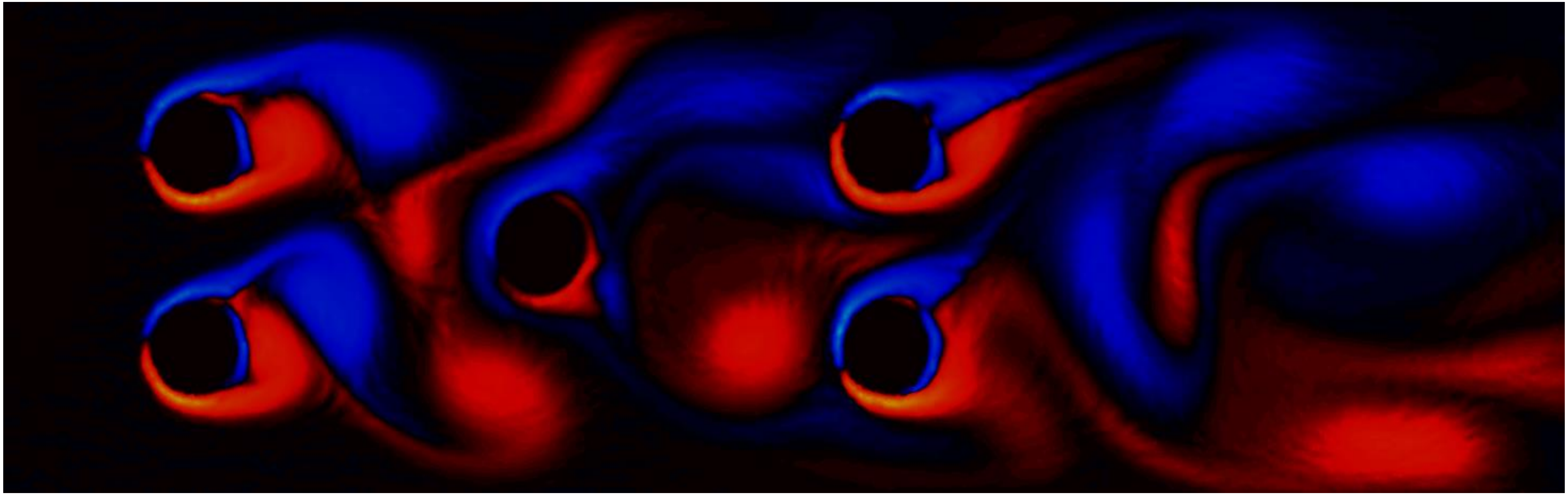
ETH zürich



Introducing tracers and turbulence modelling in BMv3

Laboratory of Hydraulics
Hydrology and Glaciology

Motivation

Riverscapes project: suspended sediment transport in floodplains

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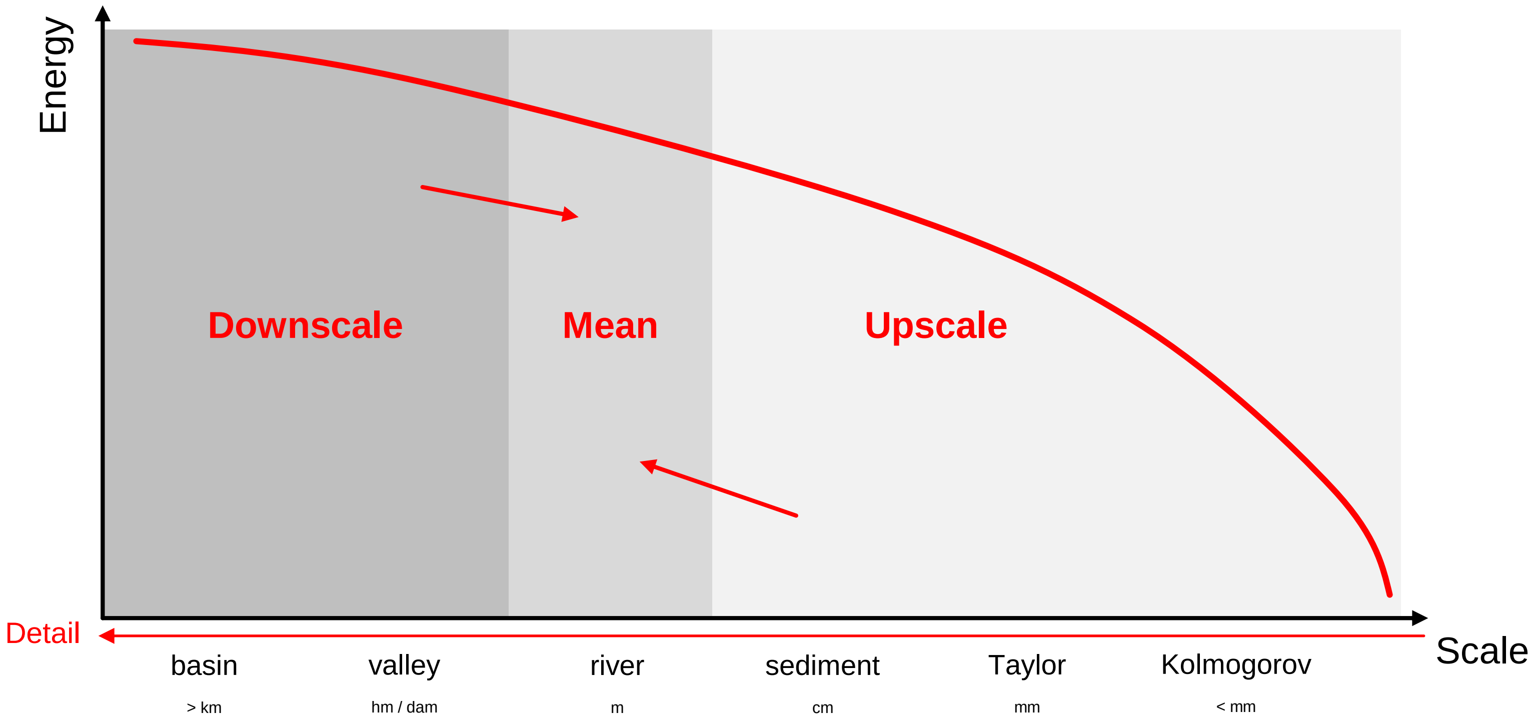
- **by extending BASEMENT v3:**
  - **Multi-component transport** module (passive tracers)
  - Depth-averaged **turbulence modelling**
  - **Suspended sediment** transport and morphodynamics

A matter of scale

- Fluvial dynamics involve a wide range of spatial and temporal scales …



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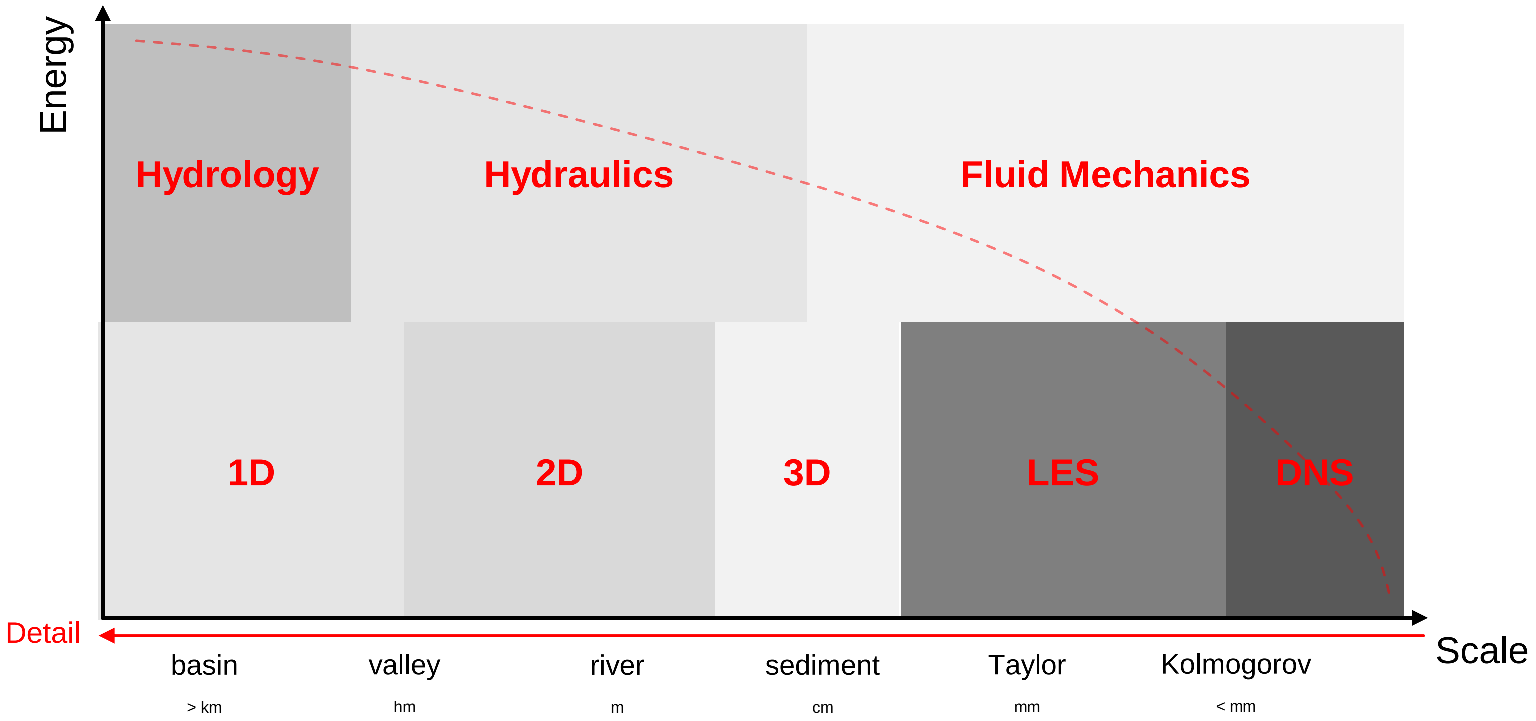

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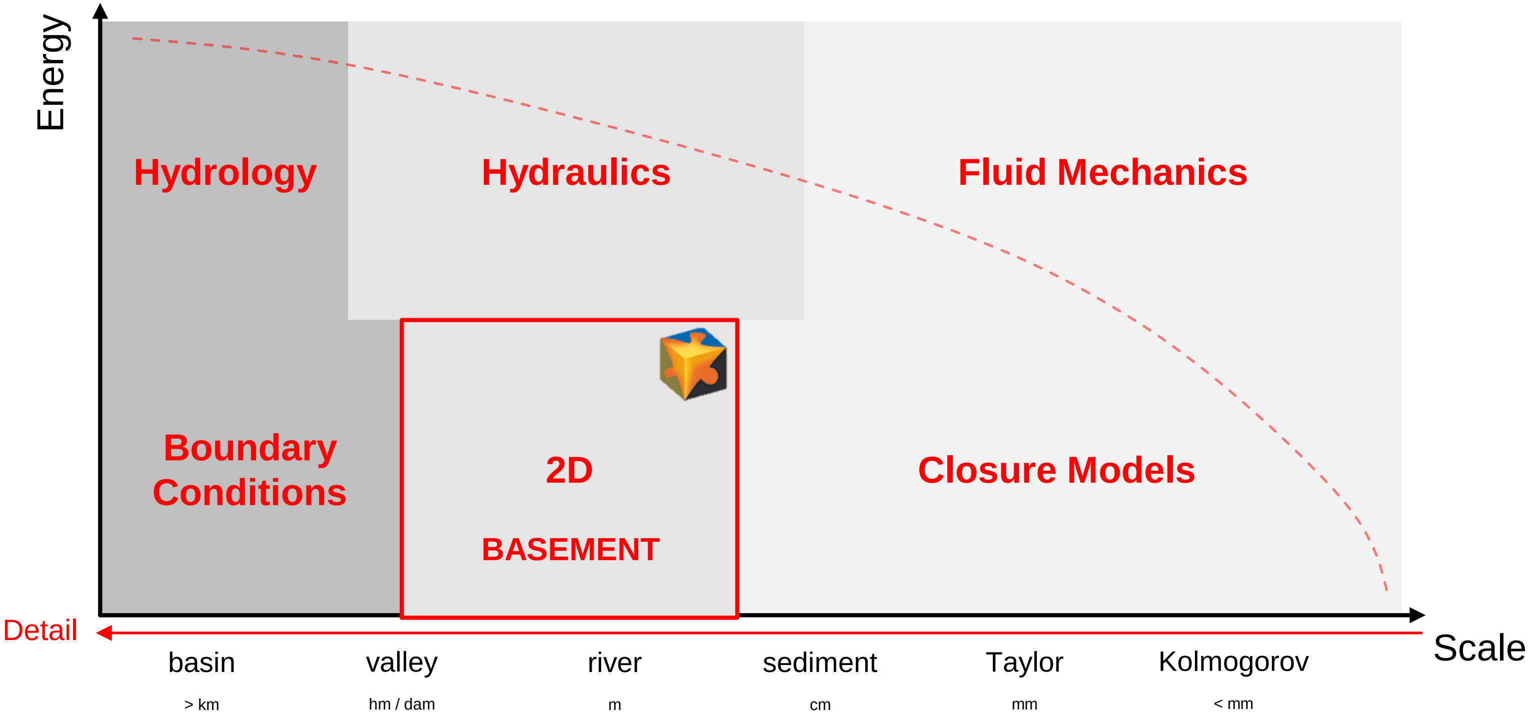

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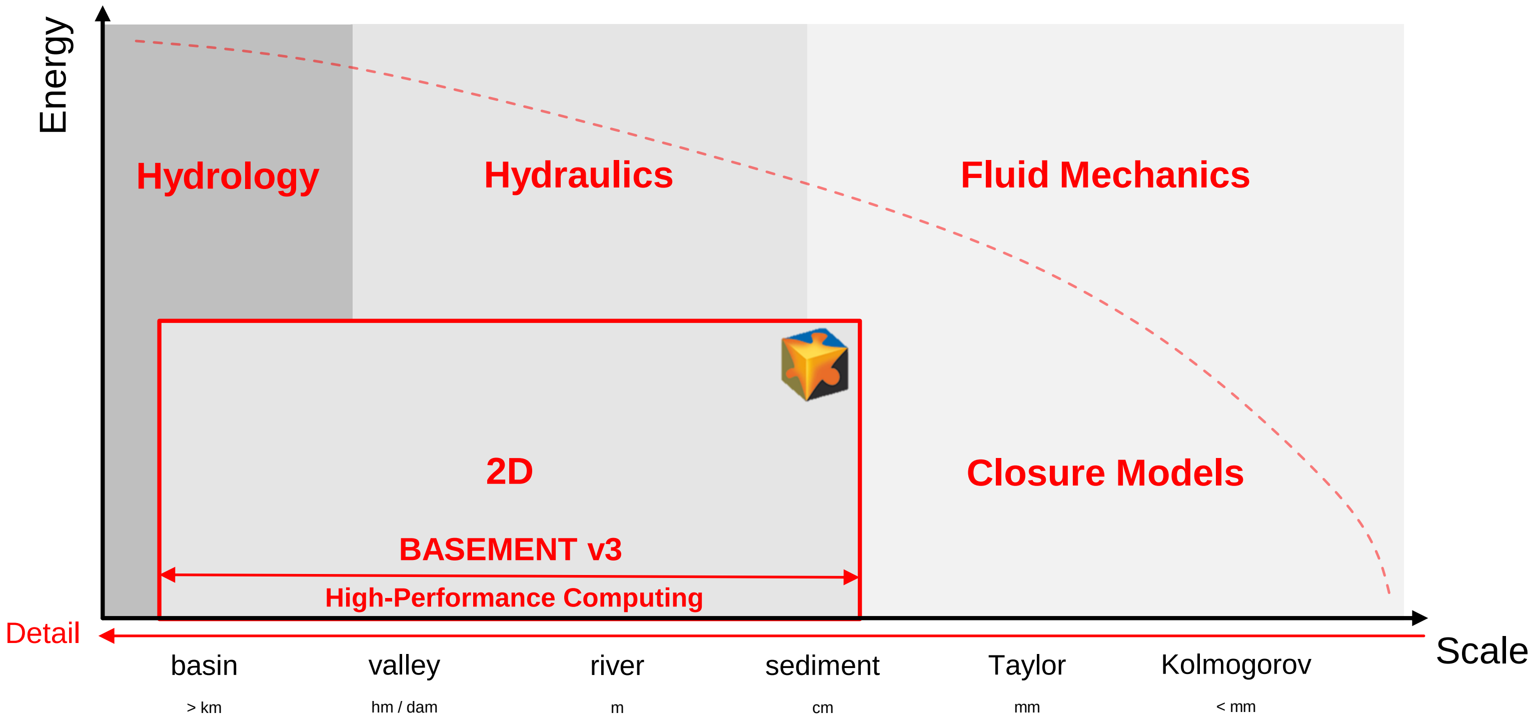
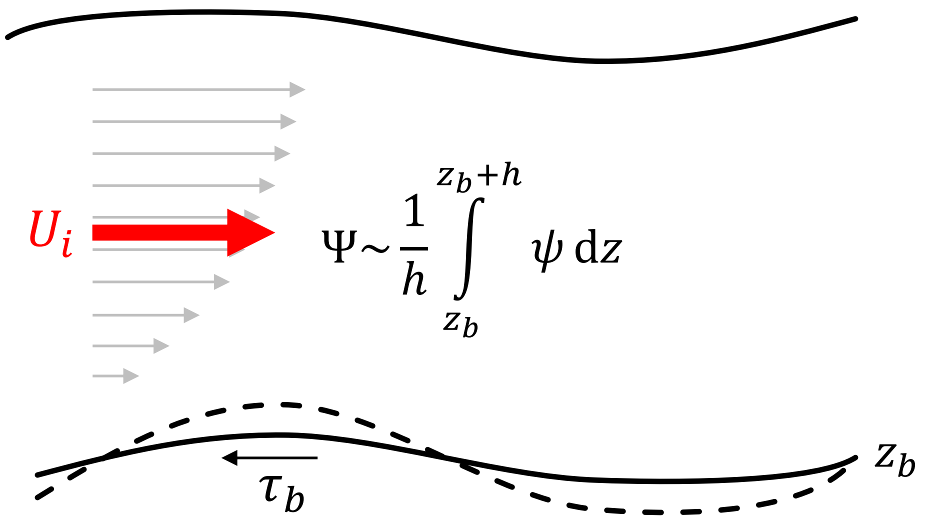


The governing equations

- For riverine flows, the following system of depth-averaged equations applies:
  - Total mass and momentum conservation

$$\frac{\partial h}{\partial t} + \frac{\partial U_i h}{\partial x_i} = -\frac{\partial z_b}{\partial t}$$

$$\frac{\partial U_i h}{\partial t} + \frac{\partial U_i U_j h}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + g_i h + \nu \frac{\partial^2 U_i h}{\partial x_i \partial x_j} - \frac{\tau_b}{\rho}$$



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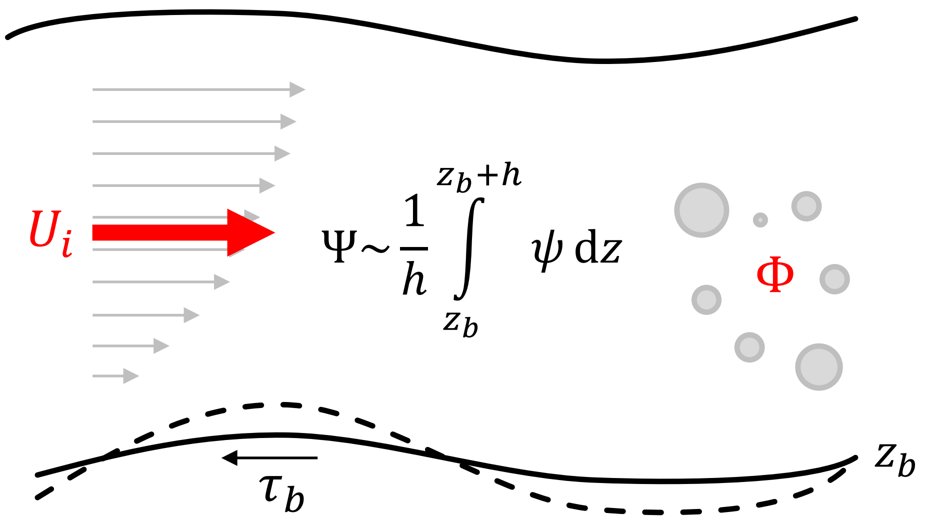

  - Specie-specific mass conservation

$$\frac{\partial \Phi h}{\partial t} + \frac{\partial \Phi U_i h}{\partial x_i} = -\boldsymbol{D_\Phi} \frac{\partial^2 \Phi h}{\partial x_i \partial x_i}$$

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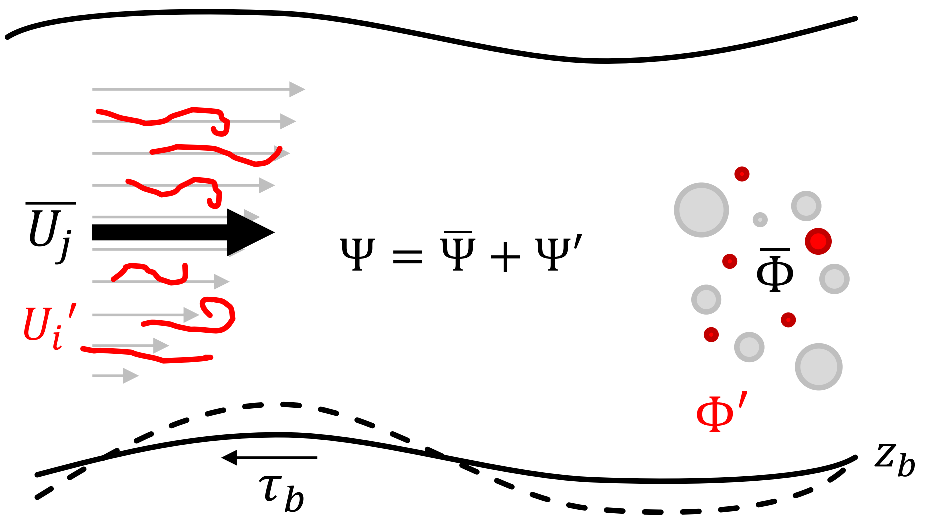
  - Specie-specific mass conservation (passive)

$$\frac{\partial \overline{\Phi} h}{\partial t}+\frac{\partial \overline{\Phi}\,\overline{U_i} h}{\partial x_i}+\frac{\partial \Phi' U_i' h}{\partial x_i}=-D_\Phi \frac{\partial^2 \overline{\Phi} h}{\partial x_i \partial x_i}$$



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Turbulent stresses

  - Specie-specific mass conservation (passive)

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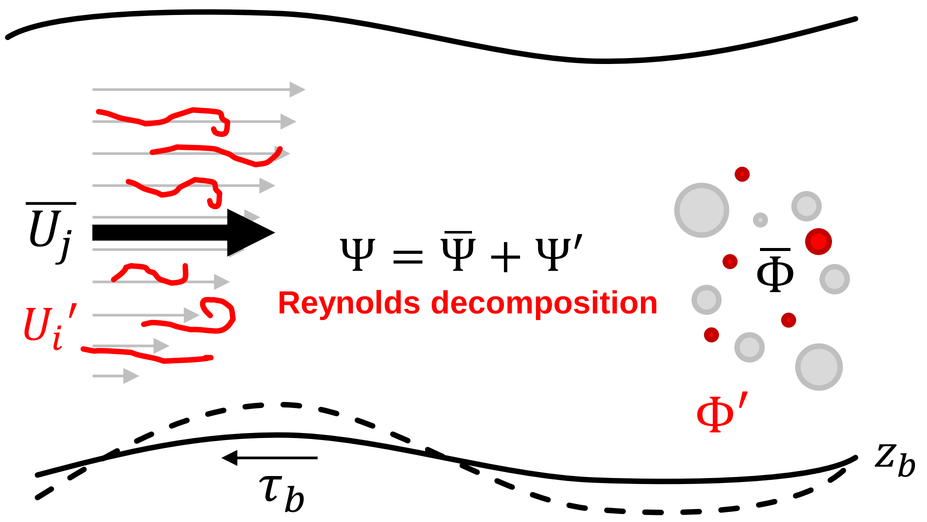
Turbulent diffusion

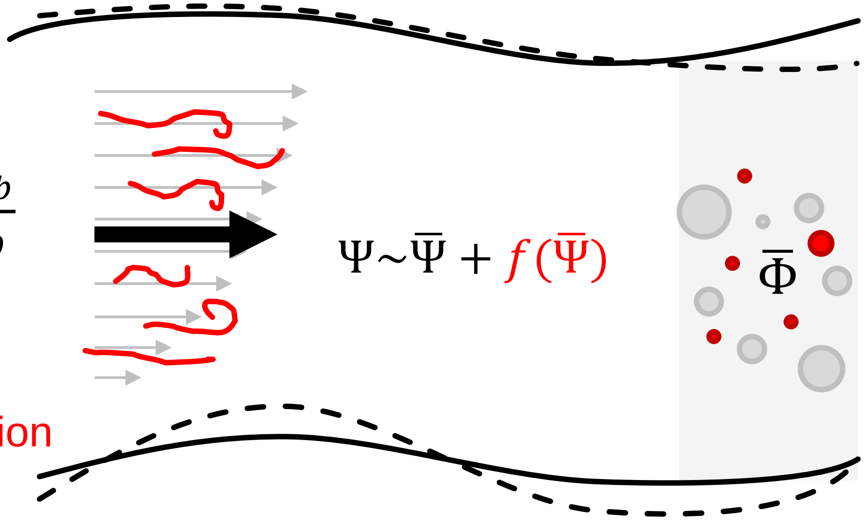


The governing equations

- In 2DH modelling turbulence is added as a dispersive-diffusive contribution
  - Total mass and momentum conservation: turbulent viscosity

$$\frac{\partial h}{\partial t}+\frac{\partial \overline{U_i} h}{\partial x_i}=-\frac{\partial z_b}{\partial t}$$

$$\frac{\partial \overline{U_i} h}{\partial t}+\frac{\partial \overline{U_i}\,\overline{U_j} h}{\partial x_j}=-\frac{1}{\rho}\frac{\partial P}{\partial x_i}+g_j h+(\nu+\boldsymbol{\nu_t})\frac{\partial^2 \overline{U_i} h}{\partial x_i \partial x_j}-\frac{\tau_b}{\rho}$$



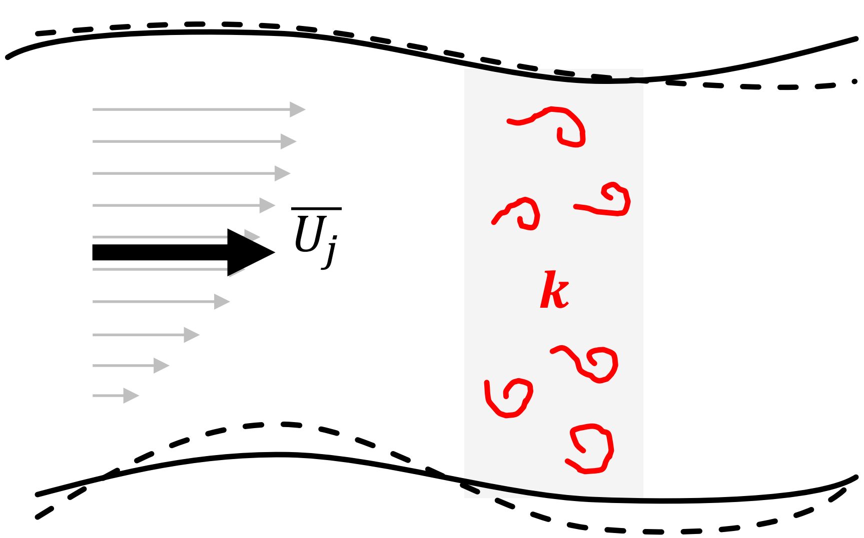
  - Specie-specific mass conservation (passive): turbulent diffusion

$$\frac{\partial \overline{\Phi} h}{\partial t}+\frac{\partial \overline{\Phi}\,\overline{U_i} h}{\partial x_i}=-(D_m+\boldsymbol{D_t})_{\Phi}\frac{\partial^2 \overline{\Phi} h}{\partial x_i \partial x_i}$$

The governing equations

- Starting point for **turbulence modelling**: the k-ϵ model
  - Total turbulent kinetic energy, $\boldsymbol{k}$

$$\frac{\partial kh}{\partial t} + \frac{\partial k\overline{U_i}h}{\partial x_i} = -\frac{\nu_t}{\sigma_k}\frac{\partial^2 kh}{\partial x_i \partial x_i} + P_k - h\epsilon$$



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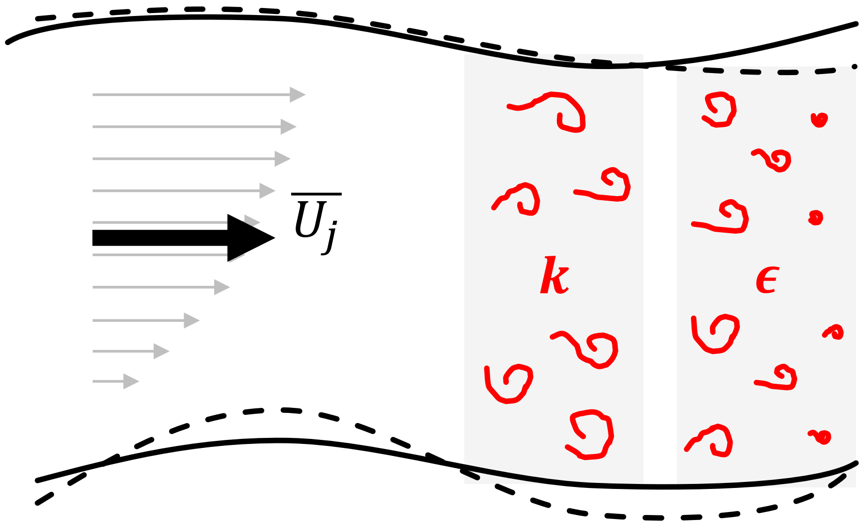
  - Turbulent energy dissipation, $\boldsymbol{\epsilon}$

$$\frac{\partial \epsilon h}{\partial t} + \frac{\partial \epsilon\overline{U_i}h}{\partial x_i} = -\frac{\nu_t}{\sigma_\epsilon}\frac{\partial^2 \epsilon h}{\partial x_i \partial x_i} + D_\epsilon$$



New features in BASEMENT v3

- Tracer module features

$$\frac{\partial \boldsymbol{\Phi} h}{\partial t} + \frac{\partial \boldsymbol{\Phi} U_i h}{\partial x_i} + \boldsymbol{D}_{\boldsymbol{\Phi}} \frac{\partial^2 \boldsymbol{\Phi} h}{\partial x_i \partial x_i} = \boldsymbol{S}_{\boldsymbol{\Phi}}$$

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- **Advection-diffusion** module features

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  - Single **multi-component** framework for many different applications:
    - **Tracers**
    - **Suspended sediment transport**
    - **Turbulence modelling**
    - Water quality: temperature, nutrients, pollutants …

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  - **Tracers**
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  - Water quality: temperature, nutrients, pollutants …
- Only source terms require **phenomena-specific closure models**
  - **Capacity, bed erosion and deposition**
  - **Turbulence generation and dissipation**
  - Radiation, bio-chemical reactions, decay …

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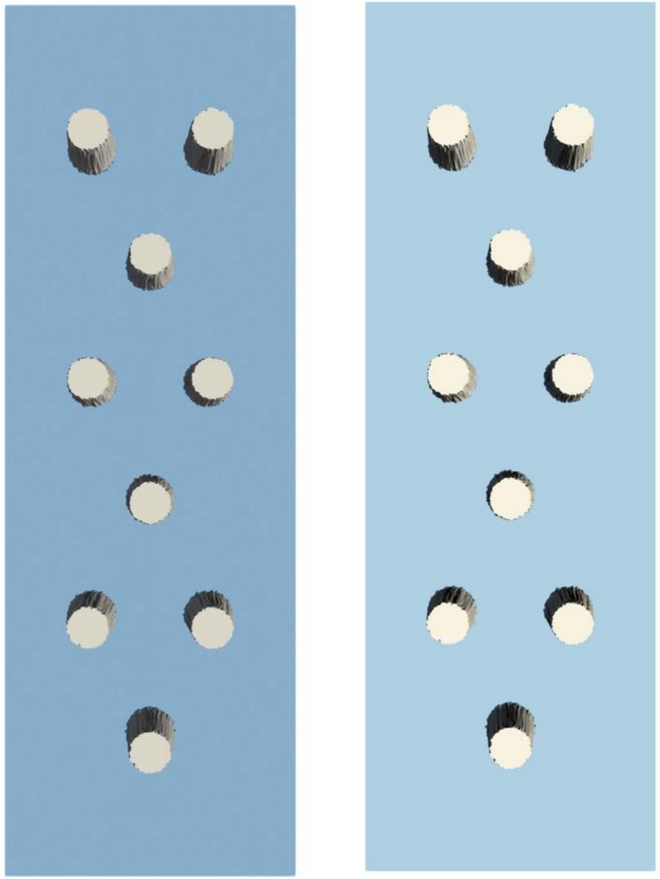
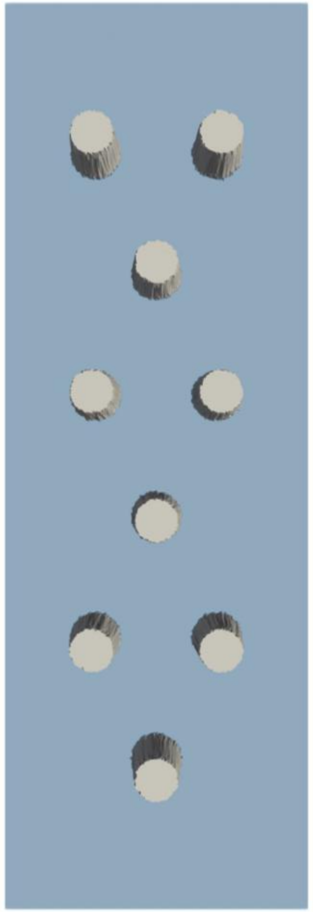


low diffusion **high diffusion**

New features in BASEMENT v3 + .json configuration

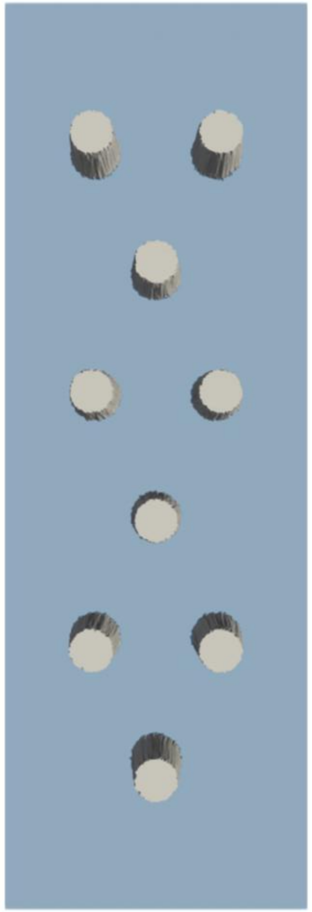


```
SCALARS:

  PARAMETERS:
    START: 1.0s
    NUM_SPECIES: 2
    SPECIES:
      SCALAR_1
        NAME: "RED INK"
        DENSITY: 1000.0
        VISCOSITY: 0.001
        DIFFUSIVITY: 0.0025
      SCALAR_2
        NAME: "BLUE INK"
        DENSITY: 1000.0
        VISCOSITY: 0.001
        DIFFUSIVITY: 0.0025

  INITIAL:
    TYPE: CONSTANT
      SCALAR_1: 0.0
      SCALAR_2: 0.0

  SOURCES:
    TYPE: REGION_DEFINED
      REGIONS:
        NAME: "RED INJECTOR"
          TYPE: "FORCING"
            SCALAR_1: 1.0
            SCALAR_2: 0.0
        NAME: "BLUE INJECTOR"
          TYPE: "FORCING"
            SCALAR_1: 0.0
            SCALAR_2: 1.0
```



```
SCALARS:

  PARAMETERS:
    START: 1.0s
    NUM_SPECIES: 1
    SPECIES:
      SCALAR_1
        NAME: "RED INK"
        DENSITY: 1000.0
        VISCOSITY: 0.001
        DIFFUSIVITY: 0.0025

  INITIAL:
    TYPE: CONSTANT
      SCALAR_1: 0.0

  SOURCES:
    TYPE: REGION_DEFINED
      REGIONS:
        NAME: "RED INJECTOR L"
          TYPE: "FORCING"
            SCALAR_1: 1.0
        NAME: "RED INJECTOR C"
          TYPE: "FORCING"
            SCALAR_1: 0.0
        NAME: "RED INJECTOR R"
          TYPE: "FORCING"
            SCALAR_1: 0.0
```

New features in BASEMENT v3

Possible applications: ***water quality***

- Tracers tend to have a **behaviour** similar to **weakly degradable/reactive** pollutants or substances;
- Tracer **concentration** provides a quick way of computing **residence times.**

New features in BASEMENT v3

- **Turbulence** module features

$$\frac{\partial \boldsymbol{k} h}{\partial t}+\frac{\partial \boldsymbol{k} \overline{U_i} h}{\partial x_i}=-\frac{\nu_t}{\sigma_k} \frac{\partial^2 \boldsymbol{k} h}{\partial x_i \partial x_i}+P_k-h\boldsymbol{\epsilon}$$

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    - Main user-defined **parameters**: density, viscosity and diffusivity

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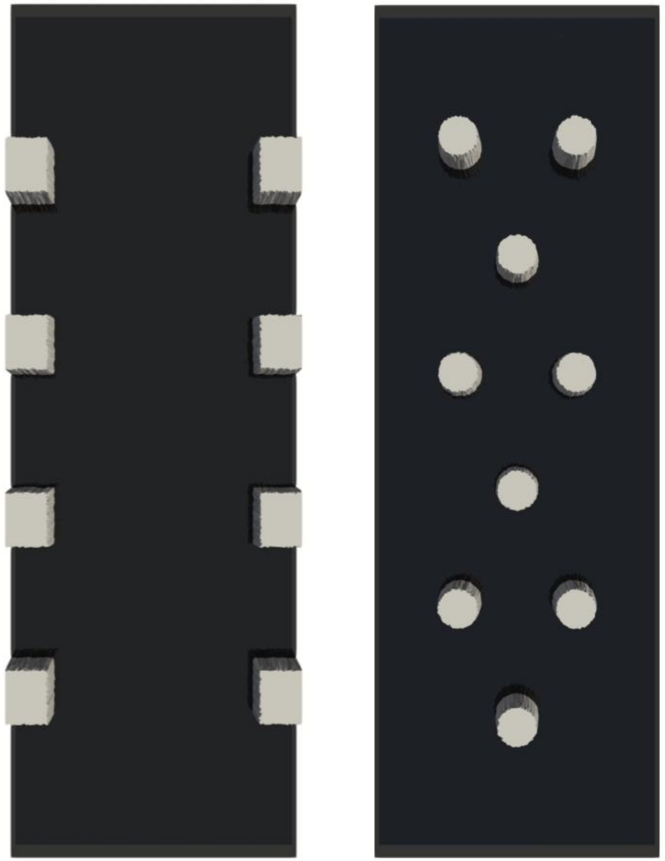
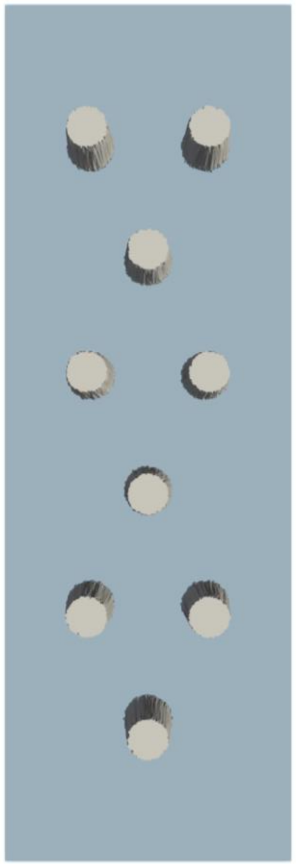


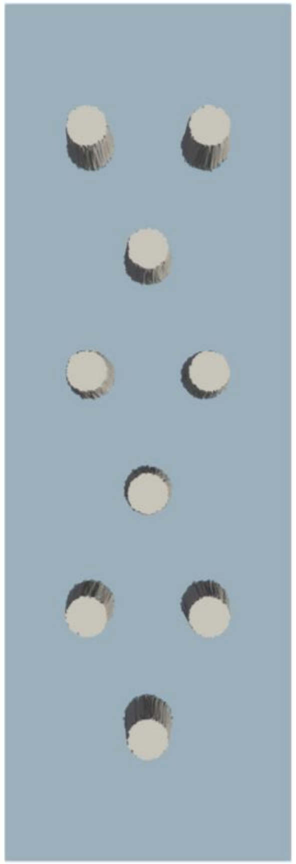
vortex trapping **vortex shedding**

New features in BASEMENT v3

+ .json configuration



turbulent energy



production term

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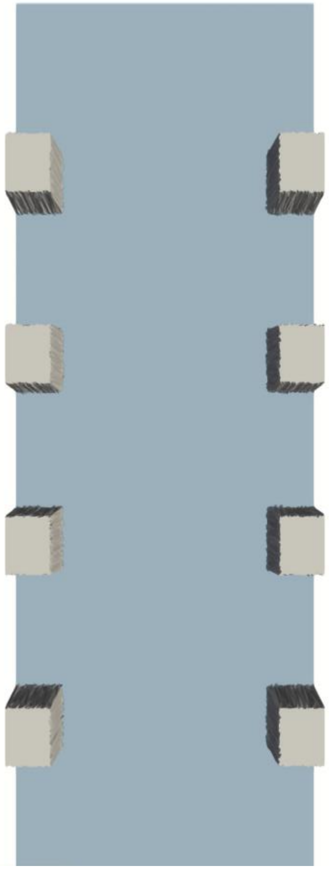
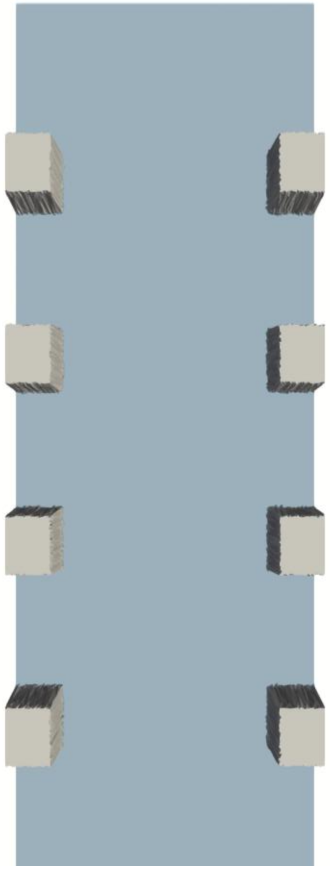
```
(HYDRAULICS)
 TURBULENCE:
  PARAMETERS:
   START: 5.0s
   MODEL: "K-EPS"
    PARAMETERS:
     Cu: 0.09
     C1: 1.44
     C2: 1.92
     sigmaK: 1.0
     sigmaE: 1.31

  INITIAL:
   TYPE: CONSTANT
    K: 0.0
    EPS: 0.0
```



turbulent energy



production term

New features in BASEMENT v3

Applications: ***flow-structure interaction***

- Flows around pillars (e.g. bridges, piers)
- Reaches with pronouced lateral structures (e.g. natural bars, hard points)
- Inundations in urban areas

production term

Future steps

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  - **Validate** the implementation with flume data
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  - Investigate mesh **upscaling and downscaling** effects
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- Modelling **guidelines**
  - **Rank** the standard **closure models** for the tests at hand
  - **Propose modifications** to common default parameters