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Abdelhafid Bousouf University Center - Mila

2024-2025 Semester 1

Water distribution and collection:

PART II: Sanitation

– Course 1 –

Chapter 01 : *Hydrological phenomena and modeling.*

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Science and Technology	GC and hydraulic	2nd year master	Urban hydraulics

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Course Objectives 1

The objective of this chapter is to:

- Understand the main hydrological phenomena that govern the water cycle (precipitation, infiltration, runoff, evapotranspiration, groundwater flow and surface).
- Identify the factors that influence these processes (climate, topography, soil, vegetation, human activities).
- Introduce the basics of hydrological modeling, an essential tool for forecasting the availability of water resources, analyzing floods, managing reservoirs and planning sustainable exploitation of water resources.

Introduction

Hydrology is the science that studies water in the environment: its distribution, its circulation and its interactions with the soil, the atmosphere and living beings.

Hydrological phenomena, such as rainfall, infiltration, runoff and evaporation, play a decisive role in water resource management. Understanding these mechanisms is essential for:

- Drinking water supply,
- L'irrigation agricole,
- Flood prevention,
- Protection of ecosystems.

However, climate variability and the impact of human activities complicate this analysis. This is why **hydrological modeling** is used to reproduce the behavior of watersheds and to predict the evolution of water resources under different conditions.

Some definitions

The model: Coming from the Latin “modulus”, the word model is defined by the Grand Larousse as “what is given to you for reference.”

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The model is first of all a mock-up which represents in a simplified way the properties of an object or a natural phenomenon.

Modeling: stems from a desire to represent in a more or less simple way a reality too complex. It can therefore be defined as a schematic representation of a physical phenomenon carried out for the purpose of studying it.

The scientist then attempts to reproduce the response of a phenomenon by simplifying the environment of his study. This approach is a "modeling".

Hydrology: is the earth science that focuses on the water cycle, that is to say the exchanges between the atmosphere, the Earth's surface and its subsoil.

In terms of exchanges between the atmosphere and the Earth's surface, hydrology is interested in precipitation (rain and snow), transpiration from plants and direct evaporation from the layer superficial terrestrial.

Surface hydrology: studies runoff, erosion phenomena, and river flows water and flooding.

Underground hydrology or hydrogeology: deals with subsoil resources, their capture, their protection and their renewal.

Urban Hydrology: Branch of hydrology concerned with the part of the water cycle affected by urbanization or affecting the functioning of the city: infiltration of water into the soil and operation of aquifers, surface water runoff, water production and distribution drinking water, collection and purification of wastewater and rainwater...

I.1 Principles of hydrological modeling

Hydrological models can have several objectives:

1. Know how a watershed works,
2. Estimate the risks of flooding, low water levels,
3. Estimate flow rates on ungauged watercourses,
4. Simulate the impact of development scenarios,
5. Simulate the impact of climate scenarios, …

I.2 Why urban sanitation?

The sanitation of urban areas, as understood in this instruction, has the object to ensure the evacuation of all rainwater and wastewater, as well as their discharge into the outlets natural in ways compatible with the requirements of public health and the environment.

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-A sanitation system allows the collection and treatment of wastewater in from the agglomeration so as to discharge purified water, i.e. less harmful, in the environment.

I.2.1 Type of wastewater

Wastewater, as the name suggests, is the result of using clean water. within the framework of the different uses.

After use in the kitchen, bathroom, toilet, the water is evacuated by suitable pipes.

- **Domestic wastewater** consists of:

1. Household wastewater from the kitchen and bathroom. It contains substances organic matter that can ferment (fats, food leftovers) and washing products.
2. Waste water from toilets which is very rich in organic matter which can to ferment and containing pathogenic germs.
3. Industrial wastewater is discharged from the various industries located in the agglomeration.

These industries can be very varied and therefore produce wastewater of very different composition. different: food, clothing, mechanical industries, etc.

In general, the law requires these industrialists to treat their wastewater before discharging it into the public network or in nature.

- **Rainwater** (runoff water): This is water from atmospheric precipitation (rain, snow, hail) which runs off roofs, the ground and facades.

The collection of wastewater and rainwater is done through what is called a network sanitation whose aim: is to collect wastewater from the different districts of a agglomeration, and transport them to a treatment plant; where they will be treated to be then either reused or released into the environment.

I.2.2 Types of sanitation system, their advantages and disadvantages

The most common sanitation systems are:

I.2.2.1. Separative system

The separate system consists of two networks: a network for wastewater and a network for rainwater.

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The separate system allows for better operation of treatment plants and a more economical sizing of the sanitation network since rainwater is evacuated through a separate network.

I.2.2.2 Unitary system (sewerage)

Which collects and transports all water (rainwater and wastewater),

It is recognized that the unitary system is interesting because of its simplicity, since only one pipeline is needed unique in each public road and a single connection for each home.

I.2.2.3. Pseudo-separative system

The meteoric waters are divided into two parts:

•On the one hand, water from road surfaces which flows through structures designed for this purpose effect: gutters, ditches, etc.

•On the other hand, water from roofs, courtyards, gardens which discharge into the sanitation network using the same connections as those for domestic wastewater.

This system is interesting when the collective waterproofed surfaces (roads, parking, etc.) represent a large area with steep slopes.

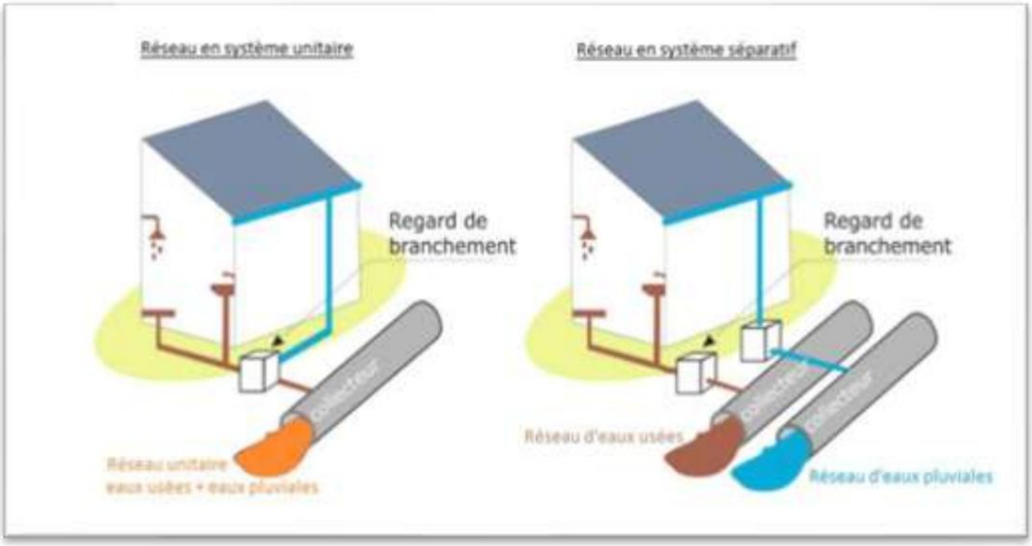

Figure 01: Comparative diagram between the combined network and the separate sanitation network.

I.2.2.4. Individual or non-collective sanitation

Individual sanitation is the system used in low-density urban areas in which the waste water from a dwelling is disposed of at the level of this dwelling itself or at outside in a bordering lot.

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I.2.2.5 The hybrid or composite system

This system provides for the partial diversion of rainwater to wastewater by means of various devices.

It is a variant of the separate system which provides, thanks to various arrangements, a partial diversion of the most polluted water from the stormwater network to the wastewater network with a view to their treatment.

I.2.2.6 The non-gravitational system

Depending on the topography of the site, this type of system avoids the installation of pipes at significant depths; hence a definite economic advantage. It also allows connections intercommunal, allowing a grouping of municipalities, and therefore a reduced need for stations purification. It is also appropriate to emphasize the watertightness of these networks which is clearly superior to gravity networks, hence limiting the risks of pollution of the natural environment and limiting the risks of infiltration of parasitic water into the network.

I.3- choice of sanitation network

The choice of network type must meet the following criteria:

- the type of system already existing and to which a connection is possible.
- The cost of production
- The existence or absence of a treatment plant
- The topography of the land (gravity or pressure flow)
- Urbanization density: in an agglomeration with dense urbanization, the system unitary is generally the most used.

I.4 Concept of downpour and intensity

We generally refer to a shower as a set of rains associated with a disturbance. well-defined meteorological. The duration of a downpour can therefore vary from a few minutes to a hundred hours.

a) General principle

The IDF curves allow the determination of the basic parameters to be transposed to the models of flood management, and flow rates to be used in calculations for the sizing of structures and networks sanitation.

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Indeed, the cost of oversizing the structures, and the damage due to their inadequacy during a heavy downpour requires determining the optimum flow rate to establish these structures. **The IDF curves** give for a period of return of the downpour **T (2, 5, 10, 20, 50, 100 years…), the maximum intensity i** as a function of **the reference duration dt.**

The development **of the IDF curves** is based on the maximum monthly precipitation intensities by time steps 5, 10, 15, 30, 60, 120, 360, 720… minutes.

b) Rainfall laws

The analysis of rainfall has made it possible to define two general laws of rainfall which can be expressed in the following way: as follows:

- For the same frequency of occurrence - therefore the same return time - the intensity of a rain is all the stronger the shorter its duration.
- Or again, for equal duration of rain, precipitation will be all the more intense as its frequency appearance time will be small (so its return time will be large).

These laws allow us to establish the relationships between the intensities, duration and frequency of appearance of rainfall can be represented according to characteristic curves: we generally speak of ***curves Intensity-Duration-Frequency (IDF).*** The notion of frequency is in fact expressed by the notion of time return.

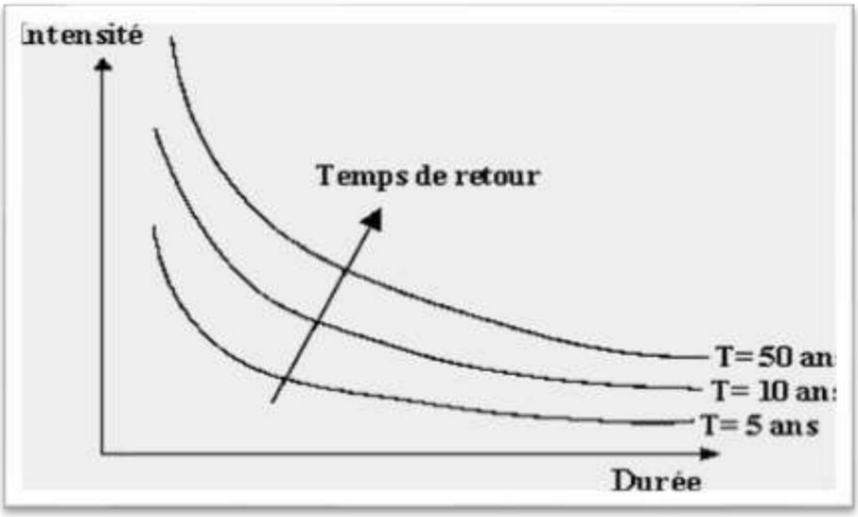

Figure 02: Intensity–Duration–Frequency (IDF) curves of rainfall.

The IDF curves constructed on the basis of a long rainfall series, recorded at the level of a station; synthesize all rainfall information, for the safety of structures and projects.

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They are used, among other things, for calculating project flow rates via rainfall modeling. synthetic and flood flow estimation.

The construction of the IdF curves consists first of all in gathering the data on the maximum rains falling for different durations of time.

For the same time intervals, we group the intensities, which allow us to have series of data which subsequently allows the construction of curves called: IDF

I.4.1 Methodology for constructing IDF curves

The methodology for constructing IDF curves includes three (03) steps:

-We calculate the empirical probability of the sample and then we adjust the sample with several laws to validate the most appropriate law,

-We determine the quantiles corresponding to chosen return periods (2, 5, 10 or 20 years)

-We adjust an empirical equation on the quantiles, which makes it possible to link to each chosen intensity, the corresponding return time.

$$I=a*t-b$$

With :

I(mm/h): Maximum rain intensity,

A and b the adjustment coefficients

t (mn): duration of rain

- **Areas of application of IDF curves**

The areas of use of IDF curves are numerous and varied, including: ÿ Stormwater drainage, ÿ Public works: sizing of structures, infrastructure

Forecasting and prediction: flood risk management (flood, low water)

ÿ Planning and management of water resources,

ÿ Agribusiness, I.4.2

Construction of IDF curves

The IDF curves are established on the basis of the analysis of showers recorded at a station during a long period. The curves obtained can therefore be constructed analytically.

I.4.3 Mathematical models of IDF curves

Its application is relatively simple:

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- For each headwater sub-basin of surface area A, we estimate the concentration time tc and the coefficient of runoff C. For a given recurrence period, we choose on the intensity-duration curve-frequency a precipitation rate I corresponding to a duration equal to the concentration time.

This allows us to calculate the flow rate, pipe diameter, flow velocity and time of course.

- For a downstream sub-basin, we take as concentration time the maximum of the times of concentration and travel times of upstream flows reaching its outlet.

The area considered will be the sum of all the upstream areas served by this outlet. The runoff coefficient will be the average weighted by the areas of the upstream sub-basins of the coefficients of these sub-basins.

The precipitation rate is taken from the IDF curve. We can then calculate the flow rate, diameter, speed and travel time and move on to the next sub-basin.

I.4.4 Analytical representation

Different formulas are proposed to represent the critical intensity of a rain as a function of its duration.

The most general form (with variable T) is:

$$i = \frac{k \cdot T^{a}}{(t + c)^{b}}$$

With :

i: total intensity [mm/h], [mm/min] or specific intensity [l/s.ha],

T: return period in years,

t: reference duration [h] or [min],

k, a, b, c: adjustment parameters.

Montana suggests a simpler formulation:

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$$i = \frac{a}{t^{b}}$$

With :

i: maximum rainfall intensity [mm/h],

t: duration of rain [minutes or hours],

T; recurrence interval (or return time) [years],

a,b: local constants, generally dependent on location (0.3<0.8).

For a given overshoot frequency, this Montana formula was adapted for Switzerland and has resulted in the following formulation (Bürki and Ziegler, 1878):

$$i = \frac{a}{\sqrt{t}}$$

I.5 Calculation of rainwater flow rates

The basic calculation for sizing a rainwater network is the (heaviest) rain likely to occur within a 10-year period (ten-year flow). During a rainfall, only the fraction of water running off is of interest to the sizing of a specific structure, called to evacuate under sufficient conditions the flow of water from this fraction of a basin considered.

The calculation of the flow rate of runoff water is done taking into account:

• characteristics of the rain (intensity, duration and spatio-temporal distribution);

•characteristics of the watershed surface (nature, degree of permeability, slope and development)

:

•hydraulic laws relating to free surface flows.

I.5.1 Choice of calculation model

There are several models for calculating flow rates, some of which are suitable for resolving forwards projects, therefore they are necessarily based on a certain empiricism and rely on elements statistics, as well as on elements of hypotheses based on experience to characterize the urban fabric.

Among the existing models we can cite:

ÿ The rational model

ÿ Caquot's superficial model

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ÿ The Mac-Math model

ÿ The Malet-Gauthier model, etc.

Choosing a suitable model depends on several factors:

- The area of the watershed
- The nature of the soil
- The slope
- The roughness of the works.

1. The rational method

This method is used for limited areas (generally less than 10 ha). The result is better for even smaller areas. Due to the good estimation of the coefficient of runoff.

The determined flow rate is proportional to the average intensity, the runoff coefficient and the area swept away.

=

With :

Q : rain flow (m3 /s)

k : intensity correction coefficient taking into account rain in space, the determination of which is a function of the elongation of the pelvis

C : runoff coefficient specific to the sub-basin

A : basin area (ha)

I: maximum rainfall intensity (in l/s/ha)

- ***The runoff coefficient Cr***

It is the ratio of the volume of water which runs off a surface to the volume of water which falls on this surface. same surface.

It plays a key role in the assessment of peak rainfall flows; which are used for network sizing. Its value varies from 0.05 to 1, it depends on several factors:

ÿ The nature of the soil

ÿ The slope of the land

ÿ Land use ÿ Population density ÿ

Rainfall duration

ÿ Air humidity

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Generally speaking, we can say that the runoff coefficient is considered to be the rate waterproofing of the sub-basin.

=

With :

Aimp : Impermeable surface,

At : Total surface area of the sub-basin

The runoff coefficient C must be determined from tables of values calculated according to the nature of the soil; here are some typical values:

(Roof, roads)…………………..0.9

- wide joint paving…………………0.6
- non-gadrooned tracks…………………0.35
- gravel driveways………………………..0.2
- wooded area………………………..0.05

The method can however be used without decomposition into elementary areas by using the following coefficients:

- very dense housing…………..0.9
- dense housing………………..0.6 to 0.7
- less dense housing…………0.4 to 0.5
- residential areas………………0.2 to 0.3
- Squares, gardens, meadows (depending on slope and permeability of the soil……..0.05 to 0.2:

• **Determination of the Weighted Runoff Coefficient**

In the case where the surface of the basin considered is formed of several food areas "Ai" to which the runoff coefficients "Cri" are assigned, the runoff coefficient is calculated weighted:

= ÿ

With :

Crp : weighted runoff coefficient

Ai : elementary surface

Cri : runoff coefficient corresponding to Ai

Intensity duration frequency curves

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• ***Rain intensity:***

The average precipitation intensity is the height of water falling during a unit of time.

a. Determination of intensity

The intensity is expressed as a function of the parameters **a** and **b** by the “Montana” formula:

i (T, F) (mm/h) = a. tc-b

a and b Montana parameter function of rainfall valid for a return period T and

a given rain duration tc.

Note = MONTANA coefficients vary depending on the region and the return period.

Example :

T = 10 years (ten-year rainfall)

Time interval tc = 15 mm

- regional values of a and b:

a = 6,7 b = 0,55

i = 1,51 mm/h

• **Maximum annual daily rainfall**

Pj= ÿ 2+ ×exp(u×ÿ (2 +))……..mm

Pjmoy: average daily rainfall (mm).

Cv: Coefficient of variation.

U: Gaussian variable.

ln: Log. Népérien.

Frequency of exceeding (%) 50	20	10	5	2	1
Return period (years) 2	5	10	20	50	100
Gaussian variable (U) 0	0.841	1.282	1.645	2.057	2.327

For drainage works, we adopt a return period of 10 years.

• **Calculation of rain frequency**

The frequency of rainfall is given by the following formula:

Pt(%) =Pj%×( ) — b

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Pj: Maximum daily rainfall (mm).

b: Climate exponent.

Pt: annual maximum daily rainfall.

tc: Concentration time (hour).

• **Concentration time**

The duration t of the downpour which produces the maximum flow Q being taken equal to the concentration time.

Concentration time is defined as the time required for a water particle to travel the longest hydraulic path from the basin boundary to the outlet.

Tc = 0,127.ÿ /

Depending on the characteristics of the drained basin, the concentration time is estimated respectively according to:

a. VENTURA (Ray) :

$$Tc = 0{,}13\sqrt{\frac{S}{p}}$$

. Tc = concentration time in hours
. S = surface area of the watershed in km²
. p = Slope in m/m

Area of validity between 1 and 20 km² or greater than 10 km² depending on the works.

b) TOWER:

$$Tc = 0{,}108\ \frac{\sqrt[3]{S.L}}{\sqrt{p}}$$

. Tc = concentration time in minutes
. S = area of the watershed in hectares
L = longest hydraulic path in meters
. p = slope in m/m

c) VEN TE CHOW :

$$Tc = 0{,}096\ L^{0{,}096} p^{-0{,}32}$$

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. Tc = concentration time in minutes
L = longest hydraulic path in meters

. p = slope in m/m Area of validity for agricultural watersheds of 1 to 2 hectares.

Note : It is complicated to find the domain of validity of the concentration time formulas, especially since according to the literature, for the same formula, the validity times vary.

- **Temps de concentration;**

Le temps de concentration ou plus long parcours de l'eau se compose de:

- Du temps t_1 mis par l'eau pour s'écouler dans les canalisations:

$$t_1 = \frac{L\,(Longueur)}{V\,(Vitesse\ de\ l'eau)}$$

- Du temps $\mathbf{t_2}$ mis par l'eau pour atteindre le premier ouvrage d'engouffrement ou bouche d'égout en surface. D'après Caquot:

$$t_2 = I_p^{-4/11}$$

Ip = pente moyenne de cheminement hydraulique sur la surface du sol (m/m).

- Du temps $\mathbf{t_3}$ du ruissellement dans un bassin qui ne comporte pas de canalisation:

$$t_3 = \frac{L}{11\sqrt{I_p}}$$

Concentration time can therefore have three aspects:

The basin does not have any pipes: **tc = t3**

The basin has a surface course then a pipeline: **tc = t3 + t1**

The urbanized basin has a main pipeline and tertiary connections : **tc = t2 + t1.**

- **Méthode simplifiée de calcul de tc pour une zone urbanisée**:

On admet un temps de circulation superficielle égale à 5 mn et une vitesse en égout égale à 1 m/s :

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$$tc = t_1 + t_2 = \frac{L}{V} + 5\ mn \qquad tc\ (mn) = \frac{L\ (m)}{60\ m/mn} + 5\ mn$$

2. Caquot Method

a. definition

Overall method for calculating the maximum flow rate corresponding to a given return period, at the outlet of an urban watershed. The use of the Caquot method was recommended in France as early as 1949.

Q (m3 / s) = KI/ U I V/ U C1/ U AW/ U

With :

Q: flow rate in m3/s

I: average slope of the watershed (m/m)

C: BV runoff coefficient

A : surface area of BV in hectares

In which the parameters (K, U, V and W) are functions of the Montana coefficients a(T) and b(T) and the latter depend on the return period (RADDEMA Mission A1) represented in the following table:

The parameters	The formulas
IN	1+0.287*b(T)
In	-0.41*b(T)
IN	0.95+0.507*b(T)
K	((0,5b (T) *a(T)) / 6,6)

Table: Characteristic coefficients of the Caqout formula.

With T: return period (years)

Note: the limits of validity of the CAQUOT formula are :

ÿ Surface area of the basin or group of basins ÿA ÿ 200 ha

ÿ Pente 0,0002 < I < 0,05

ÿ Runoff coefficient 0.2 < C < 1

ÿ The elongation coefficient: Mÿ0.80

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K, u, v, w: are coefficients which vary according to the frequency and the rainfall region considered.

Table: the different forms of the formula depending on the return period

Return period	The formula
10 years	Q = 1.430 I 0 29 Cr 1 20 A0.78
5 years	Q = 1.192 I 0 30 Cr 1 21 A0.78
2 years	Q = 0.834 I 0 834 Cr 1 22 A0.77
A year	Q = 0.682 I 0 32 Cr 1 23 A0.77

For the region would meditate and a return period of 10 years the previous formula is written

Q = 1.29 I 0 .2 1 Cr1 . 1 4 A0 .8 3

b. Calculation principle:

The superficial method leads to determining the flow rate from the physical characteristics of the basin

slope

c. Determination of parameters

• The average slope

The average gradient of this network depends not on the width of these sections but on the flows caused by each of the sections.

Imoy=ÿ ×

Li: the longest hydraulic path in the basin (case of series arrangement).

Ii: slope of the basin

• Lengthening of watersheds:

The elongation " M is defined as the ratio of the longest hydraulic path " L

" to the square root of the area of the basin considered. Its expression is as follows:

M = ÿ ÿ0, 8

L: length (in hectometres) of the longest hydraulic path
A: basin area (in hectares)

When it appears useful to seek a large approximation in the evaluation of flow rates, for example example in order to determine the characteristics of an important work or when dealing with

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a very compact or, on the contrary, very elongated basin, we can after having determined the elongation " M" corresponding, correct the calculated flow rate by multiplying it by a coefficient d'influence " m " quantitatively translating the fact that for the same surface "A", the flow rate varies inversely with the elongation "M" of said basin.

If the value of the coefficient **M** is different from **2** the flow rate will be corrected by a correction factor **m** which is given by the formula:

[. ( )ÿ(ÿ ( ))] [ÿ .

= [ ] = [ ]

With :

M: elongation coefficient

b(F) : rainfall expression parameter

f: the peak flow adjustment factor in the concentration time expression

(F= - 0,287)

Qp corresponds to a raw value, this must take into account the coefficient **m** of the shape of the basin.

Corrected Q p **= m Raw Qp**

• **Evaluation of equivalent parameters of a group of basins.**

The superficial formula developed above is valid for a pool of physical characteristics homogeneous. The application of the model to a grouping of heterogeneous sub-basins of parameters individual Aj, Cj, Ij, Lj (length of the main drain), Qpj (peak flow of the basin considered alone), requires the use of equivalence formulas for the parameters "A, C, I and M" of the grouping.

These formulas which differ depending on whether the basins constituting the grouping are in *" série "* or in *"parallel"* are expressed below:

Table: Characteristics of each sub-basin grouping:

Mass assembly	Parallel assembly
You have ÿ= =*i* 1 N	*A* *Eat* ÿ= =*i* 1 N
Creq = (ÿ N i=1 You are welcome.) / (ÿ N i=1 Eat)	*Creq* = (ÿ N i=1 You are welcome.) / (ÿ N i=1 Eat)

Yes = ÿ ÿ (N, i = 1) *That* ÿ 2 / N ÿ ÿ ÿ ÿ (ÿ ÿ (i = 1) *That* $\sqrt{Ii}$ ÿ ÿ ÿ) ÿ ÿ	*Yes* = ÿ ÿ ÿ (N) ÿ ÿ ÿ ÿ ÿ ÿ (i = 1) *IQi* ÿ ÿ ÿ ÿ / ÿ (N, i = 1) *Qi*
M = ÿ *L j* / $\sqrt{ÿ}$ *A j*	*M* = *L* / $\sqrt{ÿ}$ *A* (*Q* max)

1. Manning & Strickler Formula (1890)

The formula used for sizing collectors is:

Q = K*S*Rn * I ½

With:

Q: is the flow rate to be transmitted in m3/s.

K= 60 for concrete pipes of a unitary network or rainwater from a separate system. 70 for concrete wastewater pipes of a separate network.

K = 100 for high density polyethylene (HDPE) or polyvinyl chloride (PVC) pipes.

n = 3/4 for a unitary network or rainwater from a separate system.

n = 2/3 for wastewater.

R: is the hydraulic radius in m

I: is the slope of the collector in m/m

S: is the wetted section in m2

1.3.3 Mac Math Formula

The statement of the Mac Math formula for estimating flood discharges with return period T is:

QT = K *P *A 0.58*I0.42

Or

QT = peak flow rate in m3/s of return period Tan years

K = coefficient depending on the nature of the watershed (plant cover, topography),

P = maximum rainfall over 24 hours in m of return period Tans

A = area of the watershed in km2

I = average slope of the watershed.

Use of empirical formulas

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The one that gave the best results is called Mallet – Gauthier. We have for the calculation of the 100-year flood:

$$C = 2\,k\log(1 + A)\; S\,\frac{\sqrt{1 + 4\log T - \log S}}{\sqrt{L}}$$

The coefficients k and A depend on the topographical and climatological characteristics of the land. MEDINGUER admits that one can take for the wadis descending from the domain Atlas and circulating on the Hamada k = 0.8 and A = 20.

Conclusion

Urban hydrology allows us to analyze phenomena linked to rainfall (precipitation, runoff, infiltration) on waterproofed surfaces. The Intensity–Duration– curves Frequency (IDF) are essential to assess the probability of extreme rainfall and correctly size sanitation works. Calculating rainwater flows, based on hydrological methods and models, provides engineers with the necessary data to design reliable networks, reduce flood risks and ensure the proper operation of urban infrastructure.

Useful links

https://youtu.be/WLLeKY1ndFQ

https://youtu.be/Exvg9qXJqaQ

https://youtu.be/dMGa0pYG4c8

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