Faculty of Civil Engineering
Hochschule für Technik und Wirtschaft Dresden

Hydraulics Modelling

Unit I – General Aspects of Hydraulics Modelling

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Organizational Aspects

Schedules: Lectures, Exercises and Practicals

- **Lectures**:

  Thursdays from 11:10 – 12:40 Uhr in Zi: Z824 at HTW
  Mode: Slides, Audio & Visual and discussions.

- **Exercises/Practicals**:

  Thursdays from 13:20 – 14:50 Uhr in Zi: Z824 at HTW
  Mode: Programming (mostly Python) and Simulations (HEC-RAS)

You are encouraged to bring your own laptop in the class.

Organizational Aspects

Contact hours and contact details

You are encouraged to contact Lecturers and coordinator of the course. I can be reached at:

Name: Dr. rer. nat. Prabhas K. Yadav

Location: Zi: A210, Fakultät Bauingenieurwesen ,
TU Dresden, Andreas-Schubert-Straße 23, 01069 Dresden

Phone Nr: +49 351 462 3915

email: prabhaskumar.yadav@htw-dresden.de

Contact hours: 4:00 – 5:00 PM every Mondays (TBD)

Organizational Aspects

Course Contents

The course has following three units:

1. General Aspects of Modelling (15% of total load)
2. Surface Water Modelling (70% total load)
3. Special Topics (15% of total load)

Each topic of the course will involve Computer Programming (for exercises) and Simulations (for practicals)

Learning Materials for class lectures

(a) **Slides:**
This will be mostly used in the class lectures. Slides will be uploaded to OPAL LMS prior to the lecture day.

(b) **Reading Materials:**
Journal articles or Book chapters will be recommended for a pre-class learning and exercises/practical works

(c) **Codes:**
Jupyter notebooks (next slide) with codes written in Python, Octave (equivalent Matlab® etc.) and Spreadsheets (.xls format) will be provided to aid learning and self-learning.

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Learning Materials for Exercises/Practical

(a) **OPAL Link:**
OPAL **(check here)** will be used for distribution of lecture/lab materials and sharing information. The materials will be organized in two folder "Lecture" and "Lab". Each folder will contain slides, pdf, JUPYTER notebook (IPYNB) and source file for contents.

(b) **Jupyter Notebook for computation and visualization:**
We will use Jupyter Notebook (mostly Python) based computation for all computation in the course. You can download Jupyter Notebook from this **site**.

(c) **Surface water modeling:**
For this we will use HEC-RAS. You can download HEC-RAS from **here** and its documentation from **here**. HEC-RAS is a very large code. We will cover only a very small part of the code.

Learning Materials: Referred Books and Software

The course learning materials will be mostly from the following literature:

1. Brunner, G.W., CEIWR-HEC, 2016. *HEC-RASRiver Analysis System - User Manual*. US Army Corps of Engineers, Institute for Water ResourcesHydrologic Engineering Center (HEC). HECRAS Software: https://www.hec.usace.army.mil/software/hec-ras/default.aspx
2. Les Hamill. (2011) *Understanding Hydraulics*. 3^{th} edition, Palgrave MacMillan, Basingstoke. ISBN: 978-0-230-24275-3
3. Chanson, H., 2004. *Environmental hydraulics of open channel flows*. Elsevier Butterworth Heinemann, Amsterdam.
4. Chaudhry, M.H., 2008. *Open-channel flow*, 2. ed. ed. Springer, New York.
5. Marriott, M., Featherstone, R.E., Nalluri, C., 2016. *Nalluri & Featherstone's civil engineering hydraulics: essential theory with worked examples*, 6th edition. ed. John Wiley & Sons, Inc, Chichester, West Sussex, United Kingdom.
6. Project Jupyter (Python Programming), URL: https://www.jupyter.org (accessed 10.4.19).
7. Domenico, P.A., Schwartz, F.W., 1998. *Physical and chemical hydrogeology*, 2nd ed. ed. Wiley, New York.

Evaluation Methods

In this course "Evaluation" will be in the form of "Feedback". Minimum grade in the "Course Exam" is however required to pass the course. For "Feedback" we will a perform several different activities, such as:

- Code submission for numerical and analytical problems
- Short Quiz and Presentation of special hydraulics Modelling topics
- Modelling and simulation using HEC-RAS or Python
- Course Exam: **Project Study**

Organizational Aspects

Evaluation Methods - Project Study Requirements

- It is a group work of 3 students (individual grading)
- Selection of project topic (must be part of the course)
- Must include simulations – HEC-RAS, Python or other code
- Complete report (see format in next slide) of the project.
- Group presentation (15 min) and discussion (10 min) of the project.

Important Date: (Tentative - to be updated)

- Group members and topic selection: **27.10.2023**
- Submission of outline & schedule: **15.12.2023**
- Submission of final report: **21.01.2024**
- Presentation of project: **TBD**

Evaluation Methods - Project Study Report Format

(Tentative -To be updated)

My expectations: You are able to model a scenario using mathematical code, post-process your results and write a standard report of the project.

Report Format (Maximum 15 pages)

1. **Introduction:** points to be included–
   - General introduction to the topic
   - Specific introduction to the topic,
   - The focused topic in the report.
2. **Literature Review:** to include–
   - Theoretical development on the topic– focus on your problem.
   - Previous numerical study on the topic
3. **Methodology and Result:** to include–
   - Include which code was used and what are the assumptions.
   - Include how required data were obtained for simulations

Continued in the next slide

Evaluation Methods - Project Study Report Format

(Tentative -To be updated)

Report Format (Maximum 15 pages)

4. **Discussion:** points to be included–
   - Discuss your results (visuals and numbers) and compare them with literature
   - Include your opinion on your results
5. **Conclusion and Recommendation:** to include–
   - Summary of your finding
   - Your recommendations
6. **References:** to include–
   - Standard referencing methods must be used for all the literature.

The project report will be graded based on timely submission of reports (**group** grading) and the final presentation (**individual** grading).

Today's Contents

1. organisational aspects
2. Scope of “Hydraulics” in this course
3. Scope of “Modelling” for this course

Scope of Hydraulics in this course?

"Hydraulics" deals with application of hydrodynamics concepts for engineering practice.

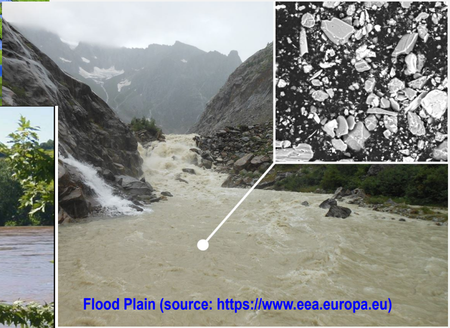
Thus **"Hydrodynamics"** or also Fluid Mechanics provides the fundamental background to hydraulics.

In this course **"Fluid"** refers to pure water or water transporting particles.

When **"Transport"** is included with fluid, the problem can then be extended to water-quality issues. We then speak of **"Environmental Hydraulics"**.

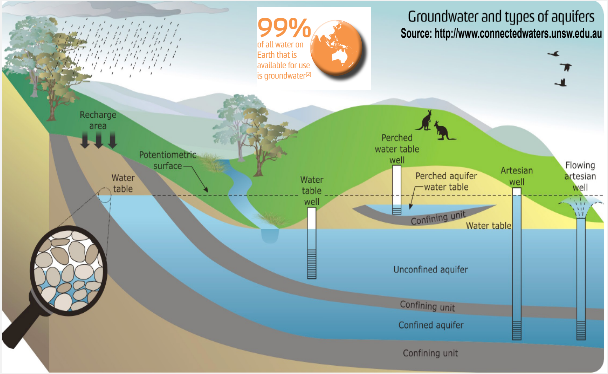
In this course we will focus on **"General Hydraulics"** and get ourselves introduced to **"Environmental Hydraulics"**.

Few scopes of hydraulics modelling



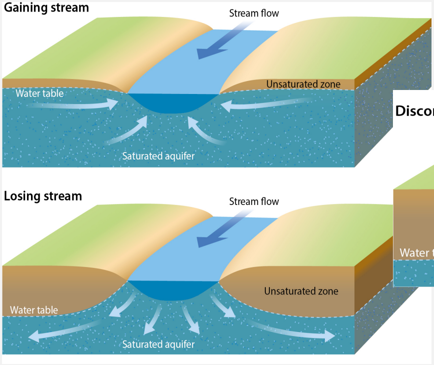
Additional scope of Hydraulics in this course

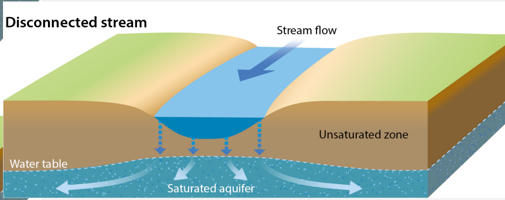
Traditionally, *Hydraulics* has been focused on **“Surface Water”** but also important is: **“Grounwater (GW) Hydraulics”**.



Additional scope of Hydraulics in this course

Traditionally, *Hydraulics* has been focused on **"Surface Water (SW)"** but also important is: **"GW–SW interaction"**





Source: http://calag.ucanr.edu

Additional scope of Hydraulics in this course

Traditionally, *Hydraulics* has been focused on **“Surface Water (SW)”** but also important is: **“Water Contamination”**

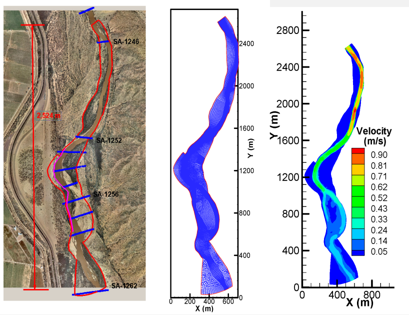
Modelling in this module

A Model used in hydraulics is to describe a "physical" or "mathematical" simulation of a prototype, or field-size situation.

A physical model

Physical model with moveable bed of the Oder River at Hohenwutzen
Source: https://www.baw.de

A mathematical model



Mathematical modelling of study middle Rio Grande River, USA
Source: https://doi.org/10.3390/w9120950

Our focus is in **Mathematical Modelling**.

Modelling in this module

Mathematical modelling of hydraulic systems

This deals with the principal of Hydrodynamics, which can be considered as a component of "Applied Mathematics". This can be:

1. **A mathematical model:** A mathematical model is a set of algebraic and differential equations that represents the interaction between the flow (transport) and process variables in space and time. A unique solution is sometime possible for this model.

2. **A numerical model:** A numerical model is an approximation of a mathematical model of some prototype situation, giving a computable set of parameters that describes the flow (transport) at a set of discrete points.

3. **A computational model:** A computational model is an implementation of a numerical model on a computer system with the relevant data from a specific site.

Modelling in this module

A mathematical model

We consider a transverse mixing of two streams with different water-quality (concentrations). A **"steady-state"** mathematical model for this is (from Chanson 2004):

$$D_m \frac{\partial^2 C_m}{\partial y^2} - V \frac{\partial C_m}{\partial x} = 0$$

The boundary conditions are:

$$C_m(0, y) = 0 \qquad \text{for } y > 0$$

$$C_m(0, y) = C_0 \qquad \text{for } y < 0$$

with

x, y = Space coordinates [L]
C_m = Mass concentration $[ML^{-3}]$
D_m = Diffusion coefficient $[LT^{-2}]$
V = Linear velocity $[LT^{-1}]$

A example scenario

Sediment-laden water from a tributary entering the clearer Chattahoochee River near Atlanta, Georgia, USA.
Source: https://www.usgs.gov

Modelling in this module

A mathematical model

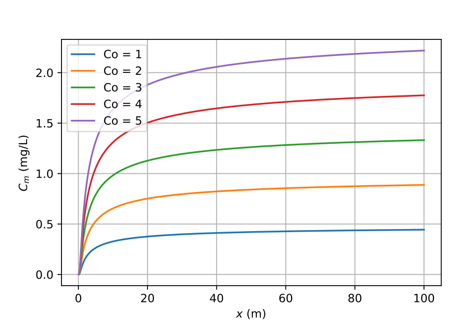
Solution of the example problem at **“steady-state”** for $\boldsymbol{x > 0}$ is (from Chanson 2004):

$$\boldsymbol{C_m(x,y) = \frac{C_0}{2}\left(1 - \mathrm{erf}\left(\frac{y}{\sqrt{4D_m\frac{x}{V}}}\right)\right)}$$

with
$\boldsymbol{C_0}$ = initial concentration in the domain $[\mathrm{ML}^{-3}]$
erf = error function (to be explained in the exercise class)

Complete calculation is at:

A example scenario



Modelling in this module

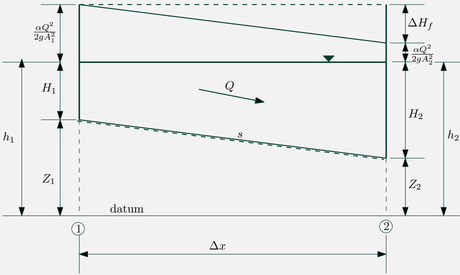
A Numerical model - channel head-loss

For the lateral flow $(q) = 0$ and $Q_1 = Q_2$, the energy conservation equation can be represented in the figure by:

$$h_1 + \frac{\alpha Q^2}{2gA_1^2} = h_2 + \frac{\alpha Q^2}{2gA_2^2} + \Delta H_f$$

with h the head, A the cross-section, α the energy correction factor and ΔH_f the friction loss in channel reach.

A example scenario



Modelling in this module

A Numerical model - channel head-loss

ΔH_f is required to be defined to solve this problem. It is usually approximated using the arithmetic average of the friction slope from:

$$\Delta H_f = \Delta x \frac{S_1 + S_2}{2}$$

with S- the friction slopes that is calculated from

$$S_x = \frac{(n_M)_x^2 \cdot Q^2}{R_x^{4/3} \cdot A_x^2}$$

for $x = 1, 2$, n_M is Manning's Coefficient and R the hydraulic radius. So the final equation to solve is

$$h_1 + \frac{\alpha Q^2}{2gA_1^2} = h_2 + \frac{\alpha Q^2}{2gA_2^2} + \frac{\Delta x}{2}\left(\frac{(n_M)_1^2 \cdot Q^2}{R_1^{4/3} \cdot A_1^2} + \frac{(n_M)_2^2 \cdot Q^2}{R_2^{4/3} \cdot A_2^2}\right)$$

This is a non-linear equation and requires numerical methods to solve.

Modelling in this module

A computational model

This is required generally for solving system of equations that do not have closed-form solution and is not solvable by simple approximations. Example of such models in Hydraulics Engineering are:

Navier–Stokes equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = -\frac{\partial p}{\partial x}\frac{1}{\rho} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + f_x$$

with u, v, w the velocity in x, y, z directions, respectively. t is time, p the pressure, ρ the fluid density, ν the kinematic viscosity, and f_x the body force in x-direction

or the 1-D system - **Saint-Vennant equation** for shallow water flow:

$$\frac{\partial A}{\partial t} + \frac{\partial (Au)}{\partial x} = 0 \quad \text{and} \quad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} = \frac{P}{A}\frac{\tau}{\rho}$$

with $A(x, t)$ cross-section, $\zeta(x, t$- the surface elevation, $\tau(x, t)$ the wall shear stress, and $P(x, t)$ the wetted perimeter.

To be continued

Modelling and Numerical Methods in next class.

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