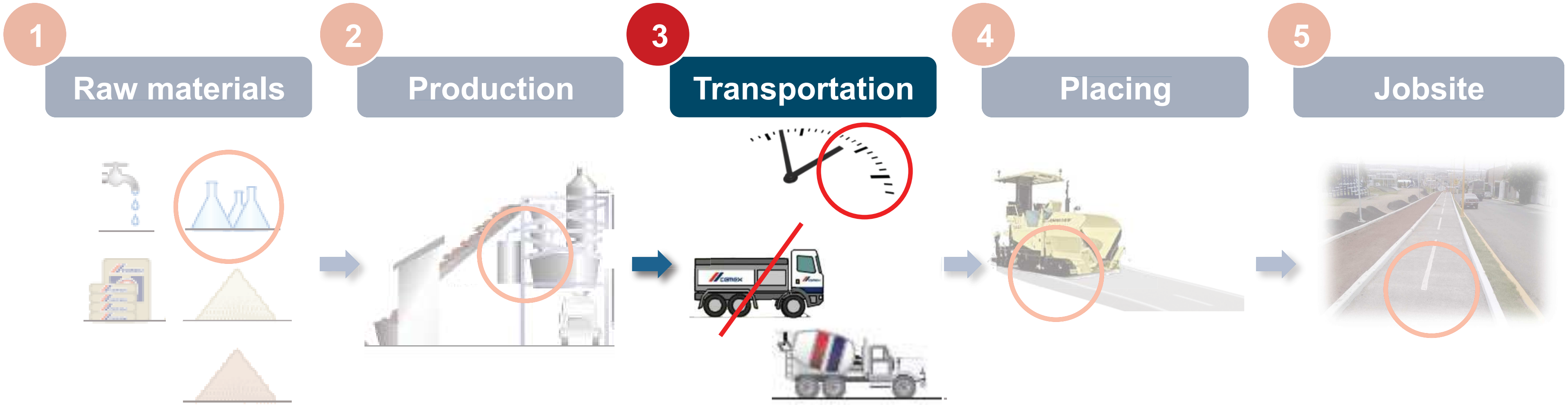
Value Chain



Asset	- Use local production equipment - Ready-Mix Plant close to the jobsite to assure logistic optimization
Quality concrete	- Mix design methodology to guaranty Strength and Permeability

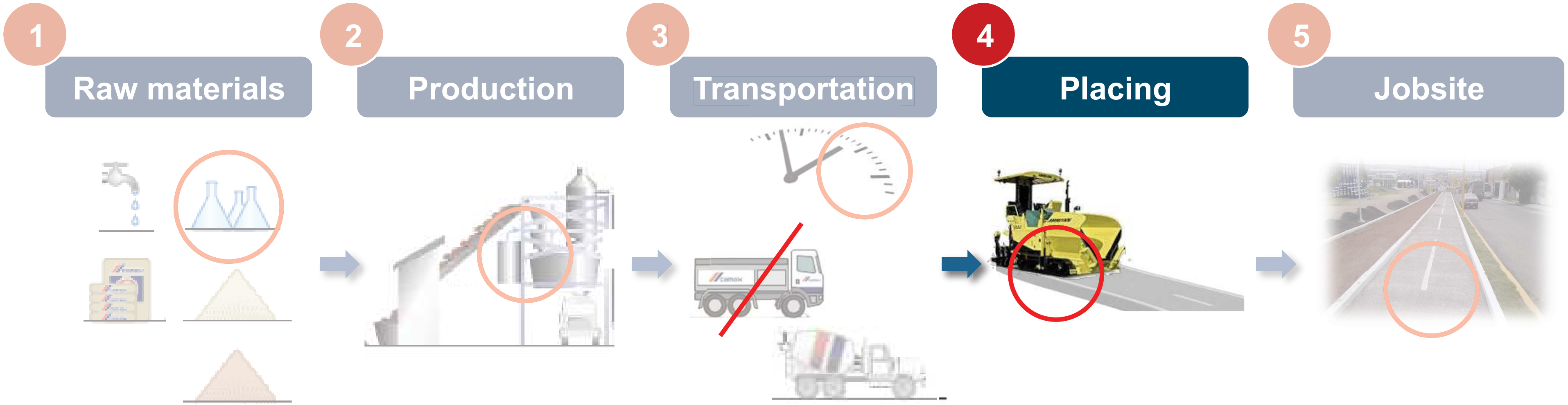
Pervious Concrete vs. Asphalt

Value Chain



Transportation	- Use existing Ready-Mix trucks - Extended workability – up to 3hours if needed

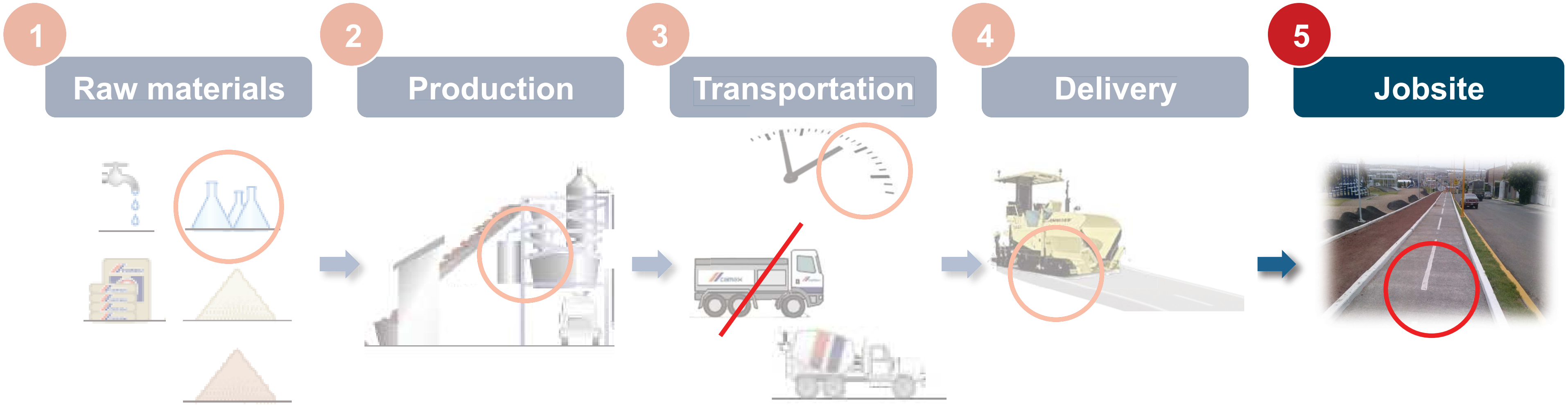
Pervious Concrete vs. Asphalt
Value Chain



Placing	- Use existing Paver / Roller equipment - Improve equipment performance and robustness (better Industrialization) - Large choice of tools depending on type of concrete - Can be done manually

Placing / Compaction Techniques

Pervious Concrete vs. Asphalt
Value Chain



Jobsite	- Better finishing: choice of colors - Better strength and durability - Faster placement and re-opening of jobsite (24hours) - Minimize lost of profits

Benefits	- Efficient solution to collect and manage Rainwater
	  - Reduction of storm water runoffs
	  - Reservoir effect: recycling of water possible
	- Easy placement and finishing
	- Green Label – LEED certification

EXAMPLES OF PERVIOUS CONCRETE – Decorative and High Perfomance

Decorative Concrete – CX France
Toulouse – April 2014

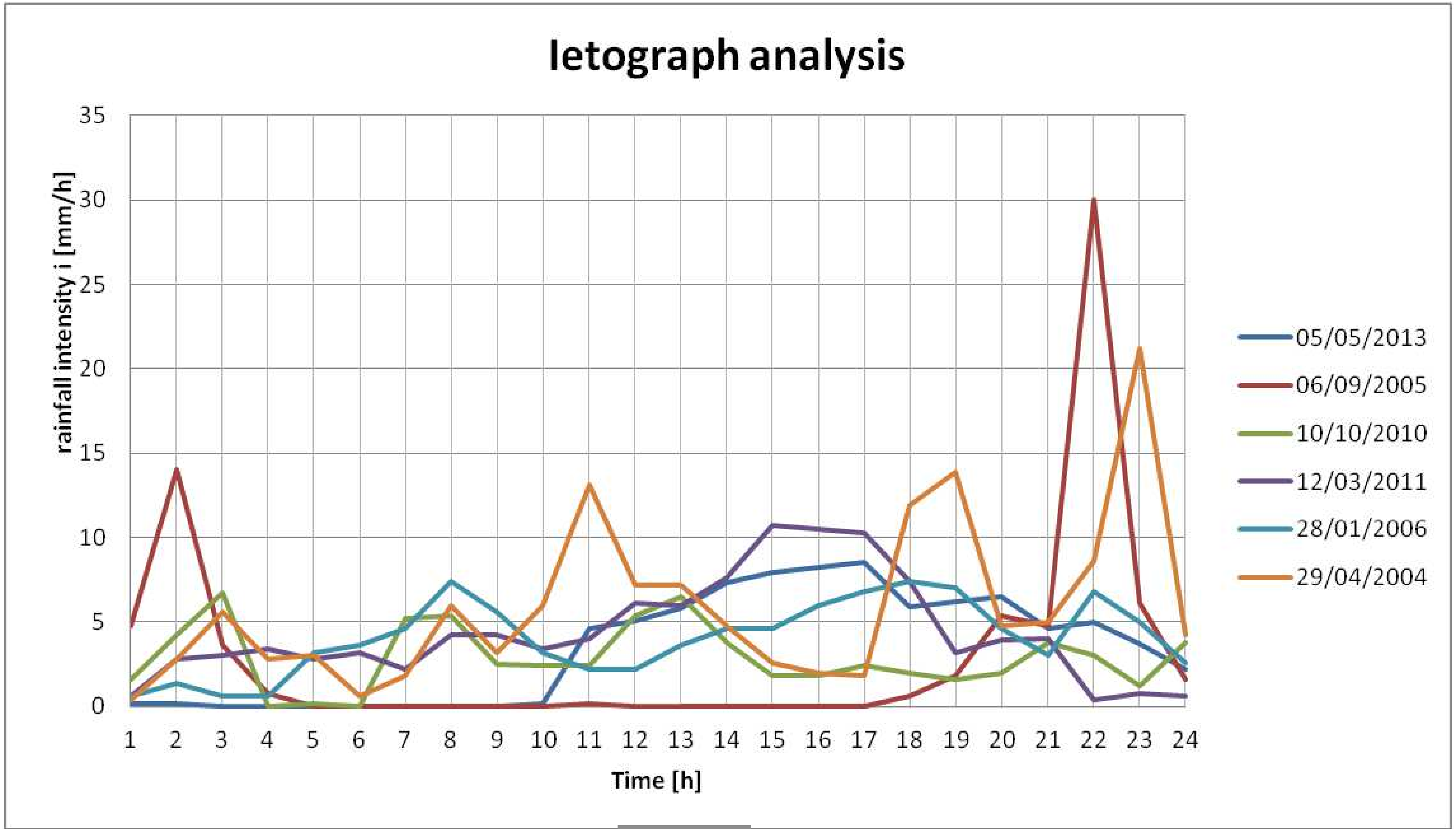
HP Pervious – CX Mexico
Mexico City – May 2014

BACK UPs

OUR PROPOSAL – Hydrological design

The design of each zone was defined based on the statistical analysis of the rain profile from 2004 to 2013 from the data coming from the Pezenas's meteorological station. The 6 worst 24-hours rains are shown in the graph below:

- **In order to build the hydrological design for the Zoo, the worst rain period from the last 10 years was used (April 19, 2004 - 140.4 mm/24 h)**
- **The return period was taken, according to safety reasons, at 10 years**

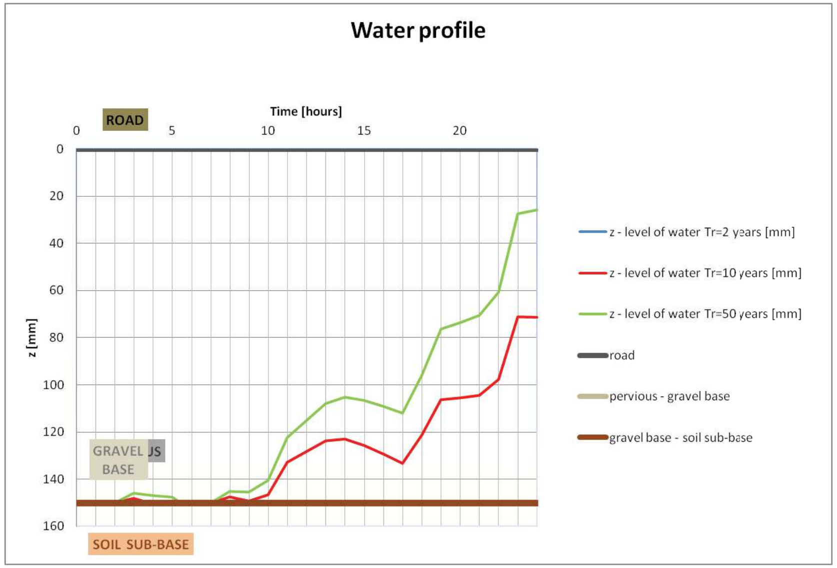


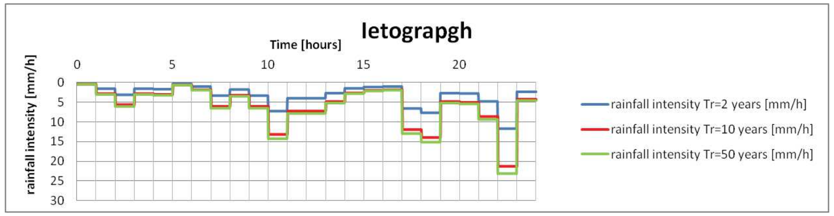
HYDRAULICAL ANALYSIS – Overall analysis (PRV1 and PRV2)

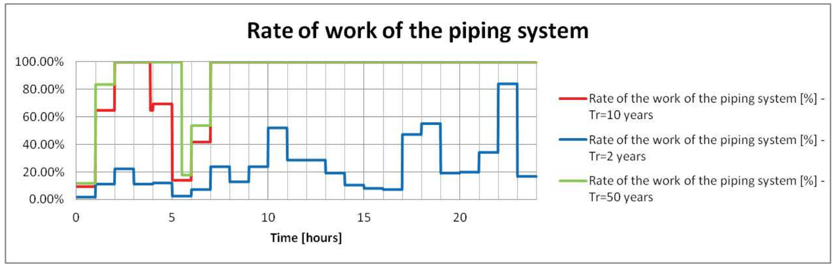
A first overall analysis of the site was done considering a overall thickness of pervious of 15 cm and no presence of gravel (in order to be in the safety side). For safety and to better simulate the presence of the 1-cm-layer of asphalt, the soil was considered impermeable (k=1exp-18 mm/s)

Hydrological Parameters	Type of Ietograph	Manual par hours
	Tr= return period [years]	10
	h=total rainfall per day f(Tr) [mm]	140.5
	Integratio's steps	Constant
	Mode of integration - for Manual (numerically defined)	Constant
	s=starting of the rainfall respect to 24 h- for Constant/Triangular ietograph	0
	e=etarting of the rainfall respect to 24 h- for Constant/Triangular ietograph	1
	at=peak position respect e-s (%) - for Triangular	50%
	a=peak rain per hour f(Tr) [mm/hour] - for Chicago ietograph	49.6
	r=peak position respect 24h- for Chicago ietograph	0.5
Geotechnical Parameters	Type of pervious	PRV-25% voids
	Type of gravel for base	Gravel base
	Type of soil for sub-base	Asphalt
	k pervious [mm/s]	11
	k gravel [mm/s]	200
	k soil [mm/s]	1E-18
Geometrical Parameters	PRV road [m2]	8443
	Densly covered hurban area [m2]	0
	Covered hurban area [m2]	0
	Not covered hurban area [m2]	0
	Grass and green park [m2]	56557
	h pervious [mm]	150
	h gravel [mm]	0
	h soil[mm]	10000

Tr=2 years	Time to empty the basin [days] - combined soil+piping system	Water is drained at the same time
Tr=10 years	Time to empty the basin [days] - combined soil+piping system	0.4836
Tr=50 years	Time to empty the basin [days] - combined soil+piping system	0.8307







PIPES CONFIGURATION

N.	Material	Shape	a [mm]	b [mm]	c [mm]	d [mm]	e [mm]	f [mm]	Lenght [m]	Difference in height [m]
1	Concrete	Circular				600			60	1

HYDRAULICAL ANALYSIS – HP PRV 1

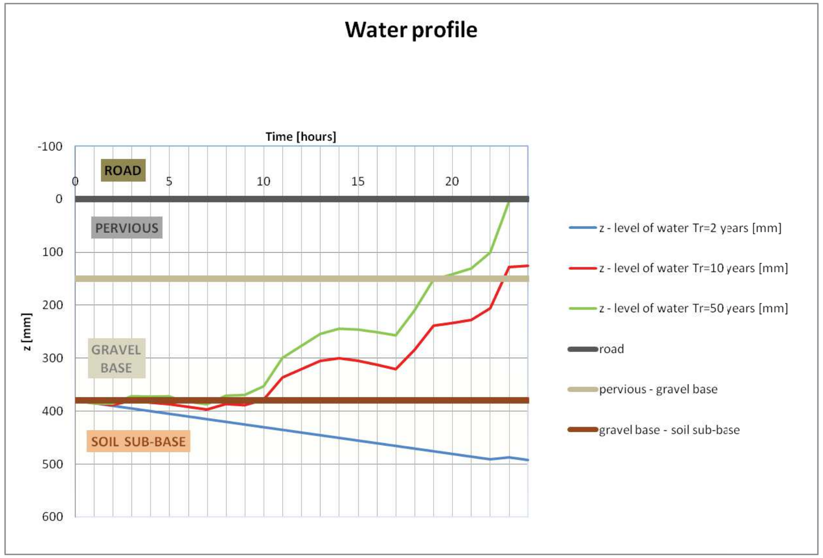
In this analysis we wanted to simulate that all the water in the zoo is dropped in the entrance zone (as happened in the last rain event). Layer of 15 cm of HP-PRV and 23 cm of LP-PRV where considered in the design. For safety the permeability of the soil was considered to be low (k=0.007 mm/s).

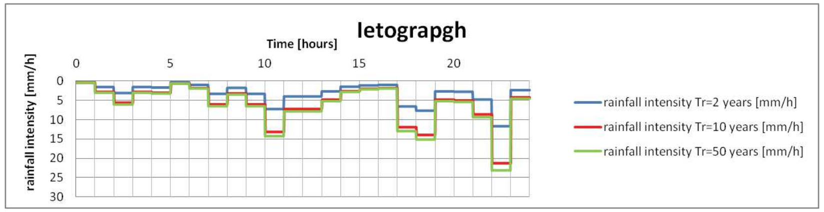
Hydrological Parameters	Type of Ietograph	Manual par hours
	Tr= return period [years]	10
	h=total rainfall per day f(Tr) [mm]	140.5
	Integratio's steps	Constant
	Mode of integration - for Manual (numerically defined)	Constant
	s=starting of the rainfall respect to 24 h- for Constant/Triangular ietograph	0
	e=etarting of the rainfall respect to 24 h- for Constant/Triangular ietograph	1
	at=peak position respect e-s (%) - for Triangular	50%
	a=peak rain per hour f(Tr) [mm/hour] - for Chicago ietograph	49.6
	r=peak position respect 24h- for Chicago ietograph	0.5
Geotechnical Parameters	Type of pervious	PRV-20% voids
	Type of gravel for base	LP-PRV
	Type of soil for sub-base	Peat
	k pervious [mm/s]	5
	k gravel [mm/s]	200
	k soil [mm/s]	0.0007
Geometrical Parameters	PRV road [m2]	1778
	Densly covered hurban area [m2]	0
	Covered hurban area [m2]	0
	Not covered hurban area [m2]	0
	Grass and green park [m2]	63222
	h pervious [mm]	150
	h gravel [mm]	230
	h soil[mm]	10000

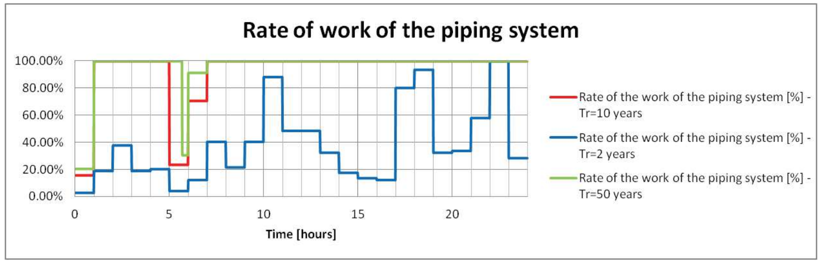
Tr=2 years	Time to empty the basin [days] - combined soil+piping system	Water is drained at the same time
Tr=10 years	Time to empty the basin [days] - combined soil+piping system	0.7655
Tr=50 years	Time to empty the basin [days] - combined soil+piping system	1.2341

PIPES CONFIGURATION

N.	Material	Shape	a [mm]	b [mm]	c [mm]	d [mm]	e [mm]	f [mm]	Lenght [m]	Difference in height [m]
1	Concrete	Circular				600			60	1





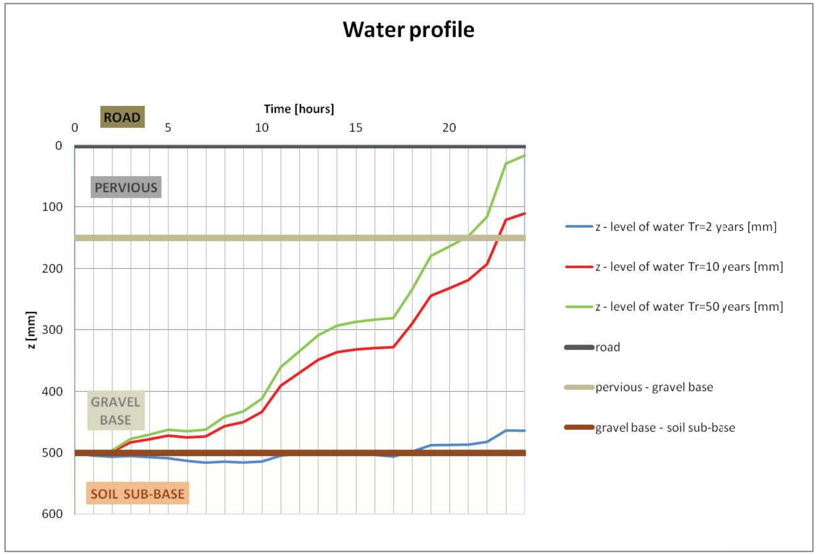


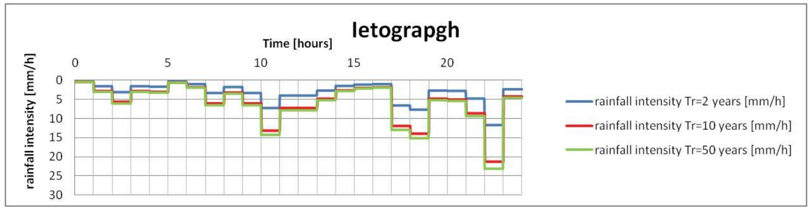
HYDRAULICAL ANALYSIS – HP PRV 2

In this analysis we wanted to simulate that all the water of the arena (fully impermeable) is going to part in front of it. Layer of 15 cm of HP-PRV and 35 cm of gravel where considered in the design. For safety the soil was considered slightly permeable (k=0.0007 mm/s). No piping system is adopted for this zone.

Hydrological Parameters	Type of Ietograph	Manual par hours
	Tr= return period [years]	10
	h=total rainfall per day f(Tr) [mm]	140.5
	Integratio's steps	Constant
	Mode of integration - for Manual (numerically defined)	Constant
	s=starting of the rainfall respect to 24 h- for Constant/Triangular ietograph	0
	e=etarting of the rainfall respect to 24 h- for Constant/Triangular ietograph	1
	at=peak position respect e-s (%) - for Triangular	50%
	a=peak rain per hour f(Tr) [mm/hour] - for Chicago ietograph	49.6
	r=peak position respect 24h- for Chicago ietograph	0.5
Geotechnical Parameters	Type of pervious	PRV-20% voids
	Type of gravel for base	Gravel base
	Type of soil for sub-base	Peat
	k pervious [mm/s]	5
	k gravel [mm/s]	200
	k soil [mm/s]	0.0007
Geometrical Parameters	PRV road [m2]	410
	Densly covered hurban area [m2]	1400
	Covered hurban area [m2]	0
	Not covered hurban area [m2]	0
	Grass and green park [m2]	0
	h pervious [mm]	150
	h gravel [mm]	350
	h soil[mm]	1000

Tr=2 years	Time to empty the basin [days] - combined soil+piping system	0.6048
Tr=10 years	Time to empty the basin [days] - combined soil+piping system	6.4376
Tr=50 years	Time to empty the basin [days] - combined soil+piping system	8.0041
PRV hydraulic design	Minimum PRV Thickness for given h gravel [mm]	150
Gravel hydraulic design	Minimum Gravel Thickness for given h pervious [mm]	350





MATERIAL NEEDED – Economical Proposal

	HP PRV 1	HP PRV 2	PRV 1	PRV 2	TOTAL
Area [m2]	1778	410	2100	4155	
Equivalent Linear length [m]	-	-	600	1188	
Excavation [mm]	380	500	-	-	
Geotextile on the total surface [y/n]	y	y	n	n	
Gravel thickness [mm]	-	350	-	-	
LP PRV thickness [mm]	250	-	-	-	
HP PRV thickness [mm]	150	150	-	-	
Aestetic PRV thickness [mm]	-	-	150	150	
Concrete holed pipe Din600 Dout704 [m]	60	-	-	-	
External surface of the pipe [m2]	132.7009	-	-	-	
Excavation volume [m3]	675.64	205	-	-	880.6
Plastic foil [m2]	-	70	-	-	70.0
Geotextile on the surface [m2]	1778	410	-	-	2188.0
Geotextile on the edges [m2]	-	-	600	1188	1788.0
Geotextile on the pipes [m2]	132.7009	-	-	-	132.7
Gravel volume [m3]	-	143.5	-	-	143.5
LP PRV volume [m3]	444.5	-	-	-	408.9
HP PRV volume [m3]	266.7	61.5	-	-	328.2
Aestetic PRV volume [m3]	-	-	315	623.25	938.3

Material	Unit	Quantity
Gravel	m3	143.5
LP PRV	m3	444.5
HP PRV	m3	328.2
Aestetic PRV	m3	938.3
Plastic foil	m2	70.0
Geotextile	m2	4108.7
Excavation	m3	880.6
Concrete holed pipe Din600 Dout704	m	60.0

MATERIAL NEEDED – Ecological Proposal

	HP PRV 1	HP PRV 2	PRV 1	PRV 2	TOTAL
Area [m2]	1778	410	2100	4155	
Equivalent Linear length [m]	-	-	600	1188	
Excavation [mm]	380	500	380	380	
Geotextile on the total surface [y/n]	y	y	y	y	
Gravel thickness [mm]	-	350	-	-	
LP PRV thickness [mm]	250	-	250	250	
HP PRV thickness [mm]	150	150	-	-	
Aestetic PRV thickness [mm]	-	-	150	150	
Excavation volume [m3]	**675.64**	**205**	**798**	**1578.9**	**3257**
Plastic foil [m2]	-	70	-	-	70.0
Geotextile on the surface [m2]	**1778**	**410**	**2100**	**4155**	**8843**
Geotextile on the edges [m2]	-	-	-	-	0
Geotextile on the pipes [m2]	-	-	-	-	0
Gravel volume [m3]	-	143.5	-	-	143.5
LP PRV volume [m3]	**444.5**	**-**	**525**	**1038.75**	**2008**
HP PRV volume [m3]	266.7	61.5	-	-	328.2
Aestetic PRV volume [m3]	-	-	315	623.25	938.3

Material	Unit	Quantity
Gravel	m3	143.5
LP PRV	**m3**	**2008**
HP PRV	m3	328.2
Aestetic PRV	m3	938.3
Plastic foil	m2	70.0
Geotextile	**m2**	**¨8843**
Excavation	**m3**	**3257**

PLACING / COMPACTION TECHNIQUES

Many methods available to place pervious concrete
Depending on the application, importance of leveling, compaction and finishing can vary.

The table below summarizes requirements of each application and provides guidance to place the pervious concrete accordingly.

APPLICATIONS		REQUIREMENTS [Level of importance]		ADVICED TECHNIQUES - EXAMPLES			
				PROPOSAL 1	PROPOSAL 2	PROPOSAL 3	PROPOSAL 4
Decorative applications		Levelling	High	Spinscreed	Manual levelling (Ruler)	PAVER w/o tamper, w/o pressure bar	Vibrating screed
		Compacting	Low	Steel pipe roller	Steel pipe roller		
		Finishing	High	Vibrating bull float	Manual finishing (trowel)	Manual finishing (trowel)	Manual finishing (trowel)
Low volume pavments		Levelling	High	PAVER w/o tamper, w/o pressure bar	Vibrating screed	Spinscreed	Manual levelling (Ruler)
		Compacting	Medium		Steel pipe roller	Steel roller compactor	Steel roller compactor
		Finishing	Medium		-	-	Manual finishing (trowel)
Roadways		Levelling	High	PAVER with tamper, w/o pressure bar	Vibrating screed	Spinscreed	Spinscreed
		Compacting	High		Steel pipe roller	Steel roller compactor	Steel roller compactor
		Finishing	High	Manual finishing (trowel)	Manual finishing (trowel)	Skipfloat	Vibrating bull float

STRUCTURAL ANALYSIS – Validation of our proposal

Structural verifications were carried out for the following loads:

- **12 Tonnes and 4-wheels vehicle in the entrance, where HP PRV is designed**
- **Golf Electric Car and Ambulance (3.5 Tonnes) in the path , where Decorative PRV is designed**

HP PERVIA

Indirect Tensile Splitting Strength [Mpa]	3.6
Flexural strength [Mpa]	4
alfa cc	0.85
gamma material	1.5
max flexural strength achievable	2.27

Q real [kN]	60
gamma load	1.6
Q design [kN]	96
a [mm]	500
b[mm]	500
s (thickness) [mm]	150
E [Mpa]	16000
Poisson's ratio	0.2
K (modulus of soil) [Mpa/mm]	0.2
a (equivalent radius of the loaded area) [mm]	282.09
D (=Et^3/(12(1-poisson^2)))	4687500000
l=(D/k)^0.25	391.27
Stress (load in the center) [Mpa]	2.21
Stress (load on the border) [Mpa]	1.13
Stress (load on the corner) [Mpa]	-0.15

DECORATIVE PERVIA

Indirect Tensile Splitting Strength [Mpa]	2.7
Flexural strength [Mpa]	3
alfa cc	0.85
gamma material	1.5
max flexural strength achievable	1.70

Q real [kN]	8.75
gamma load	1.6
Q design [kN]	14
a [mm]	350
b[mm]	500
s (thickness) [mm]	150
E [Mpa]	16000
Poisson's ratio	0.2
K (modulus of soil) [Mpa/mm]	0.05
a (equivalent radius of the loaded area) [mm]	236.02
D (=Et^3/(12(1-poisson^2)))	4687500000
l=(D/k)^0.25	553.34
Stress (load in the center) [Mpa]	0.50
Stress (load on the border) [Mpa]	0.33
Stress (load on the corner) [Mpa]	0.49

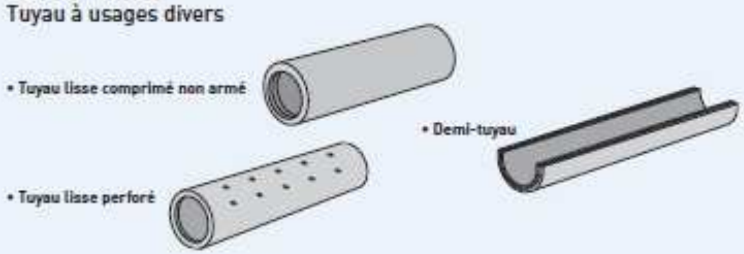
ADDITIONAL DRAINAGE SYSTEM – Example of Suppliers

CONSOLIS

BONNA SABLA

Tuyau lisse

Tuyau à usages divers



Usine de **LAMANON** [13] Dépôt **75**

Ø nominal (mm)	Série	Tuyau lisse comprimé non armé	Tuyau lisse perforé*	Demi-tuyau
		Poids (kg/ml)	Poids (kg/ml)	Poids (kg/ml)
150	-	27	27	14
200	-	37	37	19
300	-	66	66	33
400	-	110	110	55

Longueur unitaire : 1 m.

*Tuyaux percés de 4 ou 5 trous suivant diamètre, sur 4 génératrices.

DRAINAGE-SÉPARATION/GESTION DES EAUX PLUVIALES

Tuyau béton perforé 016906

CELESTIN

La compétence d'une équipe.

Désignation	Code
Tuyau béton perforé D200 Lg1 ml	N-C
Tuyau béton perforé D300 Lg1 ml	N-C
Tuyau béton perforé D400 Lg1 ml	209578
Tuyau béton perforé D500 Lg1 ml	209580
Tuyau béton perforé D600 Lg1 ml	36117
Tuyau béton perforé D800 Lg1 ml	5366

Les diamètres ci-dessus sont les diamètres intérieurs des tuyaux.

Fabemi

PLATTARD