Aalto University
School of Engineering

Modelling and Control of Water and wastewater treatment processes

WAT - E2130

Henri Haimi TkT D Sc (Tech)
Anna Mikola TkT D Sc (Tech)

Lecture outline

Course team introduction

Participants' introduction

Learning outcomes

Content and assessment of the course

- **Lectures & exercises**
- **Modelling project work**
- **Excursion**
- **Exams**

Introduction lecture: Introduction to modelling and simulation

Hands-on SUMO

First introduction exercise

Lecturer Henri Haimi

- **M.Sc. from HUT (Environmental tech.) 2001**
- **Lis.Sc. (Tech.) from HUT (Plant design) 2006**
- **D.Sc. (Tech.) from WAT 2016 Dissertation: *Data-derived soft sensors in biological wastewater treatment - With application of multivariate statistical methods***

- **Working experience:**
  - 5 years as a researcher at HUT/ Plant design
  - 1 year at Finnish Environment Institute SYKE
  - 8 years as a researcher at HUT/Aalto WAT
  - 7 years as a consultant (FCG Finnish Consulting Group Oy)
  - Professor of Practice in Aalto WAT since April 2023

Lecturer Anna Mikola

- **M.Sc. From HUT Water lab 1999**
- **Exchange year in France at ENCR 1994-1995**
- **D. Sc. (Tech.) Spring 2013 Dissertation: The effect of flow equalizationa and prefermentation on BNR**
- **Lived 5 years in Berlin, 4 children**

- **Working experience:**
  - 3 years at Nopon Oy
  - Researcher at HUT/Aalto
  - 18 years with a consultant (Kiuru&Rautiainen Oy, Ramboll Finland)
  - Post-doctoral researcher at Aalto 2013-2018
  - Visiting researcher in INSA Toulouse in 2017
  - Professor of Practice 2018-22, assistant professor (2nd term) since 2022

Lecturer for the control part Michela Mulas

Professor at the Federal University of Ceará, Department of Teleinformatics Engineering in Fortaleza, Brazil

Lecturer Sylvie Gillot

- **Engineer from INSA Lyon (1994)**
- **Master degree (DEA) from INSA Lyon (1994)**
- **PhD from University of Paris-Créteil (1997) - *Oxygen transfer in activated sludge systems: measurement and interpretation***
- ***HDR (2010) - Habilitation to supervise researches in Process Engineering***

- **Working experience:**
  - 2 years at UGENT as a post-doctoral fellow - WWT optimisation using simulation and cost analysis (1998-2000)
  - Researcher at INRAE (formely Cemagref – Irstea) since 2001
  - 8 years (2012-20) - Deputy Director of the Irstea Research Department ”Ecotechnologies”
  - Senior scientist at INRAE - Process engineering applied to WW treatment and recovery

The course team

Course assistant: Lobna Amin

Lab staff (for IT issues): Heikki Särkkä and Antti Louhio

Guest lecturers:

Sylvie Gillot, INRAE

Teemu Koskinen, Ramboll Oy

Riku Laitinen, Endress+Hauser Oy

Participants' introduction

1 minute each containing *e.g.*

- **Background?**
- **Experience with process modeling and control**
- **Main interest in wastewater and/or drinking water?**
- **Expectations for this course?**

Learning outcomes

Upon completion, the student should be able to:

Knowledge

- Understand the overall process train as well as selected process performance, the definition the main disturbances for the process operation and the identification of the process dynamics
- Be able to describe the modelling and control techniques: state-of-the-art models, basic controllers and their practical application to full scale processes
- Recognise the instrumentation available in the plants: actuators, on-line sensors/analyzers, structure of the automation system and their representation on the piping and instrumentation diagram

Skill

- Optimise plant operation in terms of resources consumption and effluent quality improvement
- Analyse and understand the on-line and off-line data available at the treatment plants
- Design the automation system for the treatment plants by means of simulator software

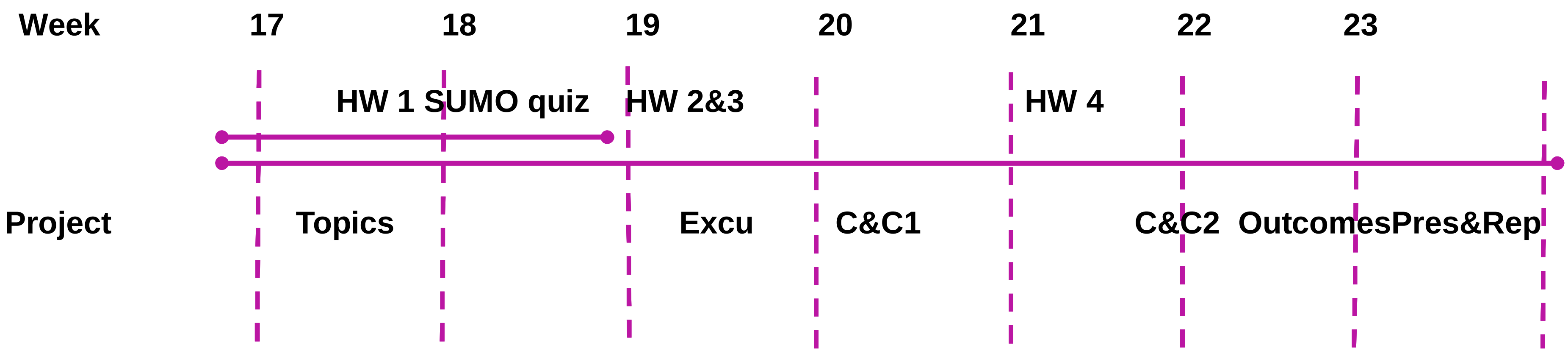
Identity

- Understand the role of a process modeller or control system designer in the treatment process design or operation team

Why process modelling and control course?

- Models are important tools in process development, design, optimization and operation.
- Modelling allows to understand more complex systems and process trains
- Process operation and control are crucial parts of well performing processes – a well-designed plant can be very badly operated!!
- Process engineers tell automation engineers what the control system needs to do

Timeline for the course



Lectures	**Intro**	* *	**Excu**	* *	* *	*	* * *
Exercise DLs			HW 1	HW 2	HW 3	HW 4	
Exams		SUMO quiz		Exam 1		Exam 2	Extra 1&2
Modelling project work	Select topics	Modelling task	Questions to Klaukkala	Control task			
Presentation					Client presentati on		Presentatio ns
Written report						1st draft + feedback	Final report

Course execution

- **Lectures and exercises in AS5**
  - Lecture sessions: 3.5 hours Wednesday afternoon and Friday morning
  - Each session will be divided into several interactive lectures, and hands-on exercises with SUMO
  - Four homework exercises
  - Additional optional sessions for homework assignments on Monday afternoons or Tuesday mornings (to be decided)
  - Get to know SUMO quiz – to be finished in MyCourses, grading pass/failed
- **Two mid-term exams**
  - 60 min at the beginning of two sessions (17.5. & 2.6.)?
- **Simulation project work**
  - Individual work with pair discussions
  - Create your own virtual treatment plant, Klaukkala WWTP
  - Demonstrate a specific operation and process control study with your process
  - Presentation of the work and results (sessions 5.6. and 7.6.)
- **Excursion to Klaukkala Friday 12.5.!!!**

Communication

- MyCourses -page
  - Lecture material available mostly before the lecture
  - Instructions for homework assignments
  - Submission of home assignments & grades
  - Information and submissions for the modelling project
- Communicating
  - *Whole course*: MyCourses & e-mail
  - Teams – for communication between students and students&staff
  - henri.haimi@aalto.fi, anna.mikola@aalto.fi, michela.mulas@aalto.fi, lobna.amin@aalto.fi

Course grading

- **30 % mid-term exams - 2 exams 20 points each**
- **40 % individual project (presentation and written report)**
  - 1/3 from the presentation, 2/3 from the written report
  - Grading scale 1 – 5
  - Based on assessment of Henri and Michela
  - 30 % homework exercises + activity during the course
  - 4 exercises, 80 points total
  - Bonus possibility up to 0.5 grade when attending the lectures
  - NOTE!! Late submission – 1 week → 50% off, more → 100% off

Grading thresholds:

1-40% of total points   **2**-52%   **3**-64%   **4**-76%   **5**-88%

Workload

Learning activity	Workload calculation (hours)	Remarks
Lectures	24	
Excercises	20	
Home assignments x4	20	5 hours per homework assignment
Reading materials	30	5-10 pages for most of the sessions
Project work	16	8 hour for computer simulations, 8 h for reporting and preparing the presentation
Midterm exam (2x)	10	5h preparation for each mid-term exam
Independent reflection	15	
In total	135	

Recent changes to reduce the workload:

- Changes in the exercises, HWs published earlier
- Improved assignment documents

OUR CASE STUDY PLANT – KLAUKKALA WWTP IN NURMIJÄRVI

Project work tasks prepared on the basis of this plant

Friday 12.5. during the course teaching session excursion to the plant, bus transportation from and back to Water lab

Special focus on instruments at the plant and process control

PEDAGOGICAL TRIAL FOR THE PROJECT WORK ☺

IDEA: Include professional context and role games into teaching

IN PRACTICE:

- **Playing the role of client and consultant in pairs**
- **Two C&C meetings during the project:**
  - 1) Introduction of the topic → questions for Klaukkala
  - 2) Testing/training for the final presentation
  - From C&C meeting 1 prepare a Teams or Zoom recording (about 10 min per topic)

Course introduction / Lectures and project work

Course books

Rieger, L., Gillot, S., Langergraber, G., Ohtsuki, T., Shaw A., Takacs, I., Winkler, S. (2012) Guidelines for Using Activated Sludge Models

Biological wastewater treatment

Author(s) / Editor(s) Henze, M., Loosdrecht, M.C.M. van, Ekama, G.A., Brdjanovic, D. Publisher IWA Publishing

Copyright Date 2008

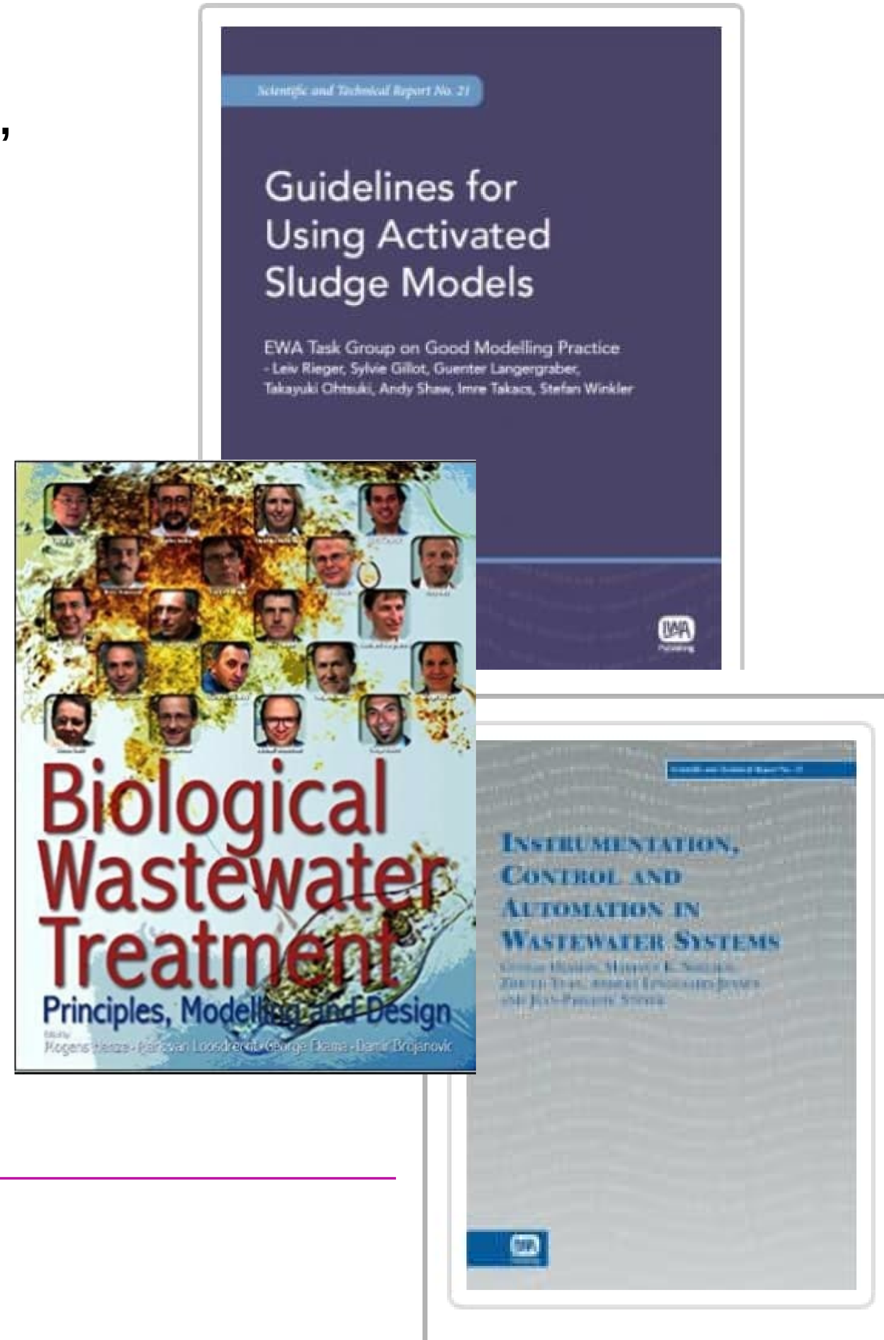
ISBN 978-1-84339-188-3

Electronic ISBN 978-1-68015-582-2

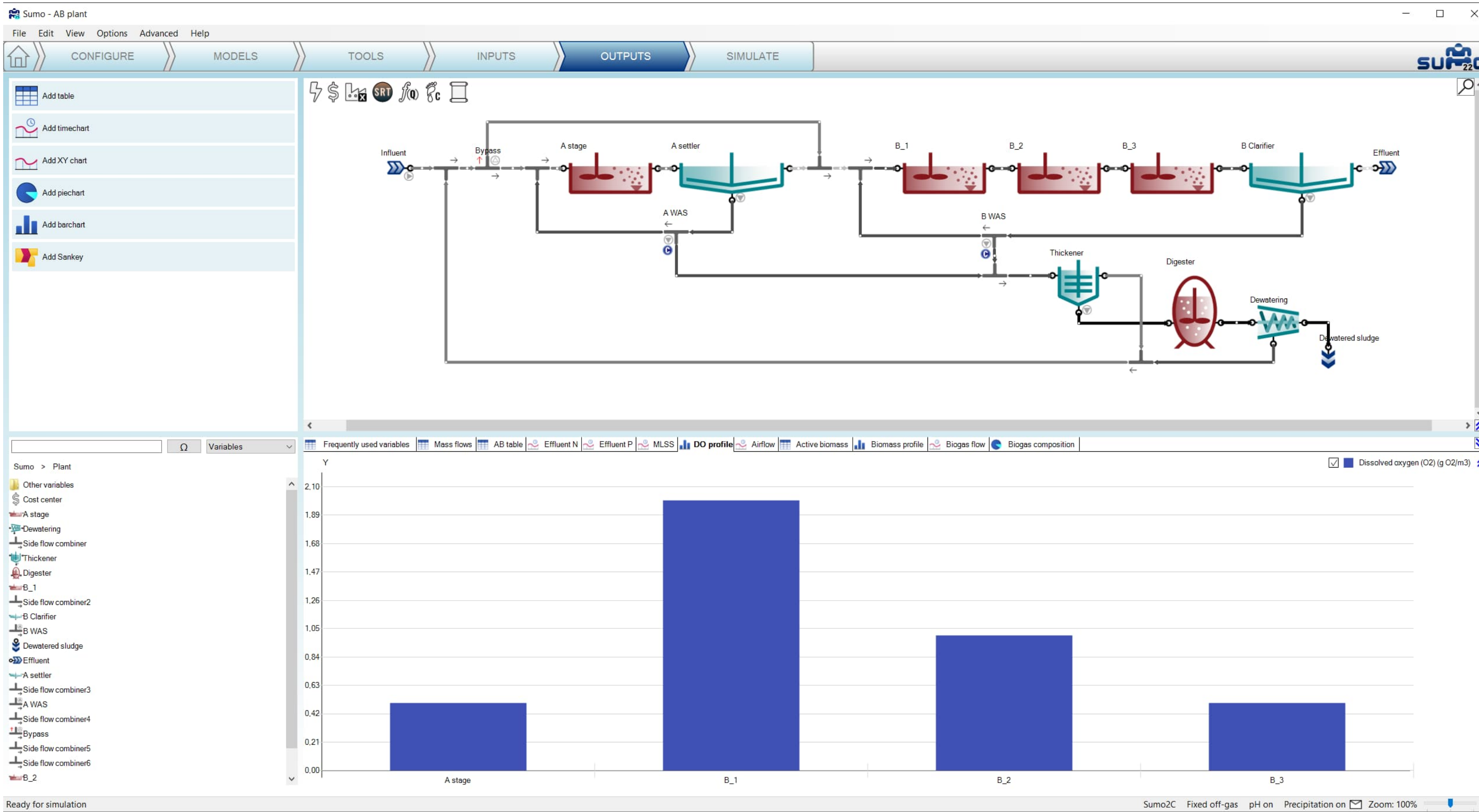
Olsson, G., Nielsen, M., Yuan, Z., Lynggaard-Jensen, A., Steyer, J.P.

(2005). Instrumentation, Control and Automation in Wastewater Systems,

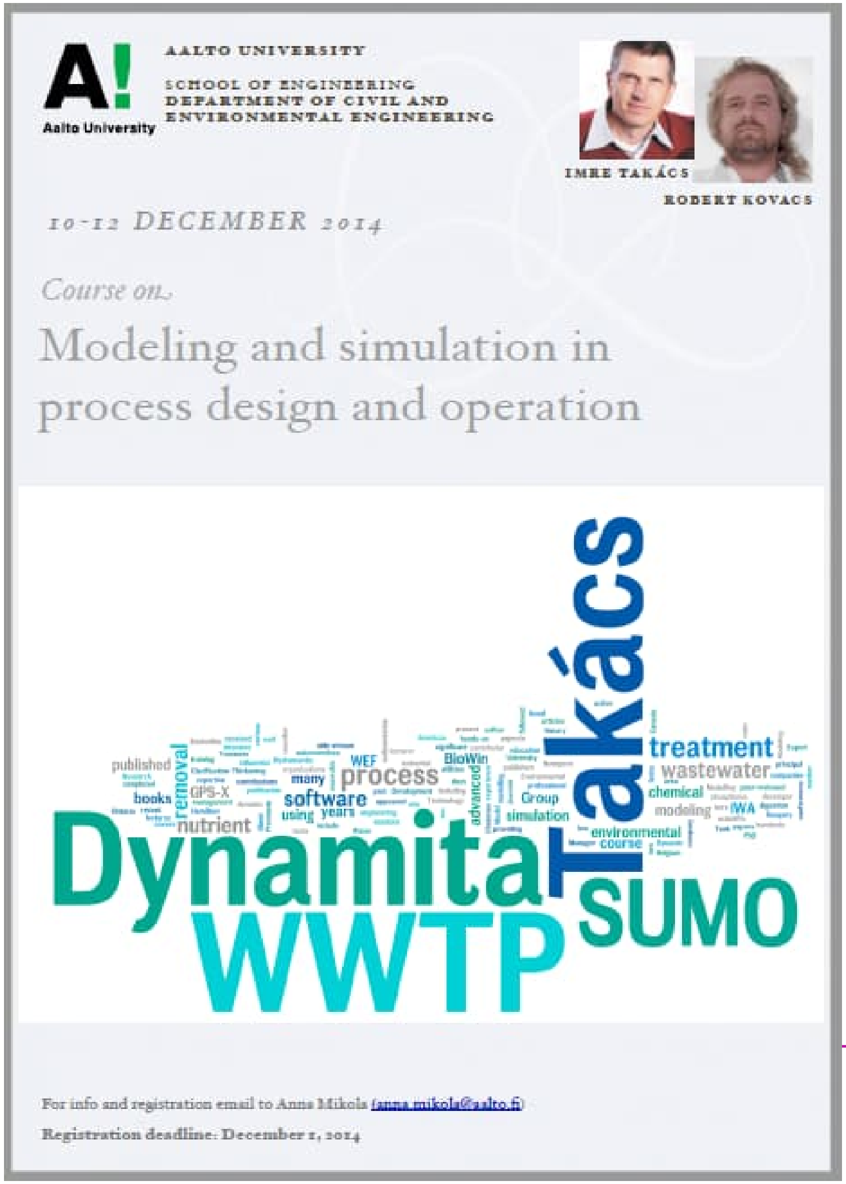
IWA Publishing, London.

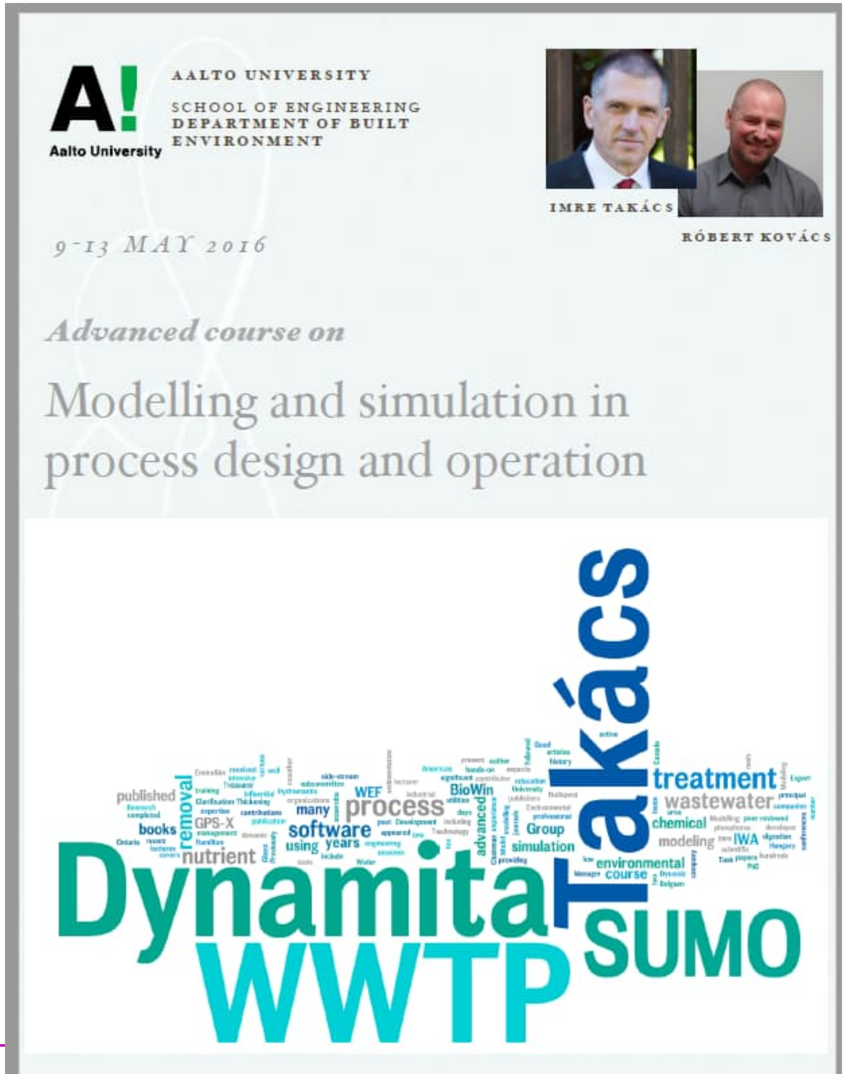


SUMO introduction



SUMO history at the lab





Important to do after the introduction lecture

Install SUMO to your computer!

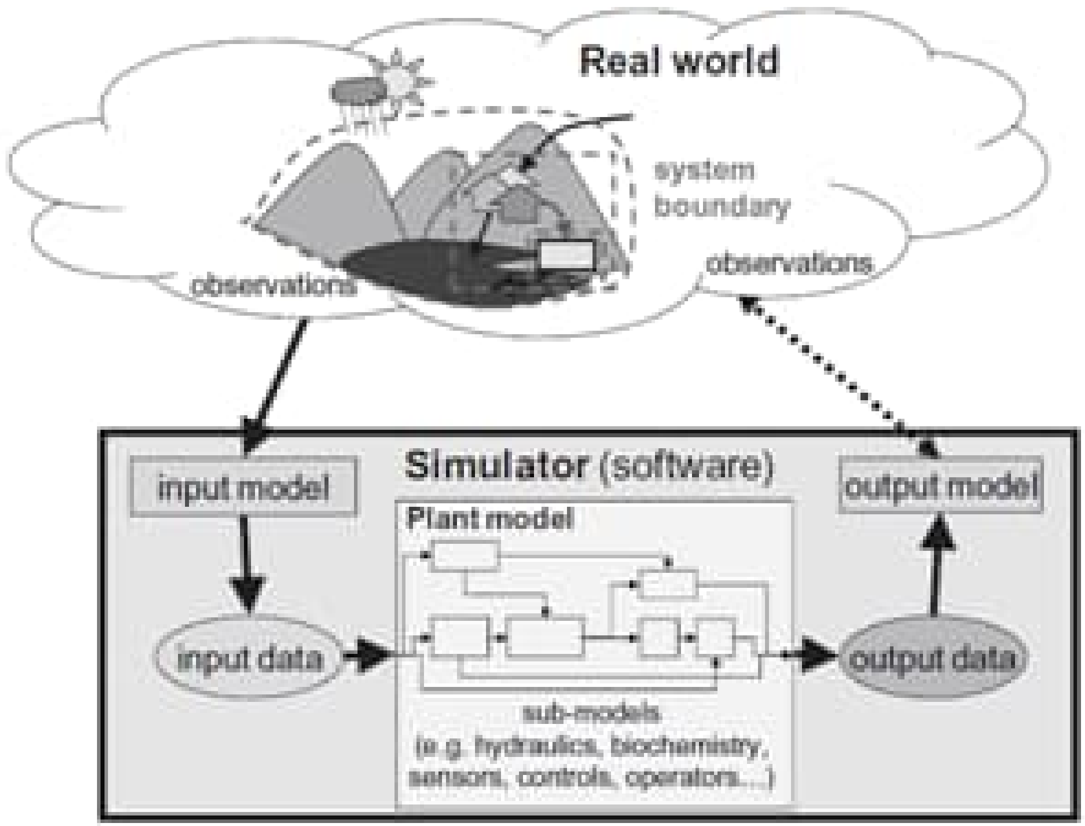
If you have problems contact Lobna or Henri!

Start to think about your project topic!!

You can read chapters 14.1. and 14.2. from the course book (Biological wastewater treatment)

Introduction to modelling

What is a model?

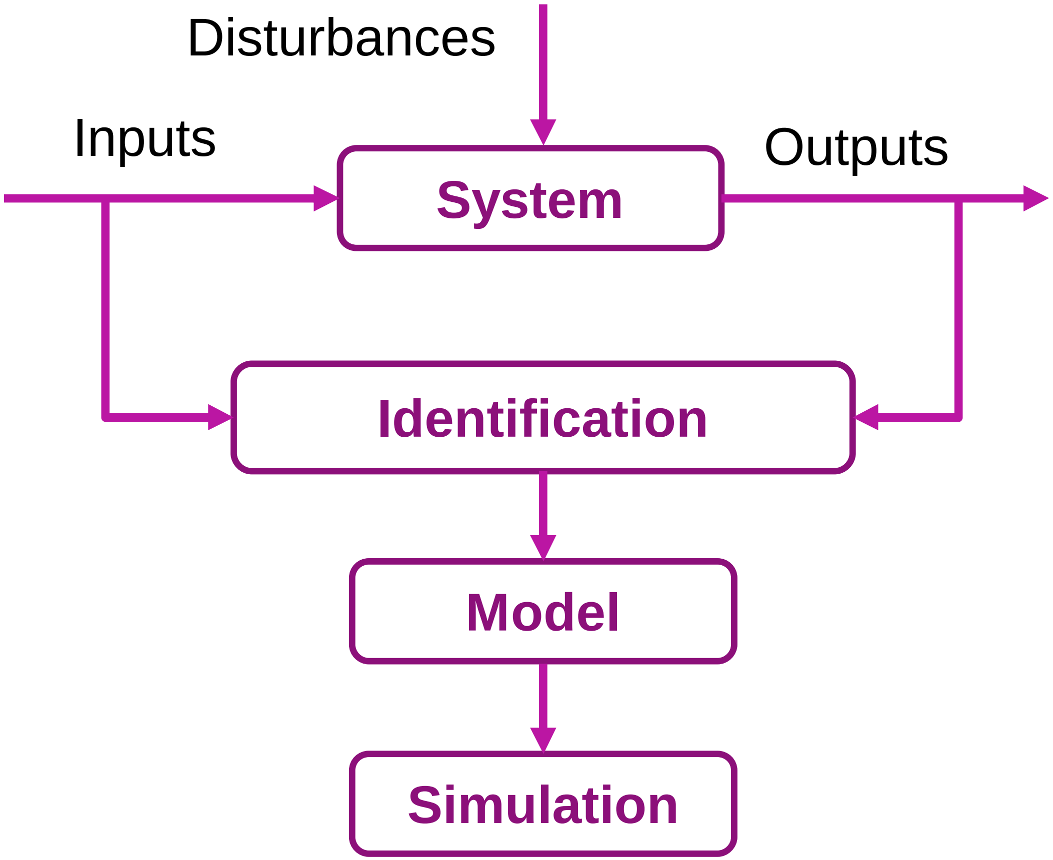


Key definitions

What is a model?

A model is a systematic representation of a real system

The **system is a defined part of the world**. The interactions with the environment (the rest of the world) are described by measurable inputs and output signals and the disturbances



Key definitions

Models in general give a **formal description of the system** and provide a representation of **what we consider the essential aspects** of that system in a usable form. They can be very different.

Mental models

Give an explanation of someone's thoughts about how something works in the real world **without involving any mathematical representation**

Graphical models

Provide a convenient way to describe the properties of a process **by means of tables or plots**

Mathematical models

Describe the relationships among the system variables in terms of difference or **differential equations**

Key definitions

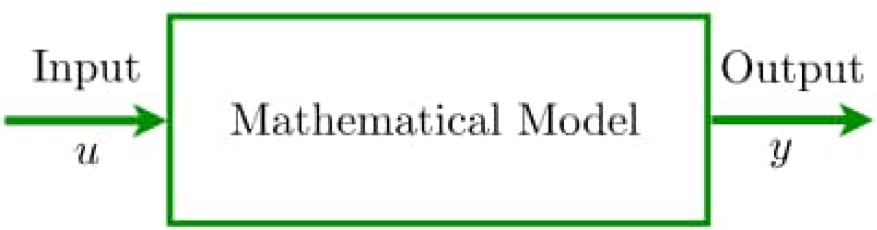
A model is a systematic representation of a real system

Calibrated models for wastewater treatment processes can be used to:

- Design
- Management
- Plant Operator Training
- Cost Investigation
- Process Control

Model Constituents

- Inputs
- Output
- State Variables
- Constants and Parameters



Key definitions

Structured models

A full understanding of the nature of the system can identifying and describing the **physical, chemical and biological laws** that govern the system.

High interdependence of the state variables makes the **calibration a difficult task**

Key definitions

Unstructured models

The model development is mainly driven by **measured data from the actual system**. Its main advantage is that highly accurate mathematical models without detailed knowledge of the system

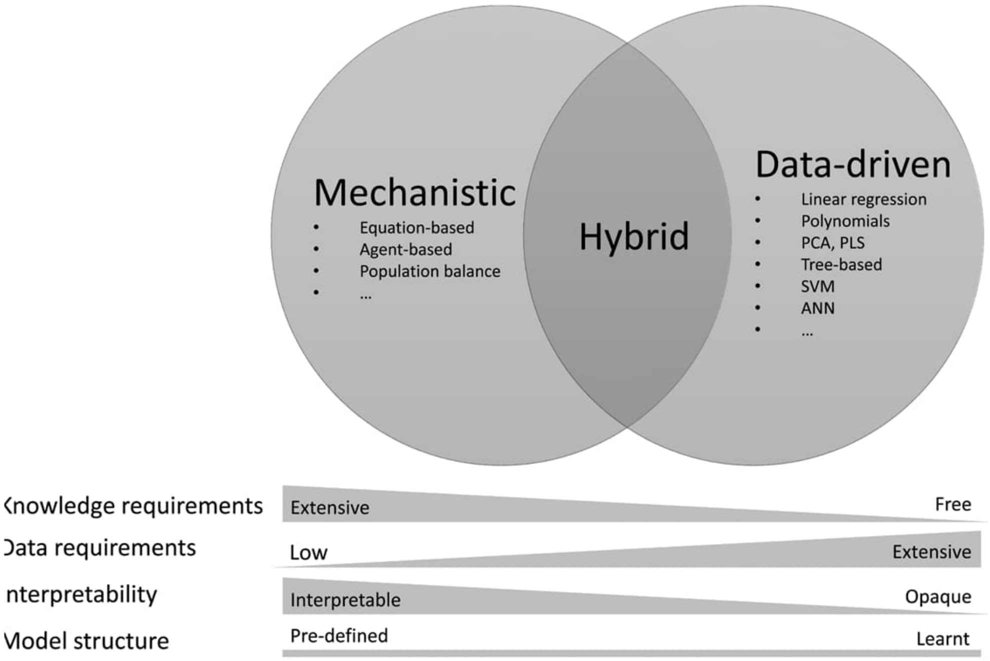
The **accuracy of the model relies on the quality of the data**

Key definitions

Hybrid models

Physical interpretable parameters that are possible to be estimated by means of statistical methods

The potential advances include a reduced demand of experimental data and **more reliable extrapolation**



Scheider et al. 2022. Hybrid modelling of water resource recovery facilities: status and opportunities

Uses of wastewater models

What is the "perfect" model?

The simplest model which does the job

What are the characteristics of a perfect models?

Science-based to the extent possible, with **reasonable use** of empirical knowledge

Include only what is essential given their intended use

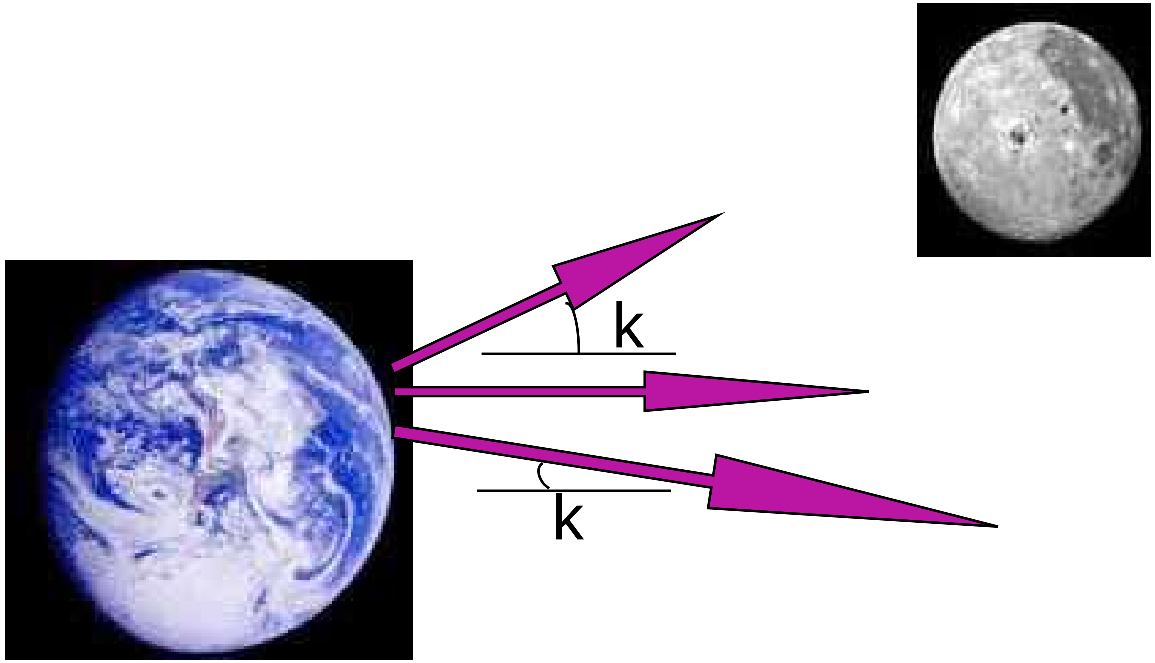
Consistent with existing and evolving practice

Adaptable as both knowledge and practice requirements evolve

G. T. Daigger
Water Science and Technology 63 (3) 516-526, 2011

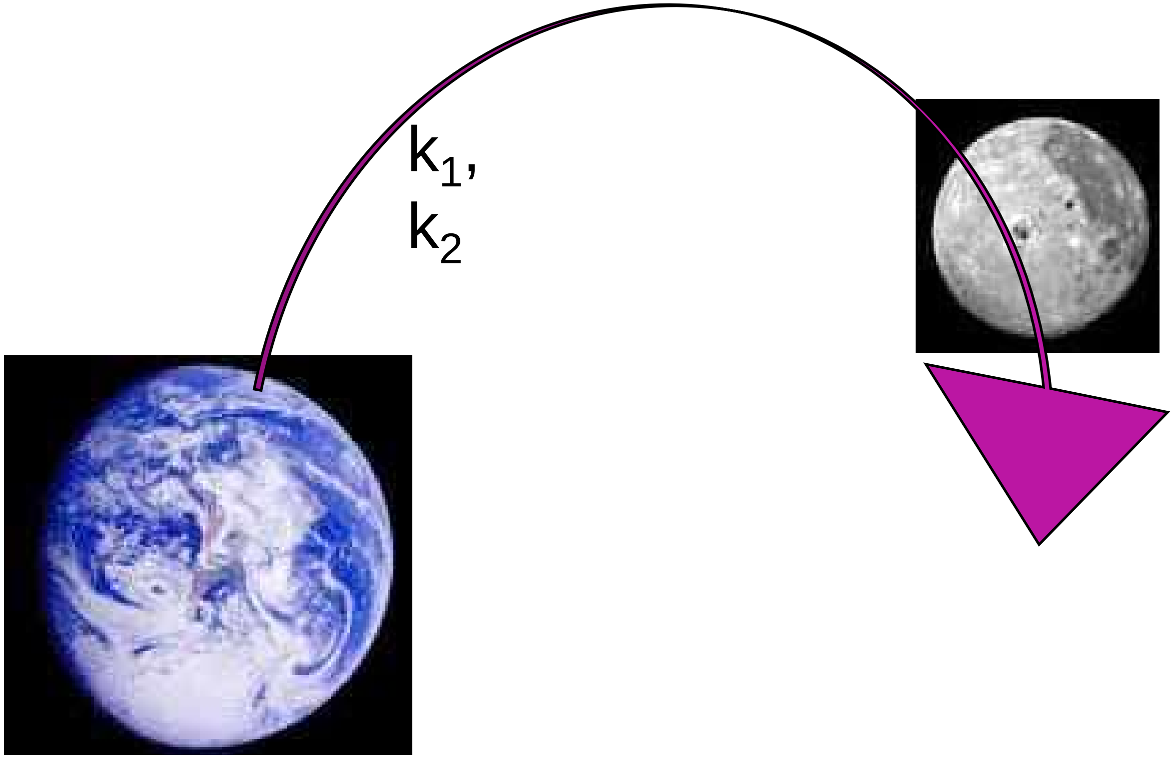
Are there too many parameters in our models?

- 1 parameter model to get to the moon



Are there too many parameters in our models?

- 3 parameter model to get to the moon



Uses of wastewater models

Why models?

Mathematical models are useful and necessary for:

- **System understanding**: to obtain and enlarge insight in different phenomena (ranging from physical laws to economic relationships)
- **System design**: simulation and operator training
- **Process control**: to quantify the effect of the manipulated variables and disturbances on the controlled variables
- **Process monitoring**: to obtain a template of the process under normal conditions or to perform root-cause analysis
- **Soft-sensing**: to estimate state variables that cannot be easily measured in real time on the basis of the available measurements
- **Optimization**: to identify constraints among decision variables and make optimal decisions

Model building exercise

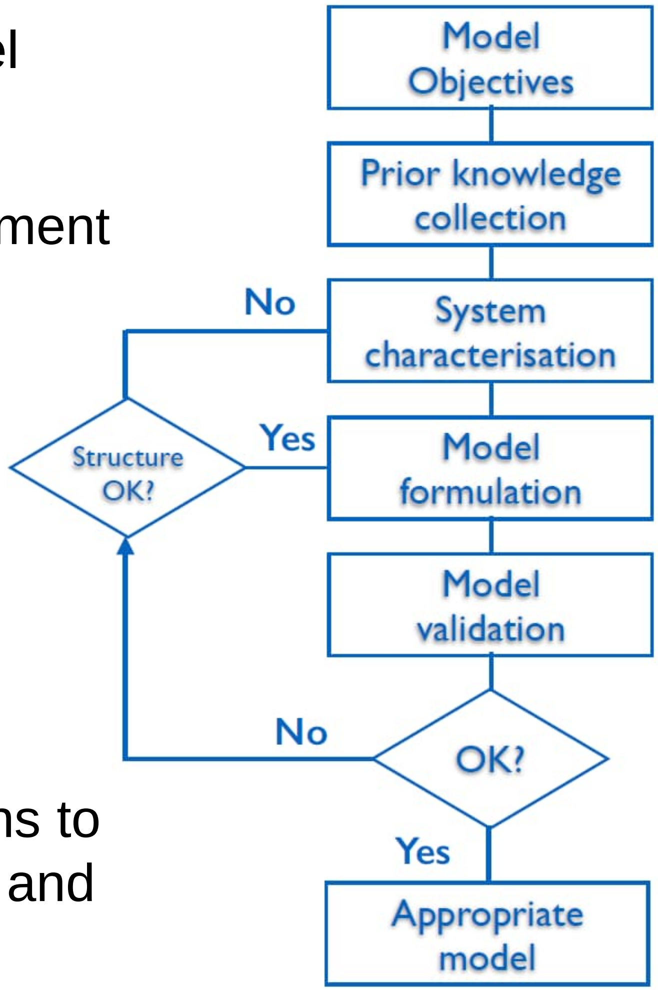
Select the **model purpose**: required model accuracy, model boundaries, …

Determine the **system parameters**: equipment sizes, volumes, process topology, …

Develop a **set of axioms** or description of the process

Evaluate the *a priori* knowledge of the process and **postulate the mechanisms within the process**

Test the constructed model by simulations to analyze/verify its behavior (at steady-state and dynamically)



Modelling platforms

Programming languages

- Matlab/Simulink
- C++
- Fortran
- Python
- ...

Commercial software

- Sumo – Dynamita
- GPS-X – Hydromantis / Hatch
- Simba – Ifak systems GmbH
- West – Mike powerd by DHI
- BioWin – Envirosim
- ...

Modelling platforms

Characteristics

- Interfaces with models of **entire wastewater treatment systems**
- Able to model entire wastewater treatment plant
- Incorporates wide range of unit processes
- Flexible and adaptable
  - Accommodates range of unit process models
  - Easily modified units to evaluate potential innovations
  - New unit processes easily formulated and incorporated
- Does not require extended learning to at least perform basic calculations
- Interfaces easily with other engineering automation tools
- Accommodates unit processes with diverse characteristics

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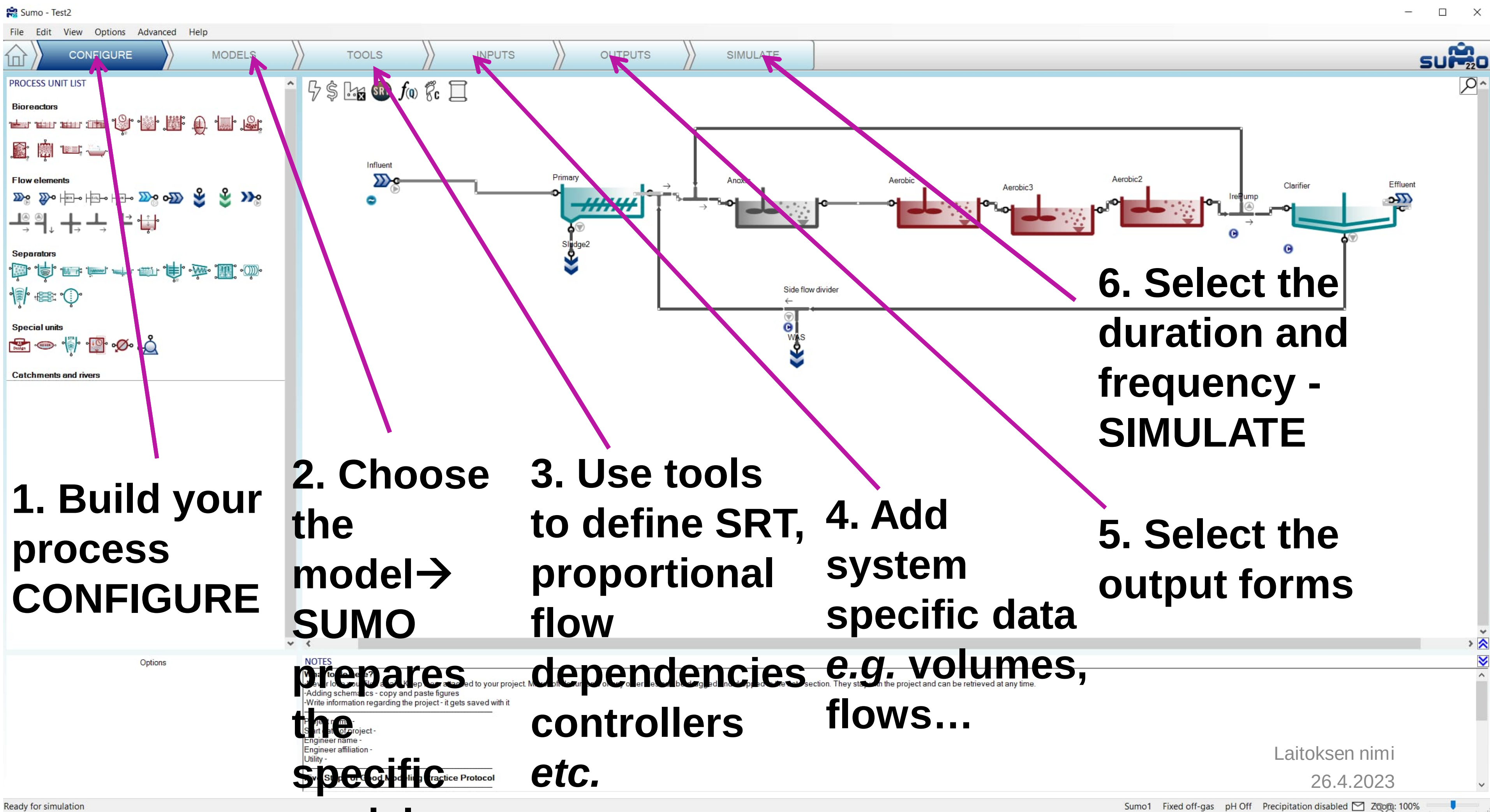
SUMO – basic principles



1. Build your process CONFIGURE

2. Choose the model→ SUMO prepares the specific model

3. Use tools to define SRT, proportional flow dependencies controllers *etc.*

4. Add system specific data *e.g.* volumes, flows…

5. Select the output forms

6. Select the duration and frequency - SIMULATE