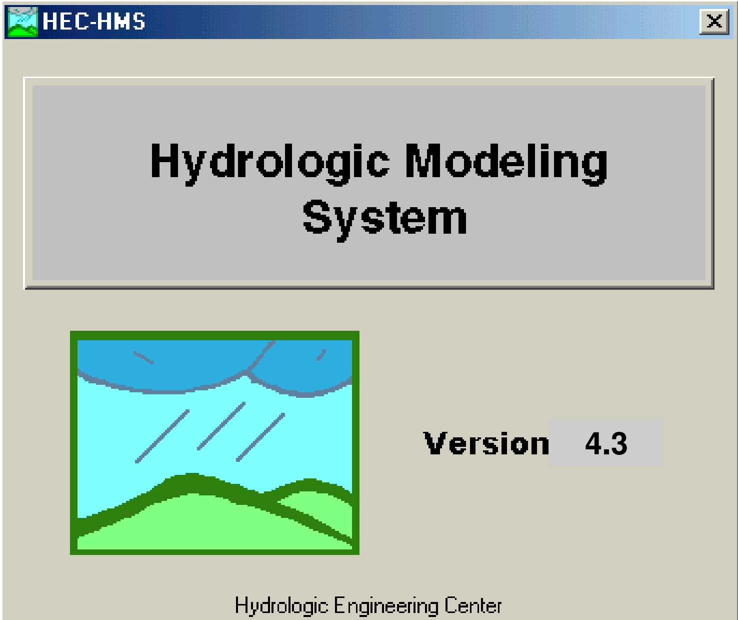
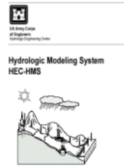
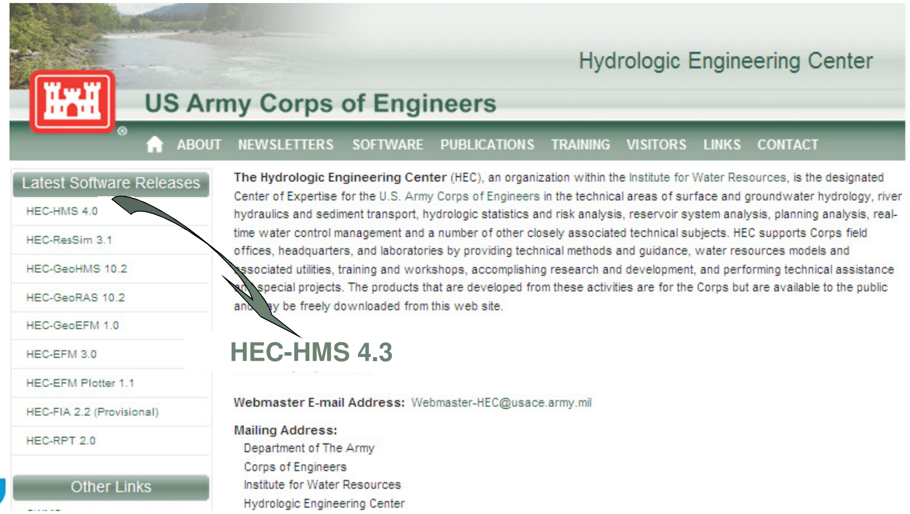




HEC-HMS

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



FLOOD ANALYSIS BASED ON THE HEC-HMS PROGRAM

- **Models implemented in HEC-HMS program and related concepts** (modelos implementados no programa HEC-HMS e conceitos afins)
- **Utilization of the HEC-HMS program** (utilização do programa HEC-HMS)

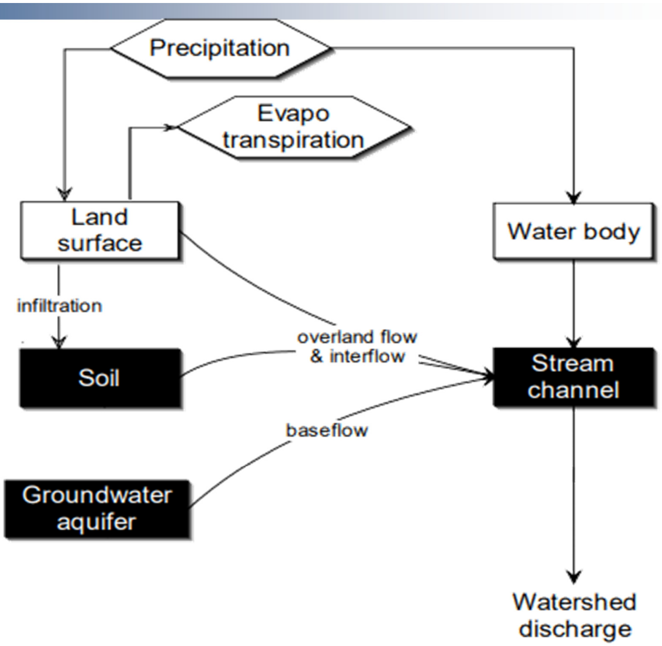


Figure 2. Typical representation of watershed runoff.

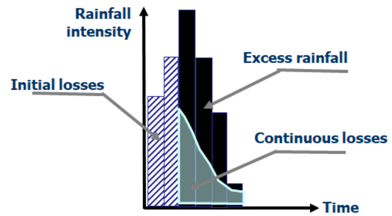
PROGRAMA HEC-HMS (cont.)

Models implemented in the HEC-HMS program and related concepts (modelos implementados no programa HEC-HMS e conceitos afins)

- **Precipitation losses: initial and continuous** (perdas de precipitações: iniciais e contínuas)
- **Excess rainfall-direct runoff models** (transformação das precipitações efetivas em escoamento direto)
- **Separation of the direct runoff and of the baseflow** (separação dos escoamentos direto e de base)
- **Propagation of flood hydrographs along rivers reaches** (propagação de hidrogramas em trechos de canal)
- **Flood routing in artificial reservoirs** (amortecimento de ondas de cheia em albufeiras)
- **Design rainfalls: values and hyetographs** (precipitações de projeto: valores e hietogramas)
- **.....**

Models for the rainfall losses (modelos de perdas de precipitação)

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



Models to transform of the excess rainfall into direct runoff under flood conditions (modelos de transformação da precipitação efetiva em escoamento direto em condições de cheia)

Table 3-2. Direct-runoff models

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

Models related to the contribution of the ground water to the flood hydrograph – baseflow (modelos referentes à contribuição do escoamento de base/esgotamento das reservas subterrâneas para o hidrograma de cheia)

Table 3-3. Baseflow models

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

(under flood design conditions the contribution of the baseflow is often neglectable)

(… em condições de projeto, a contribuição do escoamento de base é normalmente desprezável…)

Models for flood routing along river/channel reaches (modelos de propagação de hidrogramas em trechos de canal)

Table 3-4. Routing models

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 parameter

Table 5. Direct-runoff models.

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

Table 6. Baseflow models.

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

The choices for modeling channel flow with HEC-HMS are listed in Table 7. These so-called routing models simulate one-dimensional open channel flow.

Table 7. Routing models.

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

Lumped models

(modelos agregados)

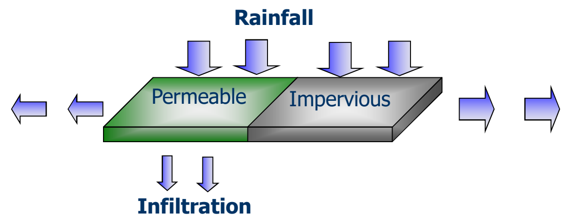
DESIGN RAINFALL ⟷ HEC-HMS PROGRAM:

- ✓ **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**
- ✓ **It also requires the specification of the design hyetograph except for some particular conditions … (USA)**

- ✓ Considera que, em cada instante, a precipitação é uniforme na área da bacia hidrográfica (modelo agregado).
- ✓ Requer a indicação da precipitação para que se pretende o cálculo do hidrograma.
- ✓ Requer a indicação do hietograma associado à anterior precipitação (… padrões implementados que, contudo, …. em Portugal, geralmente mediante o recurso a curvas intensidade- -duração-frequência).

RAINFALL LOSSES

- ✓ **The program can neglect the losses due to evaporation and evapotranspiration and take into account only the losses by infiltration… the relevant ones …**
- ✓ **The precipitation losses occur only in permeable areas; in the impervious areas all the rainfall becomes direct runoff … to address this issue the program requires the specification of the percentage of impervious areas**



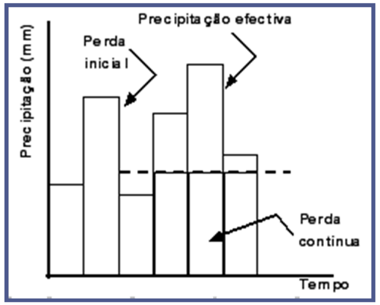
- ✓ O programa pode desprezar as perdas por evaporação e por evapotranspiração e, assim, atender apenas às perdas por infiltração … relevantes …
- ✓ Só associa perdas a áreas que não sejam impermeáveis, assumindo que, nas áreas impermeáveis, toda a precipitação é efetiva

Models for the rainfall losses more often utilized

a) Initial loss combined with a continuous loss with constant intensity

b) Soil Conservation Service (SCS) based on the curve number, CN

c) Infiltration models (Green-Ampt model)



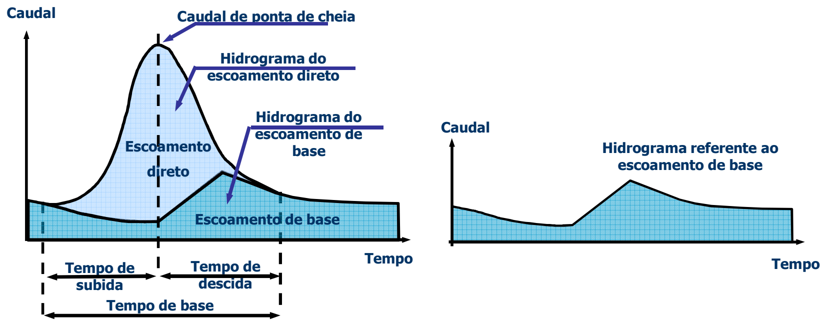
Data

a) Initial loss and rate of the continuous loss

b) CN

c) Soil/infiltration parameters

Models for the separation of the direct runoff from the baseflow



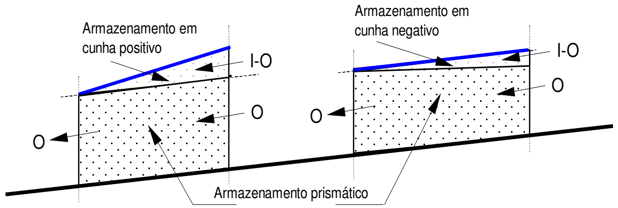
Models to transform the excess rainfall into a direct runoff flood hydrograph – based on the unit hydrograph model

Besides allowing to specify an unit hydrograph as data, the HEC-HMS program has implemented different synthetic unit hydrographs models with parameters that are established according to fundamental characteristics of the watersheds, namely physiographic characteristics easily obtained from the topographic representations:

- ✓ *Snyder synthetic unit hydrograp*
- ✓ *Soil Conservation Service, SCS, synthetic unit hydrograph*
- ✓ *Clark instantaneous synthetic unit hydrograph*

Flood routing along natural or artificial channels

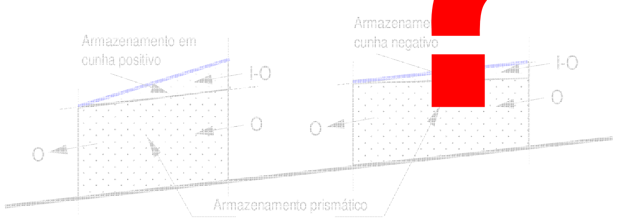
- ✓ *Lag time model (which considers that the flood wave only suffers a translation when propagating downstream, the lag time being the travel time)*
- ✓ *Muskingum model*
- ✓ *Muskinghum Cunge models*



$$\begin{cases} O2 = C0\,I2 + C1\,I1 + C2\,O1 \\ C0 = \dfrac{\Delta t/K - 2X}{2\,(1-X) + \Delta t/K} \\ C1 = \dfrac{\Delta t/K + 2X}{2\,(1-X) + \Delta t/K} \\ C2 = \dfrac{2\,(1-X) - \Delta t/K}{2\,(1-X) + \Delta t/K} \\ C0 + C1 + C2 = 1 \end{cases}$$

Flood routing along natural or artificial channels

- Lag time model (which considers that the flood wave only suffers a translation when propagating downstream, the lag time being the travel time)
- Muskingum model
- Muskinghum Cunge models



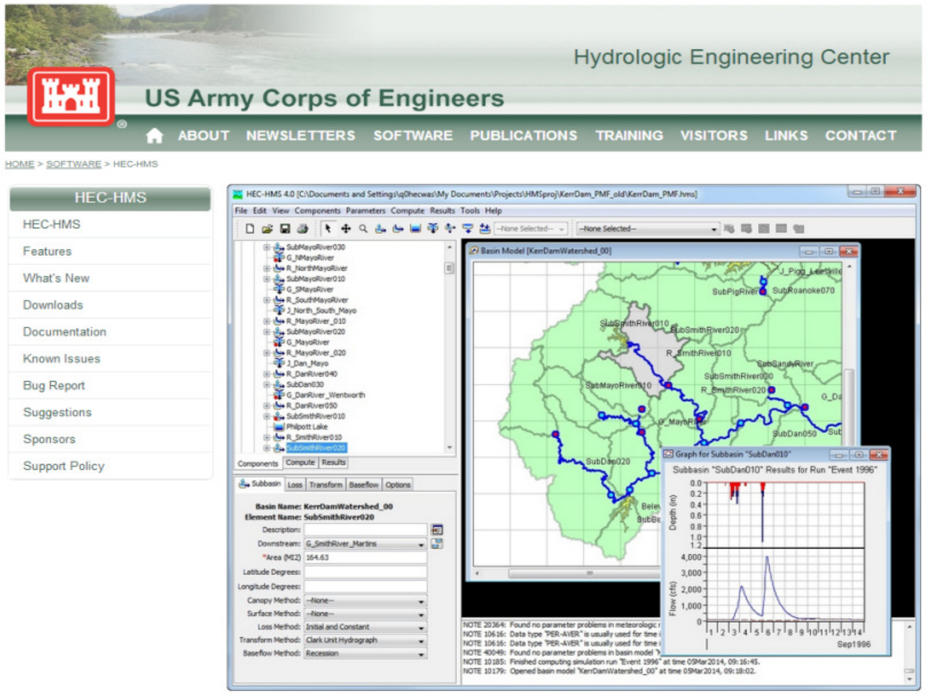
$$O2 = C0\, I2 + C1\, I1 + C2\, O1$$

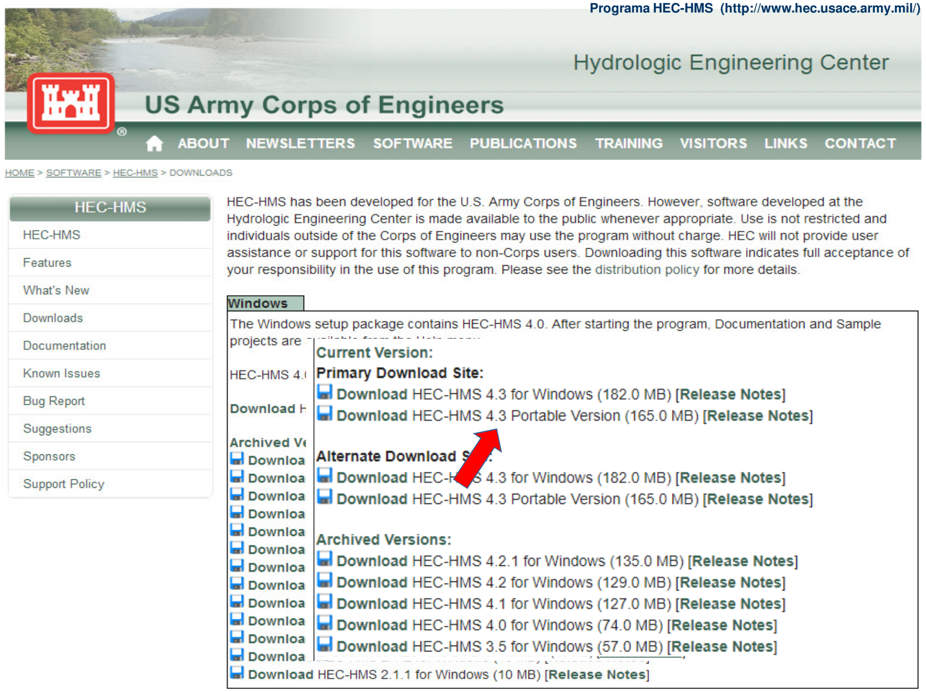
$$C0 = \frac{\Delta t/K - 2X}{2(1-X) + \Delta t/K}$$

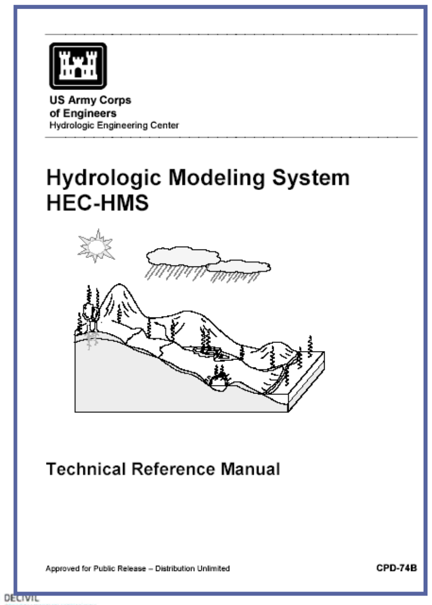
$$C1 = \frac{\Delta t/K + 2X}{2(1-X) + \Delta t/K}$$

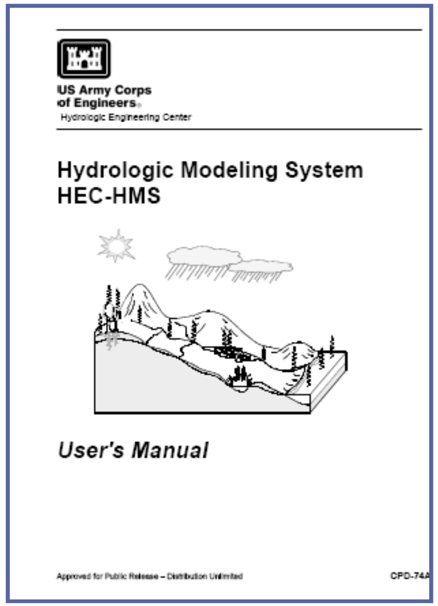
$$C2 = \frac{2(1-X) - \Delta t/K}{2(1-X) + \Delta t/K}$$

$$C0 + C1 + C2 = 1$$









Steps of the HEC-HMS application

1) Basin model (Is not a representation of the basin ... 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)

2) Temporal data/time series (precipitation, discharge, ...) and **paired data** (rating curve, ...)

3) Meteorologic model (where the analysis that is going applied to the data is specified)

4) Control specifications (computation time interval and time step)

5) Execution/run of the program (without or with parameters optimization)

Results

Steps of the HEC-HMS application

1) Basin model (Is not a representation of the basin ... 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)

2) Temporal data/time series (precipitation, discharge, ...) and **paired data** (rating curve, ...)

3) Meteorologic model (where the analysis that is going applied to the data is specified)

4) Control specifications (computation time interval and time step)

5) Execution/run of the program (without or with parameters optimization)

Project

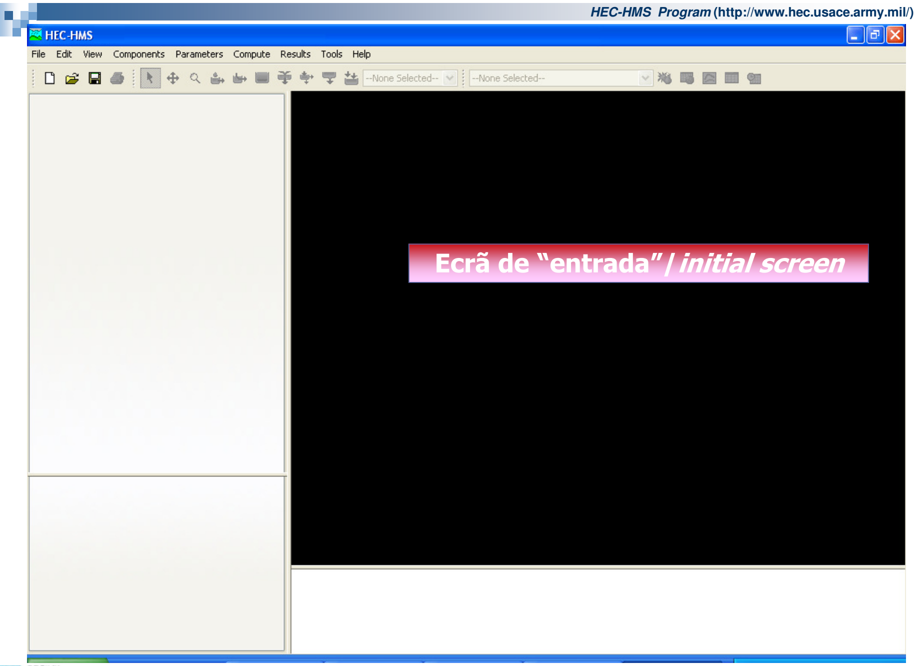
Results

Example 1

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 design effective rainfall with a return period of 50 years is 38 mm/h. Consider the application of the SCS HUS

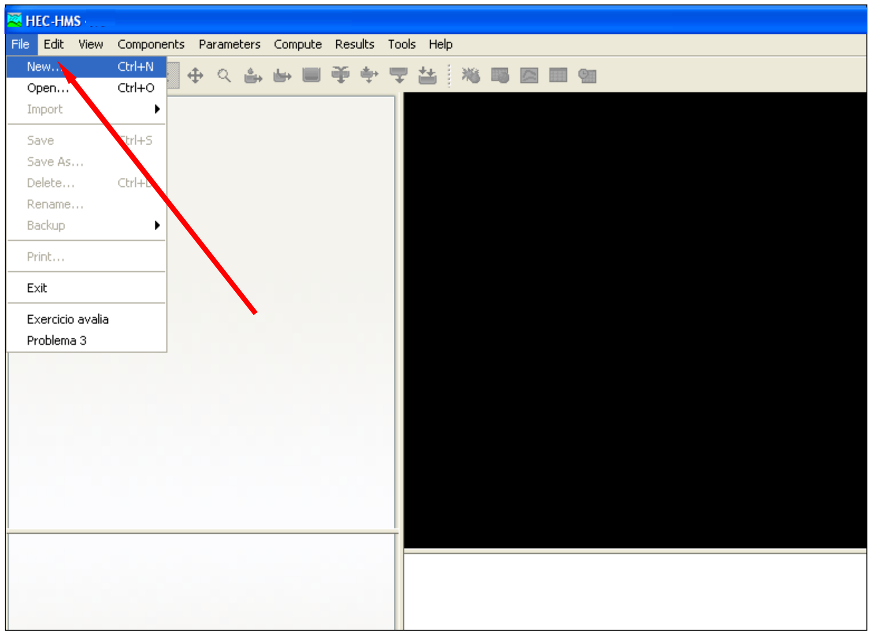
Aplique o programa HEC-HMS à análise de cheias numa bacia hidrográfica com a área de 100 km² e com o tempo de concentração de 2 h para o qual a intensidade média da precipitação efetiva de projeto com o período de retorno de 50 anos é de 38 mm/h. Considere a aplicação do HUS do SCS

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

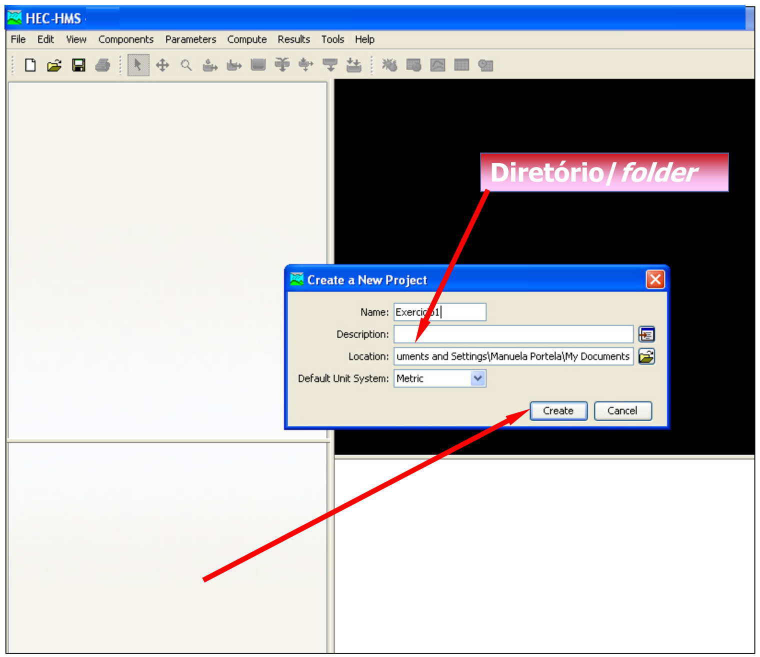


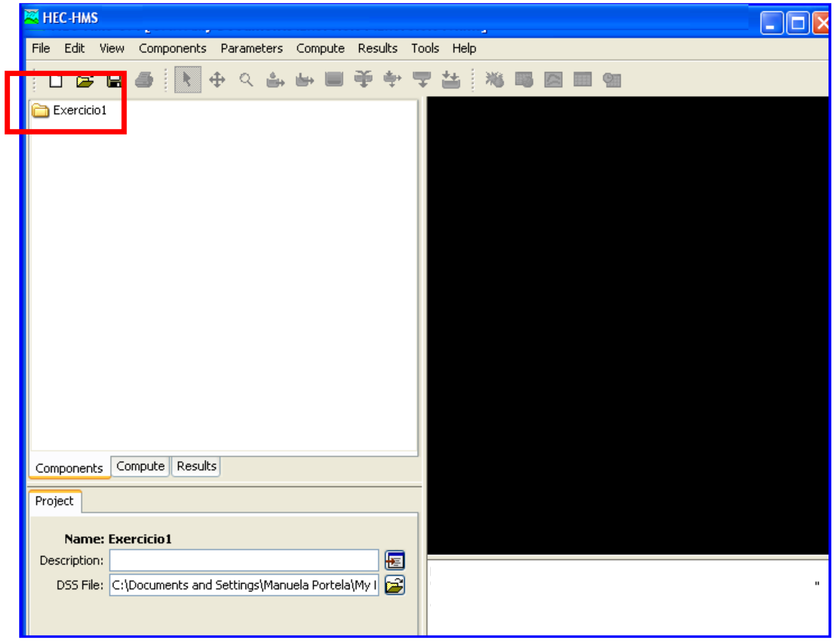
a) Tools/"setting" option for verification of the program settings (defualt setting and units system) (No TOOLS/"settings" averiguar as configurações)

b) *CREATE A NEW PROJECT* (CRIAÇÃO DE UM NOVO PROJETO)



Criar um novo projeto - opção de *New project* no *File menu (Create a new project)*

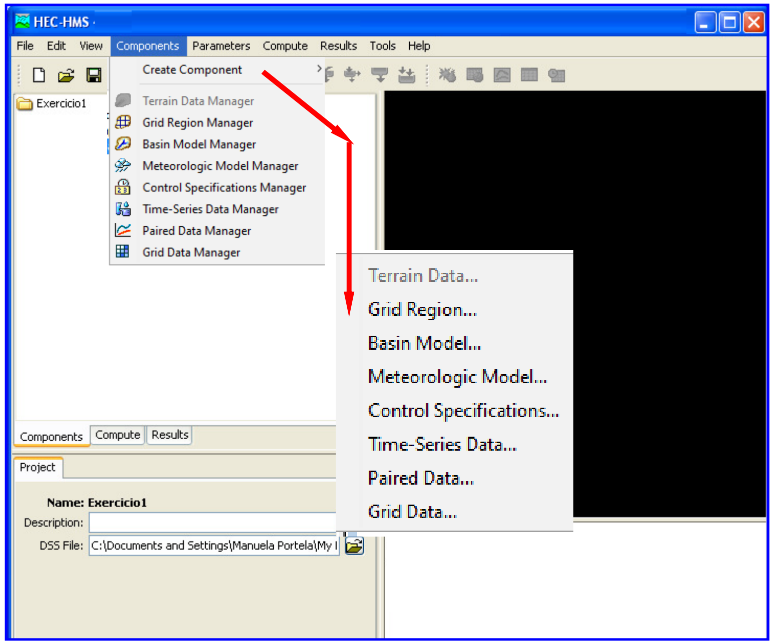


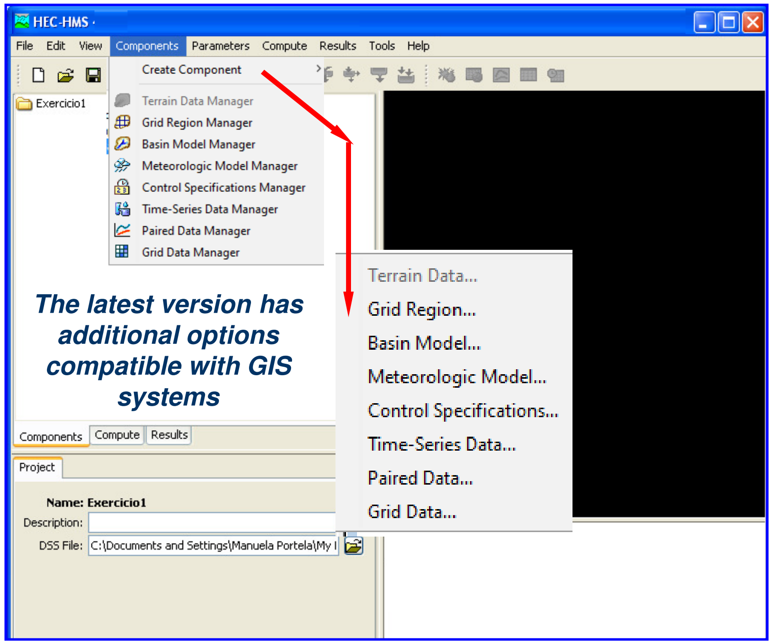


c) CRIAÇÃO DO MODELO DE BACIA / *CREAT THE BASIN MODEL*

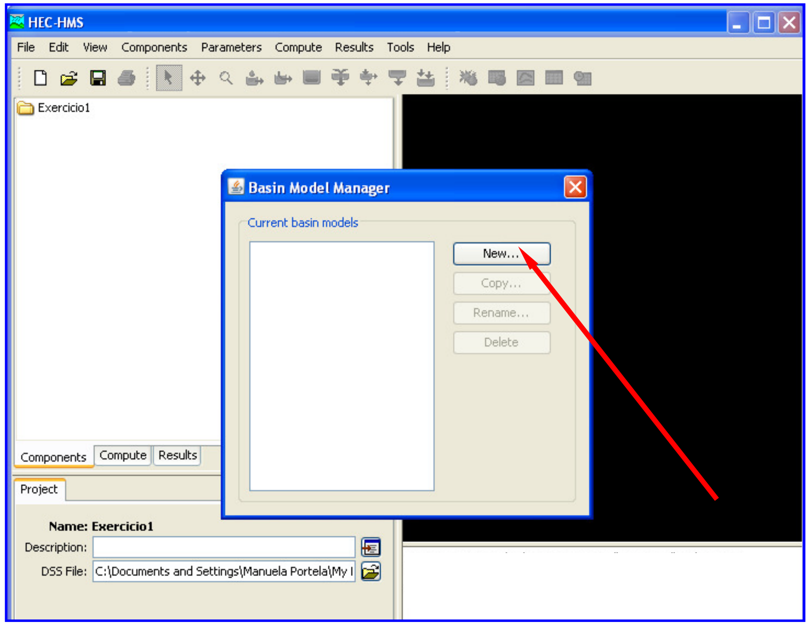
Não é a representação da bacia ... "ambiente de cálculo" : componentes do sistema (bacias hidrográficas, trechos de rio, albufeiras) e modelos e parâmetros dos modelos aplicáveis a cada componente (modelos de perdas da precipitação, do escoamento de base, de transformação da precipitação efetiva em hidrogramas de cheia, de propagação de hidrogramas, de amortecimento de ondas de cheia, etc.

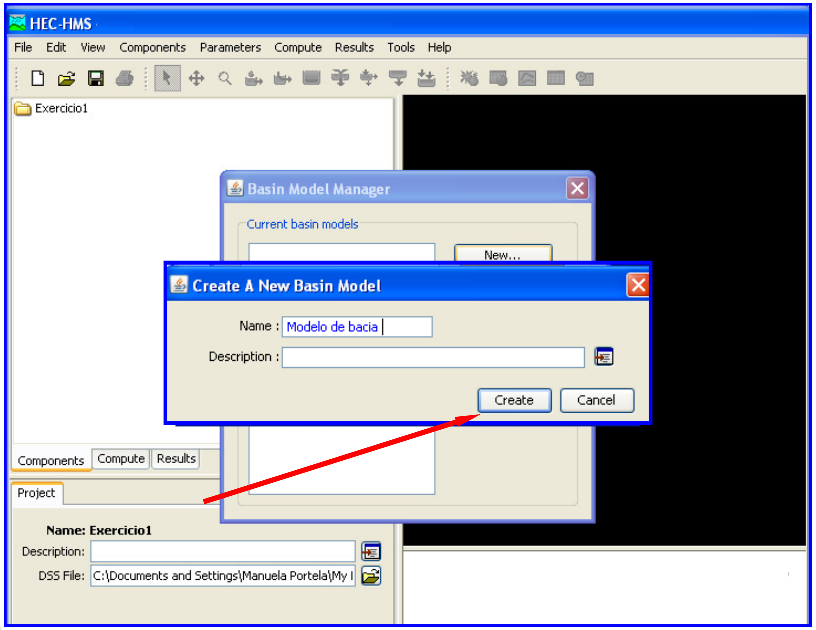
It is not the representation of the basin ... Is it only the way to define the physical components that should be accounted for (river basins, river stretches, reservoirs), models and parameters of the models applicable to each component (models for precipitation losses, for transformation of the excess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

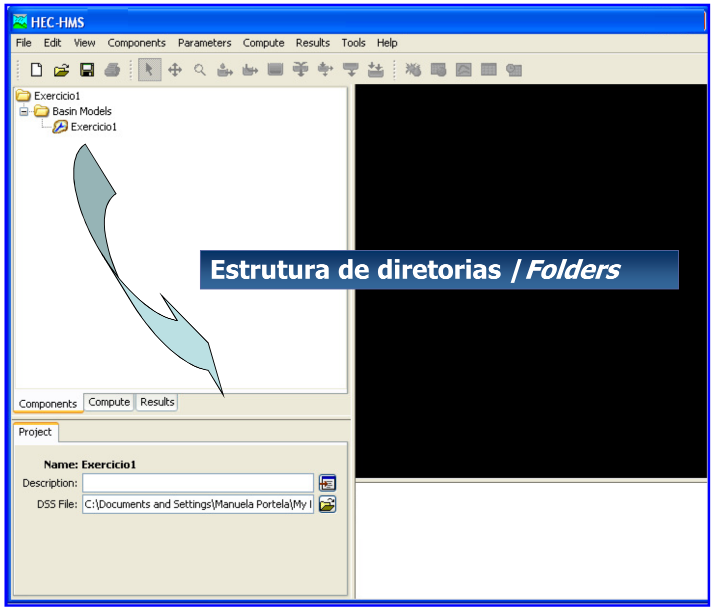




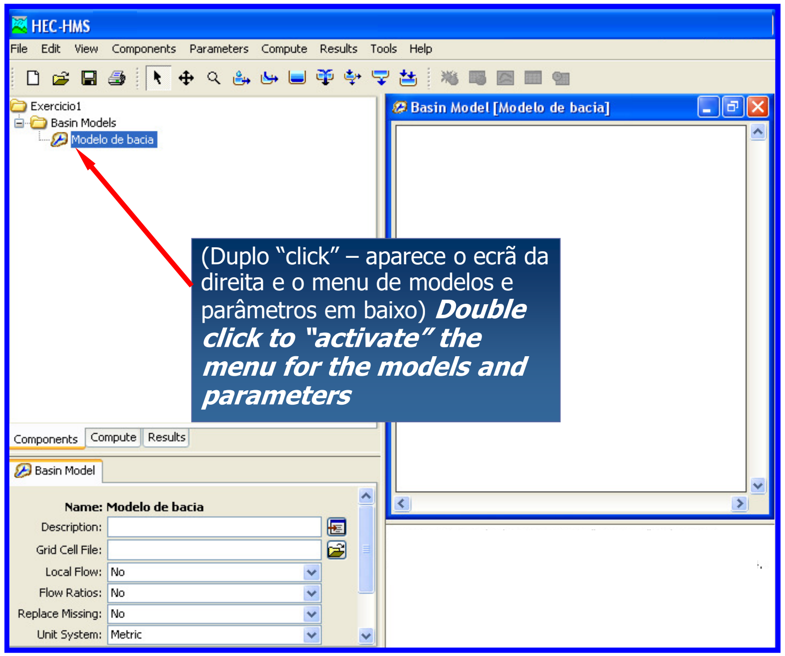
The latest version has additional options compatible with GIS systems



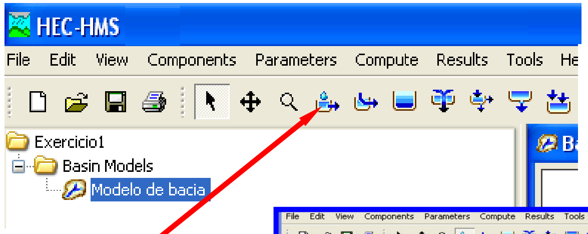


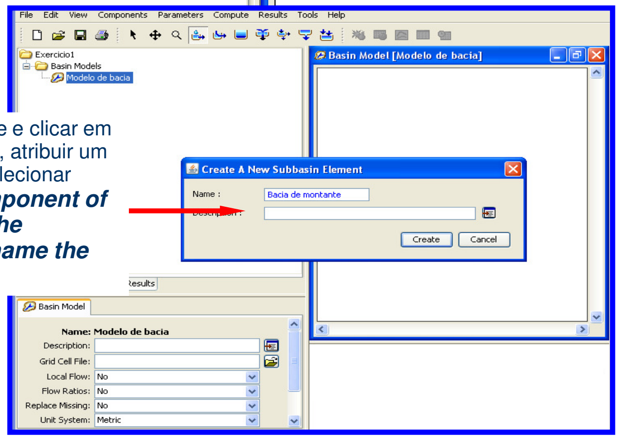


Estrutura de diretorias / *Folders*

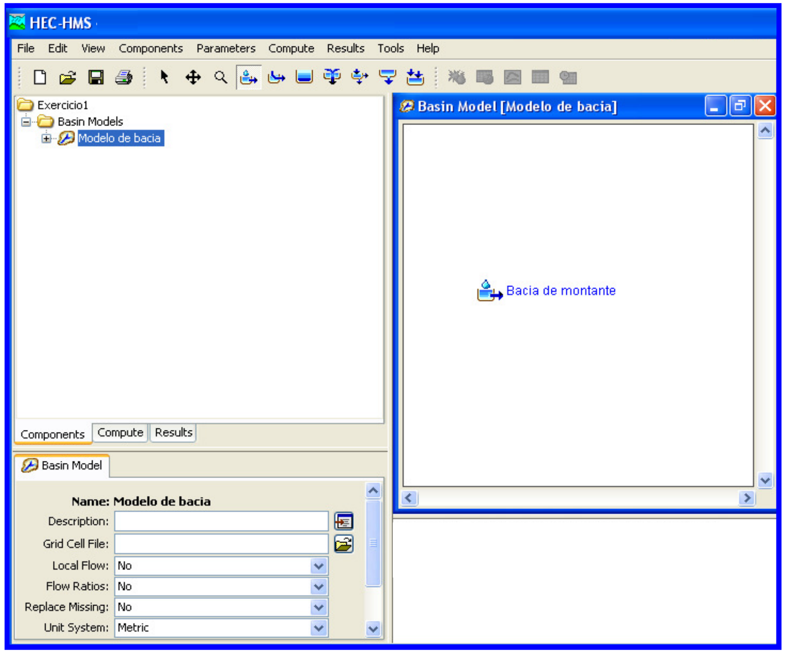


(Duplo "click" – aparece o ecrã da direita e o menu de modelos e parâmetros em baixo) ***Double click to "activate" the menu for the models and parameters***





(Selecionar a componente e clicar em cima da área de desenho, atribuir um nome à componente e selecionar criar) ***Select each component of the system; click in the "drawing" area and name the component***

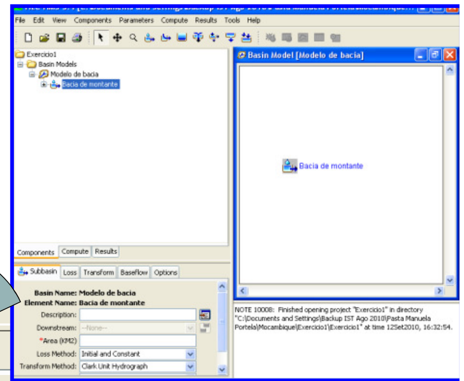


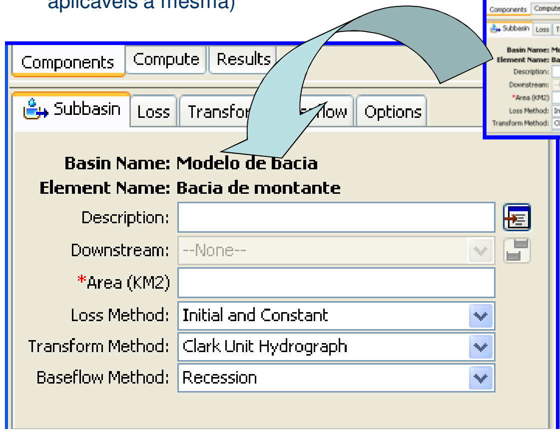
Possible components / componentes possíveis

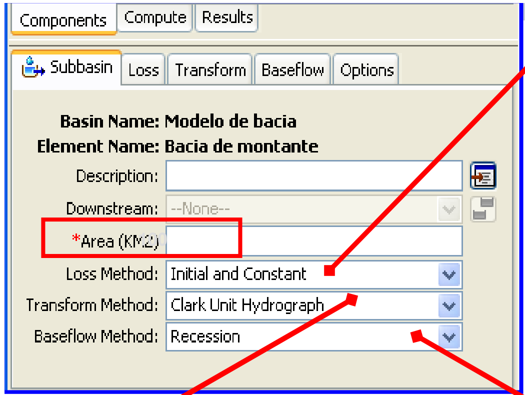
- **Subbasins (sub bacias)** - contains data for subbasins (losses, UH transform, and baseflow)
- **Reaches (trechos)**- connects elements together and contains flood routing data
- **Junctions (junções)** - connection point between elements
- **Reservoirs (reservatórios)** - stores runoff and releases runoff at a specified rate (storage-discharge relation)
- **Sinks (depressões) –** singular point with an inflow and without outflow (inflow accumulation point)

  Sources (exsurgências) – singular point with only outflow and no inflow
- **Diversions (ramificações) -** diverts a specified amount of runoff to an element based on a rating curve - used for detention storage elements or overflows

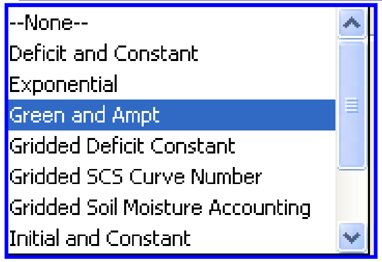
For each component, identify the applicable models and their parameters and respective values (Nas sucessivas tabelas que aparecem em baixo, à esquerda, introduzir, componente a componente, as caraterísticas da componente e os parâmetros dos modelos aplicáveis à mesma)



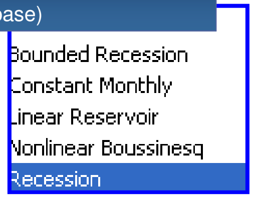


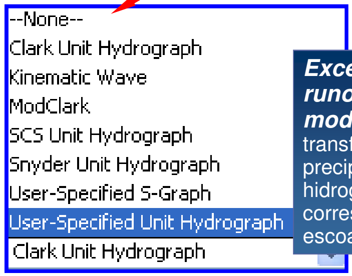


Rainfall losses models (modelos de perdas da precipitação)



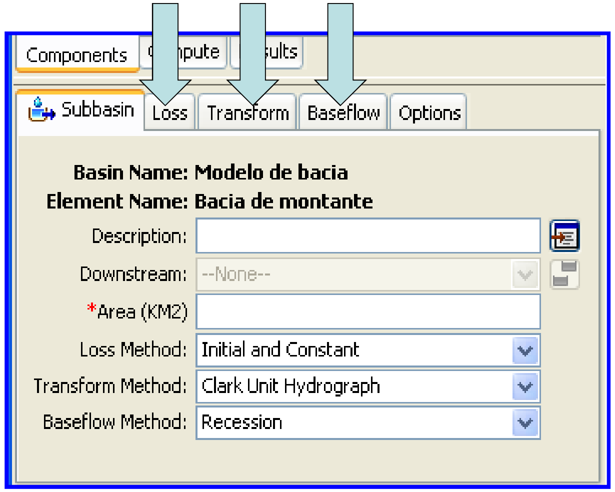
Baseflow models (modelos de escoamento de base)



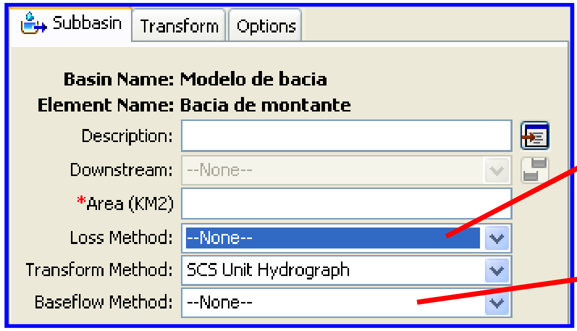


Excess rainfall-direct runoff transformation models (modelos de transformação de precipitações efetivas em hidrogramas de cheia correspondentes ao escoamento)

Each model to be applied must be identified and the values of its parameters specified (tem de se selecionar os modelos aplicáveis e para cada modelo introduzir os respetivos parâmetros)

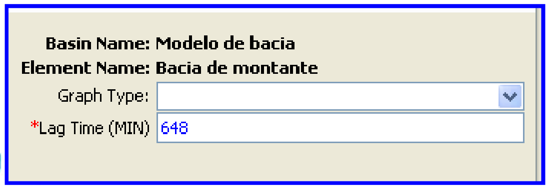


No caso do exercício 1 … *Specifically for exemple 1 …*



Sem perdas por se fornecerem logo as precipitações efetivas e sem escoamento de base

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



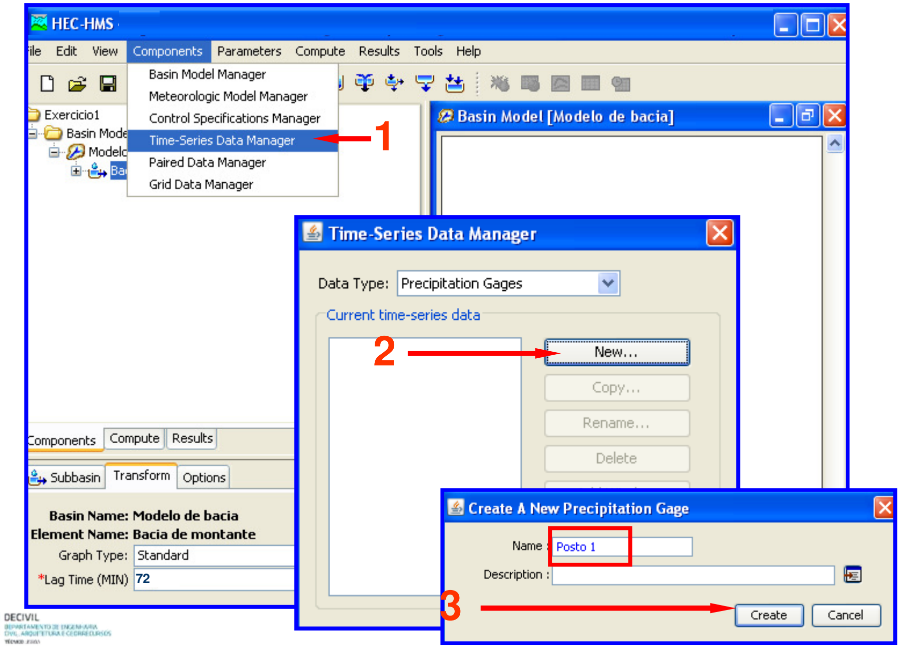
HUS do SCS com um único parâmetro: tlag=0.6 tc

SCS HUS with only one parameter: tlag=0.6 tc

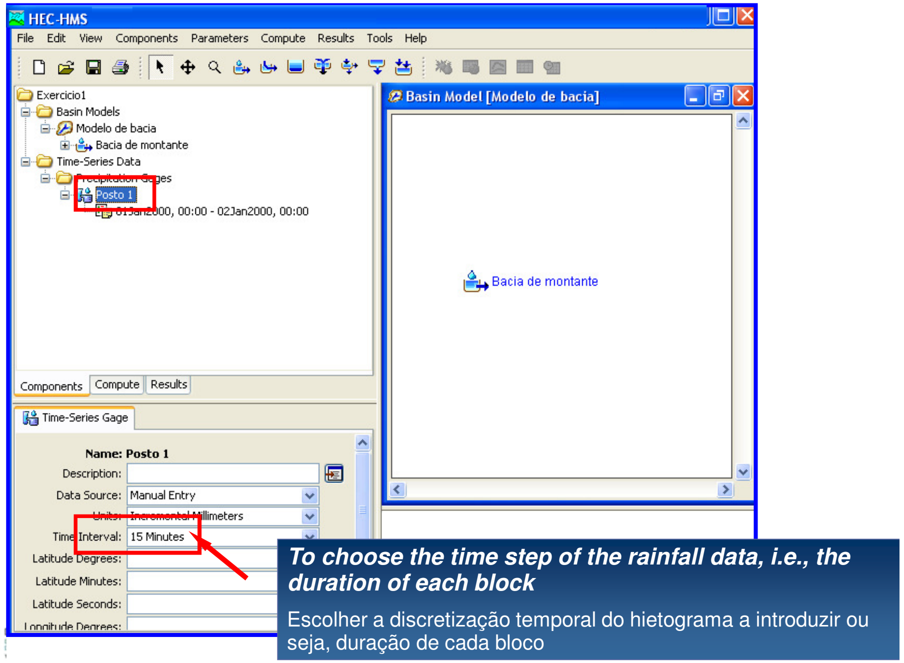
d) *DEFINITION OF THE BASE DATE* / INTRODUÇÃO DOS DADOS DE BASE

Time data or hydrologic data such as rainfall or discharge data and paired data such as rating curves, volumes storage in the reservoir

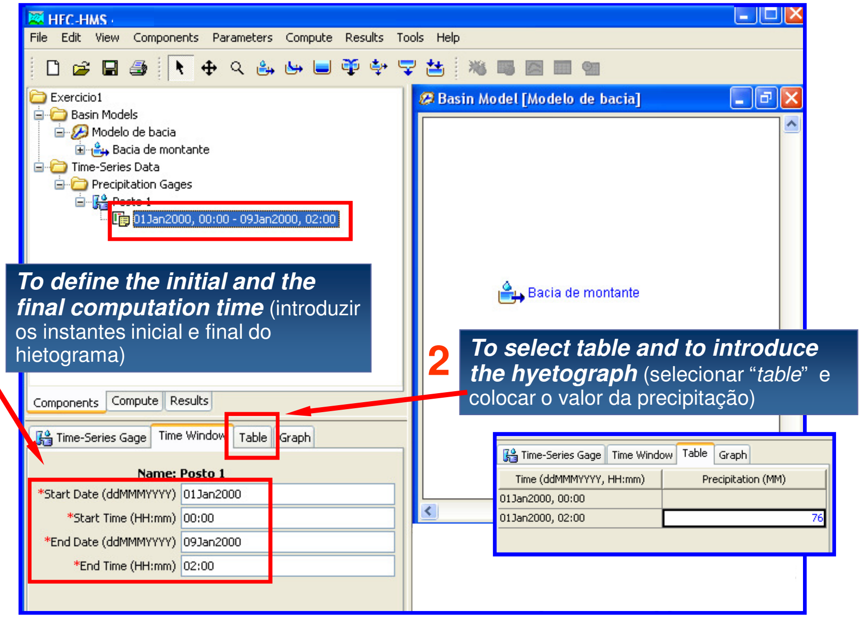
Dados temporais (*time series data manager*) referentes a dados hidrológicos tais como precipitações e caudais e dados "emparelhados" (*paired data manager*) respeitantes, por exemplo, a curvas de volumes armazenados em albufeiras que intervêm no amortecimento de ondas de cheia em albufeiras



DADOS HIDROLOGICOS / *Hydrologic data – Time series data manager*



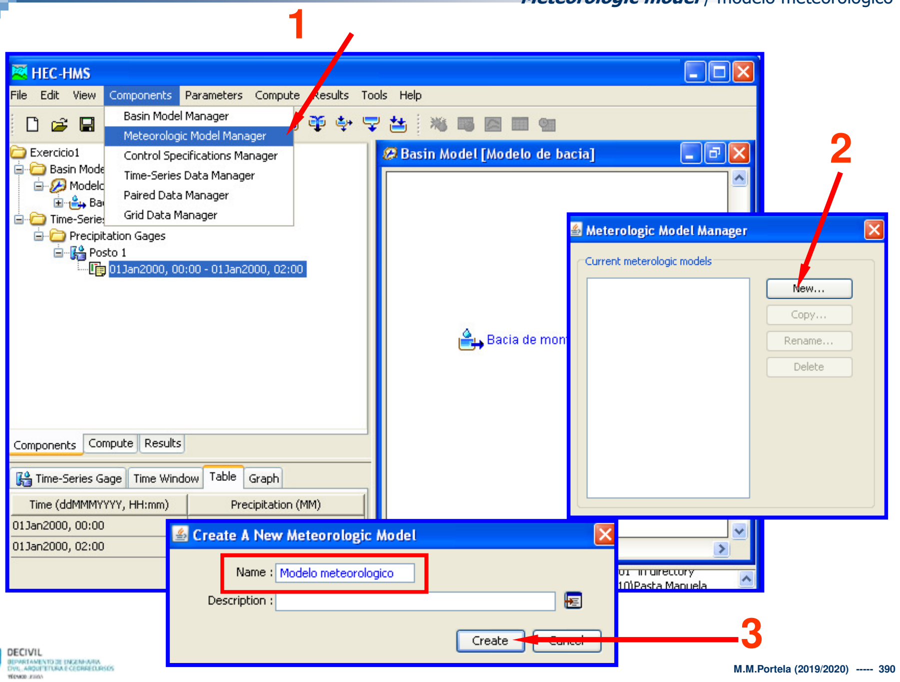
DADOS HIDROLOGICOS / *Hydrologic data – Time series data manager*

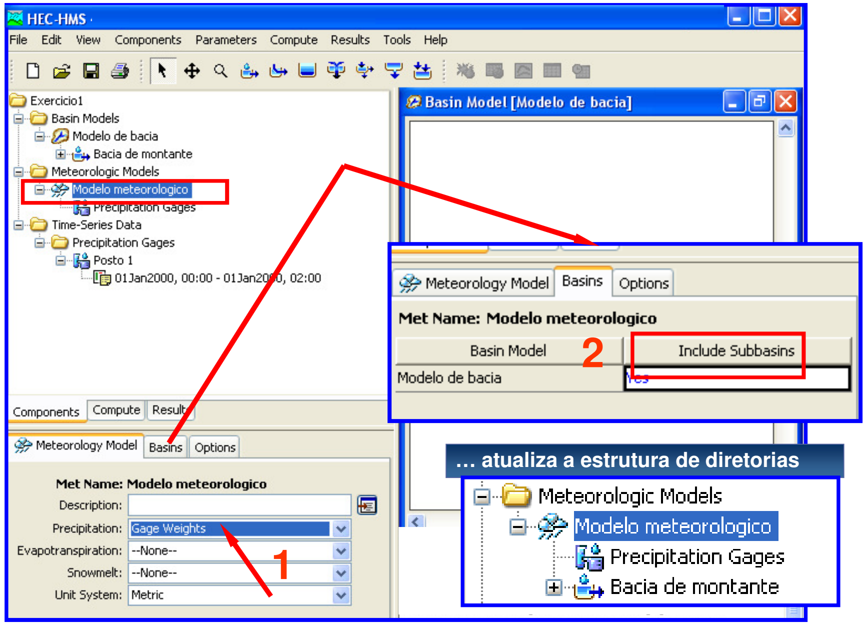


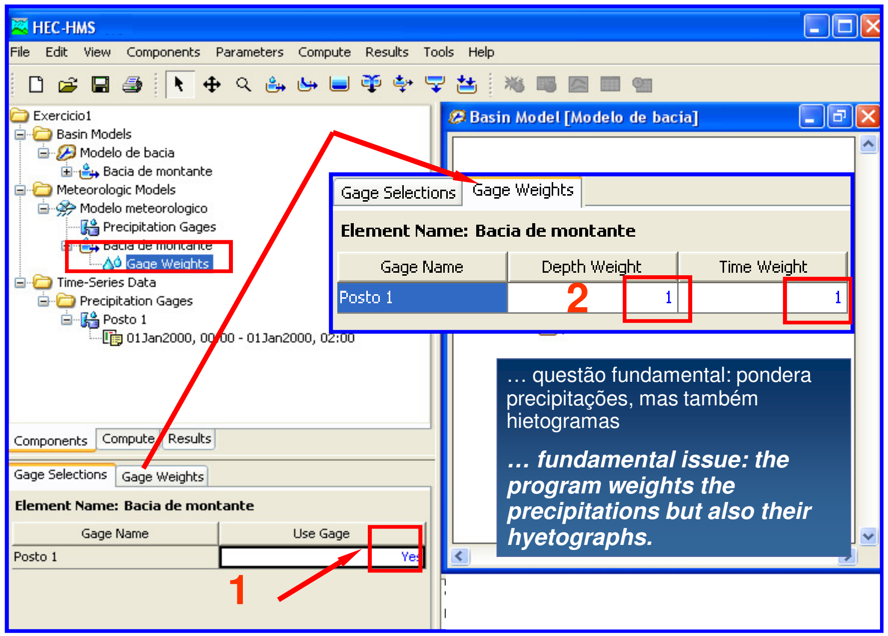
e) *DEFINITION OF THE METEOROLOGIC MODEL* – DEFINIÇÃO DO MODELO METEOROLÓGICO

The meteorologic model identifies which data should be considered and how the data should be combined (ex.: which rain gages are going to be applied and their weights, according to the Thiessen method)

O modelo meteorológico identifica, de entre os dados fornecidos, os que intervêm no cálculo e como devem ser combinados (ex.: pesos do método de Thiessen para cálculo das precipitações ponderadas nas bacias hidrográficas; podem-se fornecer tantos modelos meteorológicos quantas as combinações em vista dos dados hidrológicos



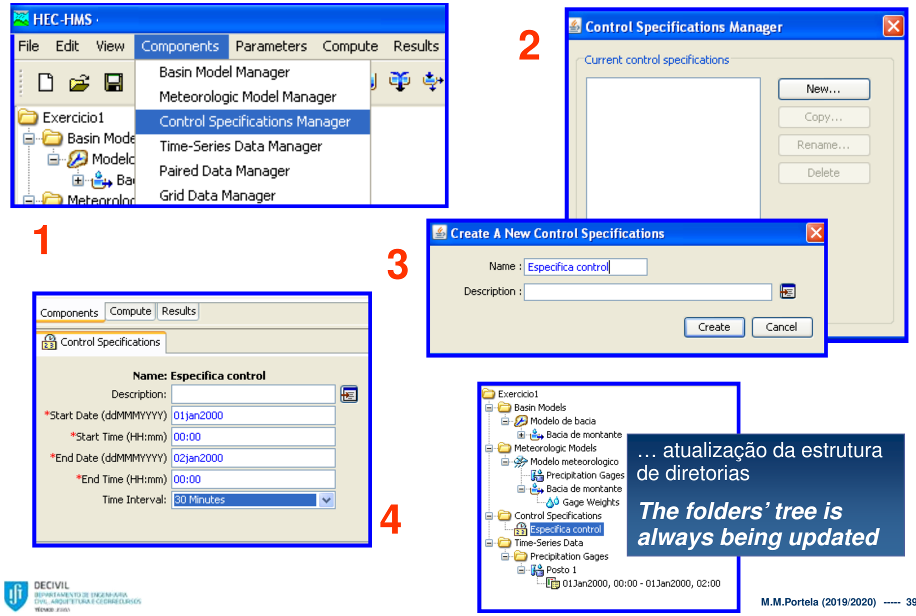




f) *DEFINITION OF THE CONTROL SPECIFICATIONS* / DEFINIÇÃO DAS ESPECIFICAÇÕES DE CONTROLO

Definição do intervalo de tempo de cálculo e do passo de cálculo

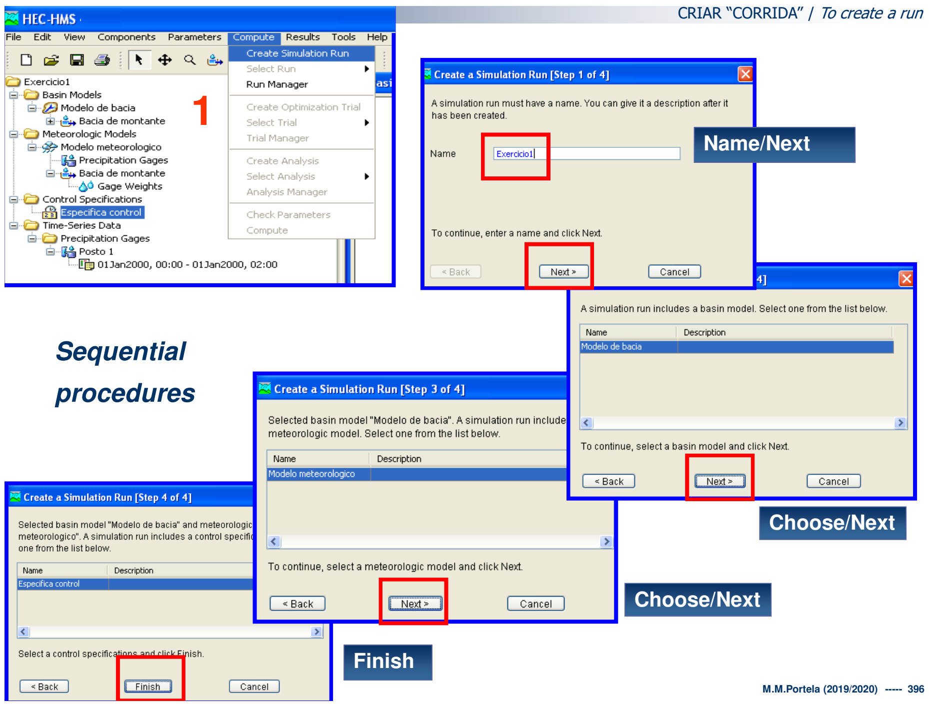
Definition of the time interval and of the time step



g) *CREATING A RUN* / CRIAÇÃO DA "CORRIDA"

Identification of the assemble of components models and data to be considered

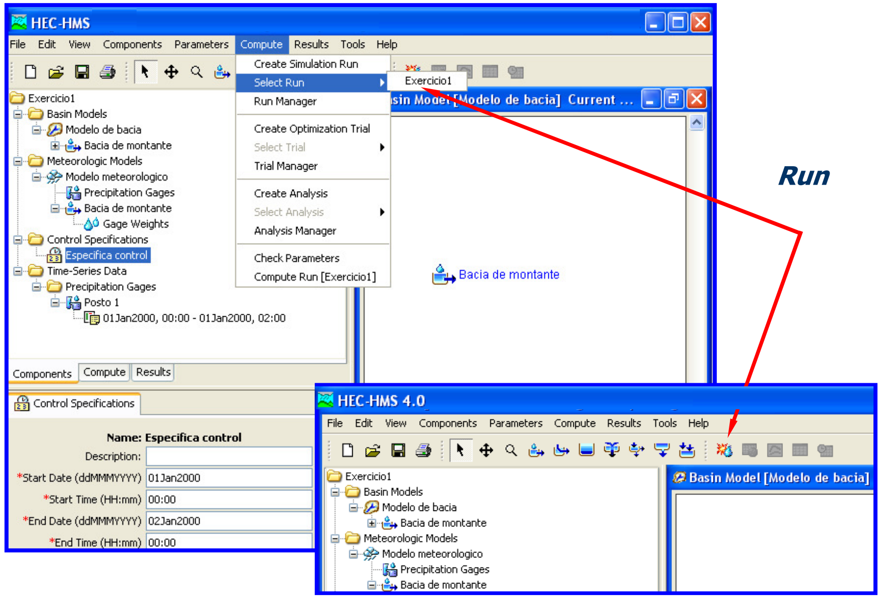
Definição do encadeado de modelos de bacia, meteorológico e referente às especificações de controlo a considerar no cálculo (num mesmo projeto podem haver diferentes modelos do anterior tipo pelo que é necessário identificar o conjunto de modelos para o qual se pretende obter resultados).



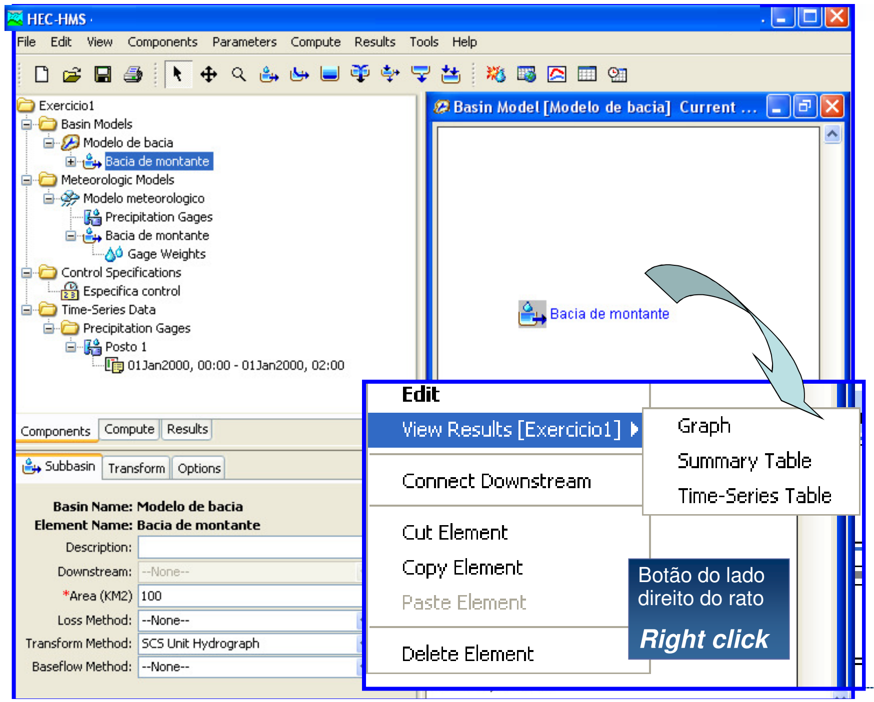
h) *RUN* / EXECUÇÃO DO PROGRAMA

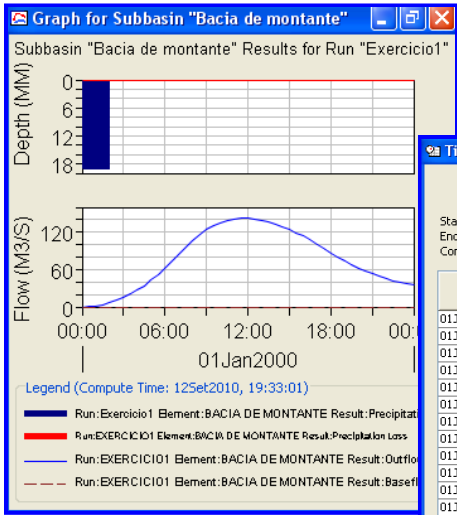
Seleção da "corrida" para a qual quer obter resultados e execução do programa

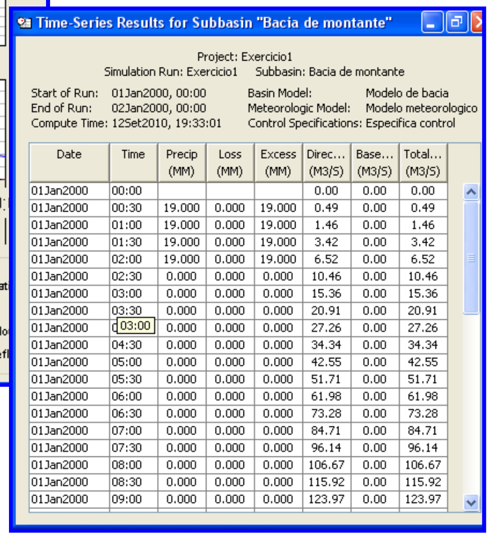
Selection of the run for which we want to get the results (there may be several runs composed upon different basin / meteorologic / control specifications models)



i) *RESULTS* / VISUALIZAÇÃO DE RESULTADOS







Time-Series Results for Subbasin "Bacia de montante"

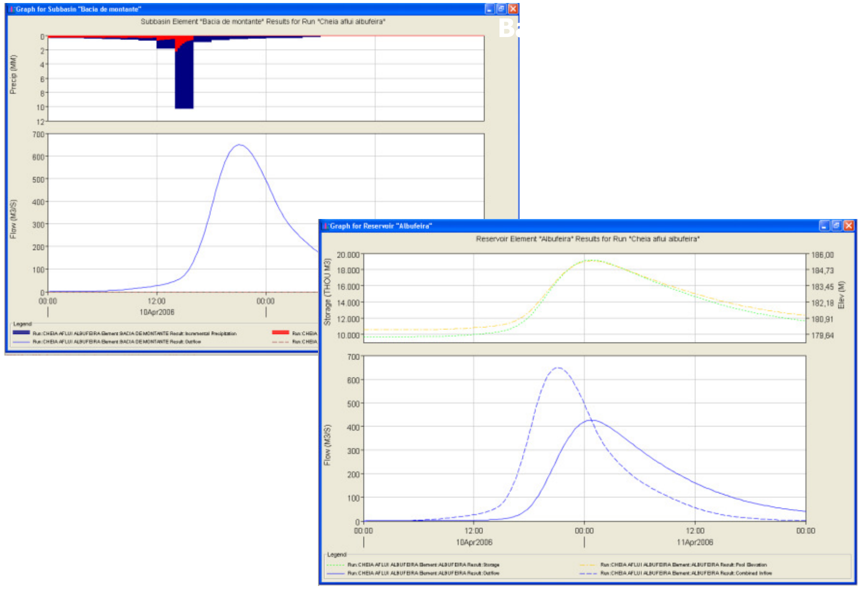
Project: Exercicio1
Simulation Run: Exercicio1 Subbasin: Bacia de montante

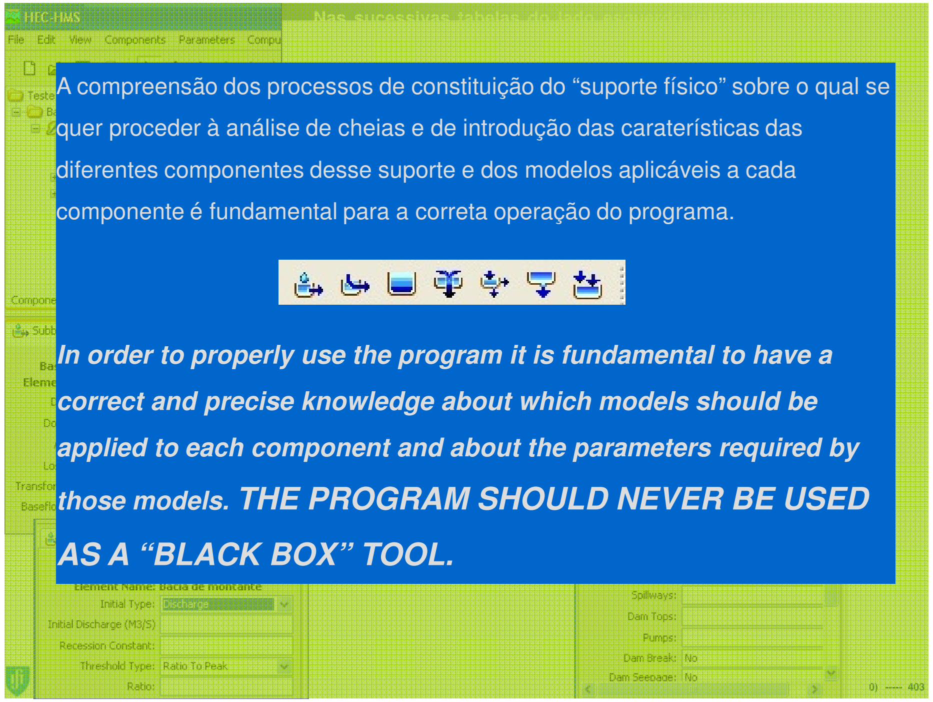
Start of Run: 01Jan2000, 00:00 Basin Model: Modelo de bacia
End of Run: 02Jan2000, 00:00 Meteorologic Model: Modelo meteorologico
Compute Time: 12Set2010, 19:33:01 Control Specifications: Especifica control

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	03:00	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

Resultados (sob a forma de gráficos ou de tabelas exportáveis para o Excel)

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





A compreensão dos processos de constituição do "suporte físico" sobre o qual se quer proceder à análise de cheias e de introdução das caraterísticas das diferentes componentes desse suporte e dos modelos aplicáveis a cada componente é fundamental para a correta operação do programa.

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.

Exemplo 2

Aplique o programa HEC-HMS à análise de cheias numa bacia hidrográfica com a área de 100 km^2 e com o tempo de concentração de 2 h para o qual a intensidade média da precipitação efetiva de projeto com o período de retorno de 50 anos é de 38 mm/h. Considere a aplicação do HUS do SCS.

Cerca de 9 km a jusante da secção de referência da bacia hidrográfica do Exemplo 1 o curso de água recebe um afluente a que corresponde a área da bacia hidrográfica de 35 km^2 e o tempo de concentração de 1 h. A bacia hidrográfica intermédia é desprezável.

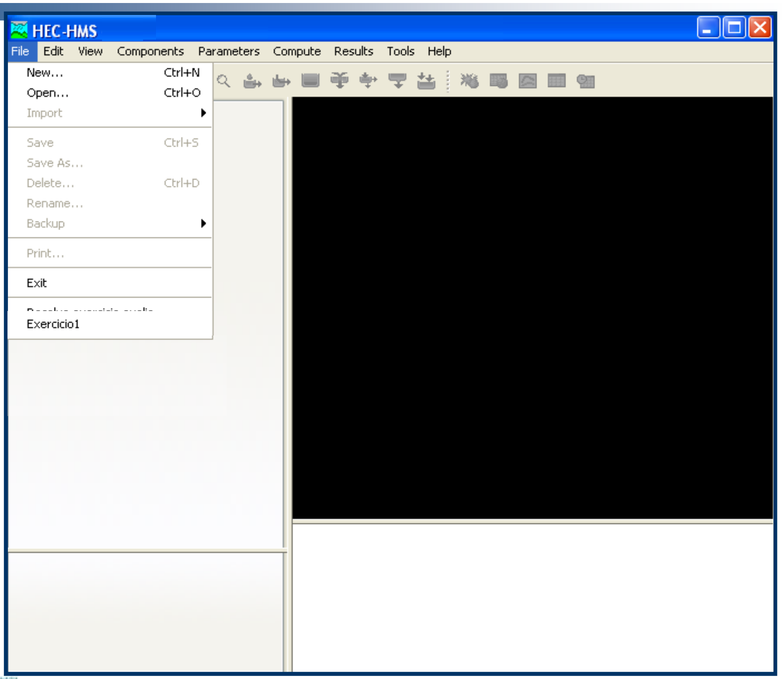
Considerando que a velocidade média de propagação do hidrograma de cheia no trecho de rio é de cerca de 0.5 m/s e que a intensidade média da precipitação efetiva de projeto antes indicada também se aplica à bacia hidrográfica do afluente, determine o hidrograma de cheia na secção de confluência do curso de água com esse afluente. Aplique o HUS do SCS e o modelo do tempo de lag na propagação.

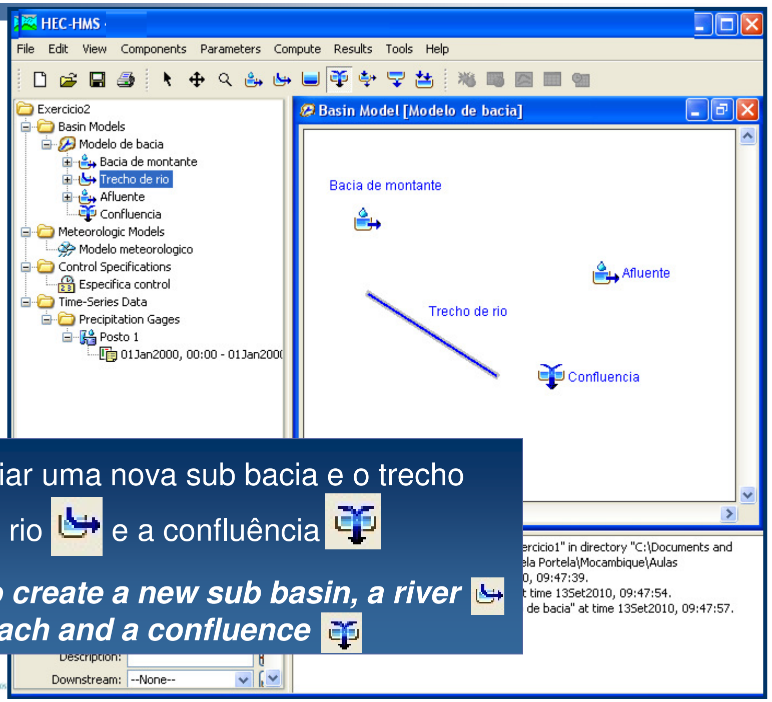
Example 2

Apply the HEC-HMS program to characterize the flood in a catchment with100 km^2 and a time of concentration of 2 h. The average intensity of excess rainfall with 50-years return period is 38 mm / h. Use the SCS HUS.

9 km downstream, there is a tributary with a catchment area of 35 km^2 and the concentration time of 1 h. The intermediate catchment area is negligible.

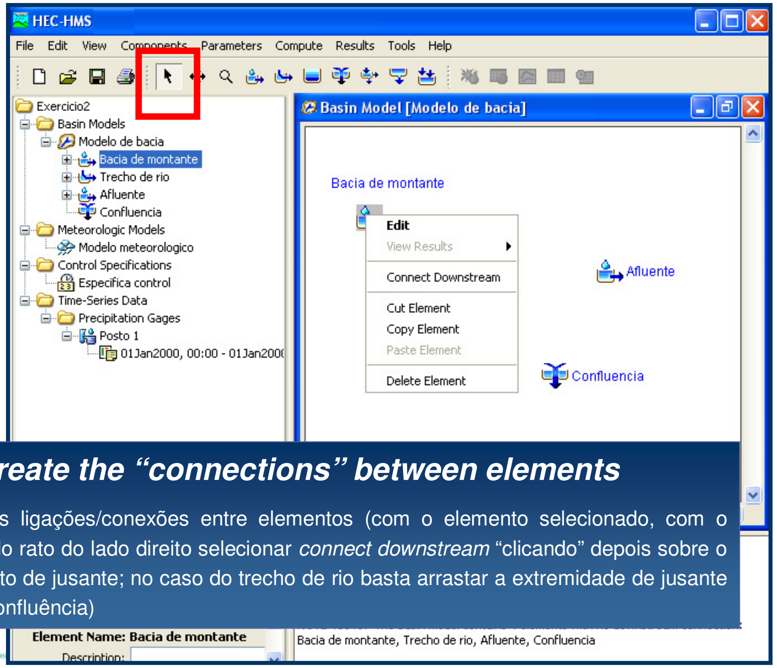
Considering that the design rainfall also applies to the catchment of the tributary and that the flood hydrograph propagates along the main river with an average velocity 0.5 m/s and, compute the flood hydrograph at the confluence. Use the SCS HUS in the catchment of the tributary and lag time model for flood routing along the main river.





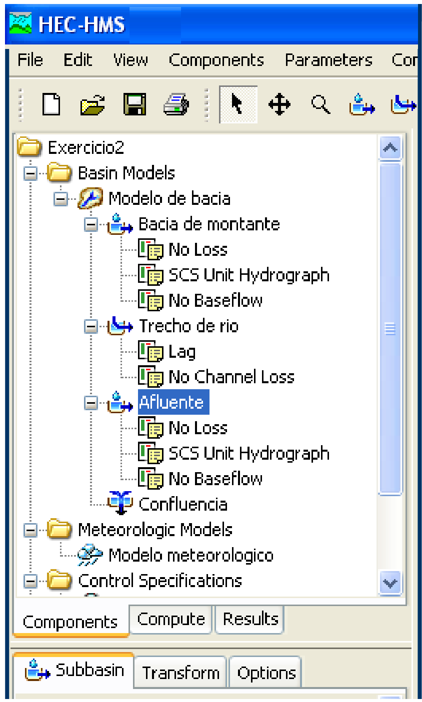
Criar uma nova sub bacia e o trecho de rio e a confluência

To create a new sub basin, a river reach and a confluence



To create the "connections" between elements

Criar as ligações/conexões entre elementos (com o elemento selecionado, com o botão do rato do lado direito selecionar *connect downstream* "clicando" depois sobre o elemento de jusante; no caso do trecho de rio basta arrastar a extremidade de jusante até à confluência)



Para os novos elementos indicam-se as caraterísticas, os modelos a aplicar e os respetivos parâmetros

Specify the models and the parameters that should be applied to the diferente elements

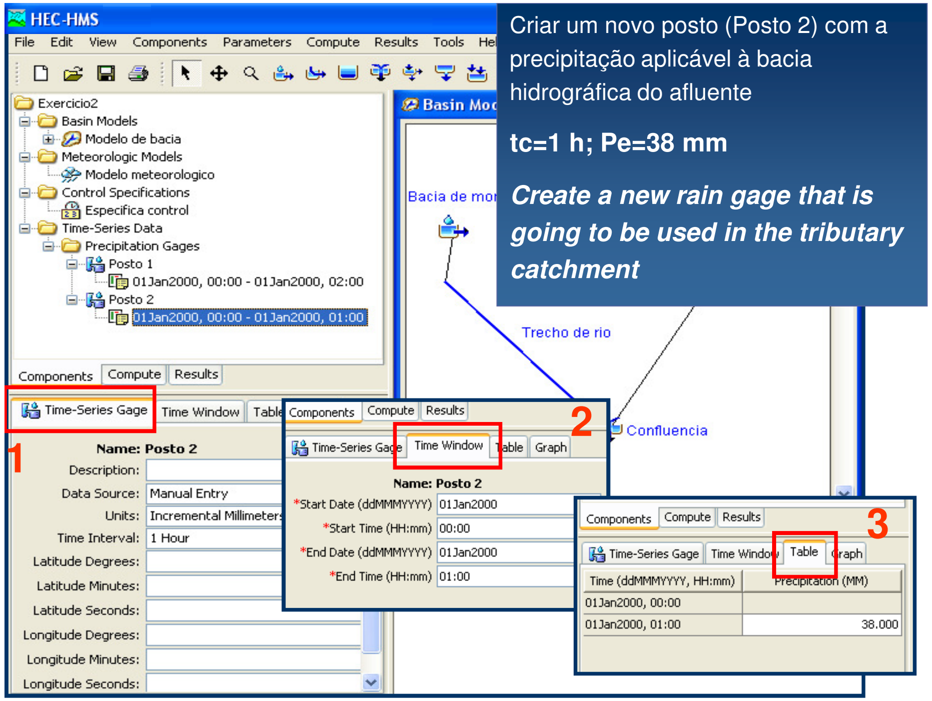
Na bacia hidrográfica do afluente: área da bacia hidrográfica – 35 km^2; sem perdas de precipitação; modelo do HUS do SCS para tlag=0.6 tc = 36 min.

No trecho de rio – propagação com base no modelo do tempo de lag para t=9000/0.5/60=300 min.

Criar um novo posto (Posto 2) com a precipitação aplicável à bacia hidrográfica do afluente

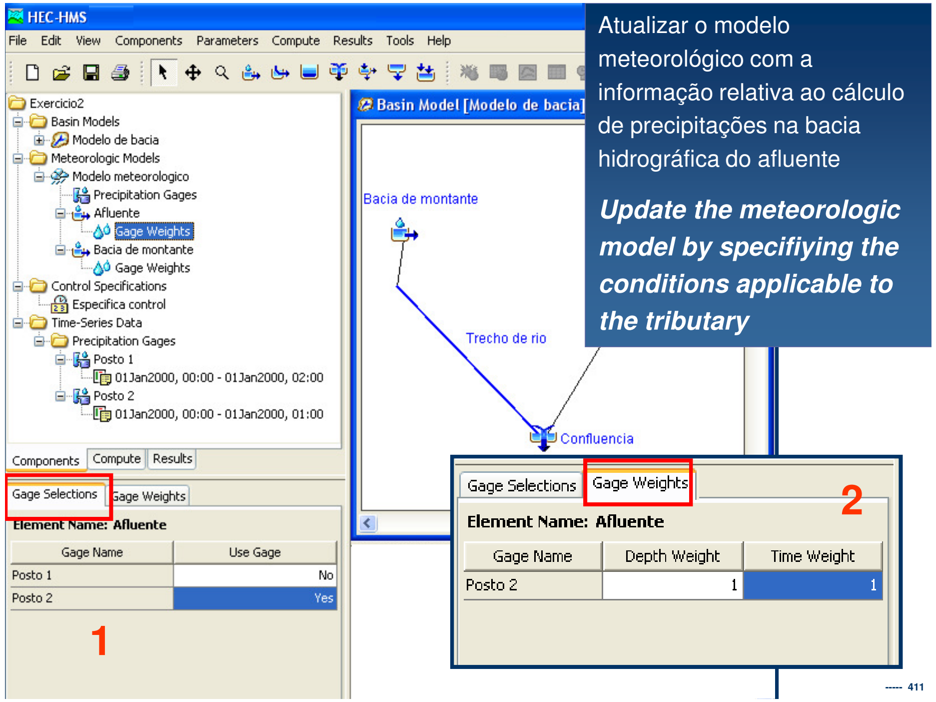
tc=1 h; Pe=38 mm

Create a new rain gage that is going to be used in the tributary catchment

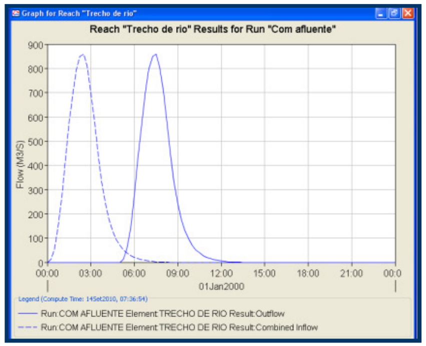


Atualizar o modelo meteorológico com a informação relativa ao cálculo de precipitações na bacia hidrográfica do afluente

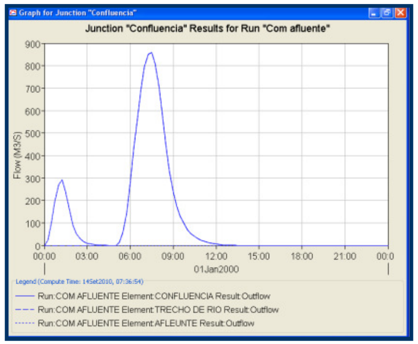
Update the meteorologic model by specifiying the conditions applicable to the tributary



The control specifications can be the same as for example 1. The same applies to the run
After running the program, the results can be seen



River reach upstream and downstream

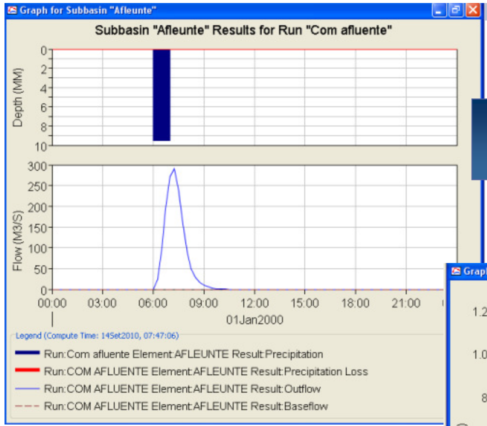


The confluence

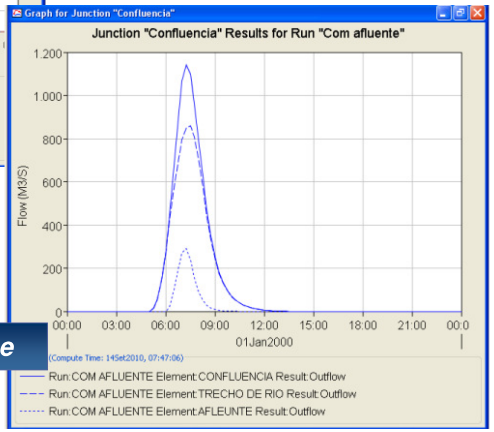
Exemplo 3

Exercício 2 mas considerando que a precipitação na bacia hidrográfica do afluente se inicia de modo a sobrepor os caudais de ponta de cheia da bacia principal e do afluente.

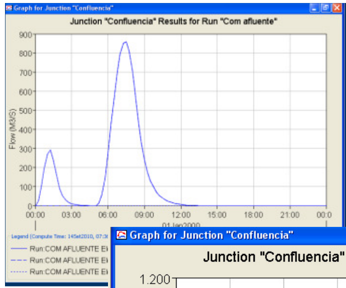
Repeat Problem 2 but aiming at superimposing the peak flood discharges at both catchments.

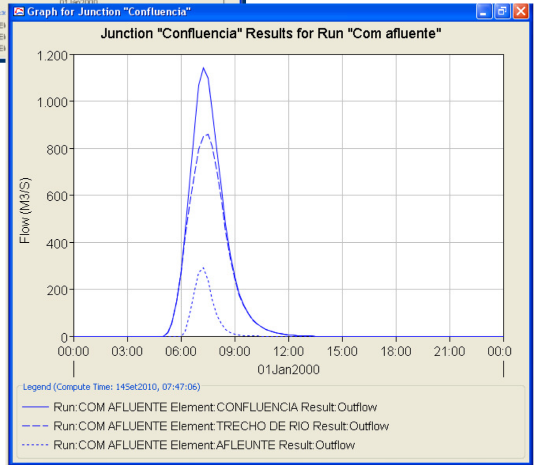


No curso de água afluente / *In the tributary*



Na confluência / *At the confluence*





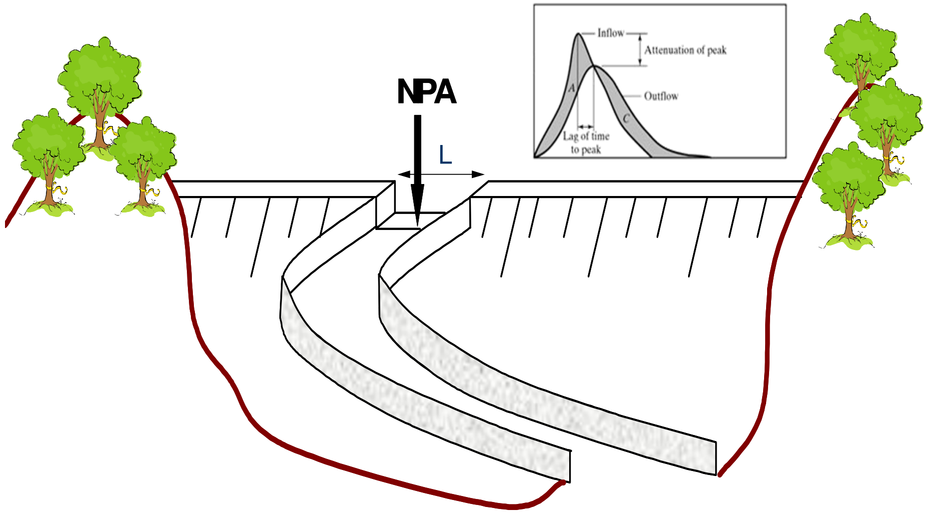
By modifying the design rainfall hyetograph, by defining initial blocks with 0 rainfall, until the peaks of the flood hydrographs are superimposed

ATTENTION: NO CALCULATIONS CAN BE MADE BEFORE RAINFALL STARTS!!!!

APPLICATION TO FLOOD ROUTING AND CONTROL IN ARTIFICIAL RESERVOIRS CREATED BY DAMS

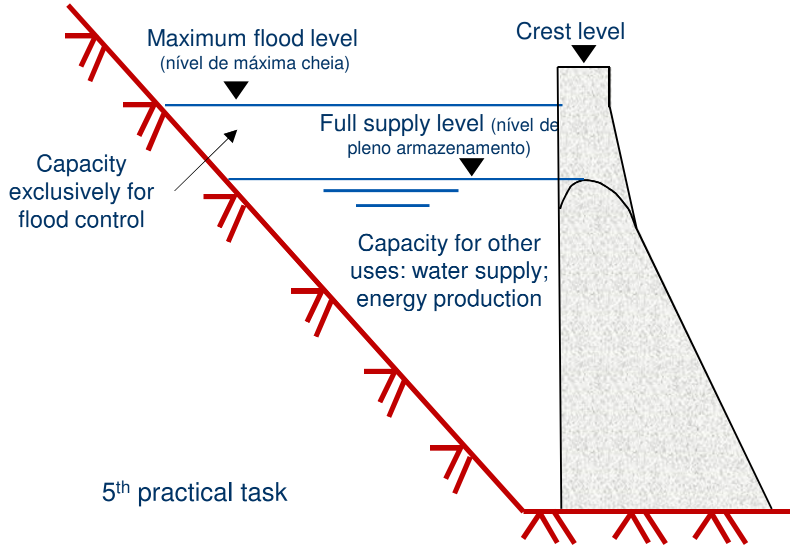
APLICAÇÃO AO AMORTECIMENTO DE ONDAS DE CHEIA EM ALBUFEIRAS

5th practical task

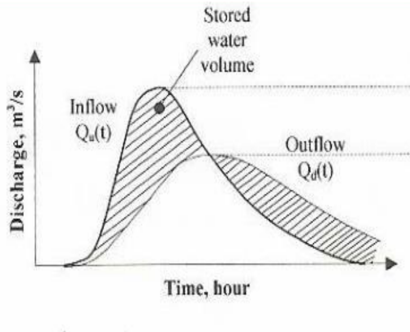


✓ Uncontrolled (without gates) broad-crested spillway (rating curve)

$$Q = C\,L\,\sqrt{2\,g}\;H^{1.5}$$

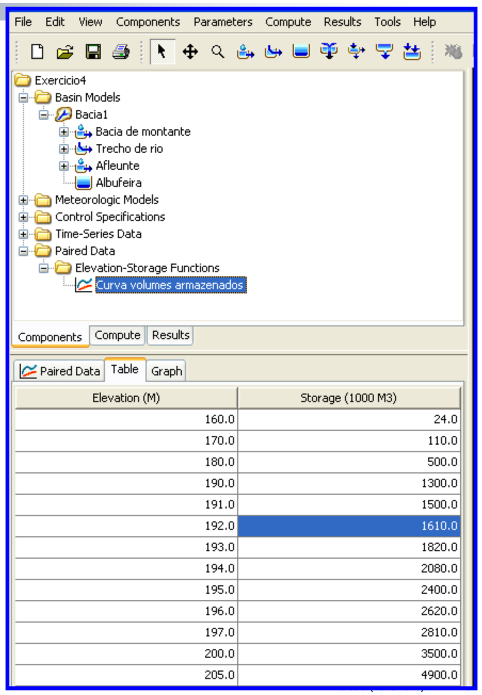


5th practical task



A flood pool with an uncontrolled spillway stores water as it is released according to the weir flow equation. The hydrograph is delayed and attenuated. The outflow hydrograph depends on the area of the reservoir and the length of the spillway.

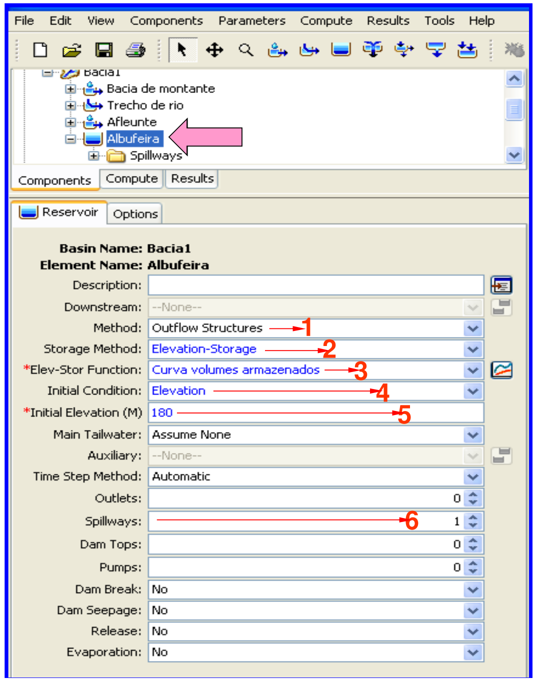
- ***In the "paired data manager", definition of the curve of the stored volumes in the reservoirs as a function of the elevation: a) selection of "elevation-storage-functions" - create; b) in the "paired data" icon that appears in the directory tree, introduction of points of the curve***
- No "*paired data manager*" introdução dos dados referentes à curva de volumes armazenados: a) seleção de "*elevation-storage-functions*" - *create*; b) no ícone de "*paired data*" que surge na estrutura de diretorias do lado esquerdo, introdução dos dados da curva.



Elevation (M)	Storage (1000 M3)
160.0	24.0
170.0	110.0
180.0	500.0
190.0	1300.0
191.0	1500.0
192.0	1610.0
193.0	1820.0
194.0	2080.0
195.0	2400.0
196.0	2620.0
197.0	2810.0
200.0	3500.0
205.0	4900.0

- ***Introduction of data for flood routing based on the options that appear when the icon that represents the reservoir is selected*** (introdução dos dados referentes ao amortecimento de cheias através das opções a que se acede quando se seleciona o ícone representativo da albufeira):

1) ***Method – Outflow structures.***
2) ***Storage method: Elevation-storage.***
3) ***Elev-Stor-function: curve with the stored volumes as a function of the elevation.***
4) ***Initial condition: Elevation.***
5) ***Initial elevation:***
6) ***Spillways:***



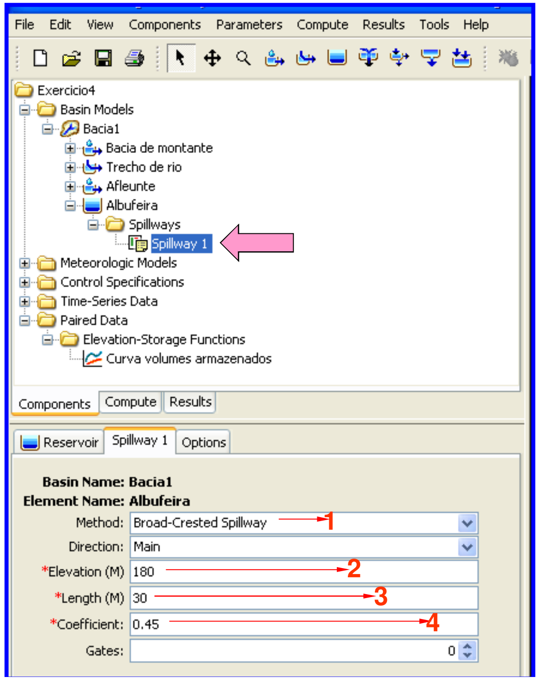
- ***Introduction of the data related to the surface spillway based on the options that appear when the icon that represents the spillway is selected*** (introdução dos dados referentes ao descarregador de superfície através das opções a que se acede quando se seleciona o ícone *spillway*)

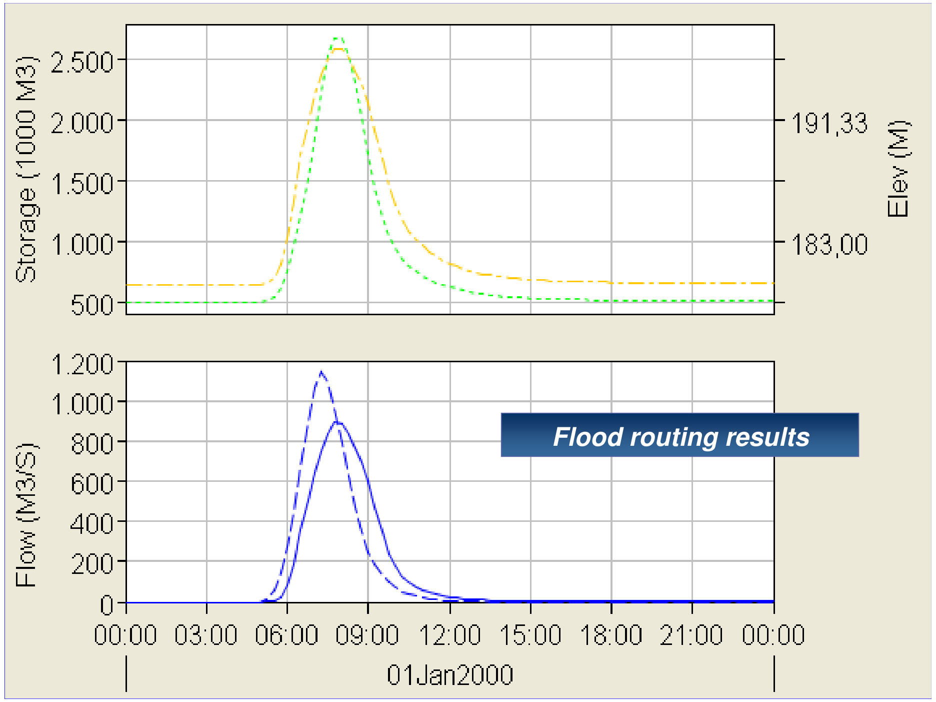
1) Method: Broad-Crested Spillway.

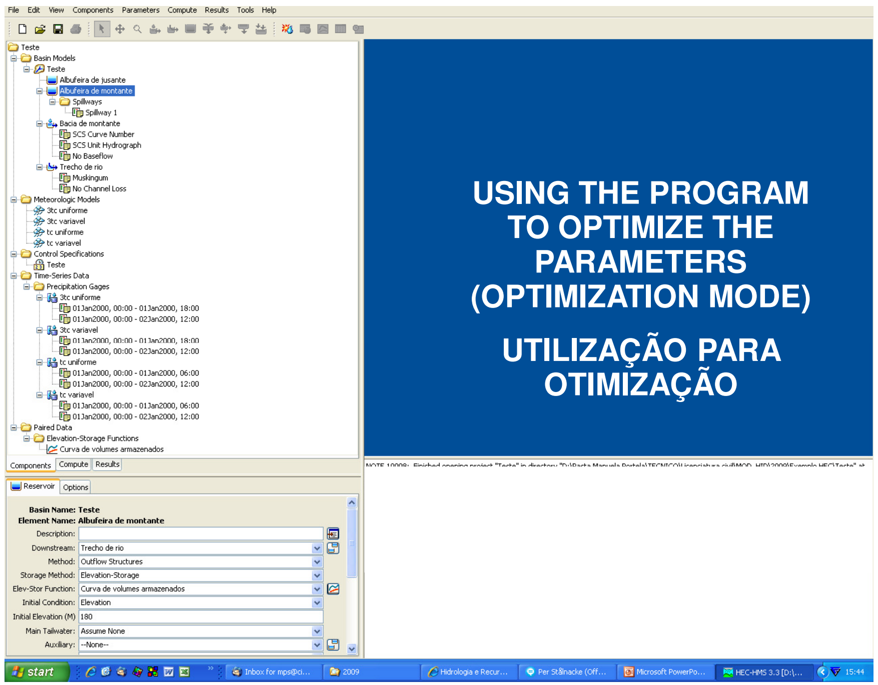
2) Elevation (M):

3) Lenght:

4) Coefficient:







USING THE PROGRAM TO OPTIMIZE THE PARAMETERS (OPTIMIZATION MODE)

UTILIZAÇÃO PARA OTIMIZAÇÃO

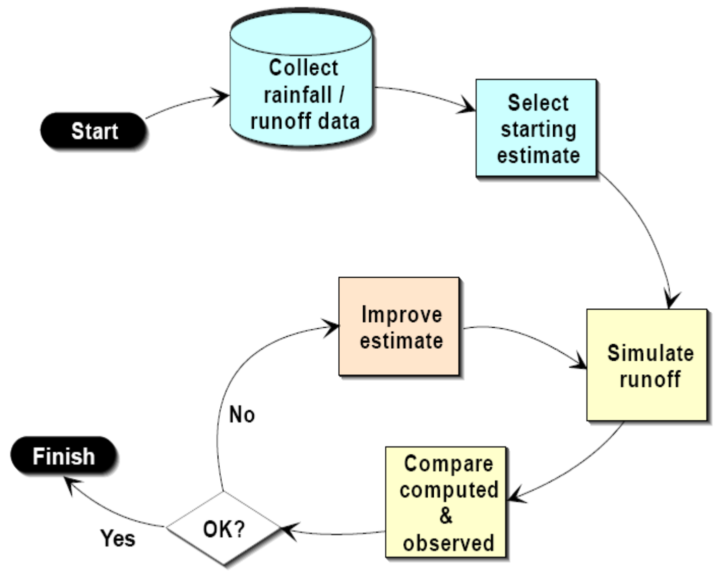


Figure 32. Schematic of calibration procedure.

… fundamental …

Equacionar bem o problema, designadamente, introduzir corretamente os dados que determinam a otimização – meta a atingir (por exemplo caudais observados). É necessário criar uma "corrida" antecedente que possibilite os elementos de partida para a otimização.

- **Criar a "otimização"**
- **Selecionar a função objetivo (o intervalo de otimização em de ser menor ou igual à duração da cheia).**
- **Selecionar os parâmetros a otimizar**

Criterion	Equation [1]
Sum of absolute errors (Stephenson, 1979)	$Z = \sum_{i=1}^{NQ} \lvert q_O(i) - q_S(i) \rvert$
Sum of squared residuals (Diskin and Simon, 1977)	$Z = \sum_{i=1}^{NQ} [q_O(i) - q_S(i)]^2$
Percent error in peak	$Z = 100 \left\lvert \frac{q_S(peak) - q_O(peak)}{q_O(peak)} \right\rvert$
Peak-weighted root mean square error objective function (USACE, 1998)	$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} (q_O(i) - q_S(i))^2 \left(\frac{q_O(i) + q_O(mean)}{2q_O(mean)} \right) \right] \right\}^{½}$

[1] Z = objective function; NQ = number of computed hydrograph ordinates; $q_O(t)$ = observed flows; $q_S(t)$ = calculated flows, computed with a selected set of model parameters; $q_O(peak)$ = observed peak; $q_O(mean)$ = mean of observed flows; and $q_S(peak)$ = calculated peak

… fundamental …

a previous complete understanding of the problem to be analyzed, namely, in what concerns the correct identification of the required data according to the parameters we want to optimized, i.e., with the optimization target. It is always necessary to run previously the model in the simulation mode in order to provide an initial solution for the optimization procedure.

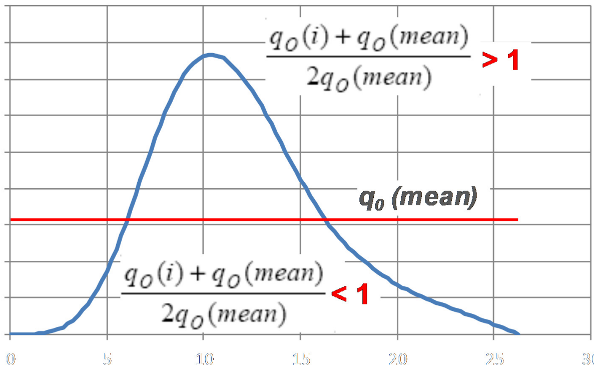
- ***Selectin of the "optimi-zation" mode***
- ***Selection of the objective function (the optimization interval can be smaller than the duration of the flood hydrograph)***
- ***Selection of parameters to be optimized***

Criterion	Equation [1]
Sum of absolute errors (Stephenson, 1979)	$Z = \sum_{i=1}^{NQ} \lvert q_O(i) - q_S(i) \rvert$
Sum of squared residuals (Diskin and Simon, 1977)	$Z = \sum_{i=1}^{NQ} [q_O(i) - q_S(i)]^2$
Percent error in peak	$Z = 100 \left\lvert \frac{q_S(peak) - q_O(peak)}{q_O(peak)} \right\rvert$
Peak-weighted root mean square error objective function (USACE, 1998)	$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} (q_O(i) - q_S(i))^2 \left(\frac{q_O(i) + q_O(mean)}{2q_O(mean)} \right) \right] \right\}^{½}$

[1] Z = objective function; NQ = number of computed hydrograph ordinates; $q_O(t)$ = observed flows; $q_S(t)$ = calculated flows, computed with a selected set of model parameters; $q_O(peak)$ = observed peak; $q_O(mean)$ = mean of observed flows; and $q_S(peak)$ = calculated peak

Criterion	Equation [1]
Sum of absolute errors (Stephenson, 1979)	$Z = \sum_{i=1}^{NQ} \lvert q_O(i) - q_S(i) \rvert$
Sum of squared residuals (Diskin and Simon, 1977)	$Z = \sum_{i=1}^{NQ} [q_O(i) - q_S(i)]^2$
Percent error in peak	$Z = 100 \left\lvert \frac{q_S(peak) - q_O(peak)}{q_O(peak)} \right\rvert$
Peak-weighted root mean square error objective function (USACE, 1998)	$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} (q_O(i) - q_S(i))^2 \left(\frac{q_O(i) + q_O(mean)}{2q_O(mean)} \right) \right] \right\}^{½}$

[1] Z = objective function; NQ = number of computed hydrograph ordinates; $q_O(t)$ = observed flows; $q_S(t)$ = calculated flows, computed with a selected set of model parameters; $q_O(peak)$ = observed peak; $q_O(mean)$ = mean of observed flows; and $q_S(peak)$ = calculated peak



Weighting factor that "forces" a better adjustment in the higher discharges (because a higher weight in assigned to them in the FO)

Criterion	Equation
Peak-weighted root mean square error objective function (USACE, 1998)	$Z = \left\{ \frac{1}{NQ} \left[\sum_{i=1}^{NQ} (q_O(i) - q_S(i))^2 \left(\frac{q_O(i) + q_O(mean)}{2q_O(mean)} \right) \right] \right\}^{½}$

[1] Z = objective function; NQ = number of computed hydrograph ordinates; $q_O(t)$ = observed flows; $q_S(t)$ = calculated flows, computed with a selected set of model parameters; $q_O(peak)$ = observed peak; $q_O(mean)$ = mean of observed flows; and $q_S(peak)$ = calculated peak

Create and Compute an Optimization Trial

Model optimization involves adjusting parameter values so that the simulated results match the observed stream flow as closely as possible. Two different search algorithms are provided that move from the initial parameter value to the final best value. A variety of objective functions are provided to measure the goodness of fit between the simulated and observed stream flow in different ways. While model optimization does not produce perfect results, it can be a valuable aid.

Before an optimization trial can be created, a simulation run using a basin model with observed flow must exist. An optimization trial is created by selecting the **Compute** ⇒ **Create Optimization Trial** menu option. A wizard steps the user through the process of creating an optimization trial. First, a name must be entered, then an existing simulation run must be selected, and finally a hydrologic element containing observed flow must be selected. The new optimization trial is added to the "Compute" tab of the *Watershed Explorer* (Figure A1). Notice the trial is added under the **Optimization Trials** folder. Select the optimization trial to open the *Component Editor (Figure A1)*. In the *Component Editor*, the user can enter a "Description", change the simulation run used by the optimization trial, and select the search method used to find optimal parameter values. Also, the user has the option of changing the tolerance and the number of iterations to control when the search for optimal parameter values ends.

Click the plus sign next to the optimization trial name to expand the *Watershed Explorer*. Select the **Objective Function** node in the *Watershed Explorer* to add a new tab to the *Component Editor* (Figure A2). On this editor the user can select the objective function from the "Method" drop-down list and change the location used for comparing observed and simulated hydrographs. In addition, start and end dates and times can be edited.

An optimization trial requires hydrologic element parameters. To add a parameter, click the right mouse button when the mouse is on top of the optimization trial's name in the *Watershed Explorer* and select **Add Parameter** (Figure A3). A new sub-node is added to the *Watershed Explorer* with the name **Parameter 1**. Figure A4 shows the editor for this new sub-node. In this editor the user selects the hydrologic element and a parameter for that element. This parameter is adjusted automatically during the optimization trial in an attempt to find a value which minimizes the difference between simulated and observed hydrographs. The user has the option to select a different initial value for the parameter, enter minimum and maximum value constraints, and select whether the parameter is locked during the optimization trial. More than one parameter can be added to an optimization trial.

An optimization trial can be computed from the **Compute** menu or from the *Watershed Explorer*. Results for an optimization trial are available from the "Results" tab of the *Watershed Explorer* and from the basin model map. Click the plus sign next to the **Optimization Trials** folder to expand the *Watershed Explorer*, "Results" tab. Select the optimization trial and the *Watershed Explorer* will expand to show all results available for the trial.

Figure A1. Optimization trial.

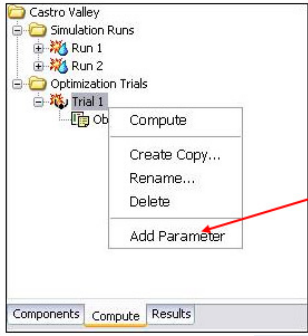


Figure A3. Add a parameter to an optimization trial.

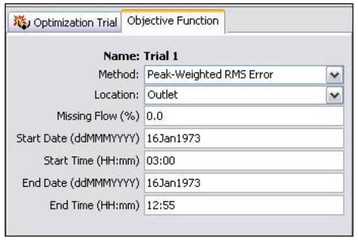
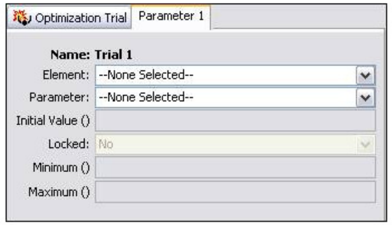


Figure A2. Objective function editor.



Release Notes

Version 4.3
September 2018

A new "univariate" method has been added. This new method works with only a single parameter. While the simplex method is powerful, it requires a minimum of two parameters in order to operate. The univariate method is now available for cases where only one parameter needs to be estimated.

Corrida do HEC com otimização

1. "Montar" o modelo de simulação, incluindo dados EH.

2. Correr normalmente.

3. Tentar criar otimização – vai ser impossível pois o hidrograma de cheia não foi atribuído à bacia hidrográfica (ou seja, não foi estabelecida a ligação entre esse hidrograma e a bacia), pelo que a otimização não tem objetivo.

4. No modelo de bacias, nas *options*, atribuir à bacia o hidrograma de cheia, tendo obviamente previamente introduzido os dados (*time series data manager*).

5. Criar uma corrida de otimização, atribuindo-lhe um nome.

6. Aceder ao ecrã de otimização: selecionar separador *compute*.

7. Selecionar otimização trial.

8. Selecionar a corrida de otimização antes criada (passo 5).

9. Escolher o modelo da função objetivo (normalmente, *peak weighted RMS error*) e o intervalo de otimização (que não pode exceder o intervalo do hidrograma observado; tem de haver caudais).

10. No nome da corrida com o botão do lado direito escolher *add parameter.*

11. Indicar qual o(s) *parameter(s).*

12. Correr otimização.

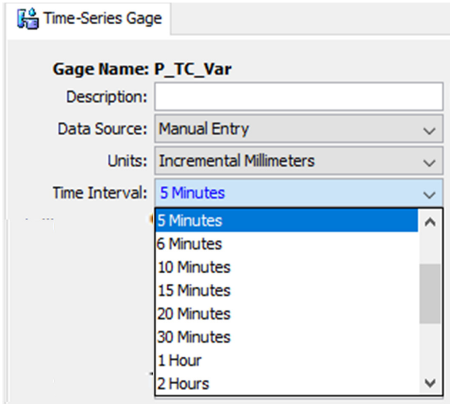
13. Nos resultados está tudo – valor da função objetivo e dos parâmetros.

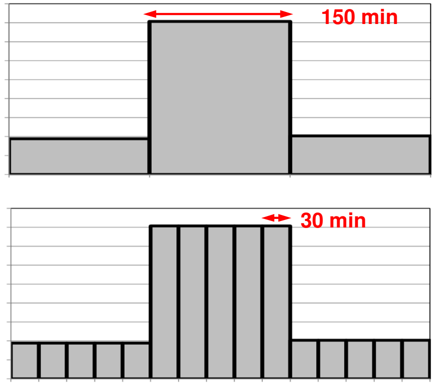
UTILIZATION OF THE HEC-HMS IN THE OPTIMIZATION MODE

1. ***Assemble the model in the simulation mode (do not forget to provide the observed discharge data)***
2. ***Run the simulation mode***
3. ***When trying, at this stage, to create an optimization run there will be an error message because no optimization target was defined. It is necessary to assign the observed discharge data to the watershed (optimization target)***
4. ***In the basin model, in the options, assign the flood hydrograph to the watershed (the flood hydrograph must have been be previously defined in the time series data manager)***
5. ***Create an optimization run and name it***
6. ***In the optimization mode, select compute***
7. ***Select optimization trial.***
8. ***Select which of the available optimization trail you want to run (from those created in step 5)***
9. ***Choose the objective function model (usually peak weighted RMS error) and the optimization interval (which can not exceed the hydrograph duration)***
10. ***For the trial, select add parameter (right button of the mouse pad)***
11. ***Select the parameter(s)***
12. ***Run optimization***
13. ***In the results everything is displayed, including the values of the objective function and of the parameters***

Some observations about the 4th practical task

✓ The duration of the blocks of the rainfall hyetographs is 2.5 h = 150 min (either for the three-block hyetograph for tc or for the 6-block hyetograph for 2tc). Such duration does not coincide with any of the allowed time steps of the time series.





✓ Each block must be split into the smallest possible number of sub blocks by adopting the highest time step, from those allowed in the HEC-HMS progrm, compatible with its original duration (**e.g., for the duration of 2.5 h, 5 sub blocks each with the duration of 0.5 h = 30 min and with 1/5 of the rainfall depth.**