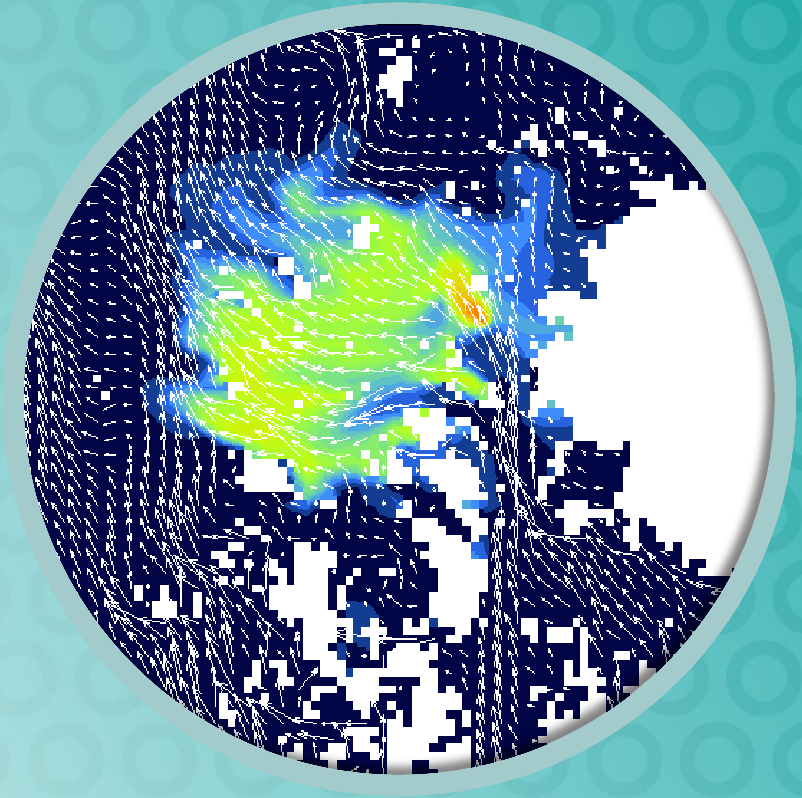
Hydrological models for assessing transport of (hazardous) substances



Janne Ropponen
Finnish Environment Institute SYKE
EnviTox webinar, 13.9.2021

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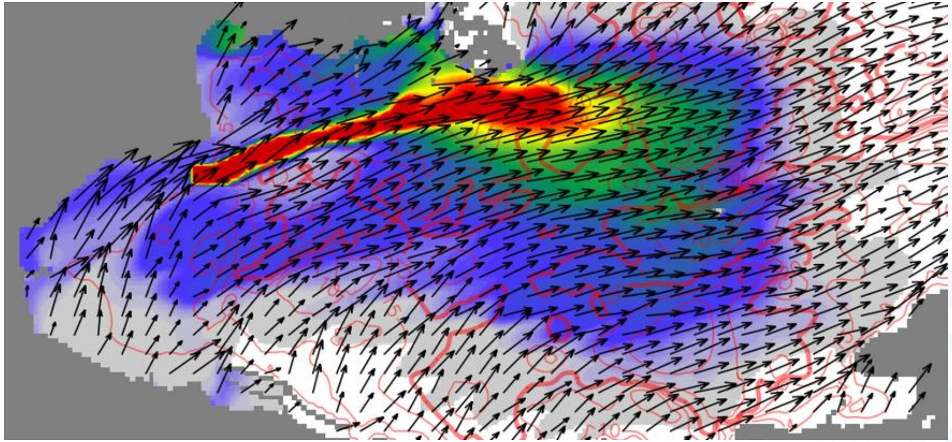

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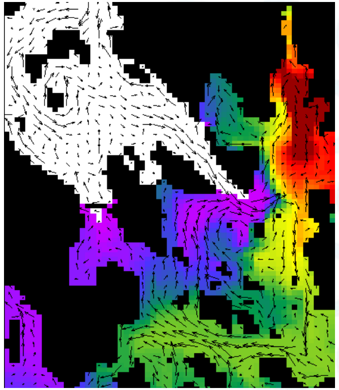
When is transport modelling (simulation) of hazardous substances needed?



- Downstream areas sensitive to pollution
  - E.g. bioaccumulation
- Transport behaviour in receiving waterbody is non-trivial
  - E.g. chain of streams and lakes
- Chemicals have a long life-time or complex decay chains
- Prediction of transport phenomena in different scenarios is required
- Accident
  - ”Operational” model needed – i.e. ready-made model automatically updated to predict at least the next few days
- **Transport of any substance can be simulated, provided that enough data about the behaviour of the substance is available**
  - Often this is the limiting factor: not enough is known about how the substance interacts in natural waters

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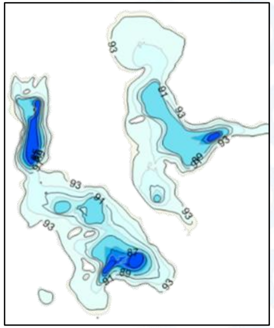
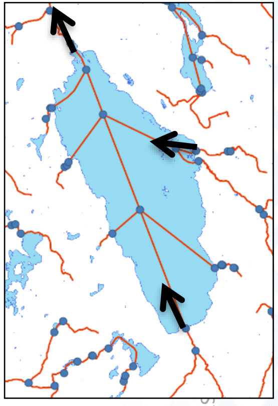
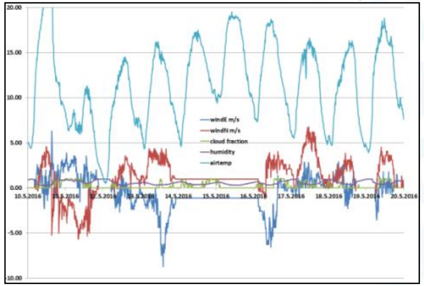
Data requirements for model building





- Data quality and resolution are crucial for successful modelling
- Requirements for hydrodynamics (physics)
  - Lake/river bathymetry (depths)
  - Inflows, outflows and/or water height
  - Weather (wind, rain, temperature, solar radiation)
- Requirements for modelled substance (biogeochemistry)
  - Sources and sinks
  - Decay rates
  - Buoyancy and similar physical charasteristics
  - Interactions (possible need to model other substances, too)
- Calibration & validation data (measurements)



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Structure of transport simulation

- Decay/evolution equations
- Chemical properties
- Biological properties

PROCESSES

- Substance release places, times and amounts
- Physical charasteristics
- Sinks
- Sediment storage

SUBSTANCE TRANSPORT

- Bathymetry
- Discharges
- Water height
- Weather
- Structures, etc.

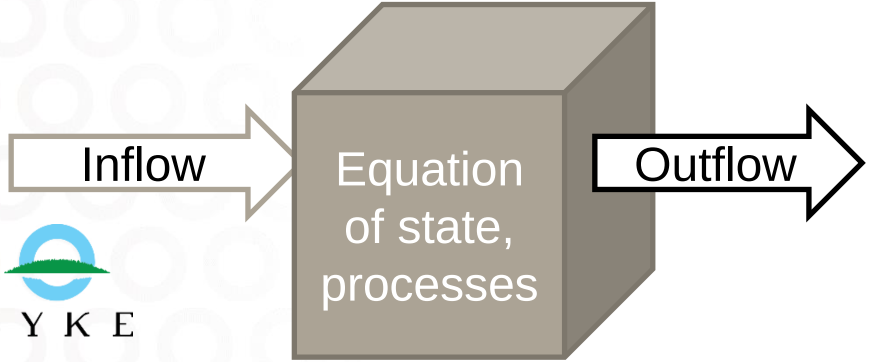
HYDRODYNAMIC MODEL
(water flow)

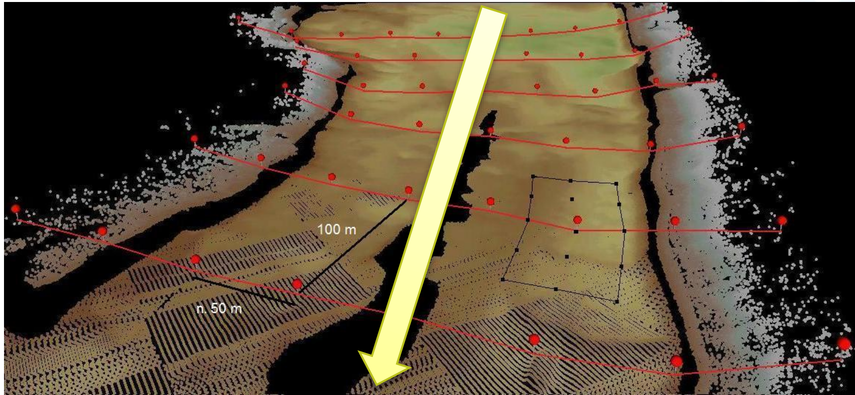
Types of transport models

Classification by calculation grid dimension

- 0-D
- Box model: fully mixed single volume
- Time evolution of concentration
- Suitable for large network of interconnected volumes
  - E.g. modelling a whole catchment system

- **1-D**
- E.g. river transport
- Division into slices where each slice is fully mixed





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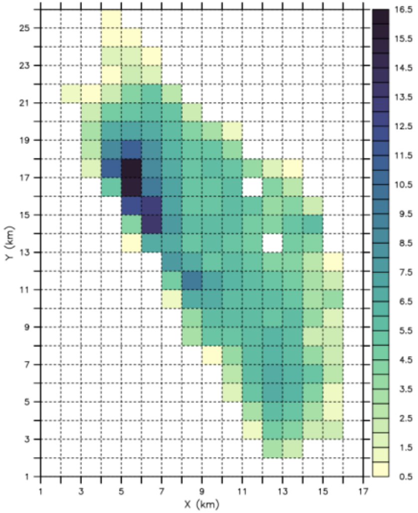
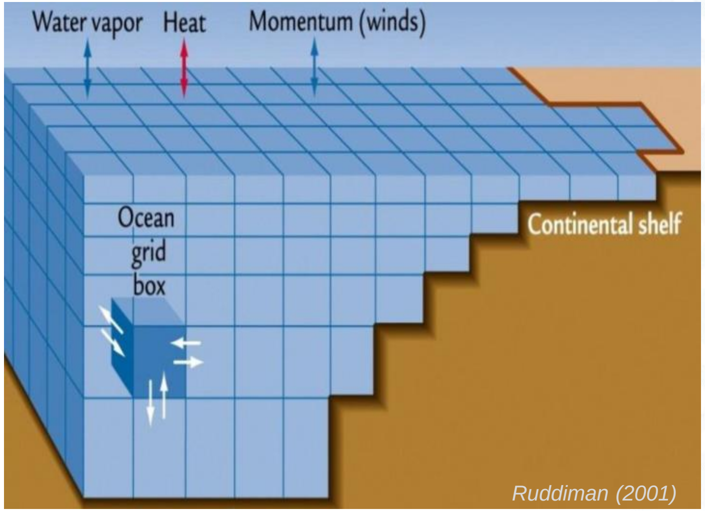
Types of transport models

Classification by calculation grid dimension

- 2-D
- E.g. lake transport
- Division into grid – structured or unstructured



- **3-D**
- Detailed transport with vertical mixing
- Division to grid in both horizontal and vertical direction



Which modelling type to choose?

- Simplest model is best!
  - Provided that it can answer the research question

- Sometimes a simple mass balance calculation that can be done by hand or in Excel is enough

- *Operational models* (as opposed to *research models*) need continuous resources to update and validate the model
    - I.e. fast prediction of what happens in the next few days

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Hydrological modelling at SYKE

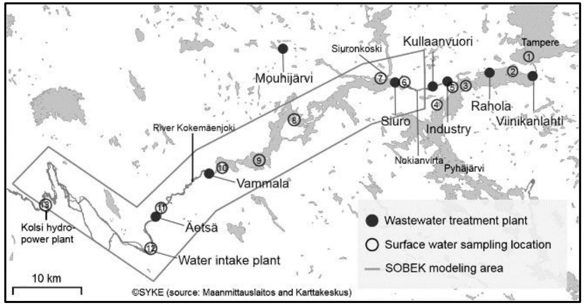
- Catchments
  - WSFS (Watershed Simulation and Forecasting System)
  - SWAT, INCA
- Groundwater
  - MODFLOW
- Lakes
  - MyLake (1-D)
  - COHERENS (3-D)
- Rivers
  - HEC-RAS
  - SOBEK

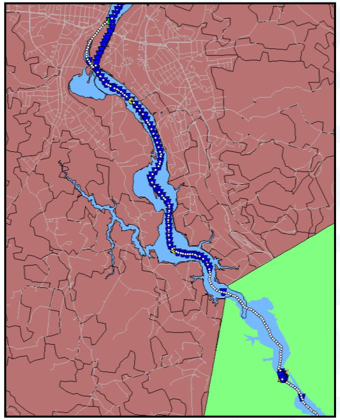
- Coast
  - FICOS (modelling system/chain)

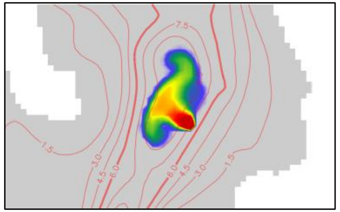
- Both commercial and free software are used
- Tool is chosen to address the research question at hand
- In-house development of code when necessary

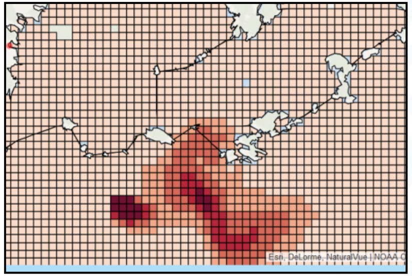
Case examples

- Vuoksi (river)
- CONPAT-project (lake+river+health)
- Keurusselkä (high resolution lake)
- FICOS (coastal combined model chain)









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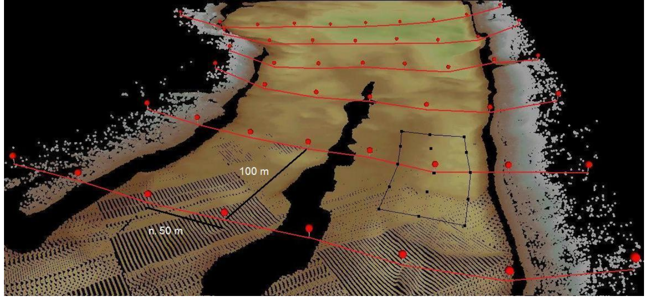
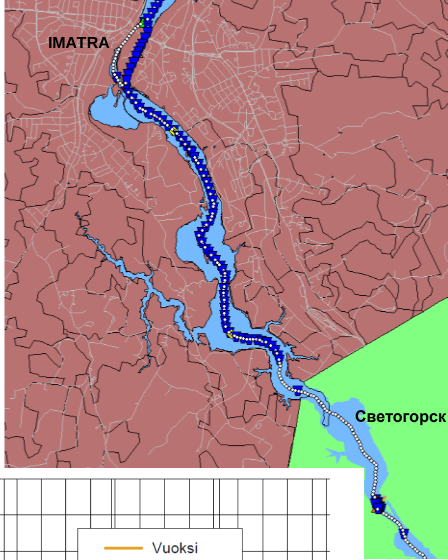
River Vuoksi





- Transport of wastewater effluent and enterecocci
- Simulations conducted for Finnish-Russian transboundary water commission
- 1-D river model (SOBEK)
- Results are enterecocci concentrations at different places in River Vuoksi

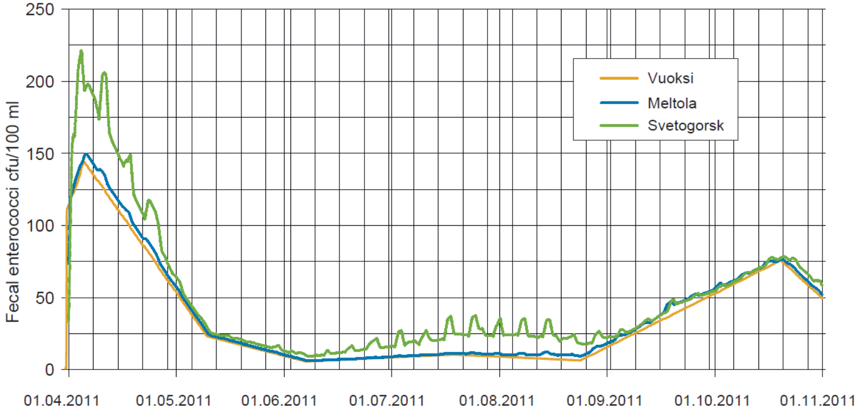
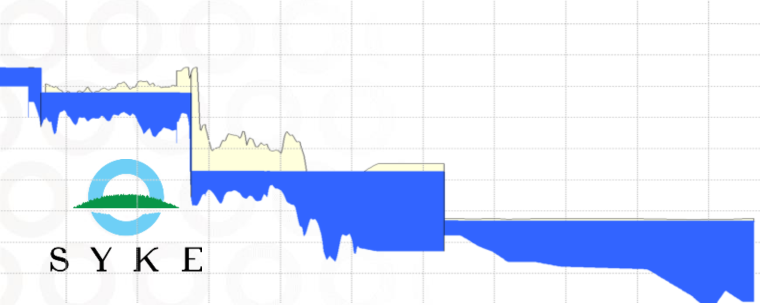


Figure 13. Amount of fecal enterococci in River Vuoksi in scenario 2a (calculated with zero mortality of the bacteria).

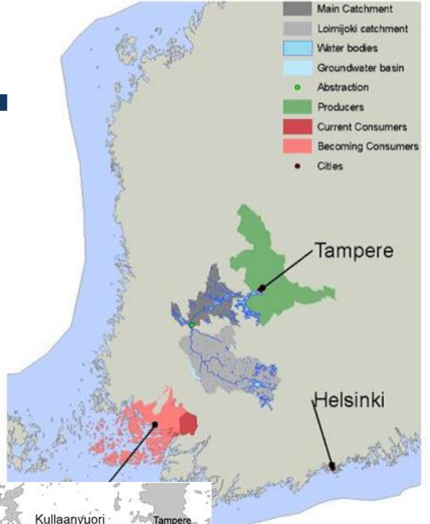


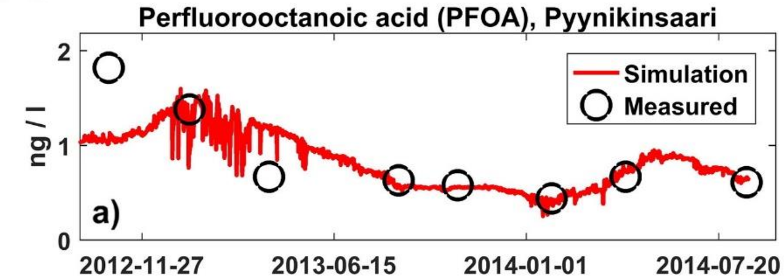
Publication

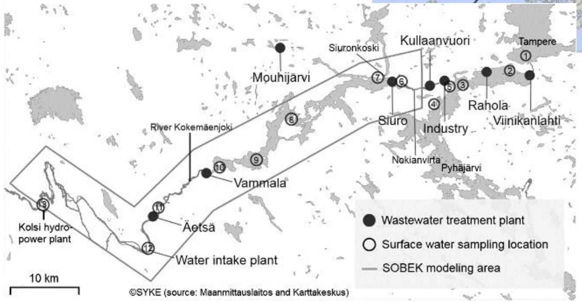
Ropponen, J., Arola, H., Kiuru, P., Huttula, T. 2013. **Nutrient and bacterial load transport in the River Vuoksi. Model based estimation of aquatic effects from present and planned wastewater treatment plants.** *Reports of the Finnish Environment Institute 36/2013*. http://hdl.handle.net/10138/42300

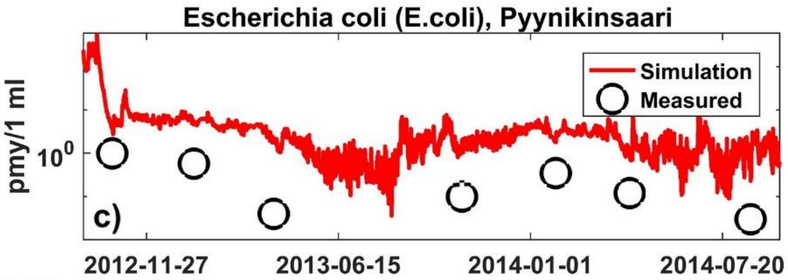
River Kokemäenjoki

- PFOA & E.coli transport in rivers (1-D) and lakes (3-D), combined to health and economic models









Publications

M. Happonen, H. Koivusalo, O. Malve, N. Perkola, J. Juntunen, T. Huttula. **Contamination risk of raw drinking water caused by PFOA sources along a river reach in south-western Finland.** Sci. Total Environ., 541 (15) (2016), pp. 74-82

J. Juntunen, P. Meriläinen, A. Simola. **Public health and economic risk assessment of waterborne contaminants and pathogens in Finland.** Sci. Total Environ., 599 (2017), pp. 873-882

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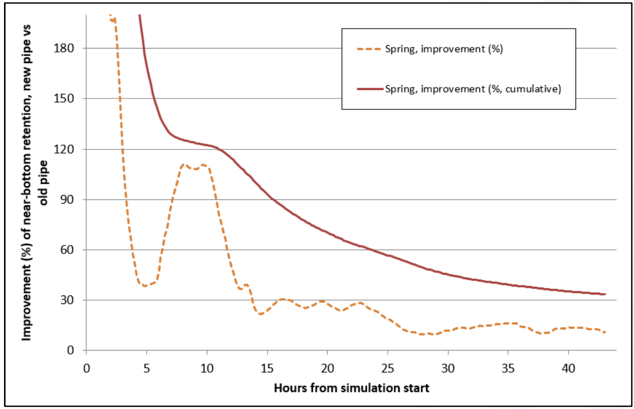
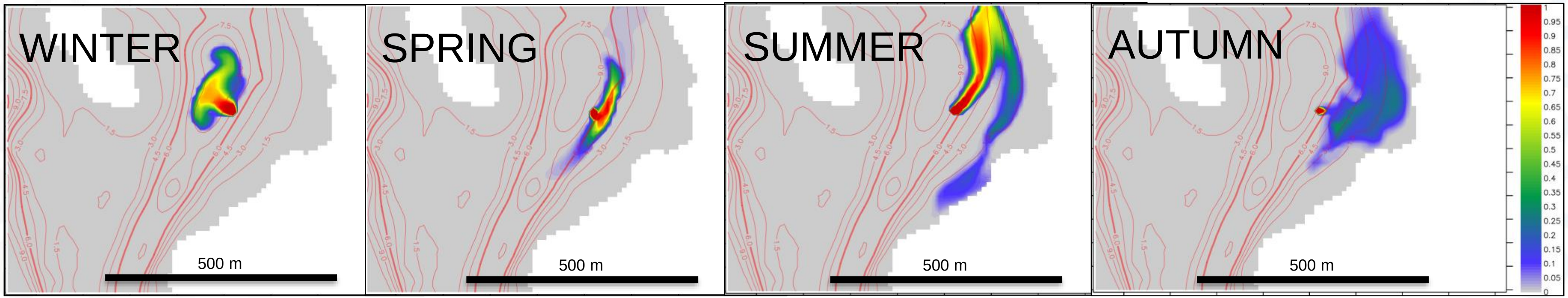
Keurusselkä – Project N-SINK

Study of nitrogen reduction in lake sediment surface

- High resolution (10 m) 3-D simulation of waste water effluent
- Study of contact time between effluent and sediment which affects the efficiency of natural nitrogen reduction
- Full year simulation with ice during winter



Bottom effluent concentration 4 hours after effluent release start



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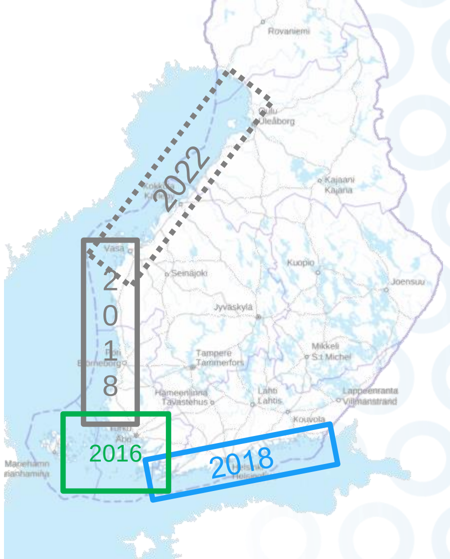
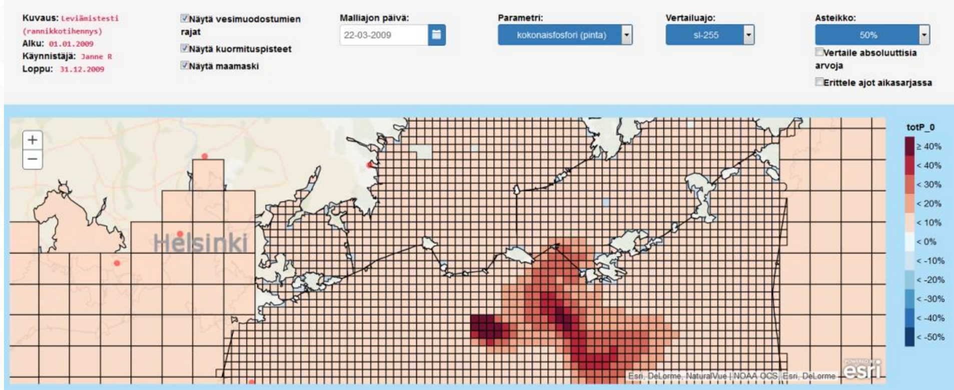
Publication

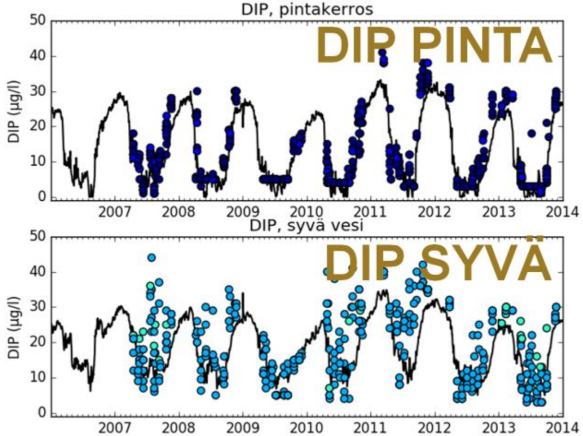
Aalto, S. L., Saarenheimo, J., Ropponen, J., Juntunen, J., Rissanen, A. J., Tiirola, M. 2018. **Sediment diffusion method improves wastewater nitrogen removal in the receiving lake sediments.** *Water Research* 138: 312-322. https://doi.org/10.1016/j.watres.2018.03.068

Coastal modelling system (FICOS)

- Hydrodynamic transport and water quality (nutrients, phytoplankton) system covering the Finnish coast
- Non-operational model, i.e. relies on historic data
- Used to study transport and effects of nutrients to sea areas
- Can be adapted to transport hazardous substances
- Combines many different models into a single system



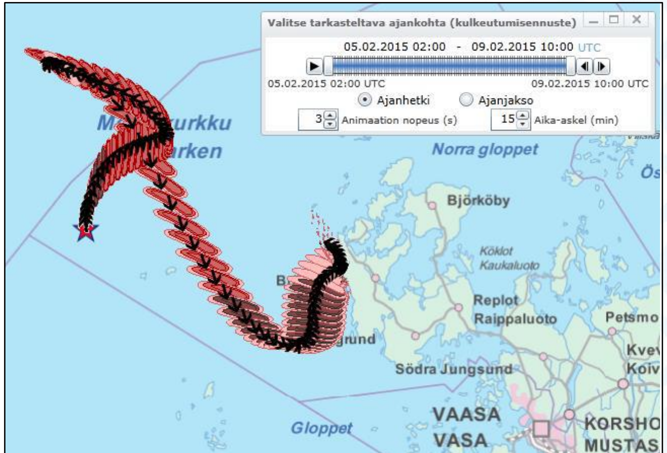




Summary

- Hazardous substance transport can be tracked in all kinds of natural waters by selecting a suitable model.
- Data of tracked substance properties is required for successful simulation
- Model chains are frequently used to assess complex transport from land to sea.

- Most models are built for specific studies (aka *research models*) – *operational models* are resource heavy, require constant updating and are available only for the riskiest cases, e.g. oil spills for the Baltic Sea (*SeaTrackWeb*).



Jolma et al, 2018. YM raportteja 24/2018.

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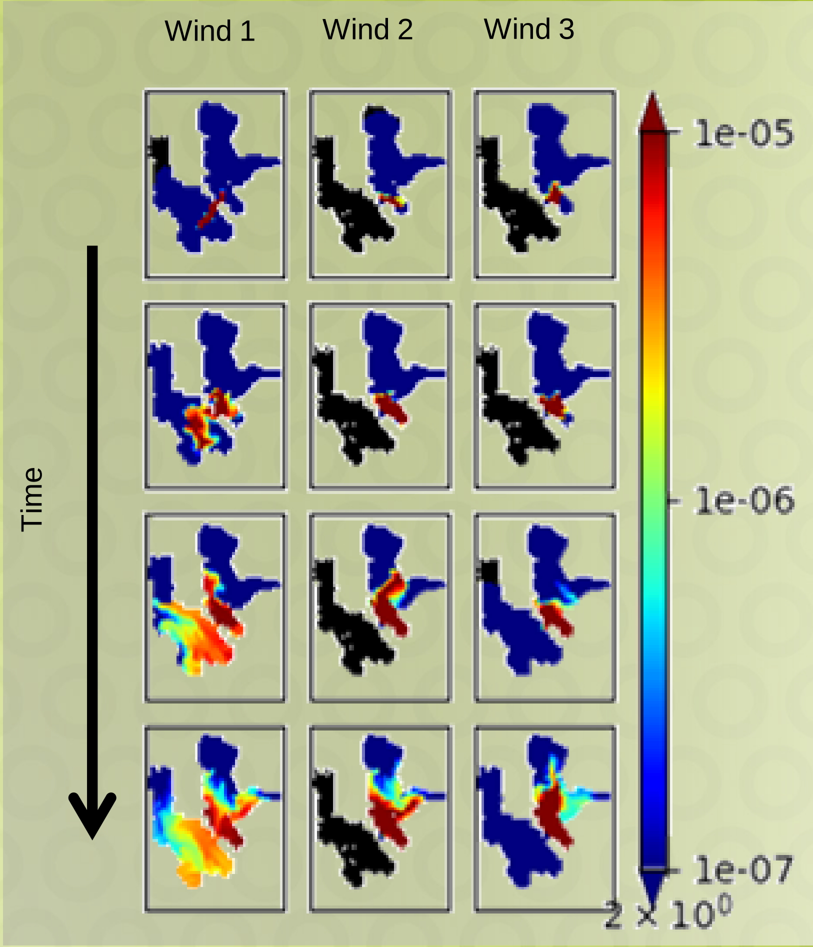
Thank you!



Publication

Juntunen, J. et al. 2019. **The effect of local wind field on water circulation and dispersion of imaginary tracers in two small connected lakes**. Journal of Hydrology, Volume 579. https://doi.org/10.1016/j.jhydrol.2019.124137

SYKE