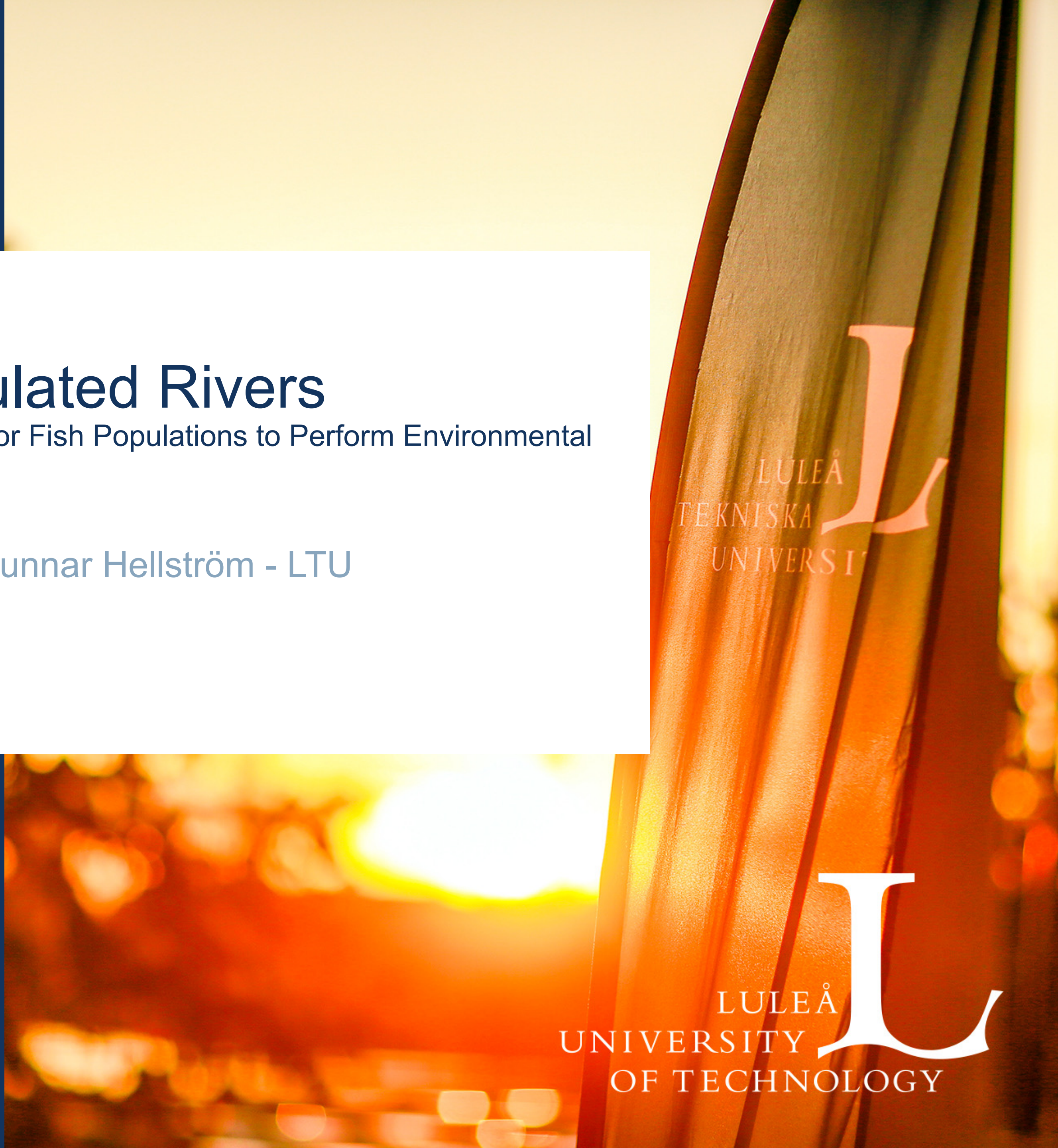
Digital Twins of Regulated Rivers

- Coupling Hydraulic Modelling with IBM for Fish Populations to Perform Environmental Flow Assessments

Frida Niemi, Anders Andersson, Gunnar Hellström - LTU
Mahboobeh Hajiesmaeili - KAU
David Aldvén - Vattenfall R&D



Agenda

1. Introduction – Background & Goal
2. Overview – Rivers & Fish Habitat
3. Model descriptions
    1. Hydraulic Modelling
    2. Individual Based Models
4. Case studies
5. Conclusions

Introduction

- **Goal:** Develop a tool to promote sustainable management of regulated rivers

- **Case-studies** of river with different **environmental preconditions**, target **species** and river **morphology**
    - Luleå älven - Mattisudden
    - Bredforsen

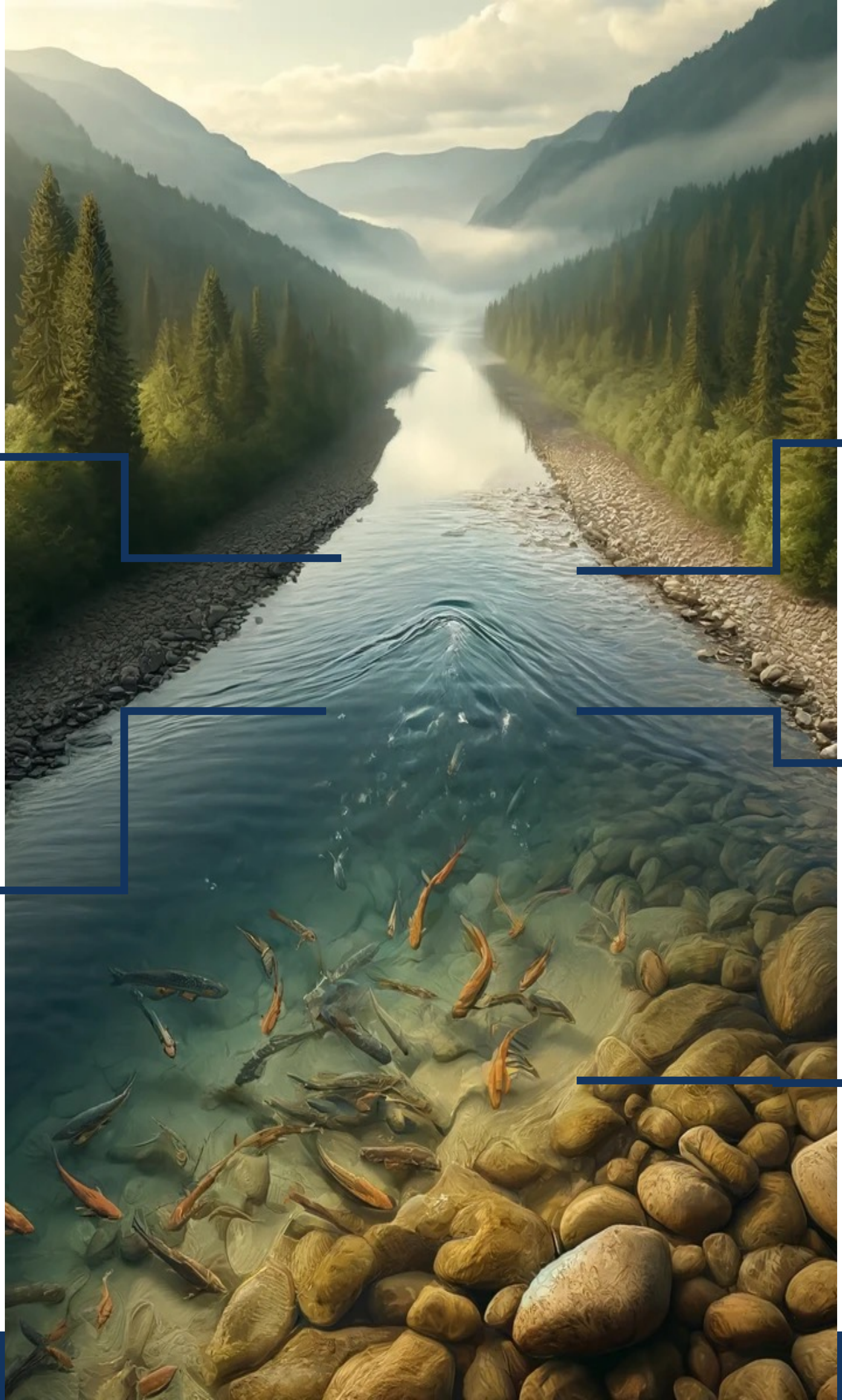
- **Method**
    - Develop **hydraulic model** over river
    - Investigate important parameters of the tool
    - **Couple** the simulations with **IBM**
    - **Investigate**
        - ➢ Hydropeaking conditions
        - ➢ Environmental flows
        - ➢ Ecological & hydraulic measures
    - Software
        - Delft3D FM – Hydraulic Modelling
        - InSTREAM – Individual Based Modelling

Overview

Hydraulic Modelling

River Topography
Bed Level – Bathymetry Resolution
Geomorphic Units
Hydraulic structures
Bed Roughness

Flow Characteristics
Velocities
Depths
Discharges
Bed shear stress
Natural or Unnatural flow discharges
Up and down ramping times
Management scenarios
Future flow scenarios – Environmental adaptions



Fish Habitat Modelling

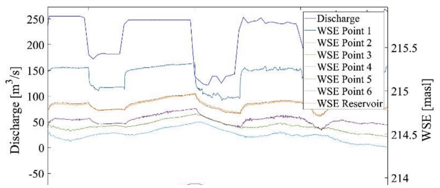
River Topography
Substrate
Spawning gravel
Hiding cover
Food availability

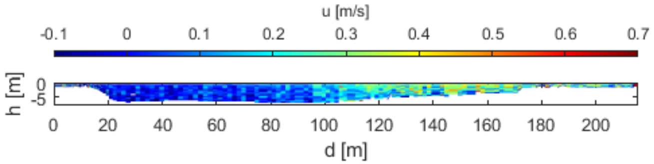
Flow Characteristics
Preferred Velocities and Depths
Preferred substrate, estimate from bed shear stress
Feeding & Hiding – Time of the day
Up and down ramping – Stranding risks

Growth & Survival
Egg development & Growth possibilities
Temperature - Season
Predation risks
Territorial behavior

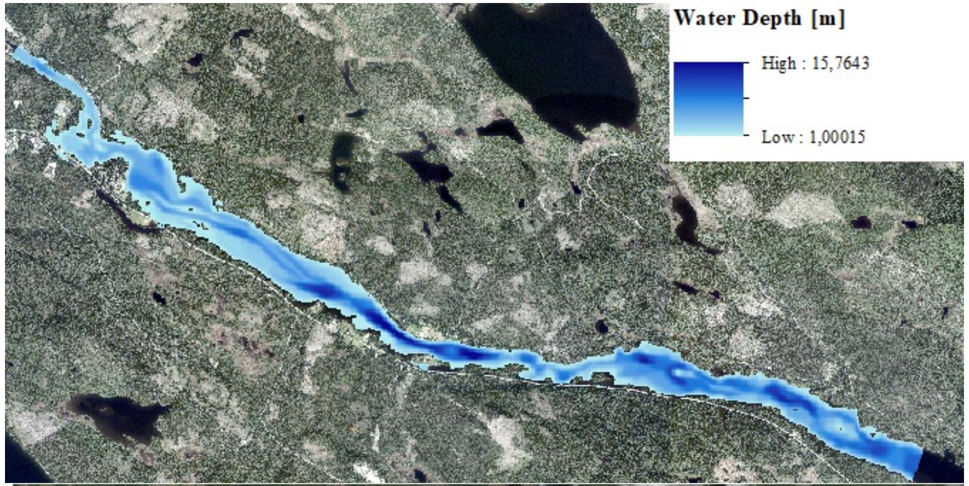
2D Hydraulic Modelling

- 2D - Hydraulic Modelling
  - Depth averaged velocities
  - Investigate steady and transient flows
  - Capture the dynamic behavior
- Validations
  - Pressure Loggers
    - Water Surface Elevation
  - ADCP
    - Velocity
    - Depth



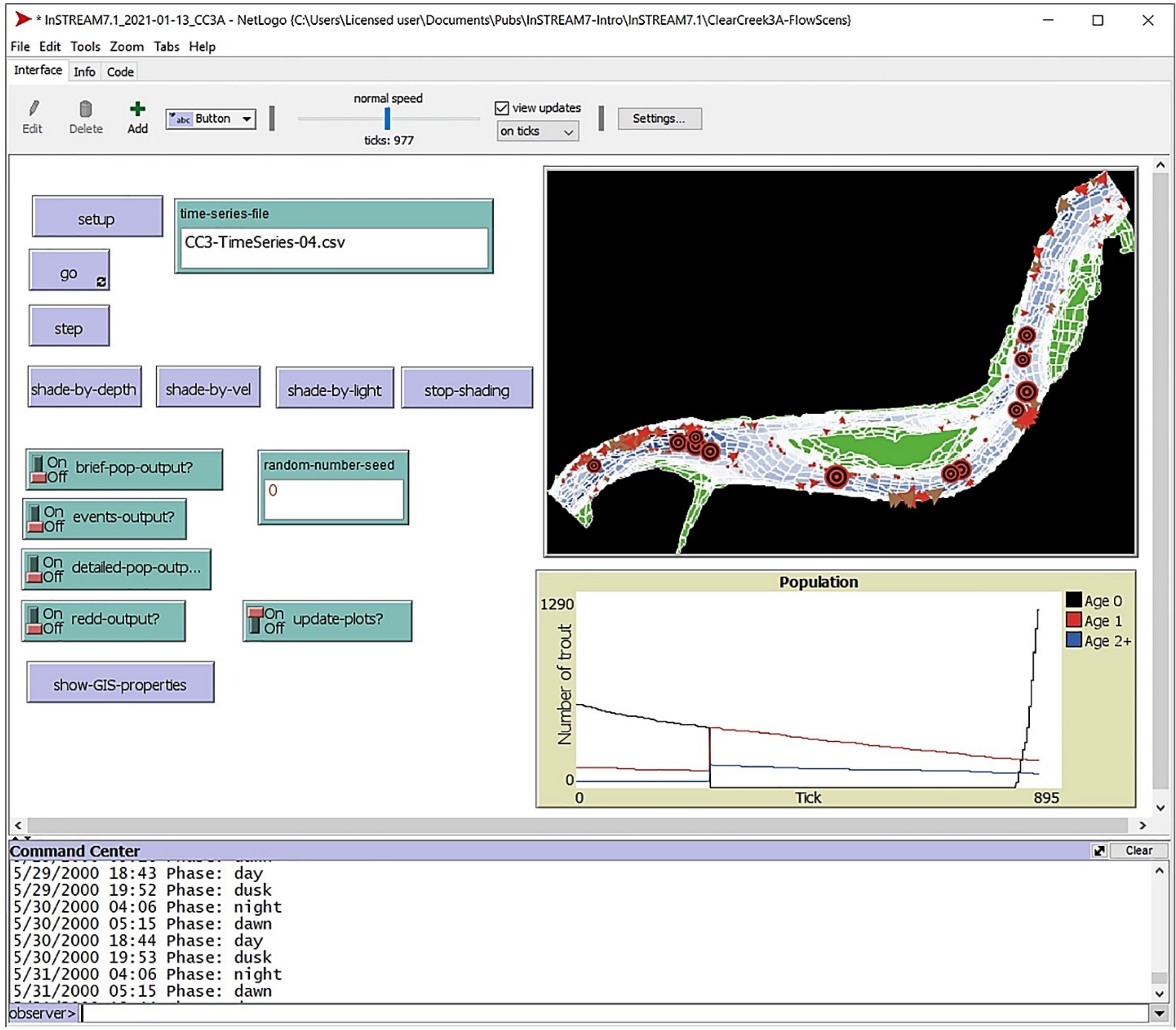


- Can use results with simpler habitat models and evaluate
  - Habitat areas for different flows
  - Down/Up-ramping effects on stranding
    - Dewatering areas
- Simplified in the behaviors of the fishes
  - Does not capture population growth and individual behavior



Individual Based Models - InSTREAM

- Habitat Cells - Geometry and River Characteristics
  - Velocity shelter
  - Hiding cover
  - Spawning gravels
- Hydraulic Input
  - Lookup table of flows and depth/velocity
  - Linear interpolation of different flows
  - Prevent unrealistic output by including a wide range of different flows
- Environment input
  - Time series of Temperature
  - Time series of Turbidity
  - Concentration of Drift Food
  - Initial fish population
- Fish behavior in each phase
  - Feeding, hiding, spawning
  - Includes territorial rules - Large fish chooses habitat cell first
- Long-term population growth
  - Redds development
  - Survival and population growth for different life-stages



Railsback, S. F., Ayllón, D., & Harvey, B. C. (2021). InSTREAM 7: Instream flow assessment and management model for stream trout. River Research and Applications, 37(9), 1294– 1302. https://doi.org/10.1002/rra.3845

First Case Study – Mattisudden

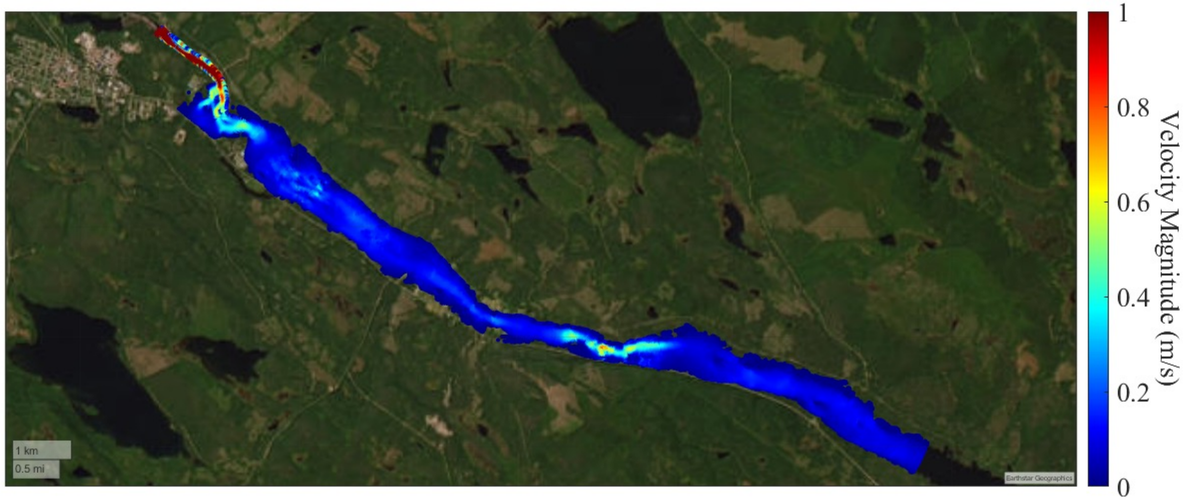
- Located between two hydropower stations
- **Grayling** targeted fish species for restoration measures
- Restore **connectivity** of a **tributary** to the main channel
  - Can **tributaries** make a difference for the **ecological system** of a regulated river?
  - Is it important to **include tributaries** in a digital twin and if so, how large must it be to be significant?

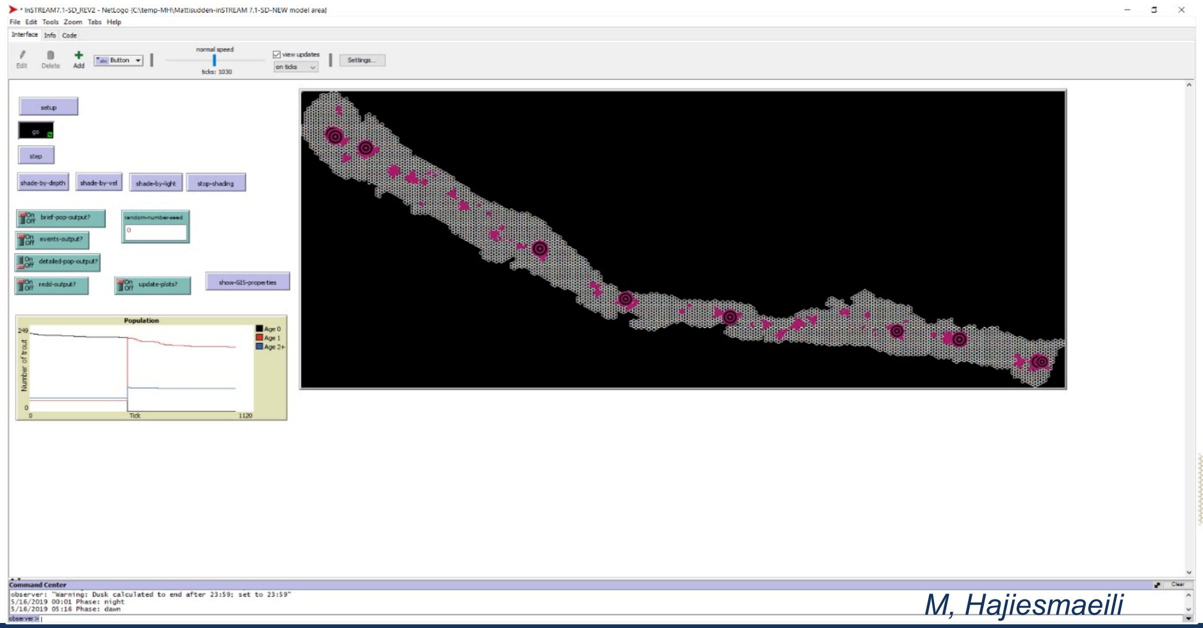
First Case Study – Ongoing work

- Hydraulic model & IBM over main reach

- This spring/summer measurements of tributary
  - Hydraulic Measurements
    - Water Level - Pressure loggers
    - Velocity measurements - ADCP or similar
  - Ecological Measurements – Field work by KAU
    - For InSTREAM model
      - Substrate
      - Habitat areas
      - Temperatures

- Connect tributary to current model and define flow cases and evaluate how well the digital twin respond to reality

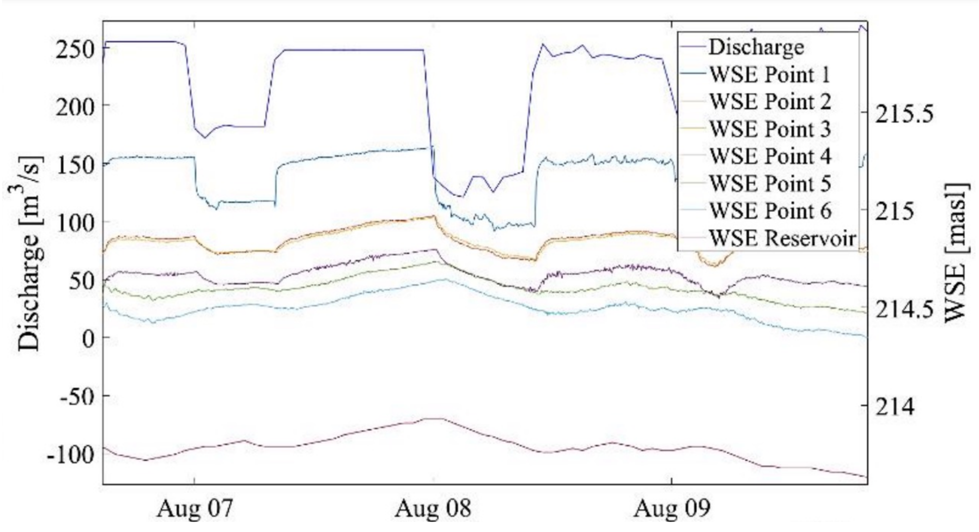




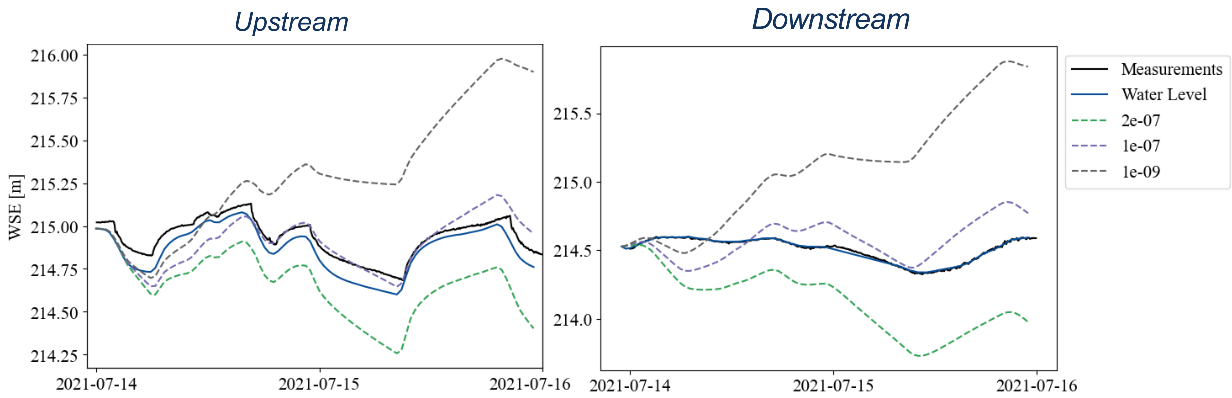
M, Hajiesmaeili

First Case Study - Challenges

- Downstream part of river dependent of the reservoir
  - **Same flow** have **different** water levels
  - InSTREAM Interpolates
  - How to capture the **dynamic behaviour** of the river in InSTREAM?
    - Lookup table → run simulations simultaneously
    - Hydrodynamic model timestep+1 > InSTREAM
    - Update flow with output from hydrodynamic model



- How to make a hydraulic model with a dependency downstream of a reservoir?
  - **Water Level –** Give accurate results, capture reservoir. Limited to flow cases measured
  - **Neumann Gradient –** Can evaluate new flow cases but does not capture reservoir..
    - Need a **reservoir dependent variable** that connects to the **gradient**

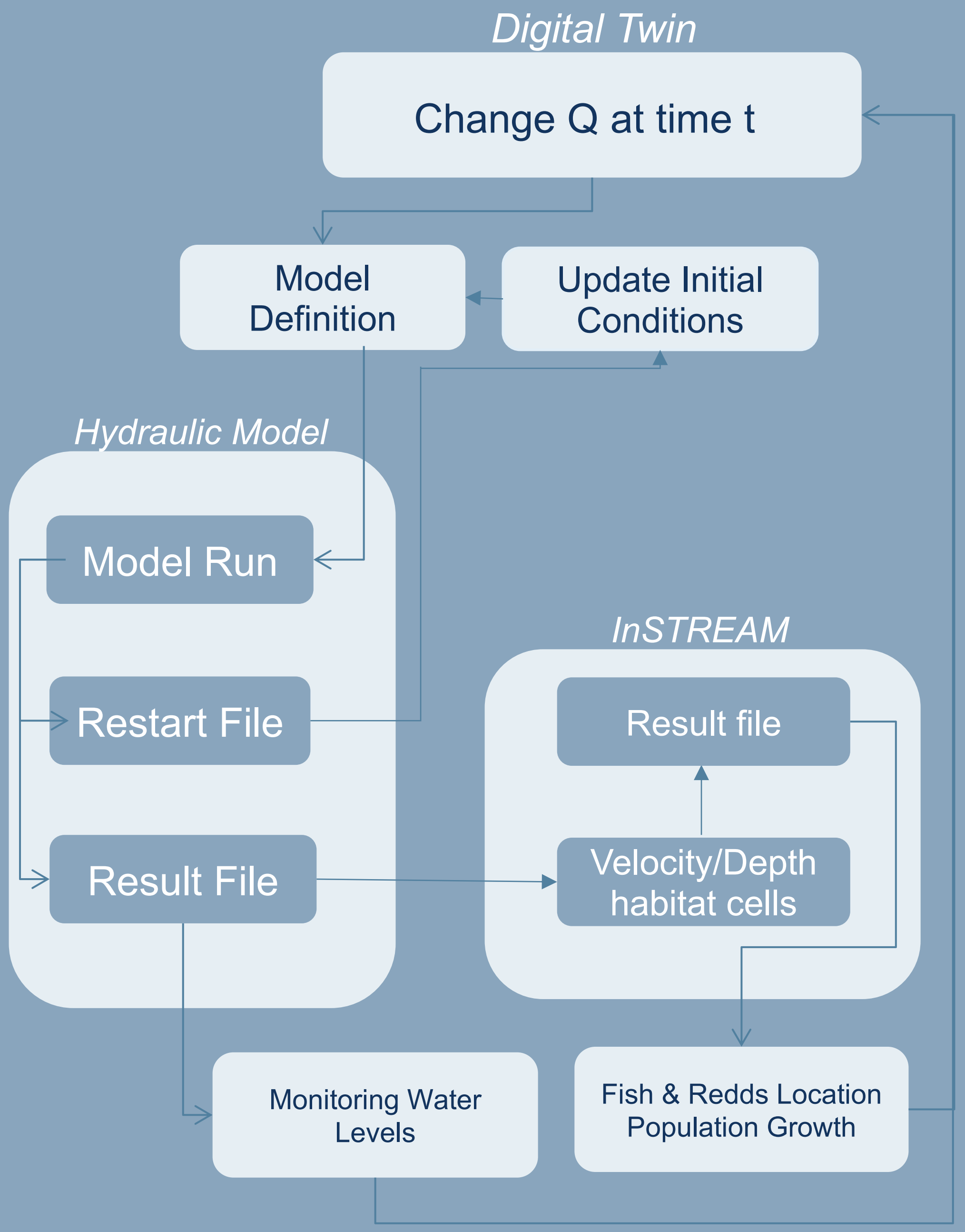


Second Case Study – Bredforsen

- Other **target species**
- Different **river morphology**
- Possible to do any **generalization** between the rivers?
- Define parameters to study for tool
  - Look more into **Real-Time Control**?
    - RTC relevant for management of river and get information real-time of areas in risk of dewatering during low flows
    - RTC not as relevant for restoration measures?

Conclusions

- Couple the hydraulic simulations with InSTREAM
  - Include dynamical behaviour – no linear integration
- What can we learn from **site specific** studies?
  - What is possible to generalize?
  - What **need** to be **included** in **a digital twin?**
- Create and **connect tributary** to main model
  - How **important** are **tributaries** for the ecological system of a regulated river?



LULEÅ
UNIVERSITY
OF TECHNOLOGY