

## ***Escoamento em rios com inundação dos leitos de cheia***

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Departamento de Hidráulica e Ambiente

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## ORGANIZAÇÃO DA APRESENTAÇÃO

- Introdução
- Enquadramento
- Caracterização experimental
- Simulação do escoamento
- Conclusões

## INTRODUÇÃO



Leito principal sem capacidade de vazão para escoar o caudal afluyente

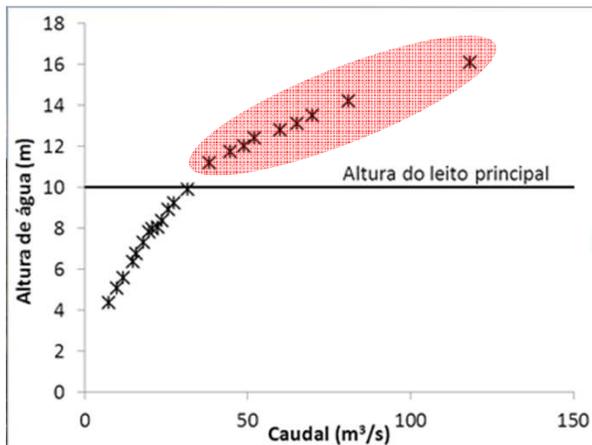
Transbordamento do leito principal e a inundaçãõ dos leitos de cheia

Canal de secção composta → interação entre os escoamentos dos leitos principal e de cheias



Bow River (Canadá) – Cheia de 2005

## INTRODUÇÃO



Leito principal sem capacidade de vazão para escoar o caudal afluyente

Transbordamento do leito principal e a inundaçãõ dos leitos de cheia

Canal de secção composta → interação entre os escoamentos dos leitos principal e de cheias

Dificuldade em estimar níveis de cheia

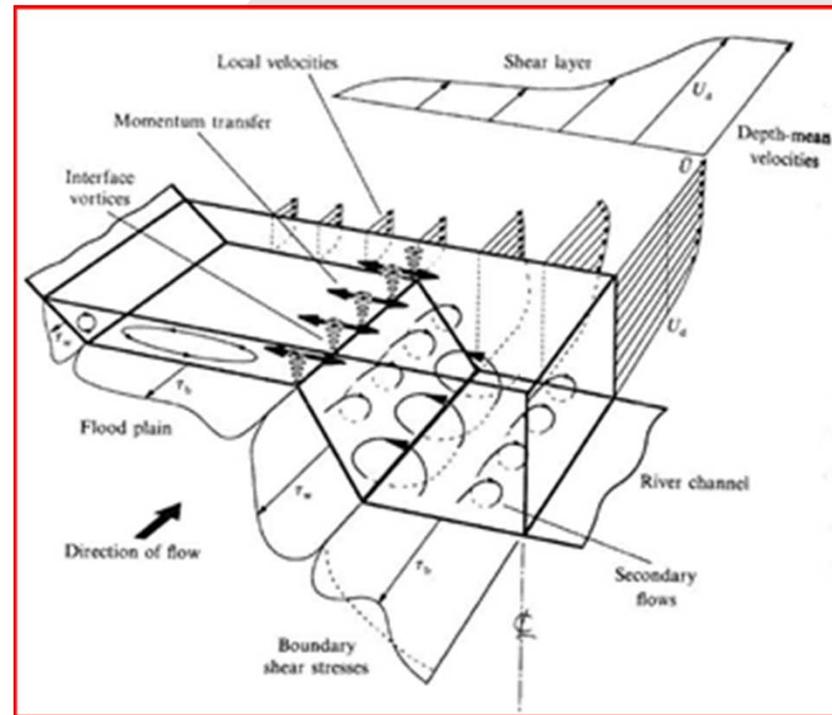


Bow River (Canadá) – Cheia de 2005

# INTRODUÇÃO



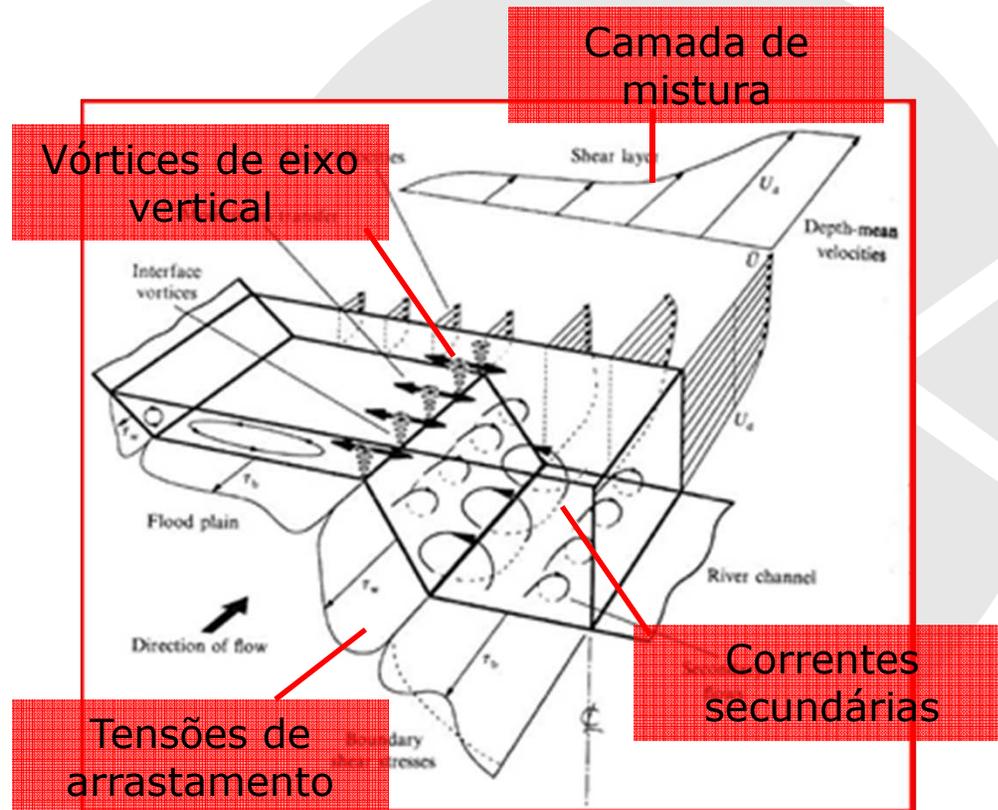
Bow River (Canadá) – Cheia de 2005



# INTRODUÇÃO



Bow River (Canadá) – Cheia de 2005



## ENQUADRAMENTO

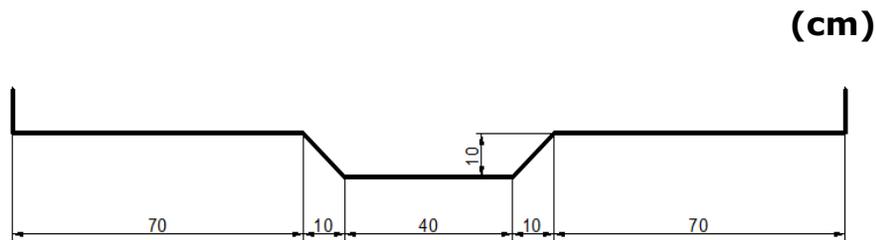
- Experiência do LNEC em estudos de cheias e inundações
- Diretiva europeia – avaliação e gestão dos riscos de inundações (fluviais)
- Interesse e atualidade científica
- Melhoria dos métodos de medição – caracterização experimental
- Tese de doutoramento em curso (IST/UTL)



## CARACTERIZAÇÃO EXPERIMENTAL

### ➤ Ensaaios em 2 canais

#### *Trapezoidal simétrico*



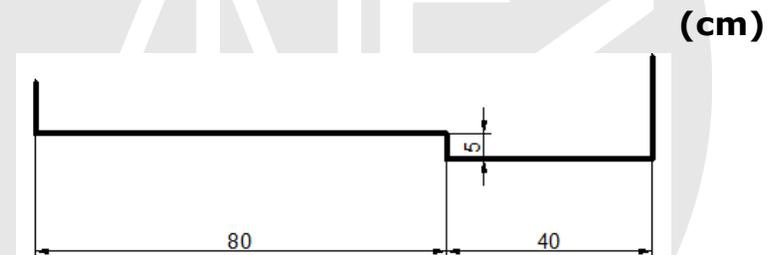
Pavilhão de hidráulica fluvial (LNEC)

Fundo de cimento alisado

Declive:  $1,1 \times 10^{-3}$  m/m

Comprimento: 10 m

#### *Retangular assimétrico*



INSA (Lyon)

Fundo de PVC

Declive:  $1,8 \times 10^{-3}$  m/m

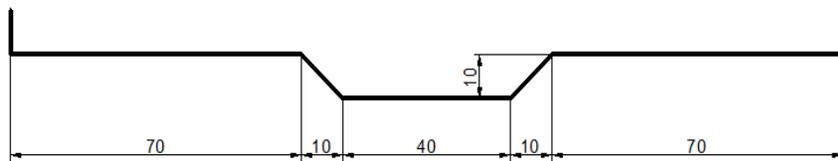
Comprimento: 8 m

## CARACTERIZAÇÃO EXPERIMENTAL

### ➤ Ensaio no canal do LNEC

*Trapezoidal simétrico*

(cm)



Pavilhão de hidráulica fluvial (LNEC)

Fundo de cimento alisado

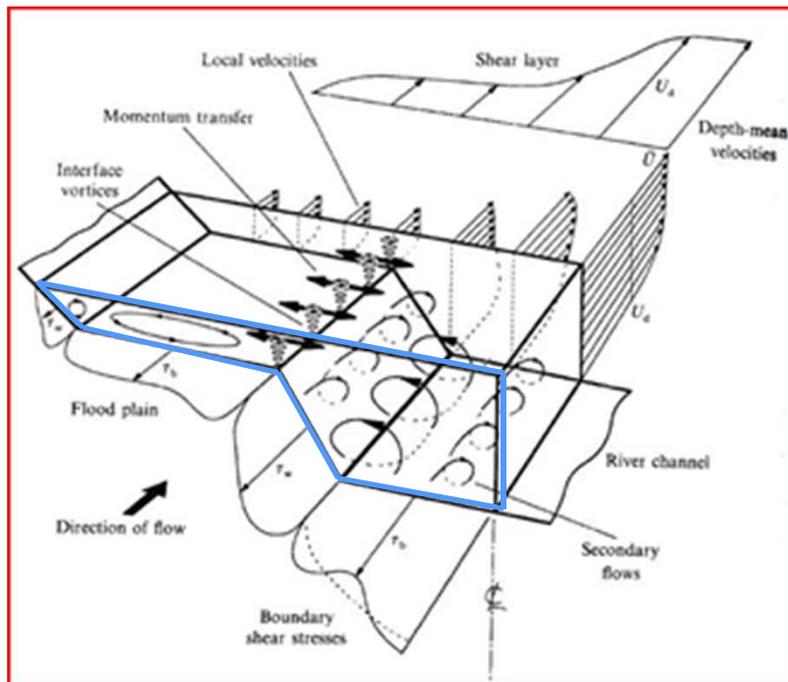
Declive:  $1,1 \times 10^{-3}$  m/m

Comprimento: 10 m



## CARACTERIZAÇÃO EXPERIMENTAL

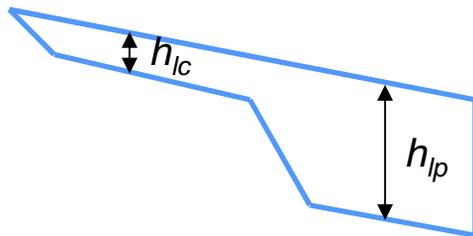
- Estudo da influência da altura de escoamento



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- Estudo da influência da altura de escoamento

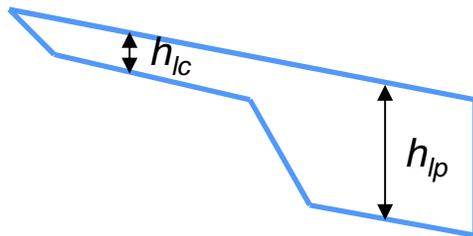
Altura relativa  $\rightarrow h_r = \frac{h_{lc}}{h_{lp}}$



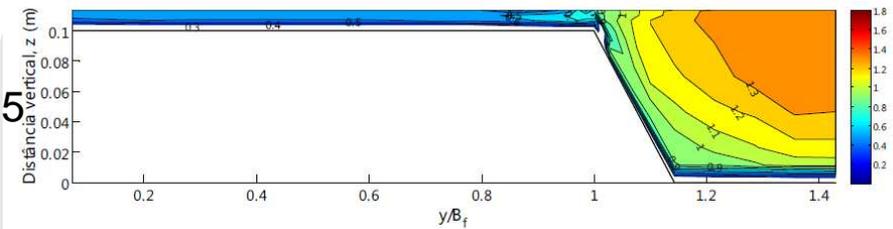
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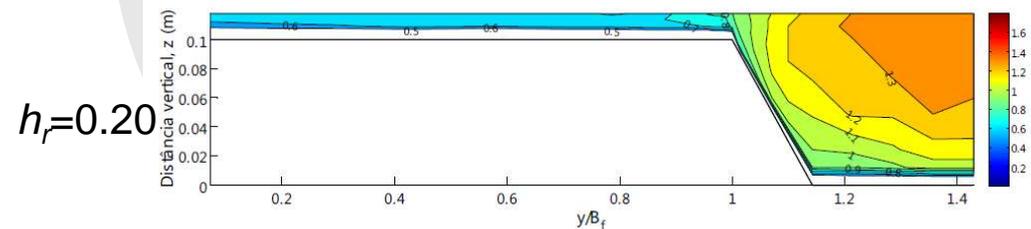
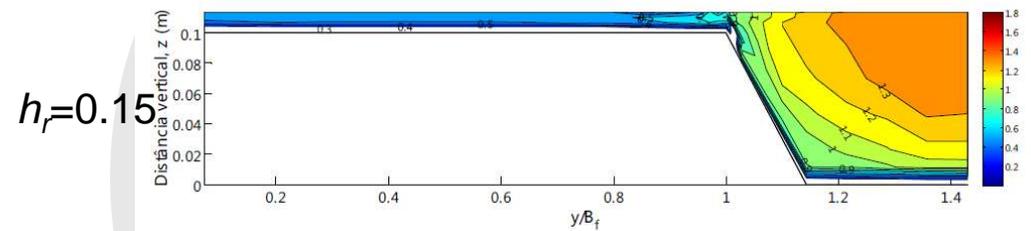
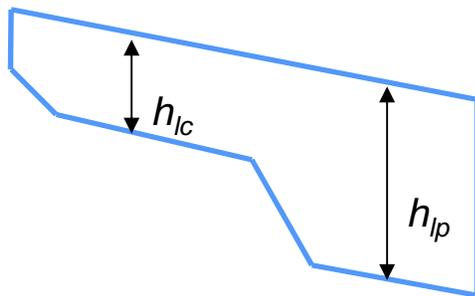
$h_r = 0.15$



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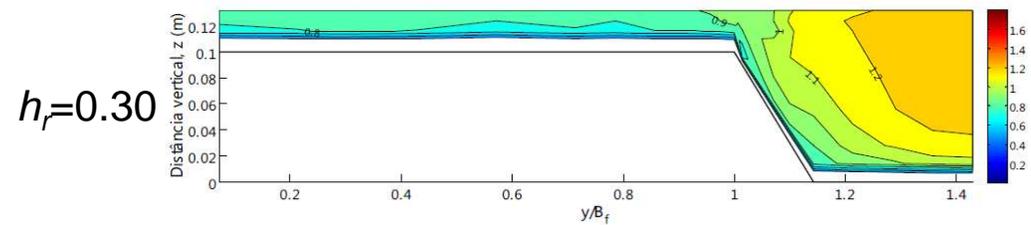
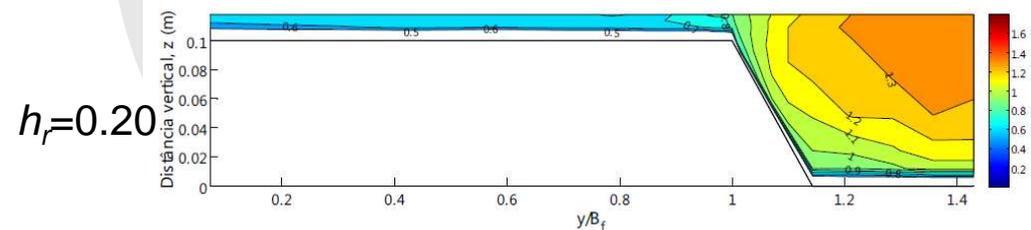
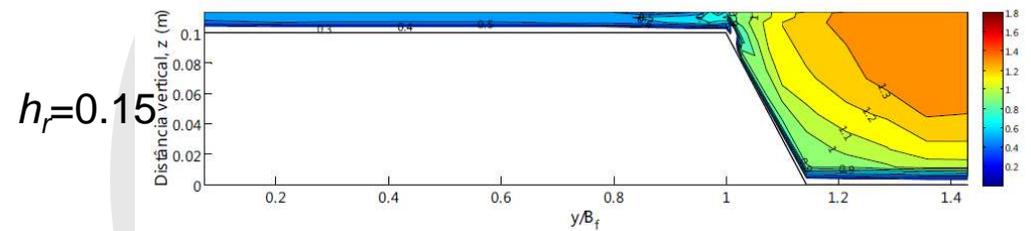
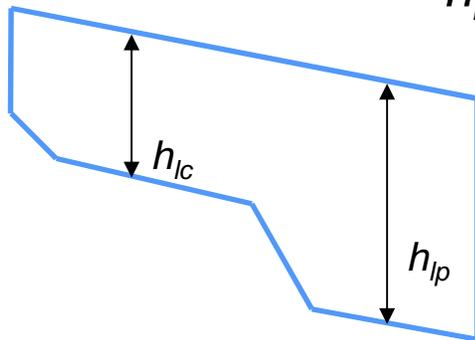
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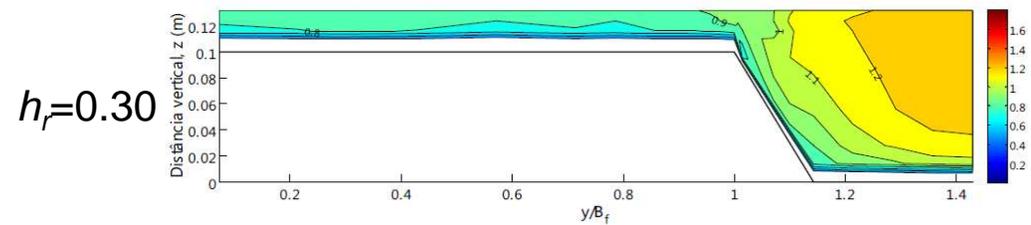
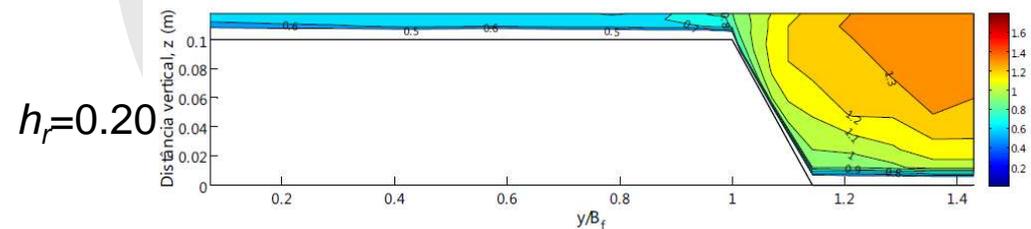
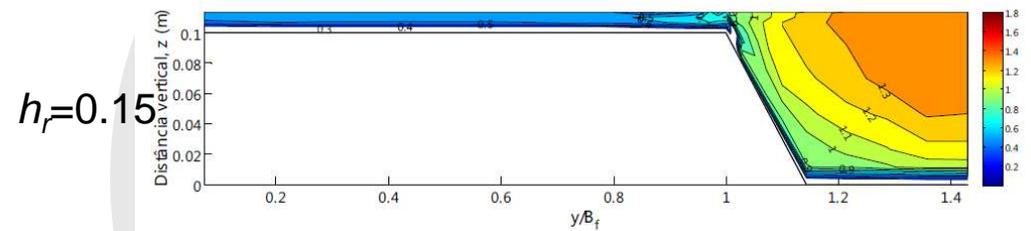
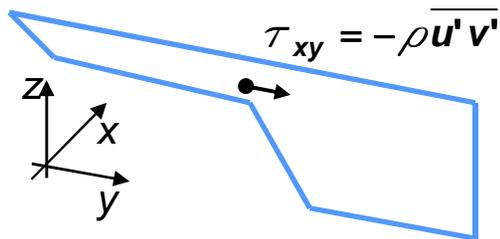
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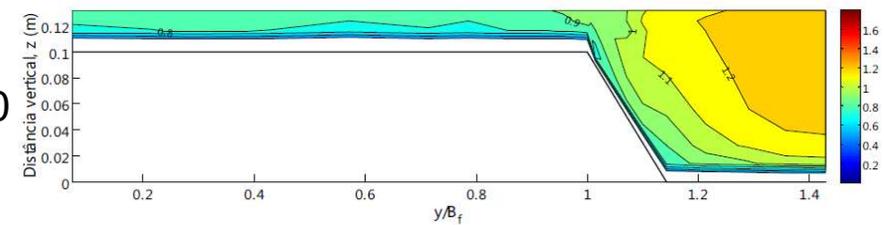
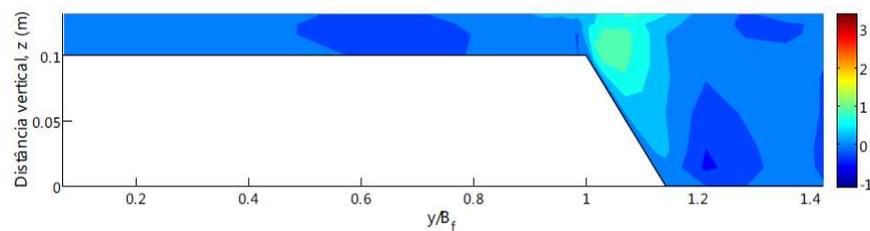
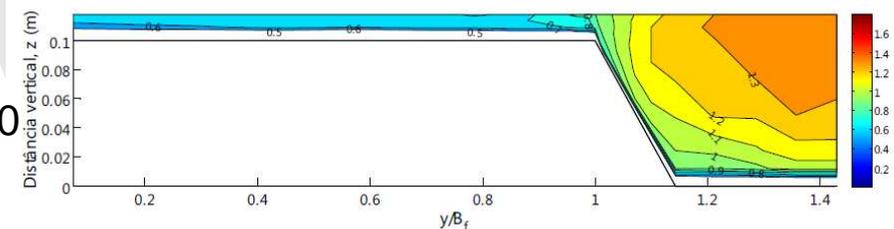
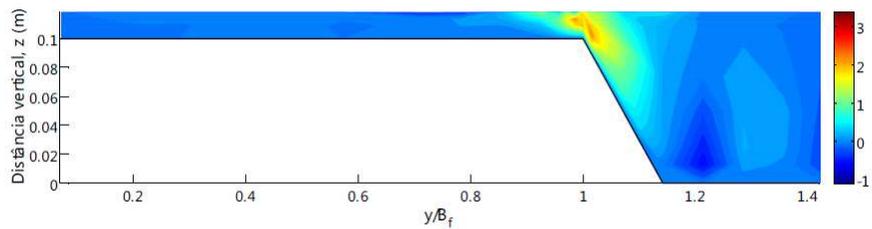
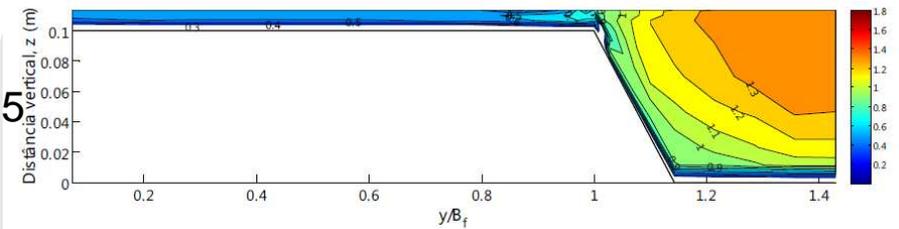
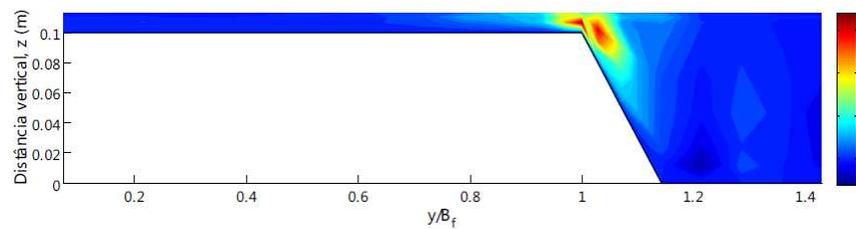
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- Estudo da influência da altura de escoamento



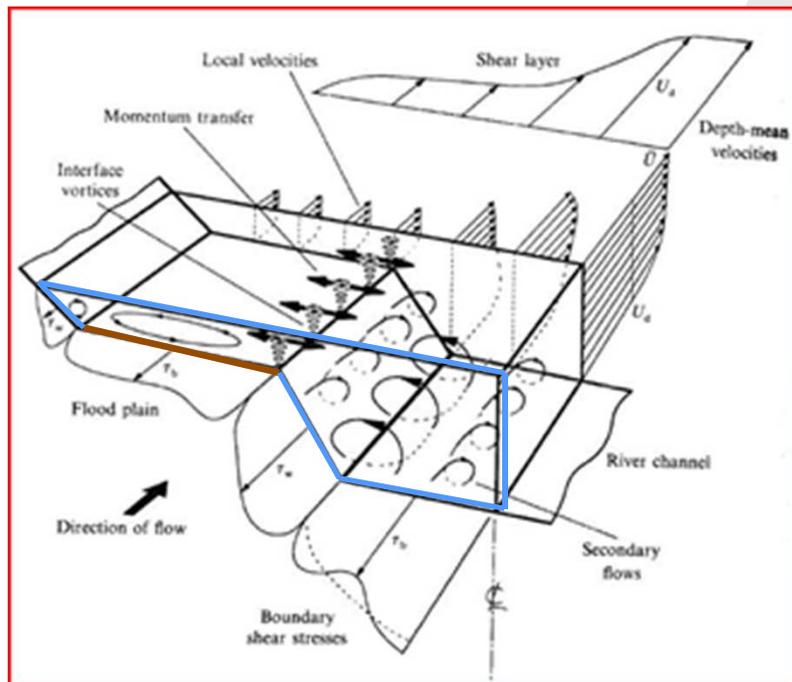
## CARACTERIZAÇÃO EXPERIMENTAL

- Estudo da influência da altura de escoamento



## CARACTERIZAÇÃO EXPERIMENTAL

- Estudo da influência da rugosidade do leito de cheias

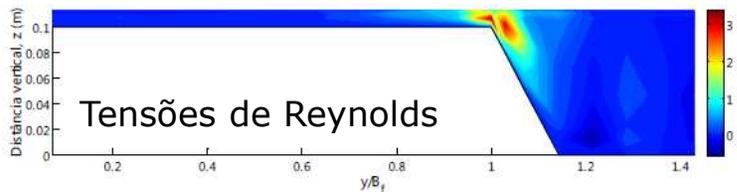
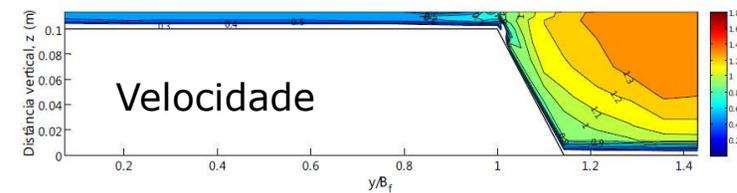


## CARACTERIZAÇÃO EXPERIMENTAL

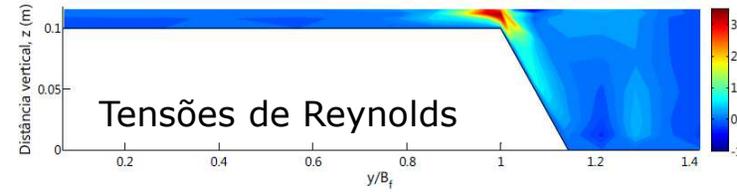
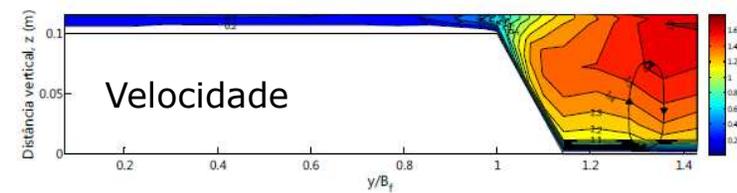
- Estudo da influência da rugosidade do leito de cheias



Fundo liso  $h_r=0.15$



Fundo rugoso  $h_r=0.15$



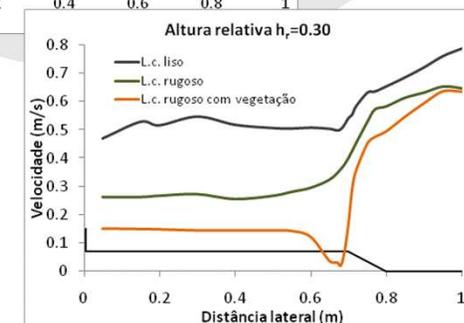
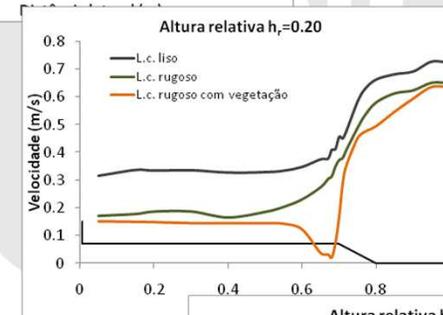
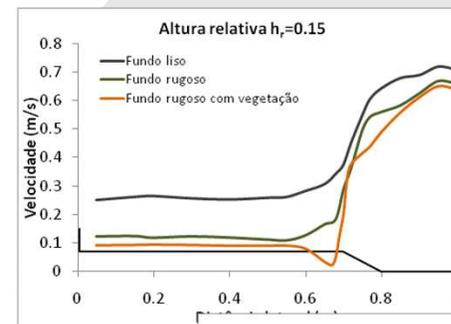
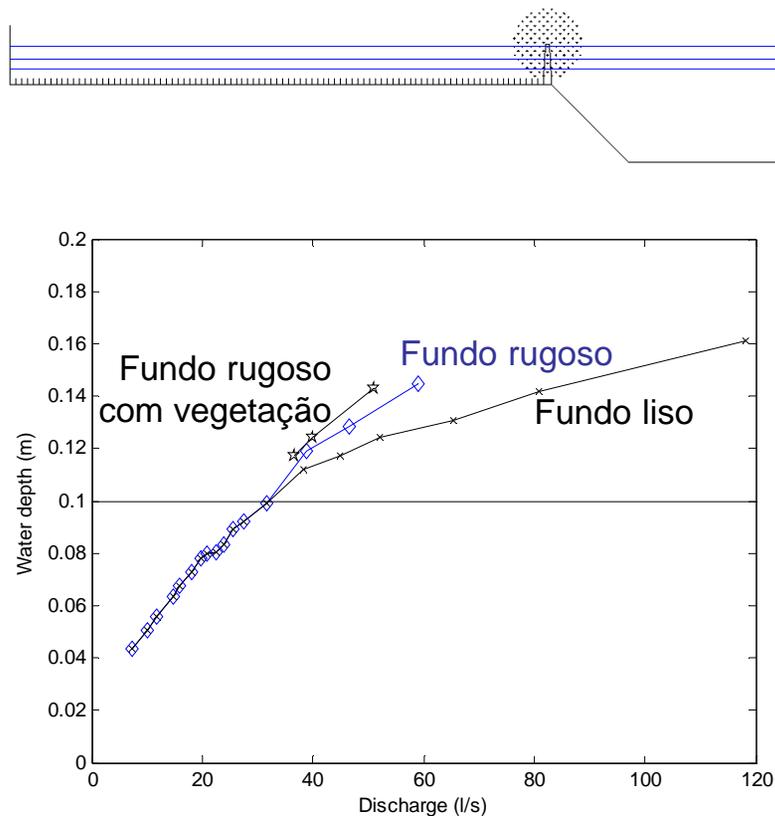
## CARACTERIZAÇÃO EXPERIMENTAL

- Influência da vegetação das margens do leito principal



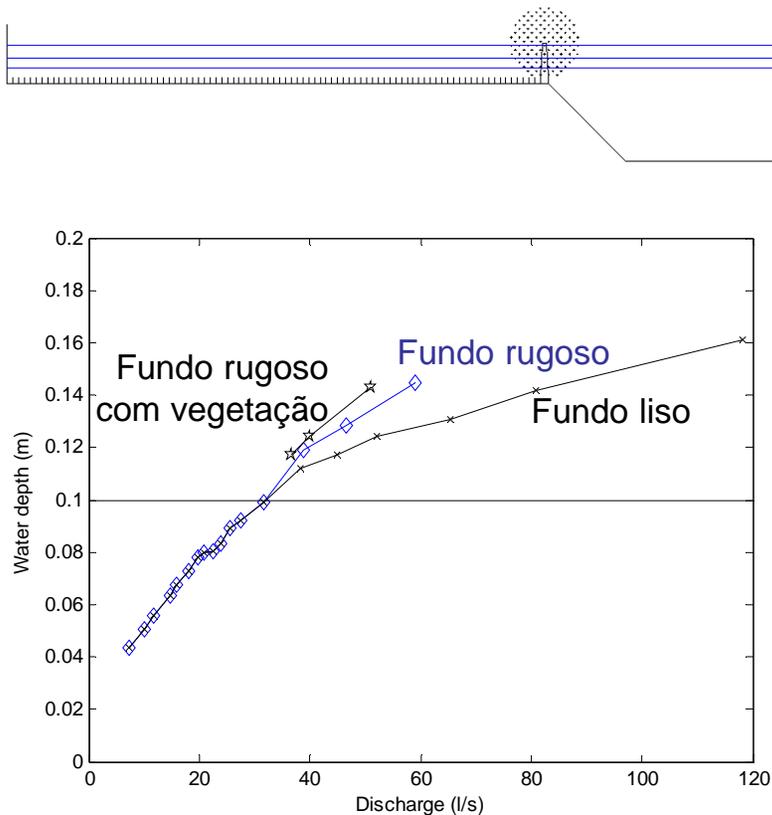
## CARACTERIZAÇÃO EXPERIMENTAL

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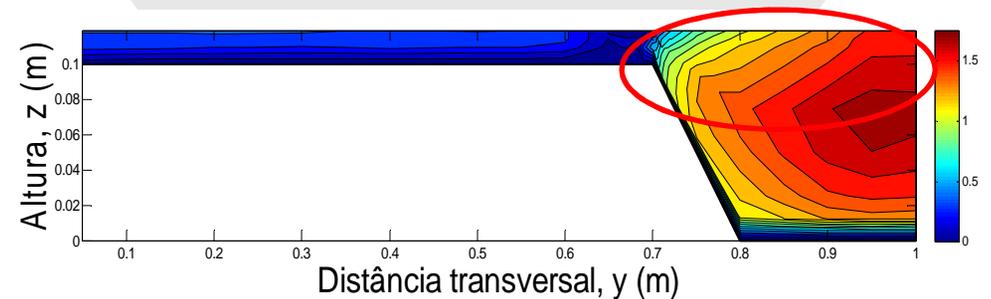
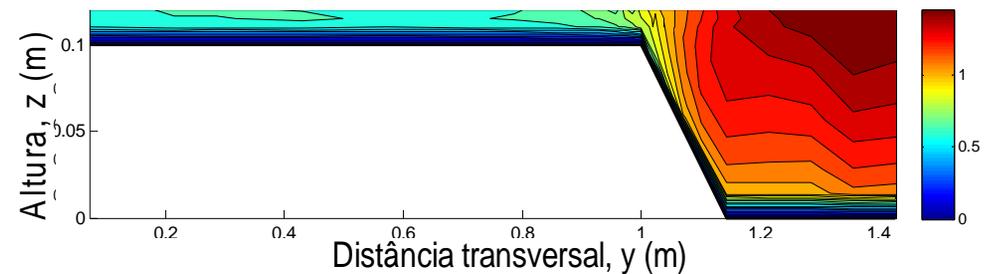


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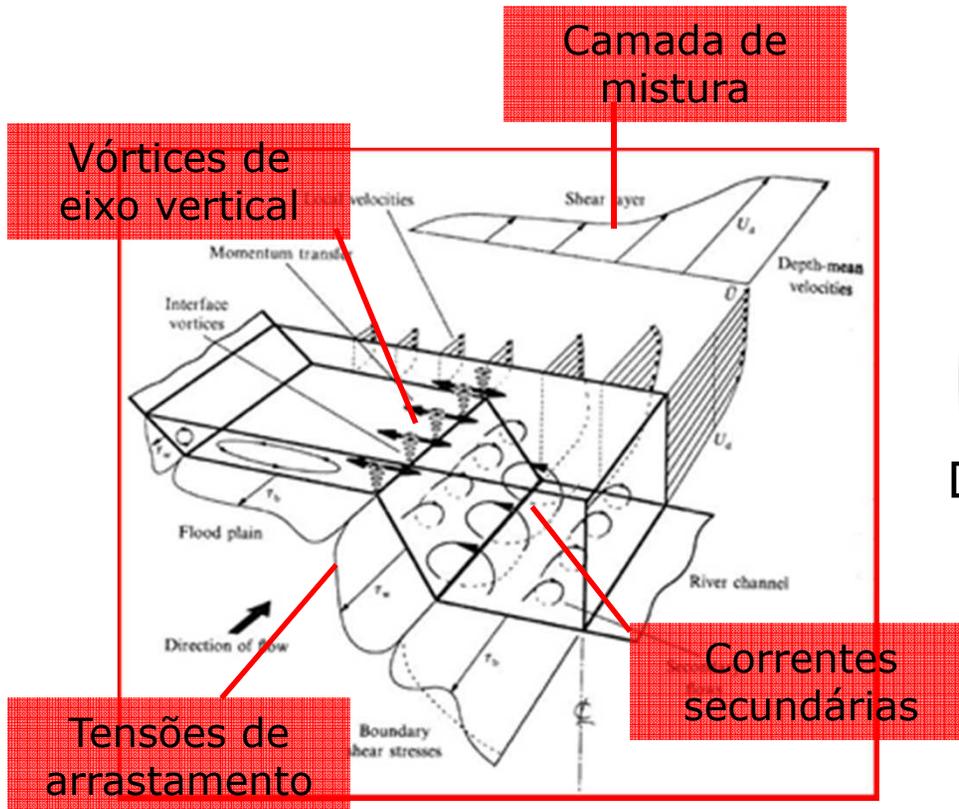
- Influência da vegetação das margens do leito principal



Presença das árvores (e.g.  $h_r=0.2$ )



# Simulação do escoamento



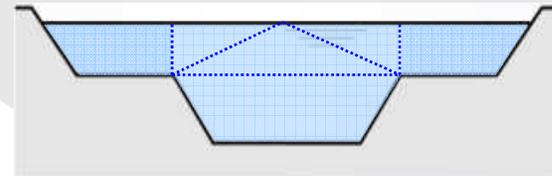
## Single Channel Method

$$Q = K R^{2/3} A S_0^{1/2}$$



## Divided Channel Method (e.g. Hec-Ras)

$$Q = \sum_i Q_i = \sum_i K_i R_i^{2/3} A_i S_0^{1/2}$$



## Simulação do escoamento

Tentativa de incluir na modelação do escoamento 1D a resistência ao escoamento provocada pela interacção entre os leitos principal e de cheias

### Métodos com diferentes divisões dos leitos:

*Weighted divided channel method – WDCM, Lambert and Myers (1998)*

### Métodos empíricos de correcção da capacidade de vazão de cada leito:

*Coherence method – COHM, Ackers (1993)*

*Debord method – DM, Nicollet and Uan (1979)*

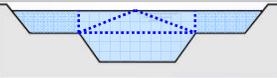
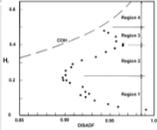
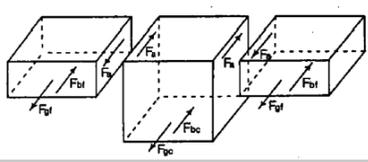
### Métodos com a inclusão das tensões tangenciais aparentes na interface:

*Exchange discharge method – EDM, Bousmar and Zech (1999)*

*Interacting divided channel method – IDCM, Huthoff et al. (2008)*

*Apperent shear force method – ASFM, Moreta and Martin-Vide (2010)*

# Simulação do escoamento

Single channel method (SCM)	 $Q = K R^{2/3} A S_0^{1/2}$
Divided channel method (DCM)	 $Q = \sum_i Q_i = \sum_i K_i R_i^{2/3} A_i S_0^{1/2}$
Coherence method (COHM)	$COH = \frac{Q^{MCU}}{Q^{MDC}}$  $Q = Q^{MDC} - DISDEF \quad \text{para a Região 1}$ $Q = Q^{MDC} \times DISADF \quad \text{para as Regiões 2 a 4}$
Debord method (DM)	$Q_{lp} = \phi K_{lp} R_{lp}^{2/3} A_{lp} S_0^{1/2}$ $Q_{lc} = \sqrt{1 + \frac{A_{lp}}{A_{lc}} (1 - \phi^2)} K_{lc} R_{lc}^{2/3} A_{lc} S_0^{1/2}$
Weighted divided channel method (WDCM)	$U_{lp} = \xi U_{lp}^{MDC-V} + (1 - \xi) U_{lp}^{MDC-H}$ $U_{lc} = \xi U_{lc}^{MDC-V} + (1 - \xi) U_{lc}^{MDC-H}$
Exchange discharge method (EDM)	$\tau_a = \frac{1}{2} \psi \rho (U_{lp} - U_{lc})^2$ 
Interacting divided channel method (IDCM) Apparent shear force method (ASFM)	$\tau_a = \frac{1}{2} \gamma \rho (U_{lp}^2 - U_{lc}^2)$ $\tau_a = \frac{1}{2} \rho C_{fa} (U_{lp} - U_{lc})^2$ $\rho \cdot g \cdot A_{lp} \cdot S_o + \{h_{int,dir} \cdot \tau_{int,dir} + h_{int,esq} \cdot \tau_{int,esq}\} - \tau_o \cdot P_{lp} = 0$ $\rho \cdot g \cdot A_{lc} \cdot S_o - h_{int} \cdot \tau_{int} - \tau_o \cdot P_{lc} = 0$

# Simulação do escoamento

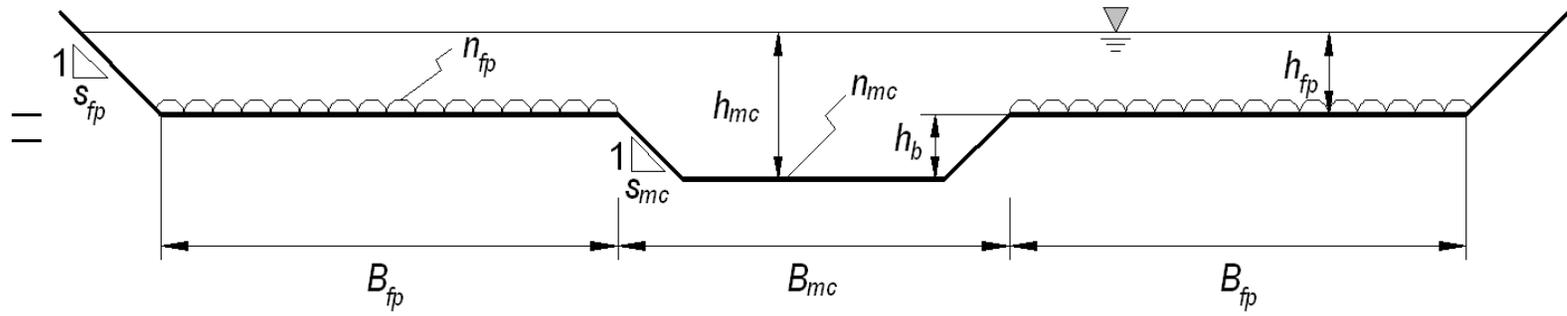
Aplicação dos métodos a um total de 610 ensaios em canais de secção composta:

Reference	$B_{fp}$ (m)	$B_{mc}$ (m)	$s_{mc}$ (-)	$S_{fp}$ (-)	$S_0$ (-)	$h_r$ (-)	N
<b>Symmetric geometry and smooth floodplains</b>							
Sellin (1964)	0.171	0.114	0	0	0.00085	0.088-0.236	6
Knight and Demetriou (1983)	0.076-0.229	0.152	0	0	0.00966	0.108-0.503	18
Myers (1984)	0.18-0.3	0.16	0	0	0.00093	0.067-0.535	33
James and Brown (1977) T1	0.572	0.279	1	1	0.001-0.003	0.002-0.311	50
James and Brown (1977) T2	0.191	0.279	1	1	0.001-0.003	0.008-0.383	42
James and Brown (1977) T3	0.191	0.279	1	1	0.001-0.003	0.02-0.423	38
James and Brown (1977) T12	0.502	0.381	1	1	0.001-0.003	0.011-0.315	19
Wormleaton and Merret (1990) s1, s2, s3	2.25	1.8	1	0	0.00103	0.041-0.5	23
Knight and Shiono (1996) s8	2.25	1.8	0	0	0.00103	0.05-0.5	8
Knight and Shiono (1996) s10	2.25	2.1	2	0	0.00103	0.051-0.464	8
Knight and Shiono (1996) s6	2.25	1.8	1	0	0.00103	0.052-0.503	8
Atabay (2001)	0.407	0.398	0	0	0.00202	0.071-0.49	13
<b>Symmetric geometry and rough floodplains</b>							
James and Brown (1977) T13	0.502	0.381	1	1	0.001-0.003	0.044-0.385	18
Wormleaton et al. (1982)	0.46	0.288	0	0	0.00043-0.0018	0.111-0.429	40
Noutsopoulos and Hadjipanos (1983)	0.225-0.425	0.15	0	0	0.0015	0.187-0.479	16
Prinos e Townsend (1984)	0.381	0.244-0.367	1	0	0.0003	0.089-0.329	40
Knight and Hamed (1984)	0.076-0.229	0.152	0	0	0.00097	0.104-0.518	48
Wormleaton and Merret (1990) s7	2.25	1.8	1	0	0.00103	0.038-0.505	8
Hu, Gi and Guo (2010)	0.35-0.35	0.3	0	0	0.001	0.341-0.528	5
Tang	0.407	0.398	0	0	0.00199-0.00207	0.172-0.603	29
<b>Asymmetric geometry and smooth floodplains</b>							
Myers (1978)	0.356	0.254	0	0	0.00026	0.086-0.394	10
Atabay (2001)	0.407	0.398	0	0	0.00204	0.165-0.499	8
Bousmar (2002)	0.4	0.4	0	0	0.0009-0.00099	0.081-0.366	4
Proust (2005)	0.8	0.4	0	0	0.0018	0.219-0.412	3
<b>Asymmetric geometry and rough floodplains</b>							
James and Brown (1977) T5	0.368	0.279	1	1	0.001-0.003	0.002-0.444	36
James and Brown (1977) T6	0.368	0.279	1	1	0.001-0.003	0.048-0.413	43
James and Brown (1977) T7	0.502	0.279	1	1	0.001-0.003	0.008-0.378	29
Rajaratnam and Ahamadi (1981)	0.508	0.711	0	0	0.00036-0.000724	0.101-0.463	7

# Simulação do escoamento

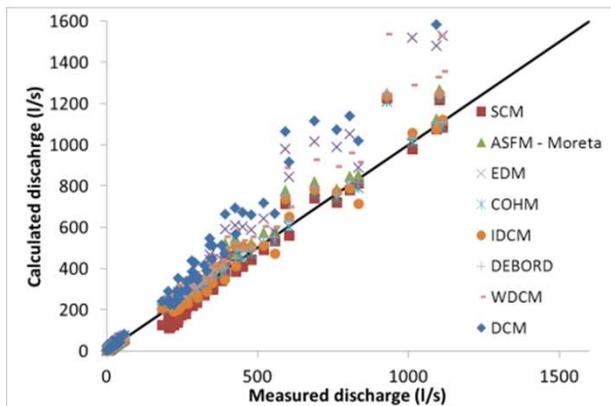
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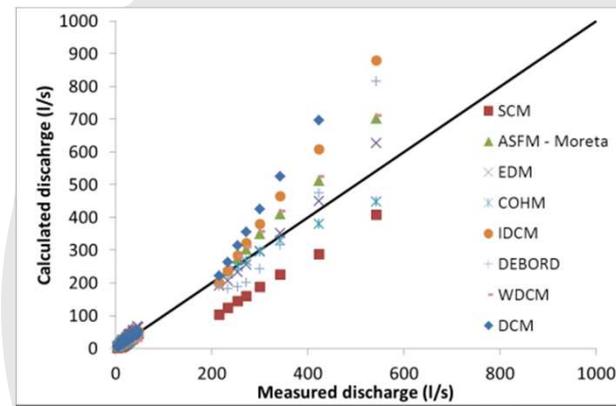


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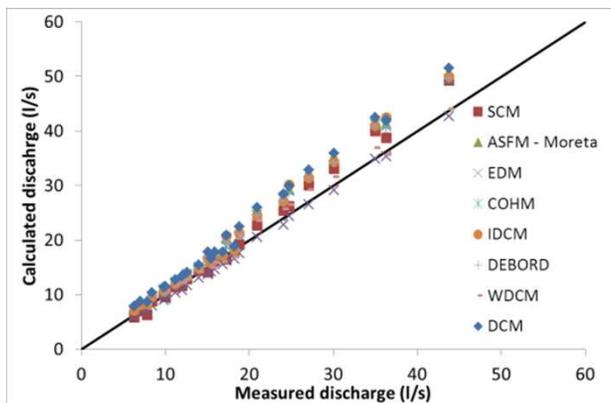
**Simétricos e leitos de cheia lisos**



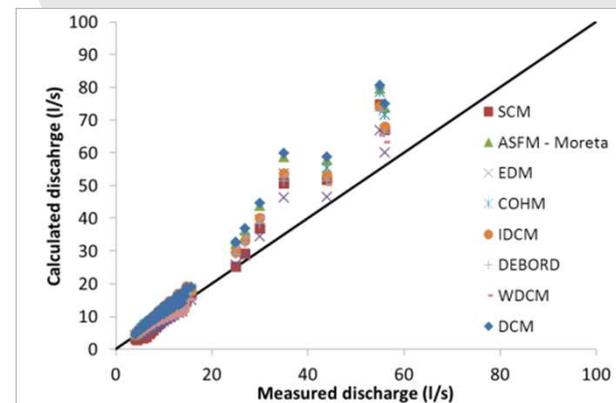
**Simétricos e leitos de cheia rugosos**



**Assimétricos e leitos de cheia lisos**

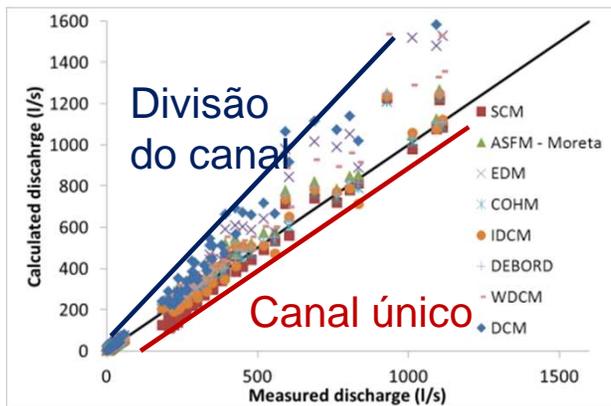


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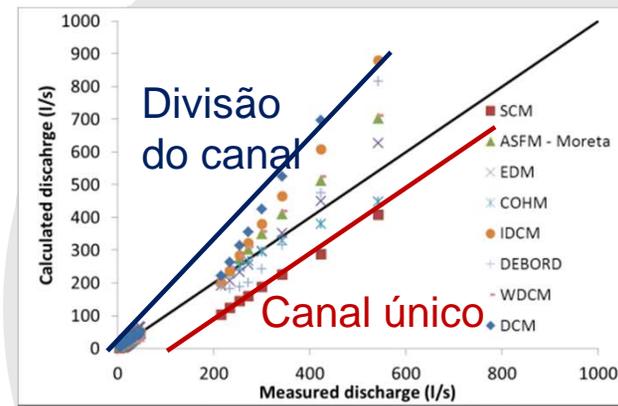


# Simulação do escoamento

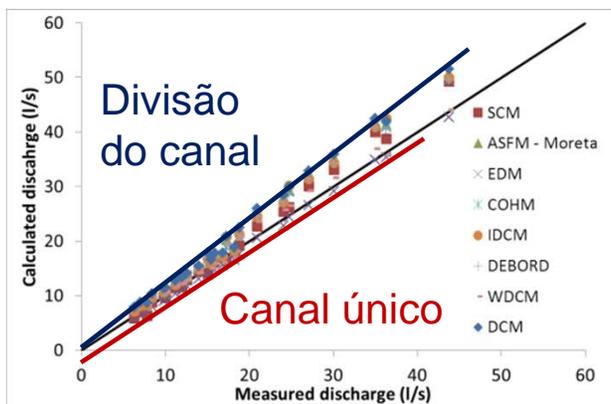
**Simétricos e leitos de cheia lisos**



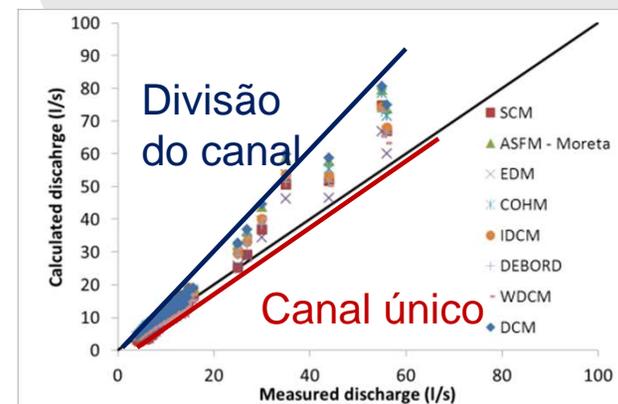
**Simétricos e leitos de cheia rugosos**



**Assimétricos e leitos de cheia lisos**



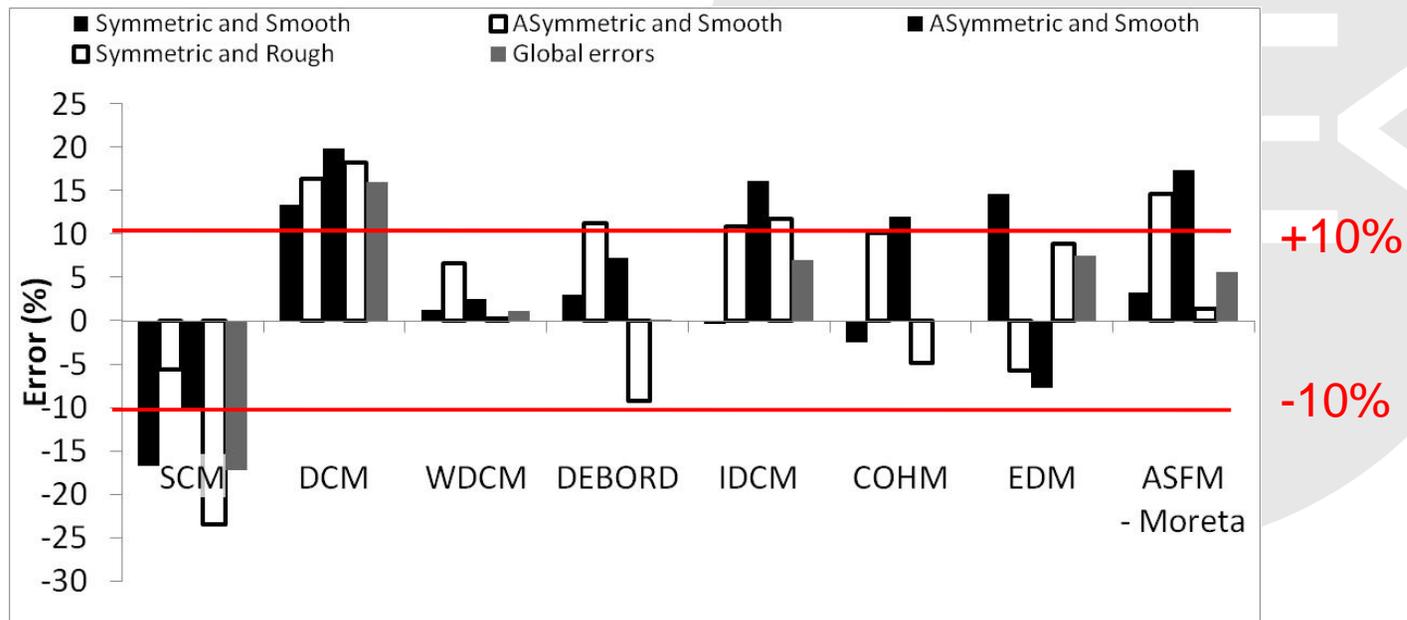
**Assimétricos e leitos de cheia rugosos**



## Simulação do escoamento

### Resultados:

$$\text{Error}(\%) = \frac{100 \times (Q^{\text{calculado}} - Q^{\text{medido}})}{Q^{\text{medido}}}$$



Canal único    Divisão  
                     do canal

## Conclusões

- A interação entre os escoamentos dos leitos principal e de cheias deve ser tida em conta
- Maior importância para alturas de escoamento pequenas e com leitos de cheia rugosos
- Necessidade de incluir esses efeitos na estimativa da capacidade de vazão