Modeling in aquatic environment

Lecture 1

Introduction

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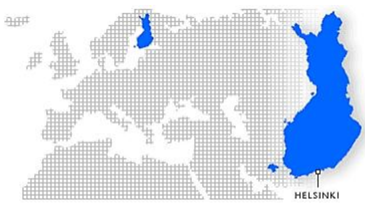
www.syke.fi/jyvaskyla

http://www.jyvaskyla.fi/international

Finland



- Total area: 338,144 km² square km 's, of which 10% is water and 69% forest; Europe's largest archipelago, including the semi-autonomous province of Åland.
- Distances: 1,160 km north to south, 540 km west to east Finland's land border with Russia (1,269 km) is the eastern border of the European Union.
- Climate: marked by cold winters and fairly warm summers. Temperatures of -20 Celsius are not uncommon in many areas. Finnish Lapland invariably has the lowest winter temperatures
- Population: 5.4 million, 71% live in towns or urban areas, 29% in rural areas
- GNP: In 2007, Finland's GNP per capita was 34,003 euros

Present weather in Finland

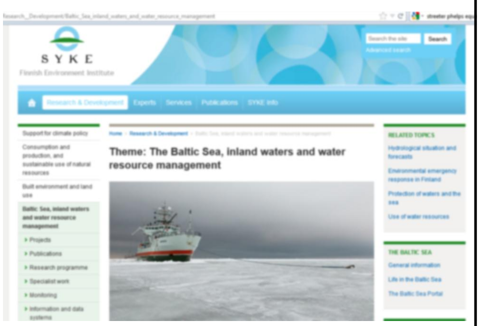
- Helsinki harbour: https://finland.fi/facts-stats-and-info/webcam/
- Lake Jyväsjärvi, Middle Finland: http://www.paijanne.org/pages/en/main.php
- Helsinki weather: http://en.ilmatieteenlaitos.fi/local-weather

SYKE?

- One of 18 state research institutes
- In www

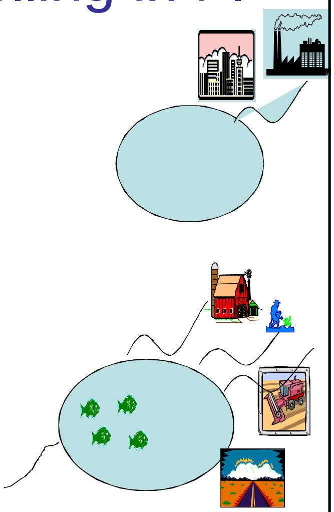
  www.syke.fi and www.environment.fi

- University of Jyvaskyla
  www.jyu.fi



Start of aquatic modelling in F.

- New legislation in late 1960's forced point loaders (like industry and municipalities) to apply permission to lead purified waste waters to recipient waters (lakes, rivers, coastal areas etc..) from the Water Courts and
- During the Assessment Procedure ("Katselmustoimitus") the effects on the water quality was assessed and also the compensations were ordered
- Models were applied for
  - Determining the optimal loads
  - Determining the effected geographical areas
  - Determining the optimal locations for water outlets
- Model applications from 1970's by Virtanen, Koponen and Sarkkula

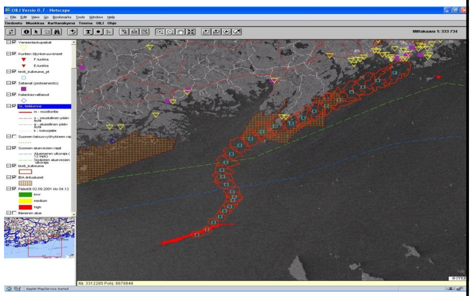


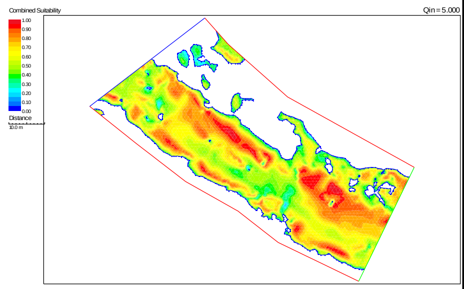
Later needs for modelling

- Problems with eutrophication and related diffuse loads increased the need of WQ assessment and modelling
- Effects of global change need to be assessed
- European wide approach: Water Framework Directive ('A *directive is a legal act of the European Union*, which requires member states to achieve a particular result without dictating the means of achieving that result.')
- Fate and transport of harmful substances (heavy metals, organic compounds etc..) is to be predicted since many recipient waters are also used for water supply
- Hydrological (water resources) modelling was fist needed for optimal water level regulation (=adjustment) of our large lakes. Modelling started in early 1980's by Vehviläinen

Presently many new needs

- Oil spill models
  - Operative models for oil combatting on sea
- Habitat modelling for river restoration (collaboration with Okayama University/Oda&Koljonen)
- Socio-economical modelling
  - See CONPAT-project: http://en.opasnet.org/w/CONPAT





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Models are useful…

- To better understand a complex phenomena or a problem
  - To develop ”cause and effect” relationship
  - To determine how different complex processes are interlinked
- Economy
  - the model is easier to manipulate than real systems
  - cost effective
- To identify optimal solutions
- To simulate and forecast future events
  - impact of pollution release/reduction scenarios on water quality (hydrology, concentrations,ecology)
  - impact of climate change and variablity
  - impact of land use (cultivation, roads, forests etc)
  - who is responsible (effect of a polluter, source apportionment

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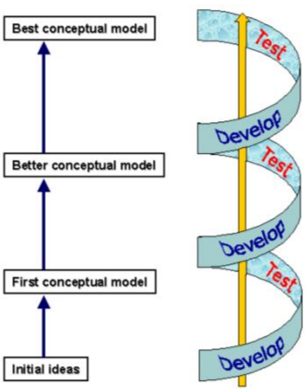
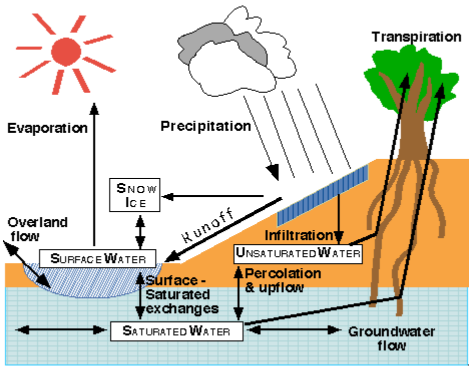
Terminology

- Conceptual model
- Mathematical models
  - process based
  - data driven approaches
- White box and black box models
- Spatial and temporal variation and scales
- Dimensions 1-D, 2-D, 3-D
- Ecological model
- Hydraulic scale model
- Analytical and numerical models

Conceptual models

- Conceptual models are simplified but most accurate concept of the real process
- They are often developping in time….





http://www.uvm.edu/giee/AV/EDU/ONLINE/M_Hydro/

Mathematical models

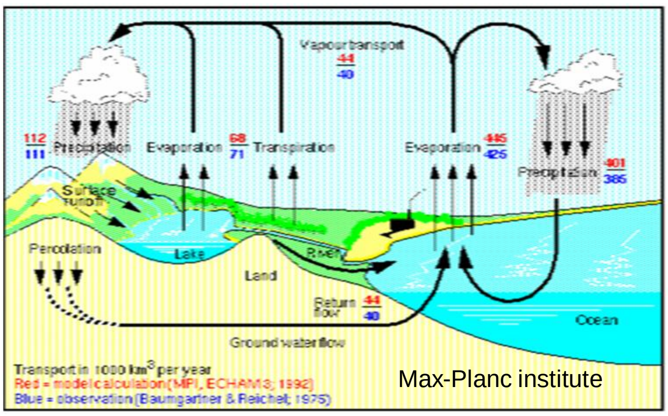
- A **mathematical model** uses mathematical language to describe a system. They are used in sciences.
- Eykhoff (1974) defined a *mathematical model* as 'a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in usable form'.
- Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, or game theoretic models. These and other types of models can overlap, with a given model involving a variety of abstract structures.

Water balance model (continuity equation):
a simple and good mathematical model

$$P = ET + dS + R$$

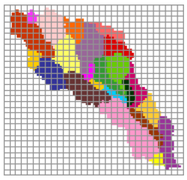
For example for oceans:
$P = ET + R + dS$

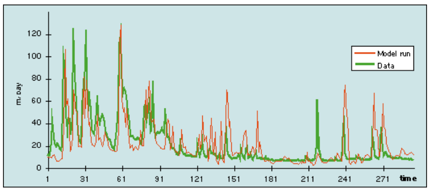
P=precipitation
R=runoff
ET=evapotranspiratio
n
dS = change in water storage; like water in ice, snow. In short term: water soil, ground, reservoirs and lakes



Spatial and temporal variation and modelling

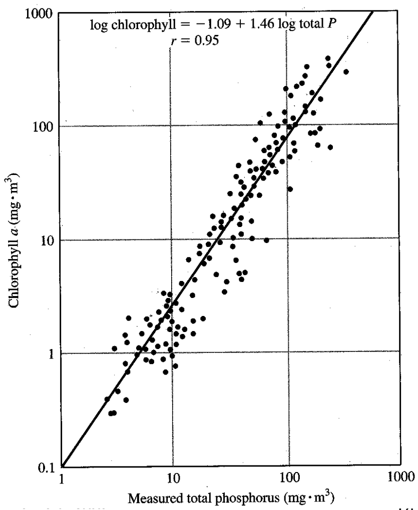
- Uses spatially distributed information and data
- Spatial analysis and GIS
- Example on spatial hydrological catchment model:
  - PLM_Integrated Modeling.ppt





Empirical models

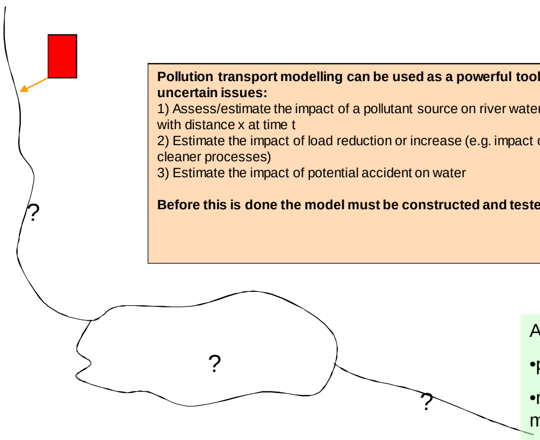
- Based on empirical experiments (e.g. data and mesurements from many lakes)
- Regression equations
- Data driven models



Time series models

- River flow series usually exhibit periodical stationarity; that is, their mean and covariance functions are periodic with respect to time.
- A class of models useful in such situations consists of periodic autoregressive moving average (PARMA) models. Allow parameters to depend on season
- The are extensions of commonly used ARMA models.
- Also in modelling river swimming water quality or river hygienic state (E.Coli)

Water quality modelling



Pollution transport modelling can be used as a powerful tool to solve many uncertain issues:
1) Assess/estimate the impact of a pollutant source on river water concentrations with distance x at time t
2) Estimate the impact of load reduction or increase (e.g. impact of new and cleaner processes)
3) Estimate the impact of potential accident on water

Before this is done the model must be constructed and tested carefully!

Alternative methods of solution:

•previous experience

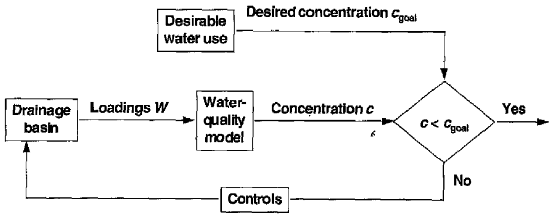
•measurements and data analysis (empirical models)

These are subjective, costly and not efficient

Water quality management

Steps in water quality management with models:

- Set the desired water use (volume) and concentration of harmful substance (excess nutrient, suspended solids, toxic compounds etc.)
- Evaluate pollution control methods and measures
- Assess the load from the catchment (drainage basin)
- Simulate the change in concentration by using the model



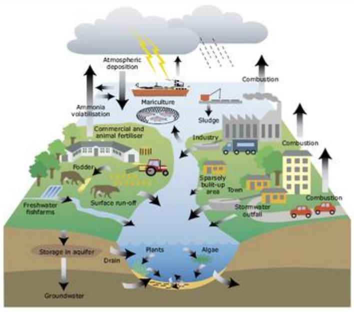
http://water.usgs.gov/owq/WQimages/image_library.htm

Point pollution

Sources and processes

- In water quality modelling the sources and processes are described with transport equations and reactions
- Different sources can be summarized as one or several sources

Figure 2.1 Overview of the aquatic nitrogen cycle and sources of pollution with nitrogen



Lake water quality modelling: Completely stirred systems (CSTR)

- Inflows of pollutants must be known or estimated
- Processes (biological, chemical and physical) of pollutants in the lake must be known or estimated
  - pollutant decay and reduction
  - pollutant transformation
  - pollutant release from sediments

Lake mass balance

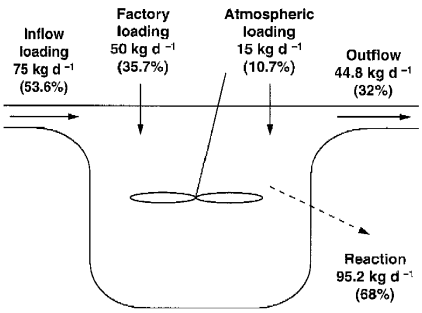
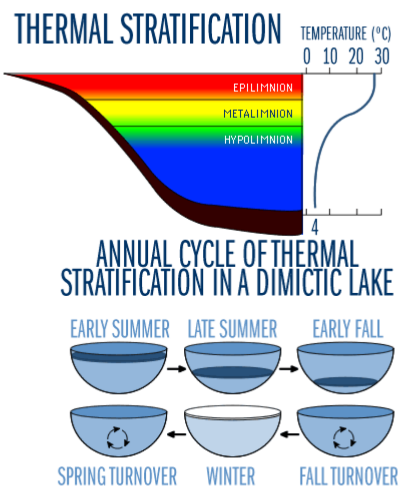


FIGURE 3.3
A mass balance for the well-mixed lake from Example 3.1. The arrows represent the major sources and sinks of the pollutant. The mass-transfer rates have also been included along with the percent of total mass inflow accounted for by each term.

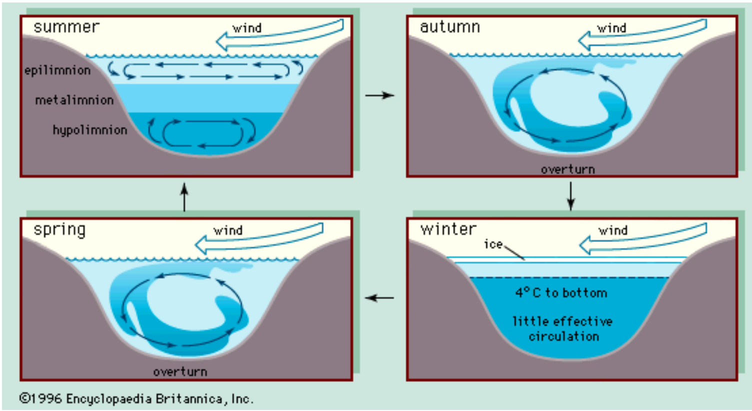
Lake Stratification and Mixing

- Due to the changes in density with temperature, lakes generally stratify in summer with warmer, lighter water overlaying colder, heavier water
- This creates a stable layering of water which can last well into the fall
- As temperatures drop in the fall, the surface water cools and gradually reaches the temperature of the bottom water
- When this occurs, we have "turnover" in which water mixes throughout all lake depths



*perec.cos.gmu.edu/Educational%20Activities/Part3%20-%20**Lake**%20Ecology.ppt -*

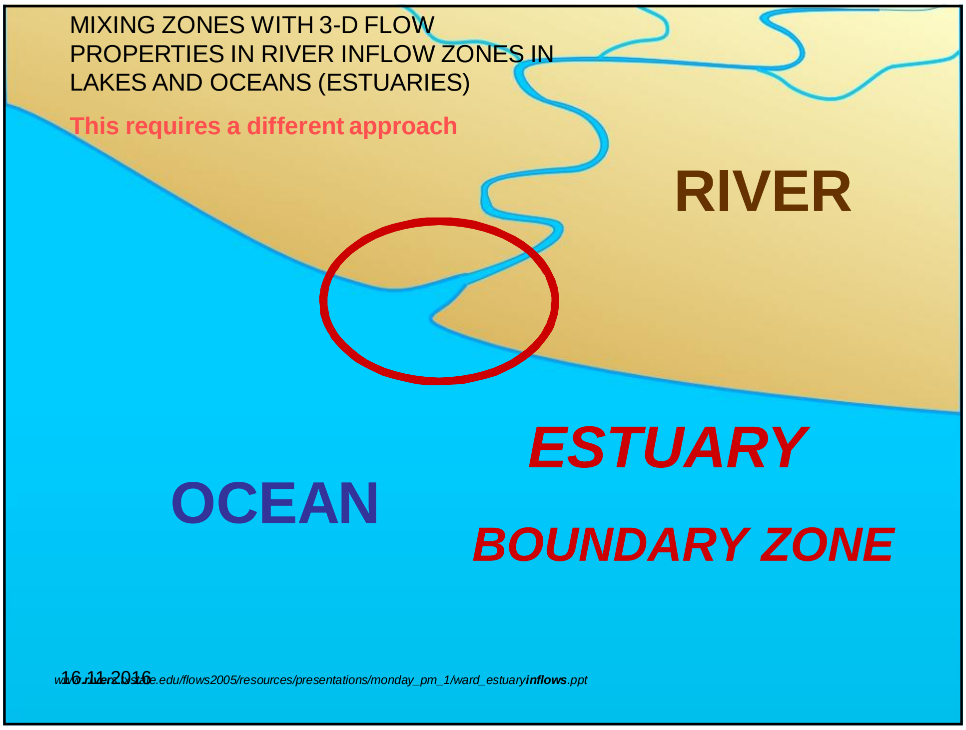
Dimictic Lakes – Annual Cycle



*perec.cos.gmu.edu/Educational%20Activities/Part3%20-%20**Lake**%20Ecology.ppt -*

MIXING ZONES WITH 3-D FLOW PROPERTIES IN RIVER INFLOW ZONES IN LAKES AND OCEANS (ESTUARIES)

This requires a different approach



*www.**rivers**.txstate.edu/flows2005/resources/presentations/monday_pm_1/ward_estuary**inflows**.ppt*

Estuaries

http://en.wikipedia.org/wiki/Image:Rio_de_la_Plata_BA_2.JPG

Lake inflow

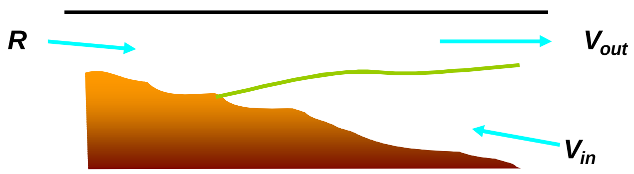
http://maps.google.fi/maps?f=q&hl=fi&geocode=&q=reuss+Lake+Lucerne,+Switzerland&ie=UTF8&ll=46.896097,8.616629&spn=0.010601,0.027809&t=h&z=16

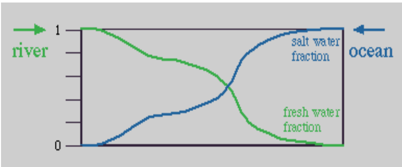
Reuss River plunging into Lake Lucerne, Switzerland: flood of summer, 2005, Image M.

Jaeggi*vtchl.uiuc.edu/people/parkerg/_private/CourseNotes/TurbCurrJapan08/Lect_5-ConceptsFrom**River**s.ppt*

Flushing times by salt water inflow from tides (Finnish *vuorovesi*)

Time required to replace the Volume of the basin V by the Volume Influx V_{in}





http://oceanografia.cicese.mx/cursos/sco/figures/fig16a1.html

Knudsen's Relations

Water Budget: $V_{out} = V_{in} + R$

Salt Budget: $V_{out}\, S_{out} = V_{in}\, S_{in}$

$$t = V \,/\, V_{in}$$

t is obtained in seconds [m^3 / m^3/s]

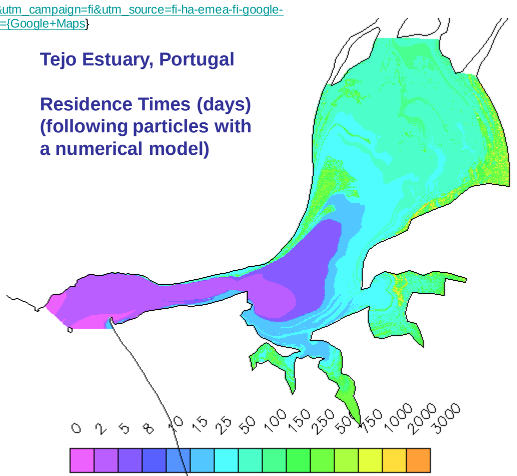
Examples from Estuaries/lagoons

The Lissaboan estuary after river Tejo see google map

http://maps.google.fi/maps?f=d&utm_campaign=fi&utm_source=fi-ha-emea-fi-google-dd&utm_medium=ha&utm_term={Google+Maps}

Tejo Estuary, Portugal

Residence Times (days) (following particles with a numerical model)



Anabela Pacheco de Oliveira

The modelling process: (the art of modelling)

- Define the objective and basic questions to be answered
- Define a conceptual model, and always revise it!
- Model selection: select the simplest model that capture the complexity of your system
  - understand the flow process and hydraulics; insert process representation; be aware of what the model can do and not do
- Build up your model
  - identification, estimation, calibration, validation
- Find relevant process parameters from the literature (e.g. using databases such as www or Elseviers "science direct")
- Use databases and existing data (such as national ('Hertta' by SYKE in Finland) database for hydrological and water quality data)
- Uncertainty analysis
  - confidence intervals, R^2, sensitivity analysis etc.

Experiments and observations

- Water inflow and outflow estimation
- Lake observation sites for circulation
  - Near the shores of the main basin
  - At the 'bottle necks'
  - Use a primary flow model for planning field measurements (if possible)
- Lake observation sites for WQ
  - Deepest site
  - Along a gradient from the loading source onwards
- Transformation processes