EXTREME HYDROLOGICAL EVENTS

FLOODS AND DROUGHTS

GENERAL CONCEPTS AND MODELS

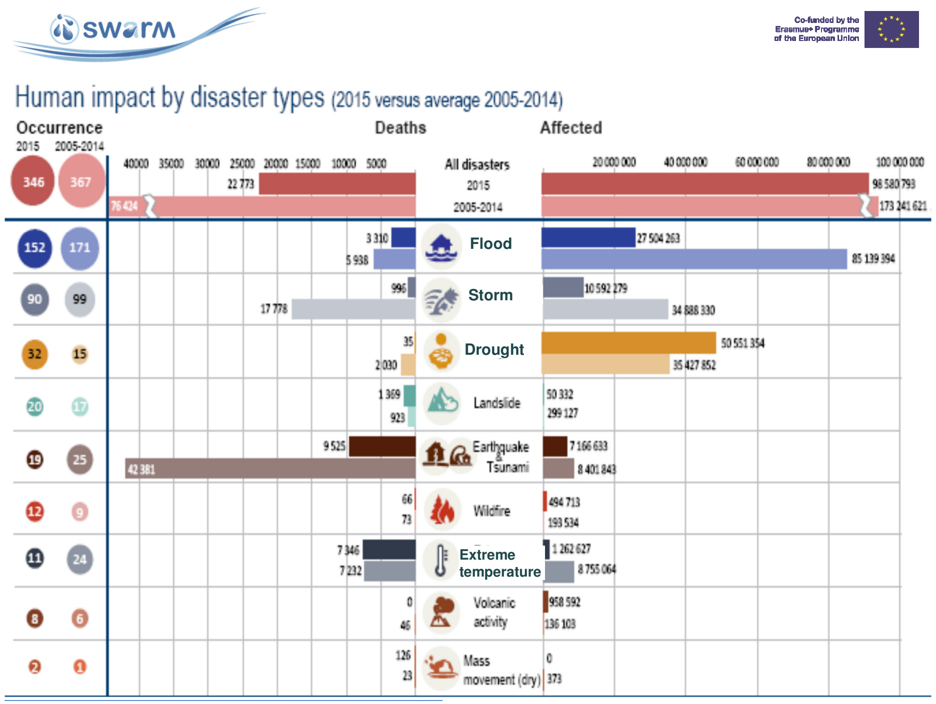
Maria Manuela Portela, Instituto Superior Técnico, Universidade de Lisboa, CERIS, Portugal

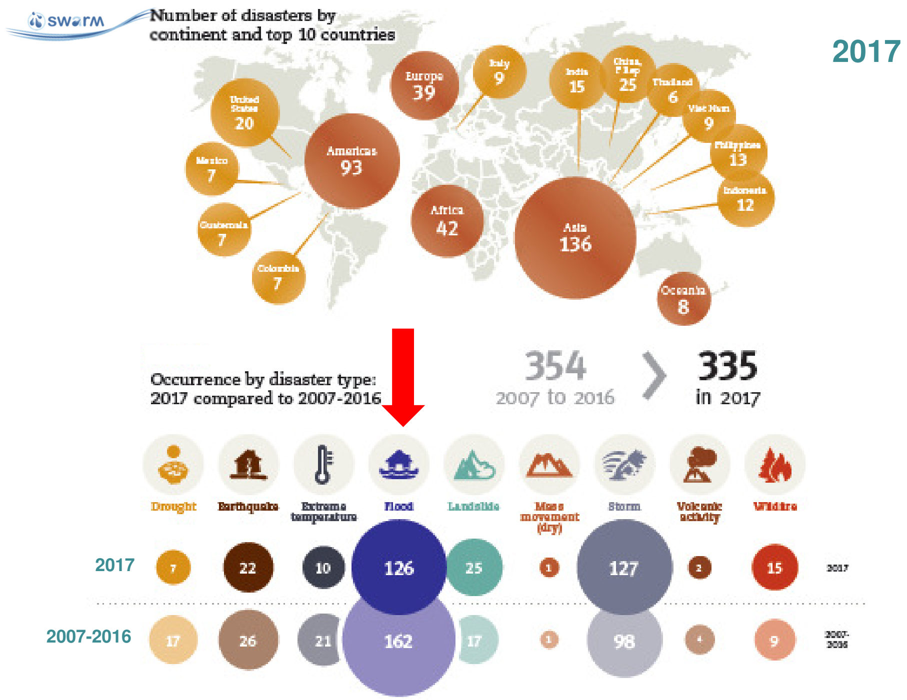
*At the scale of the Earth, **floods** are the **natural hazard that disturb more people**. They affect the areas located near the rivers, downstream dams or along lateral dikes and along the shoreline. According to the **World Meteorological Organization, the disasters caused by floods have been increasing**, due to urban expansion into floodplains … climate change*

*A flood can be defined as **a general and temporary condition of partial or complete submersion of an area …** of land usually dry … as a result of the river overtopping or of the tidal raising, or by the rapid and unusual accumulation of water from any source, mud or land collapse along the shoreline*

UNISDR
The United Nations Office for Disaster Risk Reduction

Munich RE


swarm
Co-funded by the Erasmus+ Programme of the European Union
Human impact by disaster types (2015 versus average 2005-2014)
Occurrence
2015 2005-2014
Deaths
Affected
40000 35000 30000 25000 20000 15000 10000 5000
20 000 000 40 000 000 60 000 000 80 000 000 100 000 000
346 367
All disasters 2015 2005-2014
22 773
76 424
98 580 793
173 241 621
152 171 Flood 3 310 5 938 27 504 263 85 139 394
90 99 Storm 996 17 778 10 592 279 34 888 330
32 15 Drought 35 2 030 50 551 354 35 427 852
20 17 Landslide 1 369 923 50 332 299 127
19 25 Earthquake Tsunami 9 525 42 381 7 166 633 8 401 843
12 9 Wildfire 66 73 494 713 193 534
11 24 Extreme temperature 7 346 7 232 1 262 627 8 755 064
8 6 Volcanic activity 0 46 958 592 136 103
2 1 Mass movement (dry) 126 23 0 373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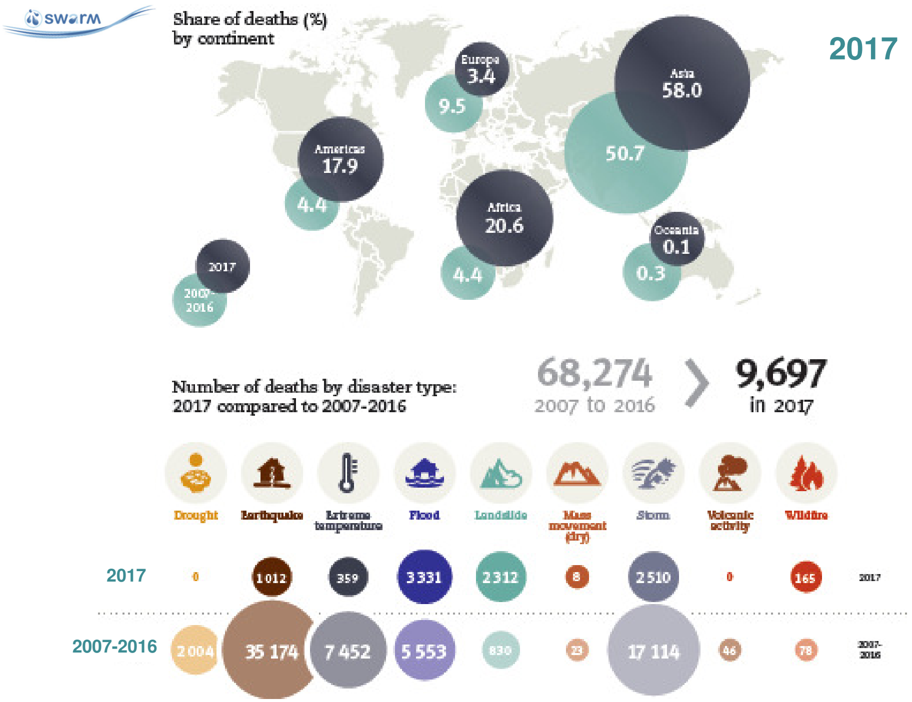
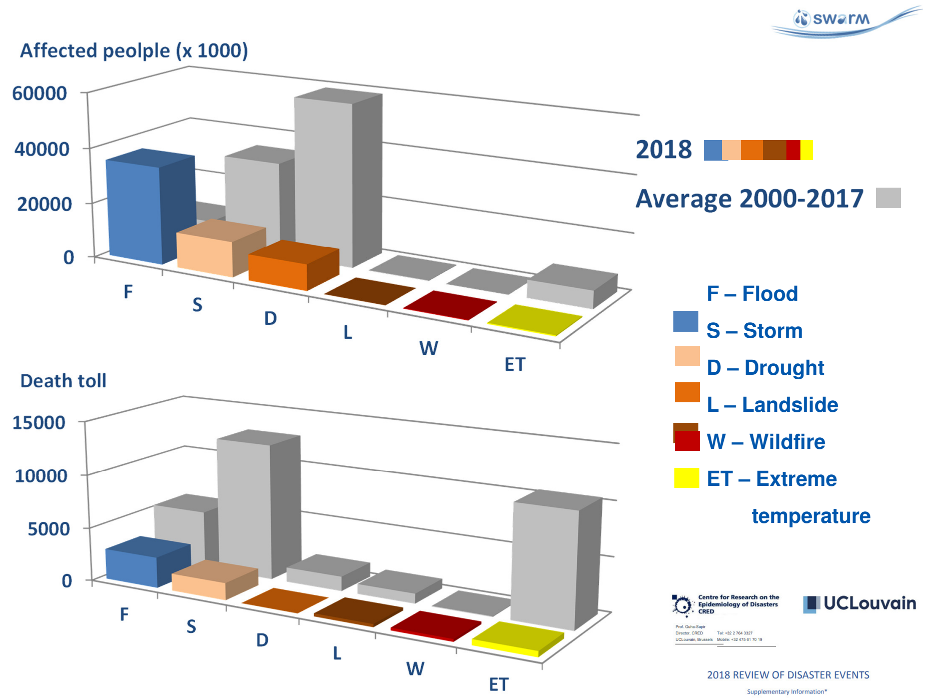
Number of disasters by continent and top 10 countries
2017
United States 20
Mexico 7
Guatemala 7
Colombia 7
Americas 93
Europe 39
Italy 9
Africa 42
Asia 136
India 15
China, P Rep 25
Thailand 6
Viet Nam 9
Philippines 13
Indonesia 12
Oceania 8
Occurrence by disaster type: 2017 compared to 2007-2016
354 2007 to 2016
335 in 2017
Drought Earthquake Extreme temperature Flood Landslide Mass movement (dry) Storm Volcanic activity Wildfire
2017 7 22 10 126 25 1 127 2 15
2007-2016 17 26 21 162 17 1 98 4 9


swarm
Share of deaths (%) by continent
2017
Europe 3.4
9.5
Asia 58.0
50.7
Americas 17.9
4.4
Africa 20.6
4.4
Oceania 0.1
0.3
2017
2007-2016
Number of deaths by disaster type: 2017 compared to 2007-2016
68,274 2007 to 2016
9,697 in 2017
Drought Earthquake Extreme temperature Flood Landslide Mass movement (dry) Storm Volcanic activity Wildfire
2017 0 1 012 359 3 331 2 312 8 2 510 0 165
2007-2016 2 004 35 174 7 452 5 553 830 23 17 114 46 78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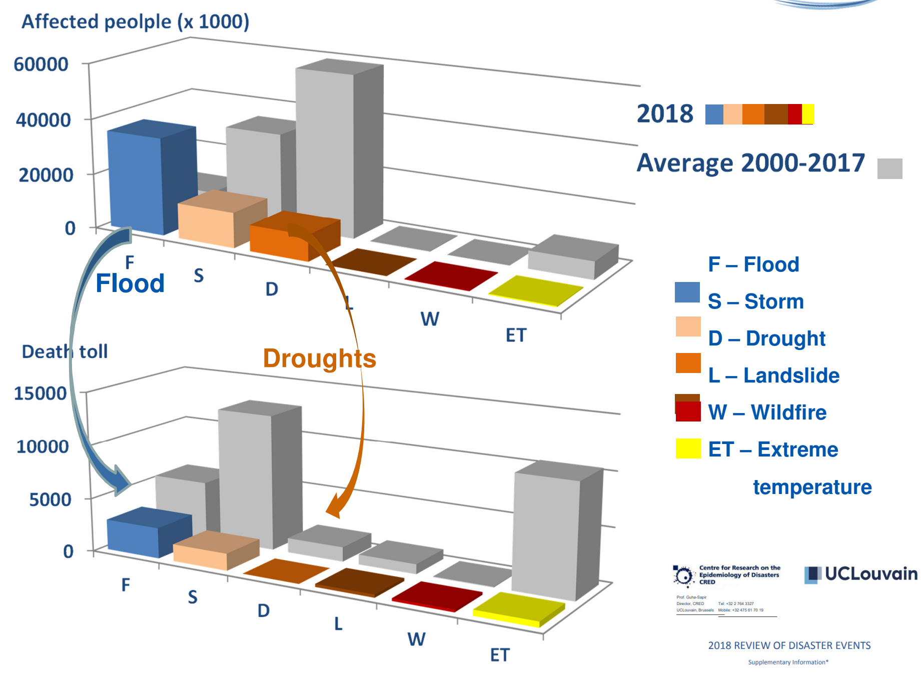
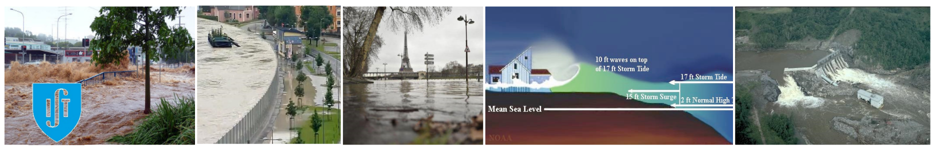
Affected peolple (x 1000)
60000
40000
20000
0
F S D L W ET
Death toll
15000
10000
5000
0
F S D L W ET
2018
Average 2000-2017
F – Flood
S – Storm
D – Drought
L – Landslide
W – Wildfire
ET – Extreme temperature
UCLouvain
2018 REVIEW OF DISASTER EVENTS



*There are different types of events that may result in floods … in terms of **river floods**, there are the **(1) progressive floods,** like those along some of the large European rivers, like Danube or Seine, and the **(2) flash floods or occurring in small watersheds**, inducing mudslide; the floods along the shoreline due to **(3) storm surges**; the floods caused by the **(4) collapse of dams and dikes**, …*

*There are different types of events that may result in floods … in terms of **river floods**, there are the **(1) progressive floods,** like those along some of the large European rivers, like Danube or Seine, and the **(2) flash floods or occurring in small watersheds**, inducing mudslide; the floods along the shoreline due to **(3) storm surges**; the floods caused by the **(4) collapse of dams and dikes**, …*



Infrastructure collapse - OROVILLE (Northern California, 235 m high - the tallest dam in the U.S; start of operation 1968) – Feb/2017

WEATHER July 24, 2018

Hundreds of People Missing after Dam Collapses in Laos

Heavy rainfall events
… heavy rainfall over a period of several days, killing ... Laos, 2018

…. Kenyan dam bursts following weeks of heavy rainfall, killing …, May/2018

Co-funded by the Erasmus+ Programme of the European Union

Concept of natural flood … although widely used does no have a precise definition *(perhaps because the floods are mostly recognized by its anthropogenic consequences)*

Gradual and progressive raising of the water surface along a river resulting in exceptional maximum heights that propagate downstream. The flood concept is always connected with the occurrence of exceptional water heights in the river and, accordingly, with exceptional river discharges.

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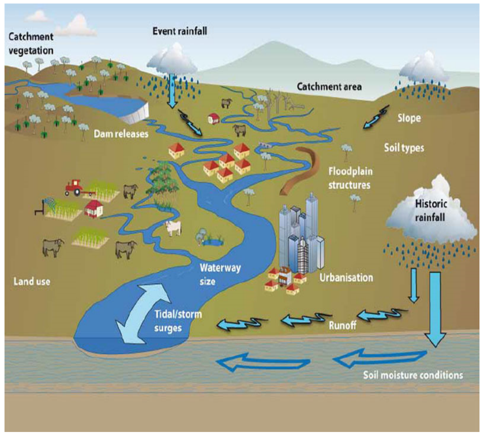

***From a hydrological point of view**, a flood is considered to occur when the watershed is fed by intensive and prolonged rainfall that results in river discharges that exceeds the normal conveyance capacity of the river, causing the overtopping of the margins and the submersion of the lateral fields.*

- ***Natural causes*** *(like intensive rainfall events)*
- ***Artificial causes*** *(dam break)*

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European Union Directive 2007/60/EC on the assessment and management of flood risks (FLOOD DIRECTIVE)

In force since 26 November 2007. It requires Member States to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to take adequate and coordinated measures to reduce this flood risk. It also reinforces the rights of the public to access this information and to have a say in the planning process – introduced in each EU country legal framework by specific decree-laws.

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European Union Directive 2007... and management...

In f... to
asse... m
flood... k
in the... ures
to red... rights of the
public ... to have a say in the
planning ... in each EU country legal
framew... decree-laws.

Each EU country must have translate the European flood directive into its own legal framework

Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

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Hydrological data
- Dishcarges records
- Maxima water depths
- Historical floods maps

FLOWCHART FOR FLOOD RISK ASSESSMENT

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Hydrological data
- Dishcarges records
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Establishment of national maps with flood hazard
- Definition of the probabilities or of the return periods to be adopted (i.e., 1% or 100-year return period)

Evaluation of the flood consequences
- Economical losses in infrastructure
- Endangered population
- Minimum life standards affected

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Production of maps with the flood risk
Risk = Probability of occurence of the hazard x its consequences

FLOWCHART FOR FLOOD RISK ASSESSMENT

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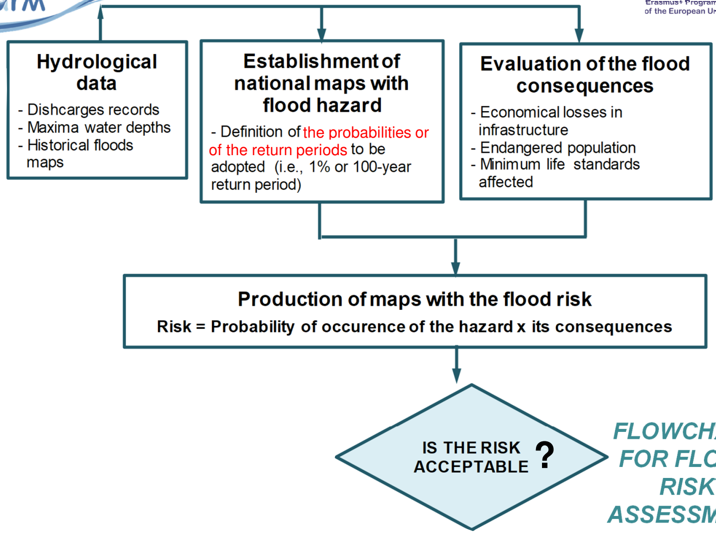

FLOWCHART FOR FLOOD RISK ASSESSMENT

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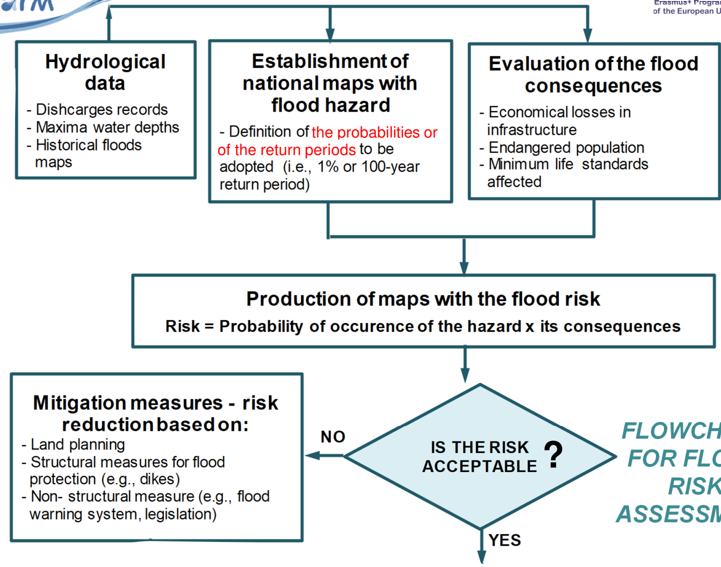

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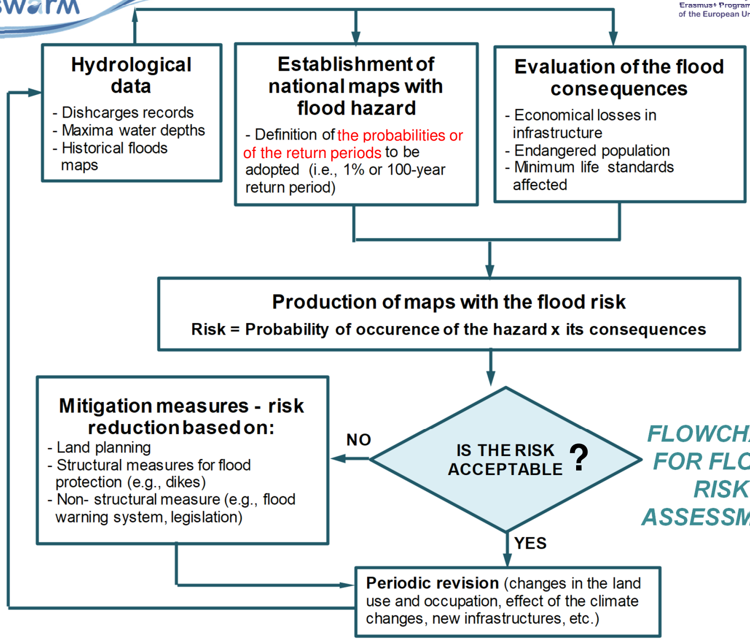

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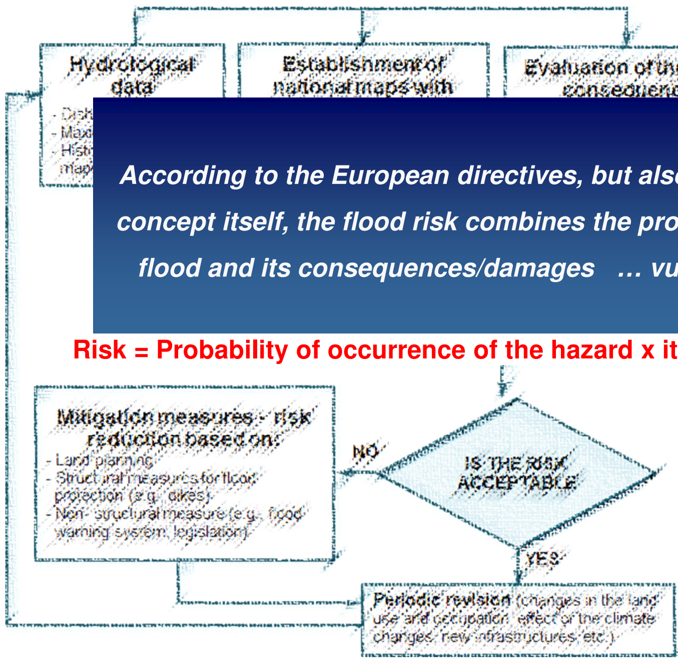
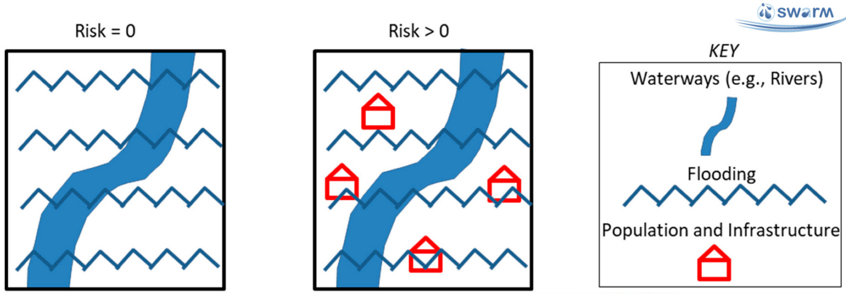


According to the European directives, but also to the risk concept itself, the flood risk combines the probability of a flood and its consequences/damages … vulnerability

Risk = Probability of occurrence of the hazard x its consequences

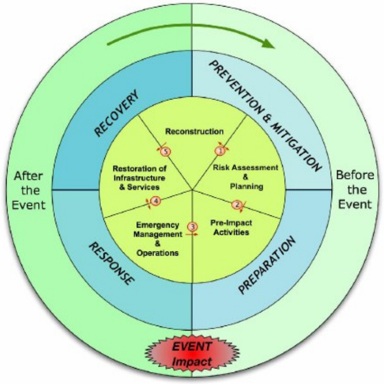
FLOWCHART FOR FLOOD RISK ASSESSMENT



Floods are always at the interface between the natural and the built environments

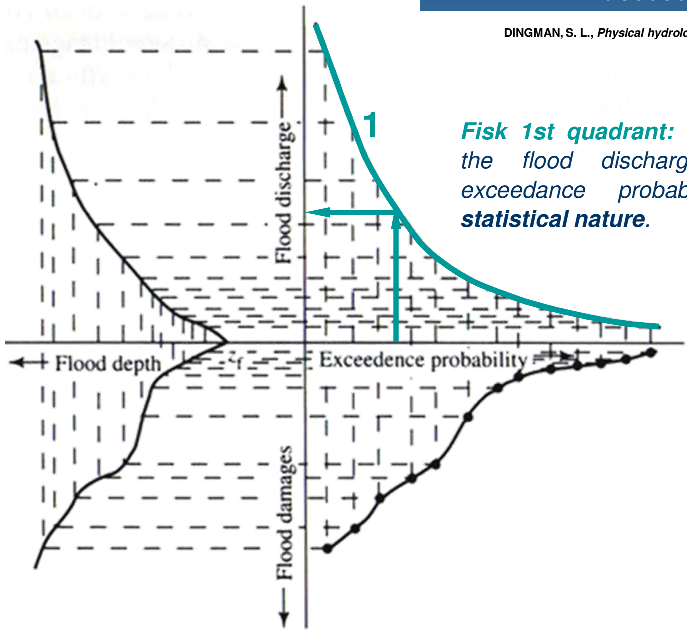
(*if there were not assets of any kind affected, the floods would not be a problem!*).

It is necessary to be prepared before the events occur in order to be able to act efficiently later, aiming at minimizing future damages.



Two D representation of the flood risk assessment

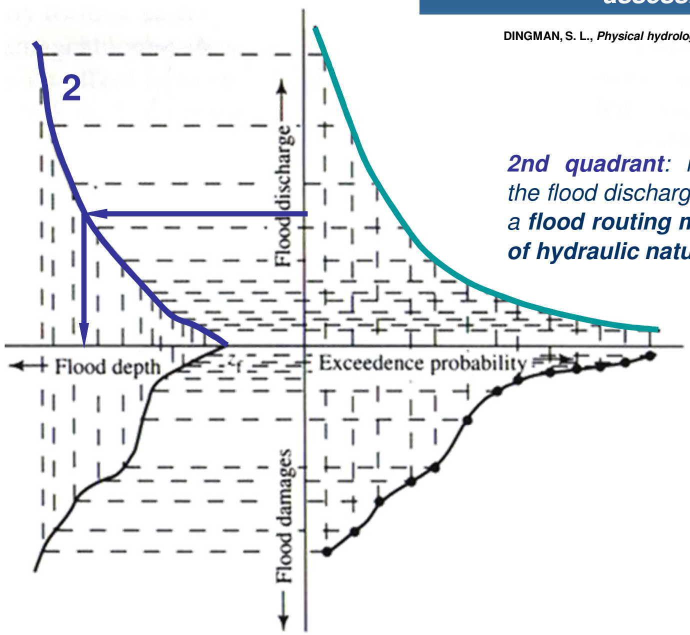
DINGMAN, S. L., *Physical hydrology*, Prentice-Hall, Inc., 1994



Fisk 1st quadrant: *relationship between the flood discharge and the non-exceedance probability – often of* ***statistical nature****.*

Two D representation of the flood risk assessment

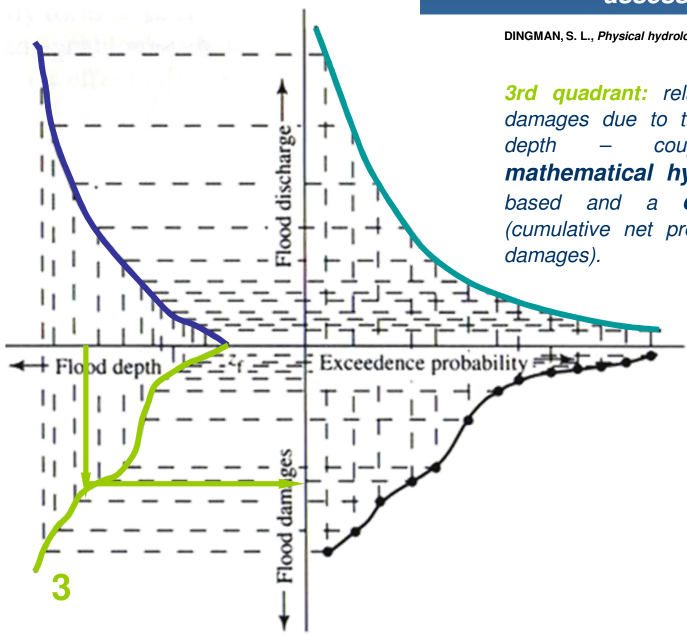
DINGMAN, S. L., *Physical hydrology*, Prentice-Hall, Inc., 1994



2nd quadrant*: relationship between the flood discharge and the flow depth, a* ***flood routing mathematical model, of hydraulic nature****.*

Two D representation of the flood risk assessment

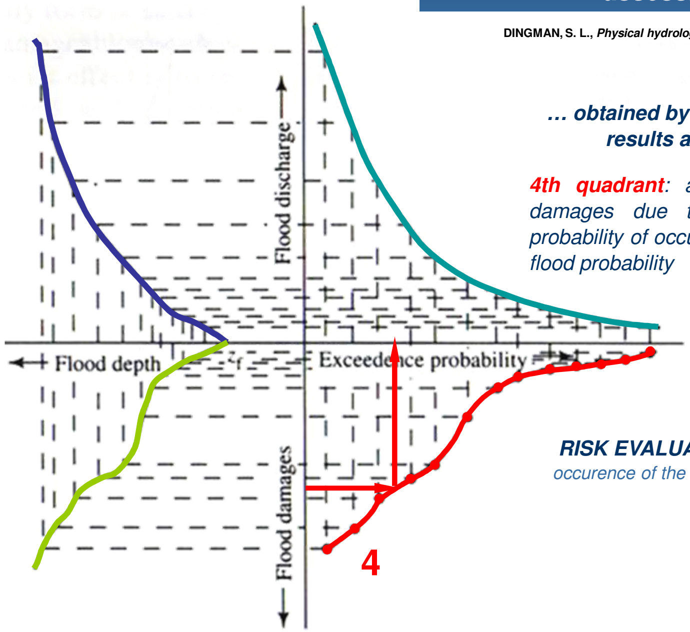
DINGMAN, S. L., *Physical hydrology*, Prentice-Hall, Inc., 1994



3rd quadrant: *relationship between the damages due to the flood and the flow depth – coupling between a* ***mathematical hydraulic model*** *GIS-based and a* ***economical model*** *(cumulative net present value of all the damages).*

Two D representation of the flood risk assessment

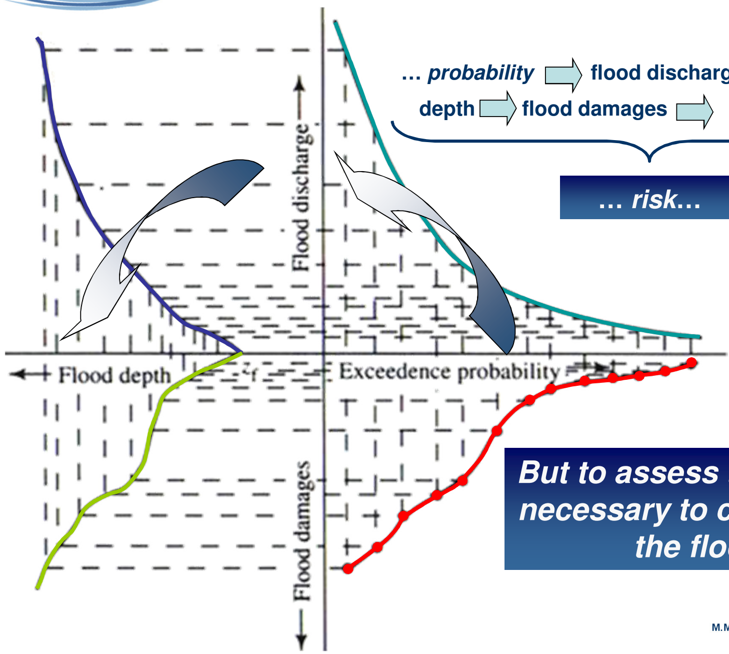
DINGMAN, S. L., *Physical hydrology*, Prentice-Hall, Inc., 1994



… obtained by coupling the previous results and relationships

4th quadrant*: assignment between the damages due to the flood and their probability of occurrence, expressed by the flood probability*

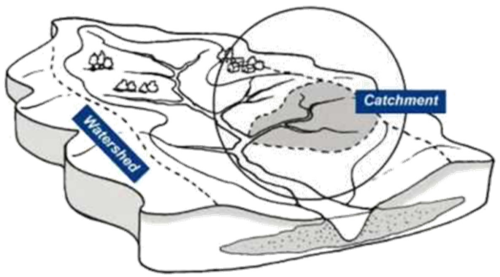
RISK EVALUATION *Risk=probability of occurence of the hazard x its consequences*

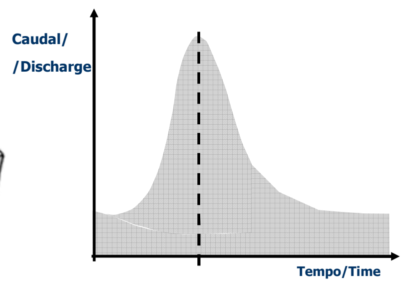


… probability → **flood discharge** → **flood depth** → **flood damages** → **probability**

… risk…

But to assess the risk it is necessary to characterize the floods

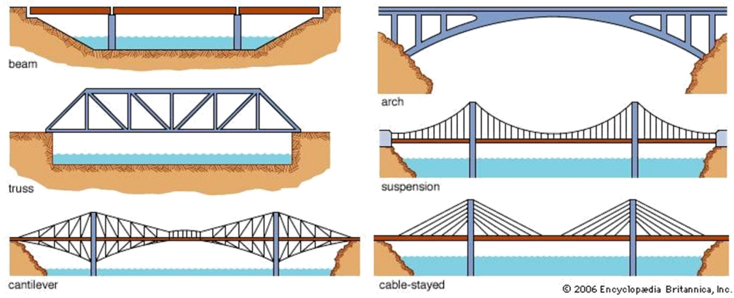


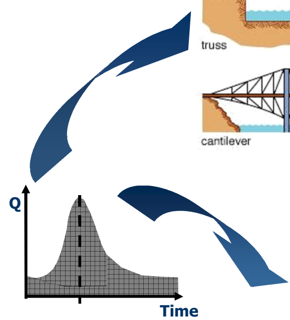


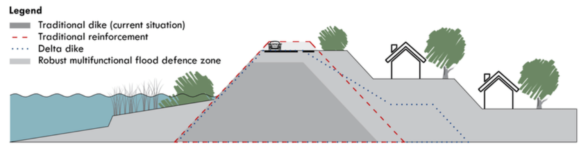
- ✓ Geographic unit adopted in the characterization: **watershed/catchment** all the processes occur at the watershed/catchment level
- ✓ Flood characterization
  - Exceptionality/probability
  - Chronological diagram – **flood hydrograph (Q versus time)**
    - Peak flood discharge
    - Flood volume

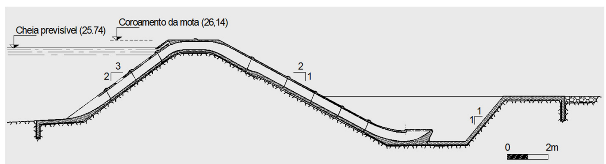
→ Depending on the purpose of the characterization

Bridge design

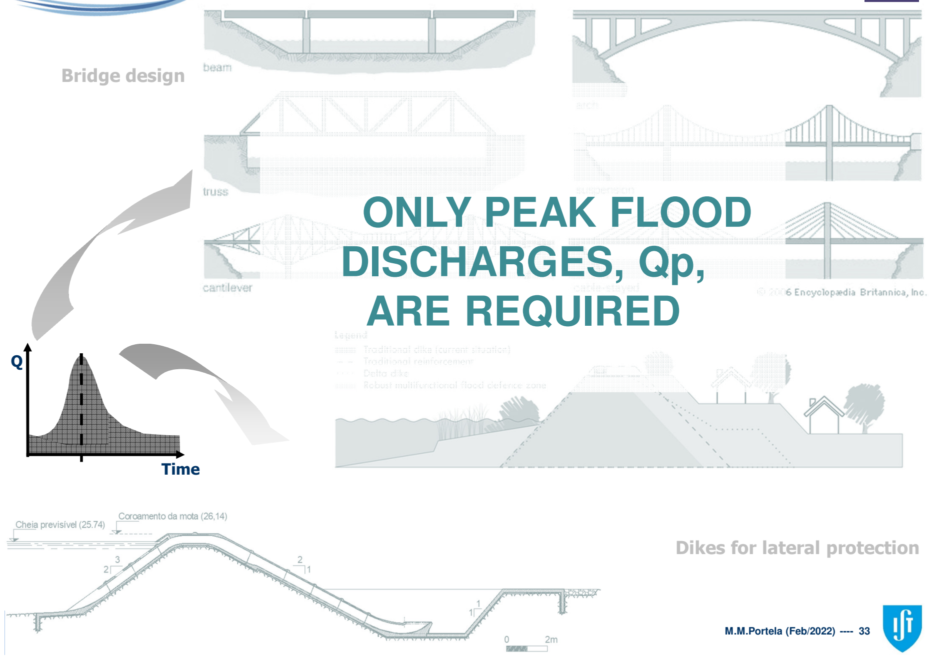






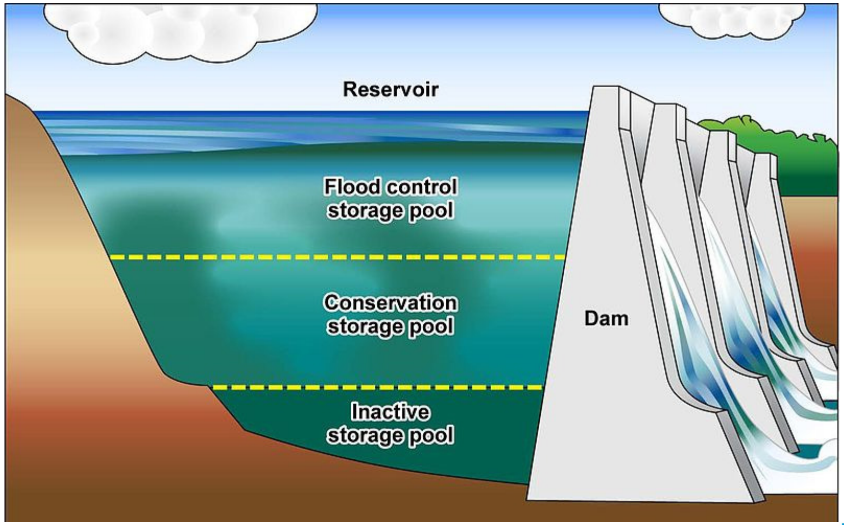


Dikes for lateral protection

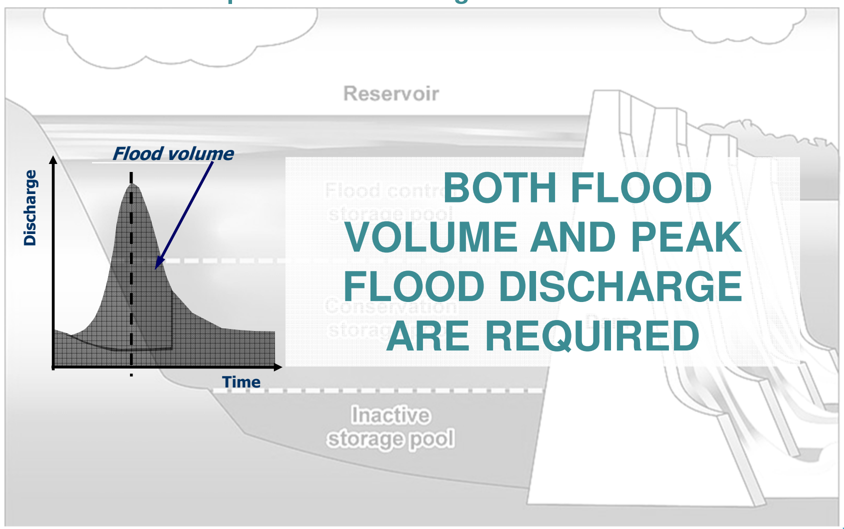


ONLY PEAK FLOOD DISCHARGES, Qp, ARE REQUIRED

Flood control in artificial reservoirs aiming at reducing the peak flood discharges downstream



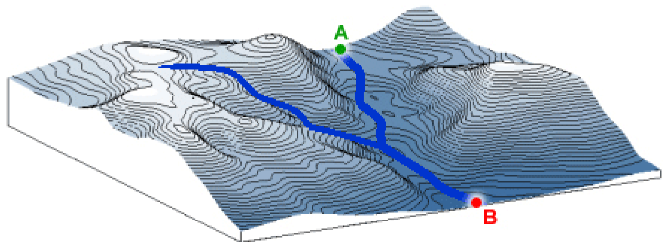
Flood control in artificial reservoirs aiming at reducing the peak flood discharges downstream



BOTH FLOOD VOLUME AND PEAK FLOOD DISCHARGE ARE REQUIRED

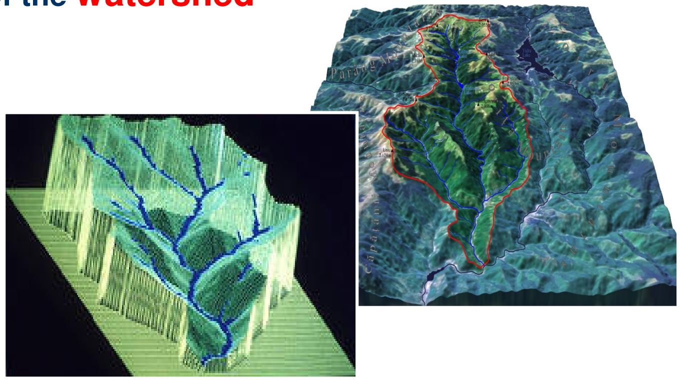
Factors that affect the natural river floods

- **Factors related to the to the time of concentration of the watershed - watershed area and relief, river networks characteristics** (*time needed for water to flow from the most remote point in a watershed from a kinematic point of view to the watershed outlet*)



Factors that affect the natural river floods

➢ **Factors related to the to the time of concentration of the watershed**

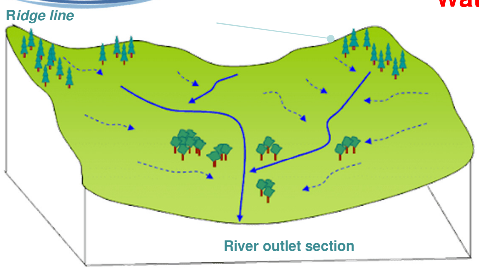


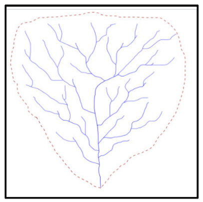
Factors that affect the natural river floods

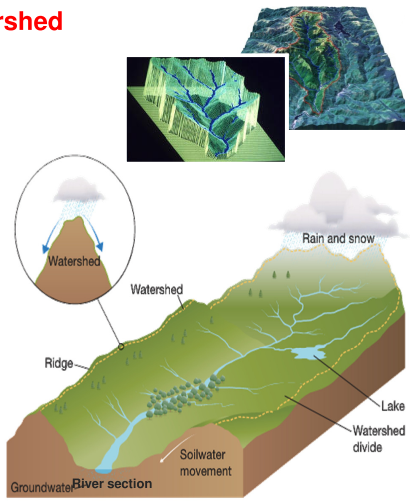
➢ **Factors related to the to the time of concentration of the watershed**

The watershed is a fundamental concept in hydrology and is the basis for understanding all the hydrological processes and for the planning and management of water resources

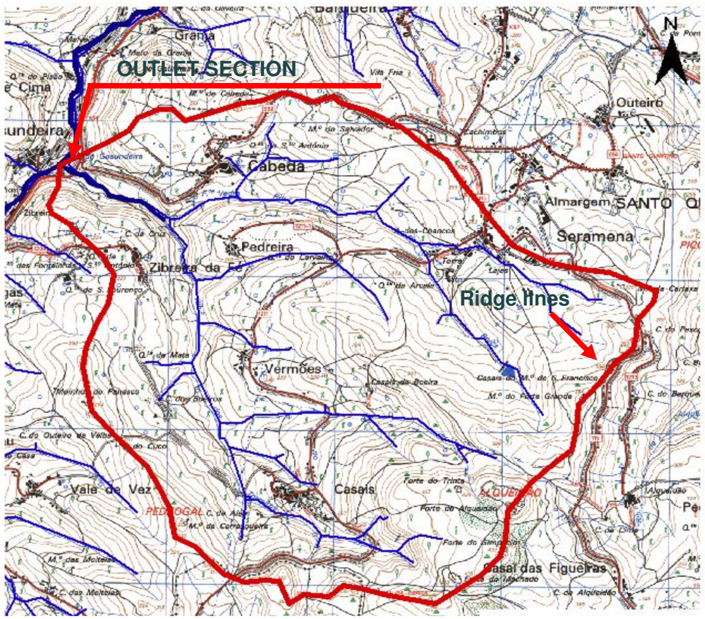
Watershed







The watershed in a given river section – outlet – is the area that collects the rainfall and drains it into that river section. Is defined by a close line connecting ridge lines and including all the rivers and streams that run downslope towards the outlet



(1/25000 topographic map)

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Factors that affect the natural river floods

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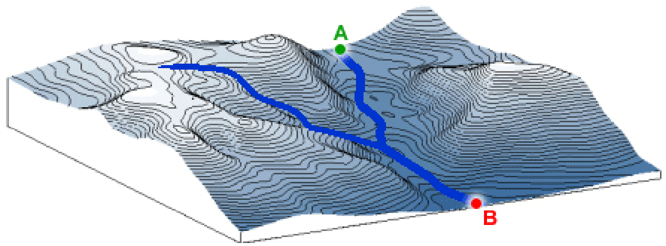

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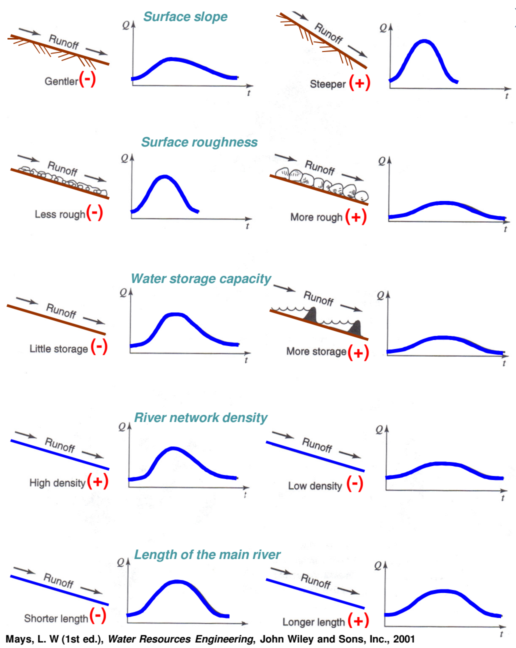
Factors that affect the natural river floods

- **Factors related to the to the time of concentration - watershed area and relief, river networks characteristics (***time needed for water to flow from the most remote point in a watershed from a kinematic point of view to the watershed outlet***)**
- **Factors related to the rainfall losses or abstractions – previous water storage and moister conditions in the watershed, vegetal cover, land use.**
- **Factors directly affecting the shape of the flood hydrograph - temporal and spatial distribution of the rainfall.**

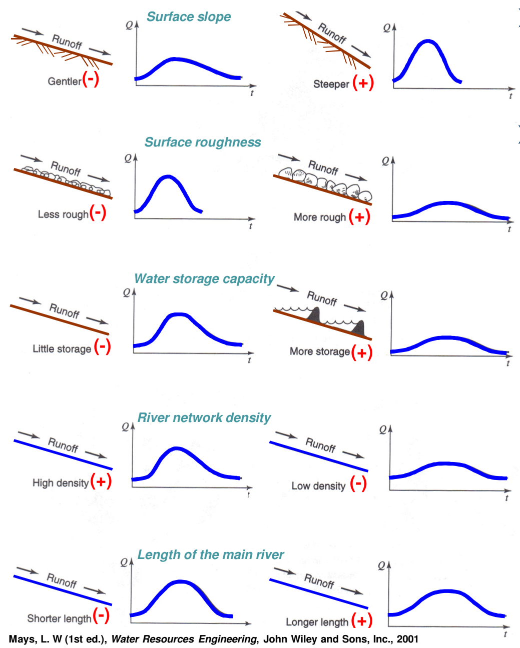
Factors related to the time of concentration .. *with all other conditions remaining unchanged*



Mays, L. W (1st ed.), *Water Resources Engineering*, John Wiley and Sons, Inc., 2001

- **Surface slope:** as the slope ↑ the peak flood discharges ↑ the flood hydrograph duraion decreases ↓

Factors related to the time of concentration .. *with all other conditions remaining unchanged*



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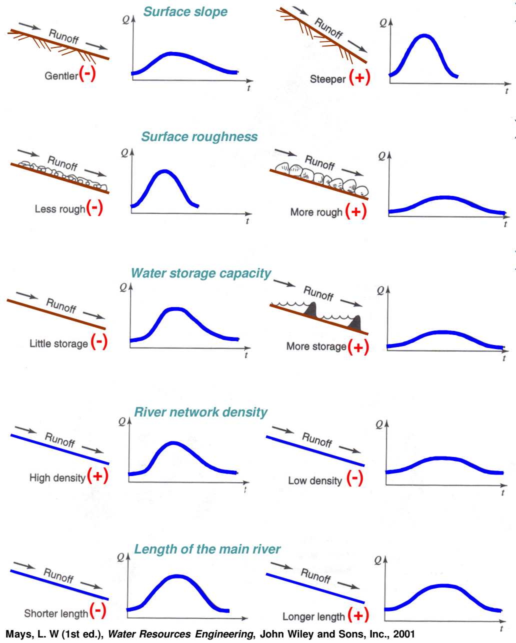
- **Surface roughness:** as the roughness ↑ the peak flood discharge ↓ decreases and the flood hydrograph duration ↑

Factors related to the time of concentration .. *with all other conditions remaining unchanged*



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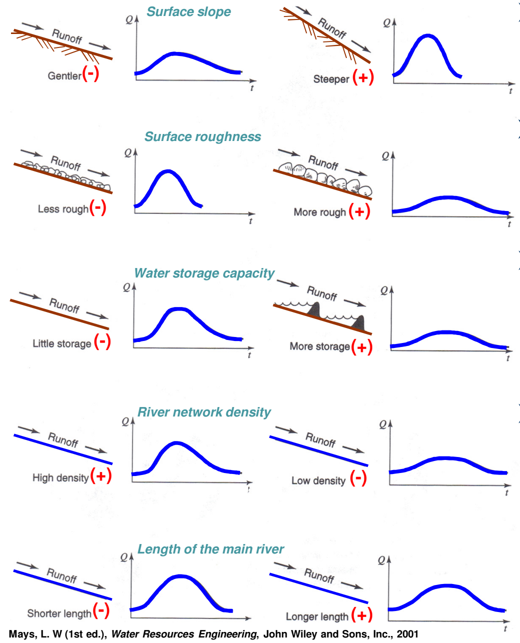
- **Surface roughness:** as the roughness ↑ the peak flood discharge ↓ decreases and the flood hydrograph duration ↑
- **Water storage capacity in the watershed:** as the storage capacity ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑

Factors related to the time of concentration .. *with all other conditions remaining unchanged*



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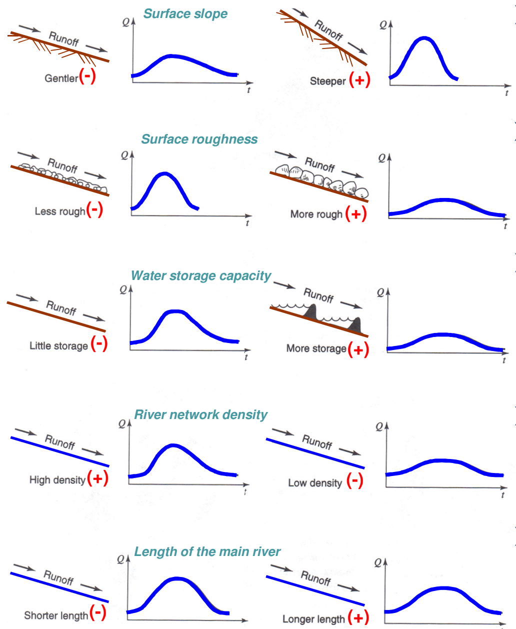
- **Water storage capacity in the watershed:** as the storage capacity ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑

- **River network density:** as the density ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑

Factors related to the time of concentration .. *with all other conditions remaining unchanged*



Mays, L. W (1st ed.), *Water Resources Engineering*, John Wiley and Sons, Inc., 2001

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- **Water storage capacity in the watershed:** as the storage capacity ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑
- **River network density:** as the density ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑

- **Lenght of the main river :** as the lenght ↑ the peak flood dis-charge ↓ and the flood hydro-graph duration ↑

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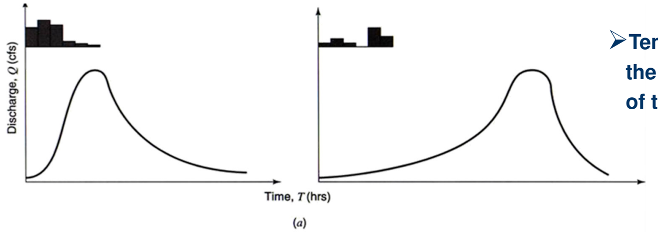
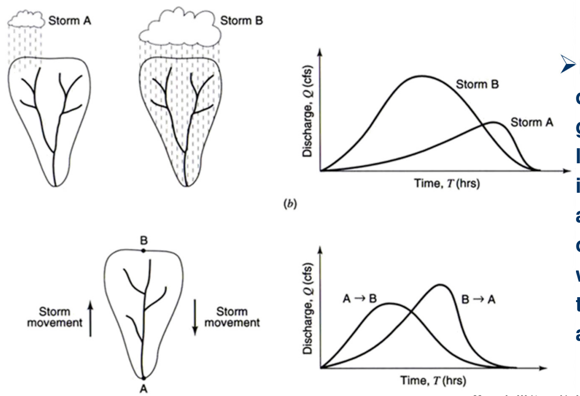
The <u>physical characteristics</u> of the watershed and of the river network that "delay" the water movement or that "promote" the natural water storage (e.g., lateral flood plains**) or that increase the rainfall losses in the watershed result in a decrease of the peak flood discharges and an increase of the duration of the flood hydrograph (**the opposite also applies**)**

When addressing a flood analysis problem it is fundamental to be aware of all the constraints that interfere in the flood characteristics and to be able of implementing models to account for them

Factors directly affecting the shape of the flood hydrograph



➢Temporal distribution of the rainfall in the shape of the flood hydrograph



➢Effect of the spatial distribution of the rainfall … generally the models are lumped, allowing to consider in each moment a kind of a average temporal distribution of the rainfall over the entire watershed and not different temporal rainfall patterns among regions

Mays, L. W (1st ed.), *Water Resources Engineering*, John Wiley and Sons, Inc., 2001

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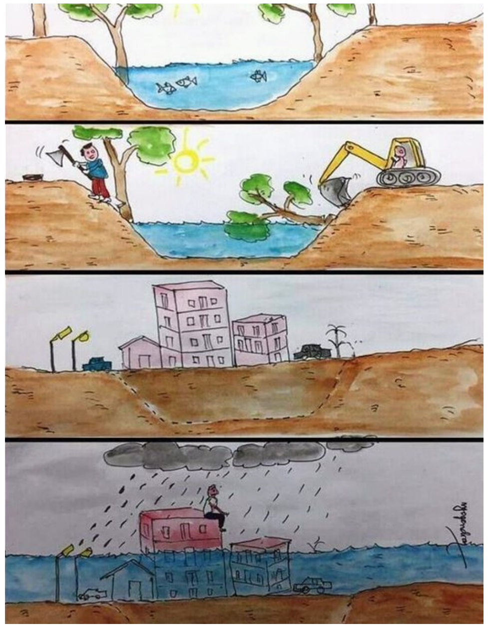
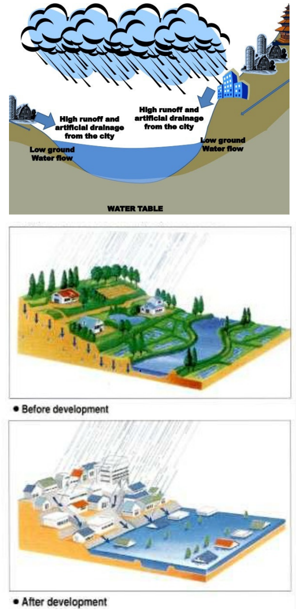
How urbanization affects floods?





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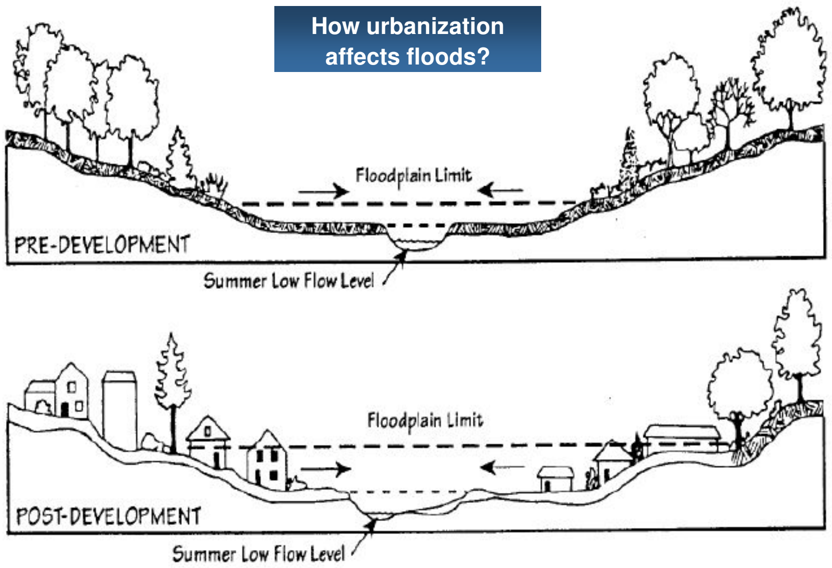
How urbanization affects floods?



Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

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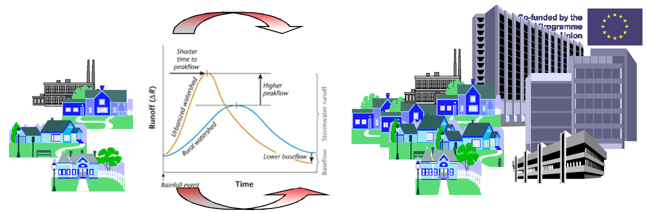
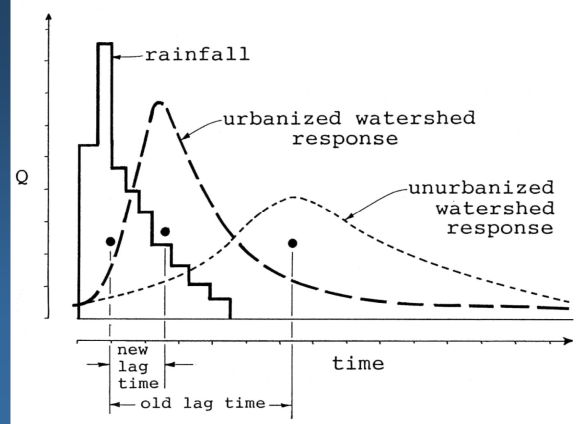
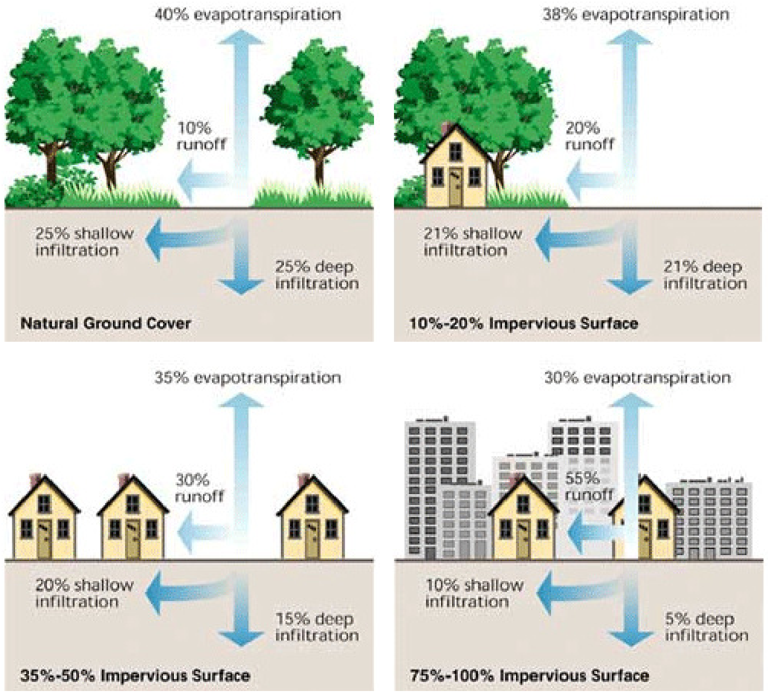
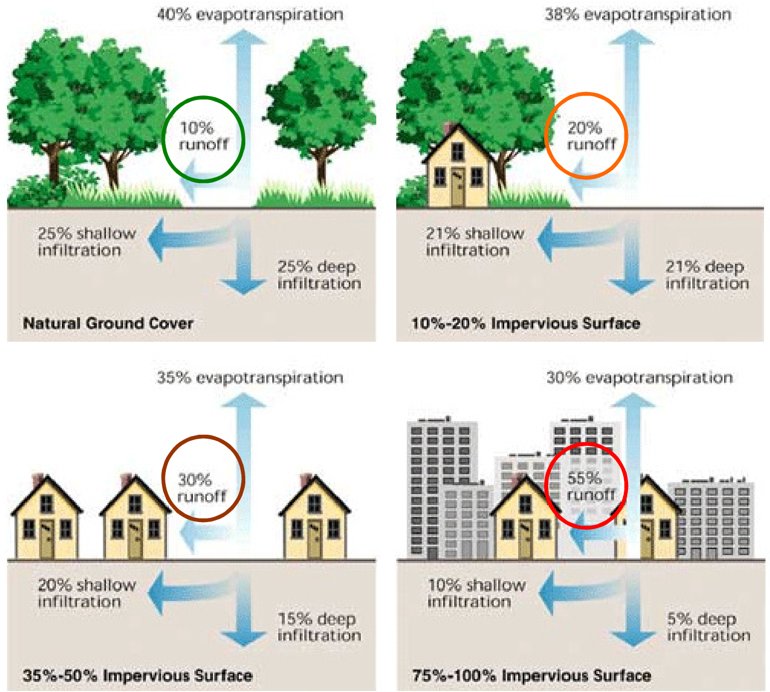
How urbanization affects floods?



It acts by decreasing the precipitation losses (due to the infiltration decrease) and by increasing the flow velocity (due to the surface roughness decrease) thus reducing the time of concentration, increasing the design rainfalls intensities and, consequently, increasing the peak flood discharges and anticipating the their occurrence







Approaches to estimate peak flood discharges or/and floods hydrographs

- Statistical methods
- Empirical formulas
- Regionalization models
- Unit hydrograph model
- Flood routing models

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Peak flood discharges (Statistical methods, Empirical formulas, Regionalization models)

Peak flood discharges and flood hydrographs (Unit hydrograph model, Flood routing models)

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swarm
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Aspects that should be accounted for when choosing the model to apply to the flood

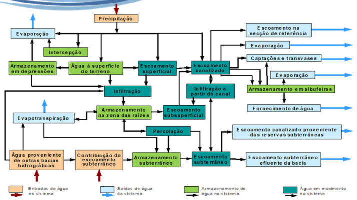
⇩

Clear understanding of the conditions/constraints of each particular flood characterization … sometimes the younger engineers begin to do the computations before thinking about the framing of the problem

- Objective: peak flood discharge and/or flood depth and/or flood volume.
- Watershed under natural conditions or not .. are there artificial reservoirs for flow/flood regulation/control?
- Watershed area – larger watersheds require more assumptions and simplifications namely when, rather then statistical tools, rainfall-runoff models are applied.
- Available data, obviously of hydrological nature, but also topographic data, namely when flood depths or flood elevations are wanted.

⇩

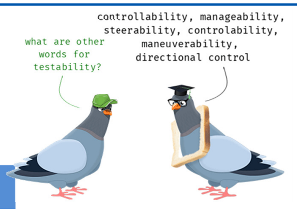
Option for the more suitable model



… the more complex a model is, the more coarse its results may be if the available data is not enough to compute the parameters of the model and to validate the model

Principles that should guide the development of a model

PARSIMONY	▪ A model should not be more complex than the necessary and should include the smallest possible number of parameters with values to compute from the data
MODESTY	▪ A model should not intend to do "too much"; there is not such thing as "the model"
PRECISION	▪ The model should not intend to describe a phenomenon with a precision higher than the capacity to measure it
TESTABILITY	▪ A model must be verifiable and it is necessary to know if it is valid or not and what are



Approaches to estimate peak flood discharges or/and floods hydrographs

- **Statistical methods** → Peak flood discharges
- **Empirical formulas** → Peak flood discharges
- **Regionalization models** → Peak flood discharges
- **Unit hydrograph model** → Peak flood discharges and flood hydrographs
- **Flood routing models** → Peak flood discharges and flood hydrographs
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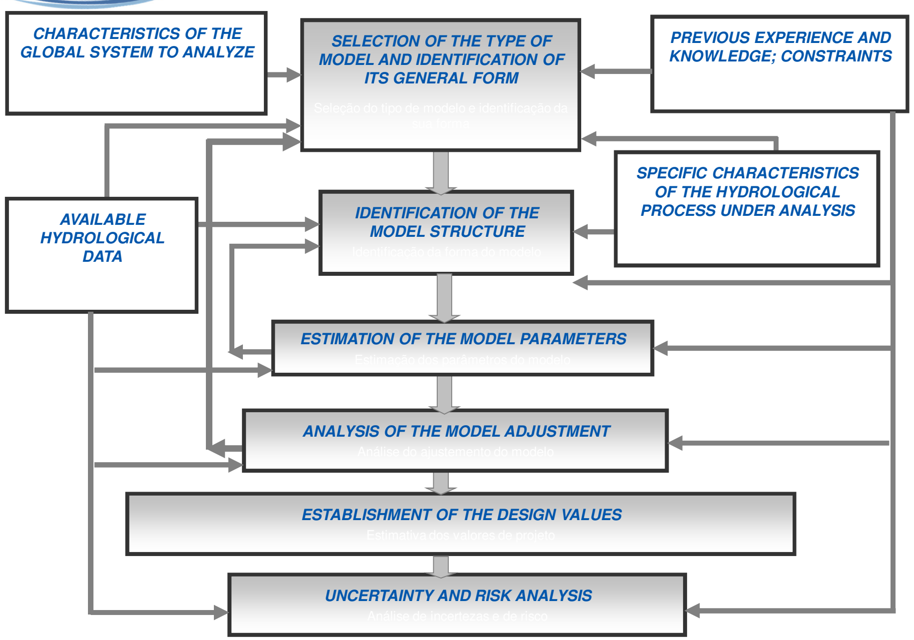
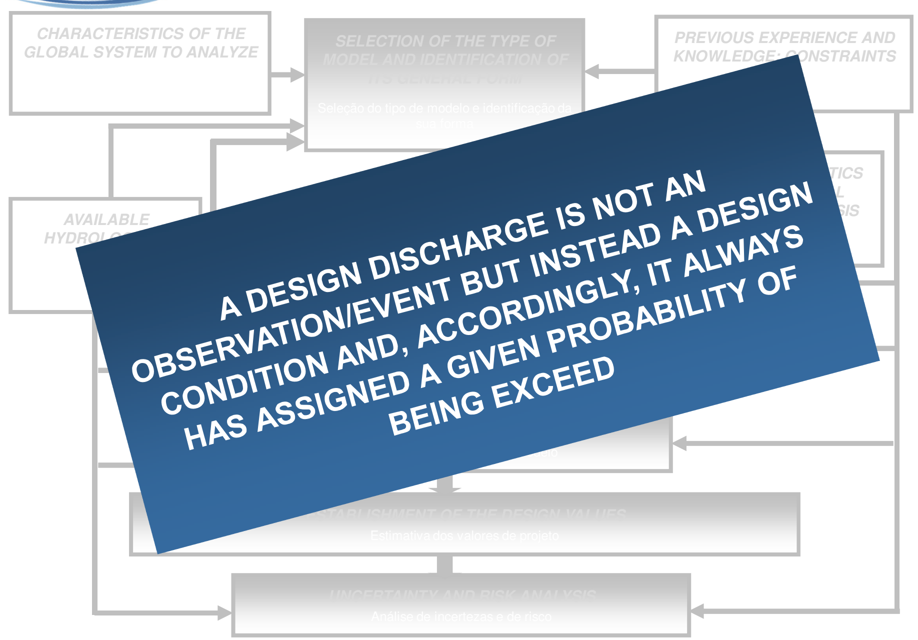




Some hydrological variables, like the **extreme rainfalls** and the **peak flood discharges, Q, they originate** are **"design" conditions** being often assigned to a **design criteria** expressed in terms of their **non-exceedance probability, F**

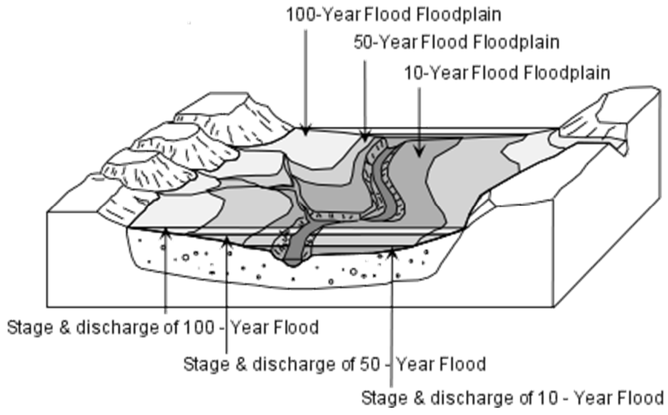
$$P(X \leq Q) = F(Q) = F$$

(Noon-exceedance probability = probability of having values smaller or equal to the considered one)

.... Noon-exceedance probability ⇔ RETURN PERIOD

RETURN PERIOD (also recurrence interval)

Average number of years between the occurrence of extreme events equal or above a given threshold - statistical concept



RETURN PERIOD

RETURN PERIOD: average number of years between extreme events equal or above a given threshold

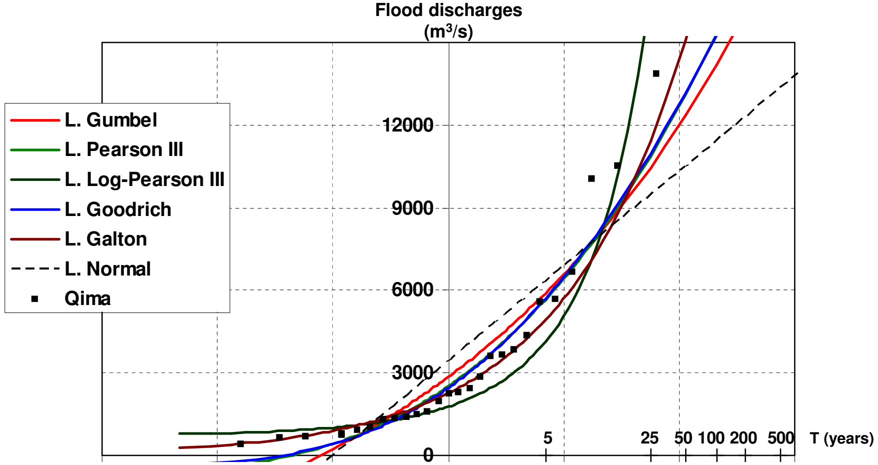
$$T = \frac{1}{1-F}$$

$$F = 1 - \frac{1}{T}$$

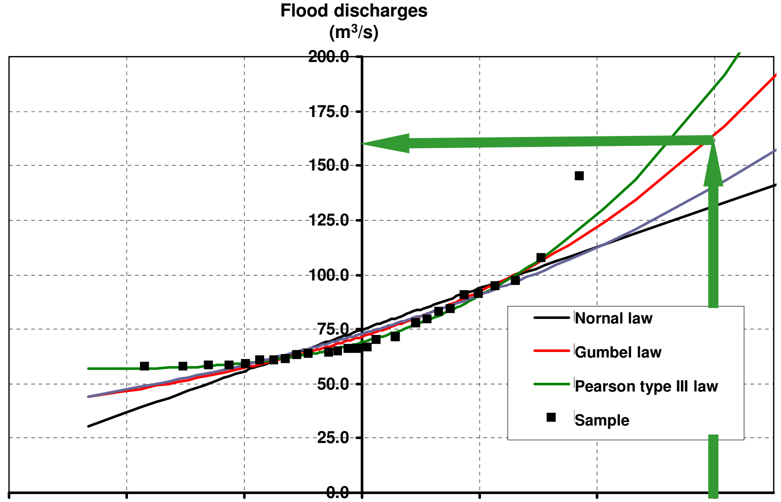
Non-exceedance probability F (%)	Return period T (anos)
0.900	10
0.980	50
0.990	100
0.998	500
0.999	1000

The concept of return period **DOES NOT CONTAIN** any notion of periodicity. The probability of the event with a given return period, T, to occur in any year is 1/T, in two consecutives years, is $(1/T)^2$ .... in i consecutive years $(1/T)^i$ ...

Adjustment of statistical laws to the available sample of peak flood discharges



Selection of the design value (for a given T) according to the law with best adjustment



Approaches to estimate peak flood discharges or/and floods hydrographs

- **Statistical methods**
- **Empirical formulas**
- **Regionalization models**
- **Unit hydrograph model**
- **Flood routing models**
- .
- .
- .

Peak flood discharges

Peak flood discharges and flood hydrographs

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Approaches to estimate peak flood discharges or/and floods hydrographs

A flood event is a consequence of a extreme rainfall with specific features and if there are not the available records compatible with the application of statistical tools, its characterization always requires a rainfall-runoff model

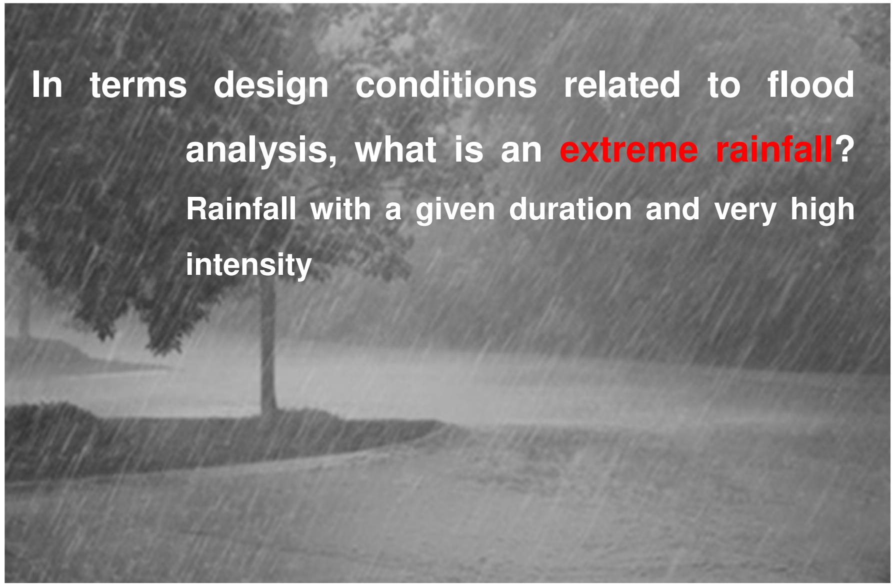
PROGRAM (tool)

Approaches to estimate peak flood discharges or/and floods hydrograph

- Statistic
- Fl

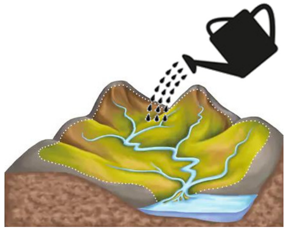
OGRAM (tool)

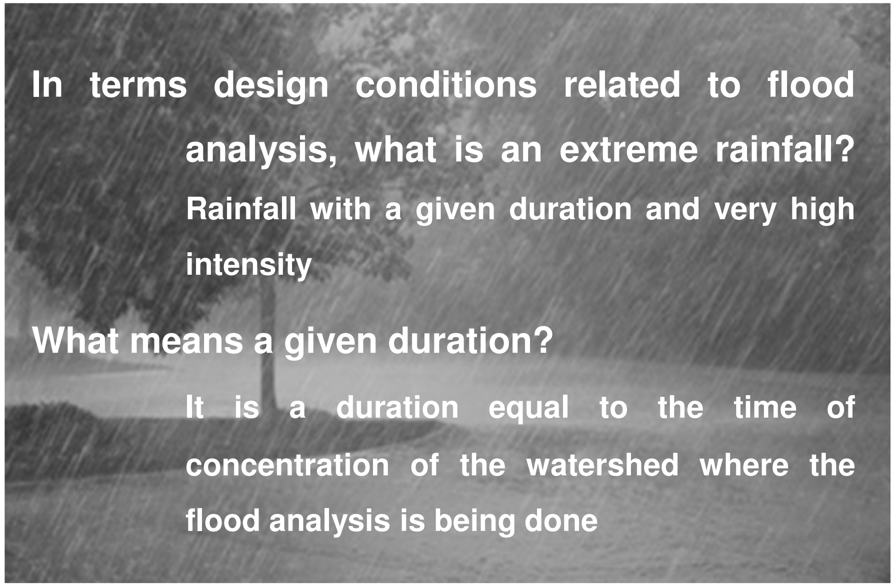
A flood event is a consequence of a **extreme rainfall** with specific features and if there are not the available records compatible with the application of statistical tools, its characterization always requires a rainfall-runoff model



$$Q \propto i \; A$$

- **Q** *peak flood discharge*
- **i** *intensity of the design rainfall*
- **A** watershed area





Time of concentration – *time needed for water to flow from the most remote point in a watershed from a kinematic point of view to the watershed outlet*)

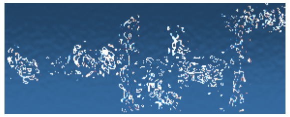
F. de Giandotti

$$t_C = \frac{4\sqrt{A} + 1.5\,L}{0.8\sqrt{h_m}}$$

F. de Temez

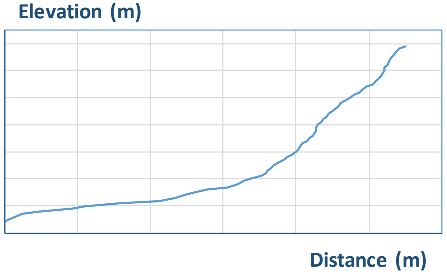
$$t_C = 0.3\left(\frac{L}{d_m^{\,0.25}}\right)^{0.76}$$

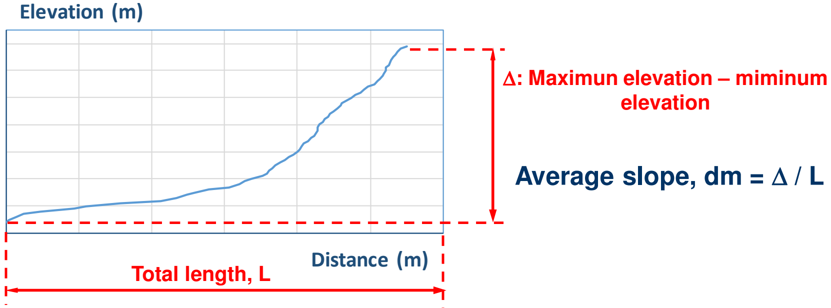
……..



- t_c – time of concentration (h)
- A – watershed area (km²)
- L – length of the main river (km)
- h_m – average height of the watershed (specific model) (m)
- d_m – average slope of the main river (without units)
- . . . . . .

Longitudinal profile of the main river *(obtained based on topographic maps/surveys)*

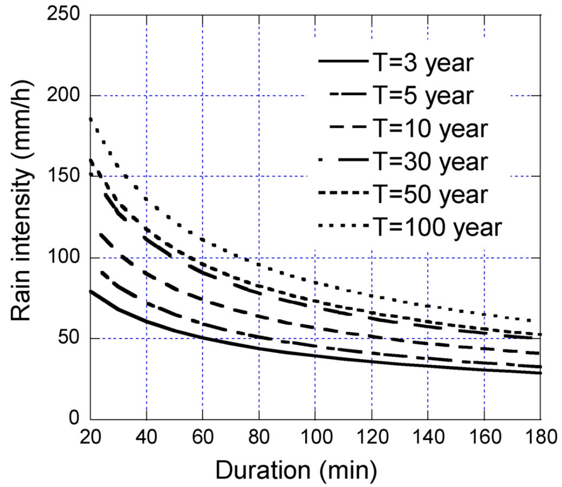




Having computed the time of concentration, how to estimate the high-intensity rainfall with duration equal to that time?

- ✓ STATISTICAL TREATMENT OF THE RECORDED RAINFALL SERIES
- ✓ INTENSITY-DURATION-FREQUENCY CURVE, IDF CURVE

INTENSITY-DURATION-FREQUENCY CURVE (relationship between the intensity of the rainfall, i, and its duration, t, for a given non-exceedance probability, expressed via the concept of return period)

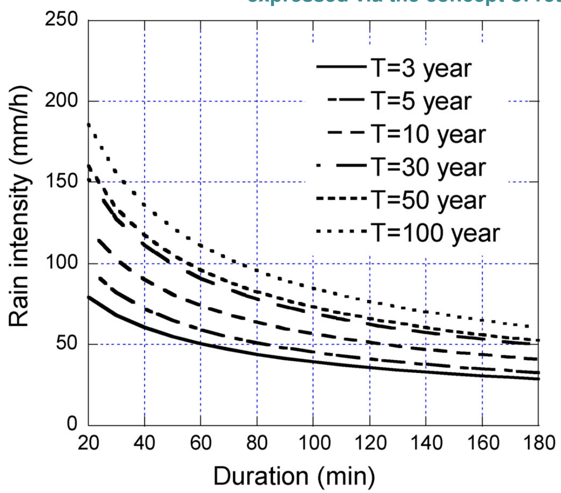


For a given return period, T expressed in years, adopted as design criteria

$$i = P/t = a\,t^{\,n}$$

with n<0

INTENSITY-DURATION-FREQUENCY CURVE (relationship between the intensity of the rainfall, i, and its duration, t, for a given non-exceedance probability, expressed via the concept of return period)



For a given **return period, T** expressed in years, adopted as design criteria

$$i = P/t = a\, t^{n}$$

with n<0

The simplest formula for peak flood discharge evaluation - the rational formula (empirical formula)

$$Q = C\, i\, A$$

(**homogeneous formula**)

- **Q** peak flood discharge with the return period of T years (m^3/s)
- **C** coefficient that mainly accounts for the rainfall losses (… type and use of the soil and return period … for T=100 years C approx. equal to 0.8)
- **i** average intensity of the total rainfall with duration equal to the time of concentration and with the return period of T years (m/s)
- **A** watershed area (m^2)

INTENSITY-DURATION-FREQUENCY CURVE

$$i = a\, t^{n} \quad \text{with } n<0$$

(available in each country or able of being establishing based on the existing rainfall records)

$$Q = C\, i\, A$$

$$C = 0{,}175\, t^{1/3}$$

… t, rainfall duration

$$C = C_{max}\left(\frac{T}{100}\right)^{n}$$

… T, Return period

$$C = 0{,}364 \log t + 0{,}0042\, r - 0{,}145$$

… r, % of impervious área

$$C = 7{,}2\,(10^{-7})\, CN^{3}\, T^{0{,}05}\left[(0{,}01\, CN)^{0{,}6}\right]^{-S^{0{,}2}} (0{,}001\, CN^{1{,}48})^{0{,}15-0{,}1\, i}\left[(R+1)/2\right]^{0{,}7}$$

…i, average rainfall intensity; S, average slope of the ground surface; R, percentage of impervious area; CN, curve number, CN

Table 1: Runoff coefficients for the Rational method

Hydrologic Soil Group	A			B			C			D		
Recurrence Interval	5	10	100	5	10	100	5	10	100	5	10	100
Land Use Or Surface Characteristics												
Business:												
A. Commercial Area	.75	.80	.95	.80	.85	.95	.80	.85	.95	.85	.90	.95
B. Neighborhood Area	.50	.55	.65	.55	.60	.70	.60	.65	.75	.65	.70	.80
Residential:												
A. Single Family	.25	.25	.30	.30	.35	.40	.40	.45	.50	.45	.50	.55
B. Multi-Unit (Detached)	.35	.40	.45	.40	.45	.50	.45	.50	.55	.50	.55	.65
C. Multi-Unit (Attached)	.45	.50	.55	.50	.55	.65	.55	.60	.70	.60	.65	.75
D. 1/2 Lot Or Larger	.20	.20	.25	.25	.25	.30	.35	.40	.45	.40	.45	.50
E. Apartments	.50	.55	.60	.55	.60	.70	.60	.65	.75	.65	.70	.80
Industrial												
A. Light Areas	.55	.60	.70	.60	.65	.75	.65	.70	.80	.70	.75	.90
B. Heavy Areas	.75	.80	.95	.80	.85	.95	.80	.85	.95	.80	.85	.95
Parks, Cemeteries Playgrounds	.10	.10	.15	.20	.20	.25	.30	.35	.40	.35	.40	.45
Schools	.30	.35	.40	.40	.45	.50	.45	.50	.55	.50	.55	.65
Railroad Yard Areas	.20	.20	.25	.30	.35	.40	.40	.45	.45	.45	.50	.55
Streets												
A. Paved	.85	.90	.95	.85	.90	.95	.85	.90	.95	.85	.90	.95
B. Gravel	.25	.25	.30	.35	.40	.45	.40	.45	.50	.40	.45	.50
Drives, Walks, & Roofs	.85	.90	.95	.85	.90	.95	.85	.90	.95	.85	.90	.95
Lawns												
A. 50%-75% Grass (Fair Condition)	.10	.10	.15	.20	.20	.25	.30	.35	.40	.30	.35	.40
B. 75% Or More Grass (Good Condition)	.05	.05	.10	.15	.15	.20	.25	.25	.30	.30	.35	.40
Undeveloped Surface[1] (By Slope)[2]												
A. Flat (0-1%)	0.04-0.09			0.07-0.12			0.11-0.16			0.15-0.20		
B. Average (2-6%)	0.09-0.14			0.12-0.17			0.16-0.21			0.20-0.25		
C. Steep	0.13-0.18			0.18-0.24			0.23-0.31			0.28-0.38		

[1] Undeveloped Surface Definition: Forest and agricultural land, open space.
[2] Source: Storm Drainage Design Manual, Erie and Niagara Counties Regional Planning Board.

(Fonte: Iowa Stormwater Management Manual

http://www.iowadnr.gov/Environmental-Protection/Water-Quality/NPDES-Storm-Water/Storm-Water-Manual)

$$Q = C\, i\, A$$

Approaches to estimate peak flood discharges or/and floods hydrographs

- Statistical methods → Peak flood discharges
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- Flood routing models → Peak flood discharges and flood hydrographs

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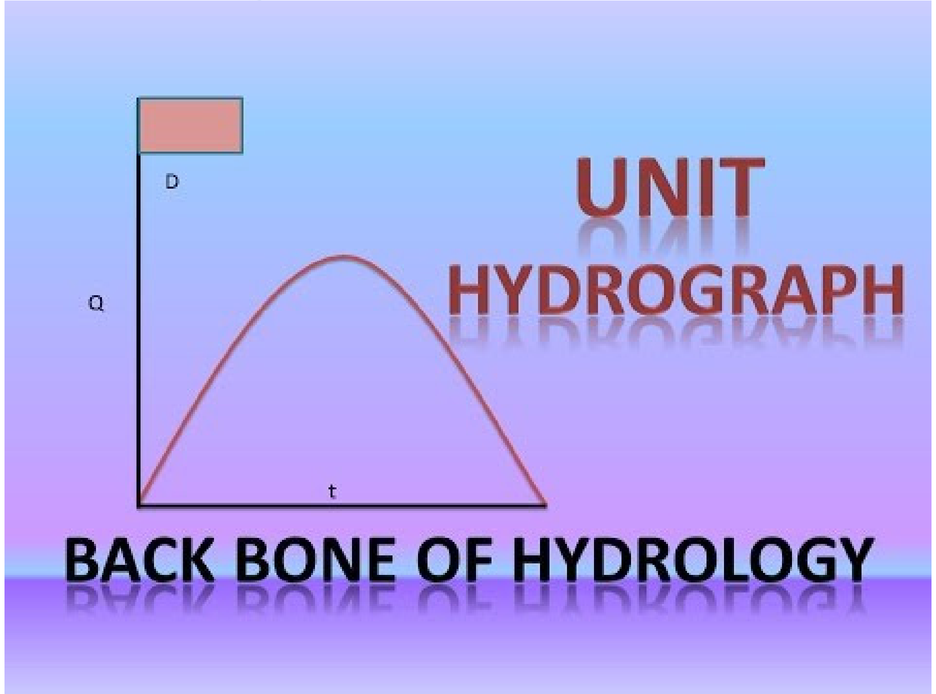
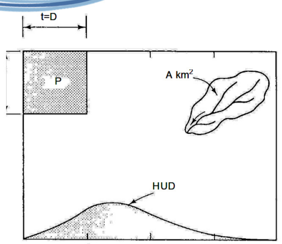
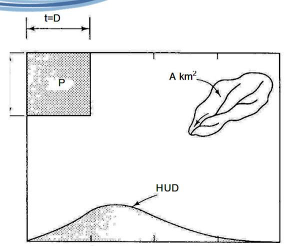




Unit hydrograph with duration D, UHD

A unit hydrograph (UH) is the hypothetical unit response of a watershed (in terms of peak discharge, runoff volume and timing) **to a unit input of rainfall. It can be defined as the direct runoff hydrograph resulting from one unit** (e.g., one mm or one inch) **of effective or excess rainfall occurring uniformly over the watershed at a uniform rate over a unit period of time, D.**



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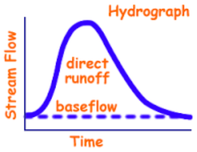
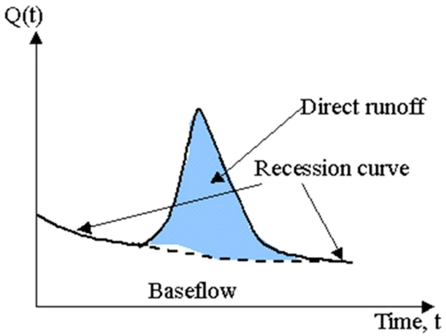
TWO PRIOR CONCEPTS

- Direct runoff
- Excess rainfall

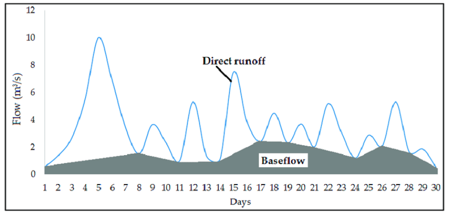
COMPONENTS OF THE FLOOD HYDROGRAPHS

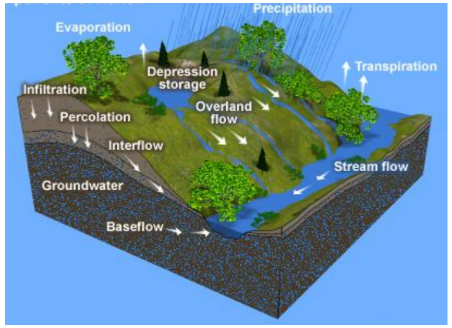
- ✓ Baseflow
- ✓ Direct runoff



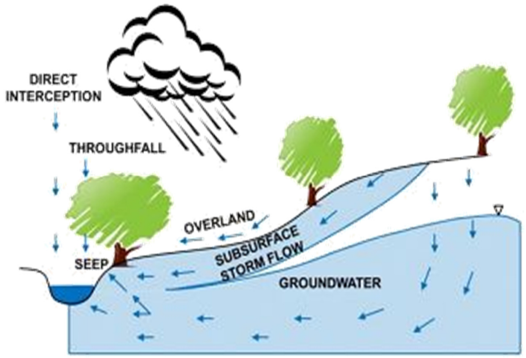


- ✓ **Baseflow**: The longer-term discharge derived from the natural water storages in the watershed, i.e., the portion of stream flow that results from the slowly seepage of water from the ground into a river.
- ✓ It depends on the wetness conditions of the watershed which in turn depends on the previous rainfall events and on the capacity of the watershed to store groundwater



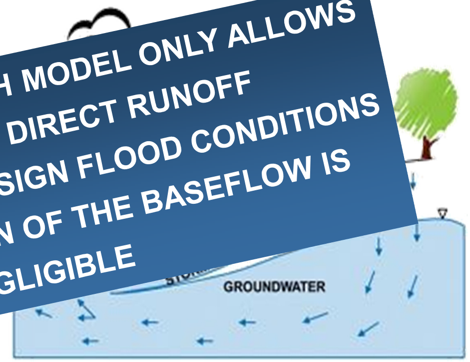


- ✓ Direct runoff (quick flow): the stream flow that represents the direct response to a rainfall event (the water that reaches the river shortly after the rainfall event beginning)
- ✓ it includes the overland flow (runoff), the lateral movement of the water in the soil profile (interflow or subsurface flow) and rainfall directly falling onto the stream/river surface



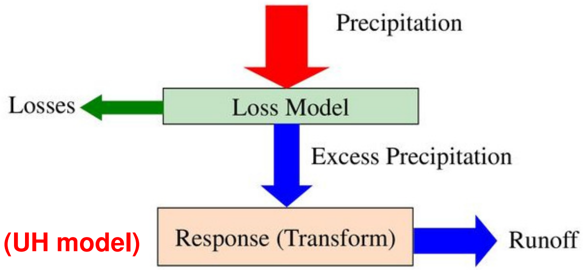
✓ Direct runoff (quick flow): the stream flow that represents the direct response to a rainfall event (the water ...
... and rainfall directly falling onto the stream/river surface

- ✓ THE UNIT HYDROGRAPH MODEL ONLY ALLOWS TO MODEL THE DIRECT RUNOFF
- ✓ HOWEVER, UNDER DESIGN FLOOD CONDITIONS THE CONTRIBUTION OF THE BASEFLOW IS NEGLIGIBLE



THE EXCESS RAINFALL IS THE (TOTAL OR GROSS) RAINFALL DEDUCED OF ALL THE RAINFALL LOSSES (in terms of the rainfall-runoff process, and not in absolute terms, obviously)

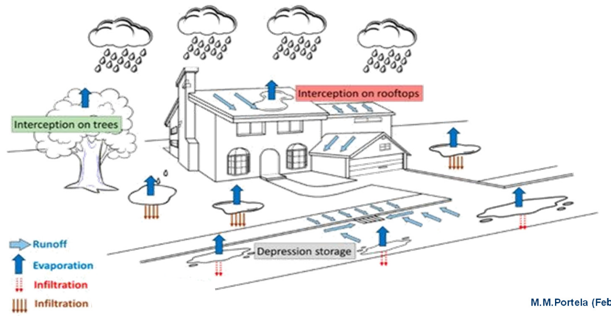
A loss is the result of the process that abstract or remove water from the total or gross rainfall; a loss model must account for all that processes

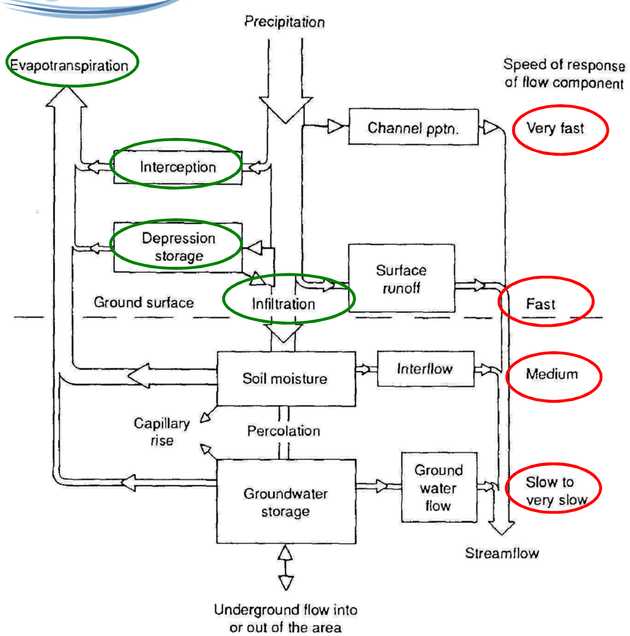


(UH model)

Processes responsible for the rainfall losses

- **Interception –** during exceptional heavy precipitations, such as those that originate floods, these losses are minor or even unimportant
- **infiltration –** the foremost relevant process in terms precipitation losses
- **Water storage –** in the surface depressions
- **Evaporation and evapotranspiration** – under several climatic constraints (with cold rainy seasons) also unimportant as for the flood events

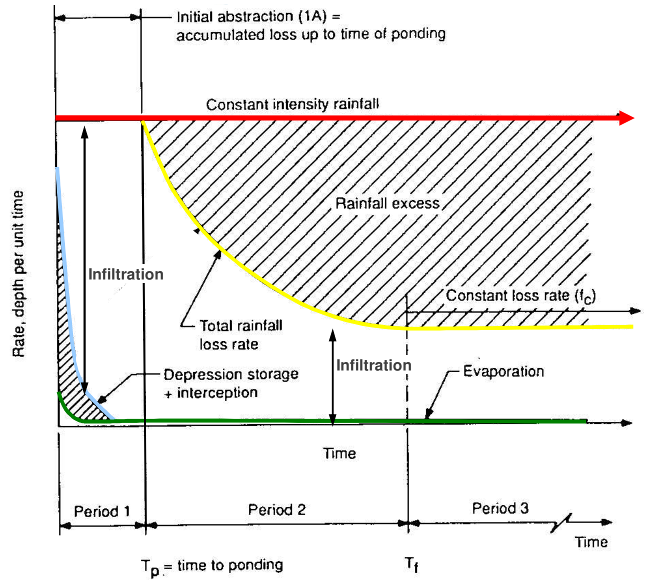




Terrestrial phase of the water cycle

Rainfall-runoff transformation

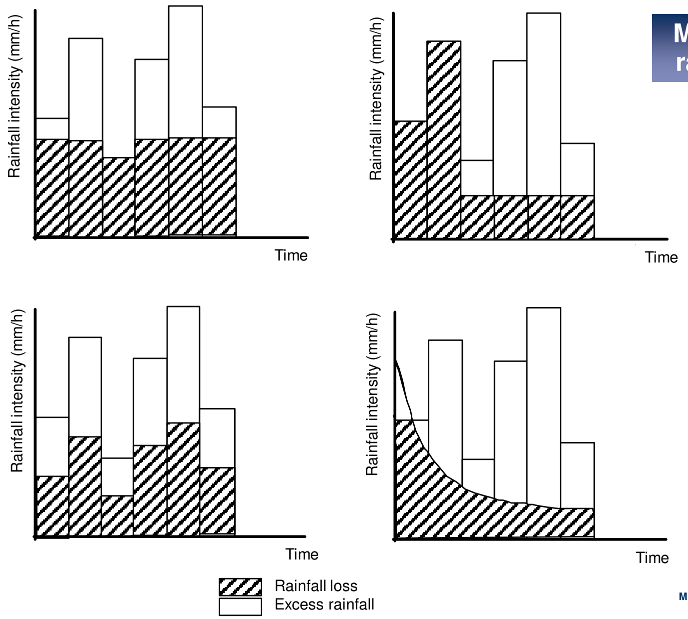
Response delay between the rainfall event and the increase of the river discharges



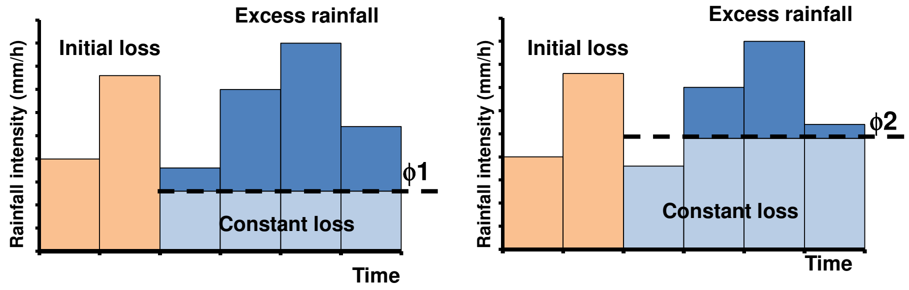
Schematic representation of the of rainfall losses and of the excess rainfall for an uniform rainfall (constant intensity)

Time to ponding – when the land surface becomes saturated (due to the rain) and ponding of water occurs in the form of surface runoff moving towards the river

Models for the rainfall losses



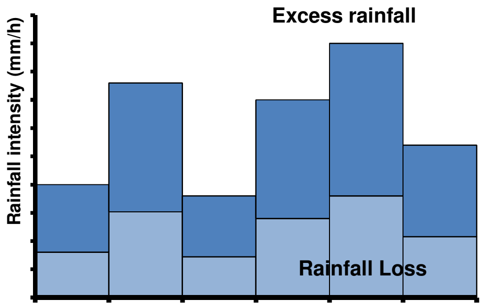
ϕ index model



The **index Φ** is defined as a **constant rate of abstraction** such that above it the surplus of the rainfall is considered as **excess rainfall**. The index integrates all the losses that occur in the process of the runoff formation (interception, retention, evaporation and infiltration) and can be combined or not with initial abstractions.

Method of W index (proportional distribution)

The proportional distribution consists in allocating the losses during the rainfall event proportionally to the quantities of rainfall fallen in each time interval. The increments of the effective rainfall are obtained by reducing the increments of the global rainfall by the W%.

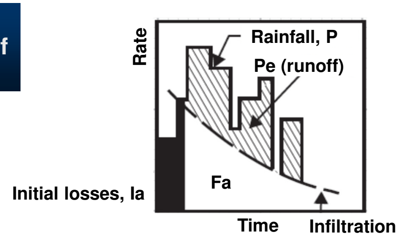


Soil Conservation Service Model for rainfall losses

Assumption: the ratio between the **rainfall depth retained in the watershed after the beginning of the surface runoff** (that is, the **continuous losses**) and a conceptual entity identified as the **potential maximum retention** is equal to the ratio between the **excess rainfall** and the **potential surface runoff.**

$$\frac{F_a}{S} = \frac{P_e}{P - I_a}$$

- F_a: Actual retention after runoff begins or continuous abstractions
- S: Potential maximum retention after runoff begins
- P_e: Excess rainfall
- $P - I_a$: Potential surface runoff



Soil Conservation Service Model for rainfall losses

Rainfall depth retained in the watershed after the beginning of the direct runoff : **Fa** = continuous losses.

Potential maximum retention: S = conventional entity that aims at representing the maximum water storage capacity in the watershed when the soil, the depressions of the terrain and the obstacles that intercept the rain were totally "saturated" resulting in an infiltration rate tending to zero; under these circumstances the intensities of the total and effective precipitation would be equal

Excess or effective rainfall: Pe

Potential surface runoff: P-Ia = rainfall minus the initial losses.

Actual retention after runoff begins or continuous abstractions

Excess rainfall

$$\frac{F_a}{S} = \frac{P_e}{P - I_a}$$

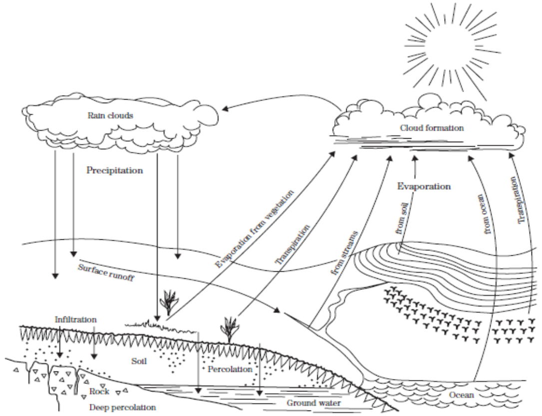
Potential maximum retention after runoff begins

Potential surface runoff

United States Department of Agriculture
Natural Resources Conservation Service

Part 630 Hydrology
National Engineering Handbook

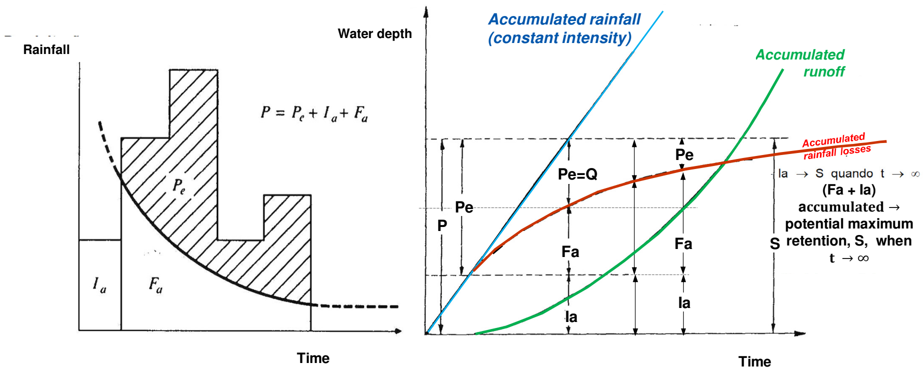
Chapter 10 **Estimation of Direct Runoff from Storm Rainfall**



National engineering handbook, 2004 section 4 capítulo 10

(210-VI-NEH, July 2004)

Soil Conservation Service Model for rainfall losses



Variables and relationship of the SCS model for precipitation losses

SCS direct runoff equation, Q = excess rainfall equation, Pe

$$Q = P_e = \frac{(P - 0.2\,S)^2}{P + 0.8\,S}$$

Potential maximum retention, S = ?

S, potential maximum retention: depends on the type of soil, its use and coverage <u>by means of the curve number, CN</u>.

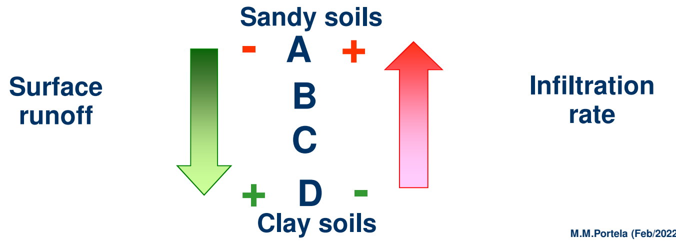
$$S = \frac{25400}{CN} - 254$$

$$S = \frac{1000}{CN} - 10$$

(S in mm, top, or in inches, bottom)

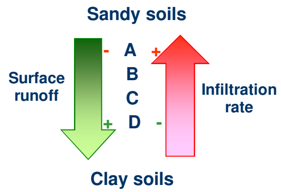
CN depends on the type of soil, its use, coverage and antecedent moisture conditions.

From an <u>hydrologic point of view, the types of soils are</u> A (low runoff potential and high infiltration rate – sand, ...), B. C e D (high runoff potential and very low infiltration rate – clay, ...).



Hydrologic Soil Group, HSG

- **A** Sand, loamy sand, or sandy loam
- **B** Silt loam or loam
- **C** Sandy clay loam
- **D** Clay loam, silty clay loam, sandy clay, silty clay, or clay



Group A: sand, loamy sand or sandy loam. Low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (> 0.30 in/hr)

Group B: silt loam or loam. Moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (rate of water transmission 0.15 – 0.30 in/hr)

Group C: sandy clay loam. Low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure (rate of water transmission 0.05 – 0.15 in/hr)

Group D: clay loam, silty clay loam, sandy clay, silty clay or clay. They have the highest runoff potential. Very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material (rate of water transmission 0.00 – 0.15 in/hr)

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United States Department of Agriculture

Natural Resources Conservation Service

Conservation Engineering Division

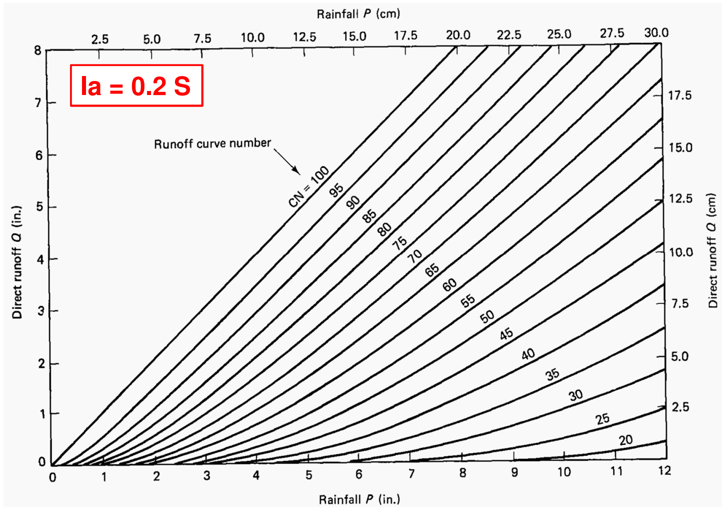
Technical Release 55

Urban Hydrology for Small Watersheds

TR-55

TABLES AND FIGURES WITH THE CN VALUES AS A FUNCTION OF THE TYPE OF SOIL AND ITS OCCUPATION IN NUMBERLESS REFERENCES

Co-funded by the Erasmus+ Programme of the European Union



Relationship among the curve number, the total rainfall and the excess rainfall or direct runoff

Table 2-2a Runoff curve numbers for urban areas 1/

Cover description: Cover type and hydrologic condition	Average percent impervious area 2/	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98			
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)					
Paved; open ditches (including right-of-way)					
Gravel (including right-of-way)					
Dirt (including right-of-way)					
Western desert urban areas:					
Natural des					
Artificial de… desert sh… and basin					
Urban districts:					
Commercial a					
Industrial					
Residential district…					
1/8 acre or less (					
1/4 acre					
1/3 acre					
1/2 acre					
1 acre					
2 acres					82
Developing urban areas					
Newly graded areas (pervious areas only, n…		77	86	91	94
Idle lands (CN's are determ… cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

TABLES AND FIGURES WITH THE CN VALUES AS A FUNCTION OF THE TYPE OF SOIL AND ITS OCCUPATION IN NUMBERLESS REFERENCES

ALL THE TABLES GIVE THE CN VALUES FOR AVERAGE ANTECEDENT MOISTURE CONDITIONS – CN(II) FOR AMC II – WHICH SHOULD NOT BE APPLICABLE TO THE DESIGN UNDER FLOOD CONDITIONS

Table 2-2a Runoff curve numbers for urban areas 1/

Cover type and hydrologic condition	Average percent impervious area	A	B	C	D
Western desert urban areas:					
Natural desert landscaping (pervious areas only) 4/		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre				81	86
1/2 acre				80	85
1 acre				79	84
2 acres				77	82
Newly graded areas (pervious areas only, no vegetation) 5/		77	86	91	94

Under design flood conditions, correction (increase) of the values given by the tables and figures to account for wetter conditions

AMC III – *wet conditions*

$$CN\,(III) = \frac{23\,CN\,(II)}{10 + 0.13\,CN\,(II)}$$

Increase CN in order to decrease the rainfall losses and, consequently, to increase the excess rainfall and the direct runoff, including the peak flood discharges

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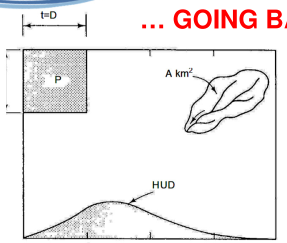
… GOING BACK TO THE UNIT HYDROGRAPH MODEL …



Unit hydrograph with duration D, UHD

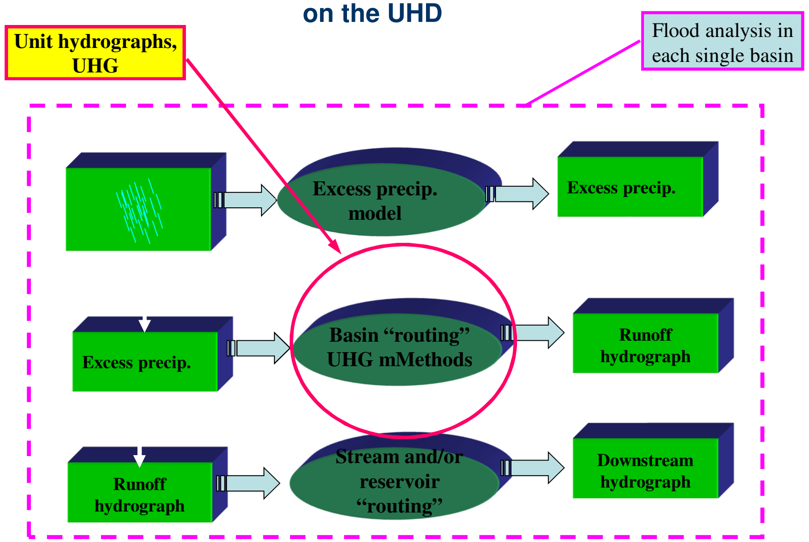
A unit hydrograph (UH) is the hypothetical unit response of a watershed (in terms of peak discharge, runoff volume and timing) **to a unit input of rainfall. It can be defined as the direct runoff hydrograph resulting from one unit** (e.g., one mm or one inch) **of effective or excess rainfall occurring uniformly over the watershed at a uniform rate over a unit period of time, D.**

TWO PRIOR CONCEPTS

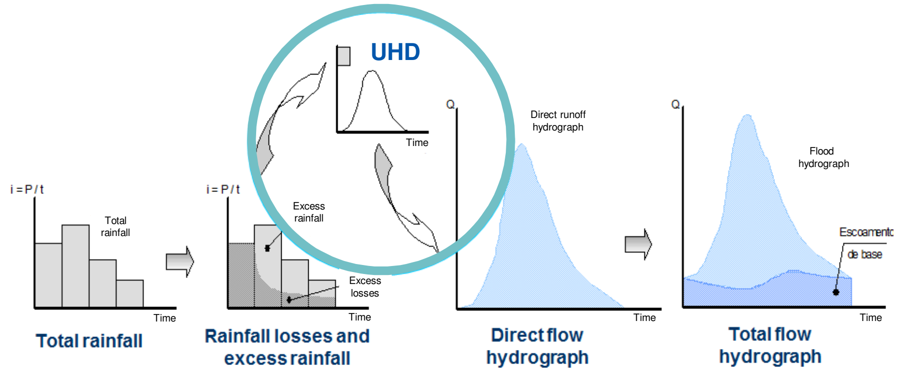
- Direct runoff
- Excess rainfall

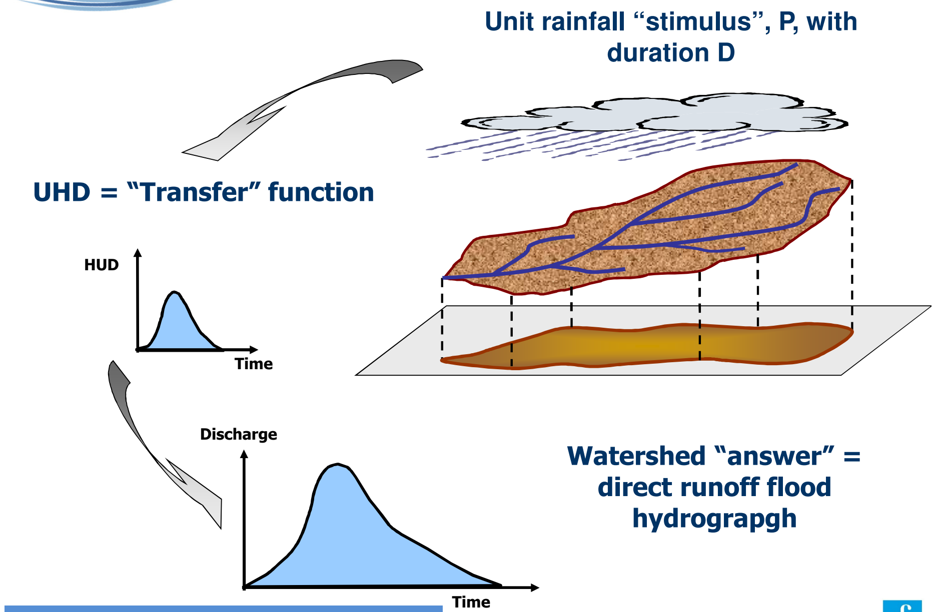
swarm

Rainfall-runoff under flood conditions assessment based on the UHD



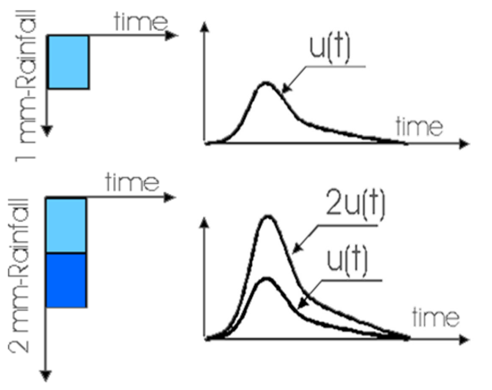
The unit hydrograph is nothing but a mathematical model (kernel) that transforms the excess rainfall into direct runoff



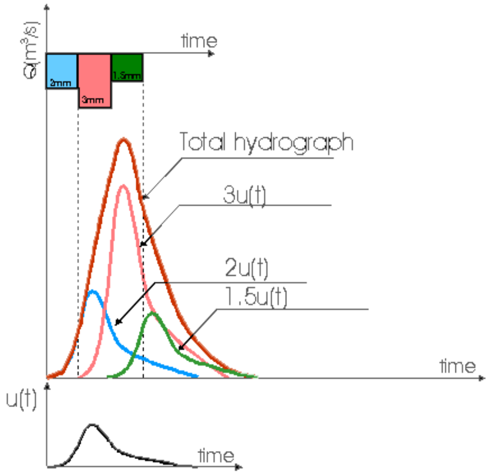


The application of the unit hydrograph theory uses two principles (which assume that the watershed is a linear system)

- ✓ **Principle of proportionality:** the direct runoff volumes produced by two different excess rainfall distributions are in the same proportion as the excess rainfall volume. This means that the ordinates of the UH are directly proportional to the storm intensity. If storm A produces a given hydrograph and Storm B is equal to storm A multiplied by a factor, then the hydrograph produced by storm B will be equal to the hydrograph produced by storm A multiplied by the same factor.



- ✓ **Principle of superposition:** the time distribution of the direct runoff is independent of the concurrent runoff from antecedent storm events. This implies that the direct runoff responses can be superposed. **If storm C is the result of adding storms A and B, the hydrograph produced by storm c will be equal to the sum of the hydrographs produced by storm A and B.**



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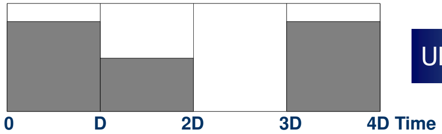
Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4



UHD for P=1 mm

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m^3/s/mm)	Direct runoff flood hydrograph				
		Flood hydrograph for each rainfall block				At the watershed outlet (m^3/s)
		P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	
0	0					
1	u1					
2	u2					
3	u3					
4	u4					
5	u5					
6	0					
7	0					
8	0					
9	0					

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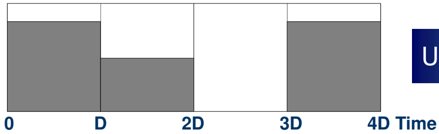
Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4



UHD for P=1 mm

Principle of proportionality

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m^3/s/mm)	Direct runoff flood hydrograph				
		Flood hydrograph for each rainfall block				At the watershed outlet (m^3/s)
		P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	
0	0	0				
1	u1	P1 u1				
2	u2	P1 u2				
3	u3	P1 u3				
4	u4	P1 u4				
5	u5	P1 u5				
6	0	0				
7	0	0				
8	0	0				
9	0	0				

swarm

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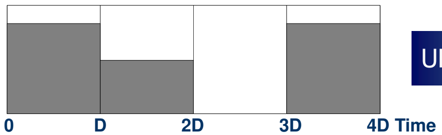
Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4



UHD for P=1 mm

Principle of proportionality

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m^3/s/mm)	Direct runoff flood hydrograph				
		Flood hydrograph for each rainfall block				At the watershed outlet (m^3/s)
		P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	
0	0	0	--			
1	u1	P1 u1	0			
2	u2	P1 u2	P2 u1			
3	u3	P1 u3	P2 u2			
4	u4	P1 u4	P2 u3			
5	u5	P1 u5	P2 u4			
6	0	0	P2 u5			
7	0	0	0			
8	0	0	0			
9	0	0	0			

swarm

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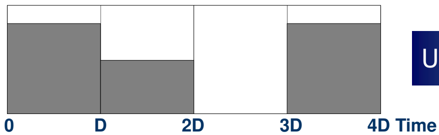
Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4

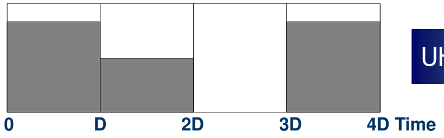


UHD for P=1 mm

Principle of proportionality

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m^3/s/mm)	Direct runoff flood hydrograph				
		Flood hydrograph for each rainfall block				At the watershed outlet (m^3/s)
		P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	
0	0	0	--	--		
1	u1	P1 u1	0	--		
2	u2	P1 u2	P2 u1	0		
3	u3	P1 u3	P2 u2	0		
4	u4	P1 u4	P2 u3	0		
5	u5	P1 u5	P2 u4	0		
6	0	0	P2 u5	0		
7	0	0	0	0		
8	0	0	0	0		
9	0	0	0	0		

Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4



UHD for P=1 mm

Principle of proportionality

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m³/s/mm)	Direct runoff flood hydrograph: Flood hydrograph for each rainfall block P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	At the watershed outlet (m³/s)
0	0	0	--	--	--	
1	u1	P1 u1	0	--	--	
2	u2	P1 u2	P2 u1	0	--	
3	u3	P1 u3	P2 u2	0	0	
4	u4	P1 u4	P2 u3	0	P4 u1	
5	u5	P1 u5	P2 u4	0	P4 u2	
6	0	0	P2 u5	0	P4 u3	
7	0	0	0	0	P4 u4	
8	0	0	0	0	P4 u5	
9	0	0	0	0	0	

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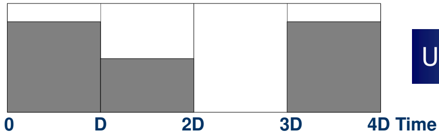
Time interval	Excess rainfall (mm)
0 - D	P1
D - 2D	P2
2D - 3D	P3=0
3D - 4D	P4



UHD for P=1 mm

Principle of proportionality

Principle of superposition

Time in D units	Unit hydrograph for 1 mm excess rainfall with duration D (m³/s/mm)	Direct runoff flood hydrograph: Flood hydrograph for each rainfall block P1 (mm)	P2 (mm)	P3=0 (mm)	P4 (mm)	At the watershed outlet (m³/s)
0	0	0	--	--	--	0
1	u1	P1 u1	0	--	--	P1 u1
2	u2	P1 u2	P2 u1	0	--	P1 u2 + P2 u1
3	u3	P1 u3	P2 u2	0	0	P1 u3 + P2 u2
4	u4	P1 u4	P2 u3	0	P4 u1	P1 u4 + P2 u3 + P4 u1
5	u5	P1 u5	P2 u4	0	P4 u2	P1 u5 + P2 u4 + P4 u2
6	0	0	P2 u5	0	P4 u3	P2 u5 + P4 u3
7	0	0	0	0	P4 u4	P4 u4
8	0	0	0	0	P4 u5	P4 u5
9	0	0	0	0	0	0

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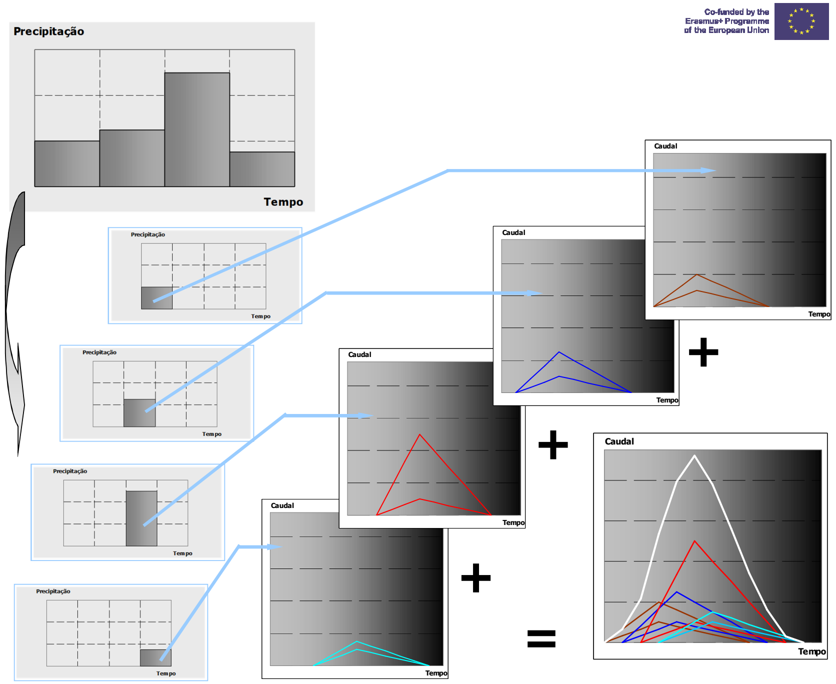

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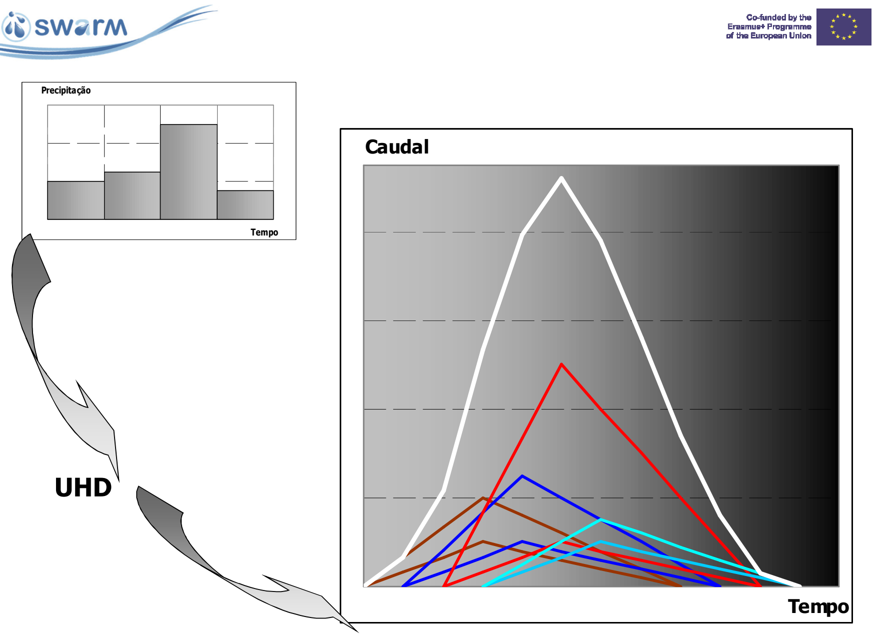
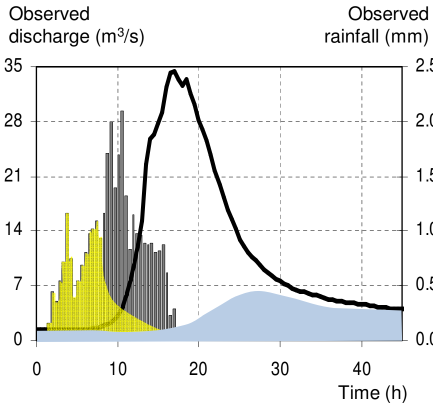


For a given watershed the unit hydrograph can be obtained by:

- **Direct approaches,** based on observed flood hydrographs and rainfall hyetographs**.**

  Only applicable if the river section where the unit hydrograph is required coincides with a stream gauging station (which seldom happens!**)**

- **Indirect approaches,** based on **synthetic unit hydrographs**, without requiring discharge data, but, instead, physiographic characteristics of the watersheds where flood analysis will be carried out.



Different types of synthetic unit hydrographs

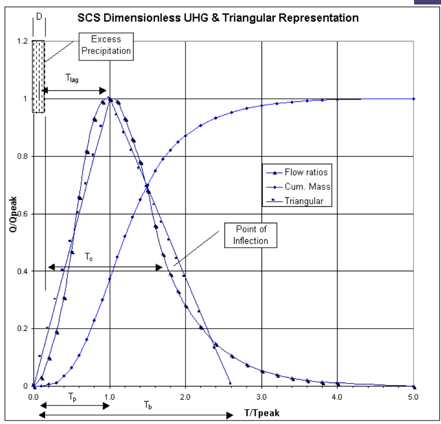
- **Empirical relationships, relating physiographic characteristics of the watershed (usually, measurable based on topographic maps) with geometric properties of the unit hydrographs like the base time, the peak flood discharge or even the shape (**Snyder Unit Hydrograph**)**

- **Dimensionless unit hydrographs (Soil Conservation Service Unit Hydrograph)**

- **Storage models aiming at representing the water storage in the watershed (**Clark Instantaneous Synthetic Unit Hydrograph**)**

Soil Conservation Service Synthetic Unit Hydrograph, SCS SUH

t/tp	q/qp	t/tp	q/qp
0.0	0.000	1.7	0.460
0.1	0.030	1.8	0.390
0.2	0.100	1.9	0.330
0.3	0.190	2.0	0.280
0.4	0.310	2.2	0.207
0.5	0.470	2.4	0.147
0.6	0.660	2.6	0.107
0.7	0.820	2.7	0.097
0.8	0.930	2.8	0.077
0.9	0.990	3.0	0.055
1.0	1.000	3.2	0.040
1.1	0.990	3.4	0.029
1.2	0.930	3.6	0.021
1.3	0.860	3.8	0.015
1.4	0.780	4.0	0.011
1.5	0.680	4.5	0.005
1.6	0.560	5.0	0.000

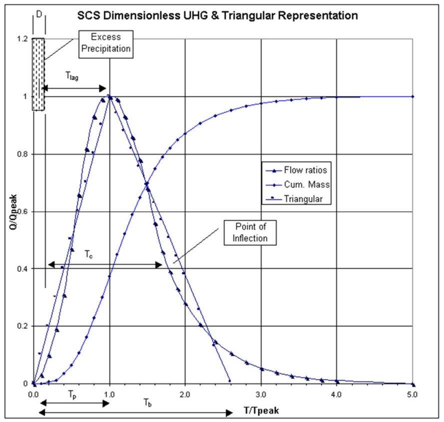


$$\text{tlag} = 0{,}6\ \text{tc}$$

$$\text{tp} = \frac{D}{2} + \text{tlag}$$

For P=1 mm

$$\text{qp} = \frac{0{,}2083\ A}{\text{tp}}$$

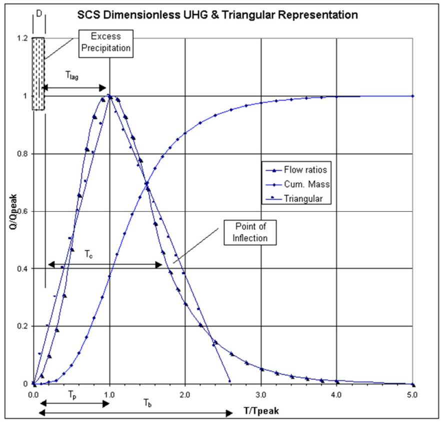


SCS SUH

$$\text{tlag} = 0{,}6\ \text{tc}$$

$$\text{tp} = \frac{D}{2} + \text{tlag}$$

- **tlag – lag time: difference between the instant of the mass center of the excess rainfall hyetograph and the instant of the peak flow discharge**
- **tc – time of concentration: time needed for the water to flow from the most remote point (from a kinematic point of view) in a watershed to its outlet)**
- **tp – time to peak: time of occurrence of the peak flood discharge of the SUH**



Data required to define the SCS Synthetic Unit Hydrograph: watershed area, A; time of concentration, tc

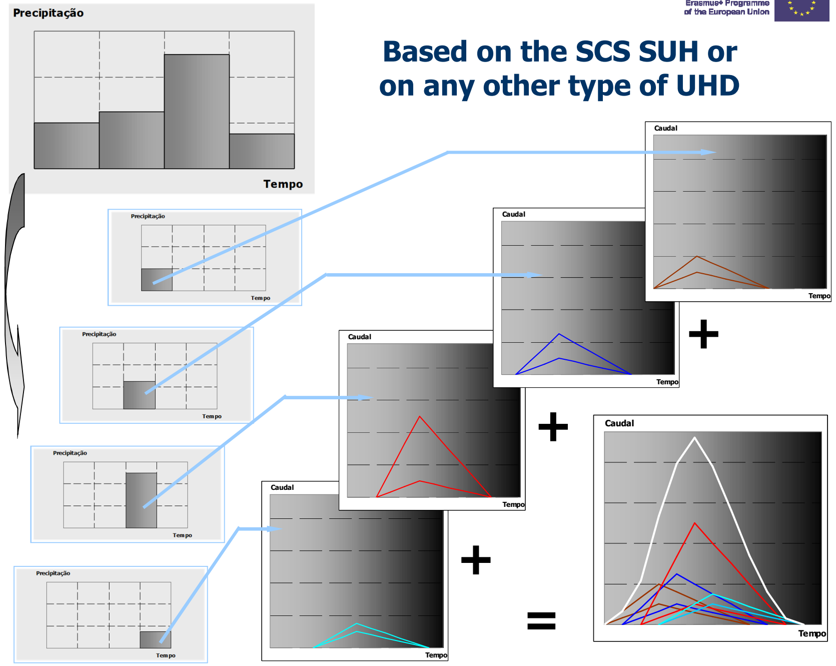
$$tlag = 0{,}6\ tc$$

$$tp = \frac{D}{2} + tlag$$

For the excess rainfall of P=1 mm

$$qp\ (m^3/s) = \frac{0{,}2083\ A\ (m^2)}{tp\ (h)}$$

Based on the SCS SUH or on any other type of UHD



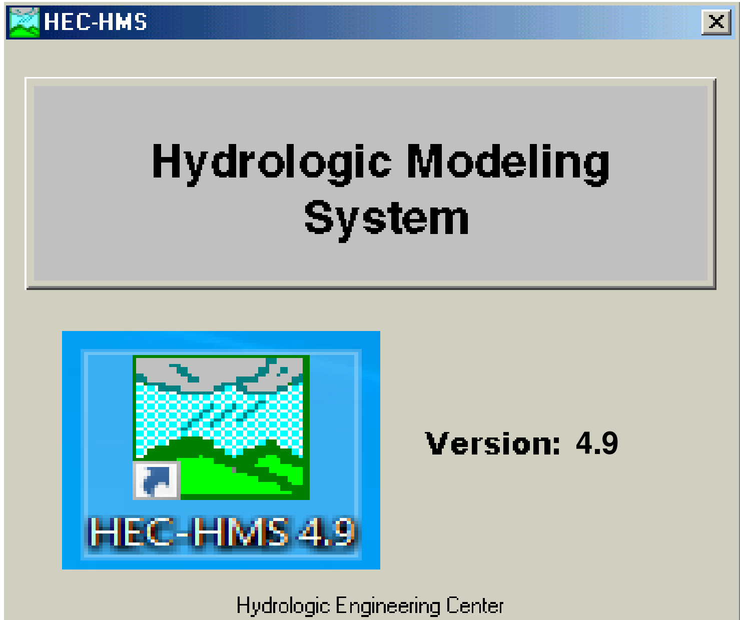
Approaches to estimate peak flood discharges or/and floods hydrographs

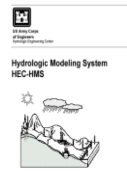
- **Statistical methods**
- **Empirical formulas**
- **Regionalization models**
- **Unit hydrograph model**
- **Flood routing models**
- .
- .
- .

Peak flood discharges (Statistical methods, Empirical formulas, Regionalization models)

Peak flood discharges and flood hydrographs (Unit hydrograph model, Flood routing models)

HEC-HMS PROGRAM
(brief presentation)

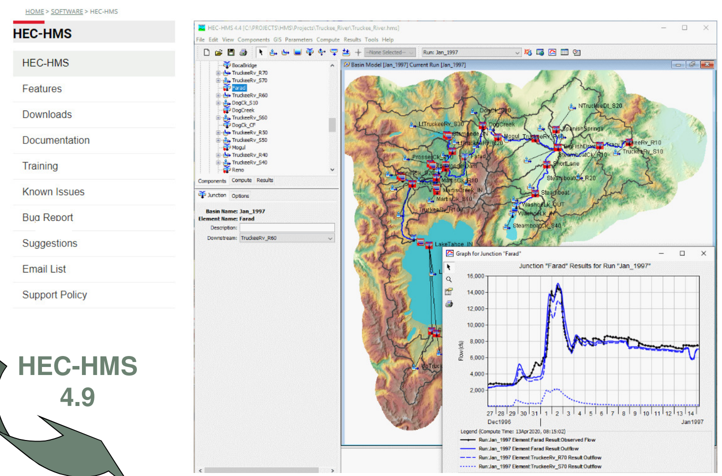




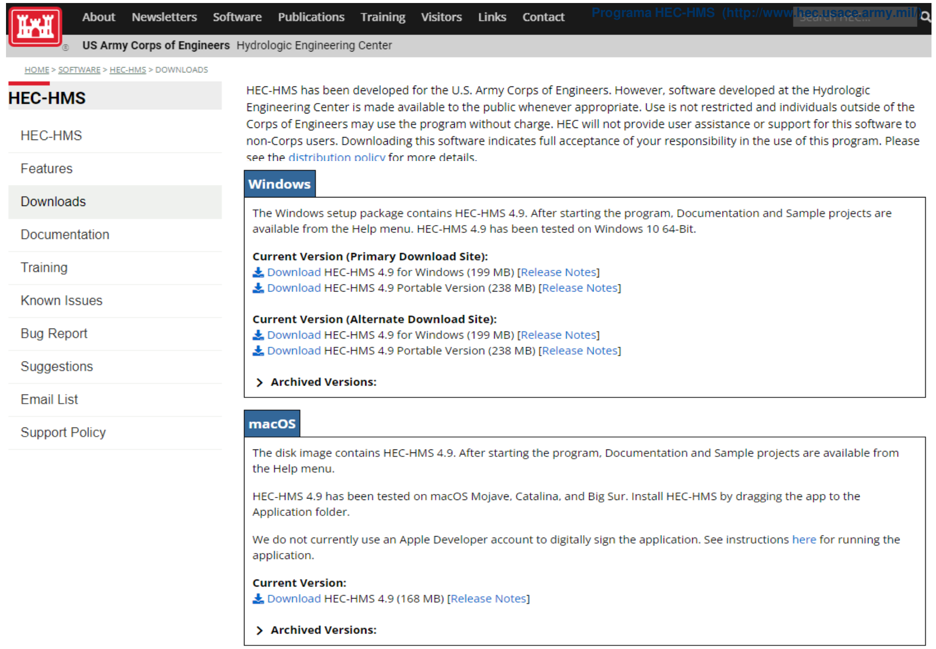
HEC-HMS

Hydrologic Engineering Center – Hydrologic Modeling System (www.hec.usace.army.mil)

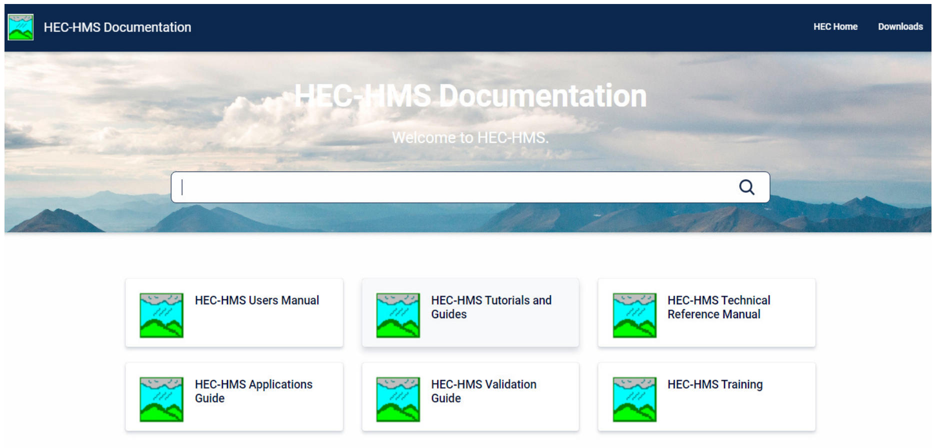
Co-funded by the Erasmus+ Programme of the European Union



HEC-HMS 4.9

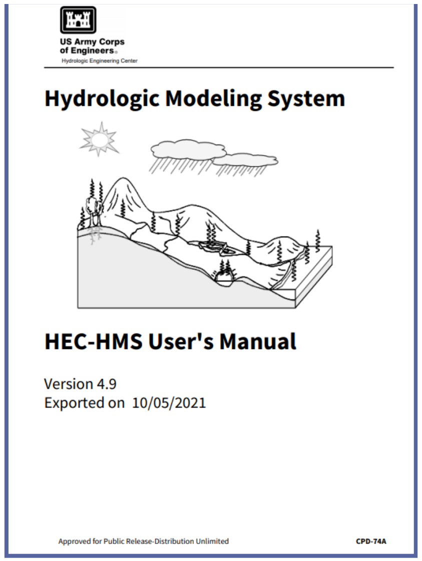


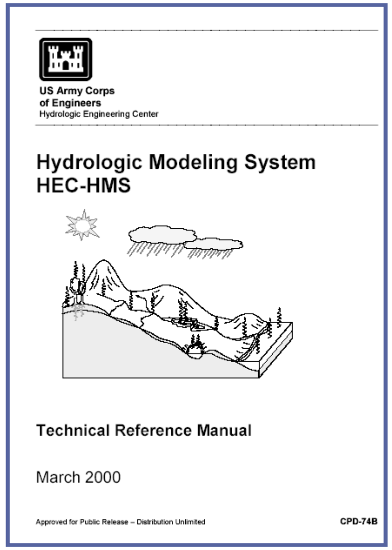
Programa HEC-HMS (http://www.hec.usace.army.mil)



HEC-HMS DOCUMENTATION

Co-funded by the Erasmus+ Programme of the European Union





(extracted from HEC-HMS Reference Manual)

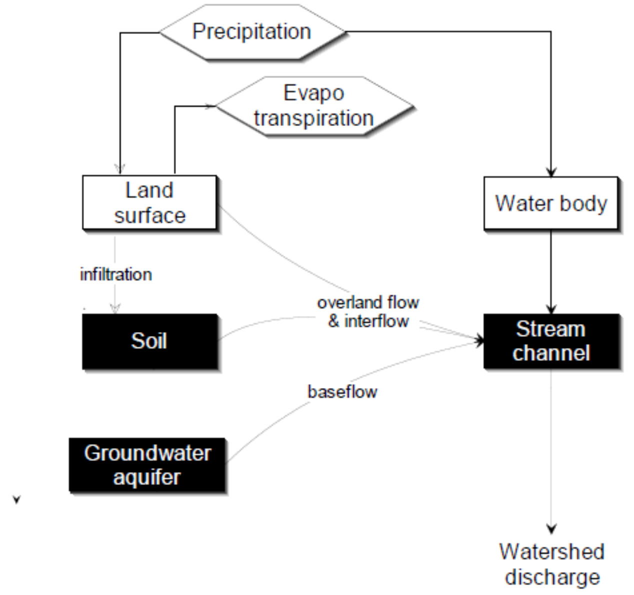
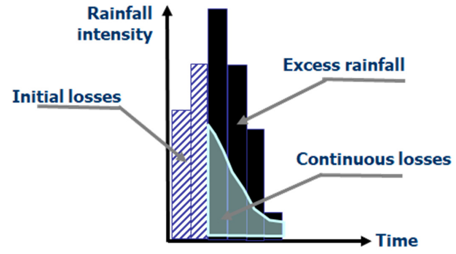


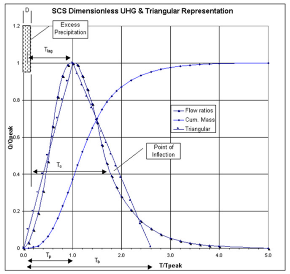
Figure 2. Typical representation of watershed runoff.

Models implemented in the HEC-HMS program: rainfall losses (extracted from the HEC-HMS Reference Manual)



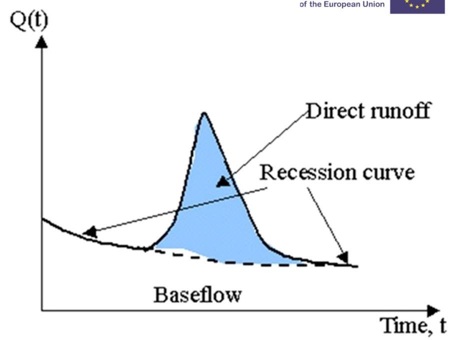
Model	Categorization
Initial and constant-rate	event, lumped, empirical, fitted parameter
SCS curve number (CN)	event, lumped, empirical, fitted parameter
Gridded SCS CN	event, distributed, empirical, fitted parameter
Green and Ampt	event, distributed, empirical, fitted parameter
Deficit and constant rate	continuous, lumped, empirical, fitted parameter
Soil moisture accounting (SMA)	continuous, lumped, empirical, fitted parameter
Gridded SMA	continuous, distributed, empirical, fitted parameter

Models implemented in the HEC-HMS program: transformation of the excess rainfall into direct runoff under flood conditions (extracted from the HEC-HMS Reference Manual)



Model	Categorization
User-specified unit hydrograph (UH)	event, lumped, empirical, fitted parameter
Clark's UH	event, lumped, empirical, fitted parameter
Snyder's UH	event, lumped, empirical, fitted parameter
SCS UH	event, lumped, empirical, fitted parameter
ModClark	event, distributed, empirical, fitted parameter
Kinematic wave	event, lumped, conceptual, measured parameter
User-specified unit hydrograph (UH)	event, lumped, empirical, fitted parameter

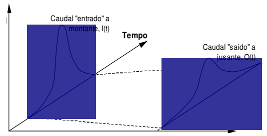
Models implemented in the HEC-HMS program: baseflow (extracted from the HEC-HMS Reference Manual)



Model	Categorization
Constant monthly	event, lumped, empirical, fitted parameter
Exponential recession	event, lumped, empirical, fitted parameter
Linear reservoir	event, lumped, empirical, fitted parameter

No baseflow – acceptable assumption under design flood analysis

Models implemented in the HEC-HMS program: flood routing (propagation)
(extracted from the HEC-HMS Reference Manual)



Model	Categorization
Kinematic wave	event, lumped, conceptual, measured parameter
Lag	event, lumped, empirical, fitted parameter
Modified Puls	event, lumped, empirical, fitted parameter
Muskingum	event, lumped, empirical, fitted parameter
Muskingum-Cunge Standard Section	event, lumped, quasi-conceptual, measured parameter
Muskingum-Cunge 8-point Section	event, lumped, quasi-conceptual, measured parameter
Confluence	continuous, conceptual, measured parameter
Bifurcation	continuous, conceptual, measured

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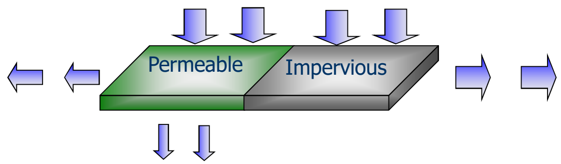
DESIGN RAINFALL

- ✓ In each time step, the program considers that the rainfall is uniform over the watershed – lumped model
- ✓ The program requires the previous establishment of the design rainfall which is part of the data
- ✓ **The precipitation losses occur only in permeable areas; in the impervious areas all the rainfall becomes excess rainfall and, consequently, direct runoff … to address this issue the program requires the specification of the percentage of impervious areas**



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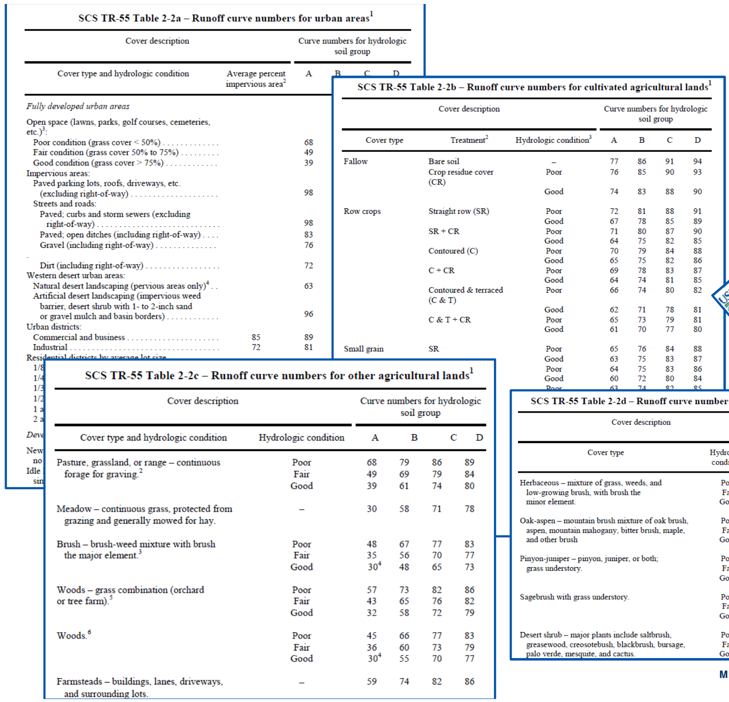
Cn tables
(extracted from the HEC-HMS Reference Manual)



SCS TR-55 Table 2-2a – Runoff curve numbers for urban areas[1]

Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68			
Fair condition (grass cover 50% to 75%)		49			
Good condition (grass cover > 75%)		39			
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98			
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98			
Paved; open ditches (including right-of-way)		83			
Gravel (including right-of-way)		76			
Dirt (including right-of-way)		72			
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63			
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96			
Urban districts:					
Commercial and business	85	89			
Industrial	72	81			
Residential districts by average lot size					

SCS TR-55 Table 2-2b – Runoff curve numbers for cultivated agricultural lands[1]

Cover type	Treatment[2]	Hydrologic condition[3]	A	B	C	D
Fallow	Bare soil	–	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C & T)	Poor	66	74	80	82
		Good	62	71	78	81
	C & T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
		Poor	64	75	83	86
		Good	60	72	80	84
		Poor	63	74	82	85

SCS TR-55 Table 2-2c – Runoff curve numbers for other agricultural lands[1]

Cover type and hydrologic condition	Hydrologic condition	A	B	C	D
Pasture, grassland, or range – continuous forage for graving.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.	–	30	58	71	78
Brush – brush-weed mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods – grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots.	–	59	74	82	86

SCS TR-55 Table 2-2d – Runoff curve numbers for arid and semiarid rangelands[1]

Cover type	Hydrologic condition[2]	A[3]	B	C	D
Herbaceous – mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen – mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper – pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub – major plants include saltbrush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Main steps of the HEC-HMS application

0) Start the program

1) Create the basin model (it is not a representation of the basin ... it is an interface where the physical components to be considered as well as the models that should be applied to each component and the corresponding parameters are identified)

0-1 or 1-2 Introduce the temporal/time data and **paired data** (precipitation, discharge, …, rating curve, storage-elevation curve…)

2) Create the meteorologic/precipitation model (how the rainfall data is going to be "handled")

3) Create the control specifications (definition of the computation time interval and time step)

4) Execute/run the program (without or with parameters optimization)

Main steps of the HEC-HMS application

0) Start the program

1) **Create the basin model** (it is not a representation of the basin ... it is an interface where the physical components to be considered as well as the models that should be applied to each component and the corresponding parameters are identified)

0-1 or 1-2 **Introduce the temporal/time data** and **paired data** (precipitation, discharge, …, rating curve, storage-elevation curve…)

2) **Create the meteorologic/precipitation model** (how the rainfall data is going to be "handled")

3) **Create the control specifications** (definition of the computation time interval and time step)

Project

4) **Execute/run the program** (without or with parameters optimization)

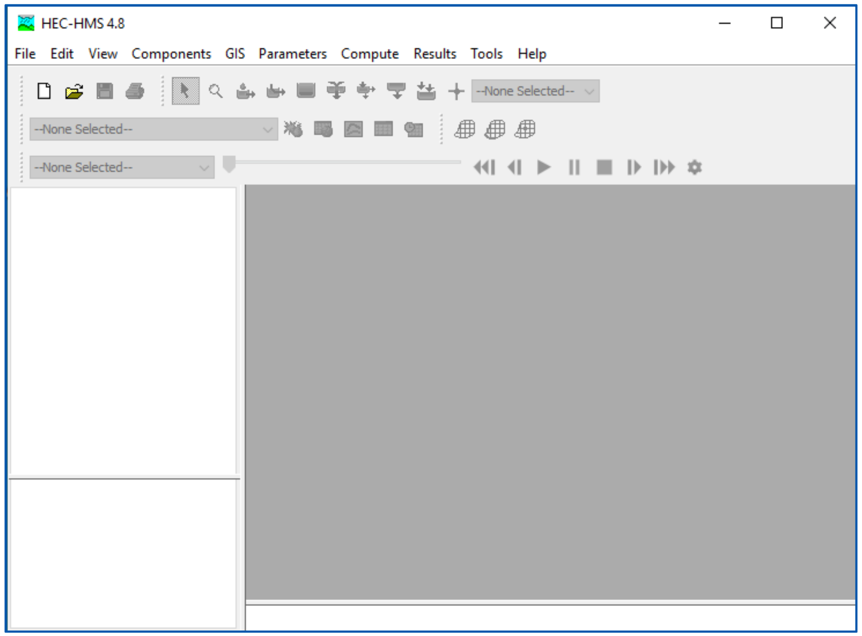
Main steps of the HEC-HMS application

There is not a mandatory and unique "pathway" when applying the program!!!

If any data or any information is missing or if is wrong/inconsistent, the program issues a message identifying the problem that can be then correct

Example

Apply the HEC-HMS program to the flood analysis in a watershed with an area of 100 km² and a time of concentration of 2 h. The average intensity of 50-year design excess rainfall is 38 mm/h. Neglect the rainfall losses and consider the application of the SCS HUS

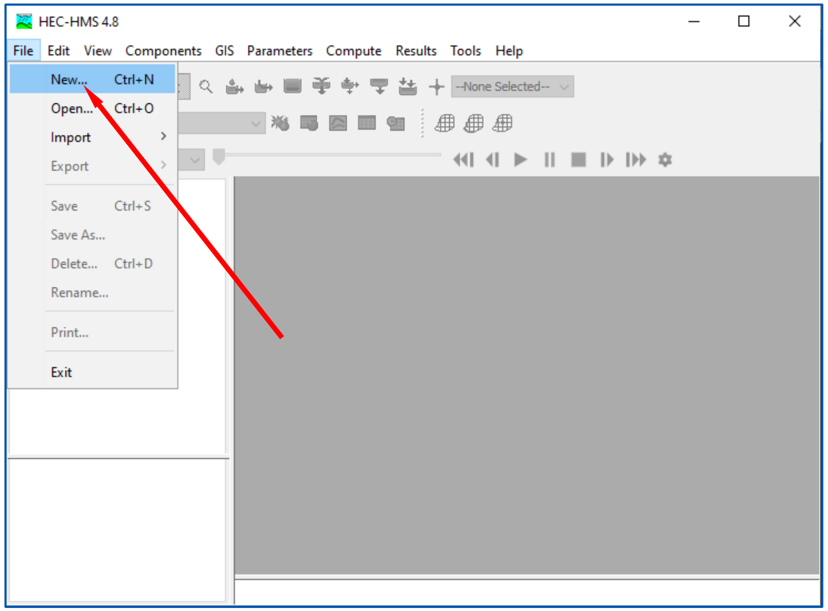


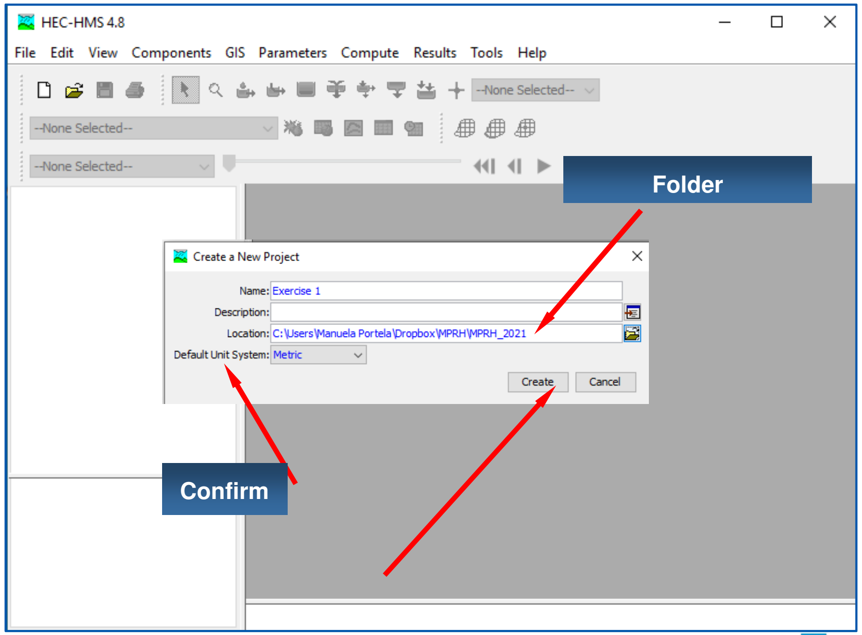
Tools/"setting" option for verification of the program settings (defualt setting and units system)

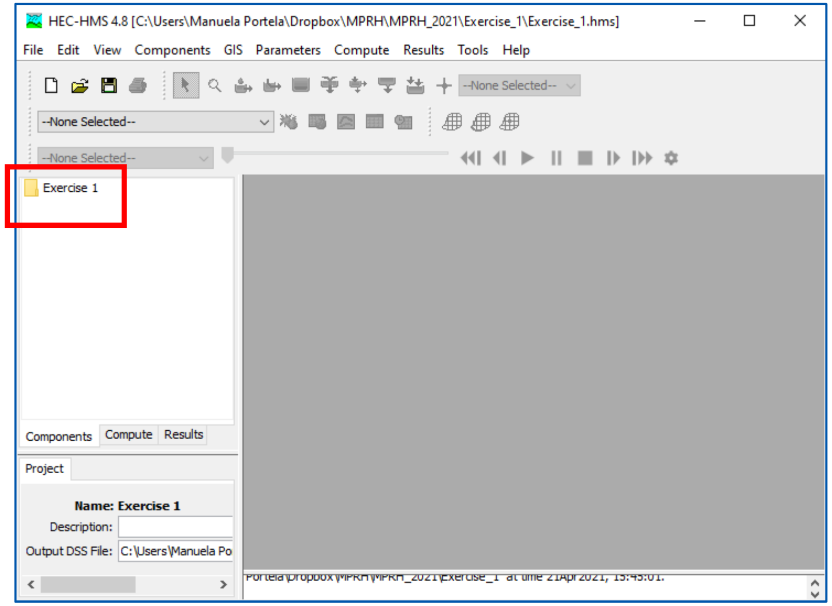
No TOOLS/"settings" averiguar as configurações

CREATE A NEW PROJECT

CRIAÇÃO DE UM NOVO PROJETO

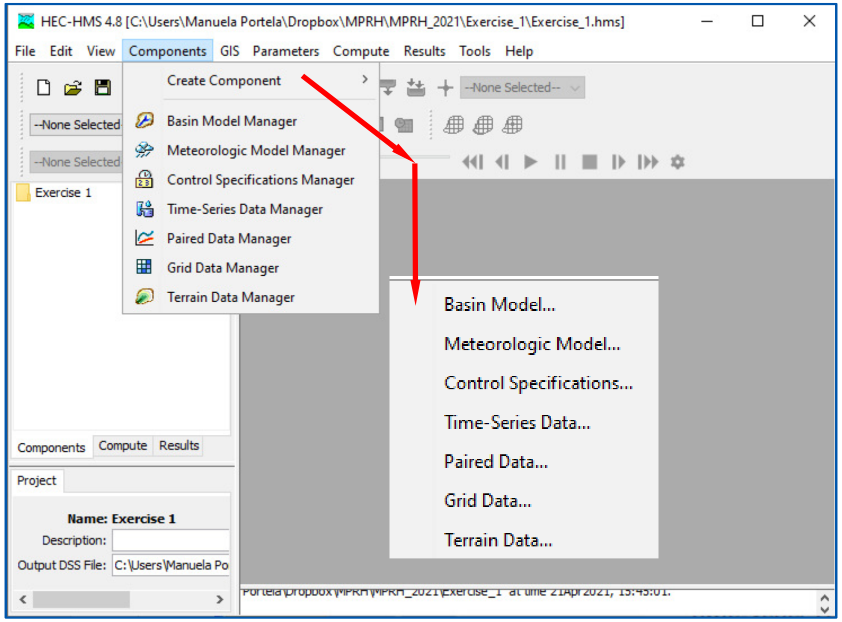


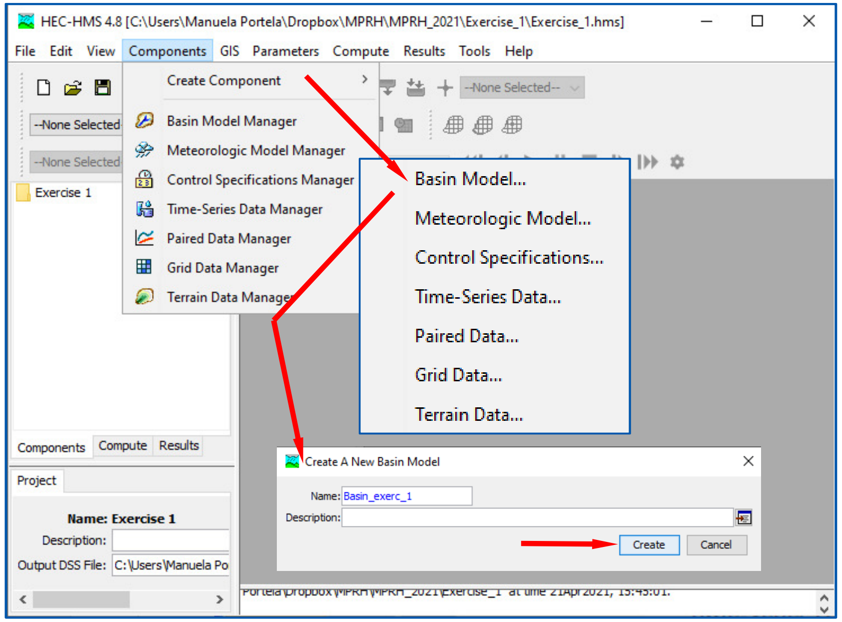


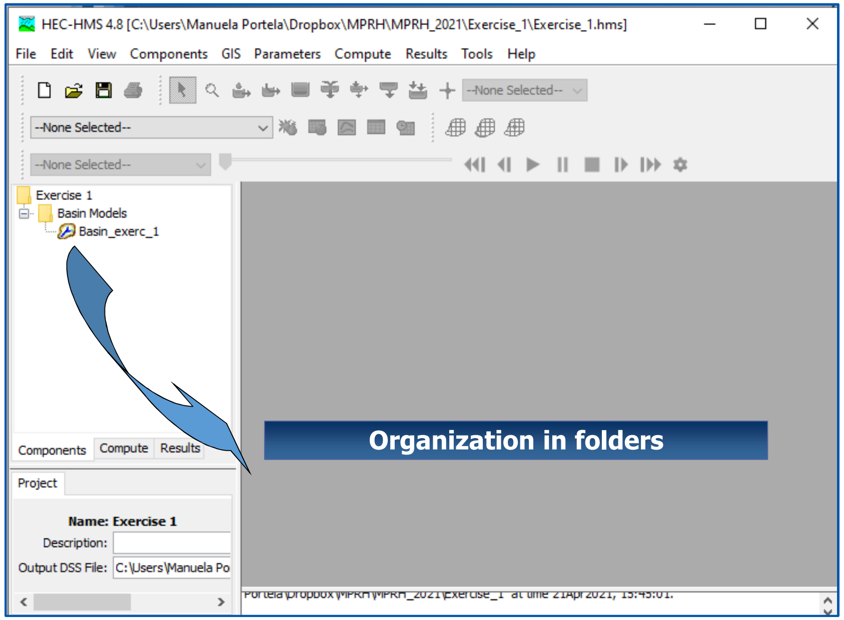


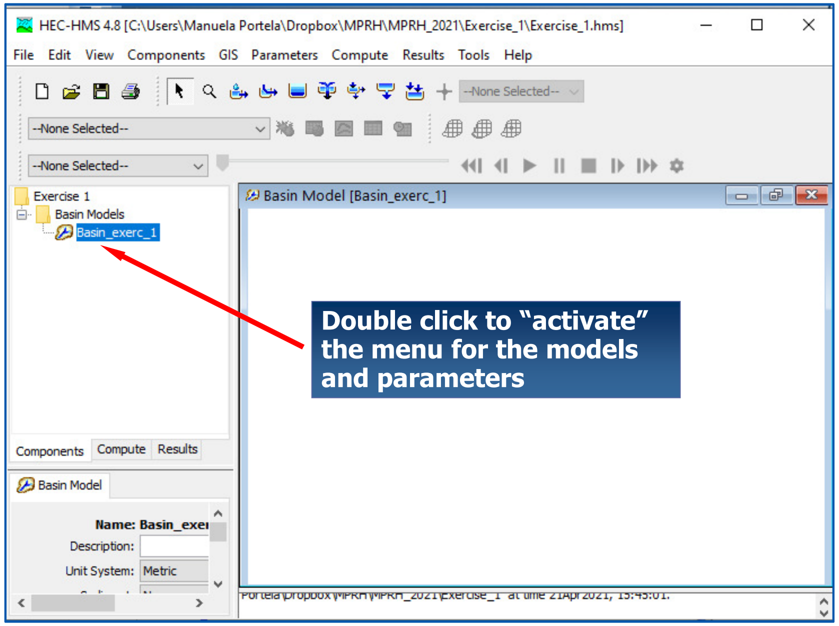
CREATE THE BASIN MODEL

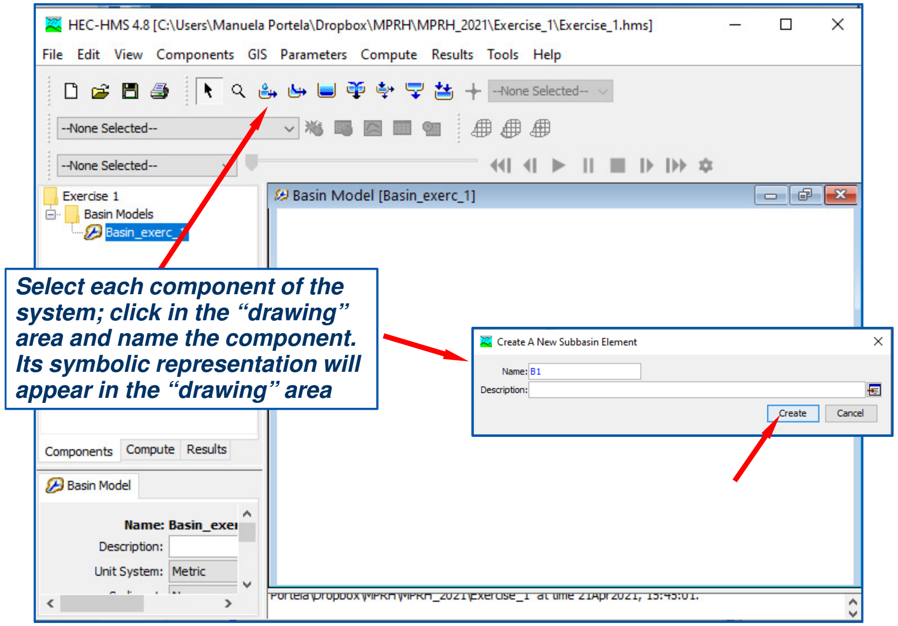
It is not the representation of the watershed ... Is it only the way to define the physical components that should be accounted for (river basins, river stretches, reservoirs), models and parameters of the models applicable to each component (models for precipitation losses, for transformation of the excess precipitation into hydrographs of flood, for flood propagation, etc.)

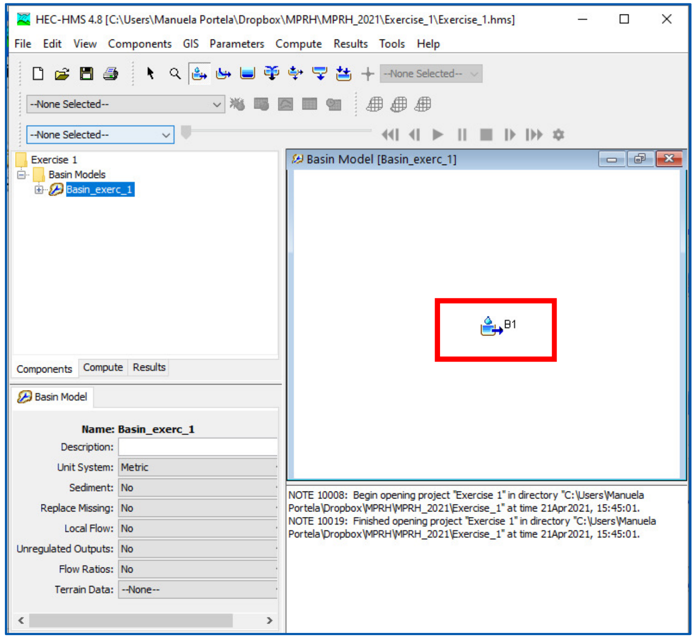





HEC-HMS 4.8 [C:\Users\Manuela Portela\Dropbox\MPRH\MPRH_2021\Exercise_1\Exercise_1.hms]
Organization in folders

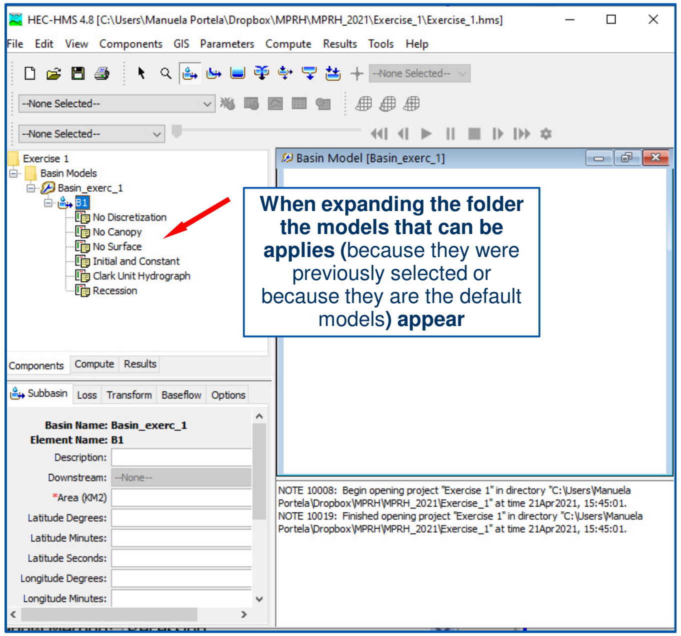

HEC-HMS 4.8 [C:\Users\Manuela Portela\Dropbox\MPRH\MPRH_2021\Exercise_1\Exercise_1.hms]
Basin Model [Basin_exerc_1]
Double click to "activate" the menu for the models and parameters


HEC-HMS 4.8 [C:\Users\Manuela Portela\Dropbox\MPRH\MPRH_2021\Exercise_1\Exercise_1.hms]
Basin Model [Basin_exerc_1]
Select each component of the system; click in the "drawing" area and name the component. Its symbolic representation will appear in the "drawing" area
Create A New Subbasin Element
Name: B1
Description:
Create
Cancel

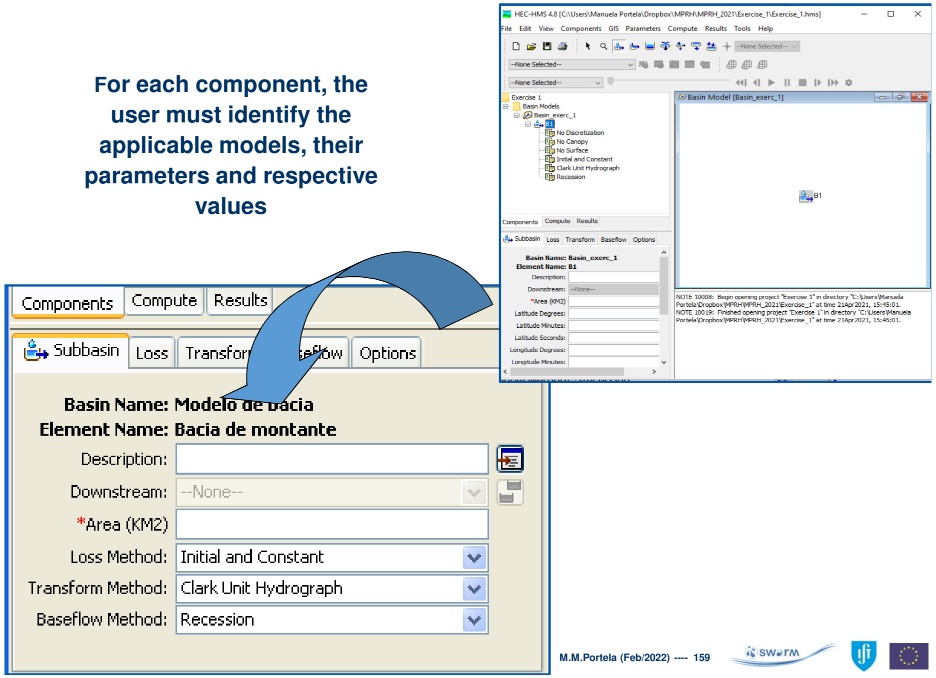

HEC-HMS 4.8 [C:\Users\Manuela Portela\Dropbox\MPRH\MPRH_2021\Exercise_1\Exercise_1.hms]
Basin Model [Basin_exerc_1]
B1
Name: Basin_exerc_1
Unit System: Metric

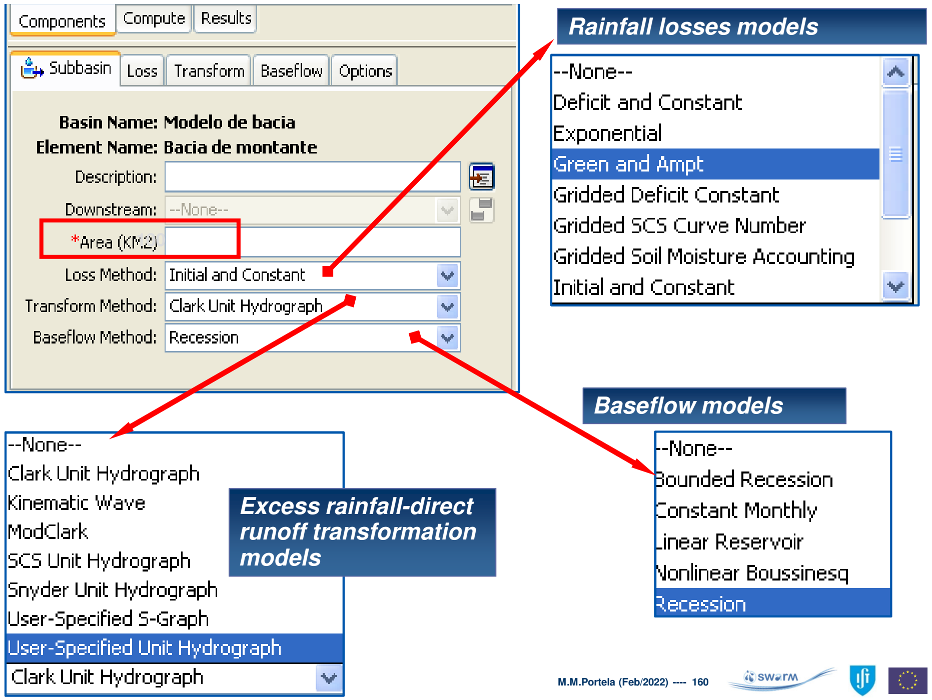
Components of the basin model – for each component, the applicable models and parameters are specified in the basin model

- **Subbasins** – subbasins/watersheds
- **River reaches** - connects elements together and contains flood routing data
- **Junctions** - connection point between elements
- **Reservoirs with outflow control structures** - stores runoff and releases runoff at a specified rate (storage-discharge relation)
- **Sinks** – singular point with an inflow and without outflow (inflow accumulation point)
- **Sources** – singular point with only outflow and no inflow
- **Diversions** - diverts a specified amount of runoff to an element based on a rating curve - used for detention storage elements or overflows

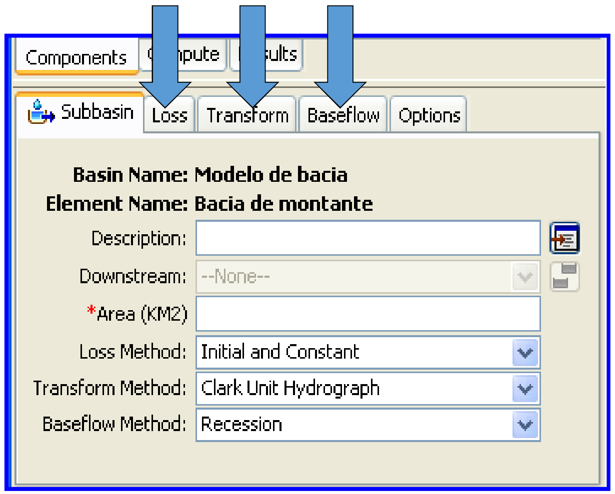


For each component, the user must identify the applicable models, their parameters and respective values

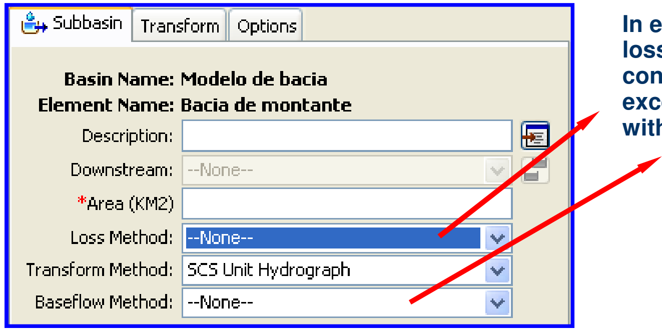




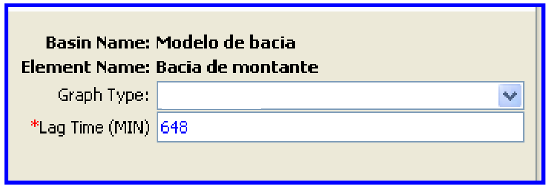
Each model to be applied must be identified and the values of its parameters specified



Specifically for exemple 1 … No caso do exercício 1 …



In example 1, without losses, because we are considering already the excess rainfall, and without baseflow

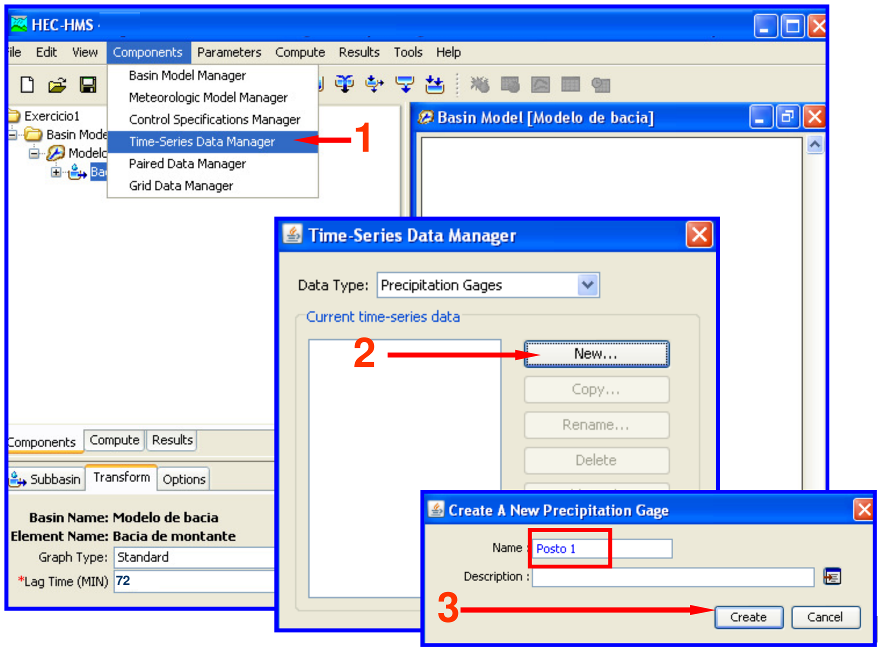


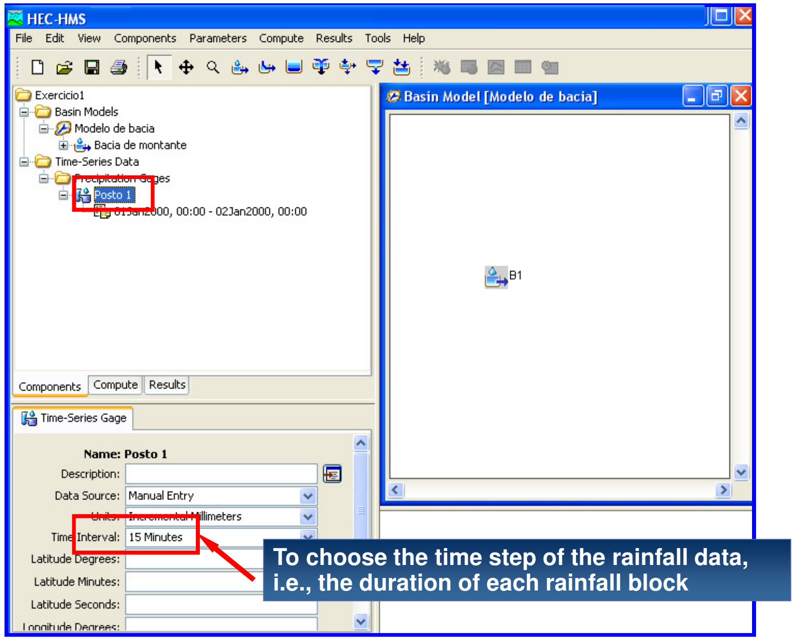
SCS HUS with only one parameter: tlag=0.6 tc

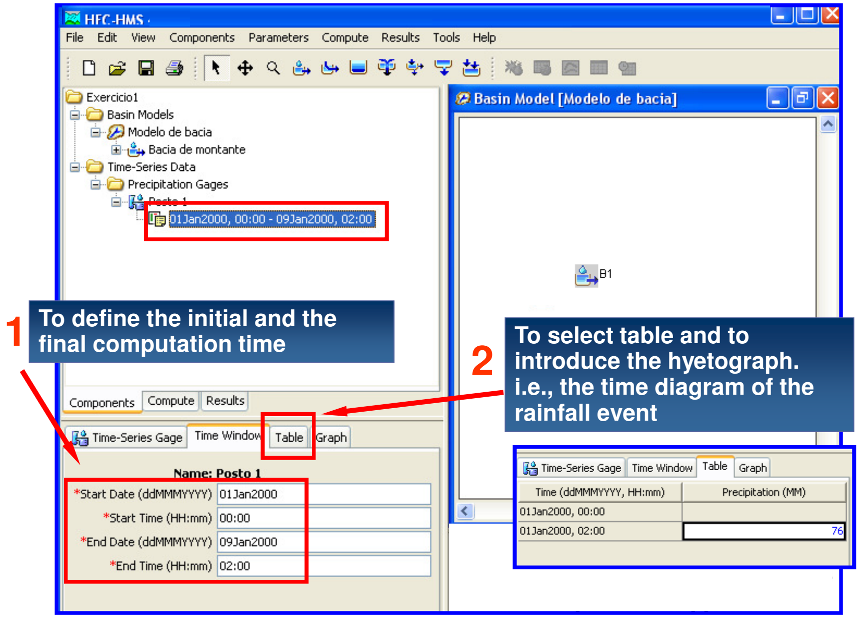
DEFINITION OF THE DATE – TIME SERIES AND PAIRED DATA

There are two types of data

- ✓ **Time data – hydrological time series – such as rainfall or discharge data and**
- ✓ **Paired data such as rating curves, volumes storage in the reservoir**

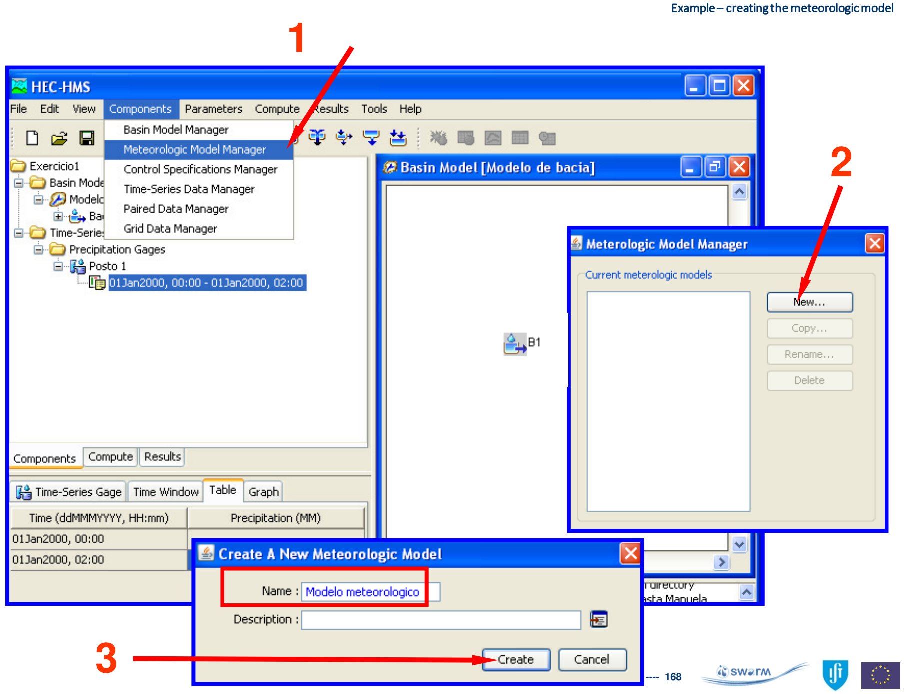


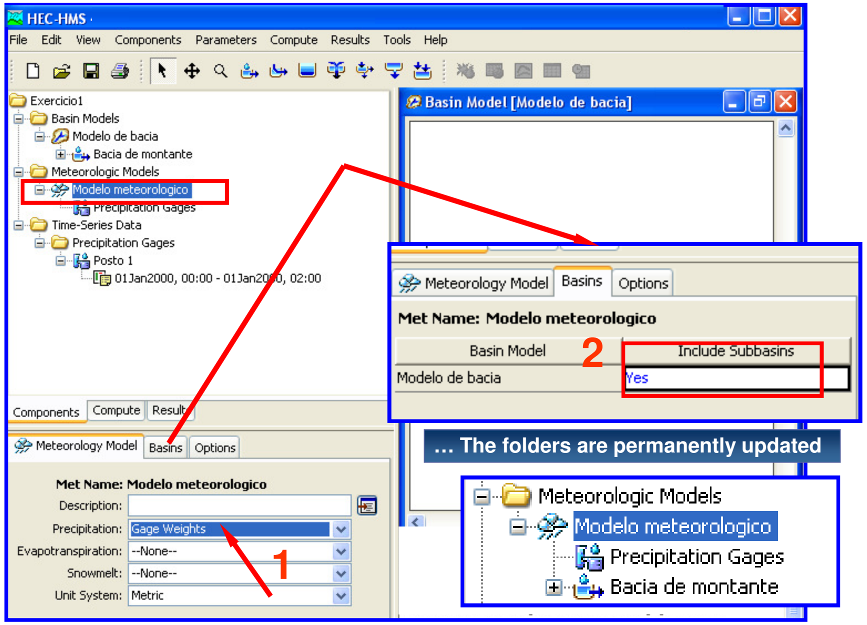


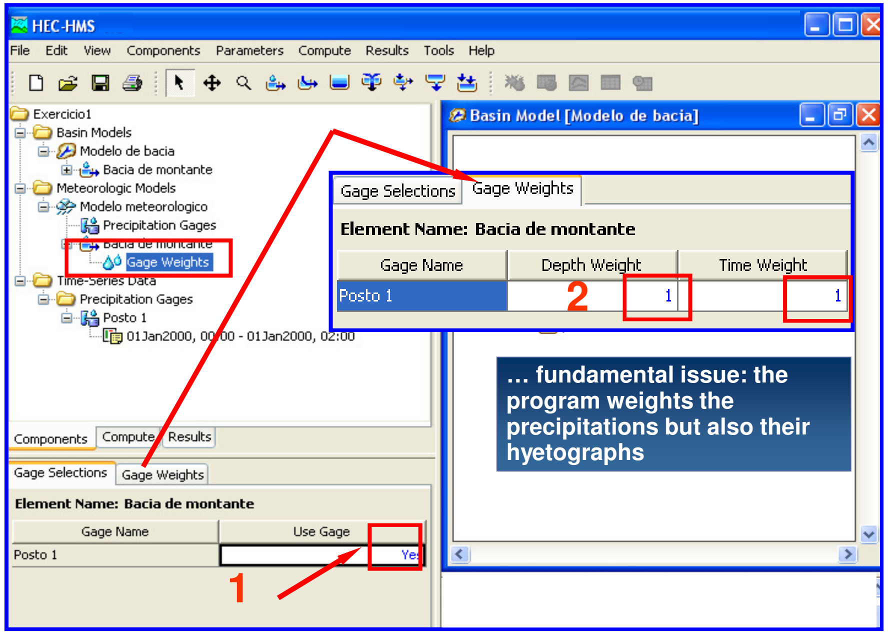


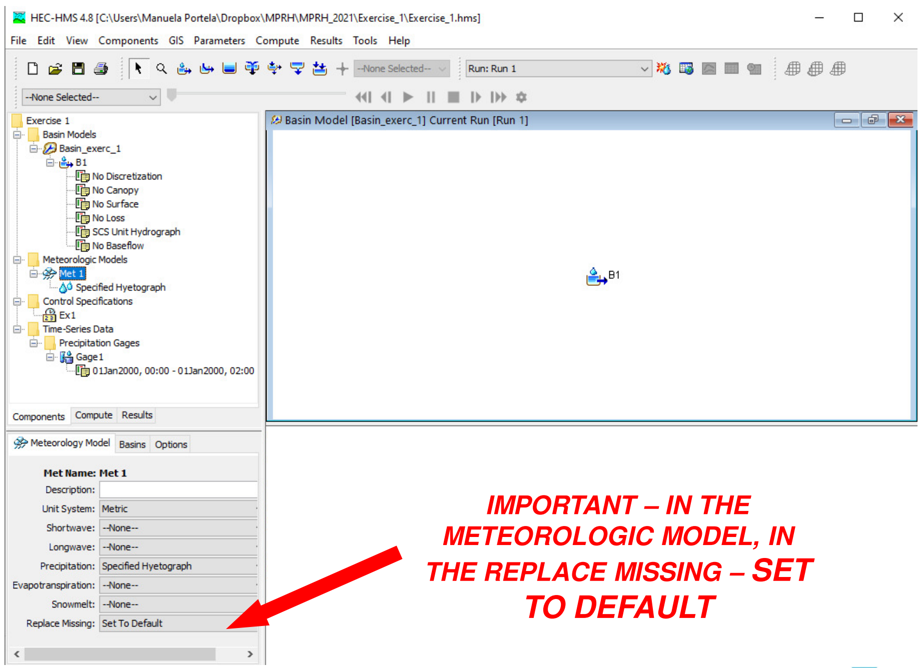
DEFINITION OF THE METEOROLOGIC MODEL

The meteorologic model identifies which data should be considered and how the data should be combined (eg.: which rain gages are going to be applied to each subbasin and their weights)





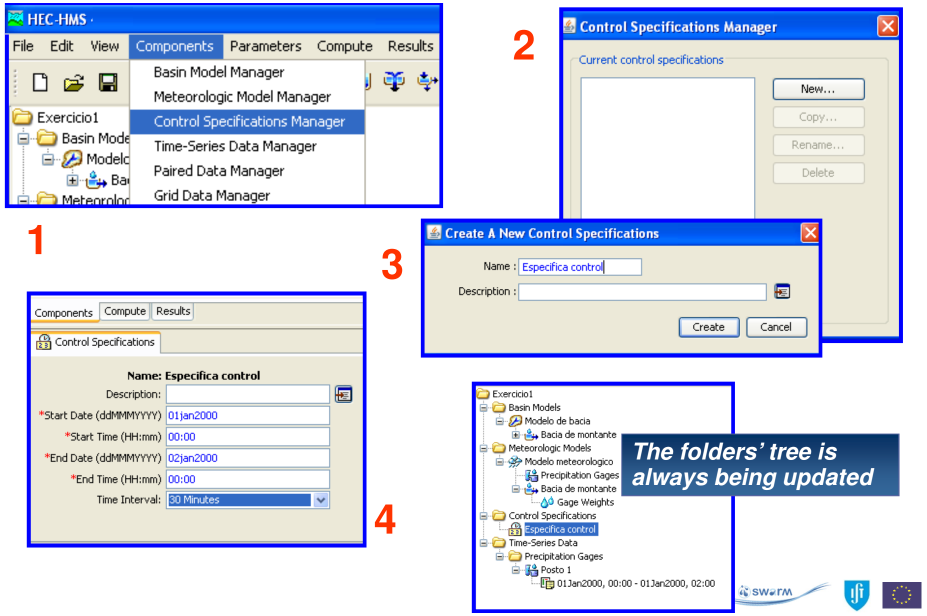




IMPORTANT – IN THE METEOROLOGIC MODEL, IN THE REPLACE MISSING – SET TO DEFAULT

DEFINITION OF THE CONTROL SPECIFICATIONS

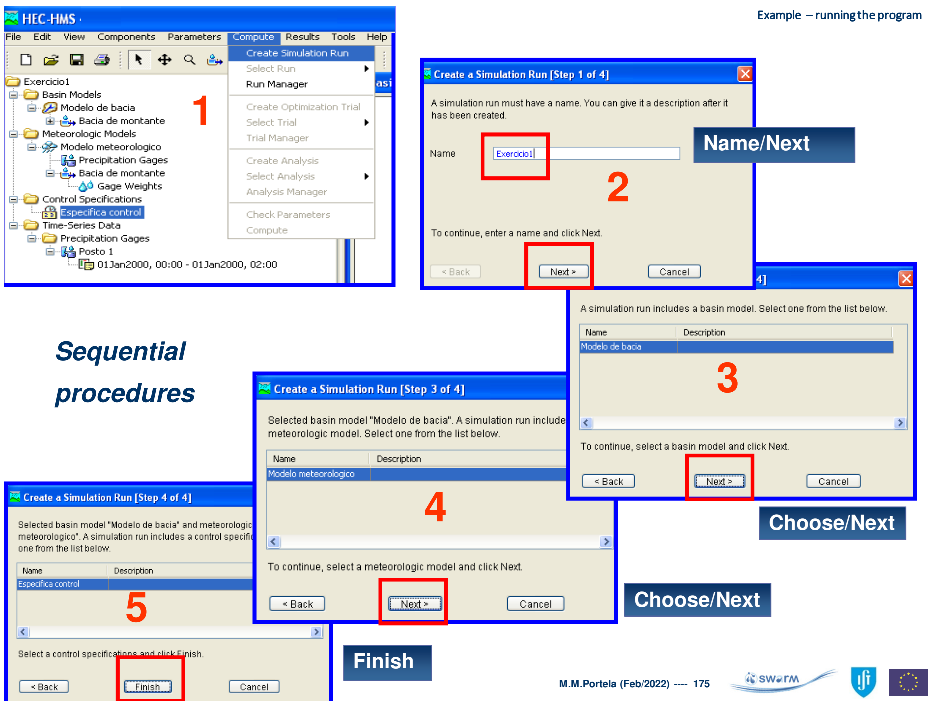
Definition of the computaion time interval and of the time step



CREATING A RUN

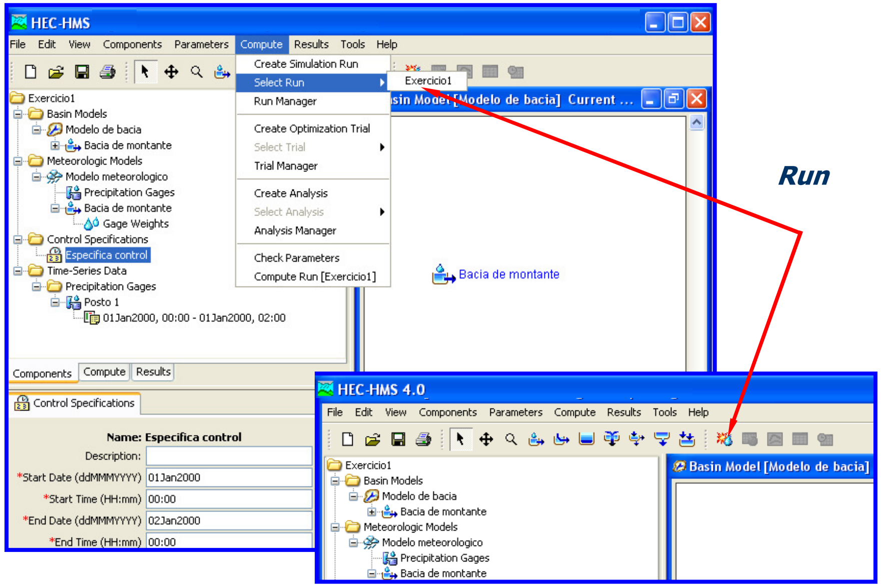
CRIAÇÃO DA "CORRIDA"

Identification of the assemble of components models and data to be considered in the HEC-HMS "run"

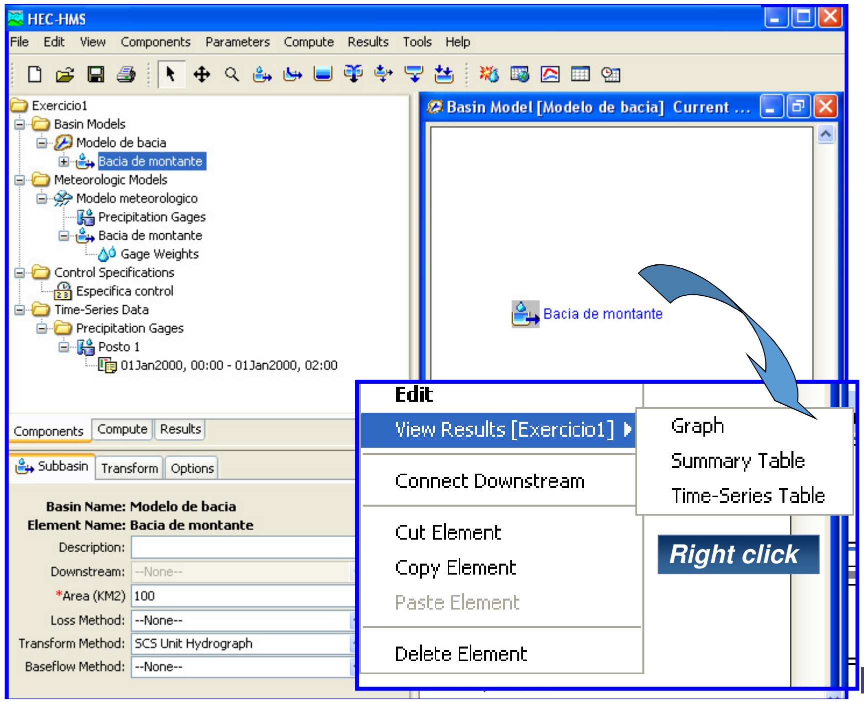


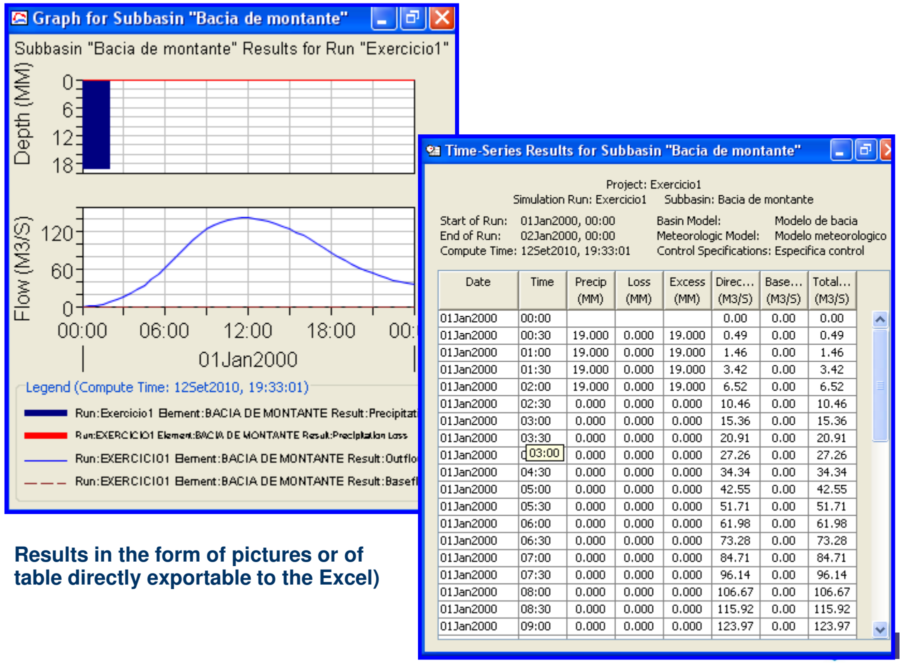
RUN THE PROGRAM

Selection of the run to be considered (there may be several runs composed upon different basin / meteorologic / control specifications models)



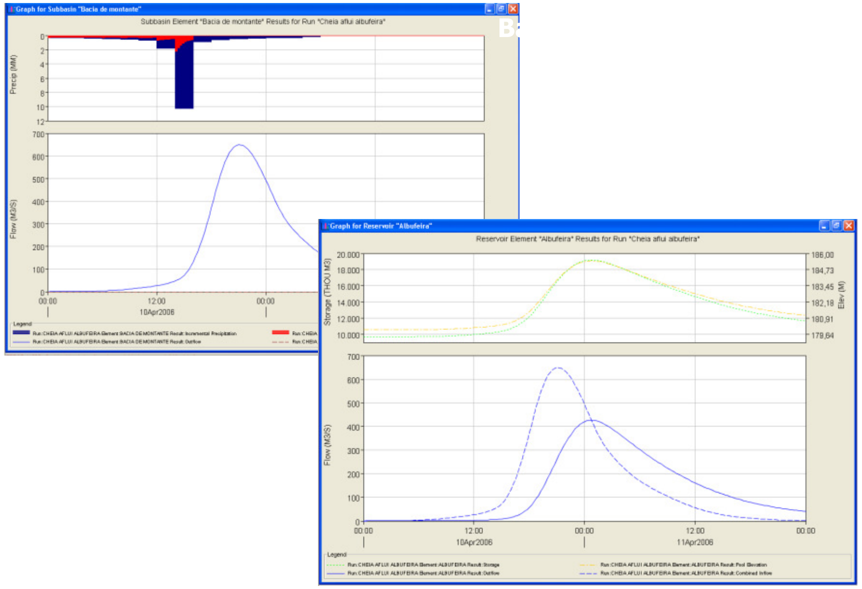
VIEWING THE RESULTS





Date	Time	Precip (MM)	Loss (MM)	Excess (MM)	Direc... (M3/S)	Base... (M3/S)	Total... (M3/S)
01Jan2000	00:00				0.00	0.00	0.00
01Jan2000	00:30	19.000	0.000	19.000	0.49	0.00	0.49
01Jan2000	01:00	19.000	0.000	19.000	1.46	0.00	1.46
01Jan2000	01:30	19.000	0.000	19.000	3.42	0.00	3.42
01Jan2000	02:00	19.000	0.000	19.000	6.52	0.00	6.52
01Jan2000	02:30	0.000	0.000	0.000	10.46	0.00	10.46
01Jan2000	03:00	0.000	0.000	0.000	15.36	0.00	15.36
01Jan2000	03:30	0.000	0.000	0.000	20.91	0.00	20.91
01Jan2000	[illegible]	0.000	0.000	0.000	27.26	0.00	27.26
01Jan2000	04:30	0.000	0.000	0.000	34.34	0.00	34.34
01Jan2000	05:00	0.000	0.000	0.000	42.55	0.00	42.55
01Jan2000	05:30	0.000	0.000	0.000	51.71	0.00	51.71
01Jan2000	06:00	0.000	0.000	0.000	61.98	0.00	61.98
01Jan2000	06:30	0.000	0.000	0.000	73.28	0.00	73.28
01Jan2000	07:00	0.000	0.000	0.000	84.71	0.00	84.71
01Jan2000	07:30	0.000	0.000	0.000	96.14	0.00	96.14
01Jan2000	08:00	0.000	0.000	0.000	106.67	0.00	106.67
01Jan2000	08:30	0.000	0.000	0.000	115.92	0.00	115.92
01Jan2000	09:00	0.000	0.000	0.000	123.97	0.00	123.97

Results in the form of pictures or of table directly exportable to the Excel)



In order to properly use the program it is fundamental to have a correct and precise knowledge about which models should be applied to each component and about the parameters required by those models. THE PROGRAM SHOULD NEVER BE USED AS A "BLACK BOX" TOOL