The Fraunhofer-Gesellschaft in Germany

- 59 Institutes
- 17,000 employees

The Fraunhofer-Gesellschaft undertakes applied research of direct utility to private and public enterprise and of wide benefit to society.

Our Customers:
- Industry
- Service sector
- Public administration
Locations of Fraunhofer IOSB

Director Site Karlsruhe
Prof. Dr.-Ing.
Jürgen Beyerer
(executive)

Director Site Ettlingen
Prof. Dr.
Maurus Tacke

Operational Costs in 2010 37,5 Mio €
Permanent employees 377
of which scientists and eng. 282
Additional student aides 130

The IOSB is connected to Karlsruhe Institute of Technology KIT
Department of Computer Sciences, Institute for Anthropomatics, Vision and Fusion Laboratory

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Core Competencies of IOSB

**Optronics:**
Electrical and optical components plus methods for signal and image processing in range from ultraviolet to thermal infrared

**System Technologies:**
Analysis, comprehension, modeling, development and control of complex systems

**Image Exploitation:**
Treatment, real-time processing, automatic and interactive information extraction from images and videos
Business Segments of IOSB

- Automation
- Energy, Environment
- Visual Inspection
- Defense
- Civil Safety & Security
1. Core competence

- **Control Systems:**
  - Model and knowledge based control methods
  - Multi-modal discrete-continuous control concepts

- **Simulation Systems:**
  - Block-oriented process modeling (SIMULINK)
  - 6D-Mechanical-Models (e.g. ADAMS/Controls)
  - Finite-Elemente-Models (FEMLAB, FEFLOW)

- **Sensor Technology:**
  - Opto-electronic sensorics
  - Image-Processing Sensorics
  - Micro-wave Sensorics

- **Diagnosis Systems:**
  - Online diagnosis methods
  - Neuro-fuzzy diagnosis tools
  - Multi-sensor fusion
  - Fieldbus diagnosis
Modelling, dynamic Simulation and Optimization of Environmental Systems

Contents

1  Groundwater Resources Management
2  Modelling of Groundwater Transport Processes
3  Modelling of Algea Growth
4  Model based Landslide Warning Systems
5  Optimization of a biological Processes
1 Groundwater Resources Management
2 Modelling of Groundwater Transport Processes
3 Modelling of Algea Growth
4 Model based Landslide Warning Systems
5 Optimization of a biological Processes
1 Groundwater Resources Management
Topographical information of the modeling area:

- Area of Municipality Beijing: 6300 km²
- Modeling Area:
Water Resources Management in Beijing

Problem

Increasing water use
- Economical prosperity
- Increase of population
- Agriculture
- Several 'dry' years

Solution Concept

Optimization of water supply systems by means of a model based Decision support system (DSS)

Project Partners (2005 - 2009)

- Fraunhofer IOSB+AST
- GMFmbH
- Beijing Water Authority
- Tsinghua University
Structure of model based decision support system

Control room

Changed Variables

Hydrological system

Measurements

Decision support

- Scenario Definition
  → Multicriteria Optimization for scenarios

Models

- Surface water
- Groundwater

Vorschlag einer optimalen Strategie

Simulation of changed input data

Changed Variables

State
Groundwater modeling

- **Groundwater model**
  
  - Slow groundwater flow (diffusions equation)
    
    $$ S_0 \frac{\partial h}{\partial t} - \nabla \cdot (k_f \nabla h) = GWR - EXPL $$

  - Independent Variable $h$ (hydraulische Höhe)
  
  - Porous medium: hydraulic conductivity $k_f$, Storage coefficient $S_0$

- $GWR = f(x,y,z,t)$ : groundwater recharge (sources)
- $EXPL = f(x,y,z,t)$ : exploitation (sinks)

- **Numerical solution of the Initial boundary value problem**
  
  - Complexes 3D finite element-model (~ 150.000 elements, ~90.000 nodes)
  
  - Dirichlet- and well boundary conditions
  
  - Groundwater surface at time $t_0$ $\rightarrow$ Initial condition
Groundwater modeling

- Generation of time dependent input data
  - GW-recharge is hard to measure
  - Exploitation of well fields is measurable, but agricultural exploitation are unknown
    → Model-based estimation of $GWR(x,y,t)$ and $EXPL(x,y,t)$

- Procedure:
  - Constituting a regional water balance
  - Derivation of regionalised input data by means of map: landuse, precipitation, water demand, lithology etc.
  - Temporal diskretisation: statistic distribution of precipitation and of agricultural water demand
Validation of Groundwater Model

- Validation of groundwater model
  - Groundwater surface for 1996-2000
  - Yearly simulation with adapted input data

- Comparison of simulation and measurements after 4 years
  - Sufficient match within model area \(\rightarrow\) depression zone
  - Deviations especially at the boundaries
Coupling of surface and groundwater models

Well field (input 2)

Well field (input 3)

Groundwater Model

Input Node

Demand Node

Simple junction

Reservoir Node

Demand Node (ecology)

Observation well

Artificial Transport Path

River
Reduction of the finite element model to a linear state space model by identification runs

Physical system (groundwater flux)

partielle differential equation (PDE)

⇒ Mathematical modeling

ordinary differential equation (ODE)

(n~100,000)

⇒ High computing time
⇒ not practicable

Model Reduction

Reduction the amount of dofs to (n~50)

⇒ Reduction of the finite element model to a linear state space model by identification runs
Reduction of groundwater model

Trajectory- and identifications-based groundwater model reduction

For optimisation: reduce FEM model (~100,000 nodes) to state-space model (~20 states)

- The spatial information is already stored in a presimulated reference-szenario $(u_{ref}, y_{ref})$

\[
\begin{align*}
\text{Ansatz:} & \quad u(t) = u_{ref}(t) + u(t), \quad y(t) = y_{ref}(t) + y(t) \\
\rightarrow & \quad \text{only small deviations \((u, y)\) w.r.t. reference model have to be modelled!}
\end{align*}
\]

Identification state space model by means of step functions applied to the finite element model

\[
\begin{align*}
\dot{x} &= Ax + Bu \\
y &= Cx + Du
\end{align*}
\]
Reduction of groundwater model

Definition of Input-/Output Variables

Input $u$
- Exploitation in counties ($u_1-u_9$)
- Exploitation in well fields ($u_{10}-u_{13}$)
- Groundwater recharge ($u_{14}$)

Output $y$
- Hydraulic head of 12 representative observation wells
Comparison of full FEM model and reduced model

A) Reduced model with 78 states:

- Punkt 1
- Punkt 2
- Punkt 3
- Punkt 4
- Punkt 5
- Punkt 6
- Punkt 7
- Punkt 8
- Punkt 9
- Punkt 10
- Punkt 11
- Punkt 12

B) Reduced model with 127 states:

- Punkt 1
- Punkt 2
- Punkt 3
- Punkt 4
- Punkt 5
- Punkt 6
- Punkt 7
- Punkt 8
- Punkt 9
- Punkt 10
- Punkt 11
- Punkt 12

Tradeoff Performance ↔ Accuracy
# Optimization of Water Resources

- **Goal-function**
  \[
  \min_{u^k, k=1, \ldots, N} \left\{ F(x^N) + \sum_{k=0}^{N-1} f_0^k(x^k, u^k, z^k) \right\}
  \]
  x: state variables
  u: control variables
  z: non-controlable inputs
  K: index of time

(z.B. complete fullfilling of demand)

- **Constraints**
  \[
  g^k(x^k, u^k, z^k) \leq 0, \quad h^k(x^k, u^k, z^k) = 0
  \]
  (e.g. minimal supply of different user groups, capacity limits) → scenario definition

- **Process model**
  \[
  x^{k+1} = f^k(x^k, u^k, z^k)
  \]
  (simplified groundwater and surface water model)

- **Numerical solution**
  - Transformation to a larg-scale nonlinear optimization problem
  - IPOPT-Solver for numerical solution
Optimisation scenario
- Scenario A: fullfilling of demand, no further constraints
- Scenario B: fullfilling of demand, increase of groundwater level at observation well 5

Results of surface water system

Miyun Reservoir
- Water level [m above sea level]
- Constraints
- Time [year]

Beijing Water System - global demand and supply
- Flow [m$^3$/s]
- Global demand
- Time [year]
Optimization Results: Groundwater

Optimisation scenario

- Scenario A: fulfilling of demand, no further constraints
- Scenario B: fulfilling of demand, increase of groundwater level at observation well 5
Software Implementation

Software modules of the water resource management system

- Szenarienmanager (Wizard)
- Mensch-Maschine-Interface
- Visualisierung- und Reporttool
- Budget-Generator
- Archivierung (Historisierung)

- Wasserbedarfsvorhersage
- Parametrierungstool für Retentionsräume
- Oberflächenwassersimulation Matlab/Simulink
- Netzeditor
  - Oberflächenwasser
  - Entscheidungsfindung durch Optimierung

- Zeitreihen
- Einzugsgebiet-modell
- Grundwassersimulation
- Modellreduktion Grundwassermodell

- Datenbank - API
  - Parameter
  - Zeitreihen
  - Karten
  - Modellstrukturen
Software Implementation

User-friendly Graphical User Interface
1 Groundwater Resources Management

2 Modelling of Groundwater Transport Processes

3 Modelling of Algae Growth

4 Model based Landslide Warning Systems

5 Optimization of a biological Processes
Temporal and spatial variety of water ingredients is described by

\[ \frac{\partial c_i}{\partial t} + \text{div}(c_i \mathbf{v}) + \text{div} q = r_i \]

whereby the temporal change of component $c_i$ is determined by

- the fluxes $q$ into and out of a control volume and
- the sources and sinks $r$ within a control volume

Important effects are

- Transport mechanisms
- Sorption/Desorption
- Chemical reactions
- Biological degradation

Developing salination in Beijing province
Transport mechanisms

- Transport by advection
  \[ q^{adv} = \text{div}(c_i \mathbf{v}) \]
- Transport by diffusion
  \[ q^{dif} = -D^{dif} \text{grad} c_i \]
- Transport by dispersion
  \[ q^{dis} = -D^{dis} \text{grad} c_i \]

→ Diffusion processes take place on a molecular scale and can be neglected
→ Coupling of PDE’s by flow velocity \( \mathbf{v} \)
Chemical reactions/biological degradation

- Chemical reaction

\[ \nu_A A + \nu_B B \rightleftharpoons \nu_C C + \nu_D D \]

- Chemical equilibrium

\[ \sum_i \mu_i \nu_i = 0 \quad \text{for} \quad p, T \]

Problems:

- Determination of chemical potential of \( i \)-th component
- Determination of reaction rates \( r_i \)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_i )</td>
<td>chemical potential</td>
</tr>
<tr>
<td>( \nu_i )</td>
<td>stoichiometric coefficient</td>
</tr>
<tr>
<td>( p^+ )</td>
<td>reference pressure</td>
</tr>
<tr>
<td>( \mu_{0i} )</td>
<td>chemical potential at</td>
</tr>
<tr>
<td></td>
<td>reference conditions</td>
</tr>
<tr>
<td>( R )</td>
<td>ideal gas constant</td>
</tr>
<tr>
<td>( \phi_i )</td>
<td>fugacity coefficient</td>
</tr>
<tr>
<td>( p_{0is} )</td>
<td>saturation vapor pressure</td>
</tr>
<tr>
<td>( f )</td>
<td>fugacity</td>
</tr>
</tbody>
</table>
Chemical reactions/biological degradation

- Reaction rate
  \[ r_i = \frac{dc_i}{dt} \]

- Reaction types
  - 0th order (constant reaction rate): \( A \rightarrow B \)
    \[ r_A = -\frac{dc_A}{dt} = \frac{dc_B}{dt} = K_0 \]
  - 1st order (radioactive decay)
    \[ r_A = -\frac{dc_A}{dt} = K_A c_A \]

- Example: Biological Degradation \( E + A \rightleftharpoons AE \rightleftharpoons E + B \)
  \[ -\frac{dc_A}{dt} = \left[ \frac{dc_A}{dt} \right]_{\text{max}} \cdot \frac{c_A}{K_M + c_A} \]
  (Michaelis-Menten)
**Adsorption/Desorption**

- Adsorption/desorption reactions
  - Henry sorption
    \[ c_i^s = K_H c_i^f \]
  - Freundlich isotherme
    \[ c_i^s = K_F (c_i^f)^n \]
  - Langmuir isotherme
    \[ c_i^s = b \left[ \frac{K_L \cdot c_i^f}{1 + K_L \cdot c_i^f} \right] \]

- Balance of component
  \[ \frac{\partial c_i}{\partial t} = \frac{1}{R} \left[ r_i - \text{div} \left( c_i \mathbf{v} \right) + \text{div} q \right] \quad \text{with} \quad R = \left[ 1 + \frac{\rho_d}{n_e K_L} \right] \]
Adsorption/Desorption

**Adsorptionsisothermen**

- **Linear**
  \[ C_a = K_D C_L \]

- **Freundlich**
  \[ C_a = K_F C_L^{1/N} \]

- **Langmuir**
  \[ C_a = \frac{n_a K_L C_L}{1 + K_L C_L} \]
Simulation of Groundwater Contaminants at Karlsruhe Harbour

**Situation:**

- PAK Contamination in several parts of Karlsruhe Rhine Harbour
- Change of groundwater flow regime induced by different levels of rhine river

**Problem:**

- How behaves the contamination zones in consideration of the permanently changing groundwater flow regime
Simulation of Groundwater Contaminants at Karlsruhe Habour

Simulation of groundwater levels at different levels of Rhine river

Rhein: Normalwasser

Rhein: Niedrigwasser

Rhein: Hochwasser
Simulation of transport of groundwater contaminants (500 days) at different levels of Rhine river.
Historische Daten
- bis ca. 1925 Sandgrube (bis ca. 8 m Tiefe)
- ca. 1925 – 1955 Ablagerung von Bauschutt, Hausmüll, Gewerbemüll
- ca. 1949 – 1955 Ablagerung flüssiger Gaswerksabfälle

Heutige Nutzung
- teilweise Freizeitgelände
- ansonsten Bewuchs von Bäumen und Gebüsch
- Größe insgesamt ca. 1,5 ha
- Abstromgebiet wird landwirtschaftlich genutzt

Morphologie
- Oberrheinische Tiefebene, Niederterrasse des Oberrheingrabens im Bereich der zentralen Grabenscholle
- Grundwasser heute in 8-9 m Tiefe u. GOK, Fließrichtung NW
- Untergrund: Sande und Kiese des OKL

Untersuchungsergebnisse
- Trennschicht OKL/MKL nicht vorhanden -> GWL ca. 32 m mächtig
- Teeröl in Phase
Project „Stürmlinger Sandgrube”

Example: Calculated maximal plume for naphthaline

- Transport
- Sorption
- Biological degradation
- Chemical reactions
1 Groundwater Resources Management
2 Modelling of Groundwater Transport Processes
3 Modelling of Algae Growth
4 Model based Landslide Warning Systems
5 Optimization of a biological Processes
3 Modelling of Algae Growth

Problem: Eutrophication

→ Toxicity
→ Hygiene
→ ‘Overturning’ of water bodies

Aim: Prediction of algae growth

→ Early warning system

Problem

→ Complexe growth models
→ Parameterisation of spatially distributed models

Idea

→ Combination of FEM and fuzzy-methoden
→ Integration of Expert knowledge
→ Non-linearities
Modelling of Algae Growth

Main factors in algae growth

- Nutrients, e.g. P, N
- Flow velocity
- Water temperature
- Light

Simplifications

- Flat water bodies $\rightarrow$ 2D
- Ideal nutrient combinations $c_N$
- Light is binary variable
- Water temperature depends on season
Modelling of Algae Growth

Coupling of Submodels (Sample)

\[ R_N = -k \cdot R_B \quad \rightarrow 1 \text{ Unit of biomass requires } k \text{ units of nutrients} \]

Complete Model

![Diagram showing the coupling of submodels for modelling algae growth. The diagram includes a fuzzy model for algae growth (Matlab) and a FEM model for flow and transport (Comsol). The equation \( R_N = -k \cdot R_B \) relates the nutrient consumption rate to the biomass production rate, with \( k \) indicating the requirement of nutrients for each unit of biomass.](image-url)
Description of biological growth by methods based on Fuzzy Logic:

Knowledge representation in Matlab
→ Knowledge in terms of “if-then” rules

Example:

IF „velocity= low“ and „Nutrients = high“ and „Temperature = high“ THEN „Biomass = high“

IF „velocity= high“ and „Nutrients= low“ and „Temperature = high“ THEN „Biomass = low“

Fuzzy sets as membership functions:

Example:

\[
\begin{align*}
\mu(T) & \quad \mu(\bar{u}) \\
\text{low} & \quad \text{low} \\
\text{middle} & \quad \text{middle} \\
\text{high} & \quad \text{high}
\end{align*}
\]
Modelling of Algae Growth

Nonlinear lookup table:

\[ R_B \left( \frac{g}{m^3 \cdot s} \right) \]

\[ T[^\circ C] \]

\[ C_N \left( \frac{g}{m^3} \right) \]

\[ \text{Biorate} := R_B = F(|\vec{u}| = \text{konst.}, C_N, T) \]
Application to Orbetello Sea

- Water body of about 27 km² at western coast of Italy
- 2 inflows and 1 outflow
- Strong Eutrophication due to intense agriculture and fish farming
Modelling of Algae Growth

Profile of Flow and Nutrients after 1h

Stationary Flow profile

Nutrients profile

\[ |\vec{u}| \left[ \frac{m}{s} \right] \]

\[ c_N \left[ \frac{g}{m^3} \right] \text{ mit } R_N = 0 \]
Modelling of Algae Growth

Profile of Biomass and Nutrients after 1h and \( k = -10 \)

\[
c_B \left[ \frac{g}{m^3} \right]
\]

\[
c_N \left[ \frac{g}{m^3} \right] \text{ mit } R_N = -k \cdot R_B
\]
1 Groundwater Resources Management
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4 Model based Landslide Warning Systems
5 Optimization of a biological Process
Model-based Landslide Warning
Model-based Landslide Warning

Disposition

- Long-term constant factors (decades, centuries)
- Magnitude

Variable Disposition

- Temporal variable
- Middle-term and short-term events
  - seasonal, monthly, daily events
  - cyclic
- Magnitude and Frequency

Activating Event

- Temporal variable
- Middle-term and short-term events
  - days, hours, minutes
- Magnitude and Frequency

Actual current disposition

debris flow process
Model-based Landslide Warning

- **Load**
- **Time**
- **Current Disposition**
- **Variable Disposition**
- **Disposition**

![Diagram illustrating model-based landslide warning system with load, time, current disposition, and variable disposition dimensions.](image_url)
1. Groundwater Resources Management
2. Modelling of Groundwater Transport Processes
3. Modelling of Algea Growth
4. Model based Landslide Warning Systems
5. Optimization of a biological Process
5 Optimization of a biological Process

Aim: Online-Optimization of a complex biological Tenside Production Process

Problem: Slow growth of biomass $\rightarrow$ number of trials is limited

Solution Concept:
5 Optimization of a biological Process

Aim: Online-Optimization of a complex biological Tenside Production Process

Approach:
- Modelling of biological behaviour (macroscopic and molecular level)
- Offline-Simulation (verification of model)
- Model based Online Process Optimization

Project duration: 1/2010 – 12/2012
Summary

Competencies in

- Control theory and system technologies
- Modeling of time-dependent and spatially distributed systems
- Model reduction for better performance
- Handling of big datasets
- Optimization of complex systems
- Treatment of systems with incomplete information
- Incorporation of fuzzy knowledge
- Representation of complex information

Ways of cooperation

- Common projects
- Mentoring of student thesis
... puuhhh .... we did it ...!

Thanks for your attention 😊 !!!
Surface water modelling

- 5 reservoirs with capacity of about 9 billion m³
- **Complete length** of the water distribution system about 400 km
- **Formal description** of the water distribution system in terms of **graph theory** (balance equation for every node)
- timesteps > 1 day → **Neglection of fluid dynamics** along the way

**Example: Reservoir Node** (balance equation):

\[
V_{j}^{k+1} = V_{j}^{k} + \Delta t \left( \sum_{i \in E(j)} Q_{i}^{k} + A_{O,j}^{k} q_{evp,j}^{k} \right), \quad A_{O,j}^{k} = f(V_{j}^{k})
\]

- **Piecewise polynomial description** of the dependency between volume V and surface A₀

  - Q: Exploitation
  - q_{evp}: Evaporation flux
  - Δt: Timestep
Structure of surface water system of Beijing region
Groundwater modeling

Generation of time-dependent input data

- **Assumptions:**
  - **Unsaturated zone** was neglected
  - **Surface water runoff** is proportional to precipitation and depends on landuse
  - **Groundwater recharge and evapotranspiration:** depend on real water supply and on landuse
  - **Exploitation:** depends on landuse and on time (seasonal demand)
  - **Agricultural demand:** is completely fulfilled (reference-scenario)
Softwaretechnische Umsetzung

- Einfaches, grafisch unterstütztes hinzufügen neuer Elemente mit Hilfe des Netzwerkeditors
- Ankopplung neuer Elemente an die Optimierung
Summary: Decision Support System for Beijing

- Simple definition of scenarios by graphical user interface
- Coupling of models on database
- Budget-based generation of time series allows complete parametrisation of groundwater model
- Network editor → easy introduction of new elements in optimization model
- System is independent of model area (only the model itself)
- Low computing time for optimization due to the use of reduced models with high quality
- Flexible definition of boundary conditions
- Water demand analyses → input data for model

### Die Folie würde ich weglassen ###
Dispersion effects is caused by

- Viscosity
- Different velocities within voids
- Void geometry

The Dispersion coefficient depends on

- Matrix material
- Flow velocity
- Scale-dependent longitudinal and transversal dispersion length $\alpha_L/\alpha_T$

\[
D_{ij}^{\text{dis}} = \alpha_L v_i \delta_{ij} + (\alpha_L - \alpha_T) \frac{v_i v_j}{|v|}
\]
Chemical reactions/biological degradation

- Ideal gas:

\[ \mu_i(p, T) = \mu_{0i}(p^+, T) + RT \ln \frac{p}{p^+} \]

- Real gas:

\[ \mu_i(p, T) = \mu_{0i}(p^+, T) + RT \ln \frac{\varphi_ip}{p^+} = \mu_{0i}(p^+, T) + RT \ln \frac{f_i}{p^+} \]

- Liquids:

\[ \mu_i(p, T) = \mu_{0i}^G(p^+, T) + RT \ln \frac{\varphi_i P_{0is}}{p^+} + \int_{p_{0is}}^{p} V_{0i}^L dp = \mu_{0i}^G(p^+, T) + RT \ln \frac{f_i^L}{p^+} \]
Chemical reactions/biological degradation

- Calculation of fugacity

\[ f_i^L = \varphi_{0i} p_{0i} \exp \left[ \int \frac{V_{0i}^L}{RT} dp \right] \]

- Mixtures of gases
  - Consideration of the activity
  - Calculation of fugacity

\[ f_i = \varphi_i x_i p \]

- activity of the i-th component

\[ a_i = \frac{\varphi_i x_i p}{p_0} \]

- Chemical potential

\[ \mu_i = \mu_{0i} + RT \ln a_i \]
Chemical reactions/biological degradation

- **Equilibrium condition**

\[
\sum_{i} \mu_{i}v_{i} = \sum_{i} \mu_{0i}v_{i} + \sum_{i} v_{i}RT \ln(a_{i}^{v_{i}}) \\
= \Delta G_{0} + RT \ln K_{a} \quad \text{for} \quad p, T \\
= 0
\]

- **Law of mass action**

→ Reaction equilibrium constant \( K_{a} \)

\[
K_{a} = \frac{a_{C}^{v_{C}} \cdot a_{D}^{v_{D}}}{a_{A}^{v_{A}} \cdot a_{B}^{v_{B}}} = \exp\left(\frac{\Delta G_{0}}{RT}\right)
\]

→ Standard enthalpy \( \Delta G_{0} \) at \((p+, T)\)

\[
\Delta G_{0} = \sum_{i} v_{i}\mu_{0i} = v_{C}\mu_{0C} + v_{D}\mu_{0D} - v_{A}\mu_{0A} - v_{B}\mu_{0B}
\]
**Adsorption/Desorption**

- **Mass balance**

\[
 m_i = c^f_i \cdot n_e + c^s_i (1 - n) \cdot \rho_s = c^f_i \cdot n_e + c^s_i \rho_d
\]

- **Equilibrium Adsorption/Desorption**

\[
 \frac{dm_i}{dt} = \frac{dc^f_i}{dt} \cdot n_e + \frac{dc^s_i}{dt} \rho_d = 0 \quad \Rightarrow \quad r_i^{sorp} = \frac{dc^f_i}{dt} = -\frac{\rho_d}{n_e} \frac{dc^s_i}{dt}
\]

- **Balance of component**

\[
 \frac{\partial c_i}{\partial t} + \text{div} (c_i \mathbf{v}) + \text{div} \ q = r_i - r_i^{sorp}
\]

- **Adsorption/desorption reactions**

  → Henry sorption
  → Freundlich isotherme
  → Langmuir isotherme
### Rheinhabengebiet

<table>
<thead>
<tr>
<th>Modellgebiet</th>
<th>1,4 km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bereich A (AA Koellestraße)</td>
<td>0,023 km²</td>
</tr>
<tr>
<td>Bereich B (AA Waidweg)</td>
<td>0,039 km²</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Bereich</th>
<th>Mächtigkeit</th>
<th>Volumen</th>
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<tr>
<td></td>
<td>Auffüllung</td>
<td>Auffüllung</td>
</tr>
<tr>
<td>A</td>
<td>5 – 7 m</td>
<td>140000 m³</td>
</tr>
<tr>
<td>B</td>
<td>3 – 5 m</td>
<td>160000 m³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bereich</th>
<th>Summe PAK (EPA) ohne Naphthalin [mg/kg]</th>
<th>Naphthalin [mg/kg]</th>
<th>Summe BTEX [mg/kg]</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>max</td>
<td>max</td>
<td>max</td>
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<td>1386</td>
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<th>Bereich</th>
<th>Summe PAK (EPA) ohne Naphthalin [mg/m³]</th>
<th>Naphthalin [mg/m³]</th>
<th>Summe BTEX [mg/m³]</th>
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<tr>
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<tr>
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<td>B</td>
<td>656</td>
<td>85</td>
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<tr>
<th>Bereich</th>
<th>Summe PAK (EPA) ohne Naphthalin [mg/kg]</th>
<th>Naphthalin [mg/kg]</th>
<th>Summe BTEX [mg/kg]</th>
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<tbody>
<tr>
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<td>max</td>
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<tr>
<td>A</td>
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<td>1,5</td>
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<td>B</td>
<td>174</td>
<td>50</td>
<td>301</td>
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<td>Z6</td>
<td>T24</td>
<td>T23</td>
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<tr>
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<td>------</td>
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<tr>
<td>Σ PAK ohne Naphthalin [mg/kg]</td>
<td>970</td>
<td>3050</td>
<td>1750</td>
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<tr>
<td>Naphthalin [mg/kg]</td>
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<td>1750</td>
<td>760</td>
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<tr>
<td>Σ BTEX [mg/kg]</td>
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<tr>
<td>Benzol [mg/kg]</td>
<td>-</td>
<td>160</td>
<td>100</td>
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**Emissionsdauer**

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<th>Emission 2003</th>
<th>Lineare Emissionsdauer (365 d/a)</th>
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<tbody>
<tr>
<td>Σ PAK ohne Naphthalin [mg/kg]</td>
<td>0,09 kg/d</td>
<td>3050 a</td>
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<tr>
<td>Naphthalin [mg/kg]</td>
<td>1 kg/d</td>
<td>147 a</td>
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<tr>
<td>Σ BTEX [mg/kg]</td>
<td>2,5 kg/d</td>
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<tr>
<td>Benzol [mg/kg]</td>
<td>1,8 kg/d</td>
<td>10 a ??</td>
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</tbody>
</table>
Simulation of salination effects in Beijing Region

- Assumptions
  - max. admissible salt concentration in correspondence to TVO Güteklasse 3
  - proportional to irrigation
  - Estimation of the saturation in the unsaturated zone
  - Neglection of diffusion and dispersion processes
  - Neglection of sorption and chemical reactions

- Spatial distribution of salt disposition in the model area
Simulation of salination effects in Beijing Region
Modular implementation of physio-chemical model part in FEM software COMSOL:

Navier-Stokes-Modul
\[ \vec{u}(U_0), p \]

Transport-Modul-I
\[ c_N(\vec{u}, c_{N_0}, R_N) \]

Transport-Modul-II
\[ c_B(\vec{u}, c_N, c_{B_0}, R_B) \]

FEM-Flow- and Transportmodell (Comsol)
\[ U_0, c_{B_0}, c_{N_0} \]
\[ R_B, R_N \]
\[ |\vec{u}|, c_N, c_B \]
Description of biological growth by Fuzzy methods:

Flow velocity
Distribution $c_N$
Water temperature
Light

Input

Growth of biomass

Output

fuzzy-algae model (Matlab)

$|\vec{u}|$

$L$

$T$

$R_B$

$C_N$
Modelling of Algae Growth

Description of biological growth by Fuzzy methods:

Flow velocity
Distribution $c_N$
Water temperature
Light

Growth of biomass

Fuzzy: description by linguistic variables

Input

Crisp: No biomass production during the night
\[ R_B = 0 \]

Output

fuzzy-algae model (Matlab)

\[ \left| \vec{u} \right| \]

\[ c_N \]