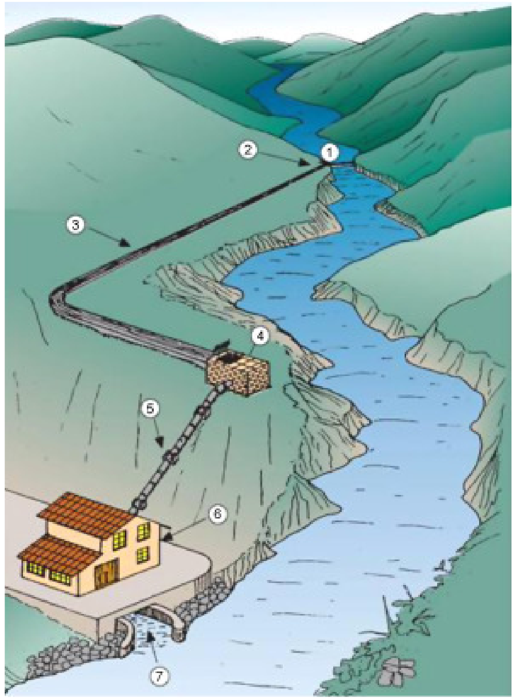
Dimensionamento preliminar do circuito hidráulico, energia anual média produzida e potência a instalar: conceitos básicos. Estimativa de custos

Maria Manuela Portela

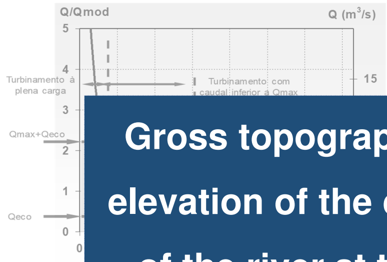
Aula		Ano letivo 2023/2024 - ENERGIA HÍDRICA Previsão das aulas teórico-práticas	
Data	N.º ordem		
19/set	1	Apresentação. Objetivo. Noções gerais	
21/set	2	O caso de estudo Caraterização geral: localização do açude e da central, configuração geral do circuito hidráulico, comprimento do canal e da conduta, queda topográfica. Delimitação e caracterização de bacia hidrográfica e de rede de drenagem	1ª PARTE
26/set	3		
28/set	4		
03/out	5		
05/out		Feriado	
10/out	6	O caso de estudo - continuação	1ª PARTE
12/out	7		
17/out	8	1ª PARTE /2º PARTE	
19/out	9	Precipitação anual média na bacia hidrográfica - recolha de dados e estimação. Cálculo da precipitação intensa com duração igual ao tempo de concentração. Cálculo da cheia de projeto (DIA 24/OUT - ENTREGA DA 1ª PARTE)	2ª PARTE
24/out	10		
26/out	11		
31/out	12		
02/nov	13	2ª PARTE / 3ª PARTE	
07/nov	14	Estimação do escoamento anual médio afluente (modelo de regionalização) (ENTREGA DA 2ª PARTE: formato digital - 8/nov; em papel - 9/nov)	3ª PARTE
09/nov	15		
14/nov	16	Caudais médios diários registados e afluentes ao AHE. Caudais ecológicos. Simulação da exploração diária da central hidroelétrica. Volumes afluentes, turbinados, descarregados e ecológicos. Cálculo da produção anual média de energia	
16/nov	17		
21/nov	18		
23/nov	19	3ª PARTE /4º PARTE	
28/nov	20	Conceção geral e pré-dimensionamento do circuito hidráulico - canal e conduta. Estimativa de custos. Análise económica (ENTREGA DA 3ª PARTE: formato digital - 4/dez; em papel - 5/dez)	4ª PARTE
30/nov	21		
05/dez	22		
07/dez	23		
12/dez	24		
14/dez	25		

ENTREGA DA 4ª PARTE EM DATA A COMBINAR

Calendário provisional das aulas e das entregas parcelares do Trabalho Prático



1	**Weir** (açude)
2 and 3	**channel** (canal)
4	**Forebay** (câmara de carga)
5	**Penstock** (conduta forçada)
6	**Powerhouse** (central hidroelétrica)
7	**Tailrace** (restituição)



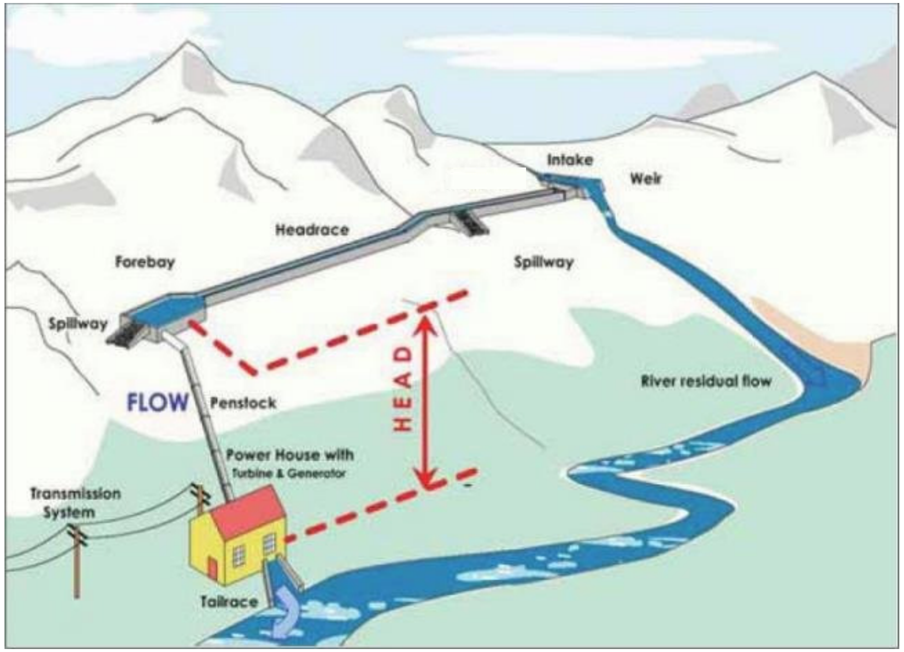
Gross topographic head ➡ approx. the elevation of the canal minus the elevation of the river at the tailrace of the power house

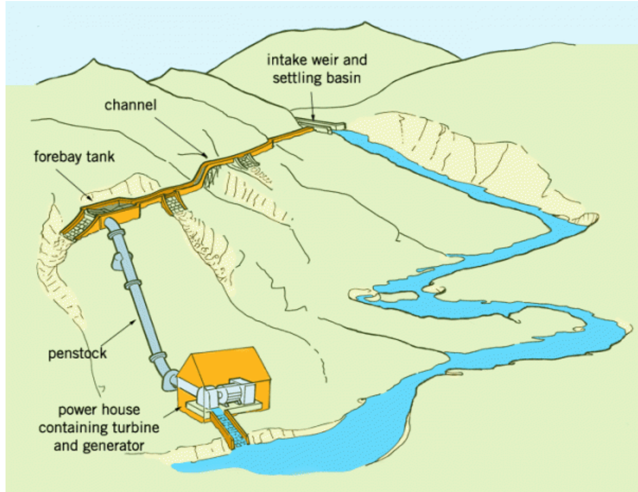
Queda topográfica bruta ➡ aprox. igual à diferença entre a cota do canal e a cota do rio na secção de restituição da central

E
P
V
$H_{energia}$
$H_{potênci}$
Q
η
*

rendimento médio global da central hidroelétrica (*average efficiency of the power house*)

preliminarmente, cerca de 97.5% e 95% de H_{bruta} respetivamente (*preliminary, 97.5% and 95% of the gross topographic head*)

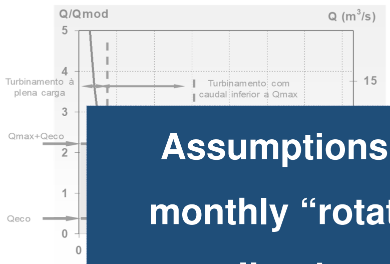


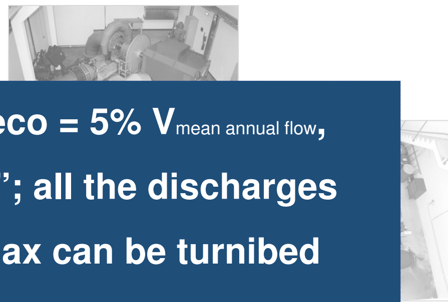


Cálculo da energia produzida e da potência a instalar

Dimensionamento das componentes principais do circuito hidráulico

Computation of the energy produced and of the installed capacity.
Design of the main components of the hydraulic circuit



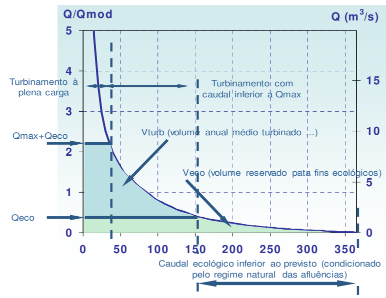


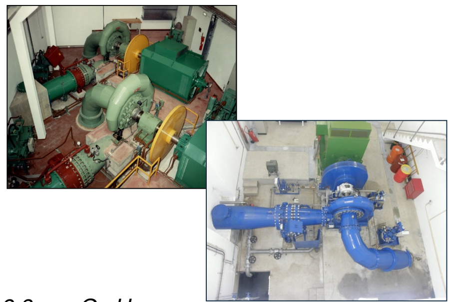
Assumptions: Veco = 5% $V_{\text{mean annual flow}}$, monthly "rotated"; all the discharges smaller than Qmax can be turnibed

Pressupostos: Veco=5% $V_{\text{escoamento aual médio}}$, "rodado" mensalmente; possibilidade de turbinar todos os caudais inferiores a Qmax

E
P
V
$H_{energia}$
$H_{potência}$
Q caudal máximo derivável (*design discharge*) (m^3/s)
η rendimento médio global da central hidroelétrica (*average efficiency of the power house*)
* preliminarmente, cerca de 97.5% e 95% de H_{bruta} respetivamente (*preliminary, 97.5% and 95% of the gross topographic head*)

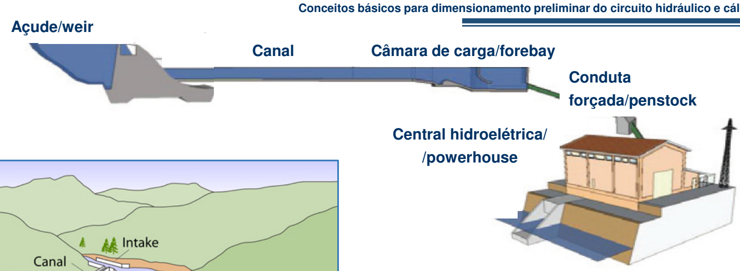
Conceitos básicos para dimensionamento preliminar do circuito hidráulico e cálculo de custos

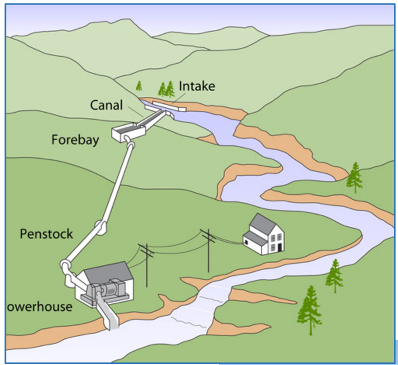




$$E = \frac{\frac{V \times H_{energia}}{3600}}{9.8 \times \eta} \qquad P = 9.8 \times \eta \times Q \times H_{potência}$$

E **Energia anual média produzida (*mean annual energy production*) (GWh)**
P **Potência a instalar (*installed capacity*) (kW)**
V **Volume anual médio turbinado (*mean annual turbined volume*) (hm^3)**
$H_{energia}$ **Queda útil de cálculo da energia (*net head for energy computation*) (m)***
$H_{potência}$ **Queda útil de cálculo da potência (*net head for installed capacity computation*) (m)***
Q **Caudal máximo derivável (*design discharge*) (m^3/s)**
η **Rendimento médio global da central hidroelétrica (*average efficiency of the power house*)**
***** **preliminarmente, cerca de 97.5% e 95% de H_{bruta} respetivamente (*preliminary, 97.5% and 95% of the gross topographic head*)**

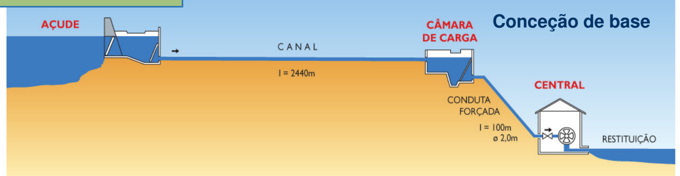




Design of the main physical components of the hydraulic circuit

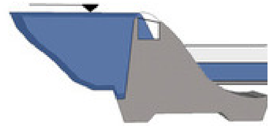
Dimensionamento das principais componentes físicas do circuito hidráulico

Conceção de base



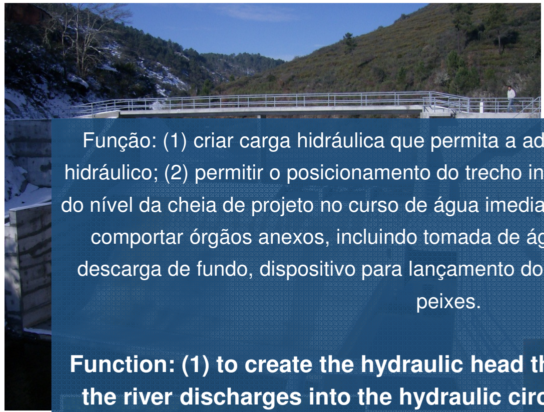
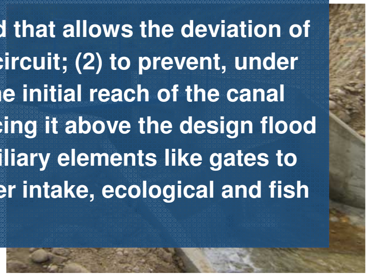
Açude munido de tomada de água do tipo tirolês

Weir with a Tyrolean-type water intake



https://www.google.com/search?q=tyrolean+water+intake+video&rlz=1C1CAFA_enPT728PT728&oq=tyrolean+water+intake+video&gs_lcrp=EgZjaHJvbWUyBggAEEUYOTIHCAEQIRigATIHCAIQIRigAdIBCDgzMDRqMGo3qAIAsAIA&sourceid=chrome&ie=UTF-8#fpstate=ive&vld=cid:45376deb,vid:Ud4C7_q4Ejg,st:0

Açude munido de tomada de água do tipo tirolês


Função: (1) criar carga hidráulica que permita a admissão de caudais ao circuito hidráulico; (2) permitir o posicionamento do trecho inicial do circuito hidráulico acima do nível da cheia de projeto no curso de água imediatamente a jusante do açude; (3) comportar órgãos anexos, incluindo tomada de água para o circuito hidráulico, descarga de fundo, dispositivo para lançamento do caudal ecológico e escada de peixes.

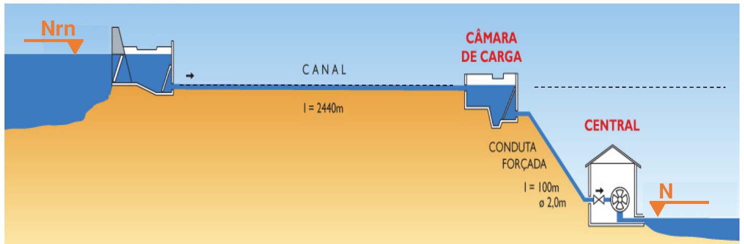
Function: (1) to create the hydraulic head that allows the deviation of the river discharges into the hydraulic circuit; (2) to prevent, under flood conditions, the overtopping of the initial reach of the canal immediately downstream the weir by placing it above the design flood level; (3) to allow the installation of auxiliary elements like gates to isolate the canal, trash racks for the water intake, ecological and fish pass ways

https://www.youtube.com/watch?v=Ud4C7_q4Ejg



Flood conditions

[PT]

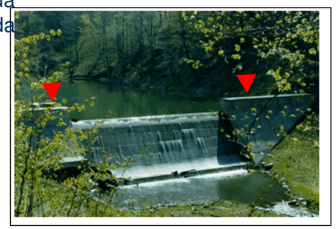


Queda bruta, H_{bruta}

... preliminarmente ...

Nrn: Nível de retenção normal = cota do talvegue na secção de implantação do açude + h1 (com h1 ~ 10 m)

Cota do coroamento do açude▼ = cota dos muros de ala laterais (tem de conter uma folga de pelo menos 1 m relativamente ao nível da cheia centenária sobre a soleira do açude) **= Nrn + Hc + 1 = NMC +1** (Hc altura de água sobre a soleira descarregadora quando da ocorrência da cheia centenária**)**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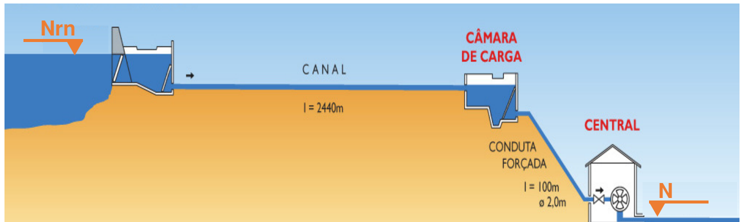
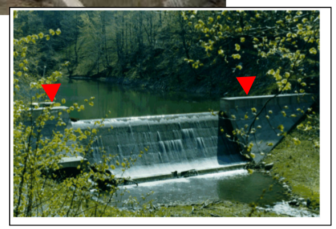


... preliminary ...

Gross Head, H_{bruta}

Nrn: Normal retention level = river bed elevation at the weir section + h1 (with h1 ~ 10 m)

Elevation of the crest of the lateral abutments▼ (at least a safety gap of 1 m in relation to the water depth over the spillway of the 100-year flood**) = Nrn + Hc + 1 = NMC +1** (Hc = water depth over the spillway under 100-year flood conditions; NMC = flood level**)**


[PT]

Cálculo da altura de água sobre a soleira descarregadora em condições de cheia

(descarga livre não controlada)

$$Qp = C\,L\,\sqrt{2\,g}\;Hc^{3/2}$$

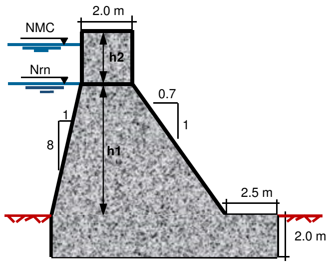
Qp caudal de ponta da cheia centenária (m^3/s) (2ª parte)

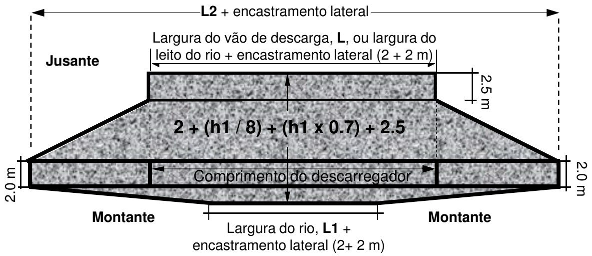
C coeficiente de vazão (0.48)

L comprimento da soleira descarregadora (m, L)

Hc carga sobre a crista da soleira descarregadora igual à diferença entre os níveis de máxima cheia, NMC, e o nível de retenção normal, Nrn (m)

Hc = NMC-Nrn ⟺ NMC = Nrn + Hc





[PT]

Conceitos básicos para dimensionamento preliminar do circuito hidráulico e cálculo de custos

Cálculo da altura de água sobre a soleira descarregadora em condições de cheia

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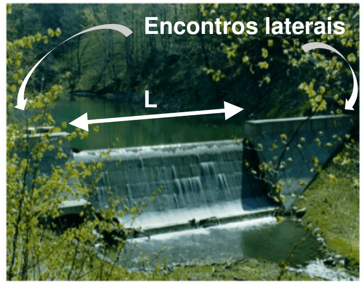

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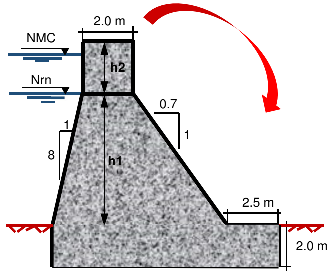


Tendo em conta a pequena altura do açude (apenas h1=10 m), para evitar o seu eventual derrube, Hc não deve exceder 3.0 a 3.5 m, se compatível com a largura do vale. Isto é, se o comprimento da soleira do descarregador não exceder a largura do vale, de modo a evitar a escavação excessiva das margens do rio

[EN]

Computation of the water depth over the spillway under flood conditions

(uncontrolled spillway)

$$Qp = C\,L\,\sqrt{2\,g}\;Hc^{3/2}$$

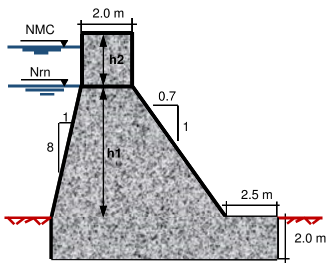
Qp 100-year peak flood discharge (m^3/s) (2nd Part)

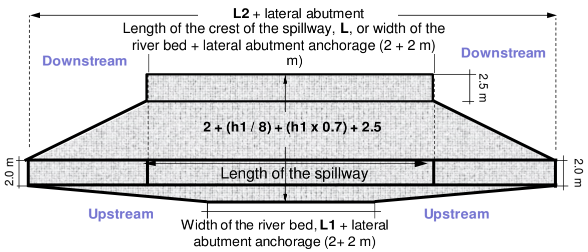
C discharge coefficient (0.48)

L length of the crest of the spillway (m, L)

Hc head over the crest of the spillway equal to the difference between the maximum flood level, NMC, and the normal retention level, Nrn (m)

Hc = NMC-Nrn ⟺ NMC = Nrn + Hc





[EN]

Conceitos básicos para dimensionamento preliminar do circuito hidráulico e cálculo de custos

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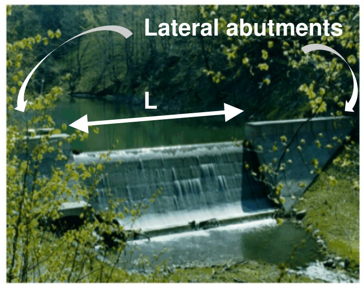

$$Qp = C\,L\,\sqrt{2\,g}\;Hc^{3/2}$$

Qp 100-year peak flood discharge (m^3/s) (2nd Part)

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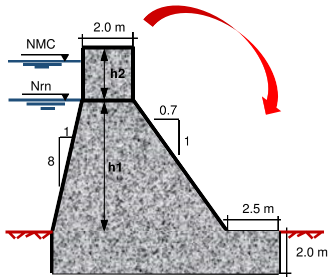
L length of the crest of the spillway (m, L)

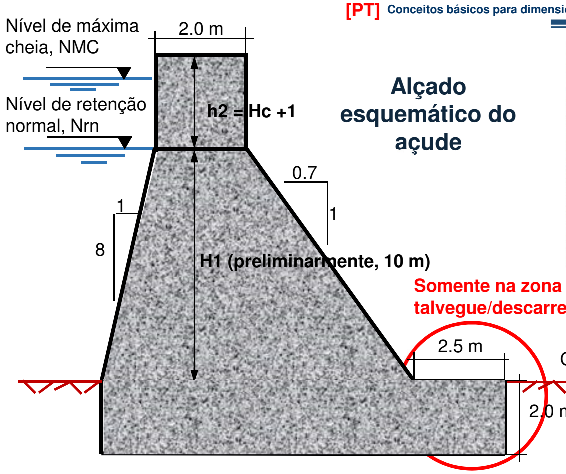
Hc head over the crest of the spillway equal to the difference between the maximum flood level, NMC, and the normal retention level, Nrn (m)

Hc = NMC-Nrn ⟺ NMC = Nrn + Hc

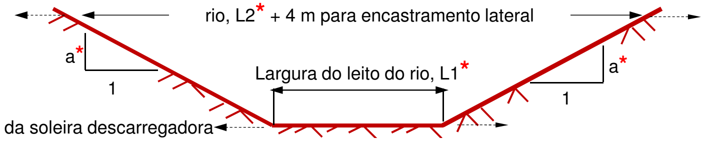


Due to the small height of the weir (only h1=10 m), to prevent its overturning, Hc must not exceed 3.0 to 3.5 m, if compatible to the width of the valley, i.e., if the length of the crest of the spillway do not exceed the width of the river valley in order to avoid excessive the excavation of the river margins

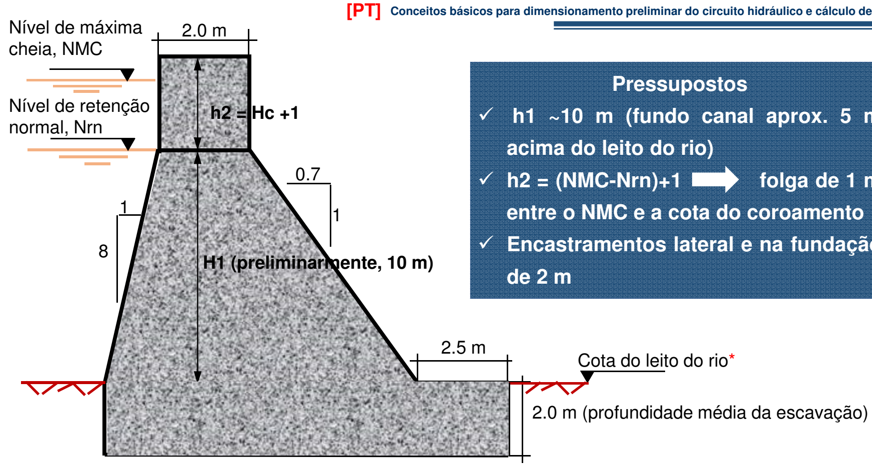
Alçado esquemático do açude



Perfil transversal esquemático do rio na zona do açude



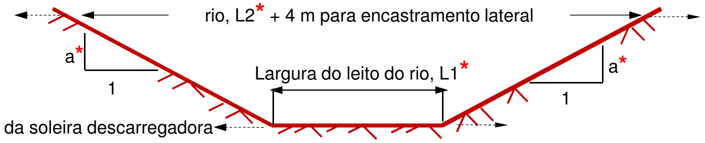
* Larguras a deduzir com base na cartografia disponível e, no caso de L2, dependentes do declive das encostas



Pressupostos

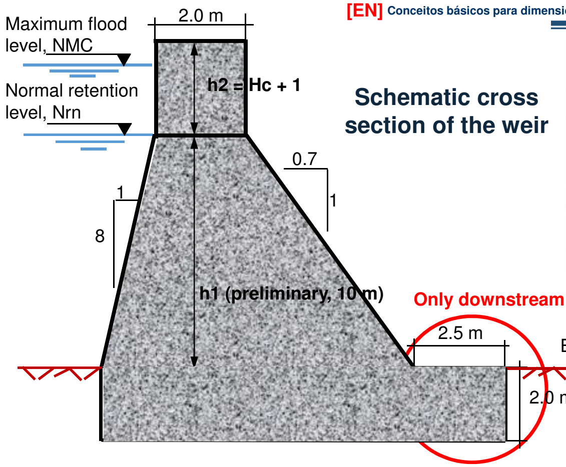
- ✓ h1 ~10 m (fundo canal aprox. 5 m acima do leito do rio)
- ✓ h2 = (NMC-Nrn)+1 ➡ folga de 1 m entre o NMC e a cota do coroamento
- ✓ Encastramentos lateral e na fundação de 2 m

Perfil transversal esquemático do rio na zona do açude

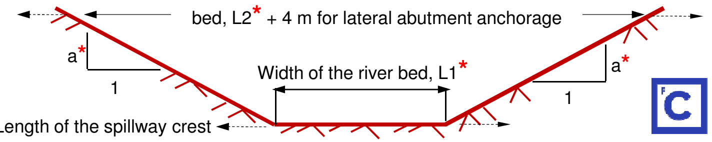


* Larguras a deduzir com base na cartografia disponível e, no caso de L2, dependentes do declive das encostas

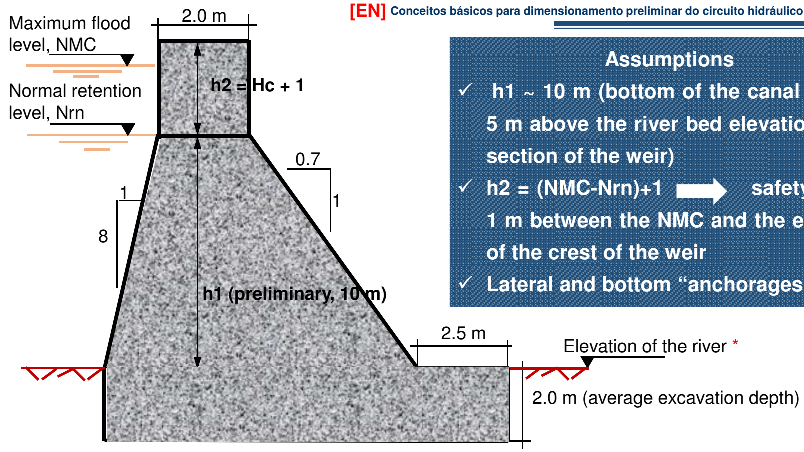
Schematic cross section of the weir



Schematic cross section of the river at the location of weir



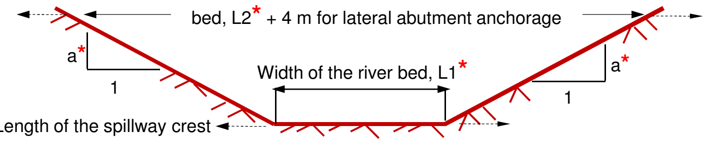
*** Widths estimated based on the available topography and, regarding L2, also depending on the slopes of the lateral hillsides**



Assumptions

- ✓ h1 ~ 10 m (bottom of the canal approx. 5 m above the river bed elevation at the section of the weir)
- ✓ h2 = (NMC-Nrn)+1 ➡ safety gap of 1 m between the NMC and the elevation of the crest of the weir
- ✓ Lateral and bottom "anchorages" of 2 m

Schematic cross section of the river at the location of weir



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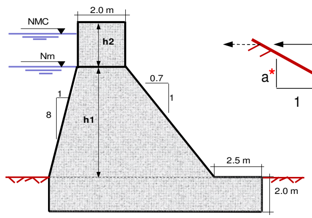
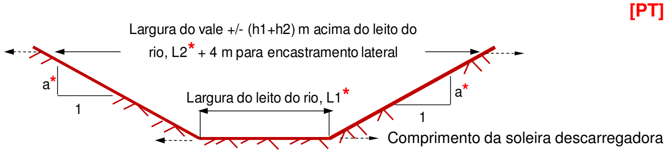
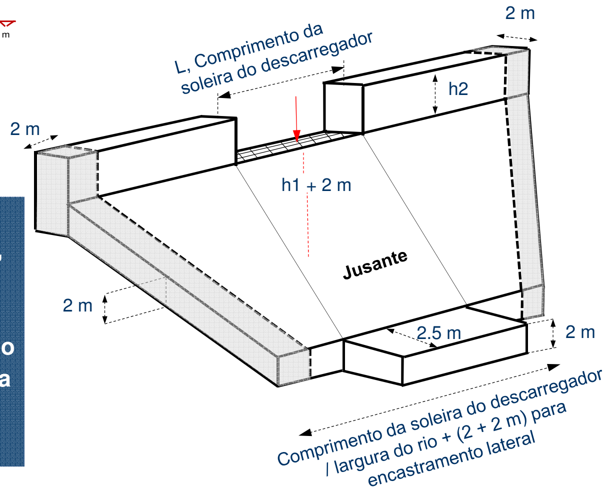
[PT]

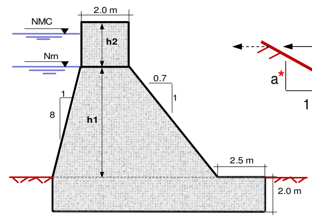


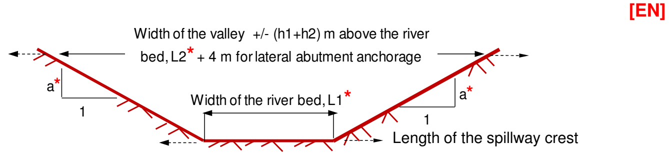


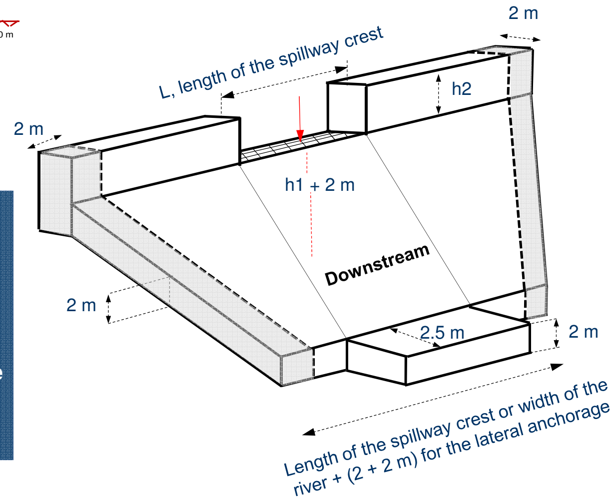


Cálculo aproximado, mas tão rigoroso quanto, possível do volume de betão tendo em conta a volumetria 3D do açude

[EN]



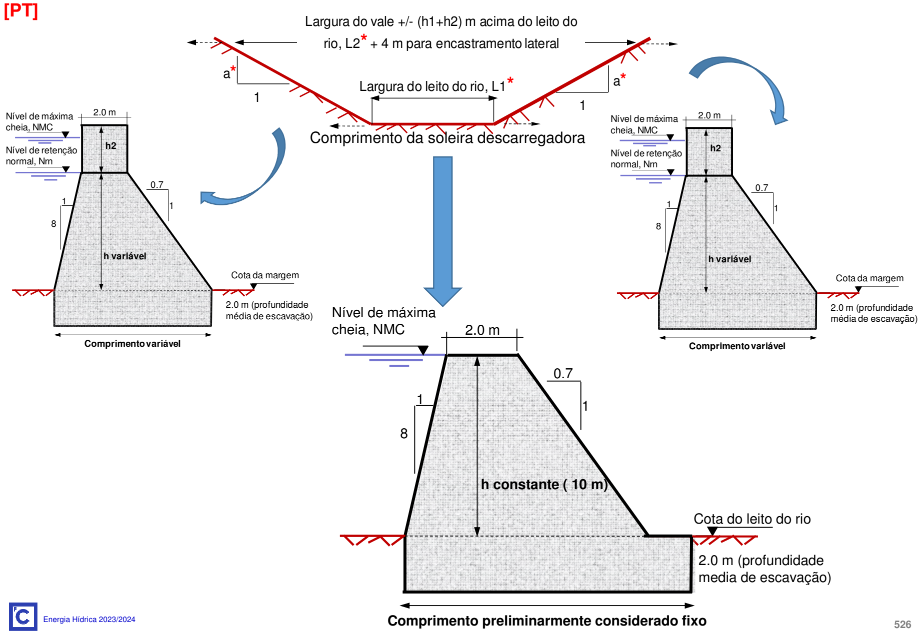




Computation, as accurate as possible, of the concrete volume taking into account the 3D shape of the weir

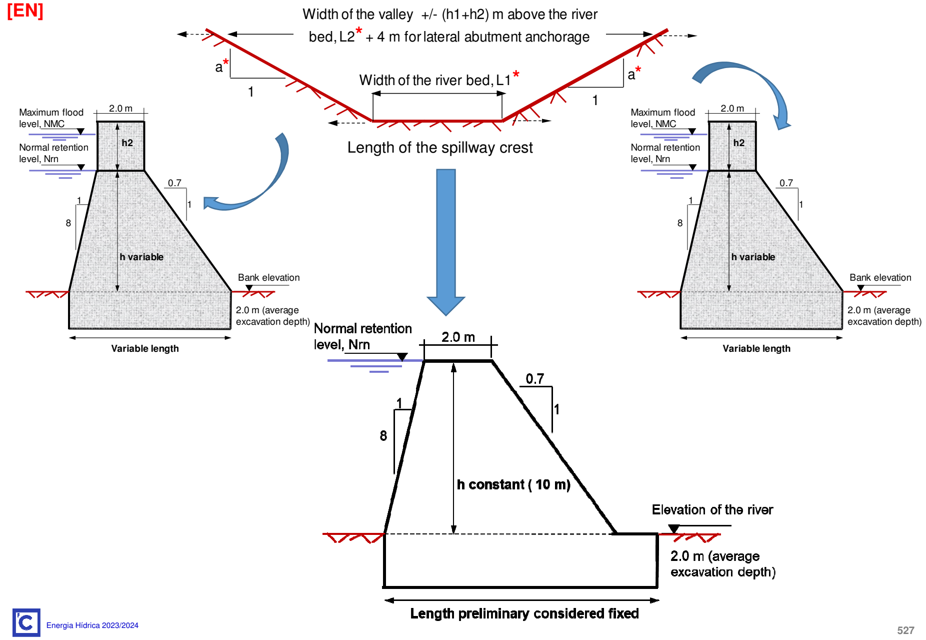
Cálculo aproximado do volume de betão tendo em conta a volumetria 3D do açude

[PT]

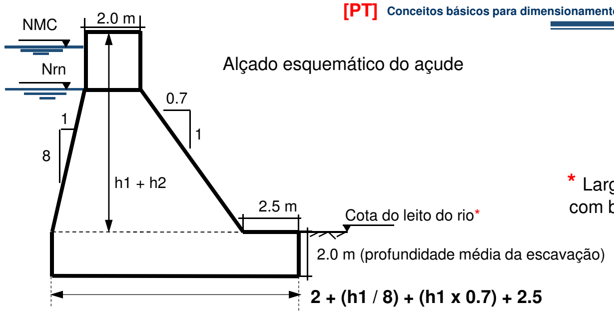


Computation of the concrete volume taking into account the 3D shape of the weir

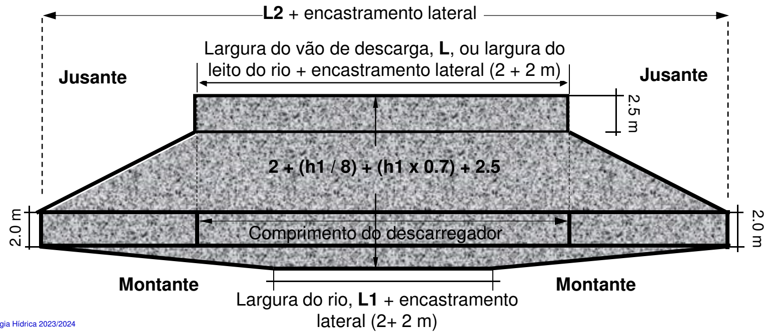
[EN]



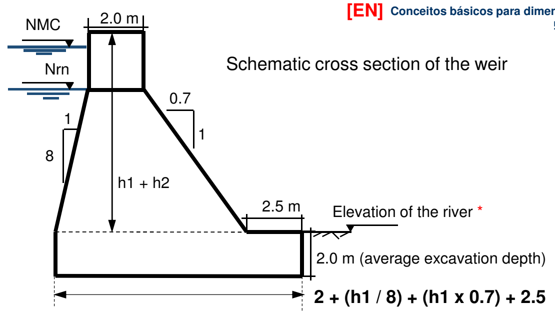
Escavação



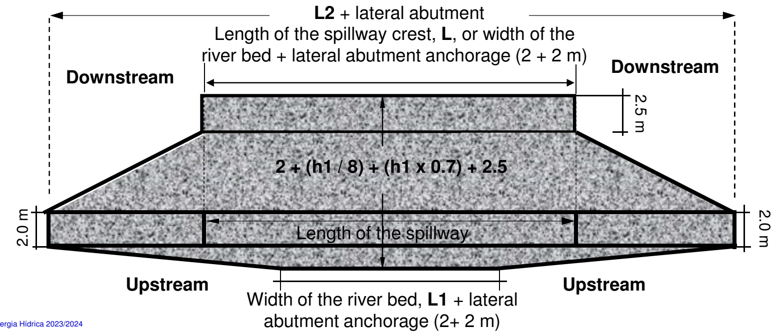
* Larguras/comprimentos a deduzir com base na cartografia disponível



Excavation



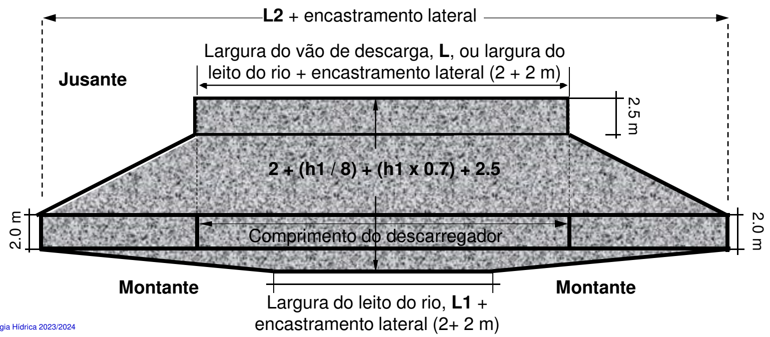
* Lengths/widths to be estimated based on the available topography



Escavação

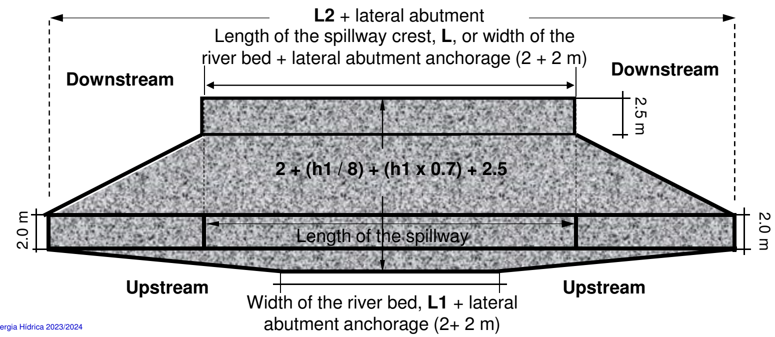
Excavation volume ~ area of the horizontal projection x excavation depth (2m)
(+ a escavação eventualmente necessária ao alargamento da zona central do rio, quando tal zona tem originalmente uma largura inferior ao comrpimento da soleira descarregadora)

Volume de escavação ~ área em planta x

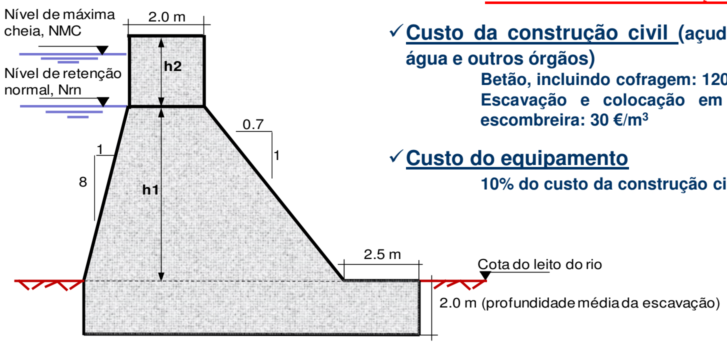


Excavation

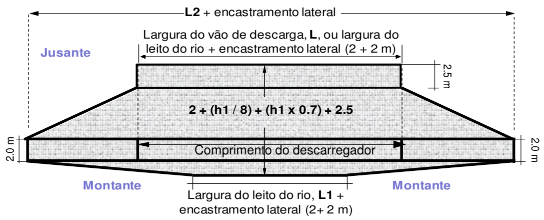
Excavation volume ~ area of the horizontal projection x excavation depth (2m)
(+ the eventual excavation required to enlarge the central zone of the river when that zone as originally a width smaller the length of the crest of the spillway)



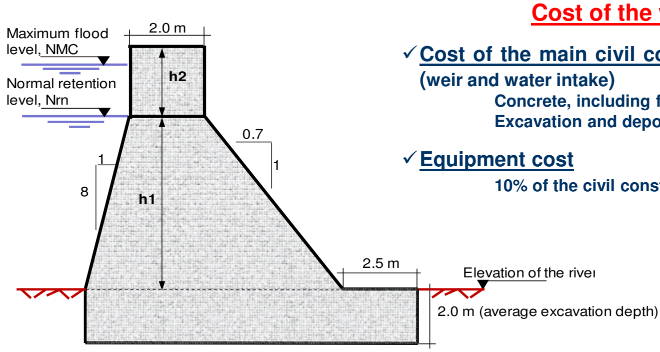
Cálculo do custo do açude



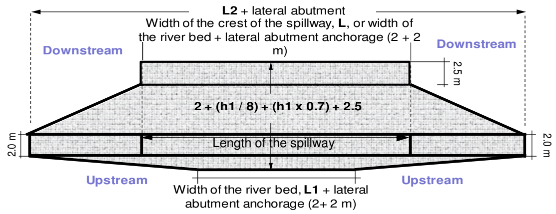
- ✓ **Custo da construção civil** (açude, tomada de água e outros órgãos)
  - **Betão, incluindo cofragem: 120 €/m³**
  - **Escavação e colocação em depósito em escombreira: 30 €/m³**
- ✓ **Custo do equipamento**
  - **10% do custo da construção civil**

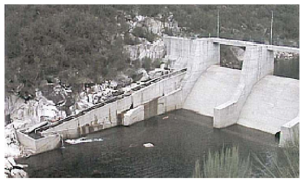


Cost of the weir



- ✓ **Cost of the main civil construction works** (weir and water intake)
  - **Concrete, including formworks: 120 €/m³**
  - **Excavation and deposition: 30 €/m³**
- ✓ **Equipment cost**
  - **10% of the civil construction cost**



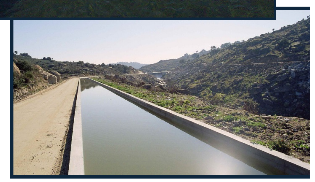
Passagem para peixes

(fishways or fish ladders)

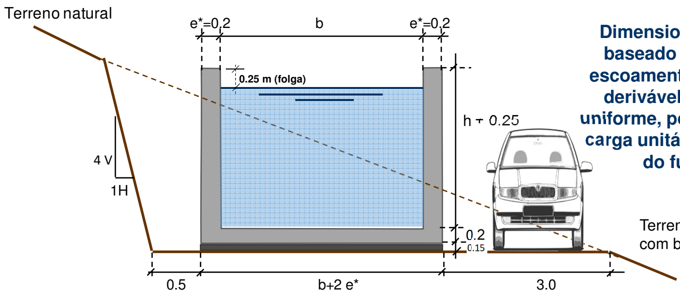



Canal (adução em superfície livre)





[PT]



Dimensionamento hidráulico baseado no pressuposto de escoamento do caudal máximo derivável, Qmax, em regime uniforme, portanto, com perda de carga unitária, i, igual ao declive do fundo do canal.

✓Pressupostos

- Declive do fundo do canal: 1 m/1 km (i = 0.001 =0.1%)
- Largura mínima do canal (rasto do canal): b >= 0.5 m
- b/h=1.5, sendo h a altura do escoamento uniforme de Qmax no canal
- Espessura das paredes do canal e da laje de fundo: e* = 0.20 m
- Espessura do betão de regularização sob a laje de fundo: 0.15 m

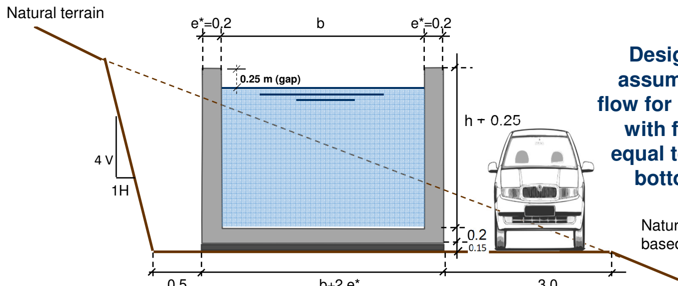
✓Fórmula de resistência ao escoamento – Fórmula de Manning-Strickler

$Q = K\, S\, R^{2/3}\, i^{1/2}$ com R = raio hidráulico = S/P; S = secção do escoamento; P = perímetro molhado; K = coeficiente (para betão aprox. 75 $m^{1/3}\, s^{-1}$)

Etapas do dimensionamento

b → h → Q ↔ Qmax

[EN]



Design based on the assumption of uniform flow for Qmax, accordingly with friction losses, i, equal to the slope of the bottom of the canal

✓Assumptions

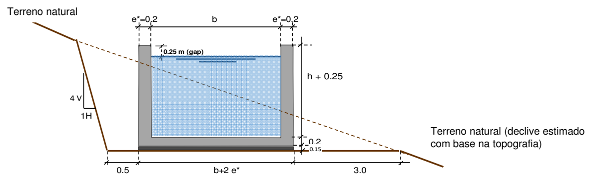
- Slope of the bottom of the canal: 1 m/1 km (i = 0.001 =0.1%)
- Minimum width of the canal: b >= 0.5 m
- b/h=1.5, h being the water depth for Qmax uniform flow
- Thickness of the walls of the canal (lateral and bottom): e* = 0.20 m
- Thickness of the ground regularization concrete: 0.15 m

✓Uniform flow head losses formula – Manning-Strickler formula

$Q = K\, S\, R^{2/3}\, i^{1/2}$ with R = hydraulics radius = S/P; S = flow cross section; P = wet perimeter; K = coefficient (75 $m^{1/3}\, s^{-1}$ for concrete)

Design steps

b → h → Q ↔ Qmax



[PT]

✓ Pressupostos

- Declive do fundo do canal: 1 m/1 km (i = 0.001 =0.1%)
- Largura mínima do canal (rasto do canal): b >= 0.5 m
- b/h=1.5 , sendo h a altura do escoamento uniforme de Qmax no canal
- Espessura das paredes do canal e da laje de fundo: e* = 0.20 m
- Espessura do betão de regularização sob a laje de fundo: 0.15 m

✓ Fórmula de resistência ao escoamento – Fórmula de Manning-Strickler

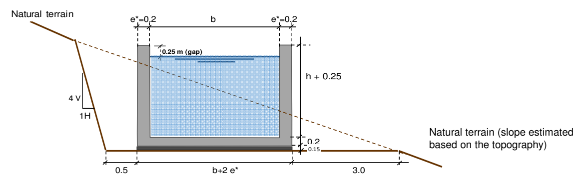
$Q_{max} = K\, S\, R^{2/3}\, i^{1/2}$ com R = raio hidráulico = S/P K coeficiente (75 $m^{1/3}\, s^{-1}$ para betão)

Etapas do dimensionamento

Arbítrio de um valor inicial para $b^{(1)}$ ➡ $h^{(1)} = b^{(1)}/1.5$ ➡ $S^{(1)} = b^{(1)}\, h^{(1)}$, $P^{(1)} = 2\, h^{(1)} + b^{(1)}$, $R^{(1)} = S^{(1)} / P^{(1)}$

➡ fórmula MS ➡ $Q^{(1)}$ ⬌ Qmax ➡ Se $Q^{(1)}$ > Qmax ➡ $b^{(2)} < b^{(1)}$; Se $Q^{(1)}$ < Qmax ➡ $b^{(2)} > b^{(1)}$

Repetição do procedimento até que $Q^{(i)} \sim$ Qmax (Opção do Excel goal seek)



[EN]

✓ Assumptions

- Slope of the bottom of the canal: 1 m/1 km (**i = 0.001** =0.1%)
- Minimum internal width of the canal: b >= 0.5 m
- b/h=1.5 , h being the water depth for Qmax uniform flow
- Thickness of the walls of the canal (lateral and bottom): e* = 0.20 m
- Thickness of the ground regularization concrete: 0.15 m

✓ Uniform flow head losses formula – Manning-Strickler (MS) formula

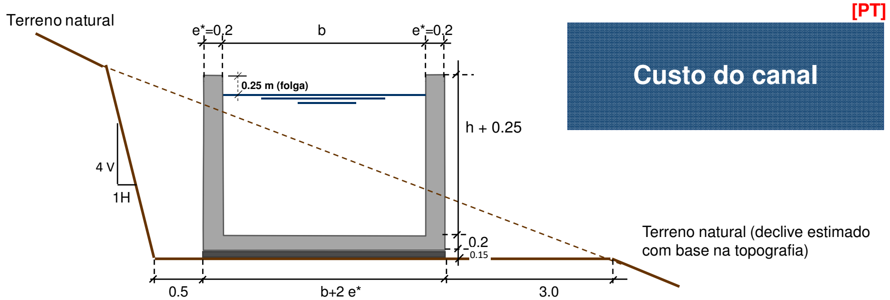
$Q_{max} = K\, S\, R^{2/3}\, i^{1/2}$ with R = hydraulics radius= S/P K coefficient (75 $m^{1/3}\, s^{-1}$ for concrete)

Design steps

Assumption of an initial value for $b^{(1)}$ ➡ $h^{(1)} = b^{(1)}/1.5$ ➡ $S^{(1)} = b^{(1)}\, h^{(1)}$, $P^{(1)} = 2\, h^{(1)} + b^{(1)}$, $R^{(1)} = S^{(1)} / P^{(1)}$

➡ MS formula ➡ $Q^{(1)}$ ⬌ Qmax ➡ If $Q^{(1)}$ > Qmax ➡ $b^{(2)} < b^{(1)}$; If $Q^{(1)}$ < Qmax ➡ $b^{(2)} > b^{(1)}$

Repetition of the procedure until $Q^{(i)} \sim$ Qmax (Excel goal seek option)



[PT]

Custo do canal

✓ Pressupostos

- Declive do fundo do canal: 1 m/1 km (i=0.001)
- Largura mínima do canal (rasto do canal): b >= 0.5 m
- b/h=1.5, sendo h a altura do escoamento uniforme de Qmax no canal
- Espessura das paredes do canal e da laje de fundo: e=0.20 m
- Espessura do betão de regularização sob a laje de fundo: 0.15 m

✓ Fórmula de resistência ao escoamento – Fórmula de Manning-Strickler

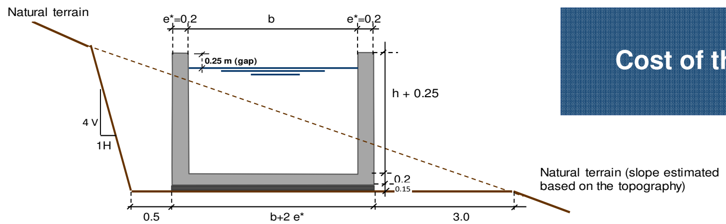
$Q_{max} = K\, S\, R^{2/3}\, i^{1/2}$ com R=raio hidráulico= S/P K coeficiente (para betão aprox. 75 $m^{1/3}\, s^{-1}$)

✓Custo da construção civil

- **Betão de regularização: 80 €/m³**
- **Betão armado: 200 €/m³**
- **Escavação e colocação em depósito: 30 €/m³**
- **Cofragem externa: 20 €/m²** ➡ **2 (h + 0.25 + 0.20) m²/m (área por metro linear de canal)**
- **Cofragem interna: 20 €/m2** ➡ **[2 (h + 0.25)] m²/m (área por metro linear de canal)**

✓Custo do equipamento

- **5% do custo da construção civil**



[EN]

Cost of the canal

✓ Assumptions

- Slope of the bottom of the canal: 1 m/1 km (i = 0.001 =0.1%)
- Minimum internal width of the canal: b >= 0.5 m
- b/h=1.5, h being the water depth for Qmax uniform flow
- Thickness of the walls of the canal (lateral and bottom): e* = 0.20 m
- Thickness of the gorund regularization concrete: 0.15 m

✓ Uniform flow head losses formula – Manning-Strickler formula

Q = K S R2/3 $i^{1/2}$ with R = hydraulics radius = S/P S = flow cross section

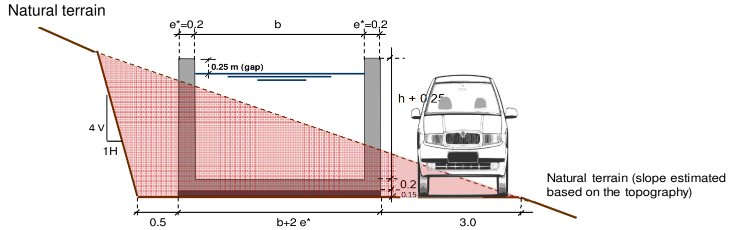
P = wet perimeter K = coefficient (75 $m^{1/3}\, s^{-1}$ for concrete)

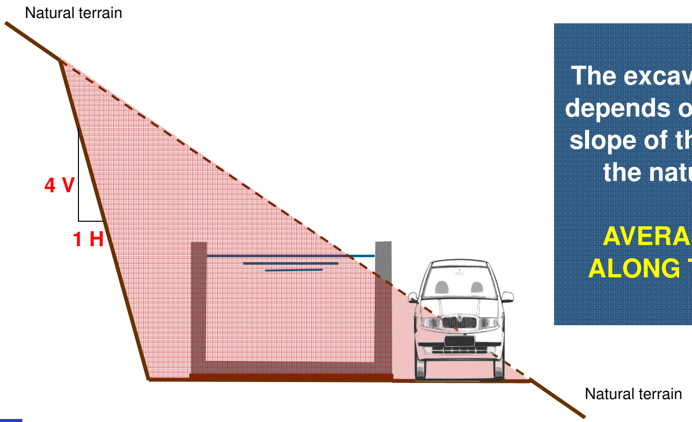
✓Civil construction cost

- **Ground regularization concrete** (15 cm thickness)**: 80 €/m³**
- **Reinforced concrete: 200 €/m³**
- **Excavation and deposition: 30 €/m³**
- **External formwork: 20 €/m²** ➡ **2 (h + 0.25 + 0.20) m²/m (area per linear meter of canal)**
- **Internal formwork: 20 €/m²** ➡ **[2 (h + 0.25)] m²/m (area per linear meter of canal)**

✓Equipment cost

- **5% of the civil construction cost**

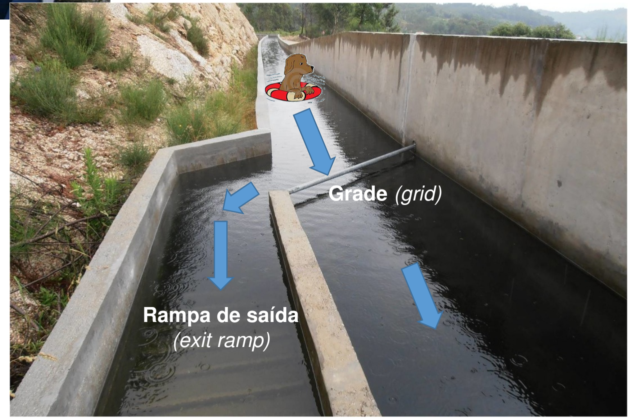




The excavation volume depends on the average slope of the hillsides of the natural terrain

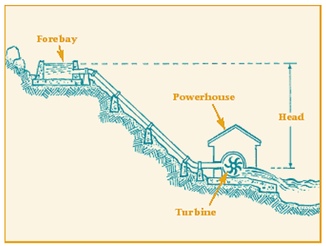
AVERAGE SLOPE ALONG THE CANAL

Rampas de salvamento do canal (canal *rascue ramps)*



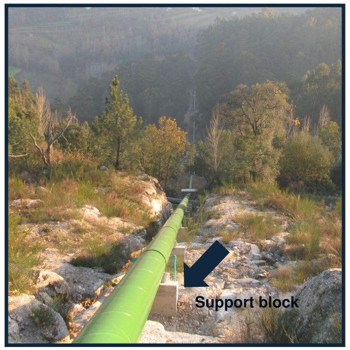
Forebay (it promotes the transition between the free surface flow in the canal and the pressurized flow in the penstock) – civil construction cost approx. equal to the cost of 50 m of canal; equipment cost equal to 25% of the civil construction cost

Câmara de carga (promove a transição entre o escoamento em superfície livre no canal e o escoamento em pressão na conduta forçada) – custo da construção civil aprox. igual ao custo de 50 m de canal; custo do equipamento igual a 25% do custo da construção civil



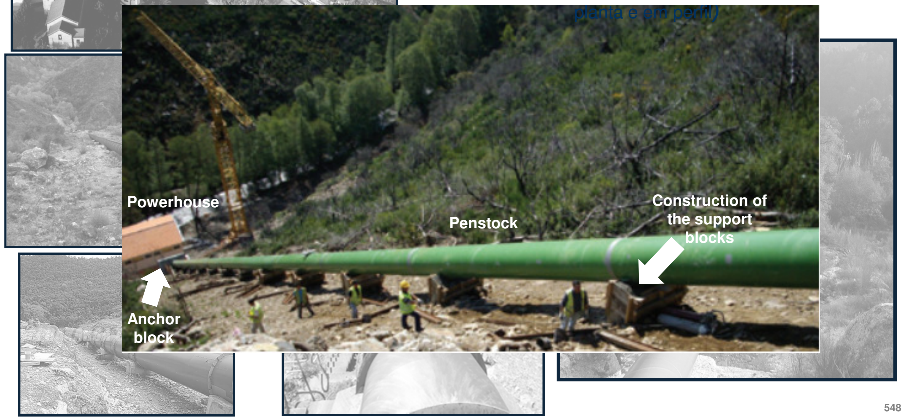
***Steel penstock** (pressurized flow) – installed in open air on support blocks and with anchor blocks in any profile singularity (curves either in plant or vertical profile)*

Conduta forçada em aço (adução em pressão) – instalada ao ar livre apoiada em maciços de apoio e dispondo de maciços de amarração nas singularidades em planta e em perfil*)*

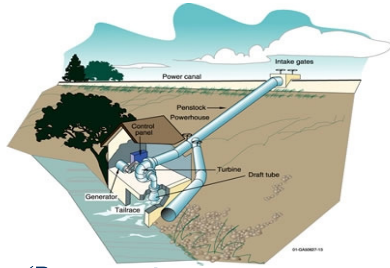


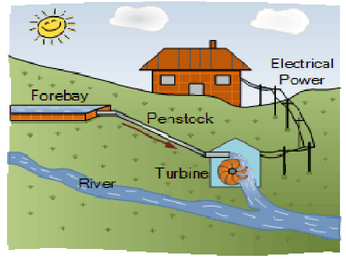
Steel penstock *(pressurized flow) – installed in open air on support blocks and with anchor blocks in any profile singularity (curves either in plant or vertical profile)*

Conduta forçada em aço (adução em pressão) – instalada ao ar livre apoiada em maciços de apoio e dispondo de maciços de amarração nas singularidades em



[PT]





✓**Pressupostos**

- **dimensionamento resultante de otimização técnico económica tendo em conta …. mas …**
- **velocidade máxima do escoamento da ordem de 3 m/s – Q = v S**
- **diâmetros, D, comerciais disponíveis de 50 em 50 mm**

✓**Fórmula de resistência ao escoamento – Fórmula de Manning-Strickler**

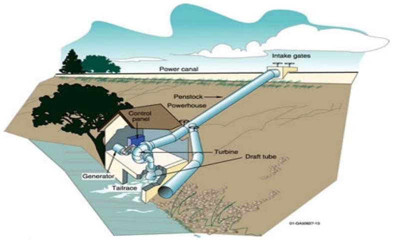
$Q = K\,S\,R^{2/3}\,J^{1/2}$ Q caudal (m^3/s); D diâmetro (m); S = π (D/2)² (m^2); R = D/4 raio hidráulico (m); J perda de carga unitária (-); K coeficiente (para aço aprox. 90 m1/3 s-1); Δh = J L perda de carga (m)

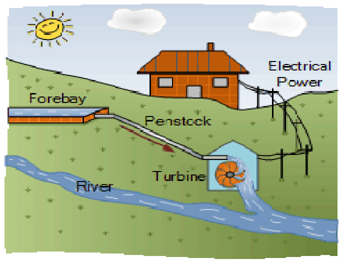
(**Nota:** analisar a perda de cota do rasto do canal adicionada com a perda de carga na conduta forçada para o caudal máximo derivável, J L, de modo a não exceder aprox. 5% da queda bruta. Relativamente a este limiar, o valor obtido deve de ter em conta ainda uma folga para atender às demais perdas de carga não contabilizadas, incluindo a perda de carga na adução)

✓**Espessura da conduta - 1 m ca (coluna da água) = 0.1 kgf/cm²; $e_{corrosão}$ = 0.1 cm)**

$$e\,(cm) = \frac{1.5 \times \frac{H_{bruta}\,(m)}{10} \times D\,(m) \times 100}{2400\,(kgf/cm^2)} + e_{corrosão}(cm)$$

[EN]





✓**Assumptions**

- **design resulting from a technical economical optimization based on the cost of the penstock versus the cost of the energy losses along the same … but …**
- **maximum flow velocity of approx. 3 m/s – Q = v S**
- **commercial diameters, D, available each 50 mm (theoretical diameter rounded to the next higher commercial diameter)**

✓**Flow resistance formula – Manning-Strickler formula**

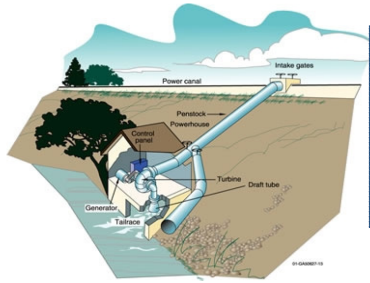
$Q = K\,S\,R^{2/3}\,J^{1/2}$ Q discharge (m^3/s); D diameter (m); S = π (D/2)² (m^2); R = D/4 hydraulic radius (m); J friction slope (-); K coefficient (for steel approx. 90 $m^{1/3}\,s^{-1}$); Δh = J L head loss (m)

(**Note:** The sum of the decrease of the elevation of the bottom of the canal with the head loss along the penstock for the design discharge, J L, and with a safety gap of a couple of meters to account for all the remaining head losses along the hydraulic circuit should not exceed approx. 5% of the gross topographic head)

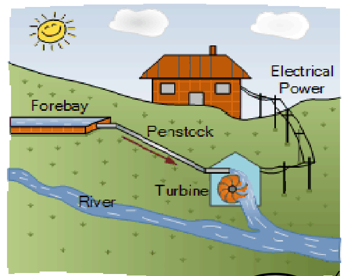
✓**Thickness of the penstock - 1 m wc (water column) = 0.1 kgf/cm²; $e_{corrosion}$ = 0.1 cm**

$$e\,(cm) = \frac{1.5 \times \frac{H_{gross}\,(m)}{10} \times D\,(m) \times 100}{2400\,(kgf/cm^2)} + e_{corrosion}(cm)$$

[PT]



Custo da conduta baseado no custo do aço

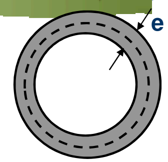


✓ **Peso da conduta**

$$peso\,(kgf/m) = \gamma_a\,(kgf/m^3) \times 2\pi \times [D(m)/2 + e(m)/2] \times e(m)$$

$$peso\,(kgf/m) = \gamma_a\,(kgf/m^3) \times \pi \times [D(m) + e(m)] \times e(m)$$

$$\gamma_a = 7800\,kgf/m^3$$ (peso específico do aço)



✓**Custo da conduta (equipamento) colocada em obra com base no custo do aço**

- $Cu_{aço}$=6 €/kgf

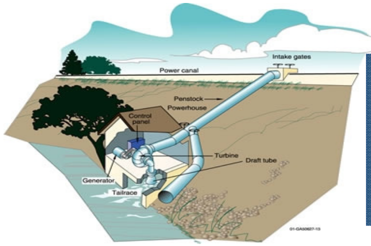
✓**Custo da construção civil por metro linear (maciços de apoio e de amarração)**

- cu = 350 €/m

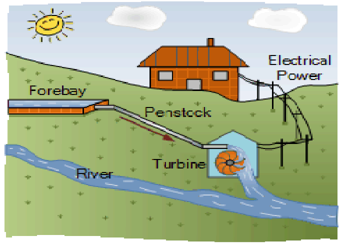
Etapas do dimensionamento

Qmax "+" v=3 m/s → $D_{teórico}$ → $D_{comercial}$ " + " Comprimento real → Perda de carga → Compatível? (Não → $D_{comercial}$)

[EN]



Penstock cost based on the steel cost

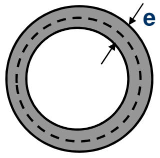


- ✓ Weight of the penstock

$$\text{weight (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times 2\pi \times [D(m)/2 + e(m)/2] \times e(m)$$

$$\text{weight (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times \pi \times [D(m) + e(m)] \times e(m)$$

$$\gamma_a = 7800\ \text{kgf/m}^3$$ (specific weight of the steel)

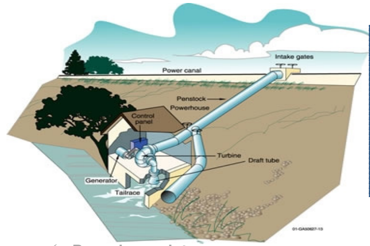


- ✓ Cost of the penstock (equipment) installed in situ based on the steel cost
  - Cu_{stell}=6 €/kgf
- ✓ Cost of the civil construction by linear meter (support and anchor blocks)
  - cu = 350 €/m

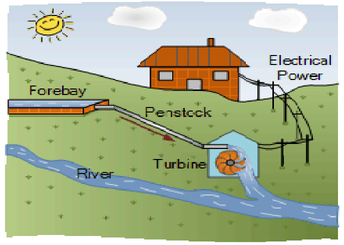
Design steps

Qmax "+" v=3 m/s ➡ $D_{theoretical}$ ➡ $D_{commercial}$ " + " Real lenght ➡ Head losses ➡ Compatible? — No ⬅ (back to $D_{commercial}$)

[PT]



Dimensionamento da conduta

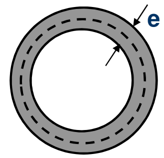


- ✓ Peso da conduta

$$\text{peso (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times 2\pi \times [D(m)/2 + e(m)/2] \times e(m)$$

$$\text{peso (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times \pi \times [D(m) + e(m)] \times e(m)$$

$$\gamma_a = 7800\ \text{kgf/m}^3$$ (peso específico do aço)



- ✓ Custo da conduta (equipamento) colocada em obra com base no custo do aço
  - $Cu_{aço}$=6 €/kgf
- ✓ Custo da construção civil por metro lineae (maciços de apoio e de amarração)
  - cu = 350 €/m

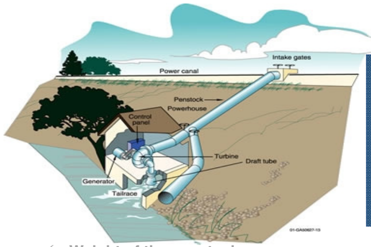
Etapas do dimensionamento

Qmax "+" v = 3 m/s ➡ Qmax = v S*, $S^* = \pi\,(D_{teórico}/2)^2$ ➡ $D_{teórico}$ ➡ $D_{comercial}$ ➡ $S = \pi\,(D_{comercial}/2)^2$, $R_{hidráulico} = D/4$ ➡

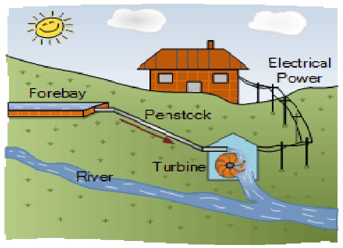
formula de MS ➡ J (perda de carga unitária) ➡ Δh = i x comprimento real = Perda de carga na conduta forçada ⬌

⬌ Compatível com o pressuposto de máxima perda de carga total de (1-0.95) da queda bruta (… atender à diminuição da cota do canal + folga para outras perdas de carga …) ➡ Não ➡ próximo $D_{comercial}$; Sim ➡ $D_{comercial}$

[EN]



Design of the penstock

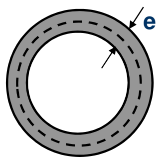


- ✓ Weight of the penstock

$$\text{weight (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times 2\pi \times [D(m)/2 + e(m)/2] \times e(m)$$

$$\text{weight (kgf/m)} = \gamma_a\,(\text{kgf/m}^3) \times \pi \times [D(m) + e(m)] \times e(m)$$

$$\gamma_a = 7800\ \text{kgf/m}^3$$ (specific weight of the steel)



- ✓ Cost of the penstock (equipment) installed in situ based on the steel cost
  - $Cu_{aço}$=6 €/kgf
- ✓ Cost of the civil construction by linear meter (support and anchor blocks)
  - cu = 350 €/m

Design steps

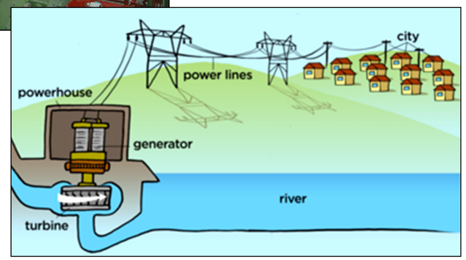
Qmax "+" v = 3 m/s ➡ Qmax = v S*, $S^* = \pi\,(D_{theoretical}/2)^2$ ➡ $D_{theoretical}$ ➡ $D_{commercial}$ ➡ $S = \pi\,(D_{commercial}/2)^2$, $R_{hydraulic} = D/4$ ➡

MS formula ➡ J (friction losses) ➡ Δh = J x real length = penstock head losses ⬌

⬌ Compatible with the assumption of total maximum head losses of (1-0.95) of the gross head (… account for the decrease of the elevation of the canal bottom + a safety gap for additional head losses …) ➡ No ➡ next $D_{commercial}$; Yes ➡ $D_{commercial}$

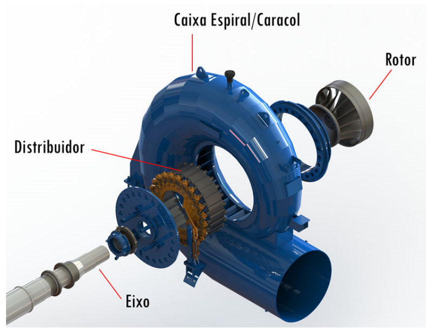
Central hidroelétrica

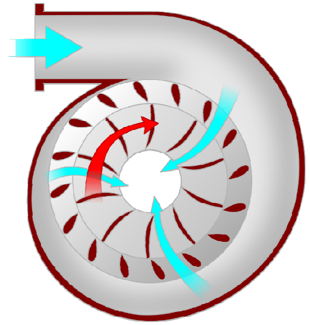
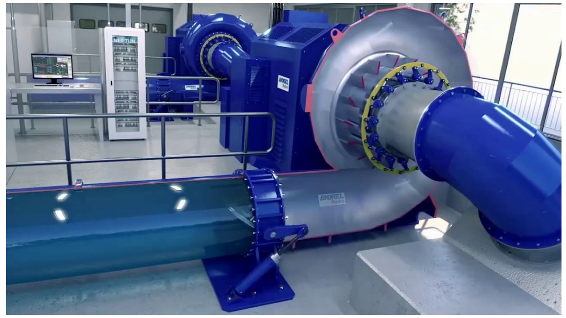
Powerhouse



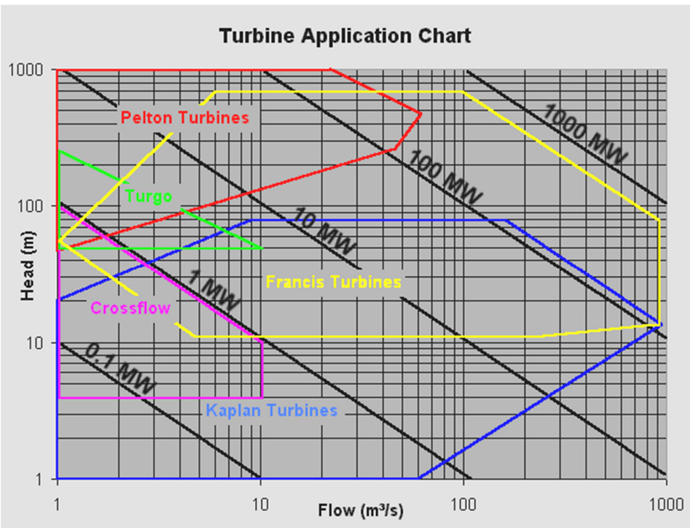


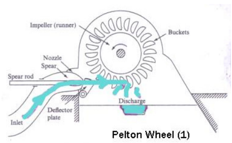
Pelton turbine (impulse turbine, high head, with vertical or horizontal shaft)

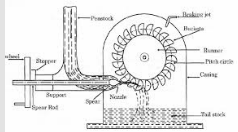
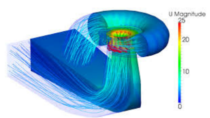
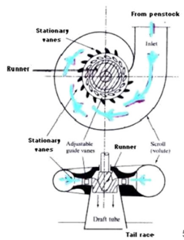


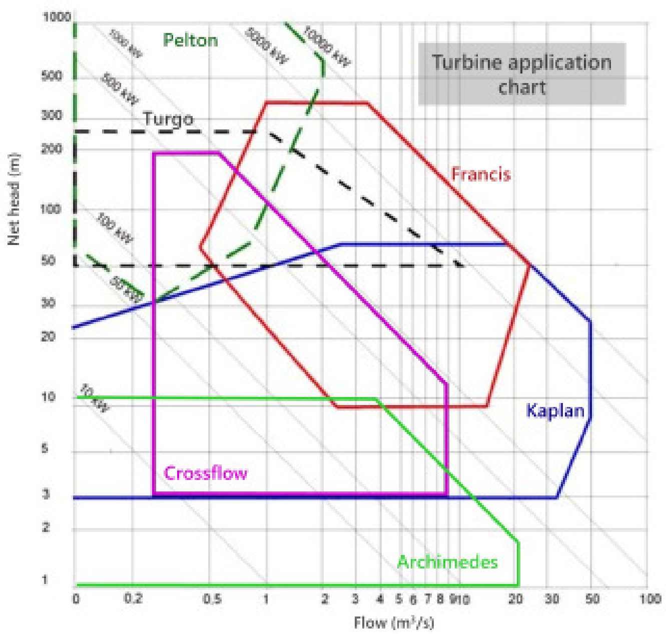



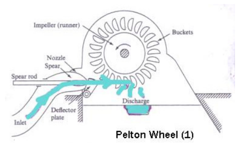
Francis turbine (reaction turbine, medium head)

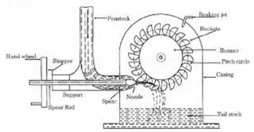
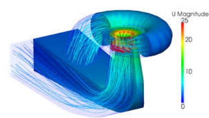
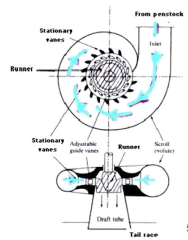


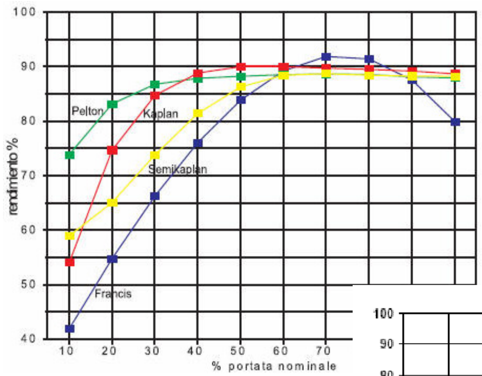




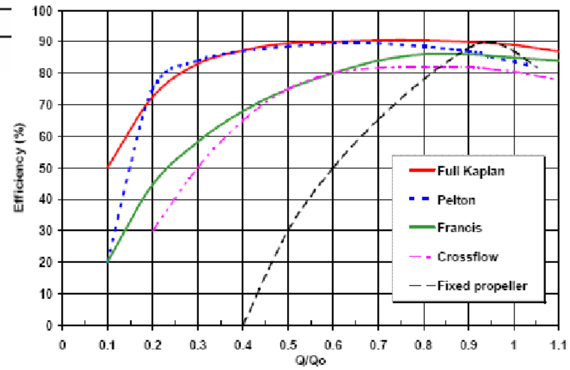


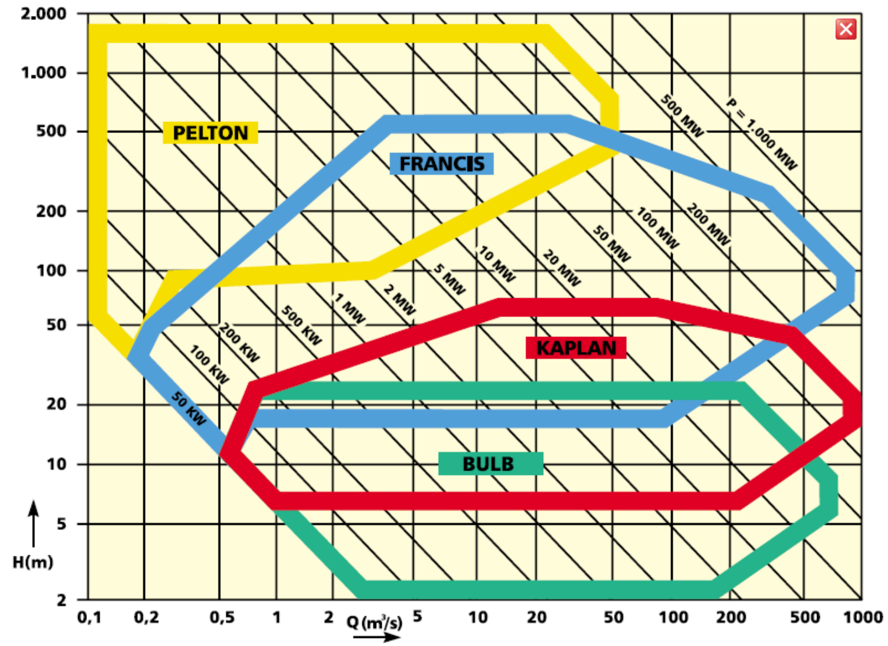


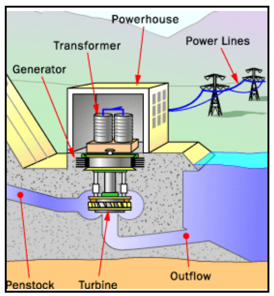
Curvas de rendimento de diferentes tipos de turbinas – variação acentuada conforme varia o caudal turbinado

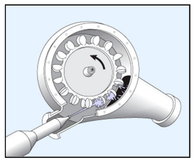
(efficiency curves for different types of turbines – marked variation as the turbined discharge varies)

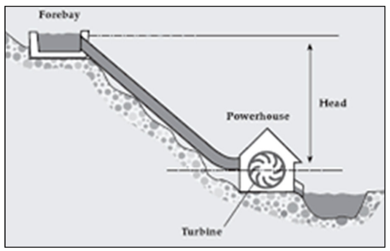


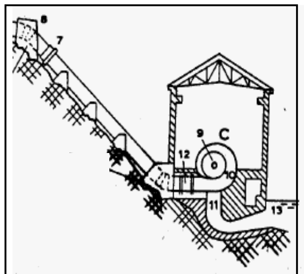
(fornecidas pelo fabricante)
(provided by the manufacture)







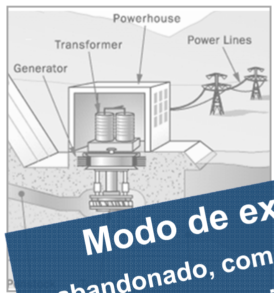


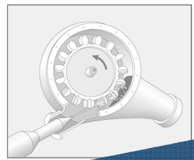


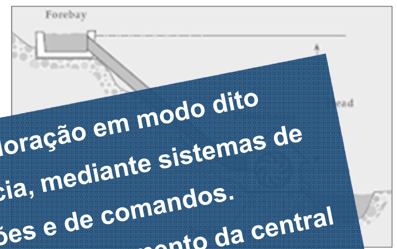
✓ **Custo de uma central hidroeléctrica a céu aberto, incluindo subestação anexa**:

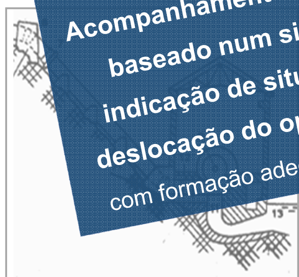
$$ct = K_P \; P^{0.7} \; H_{potência}^{-0.35}$$

em que ct (€) é o custo total; K_P um fator igual a 5000000 ou a 4500000, para turbinas do tipo Pelton e do tipo Francis, respetivamente; P (MW) a potência instalada; e e $H_{potência}$ (m) a queda de cálculo da potência. Do anterior custo total, admite-se que 75% sejam custos dos diferentes equipamentos instalados na central e 25%, custos com a construção civil.



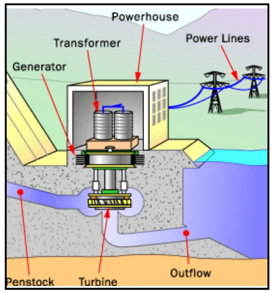


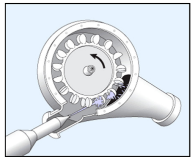


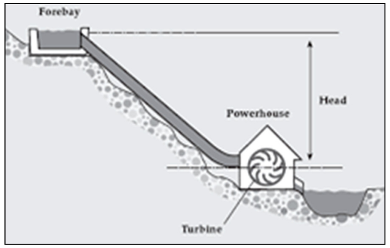


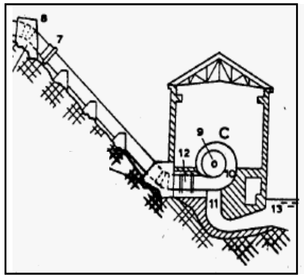
Modo de exploração: exploração em modo dito abandonado, com controlo à distância, mediante sistemas de teletransmissão de informações e de comandos. Acompanhamento de proximidade do funcionamento da central baseado num sistema de mensagens para telemóvel, com indicação de situações anómalas ocorridas que requeiram a deslocação do operador local (geralmente apenas um operador local com formação adequada**) e, se necessário, de técnicos adicionais**

um fator igual a 5000000 ... turbinas do tipo Pelton e do tipo ... respetivamente; P (MW) a potência instalada; e $H_{potência}$ (m) a queda de cálculo da potência (m). Do anterior custo total, admite-se que 75% sejam custos dos diferentes equipamentos instalados na central e 25%, custos com a construção civil.





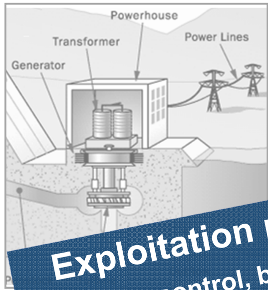


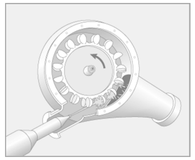


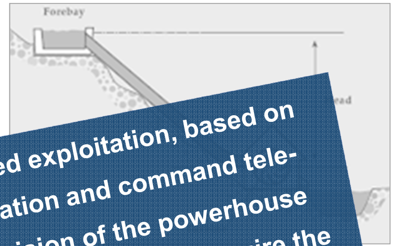
✓ **Cost of an open air powerhouse, including substation:**

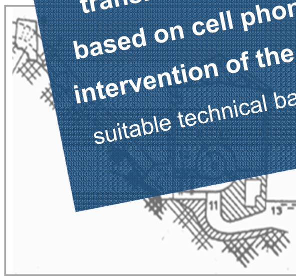
$$ct = K_P \, P^{0.7} \, H_{potência}^{-0.35}$$

where ct (€) is the total cost; K_P is a factor equal to 5000000 or to 4500000 for Pelton and Francis turbines, respectively; P (MW) is the installed capacity; and $H_{potência}$ (m) is the net head considered in the computation of the installed capacity. From the previous cost, it can be considered that approximately 75% are equipment costs and 25%, civil construction costs



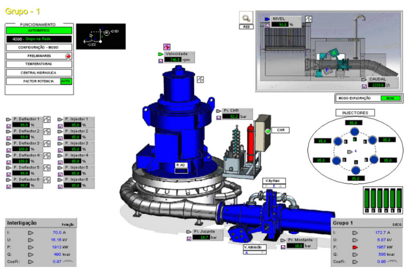


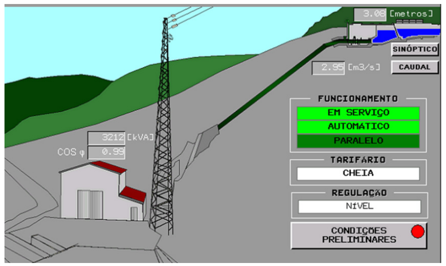


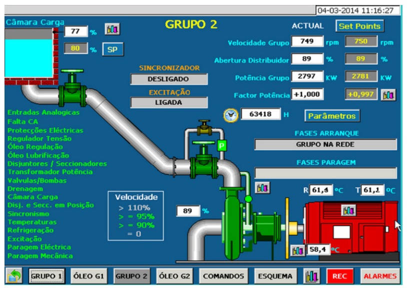


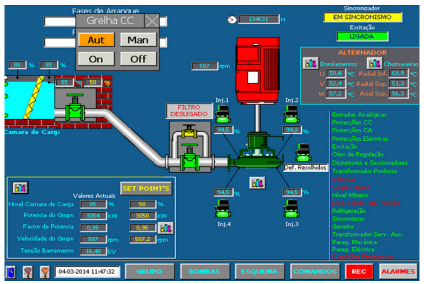
Exploitation mode: abandoned exploitation, based on remote control, by means of information and command tele-transmission systems. Local supervision of the powerhouse based on cell phone messages when the anomalies require the intervention of the local operating staff (general only one person with suitable technical background) **or and, if necessary, of an additional technical support team**

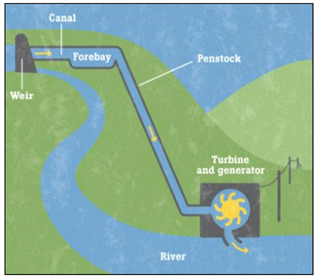
... cost; K_P is a factor equal to ... 4500000 for Pelton and Francis turbines, respectively; P (MW) is the installed capacity; and H_{power} (m) is the net head considered in the computation of the installed capacity. From the previous cost, it can be considered that approximately 75% are equipment costs and 25%, civil construction costs









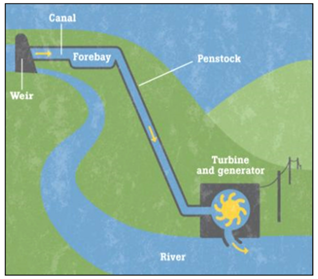


✓ **Outros custos de investimento**
- **Estudos e projetos**
- **Fiscalização**
- **Ligação à rede elétrica nacional**
- **Acessos (obra e exploração)**
- **Imprevistos, estaleiro, ensecadeiras, desmatação/desflorestação, desvio provisório**
- **Aquisição de terrenos**

✓ **Custos anuais**
- **operação** (~1.5 x salário mínimo)
- **manutenção**
- **administrativos** (2500 €/MW)
- **de utilização e licenciamento** (1% da receita anual média)

Ligação à rede: 70 €/m + 40000 € para o painel na subestação

[EN]



✓ **Other investment costs**

- Studies and designs
- Site supervision
- Connection to the electrical grid
- Roads (for construction and exploitation)
- Unforeseen, site facilities, coffer dams, river bypass, deforestation)
- Land acquisition

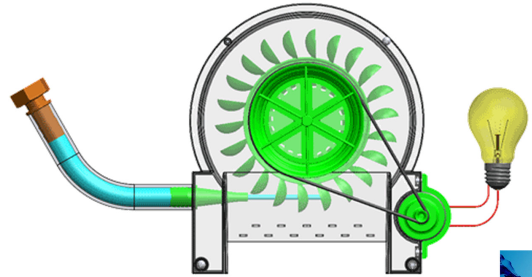
✓ **Annual costs**

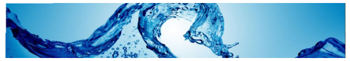
- Operation (~1.5 x minimum wage)
- Maintenance
- Administrative (2500 €/MW)
- Licensing and exploitation (1% the mean annual income)

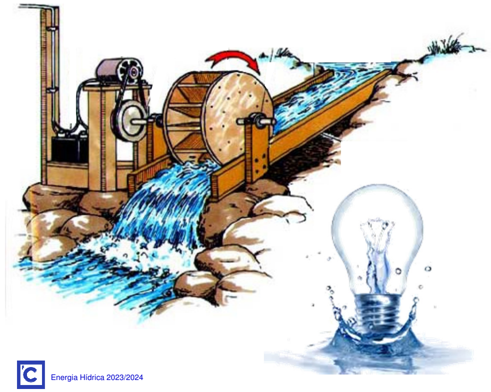
Ensecadeira (*coffer dam*)

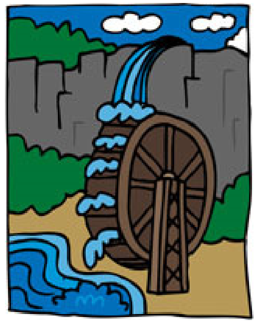
Connection to the grid: 70 €/m + 40000 € for the substation panel

Energy income









[PT]

Receita

Custo unitário de venda da energia produzida: .... €/kWh?

(preço de mercado)

[EN]

Receita

Energy unit sale price: .... €/kWh?

(market price)

CRITÉRIOS DE ANÁLISE ECONÓMICA
ANÁLISE DA VIABILIDADE ECONÓMICA DE SOLUÇÕES ALTERNATIVAS DE UM MESMO PROJETO

Economical analysis criteria
Economical feasibility study of the alternative solutions of a same project

Maria Manuela Portela

Um projeto visa a **satisfação** de um dado objectivo representando, normalmente, **uma das vias possíveis** para satisfazer esse objectivo, vias por vezes concorrentes entre si ou até mutuamente exclusivas

Necessidade de avaliar em que medida o projeto **satisfaz** ou não o objectivo

Definição de projetos alternativos tecnicamente viáveis

Comparação dos diferentes projetos numa base comum

Critérios de análise económica

A project aims at satisfying a specific objective, often representing one of the possible ways to comply with that same objective. Those ways often compete each other or even are mutually exclusive

Evaluation to which extend the project fulfills or not the objective

Definition of alternative solutions of a same project **all of them technically feasible**

Comparison of the different solutions in a common basis

Economic analysis criteria

FLUXOS MONETÁRIOS (custos e receitas)

… numa dupla perspetiva: montante e ocorrência ao longo do tempo (calendarização). Quanto mais rigorosas forem as estimativas dos fluxos monetários inerentes ao projeto, tanto mais os resultados da análise económica poderão contribuir para a comparação de soluções e para a fundamentação de decisões ou seja, para a identificação, de entre projetos alternativos tecnicamente viáveis, do melhor projeto.

MONETARY FLOWS OR CASH FLOWS (cost and incomes)

… in a double perspective: amount and occurrence in time (time schedule). The more precise are the estimates of the monetary fluxes the more the results from the economic analysis will contribute to the comparison and to the identification of the more correct and profitable solution among the alternatives solution of a same project, all of them technically sound.

CONSTANT MARKET PRICE SYSTEM referred to a particularly year, generally the first year of the exploitation period – this price system avoids the consideration of the inflation by considering that it equally affects all the monetary components of the system.

Monetary flows: investment cost, including reposition cost, as costs occurring at specific moments; exploitation and maintenance costs, as annual cost; incomes, ….).

SISTEMA DE PREÇOS DE MERCADO CONSTANTES rederidos a um dado ano, geralmente, o ano de início de exploração – tal sistema evita, em certa medida, a consideração da inflação admitindo que a mesma afeta de igual modo todas as componentes do projeto.

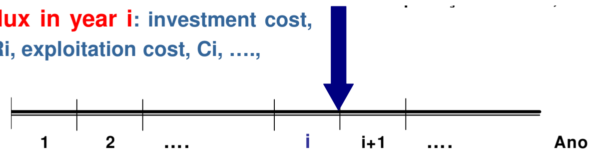
Custos de investimento, correspondendo, muito frequentemente, a gastos pontuais no tempo; custos de exploração e de manutenção, como encargos normalmente anuais; custos de reposição dos equipamentos e receitas

- PERÍODO DE ANÁLISE: período de tempo a que se refere a análise económica e para o qual são comparados (em termos económicos) os custos e as receitas tendo em vista apreciar a viabilidade do projeto ou identificar o projeto mais vantajoso (período de vida útil do projeto, horizonte de planeamento, questões relacionadas com o licenciamento…).

  Ao longo deste período considera-se que os fluxos monetários são sempre atribuídos ao fim do ano a que se referem.

Period of analysis (often the lifetime of the most relevant components): **period of time considered in the comparison - in economical terms - of the costs and of the benefits. The appraisal of the economic feasibility of the project and the comparison among alternative solutions of a same project is done for that period. Any monetary flow during the period of analysis is always assigned to the end of the year to which it refers**

Monetary flux in year i: investment cost, Ii, income, Ri, exploitation cost, Ci, ….,



Taxa de atualização

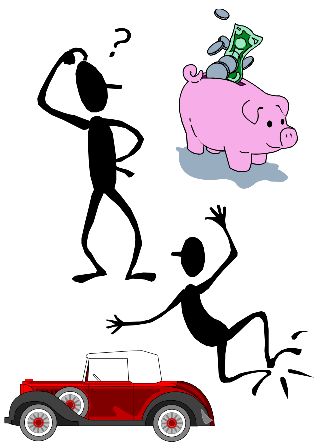
Os fluxos monetários ocorrem em diferentes instantes: fluxos passados, presentes e futuros que não são diretamente comparáveis entre si. A transferência no tempo da possibilidade de dispor de um bem tem a caraterística de uma troca entre bens diferentes.
A taxa dessa troca desempenha o papel de uma relação de preço – taxa de atualização anual, t, prevalecente num certo momento (quanto estou disposto a deixar de consumir hoje para consumir no futuro ou quanto não consumirei no futuro por preferir consumir hoje).

DISCOUNT RATE

Cash flows occurring at different instants are not directly comparable. The transference of the ownership of a good from the present to the future, or vice-versa, has the characteristic of a asset/good exchange.

The rate of that exchange is the discount rate.

It measures how much I am willing to save in the present in order to spend in the future or, on the contrary, if I prefer to consume today because I know that it is not worthwhile to save for the future.



DISCOUNT RATE - THE INTEREST RATE USED IN THE DISCOUNTED CASH FLOW ANALYSIS TO DETERMINE THE PRESENT VALUE OF FUTURE AND PAST CASH FLOWS

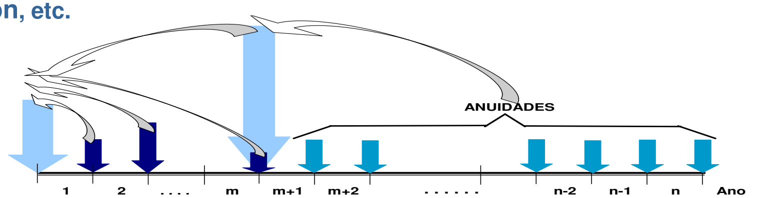
Total Monthly Income	$	
Savings		**Monthly Amounts**
Savings Accounts	$	
Individual Investments	$	
Other	$	
Other	$	
Other	$	
Total Savings	$	-
Debt Payments		
Mortgage	$	
Mortgage	$	
Bank Loans	$	
Car lease/Loan	$	
Credit Cards	$	
Other	$	
Other	$	
Total Debt Payments	$	-
Fixed Expenses		
Home		
Real Estate Taxes	$	
Maintenance Fees	$	
Other	$	

A taxa de atualização, t, permite calcular o valor que se atribui num dado instante a um fluxo monetário ocorrente num instante diferente.

A fixação da taxa de atualização, t, reflete a escolha entre consumir hoje ou no futuro e tem em conta, entre outros fatores, a taxa de juro do mercado, a disponibilidade de capitais, o risco associado ao projeto, a inflação esperada, etc.

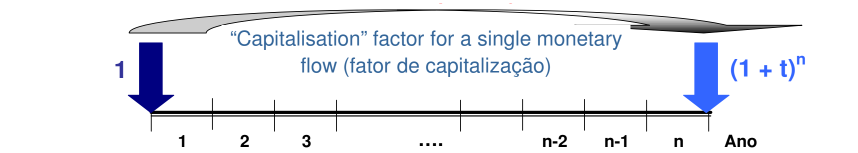
The discount rate, t, allows to assign a present value to monetary flows/cash flows (referred to a market price system) that occurred in the past or will occur in the future.

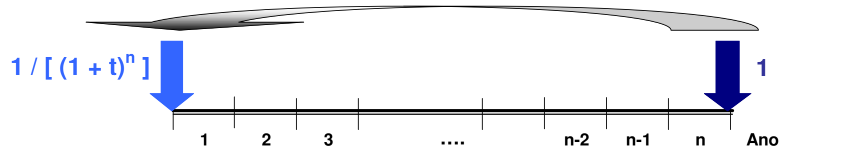
The value adopted for the discount rate, t, reflects the choice between consuming today instead of consuming in the future or vice-verse and takes into account, among other factors, the market interest rate, the availability of the capital, the bank interest rate, the risk of the project, the expected inflation, etc.



Time transference of monetary flows/cash flows in a system of constant market prices

Let n denote the length (expressed in years) of the period of analysis, from year 1 to year n. One monetary unit of today will be change in year n by $(1+t)^n$ monetary units and one monetary unit of year n will be change today by $1/(1+t)^n$ units (discount factor)



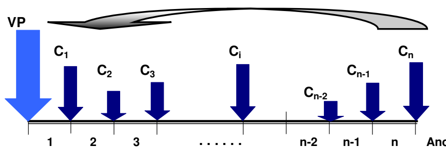


.... expresses the increase/decrease suffered by monetary fluxes when transferred in different "time" directions - present worth or value factor for a single monetary flux

[PT]

1. **Fator de atualização** fornece a **depreciação** sofrida pelos **fluxos monetários** quando transferidos para o presente. O **valor presente**, VP, de **uma unidade monetária** que venha a ocorrer no **ano i é dado por:** $VP = \frac{1}{(1+t)^i} C_i$

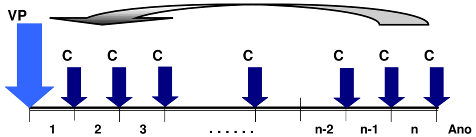
2. O **valor presente, VP, de uma sequência de custos Ci designa-se por valor acumulado atualizado para o início do 1º ano sendo dado por:**



$$VP = \frac{1}{(1+t)} C_1 + \frac{1}{(1+t)^2} C_2 + \frac{1}{(1+t)^3} C_3 + \cdots + \frac{1}{(1+t)^{(n-1)}} C_{n-1} + \frac{1}{(1+t)^n} C_n = \sum_{i=1}^{n} \frac{1}{(1+t)^i} C_i$$

3. Ou, se os fluxos monetários forem constantes (*or if the monetary fluxes are constant i.e., if they represent an annuity);*

$$VP = \sum_{i=1}^{n} \frac{1}{(1+t)^i} C_i = C \sum_{i=1}^{n} \frac{1}{(1+t)^i} = C \frac{(1+t)^n - 1}{(1+t)^n\, t}$$

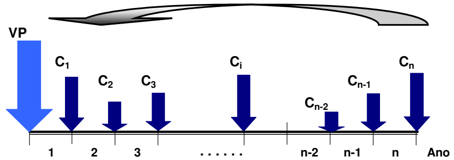


[EN]

1. **The "actualization" or discount factor evaluates the depreciation suffered by the monetary flows/cash flows when transferred from the future to the present. The present value, VP, of C_i monetary units assigned to the end of year i is given by:**

$$VP = \frac{1}{(1+t)^i} C_i$$

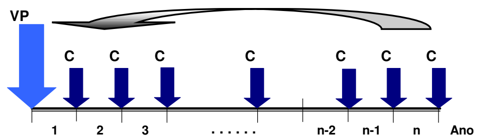
2. **The present value of a sequence of monetary flows referred to the first year of the analysis period - accumulated net present value or simply net present value - is given by:**



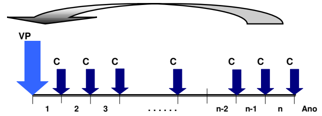
$$VP = \frac{1}{(1+t)} C_1 + \frac{1}{(1+t)^2} C_2 + \frac{1}{(1+t)^3} C_3 + \cdots + \frac{1}{(1+t)^{(n-1)}} C_{n-1} + \frac{1}{(1+t)^n} C_n = \sum_{i=1}^{n} \frac{1}{(1+t)^i} C_i$$

3. If the monetary fluxes are **constant**, i.e., if they represent an **annuity**:

$$VP = \sum_{i=1}^{n} \frac{1}{(1+t)^i} C_i = C \sum_{i=1}^{n} \frac{1}{(1+t)^i} = C \frac{(1+t)^n - 1}{(1+t)^n\, t}$$

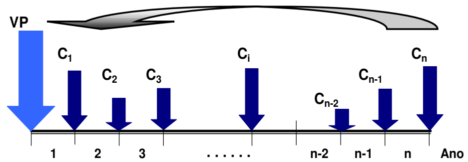


VP: valor presente ou valor acumulado atualizado para o início do 1º ano



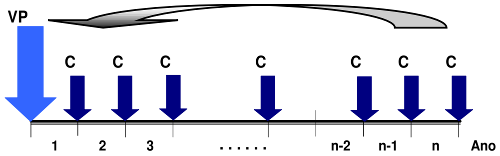
$$\frac{(1+t)^n - 1}{(1+t)^n\, t}$$

Fator de atualização à taxa t para o começo do período de n anos de uma série **uniforme de fluxos monetários (anuidades)** ocorrentes no fim de cada ano.

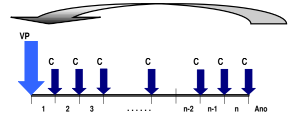


Custos ocorrentes no futuro (reposição de equipamentos).

Anuidades ocorrentes no futuro (receita, se avaliada na base da receita anual média).

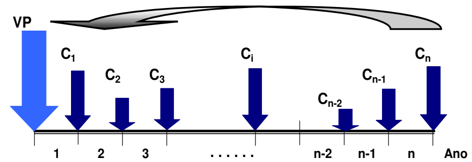


Present value or cumulative presente value, VP, referred to the beginning of the first year



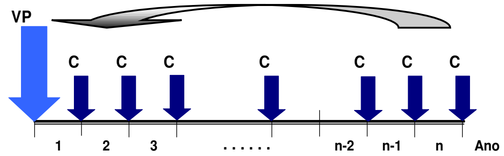
$$\frac{(1+t)^n - 1}{(1+t)^n\, t}$$

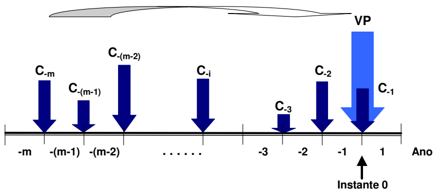
"Actualization" or **discount factor** for the discount rate t and for the beginning of the first year of the period with annuities, each one occurring at the end of each year: **present worth factor for an uniform series**



Future cost, e.g., reposition cost or O&M costs

Future annuities, e.g., expected annual inconnes



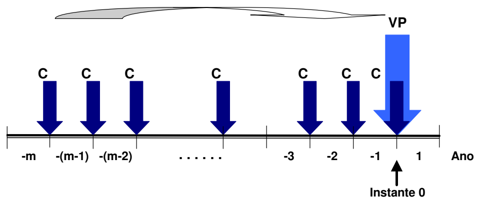


$$VP = C_{-1} + C_{-2}\,(1+t) + C_{-3}\,(1+t)^2 + \cdots$$

$$\cdots + C_{-(m-1)}\,(1+t)^{(m-2)} + C_{-m}\,(1+t)^{(m-1)} = \sum_{i=1}^{m} (1+t)^{(i-1)}\, C_{-i}$$

$$VP = \sum_{i=1}^{m} (1+t)^{i-1}\, C_{-i} = C \sum_{i=1}^{m} (1+t)^{i-1} =$$

$$= C\,\frac{(1+t)^{(m-1)}}{t}$$



$$\frac{(1+t)^{(m-1)}}{t}$$

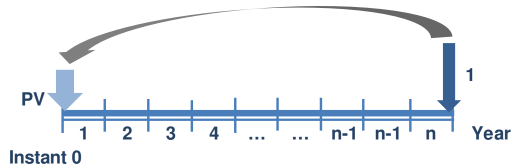
Fator de capitalização à taxa t para o termo do período de m anos de uma série uniforme de fluxos monetários (anuidades) ocorrentes no fim de cada ano

Capitalization factor for the discount rate t and for the end of the period of m years with annuities, each one occurring at the end of each year

SUMMARY

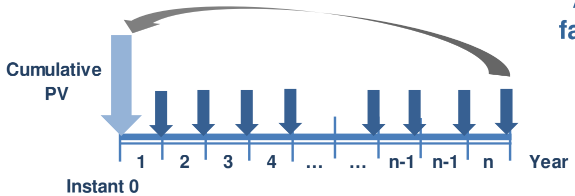
PRESENT VALUE, PV, OF FUTURE MONETARY FLOWS/CASH FLOWS

(all the monetary flows are referred to a constant market price system for the beginning of year 1 – instant 0 – and allocated to the end of the year in which they occur; the instant 0 is the end of year -1/beginning of year 1)



"Actualization" or discount factor for **single monetary flow in year n**

$$\frac{1}{(1+t)^n}$$



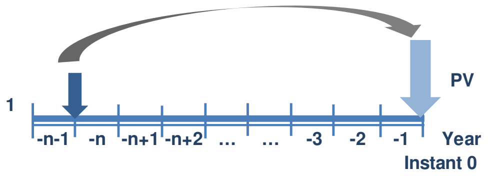
"Actualization" or discount factor for a **series of future annuities** during n years

$$\frac{(1+t)^n - 1}{(1+t)^n\, t}$$

SUMMARY

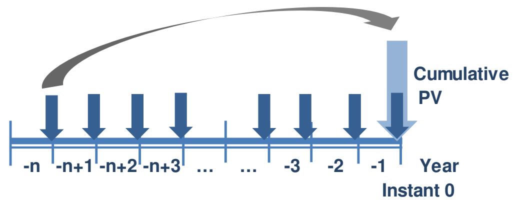
PRESENT VALUE, PV, OF PAST MONETARY FLOWS

(all the monetary flows are referred to a constant market prices for the beginning of year 1 – instant 0 – and allocated to the end of the year in which they occur; the instant 0 is the end of year -1/beginning of year 1)



“Actualization” or discount factor for single monetary flow in year n

$$(1+t)^n$$



‘”Capitalization”” or discount factor for a series of past annuities during n years

$$\frac{(1+t)^{(n-1)}}{t}$$

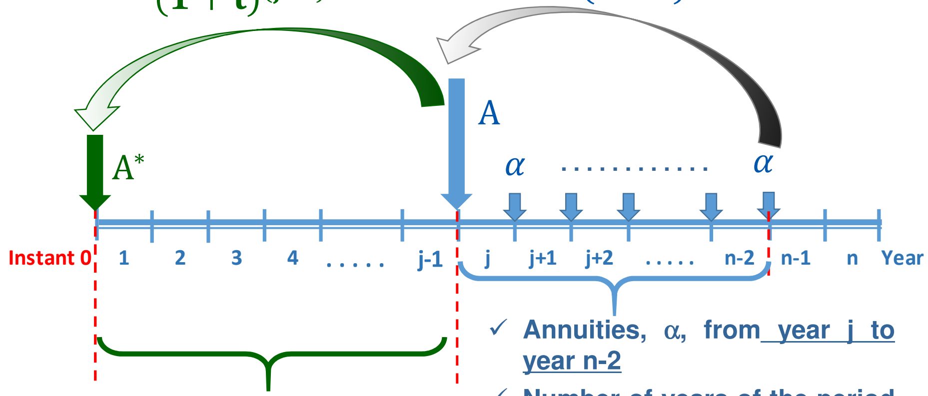
Appointment

Present value referred to instant 0, A*, of the sequence of annuities

$$A^* = A\frac{1}{(1+t)^{(j-1)}}$$

Cumulative present value, A, of the sequence of annuities – referred to the beginning of the first year with annuities

$$A = \alpha\frac{(1+t)^{[(n-2)-j+1]}-1}{(1+t)^{[(n-2)-j+1]}\,t}$$

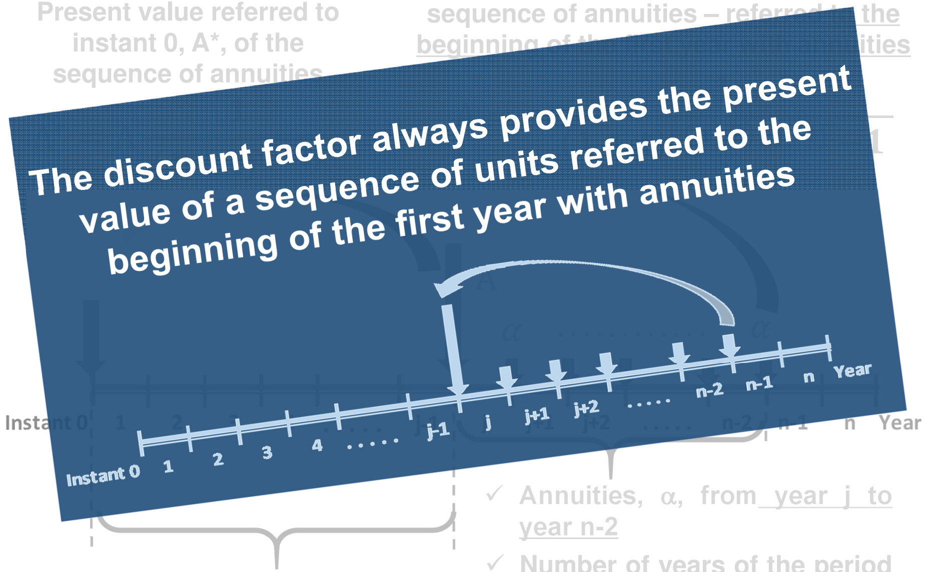


- ✓ Annuities, α, from year j to year n-2
- ✓ Number of years of the period with annuities: [(n-2) – j +1]
- ✓ Number of years: (j-1)

Appointment

Present value referred to instant 0, A*, of the sequence of annuities

Cumulative present value, A, of the sequence of annuities – referred to the beginning of the first year with annuities



- ✓ Annuities, α, from year j to year n-2
- ✓ Number of years of the period with annuities: [(n-2) – j +1]
- ✓ Number of years of (j-1)

ECONOMIC INDICATORS

The assessment of the economic feasibility of a project technically sound or the comparison between alternative solutions of a same project all of them technically sound are based on economic indicators:

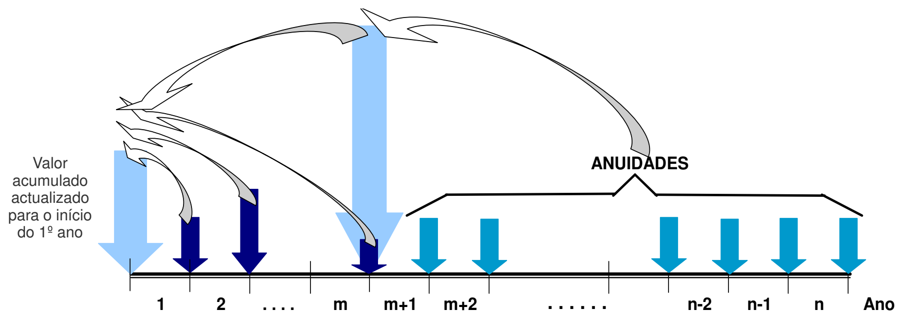
- **Net present value, NPC** (valor atualizado líquido, VAL);
- **Benefit/cost ratio, B/C** (índice benefício/custo);
- **Internal rate of return, IRT** (taxa interna de rentabilidade, TIR);
- **Payback period** (período de recuperação do investimento).

NOTATION:

n	lifetime of the project = period of analysis
t	discount rate (taxa de atualização)
Ii	Investment cost in year i
Oi	operation and maintenance cost, O&M, in year i;
Ri	income in year i
Si	reposition cost in year i

ASSUMPTION: CONSTANT MARKET PRICE SYSTEM (referred to moment 0)

[PT]



$$I = \sum_{i=1}^{m} \frac{1}{(1+t)^i} I_i$$

Investimentos

$$O = \frac{\sum_{i=1}^{n-m} \frac{1}{(1+t)^i} O_i}{(1+t)^m}$$

Custos de operação e de manutenção

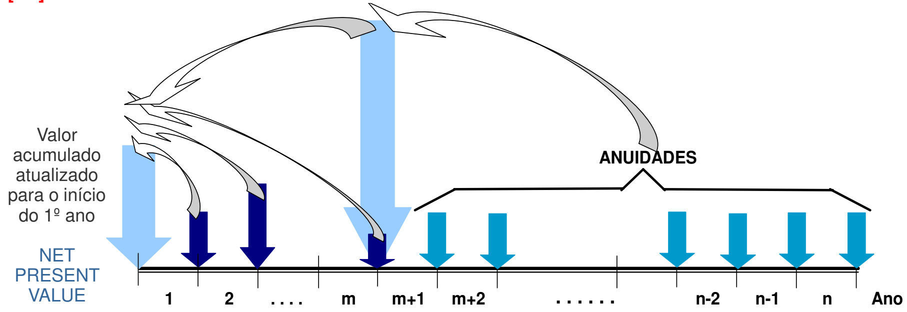
$$S = \frac{S_i}{(1+t)^i}$$

Custo de reposição

$$R = \frac{\sum_{i=1}^{n-m} \frac{1}{(1+t)^i} R_i}{(1+t)^m}$$

Receitas

[EN]



$$I = \sum_{i=1}^{m} \frac{1}{(1+t)^i} I_i$$

Investment costs

$$O = \frac{\sum_{i=1}^{n-m} \frac{1}{(1+t)^i} O_i}{(1+t)^m}$$

O&M annuities

$$S = \frac{S_i}{(1+t)^i}$$

Reposition costs

$$R = \frac{\sum_{i=1}^{n-m} \frac{1}{(1+t)^i} R_i}{(1+t)^m}$$

Incomes annuities

Each cash inflow/outflow is discounted back (…forwards) to its present (… future) value (PV). All the values thus obtained are summed = NPV (net present value)

[PT]

VALOR ATUALIZADO LÍQUIDO, VAL

(NET PRESENT VALUE)

O VAL representa a soma acumulada atualizada dos benefícios esperados deduzidos dos custos esperados, uns e outros durante o período de vida do projeto:

$$VAL = R - I - O - S$$

Se o VAL é negativo, o projeto deve ser rejeitado pois o valor atualizado dos benefícios não compensará o valor atualizado dos custos. Admitindo que não existem restrições à disponibilidade inicial de capital, de entre projetos alternativos com VAL positivo deve ser escolhido o que apresentar maior VAL.

[EN]

NET PRESENT VALUE, NPV

(valor atualizado liquído, VAL)

The NPV is the difference between the present values of all the cash inflows and the present values of all the cash outflows over the period of analysis

$$NPV = R - I - O - S$$

If the NPV is negative, the project must be rejected as the net present values of the cash inflows will not compensate those of the cash outflows.

Assuming that there are no restrictions related to the initial capital availability, among alternative projects with positive NPV, the one with the highest NPV should be chosen.

ÍNDICE BENEFÍCIO/CUSTO, B/C
(*BENEFIT/COST RATIO*)

O B/C representa o valor presente da "riqueza" gerada pelo projeto por unidade de "recurso atualizado utilizado":

$$B/C=\frac{R-O}{I+S}$$ ou $$B/C=\frac{R}{I+S+O}$$

A primeira definição é mais coerente uma vez que agrega os fluxos monetários anuais ocorrentes durante a vida útil do projeto.

Se B/C é menor do que 1 o projeto não apresenta viabilidade. Se B/C é igual a 1 o projeto tem um interesse marginal e se é maior do que 1 o projeto é economicamente viável, sendo tanto mais viável quanto maior for B/C.

Um valor unitário de B/C conduz a um VAL igual a zero.

BENEFIT/COST RATIO, B/C
(Índice benefíio/custo)

The B/C represents the added present value of the cash inflow generated by the project per unit of the present value of the cash outflow (ratio between present values of the benefits and costs)

$$B/C=\frac{R-O}{I+S}$$ $$B/C=\frac{R}{I+S+O}$$

The first definition is more coherent as it aggregates in the numerator all the monetary flows that occur annually during the life of the project.

If B/C is less than 1 the project is not economically profitable, that is, is expected to deliver a net present value. If B/C is equal to 1 the project has a marginal interest and if it is greater than 1 the project is economically profitable, the more profitable the greater the B/C.

A unit value of B/C leads to a NPV equal to zero.

TAXA INTERNA DE RENTABILIDADE, TIR
(*INTERNAL RATE OF RETURN*)

A TIR é definida como sendo a taxa de atualização que torna o VAL nulo.

$$VAL=\frac{\sum_{i=1}^{n-m}\frac{1}{(1+TIR)^i}(R_i-O_i)}{(1+TIR)^m}-\sum_{i=1}^{m}\frac{1}{(1+TIR)^i}I_i-\frac{S_i}{(1+TIR)^i}=0$$

É determinada de modo iterativo.

Se a taxa de atualização for igual à TIR, o VAL torna-se nulo e o B/C, unitário.

De entre projetos alternativos com diferentes TIR, o projeto mais vantajoso é o que apresentar maior TIR, sendo economicamente viável se tal taxa superar a taxa de atualização, t.

INTERNAL RATE OF RETURN, IRT
(taxa interna de rentabilidade, TIR)

- ✓ The IRT is the discount rate that makes the net present value, NPV, equal to 0 and the benefit/cost ratio, B/C, equal to 1
- ✓ It computation is based on an iterative procedure
- ✓ Among projects/alternative solutions of a same project, the one with the highest IRT is the economically more advantageous
- ✓ If the IRT is greater then the applicable discount rate, t, the NPV witll be positive and the B/C greater than 1 and the project will be economically profitable
- ✓ If the IRT is smaller then the applicable discount rate, the project/alternative solution is not economically profitable because its cash outflows are greater then the cash inflows

PERÍODO DE RECUPERAÇÃO DO INVESTIMENTO, T
(*PAYBACK PERIOD)*

O período de recuperação do investimento, T, é determinado com base no ***cash-flow*** **acumulado atualizado** e representa o **número de anos até que os benefícios se compensem os custos**, uns e outros acumulados atualizados. De entre **projecos alternativos com diferentes T** o **mais vantajoso** é o que apresentar **menor T.**

PAYBEACK PERIOD
(período de recupração do investimento)

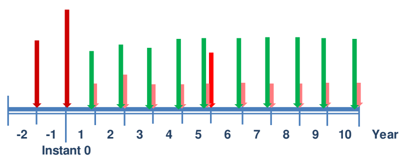
The payback period it refers to the number of years it takes to recover the cost of an investment, in terms of present values. It is estimated based on the cumulative discounted cash flows (cashflow acumulado descontado)

Among alternative solutions of a same project, the one with the smallest payback period is the more advantageous

Years	Present Value of USD 1 @10.81%	Present value of cash flows	Discounted present value of cash flows	Cumulative present value of cash flows
0	-	-2992584	-	-
1	0.902	427258.65	385387.30	385387.30
2	0.814	427258.65	347788.50	733175.80
3	0.735	427258.65	314035.10	1047211.00
4	0.663	427258.65	283272.50	1330483.00
5	0.599	427258.65	255927.90	1586411.00
6	0.54	427258.65	230719.70	1817131.00
7	0.488	427258.65	208502.20	2025633.00
8	0.44	427258.65	187993.80	2213627.00
9	0.397	427258.65	169621.70	2383249.00
10	0.358	427258.65	152958.60	2536207.00
11	0.323	427258.65	138004.50	2674212.00
12	0.292	427258.65	124759.50	2798971.00
13	0.263	427258.65	112369.00	2911340.00
14	0.238	427258.65	101687.60	3013028.00
15	0.215	427258.65	91860.61	3104889.00

Each cash inflow and outflow is discounted back (…forwards) to its present value (PV). Then all are summed. Therefore, NPV is the sum of all terms

Year, i	Investment cost, I (1000 €)	Reposition cost, S (1000 €)	Annual O&M, O&M (1000 €)	Annual incomes, R (1000 €)
-2	580			
-1	1200			
1			10	200
2			20	250
3			10	280
4			12	280
5		360	12	400
6			12	400
7			12	400
8			12	400
9			12	400
10			12	400



Discount rate, t 0.06	Cash flow				
	Discounted present value (discounted PV)) (1000 €)				Cumulative discounted PV
Year, i	I	S	O&M	R	(1000 €)
-2	-614.80				-614.80
-1	-1200.00				-1814.80
1			-9.43	188.68	-1635.55
2			-17.80	222.50	-1430.86
3			-8.40	235.09	-1204.16
4			-9.51	221.79	-991.88
5		-269.01	-8.97	298.90	-970.95
6			-8.46	281.98	-697.43
7			-7.98	266.02	-439.39
8			-7.53	250.96	-195.95
9			-7.10	236.76	33.71
10			-6.70	223.36	250.36

Net present value, NPV (1000 €)	250.36
Benefit/cost ratio, B/C	1.1201
Payback period	year 9
Internal rate of return, IRT	0.0831

Year, i	Investment cost, I (1000 €)	Reposition cost, S (1000 €)	Annual O&M, O&M (1000 €)	Annual incomes, R (1000 €)
-2	580			
-1	1200			
1			10	200
2			20	250
3			10	280
4			12	280
5		360	12	400
6			12	400
7			12	400
8			12	400
9			12	400
10			12	400

$(1+t)^{-i-1}$

$\frac{1}{(1+t)^{i}}$

Discount rate, t	Cash flow				
0.06	Discounted present value (discounted PV)) (1000 €)				Cumulative discounted PV (1000 €)
Year, i	I	S	O&M	R	
-2	-614.80				-614.80
-1	-1200.00				-1814.80
1			-9.43	188.68	-1635.55
2			-17.80	222.50	-1430.86
3			-8.40	235.09	-1204.16
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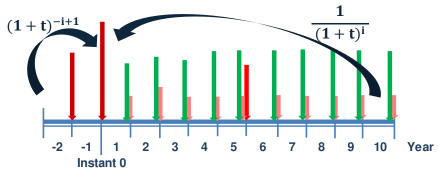
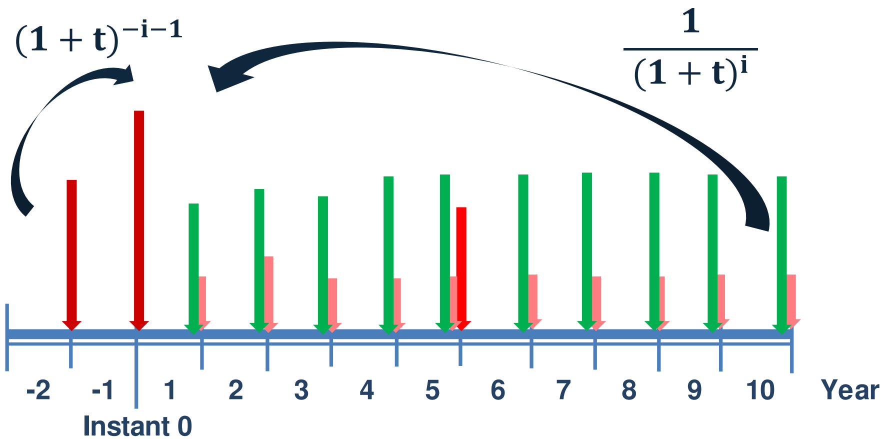
7			-7.98	266.02	-439.39
8			-7.53	250.96	-195.95
9			-7.10	236.76	33.71
10			-6.70	223.36	250.36

Iterative procedure imposing NPV=0 and changing t

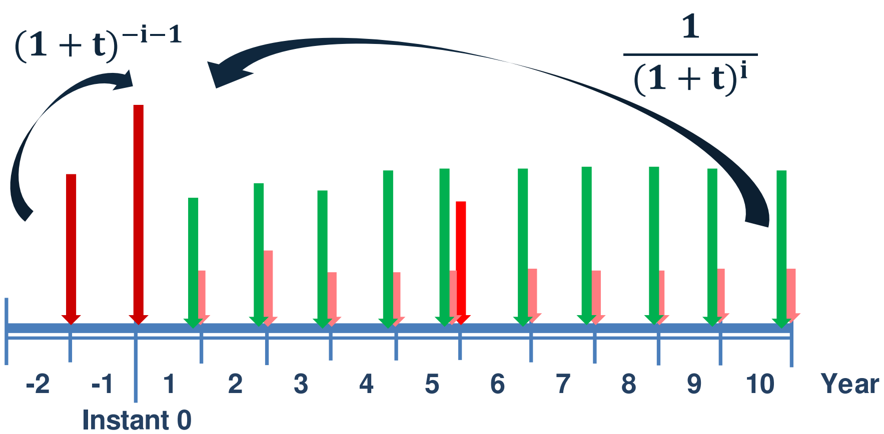
Net present value, NPV (1000 €)	250.36
Benefit/cost ratio, B/C	1.1201
Payback period	year 9
Internal rate of return, IRT	0.0831



It is advantageous to represent the temporal allocation of the monetary flows in order to easily identified the “gap” in time to consider when computing the different discounted present values



Regardless the notation, the exponent is always the NUMBER OF YEARS (“gap” time) between the END OF THE YEAR in which the monetary flow occurred and INSTANT 0



(1) Período de avaliação (época normal) - 05 a 19 de janeiro 2023
(2) Entrega da último trabalho - 28 de dezembro/2023 (Segurança C8)
(3) Exame de época normal - 12 de janeiro/2024
(4) Exame de recurso - 8 fevereiro/2024
(4) Orais

	Dia 8 de janeiro	Dia 9 de janeiro
10:00	CABRIL	OVIL
11:00	BESTANÇA	AVELAMOS
12:00	OLO	SORDO
13:00		MARÃO
15:00		
16:00		
17:00		
18:00		

51532 Rita Maria dos Santos Martinho 51537 Daniel Almeida Leão Franco Silva 54865 Henrique Costa Calado	Rio Sordo
54877 Guilherme Duarte Mariano 54864 Margarida Isabel Luís 54861 Matilde Vieira Linhares Figueira 54880 Miguel Dias Cardadeiro	Rio Avelames
51519 Vivian Nepumucena de Sousa 51857 Ludmila Patrícia Furtado Fernandes 54887 João Alexandre Festas Gomes Pestana 51528 João Pereira	Rio Bestança
60485 Miguel Luís João de Carvalho 60484 Tiago Alexandre de Castro Moura da Silva Pe 62425 Jonathan-Fridtjof Krause	Rio Ovil
53555 Laura Cardoso Pereira 59463 Rafael Marques Silva 60486 Daniela Tavares Sousa Almeida 60487 David José Bernardino Ferreira	Rio Cabril
54886 Miguel de Jesus Ferreira Anacleto 54875 Diogo Vilardell Gomes Rodrigues 54881 Rodrigo Miguel Garcia Matias	Rio Marão
49711 Sandro Miguel Marques Eugénio 51973 João Miguel de Almeida Xavier 53241 Vasco Maria Homem de Figueiredo dos Sant	Rio Olo

DEZEMBRO 2023

SE	TE	QU	QU	SE	SA	DO
				1	2	3
4	5	6	7	8	9	10
11	12	13	14		16	17
18	19	20	21	22	23	24
25	26	27		29	30	31

JANEIRO 2024

SE	TE	QU	QU	SE	SA	DO
1	2	3	4	5	6	7
		10	11		13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FEVEREIRO 2024

SE	TE	QU	QU	SE	SA	DO
			1	2	3	4
5	6	7		9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29			


HYDROPOWER
WATER
FLOW
AIR
TURBINE
HYDROELECTRIC
DUE
FLOOD
DEVELOPMENT
DAMS
FALL
HYDROELECTRICITY
HYDRAULIC
MILLS
ALSO
FALLING
GRAVITY
TURBINES
ENERGY
PER
HEAD
POWER
USED
COMPRESSED
EFFICIENCY
DENSITY
LEVEL
HEIGHT
WHEELS
EARLY
DEVELOPED
AVAILABLE
NETWORKS
ANCIENT
RIVER
AMOUNT
HISTORY
UNIT
METHOD
CHAMBER
SOURCE
SINCE
HIGH
HYDRO
CANALS
SMALL
DESIGN
BUILT
CALIFORNIA
USE
USES
WITHOUT
RESERVOIRS
IRRIGATION
DEMAND
TYPES
CALCULATION
OUTLET
WHEEL
SYSTEMS
ACCELERATION
ALLOWED
CHINA
KILOWATTS
WEIGHT
RATE

THE END!


THANK YOU
FOR YOUR
ATTENTION