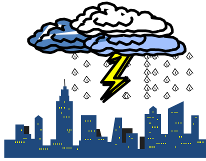
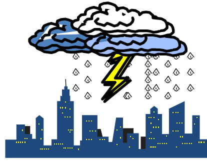
Urban Hydrology class: The rational method

luca.rossi@epfl.ch

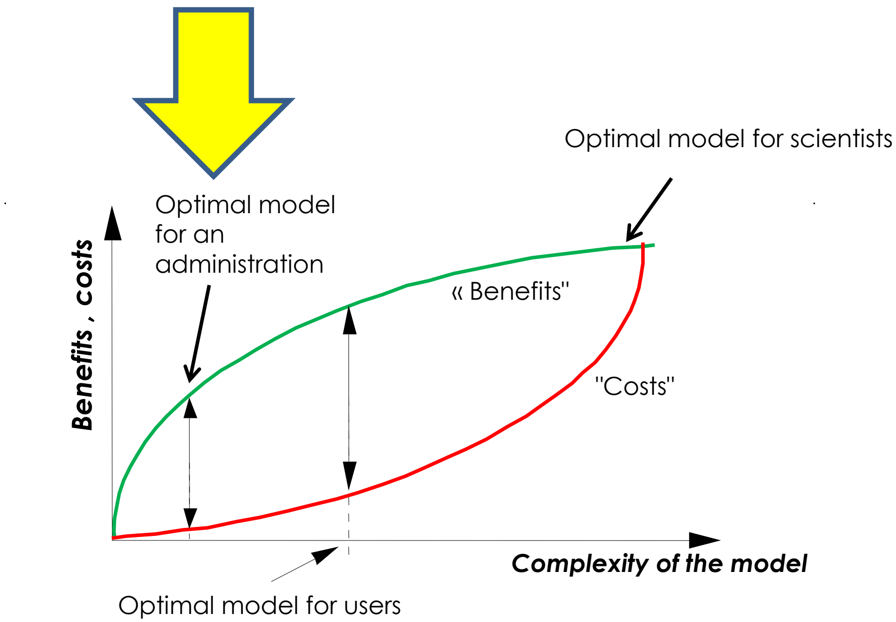
Rational Method - Table of content

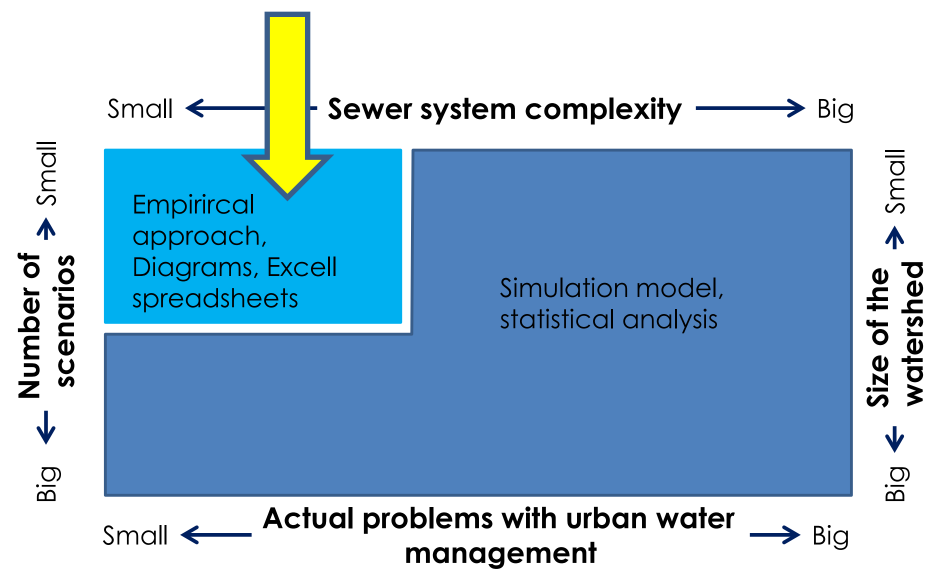


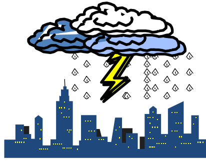
Rational method - introduction



- Sizing of a sewer network with 2 equations: rational method and Strickler
- Simple methods but not simplistic!
- This approach is still being suggested by several cantons…







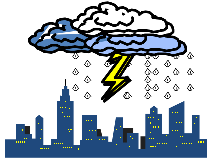
Rational method - introduction

$$Q = C \cdot i \cdot A$$

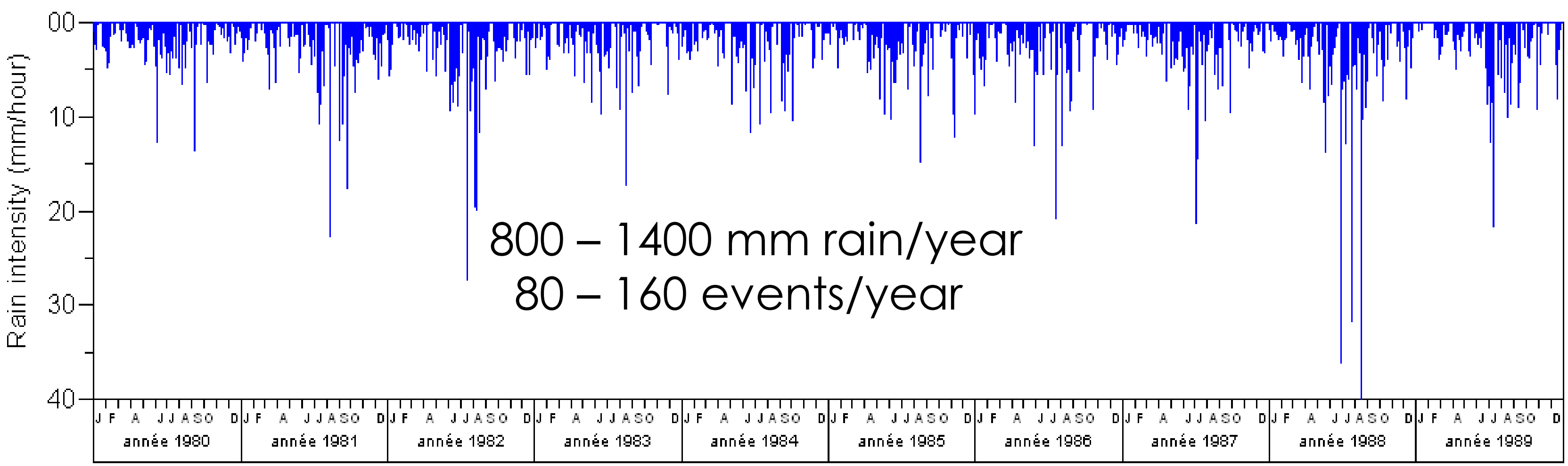
Q: Design discharge (l/s)
C: Runoff coefficient (dimensionless)
i: Design rainfall intensity (mm/h or $l/m^2/s$)
A: Watershed drainage area (ha or m^2)

- Need information on rain intensity/frequency and imperviousness of the watershed
- Valid for small, urban, homogeneous watershed
- Only for estimating peak flows
- Numerous concepts integrated in a simple formula!

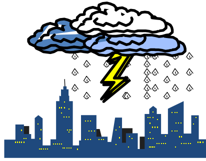
The Rational Method
Rainfall intensity

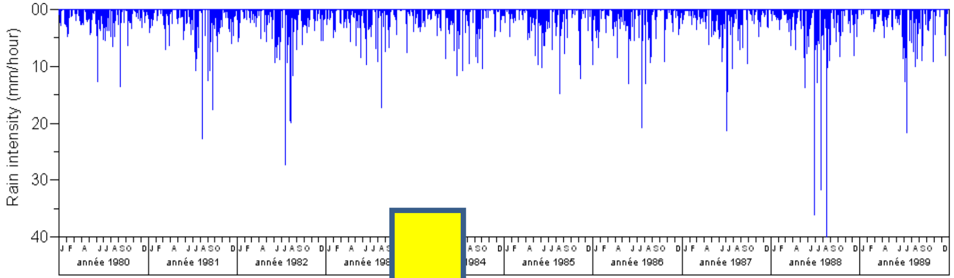


- Key parameter: rainfall
- Variable rain in space and time…
- Climate change?
- Return period ? 5 years? 10 years? 20 years?
- "Alea du ruissellement": 300 years !!!

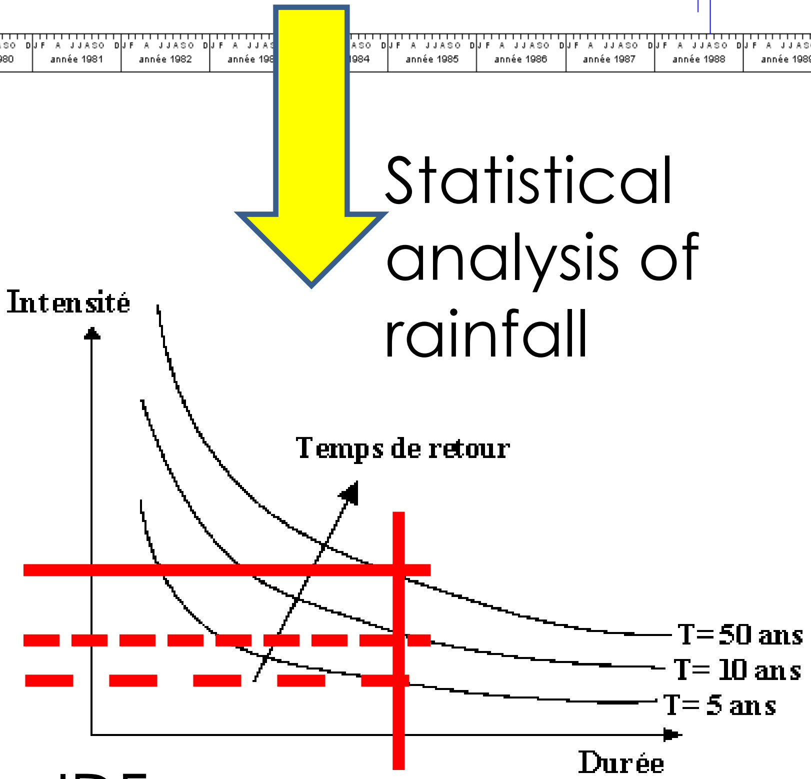


The Rational Method
Rainfall intensity



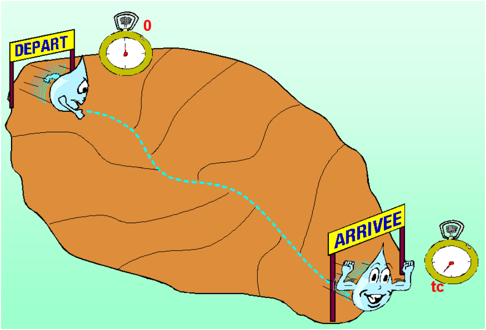


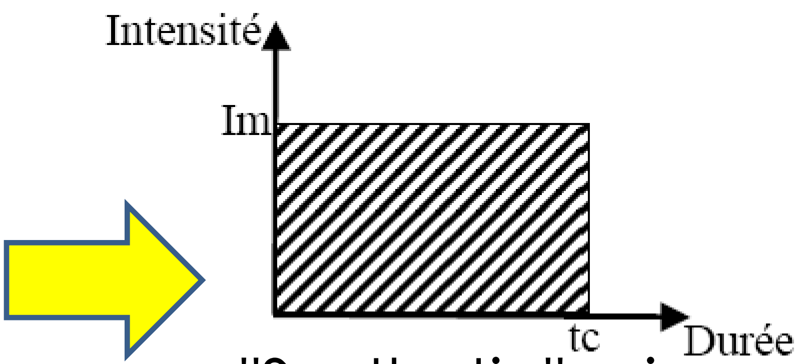
Statistical analysis of rainfall



IDF curves

Duration≈ Concentration time Tc
Longest time taken by a drop to reach the outlet



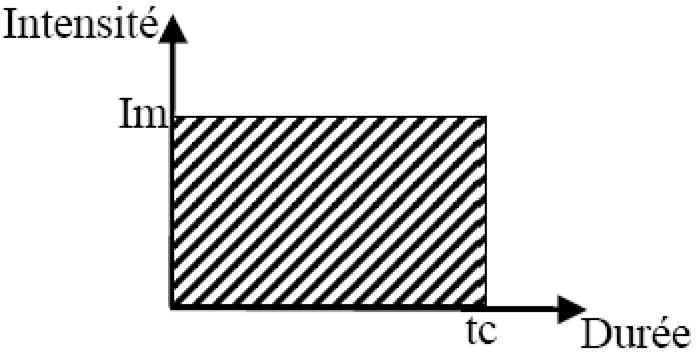


"Synthetic" rain

The Rational Method
Rainfall intensity

Design rainfall:

- Synthetic rainfall
- Simple shape
- Integrate statistical rainfall information
- Must reproduce the same hydrological response as real rain events



Rational method
Rainfall intensity

- Based on IDF curves (intensity/duration/frequency)
- A dedicated return period must be selected (typically 5 to 20 years)
- Local conditions must be considered

Talbot Formula: $$i(T;t) = \frac{a \cdot T}{b \cdot T + t}$$

Montana Formula: $$i(T;t) = a \cdot T \cdot t^{b \cdot T}$$

Keiffer Chu Formula: $$i(T;t) = \frac{a \cdot T}{t^{b \cdot T} + c \cdot t}$$

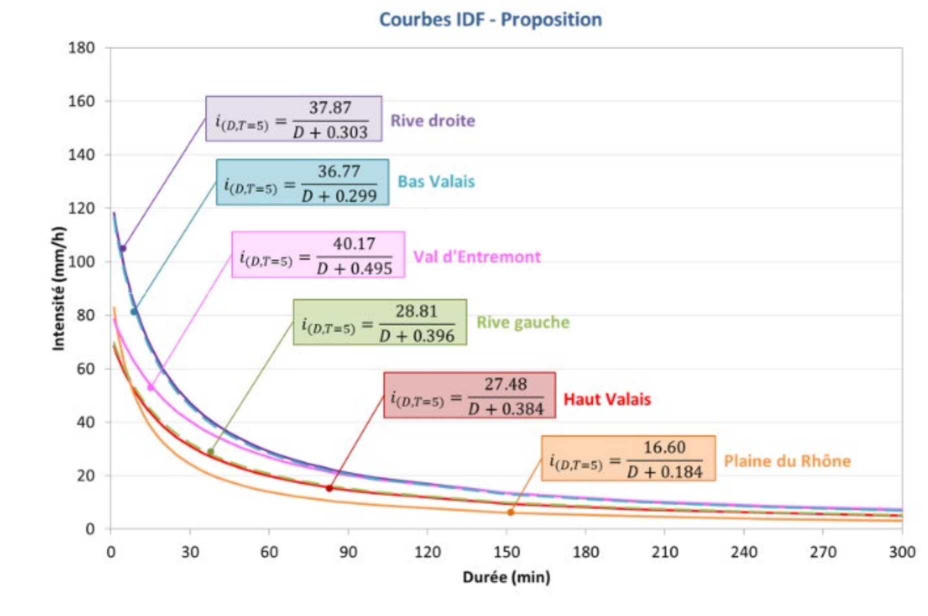
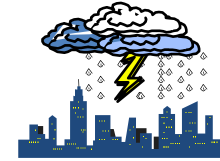


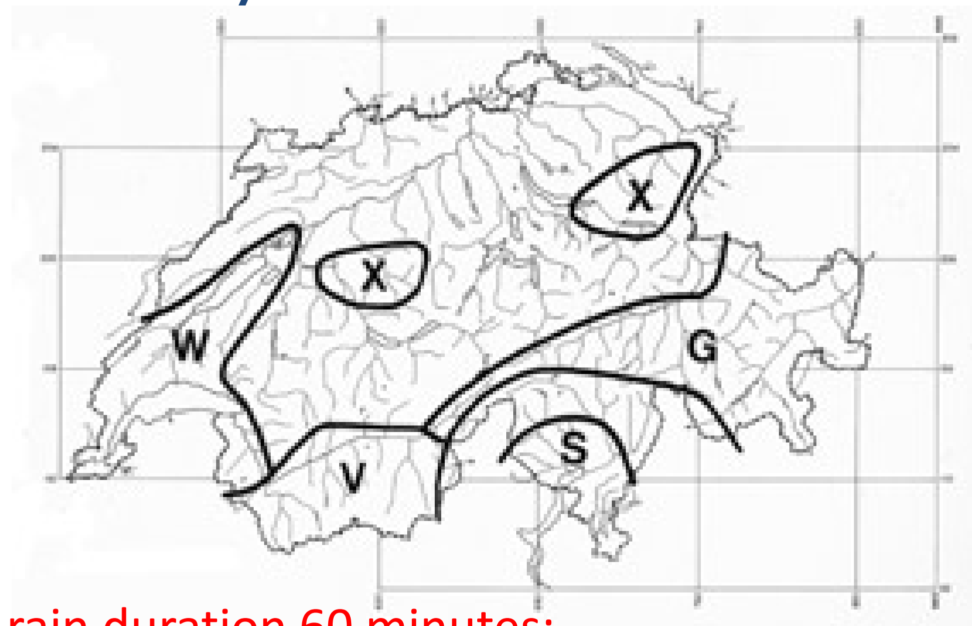
Figure 2 : Courbe IDF pour chacune des régions du Valais (CREALP, 2016)

T: Return period
t: duration of the rain event
a,b,c: local coefficient

Rational method
Rainfall intensity



$$i = \frac{K}{t+B}$$

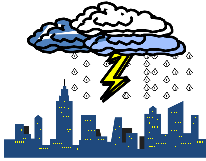


i: Design rainfall intensity (l/s ha)
K: f(return period, location)
t: rainfall duration (min)
B: Local constant (min)

Example: Zone W, return period 1 year, rain duration 60 minutes:
2700/(60+12) = 37.5 l/s/ha = 13.5 mm/h

Zones d'intensité	Valeur de K pour fréquences n = 1 jusqu'à n = 1/10				Valeur de B
	1	1/2	1/5	1/10	
V	1050	1359	1700	2100	6
G	1900	2450	3000	3750	10
W	$\boxed{2700}$	3500	4300	5400	$\boxed{12}$
X	4050	5250	6500	8100	12
S	6000	7800	9600	12000	25
Autres domaines	3400	4400	5400	6750	12

Rational method: rainfall intensity



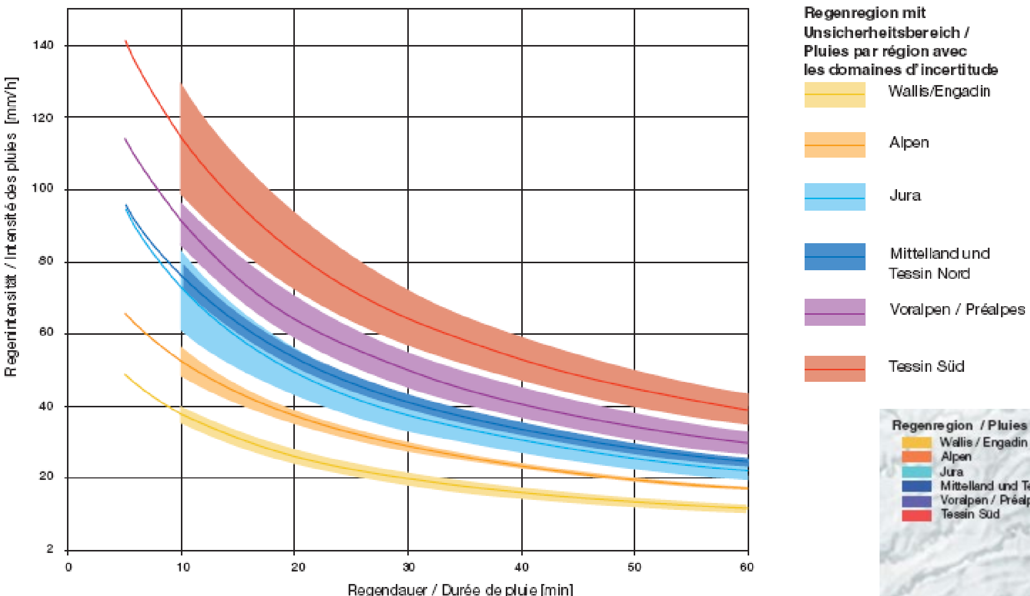
Vereinigung Schweizerischer Strassenfachleute
Union des professionnels suisses de la route
Unione dei professionisti svizzeri della strada
Association of Swiss Road and Traffic Engineers

Schweizer Norm
Norme Suisse
Norma Svizzera
Swiss Standard

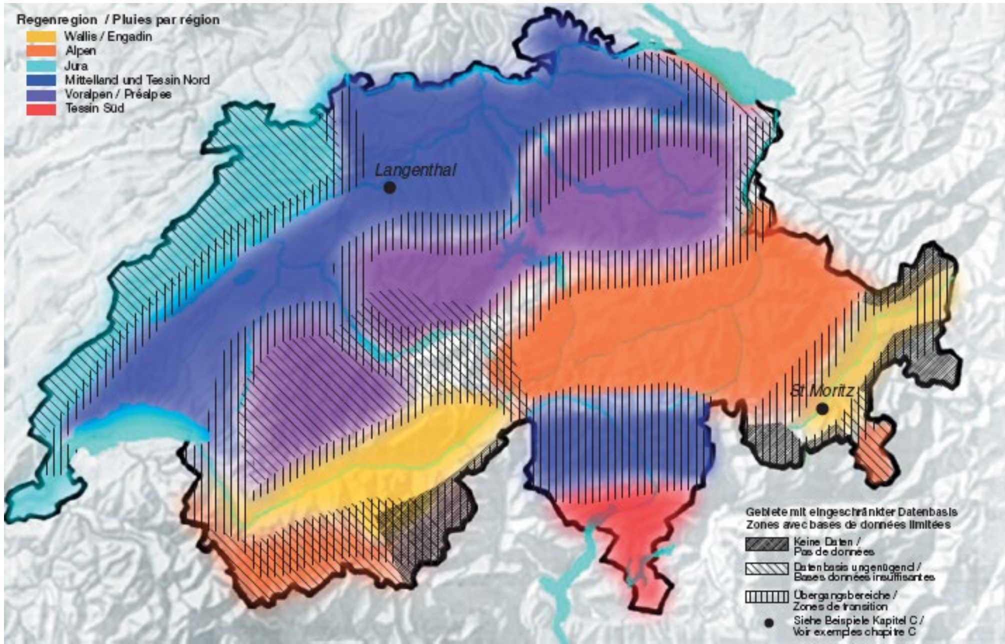
SN 640 350

EINGETRAGENE NORM DER SCHWEIZERISCHEN NORMEN-VEREINIGUNG SNV NORME ENREGISTREE DE L'ASSOCIATION SUISSE DE NORMALISATION

$$i\,(t,T) = \frac{a_T}{t + b_T}$$



i (t, T)	intensité d'une pluie de durée t et un temps période de retour T [mm/h], avec valeur de convertissement l/(s*/ha) : 2,78 = [mm/h]
t	durée de pluie [h]
T	temps de retour [années]: intervalle dans lequel une certaine intensité de pluie a été en moyenne atteinte ou dépassée au moins une fois
a_T	coefficient (tableau 1)
b_T	coefficient (tableau 1)



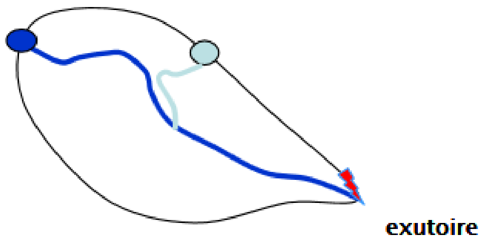
Lausanne, 1 an, t = 60 min:

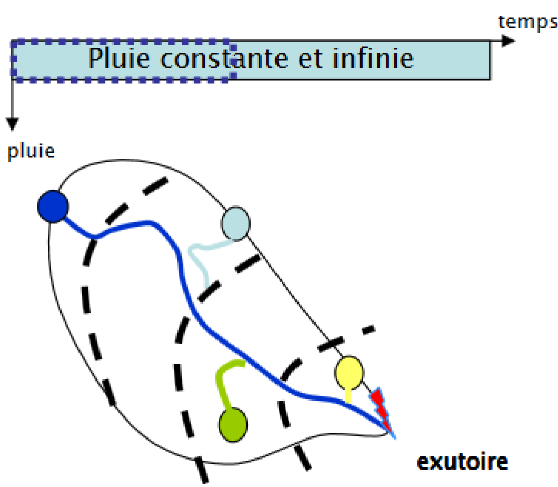
Hörler / Rhein:	37. 5 l/s/ha
VSS:	53.8 l/s/ha
	(51.5 - 56.2)

Rational method: rainfall intensity

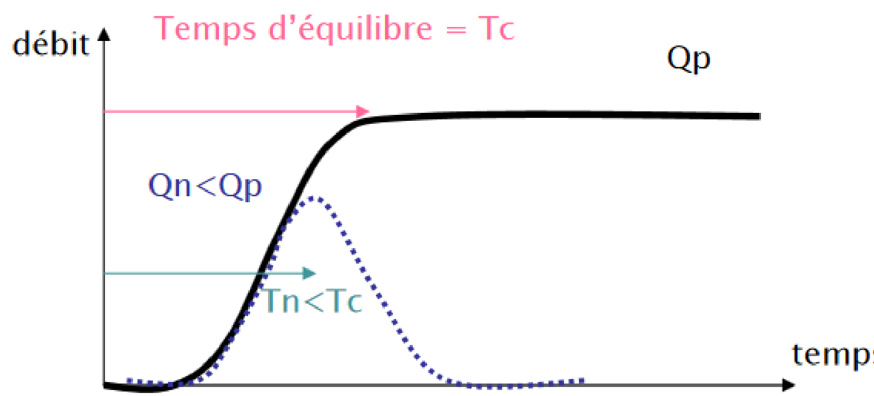
Le bassin versant - Isochrones

Temps de concentration **& Hydrogramme de crue :**



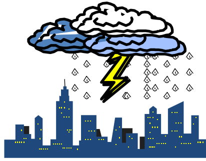


Une pluie homogène (invariante par translation) et uniforme (invariante dans le temps) incidente sur le BV va engendrer une croissance des débits à l'exutoire jusqu'à une valeur maximale pour laquelle tout le bassin contribuera au débit à l'exutoire. Une fois le débit maximum atteint, l'hydrogramme reste sur cette valeur plateau tant que la pluie constante incidente dure.



https://www.youtube.com/watch?v=BZK5isMxVBY

Rational method
Rainfall intensity



- How to estimate "t" ?
- Crucial point in the rational method
- Basically: t = concentration time t_c

$$i = \frac{K}{t+B}$$

$$t_c = t_{runoff} + t_{transport}$$

Via iterations knowing Q and V (flow velocity in the sewer system)

Empirical formulations :
f(slope, size of the watershed, rain intensity…)

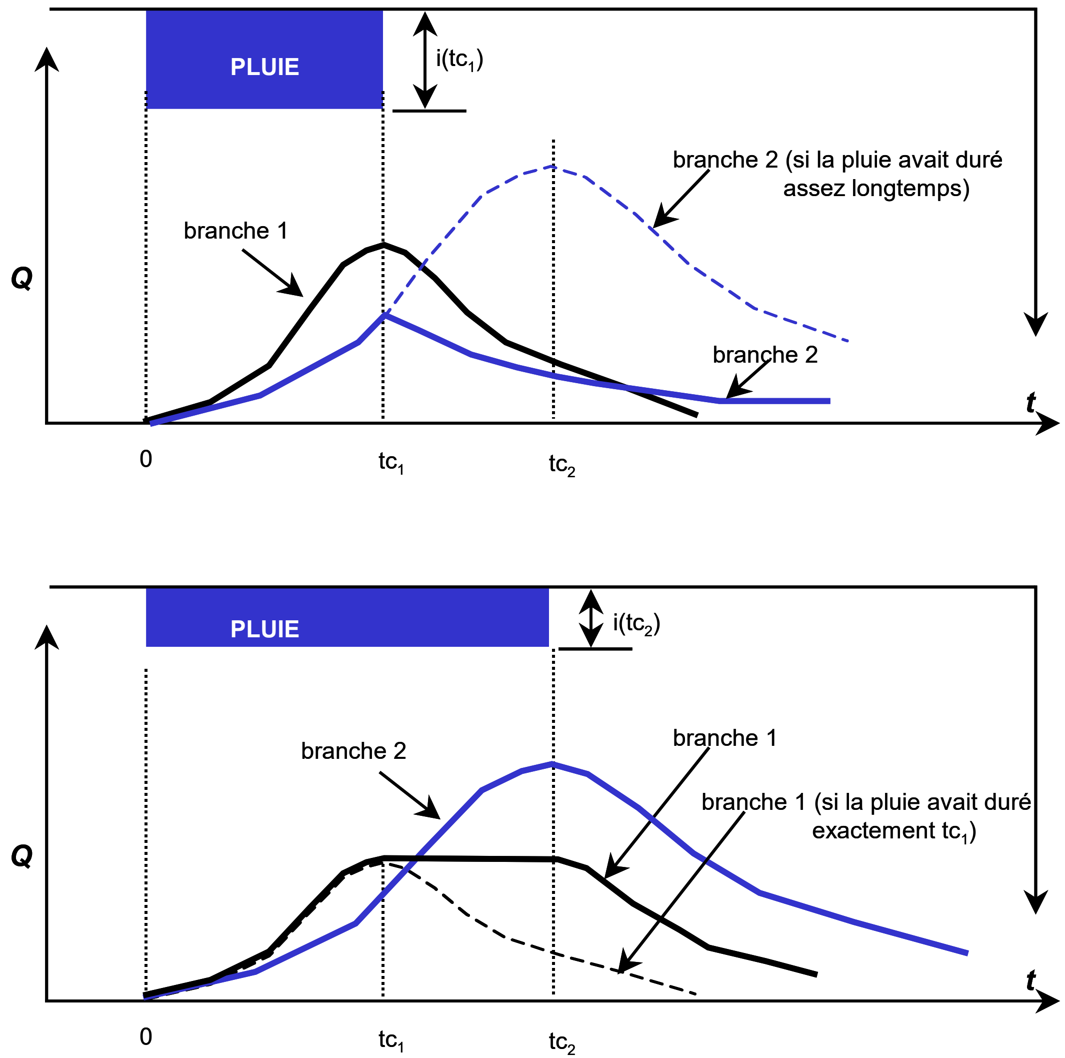
Or global estimation:

Dense urban area:	5 min
Sub-urb:	10 to 20 min
Dispersed habitat:	20 to 30 min

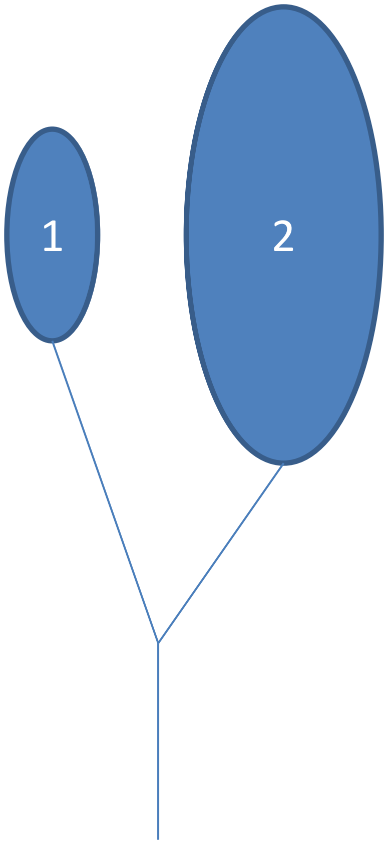
Limitations:
No storage capacity in sewers
No spatial variability of rain events

Rational method: Rainfall intensity

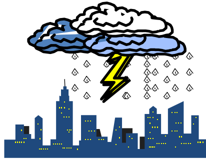
- How to estimate "t" ?



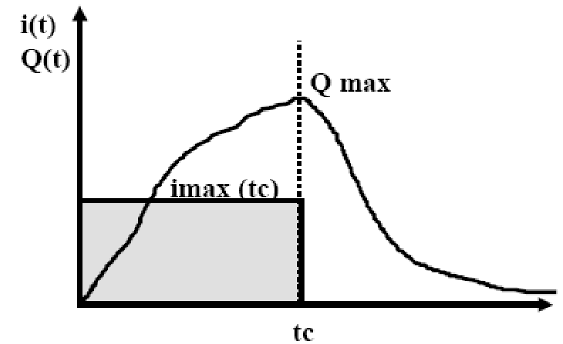
$$i = \frac{K}{t + B}$$



Rational method
Rainfall intensity



Very simple method to evaluate stormwater flowrate

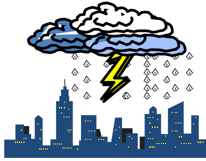


$$Q = C \cdot i \cdot A$$

Q: Design discharge (l/s)
C: Runoff coefficient (dimensionless)
i: Design rainfall intensity (mm/h or l/m²/s)
A: Watershed drainage area (m²)

Hypothesis: Q_{max} is observed if rain duration ≥ concentration time t_c
Q_{max} is proportional to i_{max}
Q_{max} and i_{max} have the same return period
C = constant

The Rational Method
Runoff coefficient

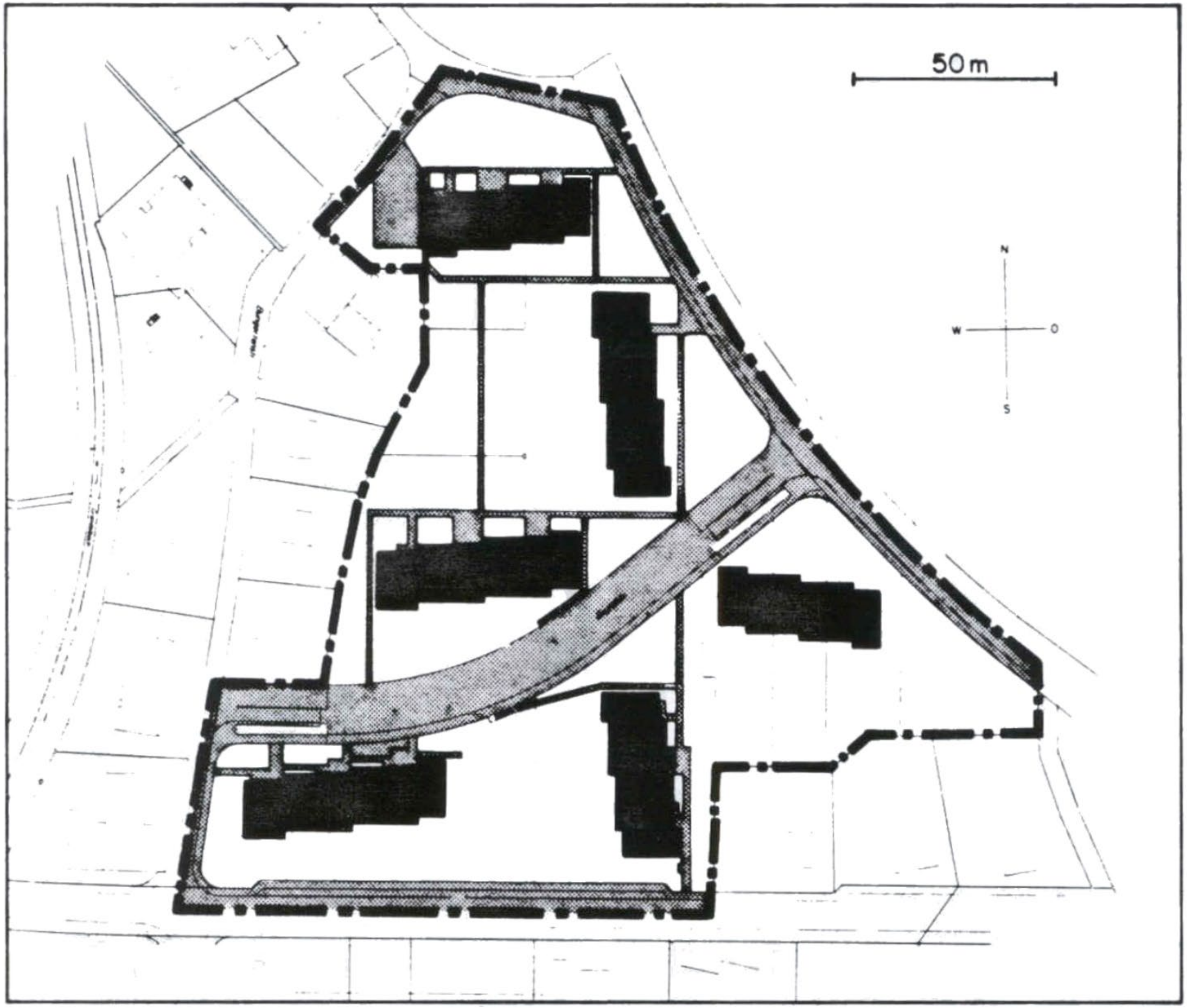


Runoff coefficient accounts for:

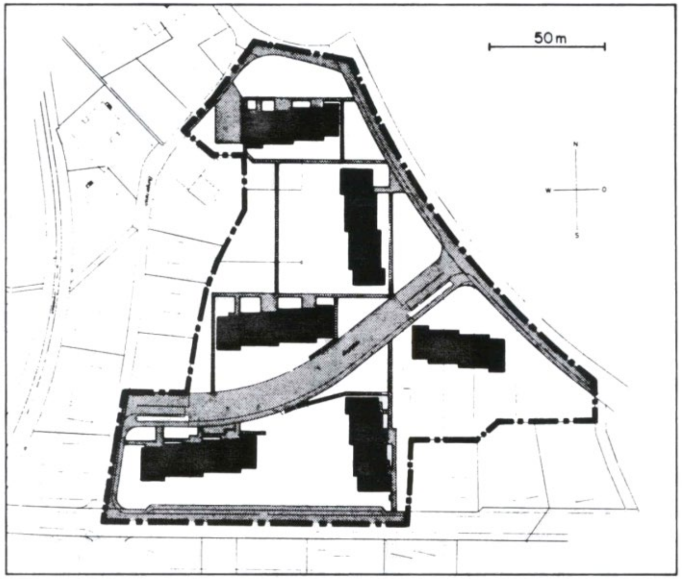
- Initial losses at the beginning of a rain event (1-5 mm: storage, infiltration…)
- Imperviousness of a watershed (at maximal development)
- Effective contribution of runoff

Surfaces imperméables	α_s	Surfaces perméables	α_s
Eternit	0.95	Jardins, prés	~0
Tôle, verre	0.95	Parcs	~0
Tuile	0.90	Forêts	~0
Asphalte	0.80	Prairies escarpées	
Béton	0.80	sol très perméable	~0
Pavage	0.50	moyennement perméable	~0
Toits plats recouverts de gravier	0.25	peu perméable	0.3-0.5
Tout venant compacté	0.25	Vignobles	0.3-0.5
Pavé gazon	0.15		

The Rational Method : Runoff coefficient



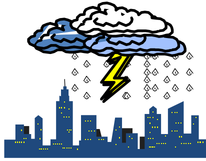
The Rational Method : Runoff coefficient



$$\psi_s = \sum_{i=1}^{n} \gamma_i \cdot \alpha_{si}$$

type de surface	α_s	**surface effective**		ψ_s
		[m²]	γ [%]	
toits:				
toits plats recouverts de gravier	0.25	3'795	16.5	0.04
rues:				
asphalte	0.80	2'253	9.8	0.08
parcs-auto, places, accès:				
asphalte	0.80	2'734	11.9	0.10
pavage	0.50	1'204	5.2	0.03
espaces verts et surfaces non drainées	0	13'028	56.6	0
total		23'014	100.0	0.25

The Rational Method
Runoff coefficient



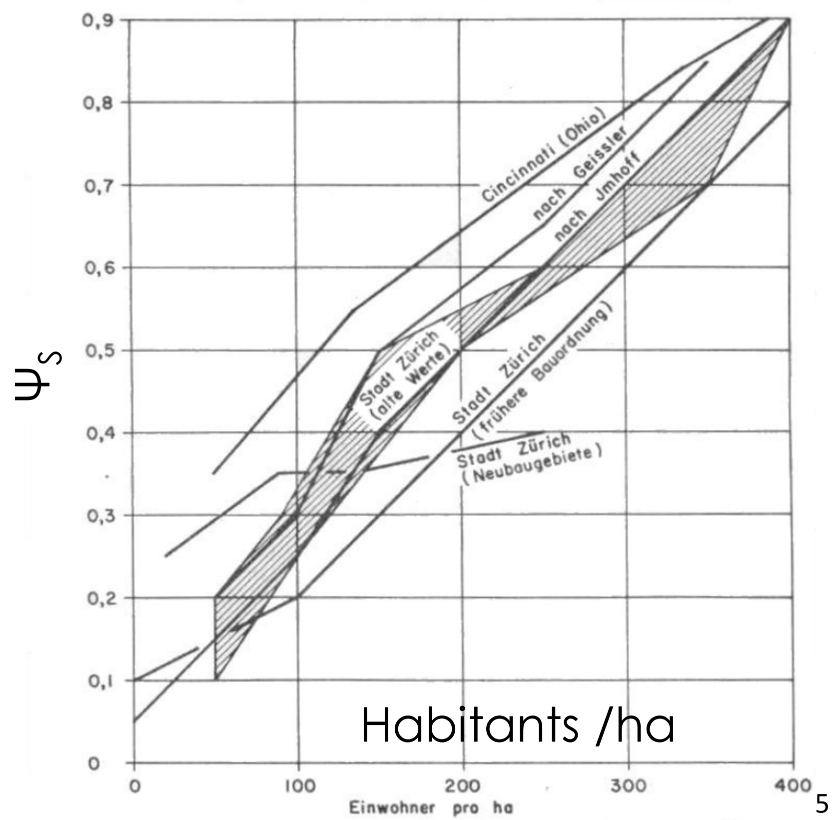
Approximation for the runoff coefficient:

City center, highly urbanized:	0.6 – 0.9
Sub-urb:	0.2 - 0.6
Industrial area:	0.4 - 0.8
Roofs, streets:	0.8 – 0.9

Effective contribution
"coefficient d'écoulement":

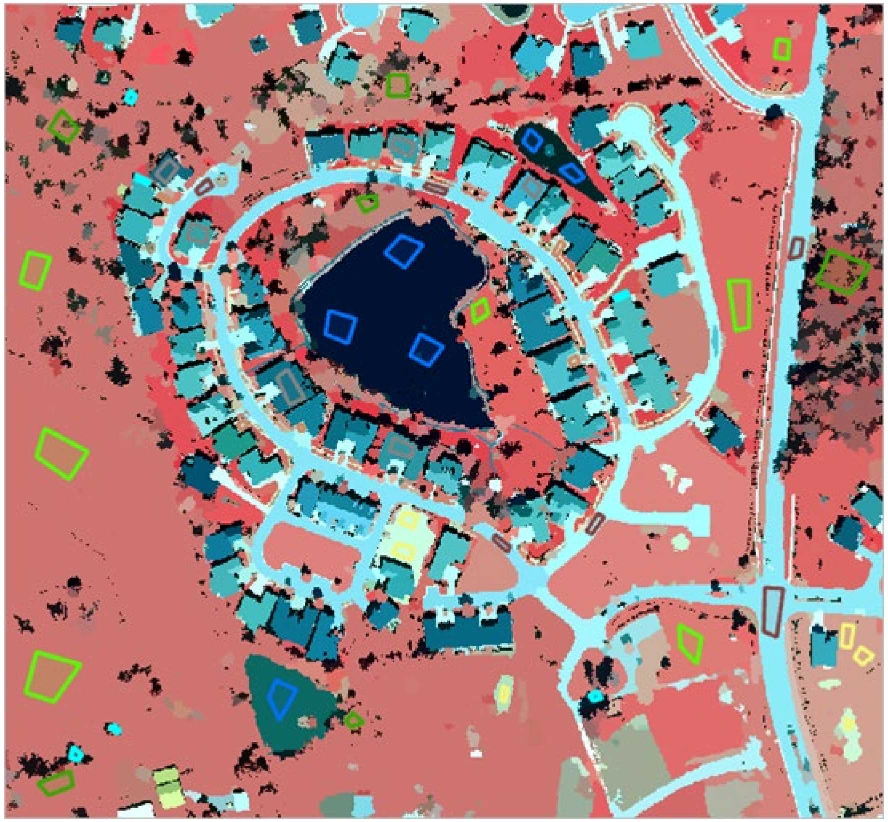
$$\psi_S = 0.85 \cdot \gamma$$

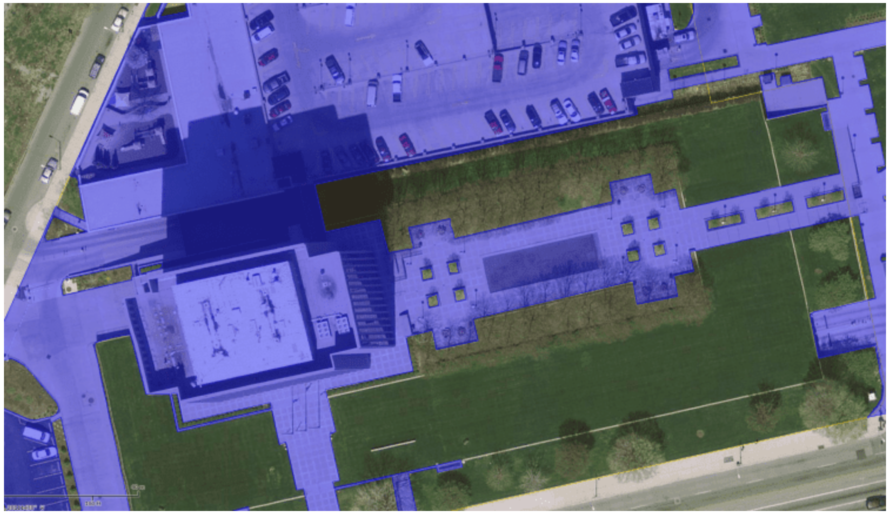
γ[-] : total impervious fraction of the considered catchment



The Rational Method
Runoff coefficient

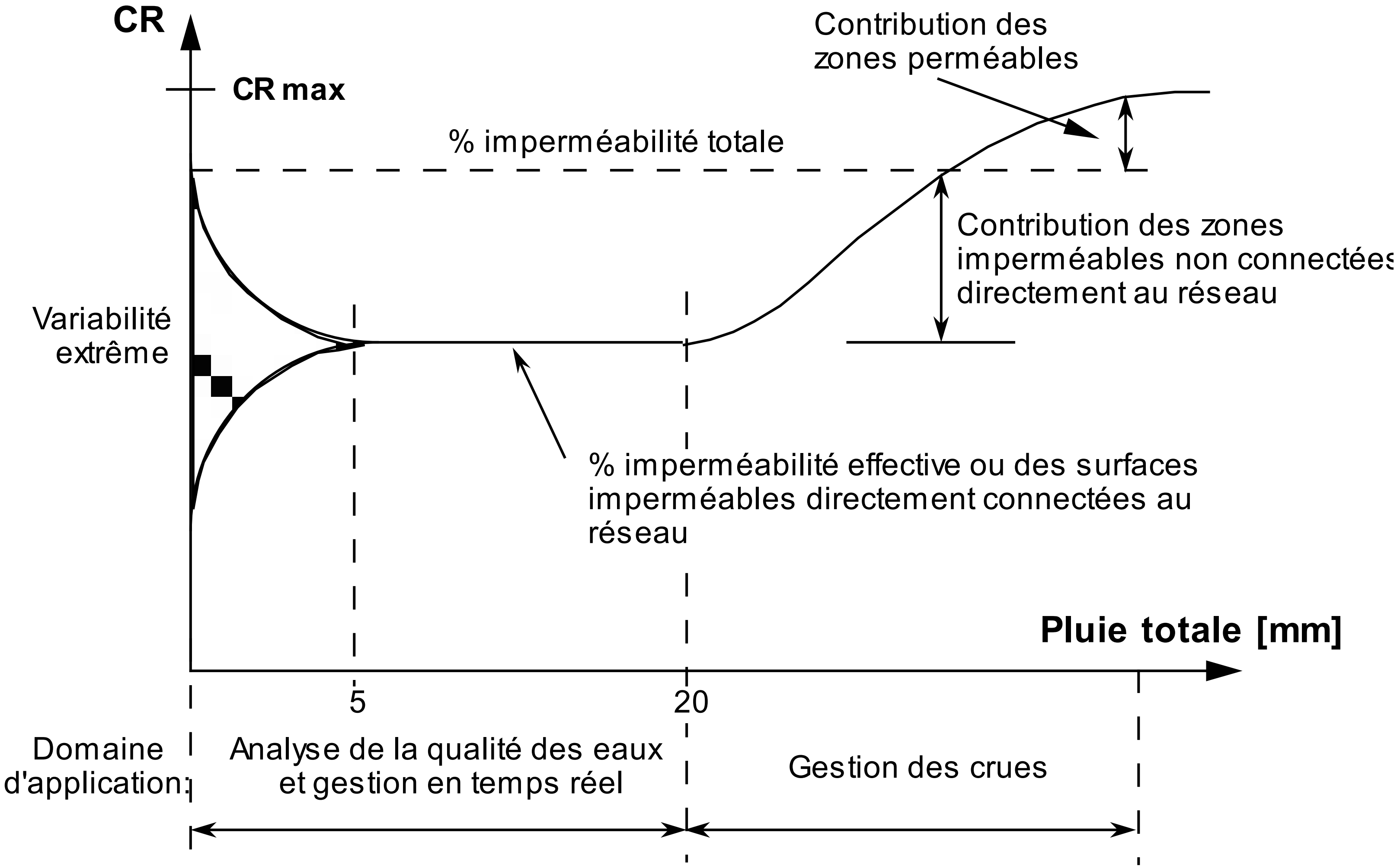
Estimation of impervious surfaces with spectral imagery



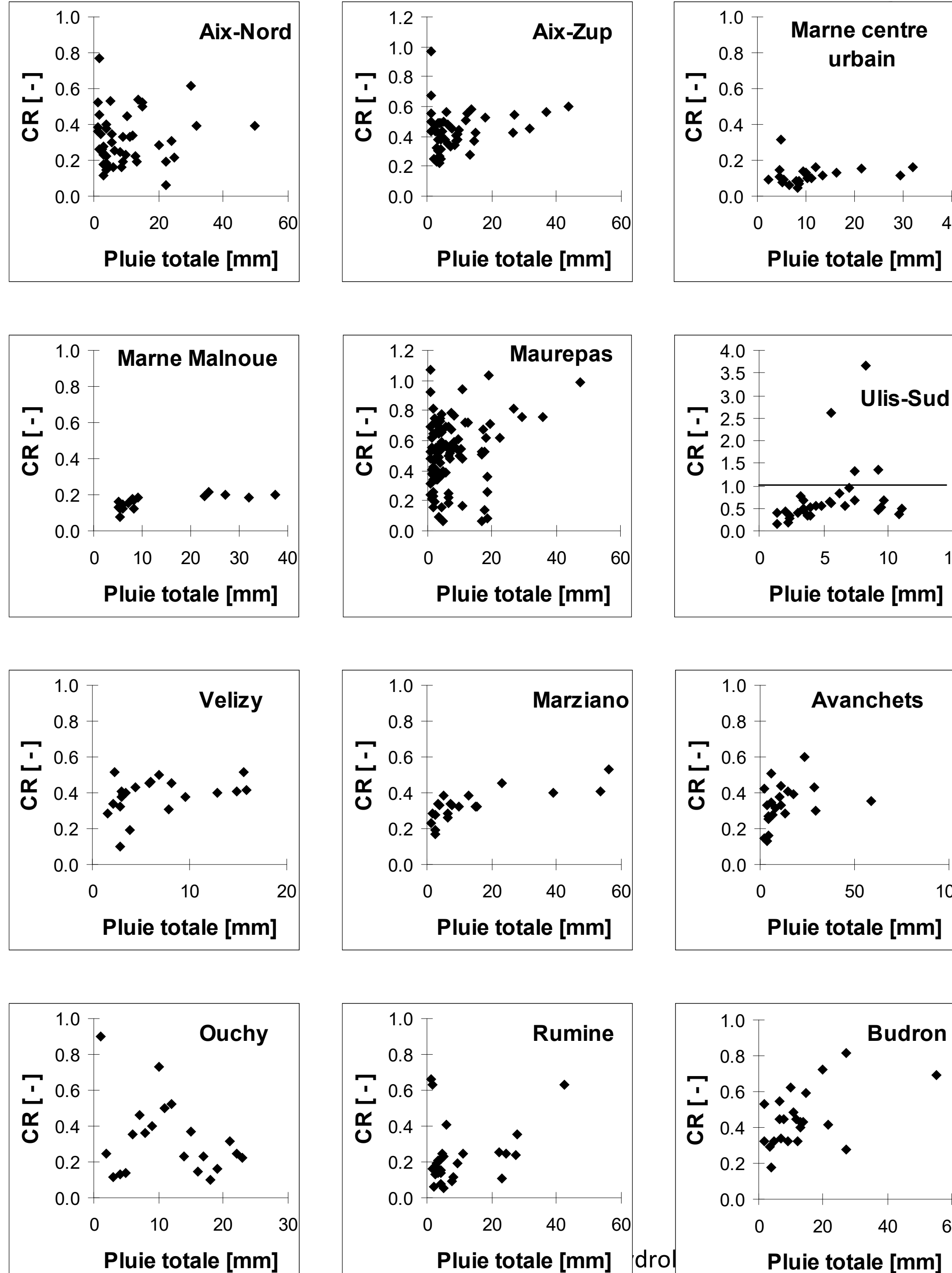


https://learn.arcgis.com/fr/projects/calculate-impervious-surfaces-from-spectral-imagery/
https://eijournal.com/print/articles/changing-the-landscape-of-impervious-surface-mapping

The Rational Method
Runoff coefficient



Measurements of runoff coefficient



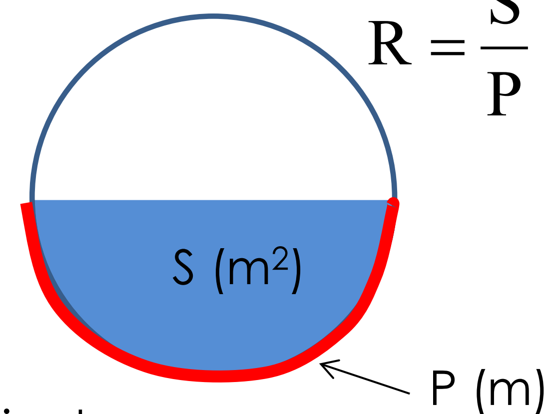
Rational Method - Table of content

Rational method

Calculation of stormwater flowrate

Manning-Strickler formulation.
Uniform and permanent flow as hypothesis !

$$R = \frac{S}{P}$$



$$Q = K \cdot S \cdot R^{2/3} \cdot J^{1/2}$$

Q:	Design discharge (m^3/s)
K:	Roughness coefficient ($m^{1/3}/s$)
	= Strickler coefficient, 1/n Manning coefficient
S:	Wetted surface (m^2)
R:	Hydraulic radius (m)
J:	Slope (-)
P:	Wetted perimeter (m)

$$D = \left(\frac{4^{5/3}}{\pi} \cdot \frac{Q}{K \cdot \sqrt{J}} \right)^{3/8}$$

Rational method

Calculation of stormwater flowrate

Le dimensionnement hydraulique

Dr Jean-Louis Boillat
Dr Michael Pfister
Laboratoire de constructions hydrauliques (LCH)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

4.28. 16

...RTEMENT DES INNERN

MITTEILUNGEN
DES AMTES FÜR WASSERWIRTSCHAFT
herausgegeben unter der Leitung von
Dr. CARL MUTZNER

Nr. 16

Beiträge zur Frage der Geschwindigkeitsformel und der Rauhigkeitszahlen für Ströme, Kanäle und geschlossene Leitungen

von

Dr. A. STRICKLER
Chef der Sektion für Niederdruckanlagen und Schiffahrt

Mit 1 Textfigur, 14 Tabellen und 41 Beilagen

ZU BEZIEHEN
BEIM SEKRETARIAT DES EIDG. AMTES FÜR WASSERWIRTSCHAFT
BOLLWERK 27, BERN

Preis Fr. 5.—

Bern 1923

Rösch, Vogt & C°, Bern

Essential, but not considered for this class !

Les jonctions avec des écoulements torrentiels

Dr Michael Pfister & Timur Gökok
Laboratoire de constructions hydrauliques (LCH)
Ecole Polytechnique Fédérale de Lausanne (EPFL)

Prof. Dr Corrado Gisonni
Department of Civil Construction and Environmental Engineering and Industrial Design (DICDEA), Seconda Università di Napoli (SUN)

Rational method

Calculation of stormwater flowrate

$$Q_C = \frac{\pi}{4^{5/3}} K \sqrt{J_o} D^{8/3}$$ Eq. 6

$$A = \frac{4}{3} D^2 Y^{3/2} \left[1 - \frac{Y}{4} - \frac{4Y^2}{25} \right]$$ Eq. 15

$$q = \frac{Q}{K \sqrt{J} D^{8/3}}$$ Eq. 14

$$Q = AV$$ Eq. 1

$$Y = 0.926 \left[1 - \sqrt{1 - 3.11 q} \right]^{1/2}$$ Eq. 13

$$\chi = \frac{K \sqrt{J_o} D^{1/6}}{\sqrt{g}}$$ Eq. 22

$$Y = \frac{h}{D}$$ Eq. 12 $\Leftrightarrow$

$Y_C = 0.92 - 30 J_o$ pour $J_o < 0.0125$

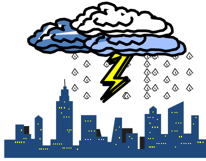
$Y_C = 0.55$ pour $J_o \geq 0.0125$

Eq. 16, 17

$$F = \frac{Q}{\sqrt{g h^4 D}}$$ Eq. 18 $\Leftrightarrow$ $0.80 < F < 1.20$

Rational method

Calculation of stormwater flowrate



Limitations regarding flow velocities:

V_{max}: 4 m/s (to avoid abrasion in the pipes, ≈ 15 km/h)

For stormwater and combined sewer systems (to avoid deposits):

V_{min}: ≥ 0.6 m/s , $Q \approx 0.1\ Q_{max}$
≥ 0.3 m/s , $Q \approx 0.01\ Q_{max}$

For wastewater in separated systems:

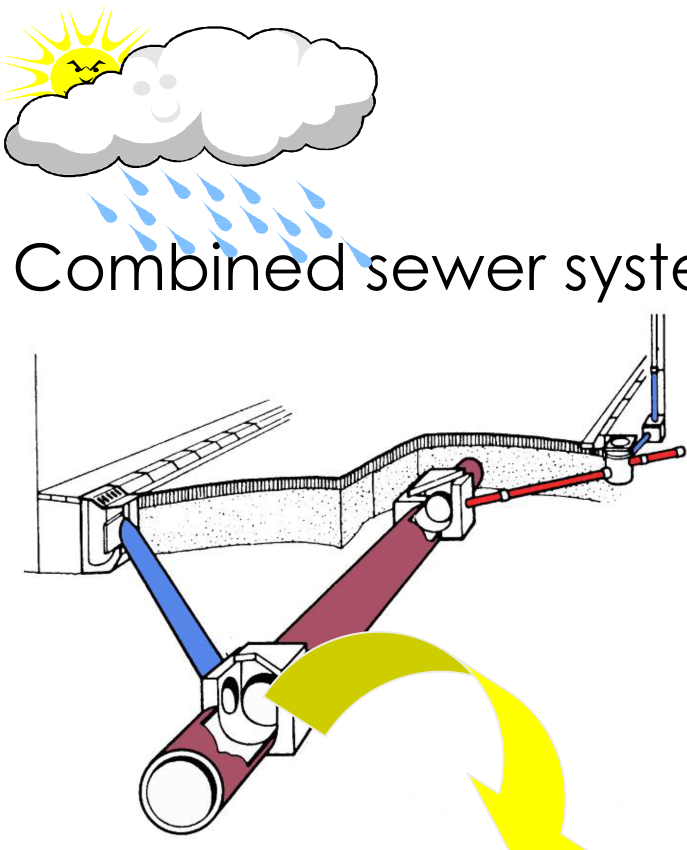
V_{min}: > 0.5 to 0.7 m/s , $Q \approx 0.5$ to $1\ Q_{max}$
≥ 0.3 m/s , $Q \approx 0.01\ Q_{max}$

h_{min}: $\geq 0.2\ \varnothing$ for average actual flowrate

Rational Method - Table of content

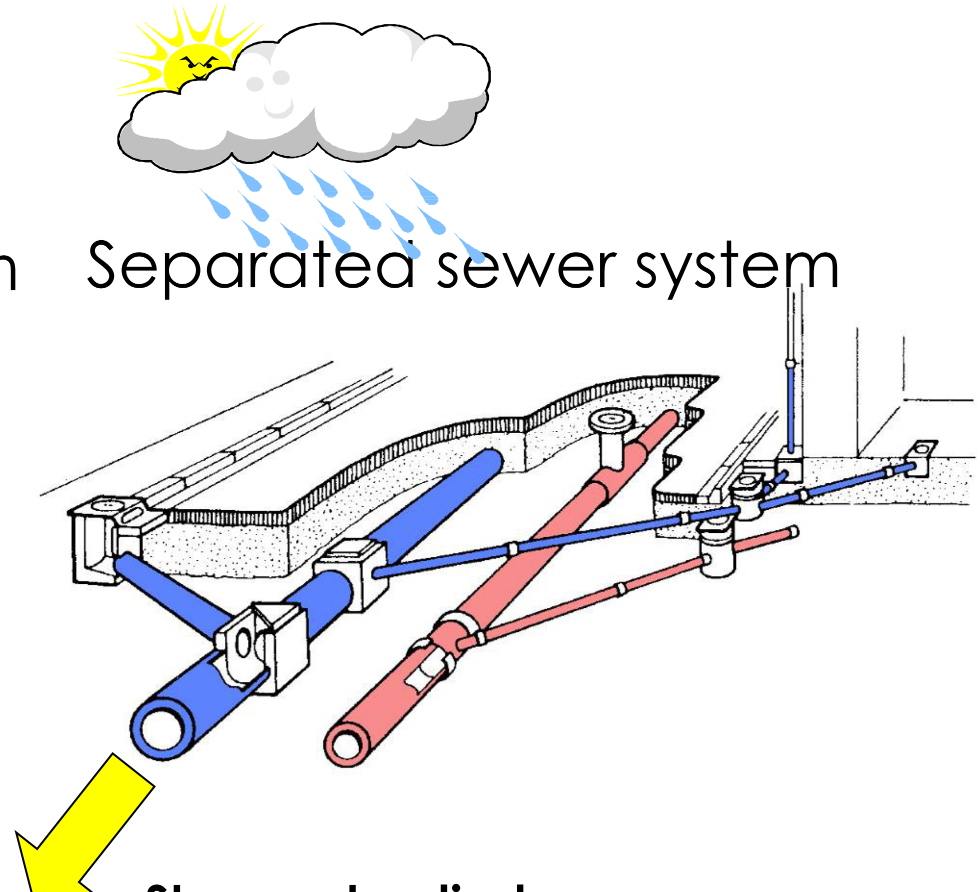
Building a sewer network

Combined sewer system



CSOs

Separated sewer system



Stormwater discharges

Morphology of a sewer network

Sewer network =

All sewers and channels

- Primary drainage (sewers)
- Interceptor, collecting sewer
- Discharge pipes

\+

Special structures

- Link surface – underground (collecting and visiting structures)
- Link sewer – environment
- Treatment structures

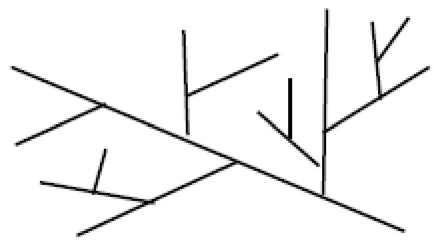
Morphology of a sewer network

Flow conditions:

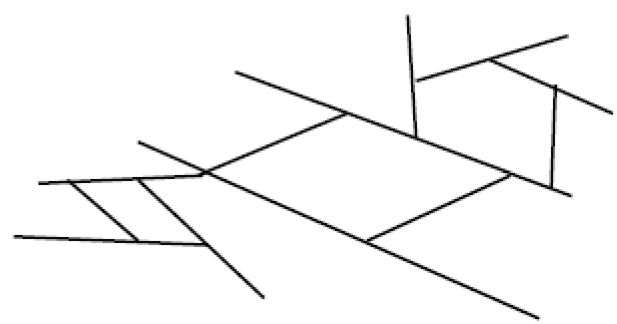
- Gravitational flow
- Free surface flow
- Transition flow
- Possibility of exceptional pressurized flow conditions
- For wastewater, rare cases of pressurized flows

Sewer structure:

- Ramification network (réseau ramifié)

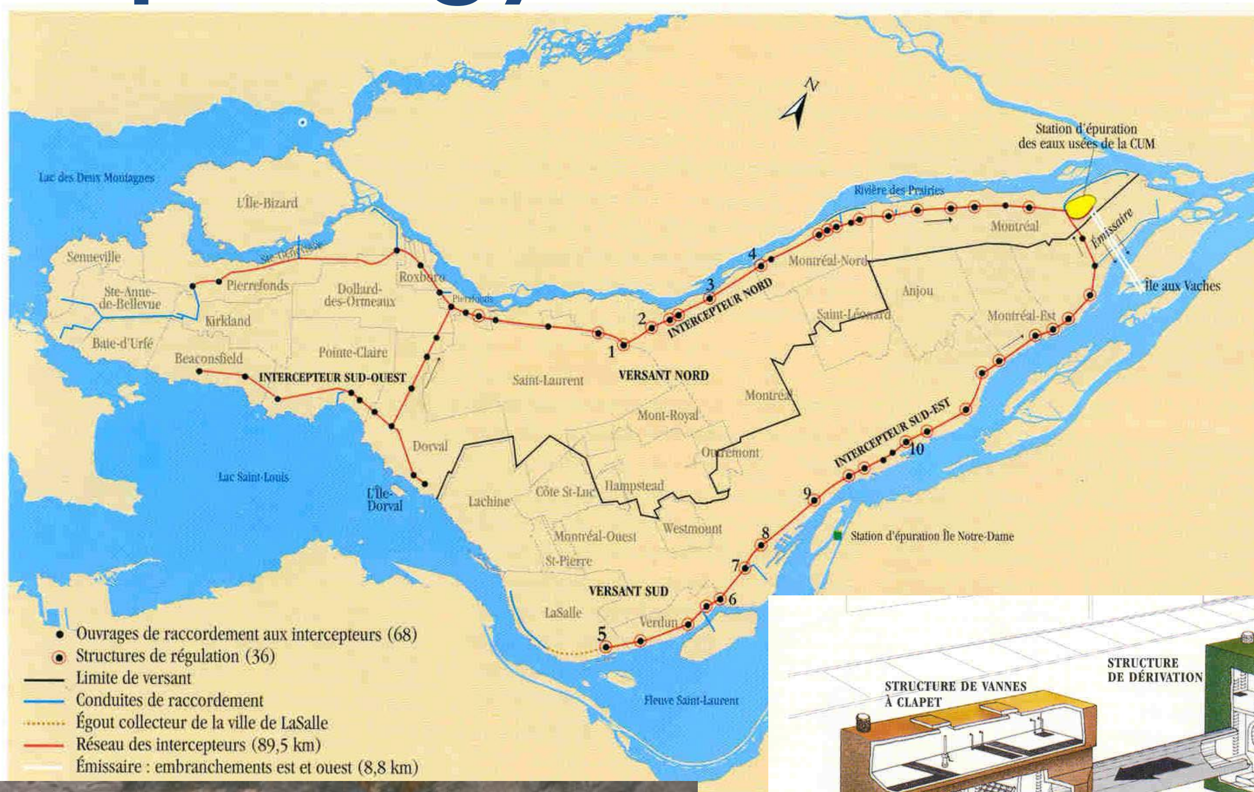


- Mesh network (réseau maillé)

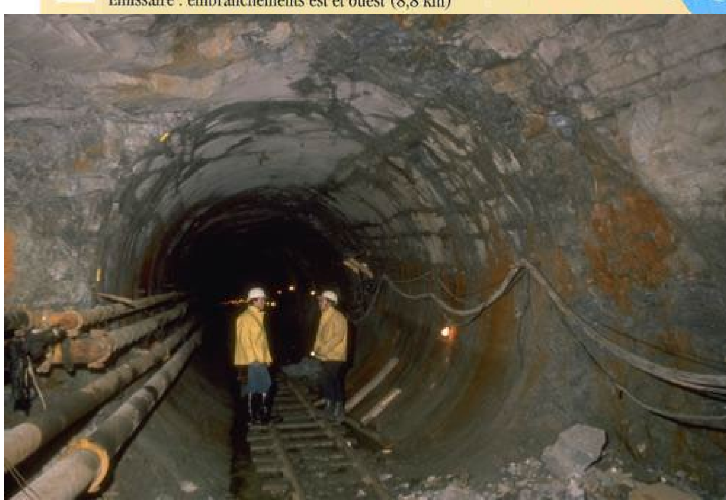


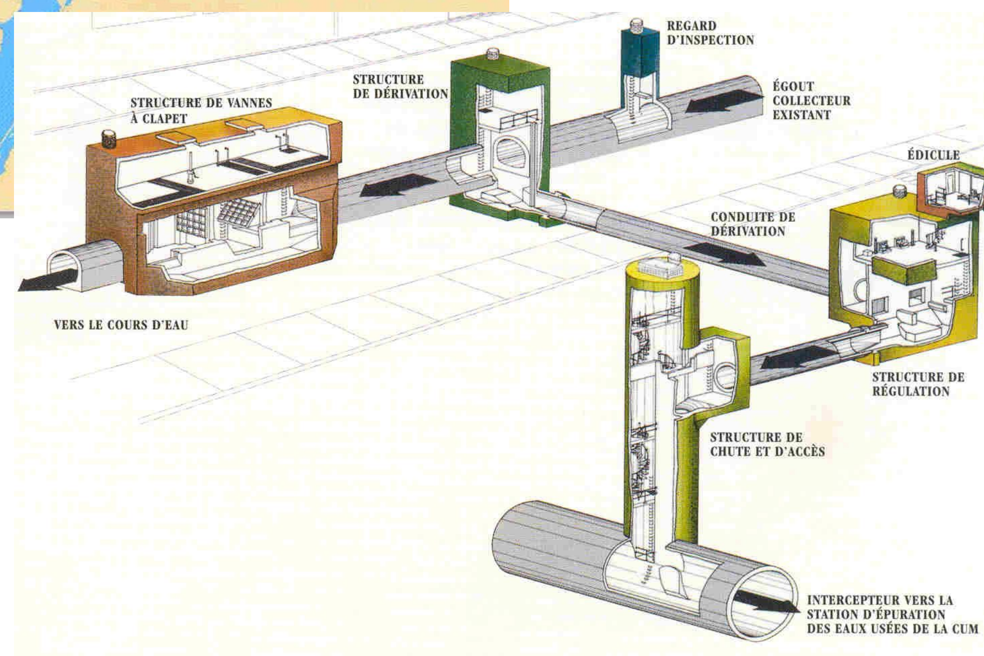
- Unique or multiple outlets

Morphology of a sewer network



Example of the interceptors system for the CUM (Communauté urbaine de Montréal)

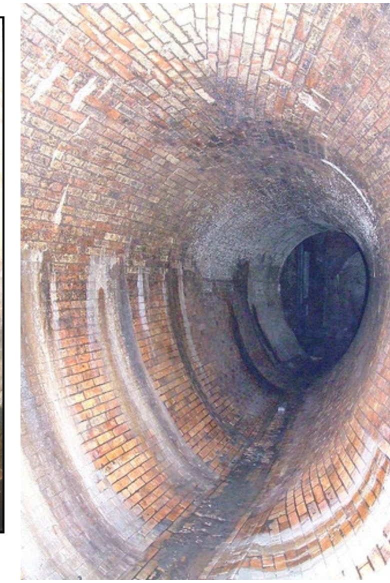


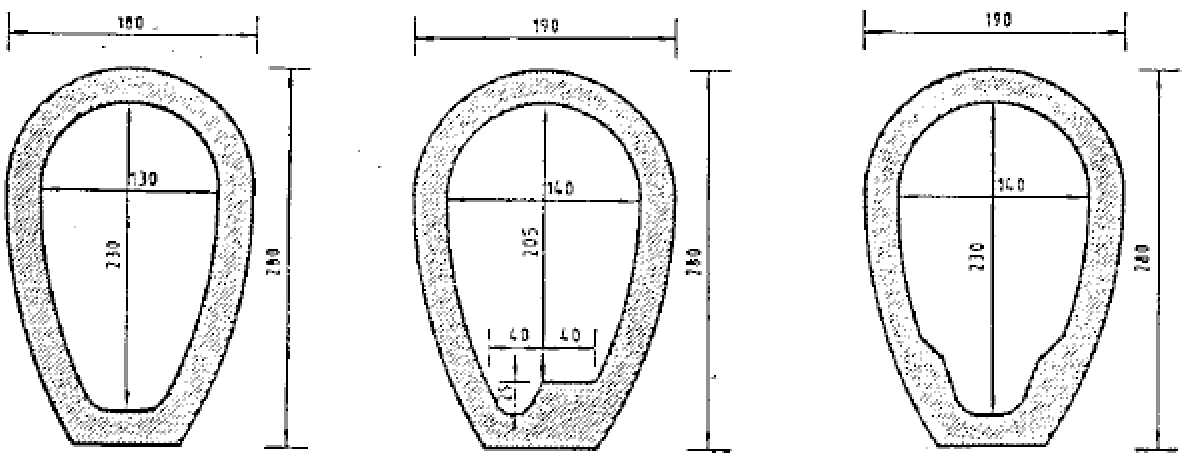


Morphology of a sewer network

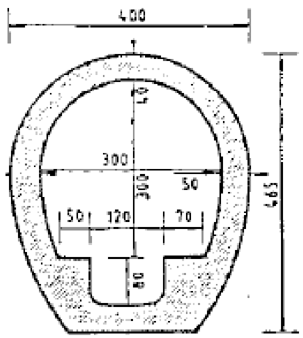
Type and shape of sewers:

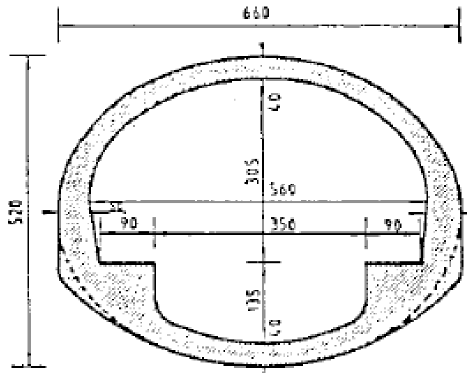
- Circular (from Ø 10 cm to > 4 m)
- Egg-shaped (ovoid) (height 1 to 2 m)
- Special profiles (sewer inspection)

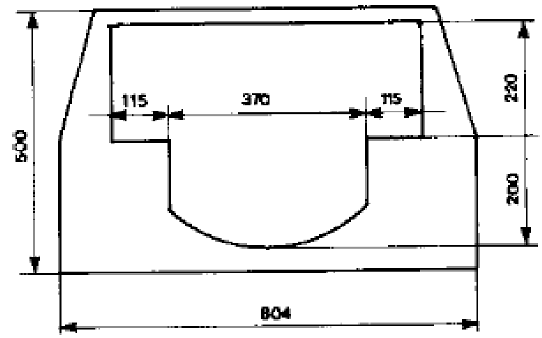




Morphology of a sewer network







Discharge pipes

Morphology of a sewer network

Expected characteristics for sewers:

- Watertight (exfiltration / infiltration of wastewater)
- Inert regarding pollutants
- Structural stability for pressurized situations
- Low rugosity

Materials

- Cast-iron (“fonte ductile”) (special case)
- Plastic (PVC, PE, PP… < Ø 50 cm)
- Fibrociment (asbestos ciment)
- Concrete (prefab)
- Reinforced concrete (big sections)

Morphology of a sewer network

Special structures

Link surface – underground

- Collecting structures
  - Connection of households
  - Intake screen
- Visiting structures

Link sewer system – receiving waters

- Discharge pipes
- Combined sewer overflows

Storage structures

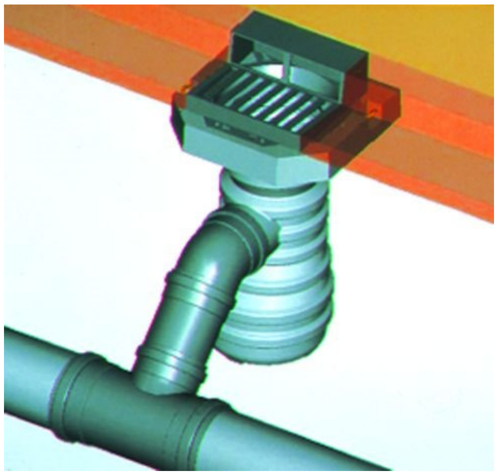
- Detention basins
- At-source storage

Structure linked with sewer functioning

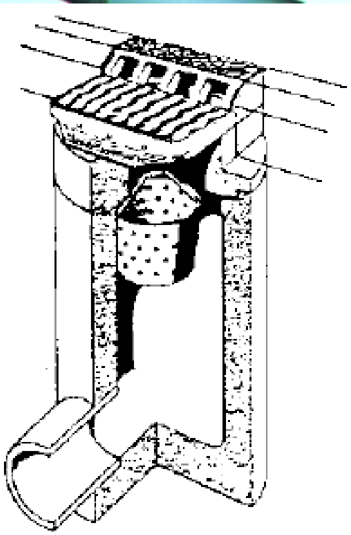
- Flush gates
- Sand trap
- Siphons
- Pumping stations
- Pre-treatment

Morphology of a sewer network

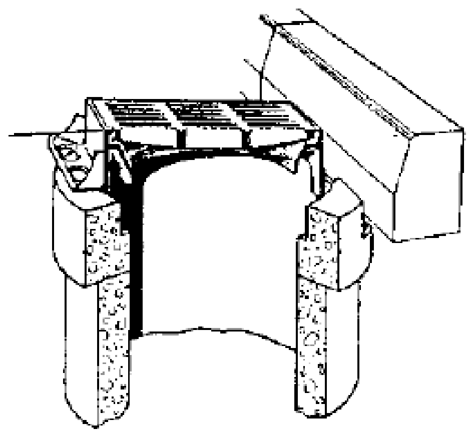
Collecting structures



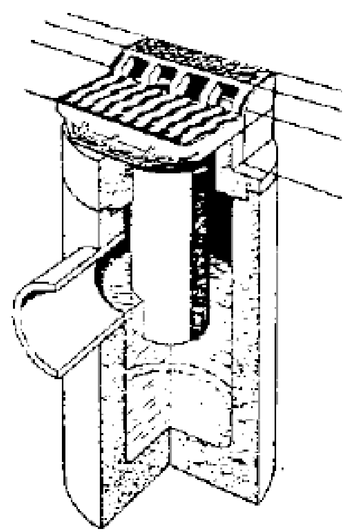
— Couronnement d'un avaloir



— Bouche sans décantation



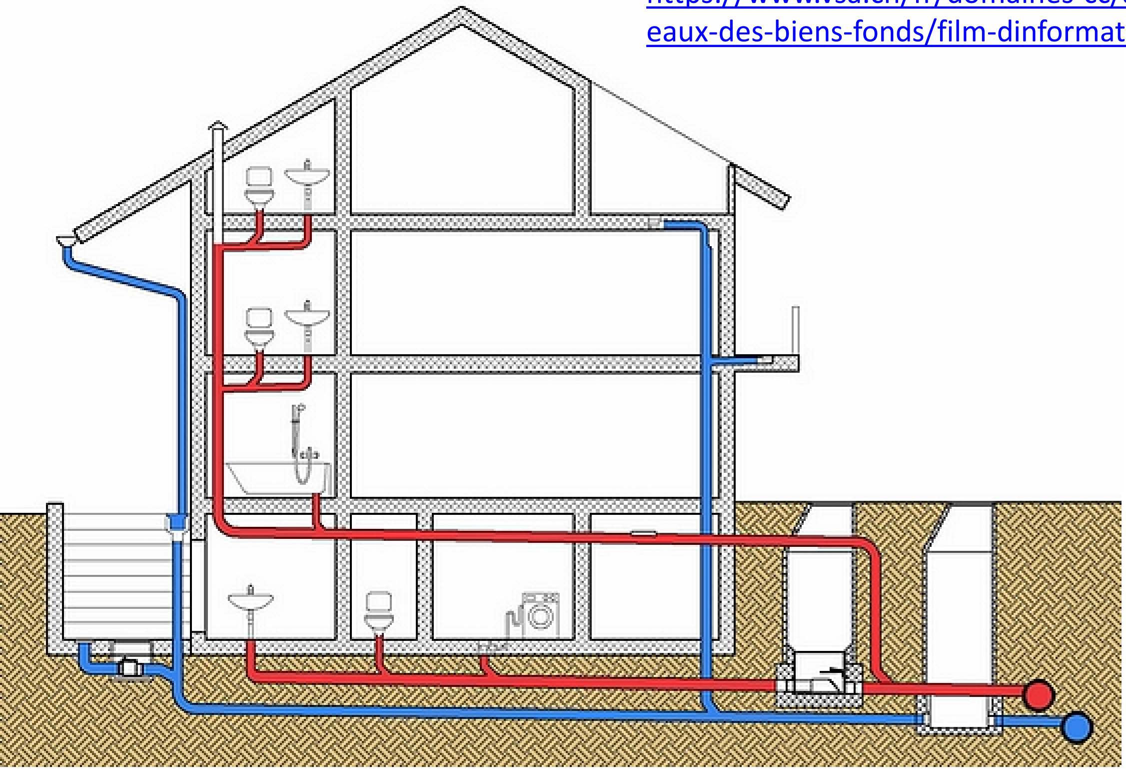
— Bouche à grille



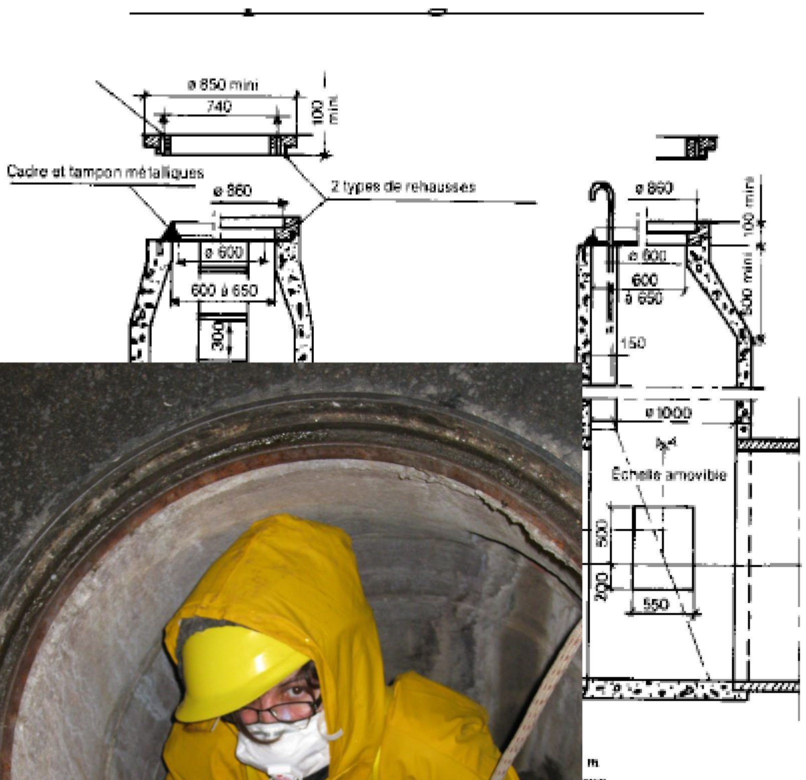
— Bouche à décantation

Morphology of a sewer network

https://www.vsa.ch/fr/domaines-cc/assainissement/evacuation-des-eaux-des-biens-fonds/film-dinformation/



Morphology of a sewer network



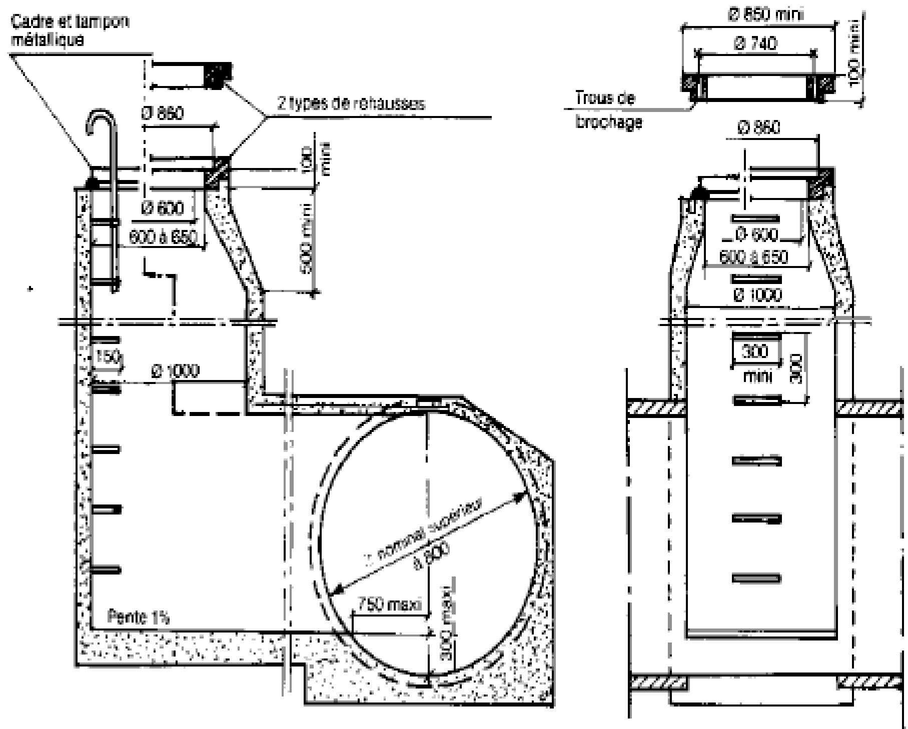
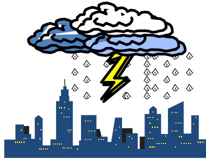


Fig. 57 - Regard de visite à section circulaire de 1 m de diamètre, à accès latéral en dérivation d'une canalisation de diamètre nominal supérieur à 0,80 m. Variantes : avec échelle encastrée, avec échelons saillants.

!!! SECURITY !!!

Morphology of a sewer network

Building up a sewer network: generalities



Variables:

1. **Watershed characteristics**
   - Rain
   - Topography
   - Hydrography
   - Geology
2. **Urban characteristics**
   - Size and typology
   - Imperviousness
   - Existing drainage system
   - Future expected developments
3. **Constraints linked with sewers**
   - Transport conditions (slope…)
   - Maintenance conditions
   - Reduction of nuisances

Building up a sewer network: generalities

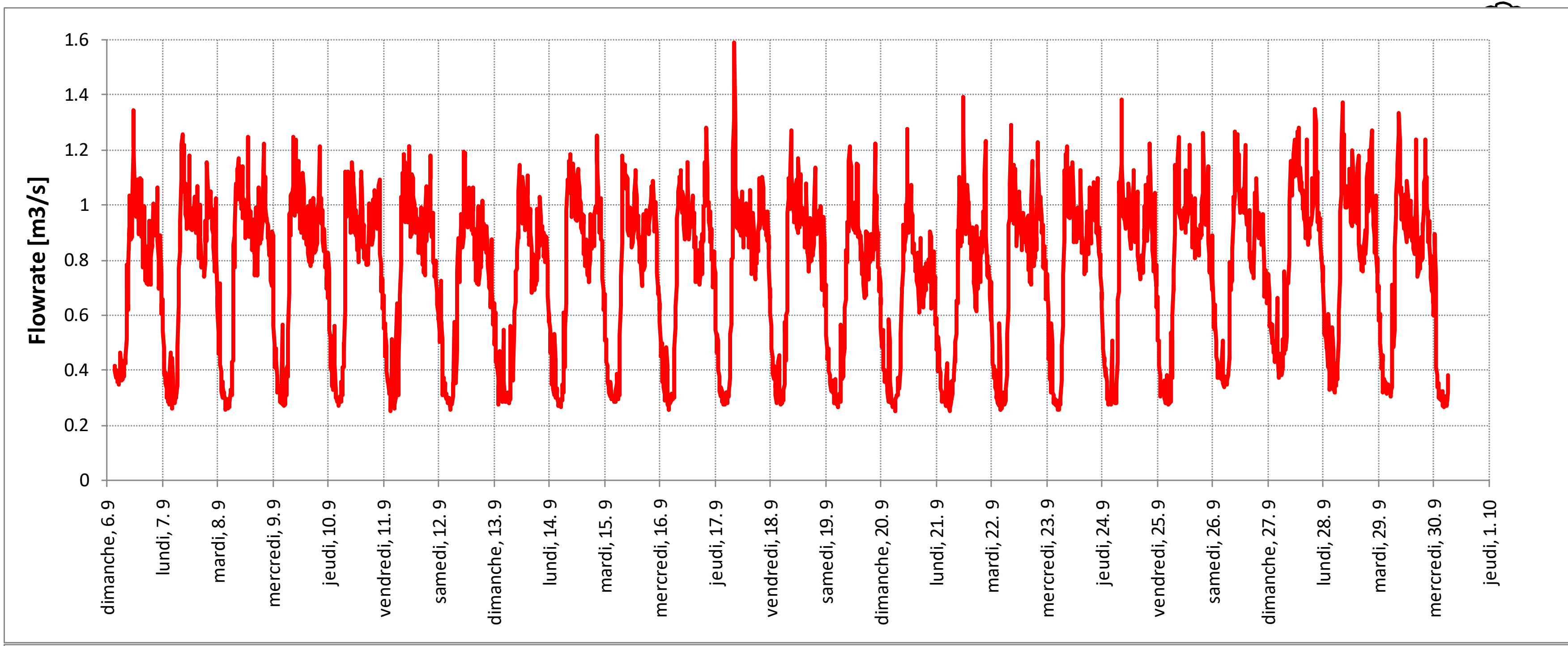
Procedure:

1. Selection of the type of drainage system
2. Selection of the type of network
3. Localization of discharge points
4. Identification of environmental requirements
5. Need, type and localization of storage capacities
6. Implementation of treatment plants
7. Mapping of the network
8. Sizing of the network
9. …

No global rules, no unique solutions !

Different scenarios must be considered !

Lausanne WWTP entrance



CHUV Outlet