WATER KNOWLEDGE

Optimized Groundwater Management

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Groundwater problems and optimization (examples)

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Important resource for water supply and component of aquatic environment – endangered due to depletion and pollution

- ⇨ Minimizing cost of raw water extraction and treatment
- ⇨ Minimizing impact of groundwater extraction on environment (stable groundwater system in ecological valuable areas)
- ⇨ Minimizing cost and maximizing effects of pollution protection and remediation

Impact on properties (high groundwater table)

- ⇨ Minimizing cost of groundwater withdrawal
- ⇨ Minimizing damages due to groundwater table rise

Groundwater problems and optimization (examples)

Groundwater modeling

⇨ 3-dimensional in a heterogeneous subsoil system
⇨ Transient up to 100 years and more (remediation of polluted aquifers)
⇨ Finite-element-models with up to 1 Mio. elements

Optimization

⇨ Large problem size (up to hundreds of variables)
⇨ Transient (thousands of time steps)

What to do?

⇒ **Simplification and downsizing (model / problem reduction)**
⇒ **Parallel / cluster computing / GRID-computing**

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Practical example – Binsheimer Feld

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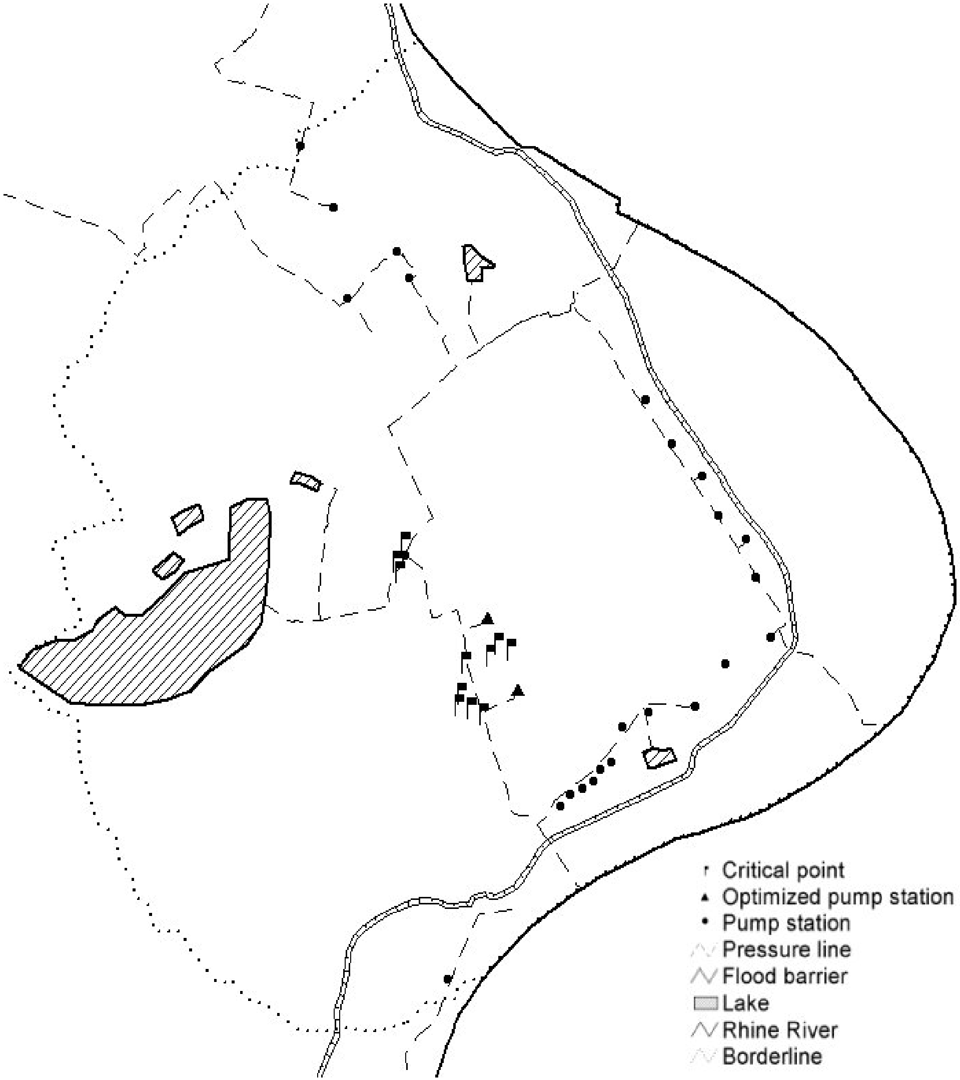
- ⇨ Situated at the Lower Left Rhine, western part of the North-Rhine-Westphalia coal mining area
- ⇨ Subsidence caused by active mining
- ⇨ River Rhine is the dominating boundary condition
- ⇨ Numerous groundwater pumps prevent surface water logging

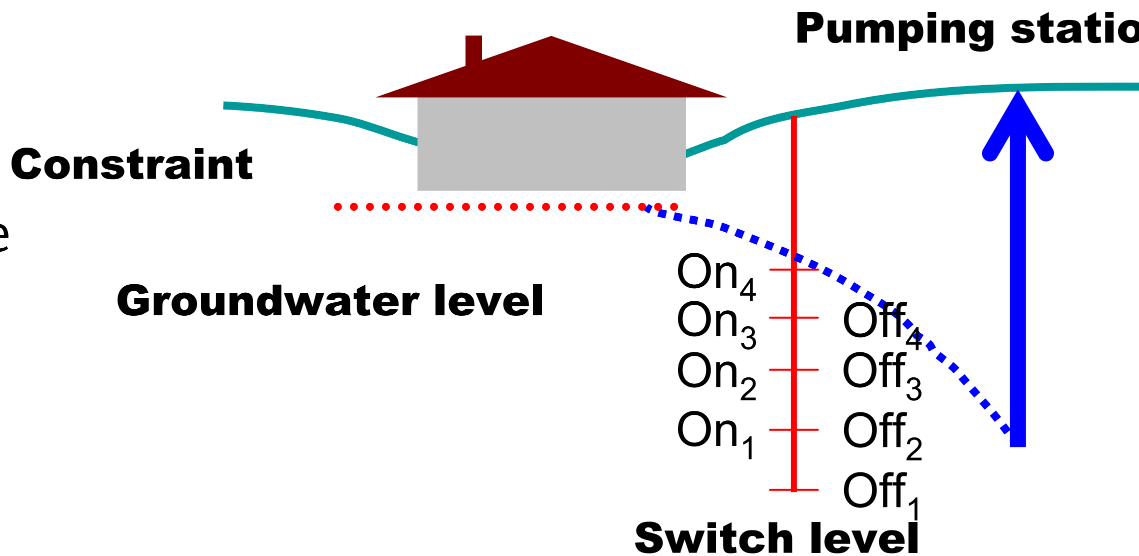


Objective

- ⇨Optimization of pump control for drainage measure at Binsheimer Feld
- ⇨Constraints: maintain a depth of groundwater table of 1 m below surface at 10 critical points

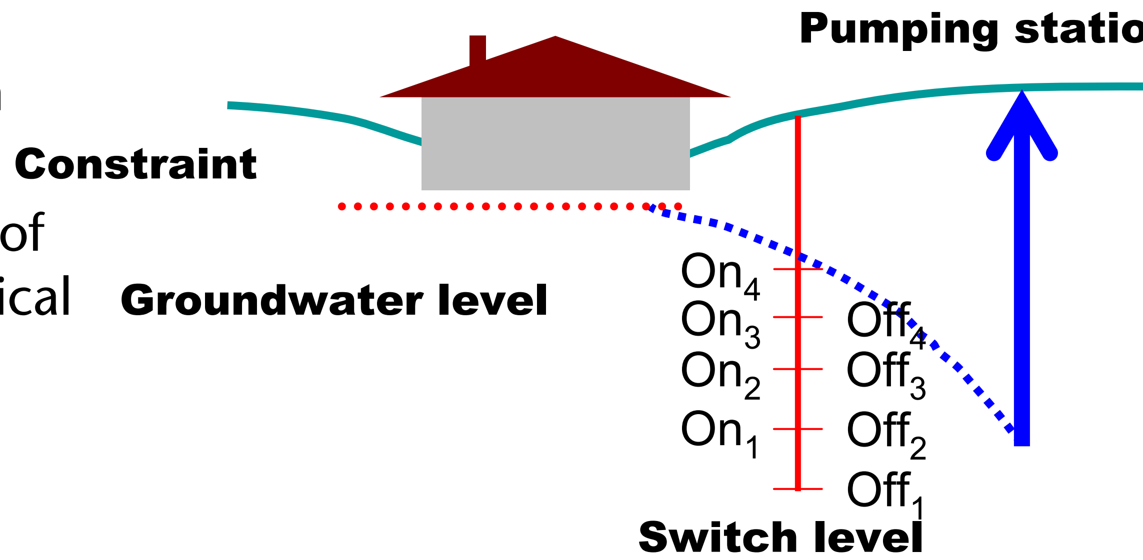
Pump control

- Considering 3 pumping stations
- Each pumping station is controlled by a control observation
- Each pumping station consists of more than one pump.
- Pumping station control
  - static (on / off)
  - continuously variable
  - Mixed→ **control variables**
- Extracting a minimum amount of water for drinking water supply



Problem definition

- Goal: minimization of operational cost for pumps maintaining a given depth to water level
- Decision variables: switch levels for pumps
- Constraints: upper levels of groundwater table at critical points
- Objective function:
  - Overall pump capacity
  - Operational cost fixed contract (mode of payment)
  - Operational cost adaptive contract



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Tools

- ⇨Transient groundwater flow model FEFLOW®
- ⇨Optimization software OpTiX®
- ⇨Pump control description and interfacing between FEFLOW and OpTiX using FEFLOW´s internal program interface called Interface Manager (IFM)

Tools

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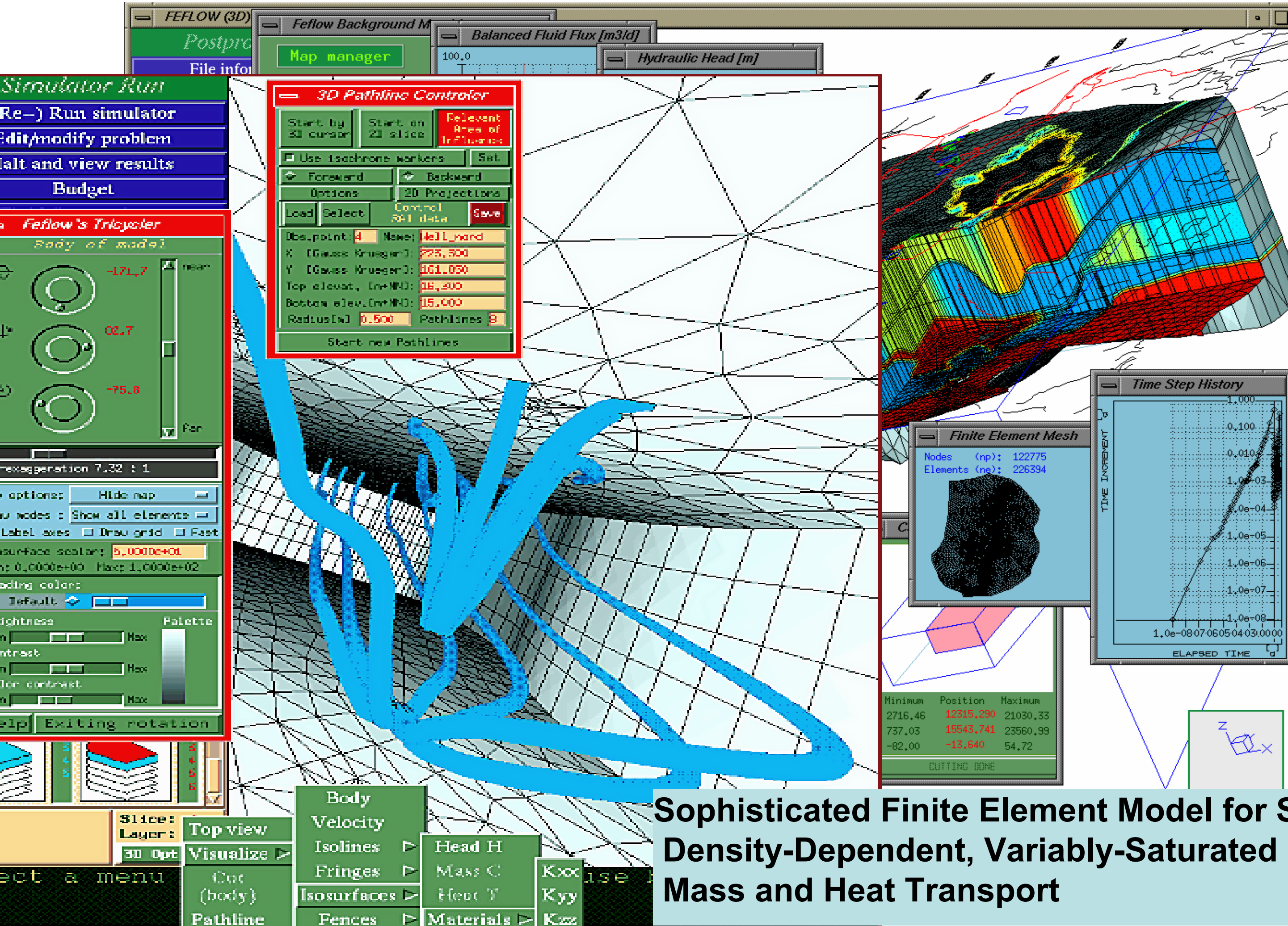
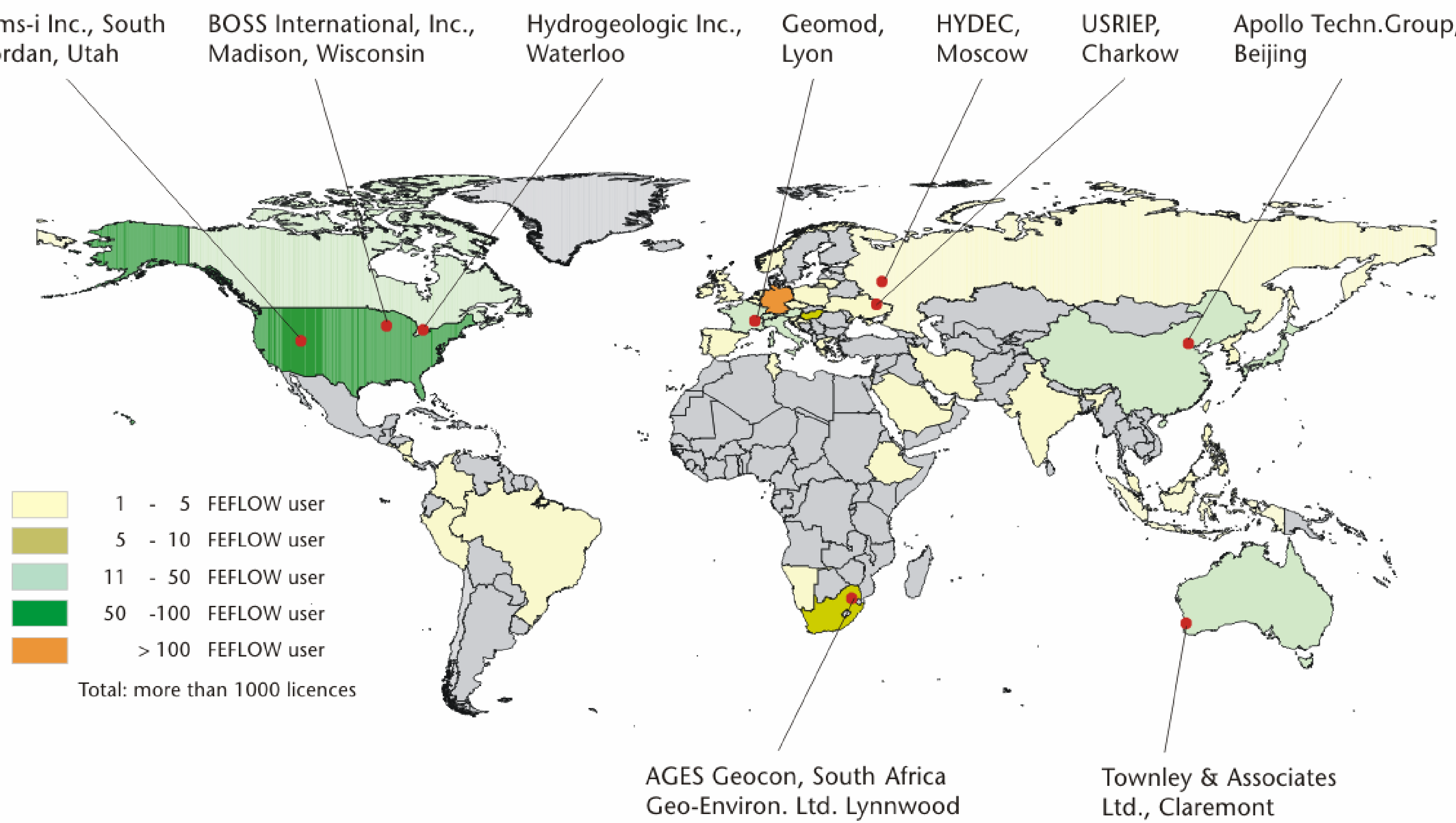
FEFLOW®



Sophisticated Finite Element Model for Simulating Density-Dependent, Variably-Saturated Groundwater Flow wi Mass and Heat Transport

FEFLOW-licences and FEFLOW-distributors word-wide



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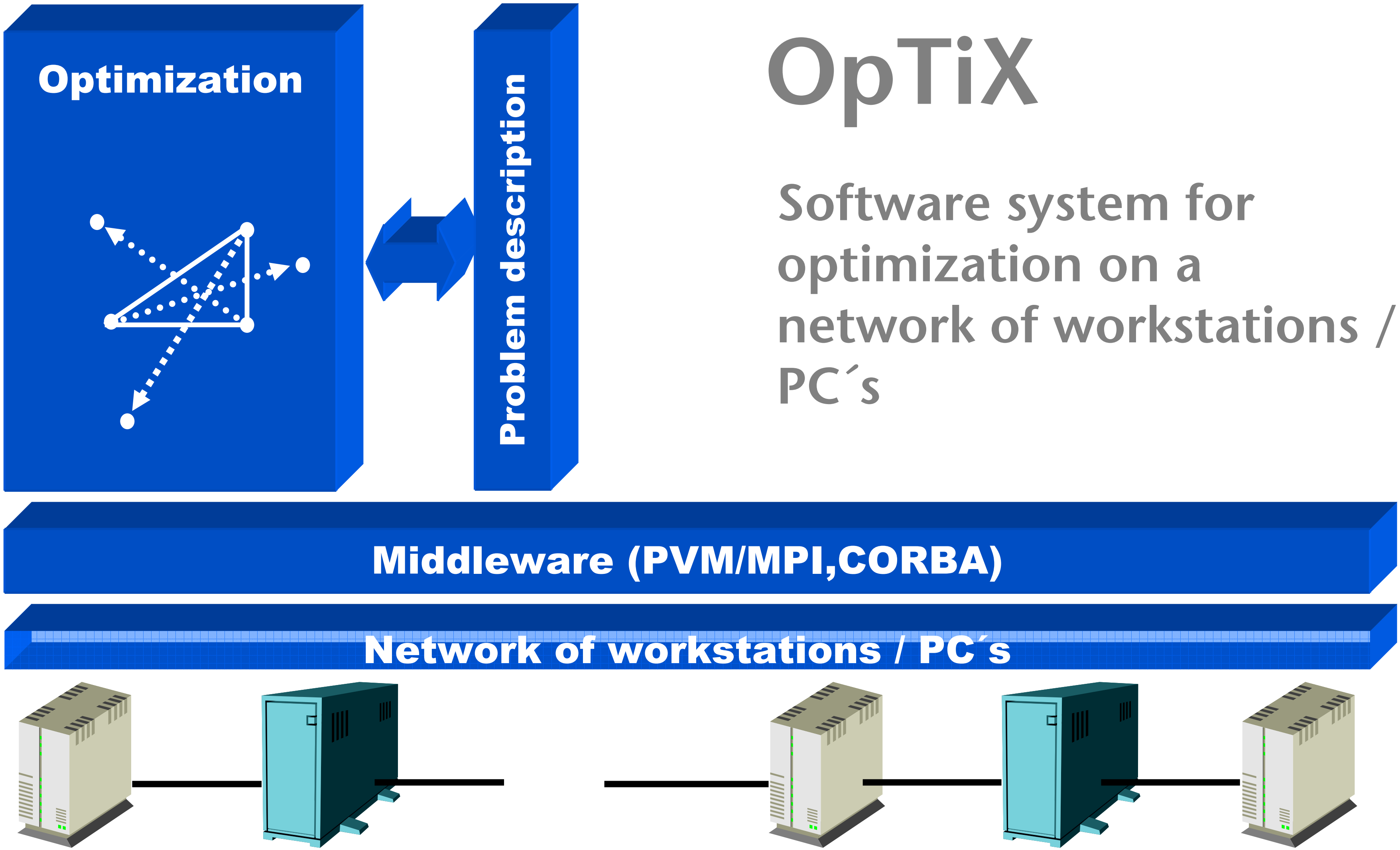
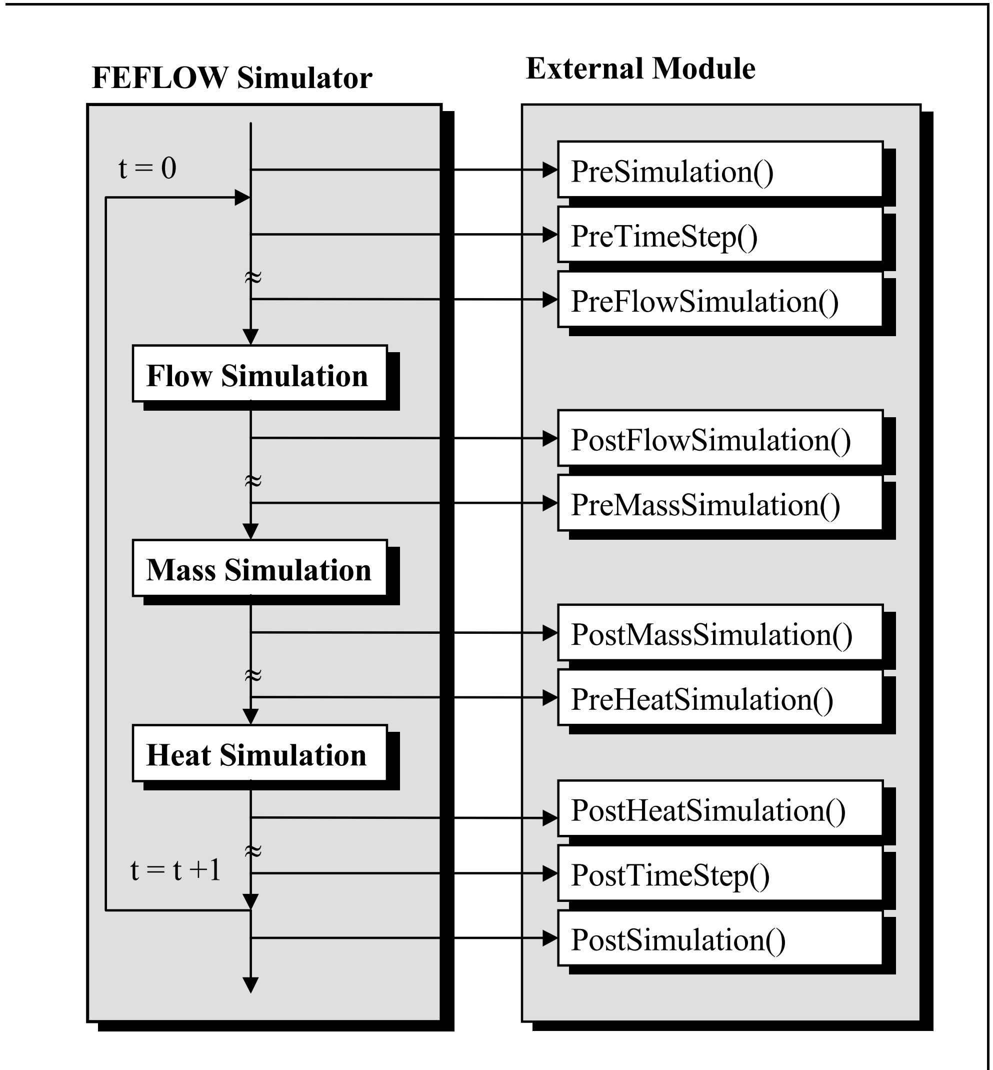
OpTiX

Software system for optimization on a network of workstations / PC´s



IFM


FEFLOW Simulator
External Module
t = 0
PreSimulation()
PreTimeStep()
PreFlowSimulation()
Flow Simulation
PostFlowSimulation()
PreMassSimulation()
Mass Simulation
PostMassSimulation()
PreHeatSimulation()
Heat Simulation
PostHeatSimulation()
t = t +1
PostTimeStep()
PostSimulation()

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Tool interaction

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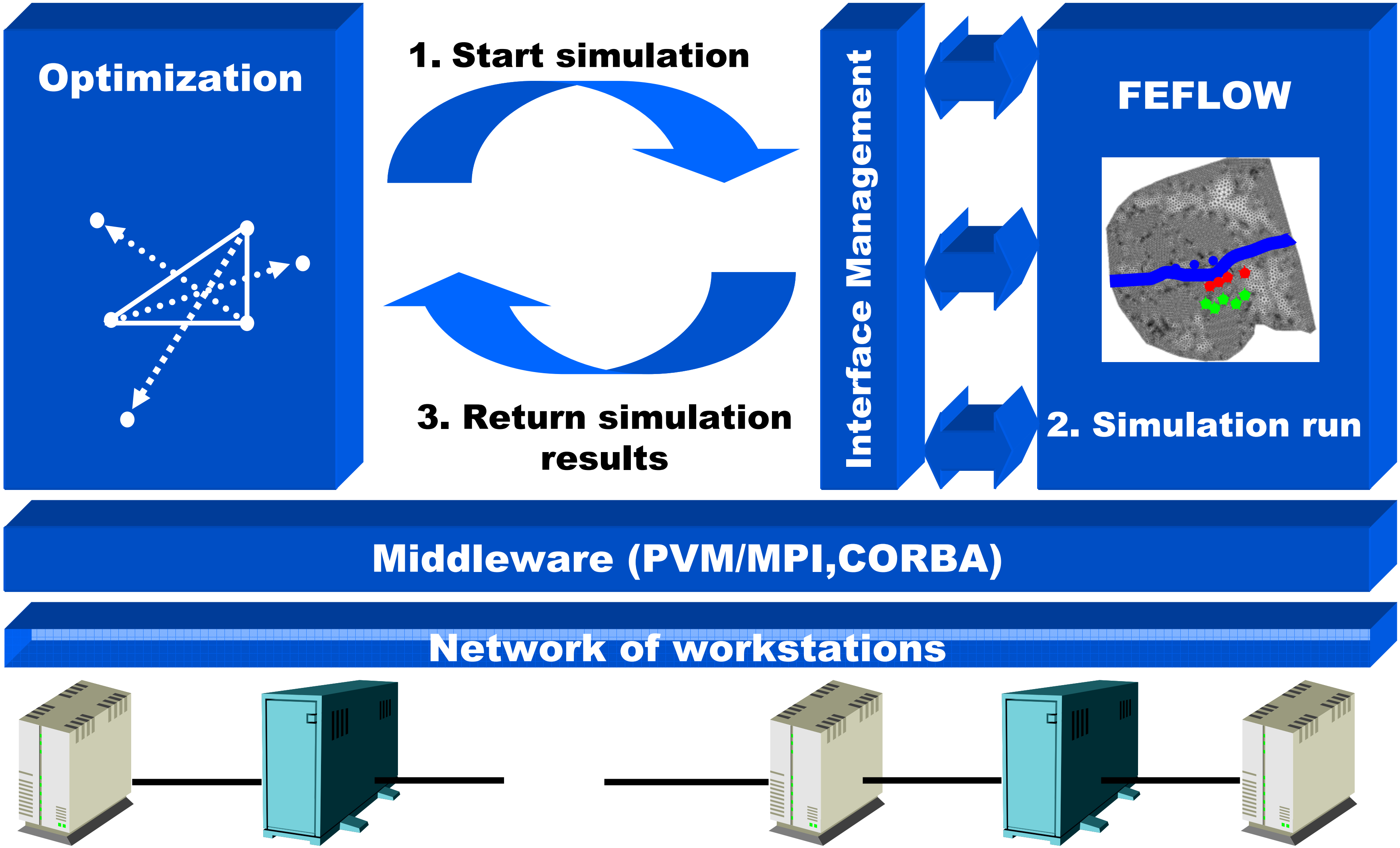
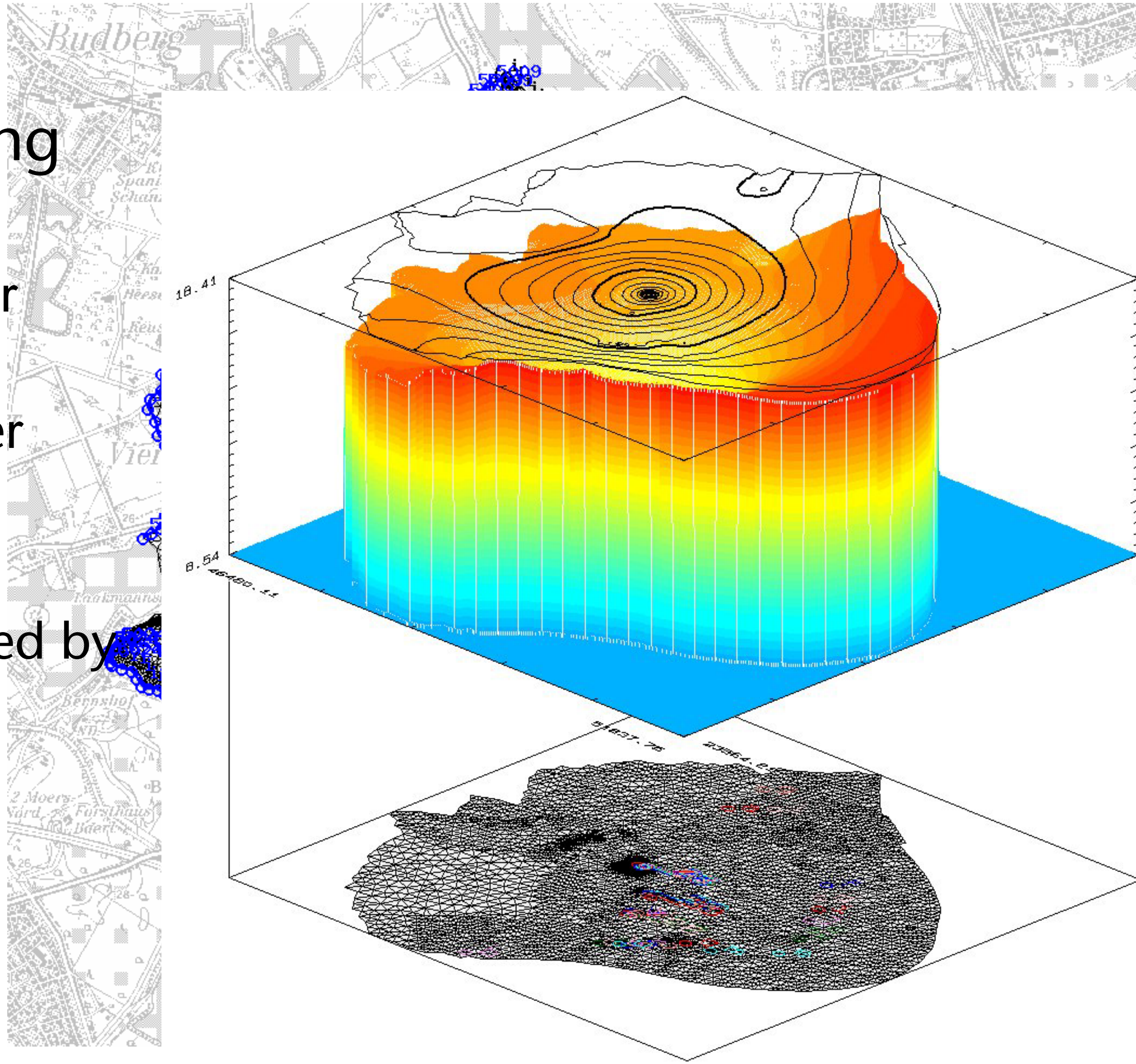


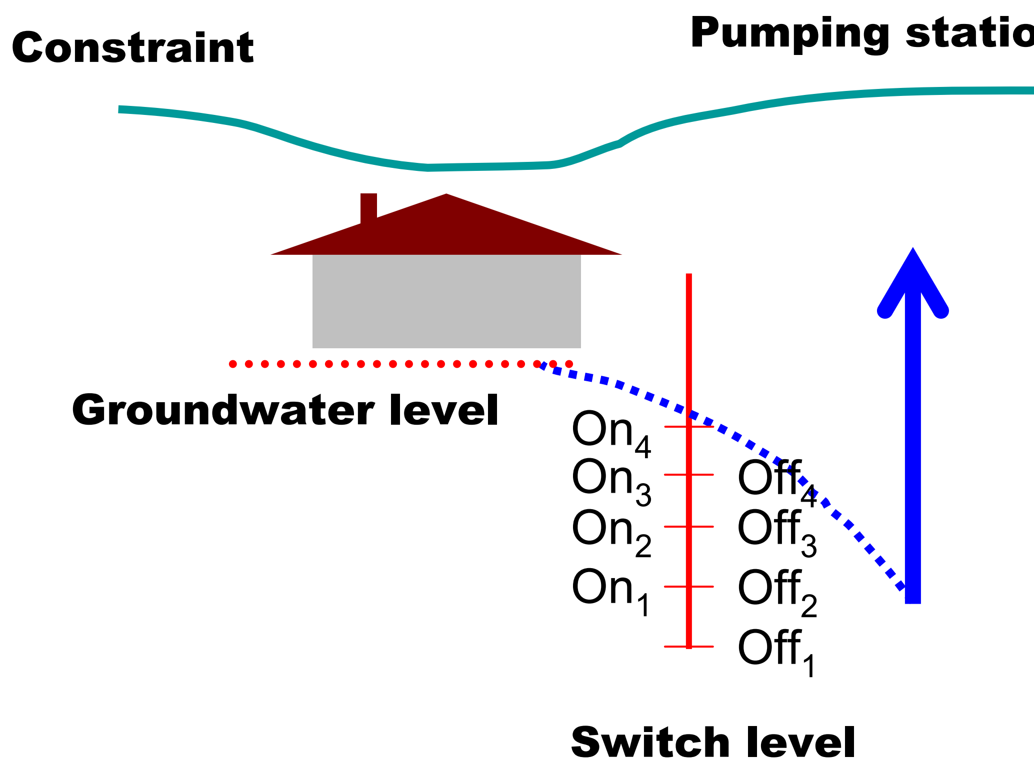
Tools

- Transient 2D ground water flow model using FEFLOW
  - Transient groundwater recharge
  - Transient surface water levels
  - Transient pump rate
  - Land subsidence caused by mining

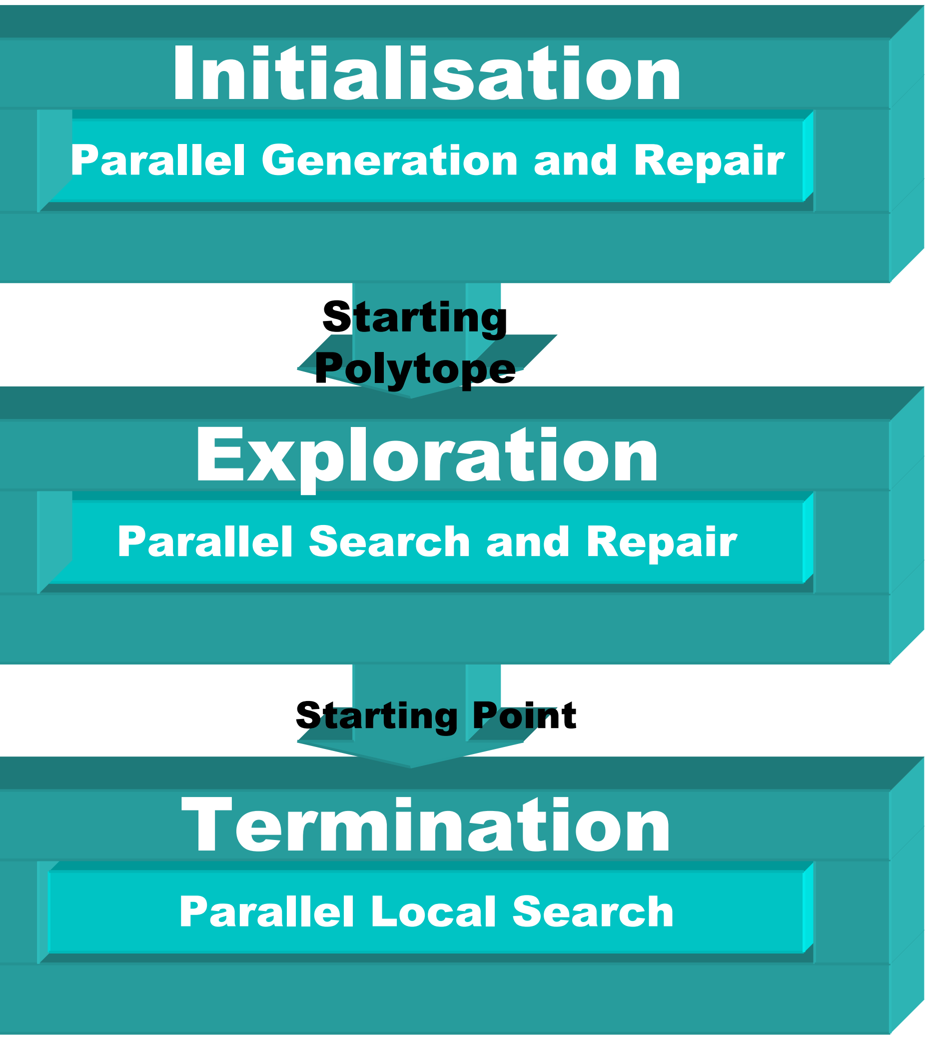


Tools

- Pump control description using FEFLOW´s Interface Manager (IFM)
  - Getting water levels at control observation points
  - Calculating resulting pump rate
  - Sets pump rate in FEFLOW model
  - Control of water level at critical points



Optimization software OpTiX - Distributed Polytope Algorithm



<u>Calculate starting polytope</u>

- Parallel random generation of s points on p hosts
- Parallel binary search for repairing infeasible points

<u>Exploration of search space</u>

- Parallel l-fold reflection/ contraction of e points on weighted center of gravity
- Parallel repair

<u>Termination</u>

- Parallel local search
- No repair of infeasible points

Definition of operational cost

cost =

$$f_1(c_1,v_1,p_1,r_1)+f_2(c_2,v_2,p_2,r_2)+f_3(c_3,v_3,p_3,r_3)$$

- ⇨ ***c: energy costs***
- ⇨ ***v: energy per pump rate***
- ⇨ ***p: allowed maximum rate***
- ⇨ ***r: relative minimum amount of energy consumption***

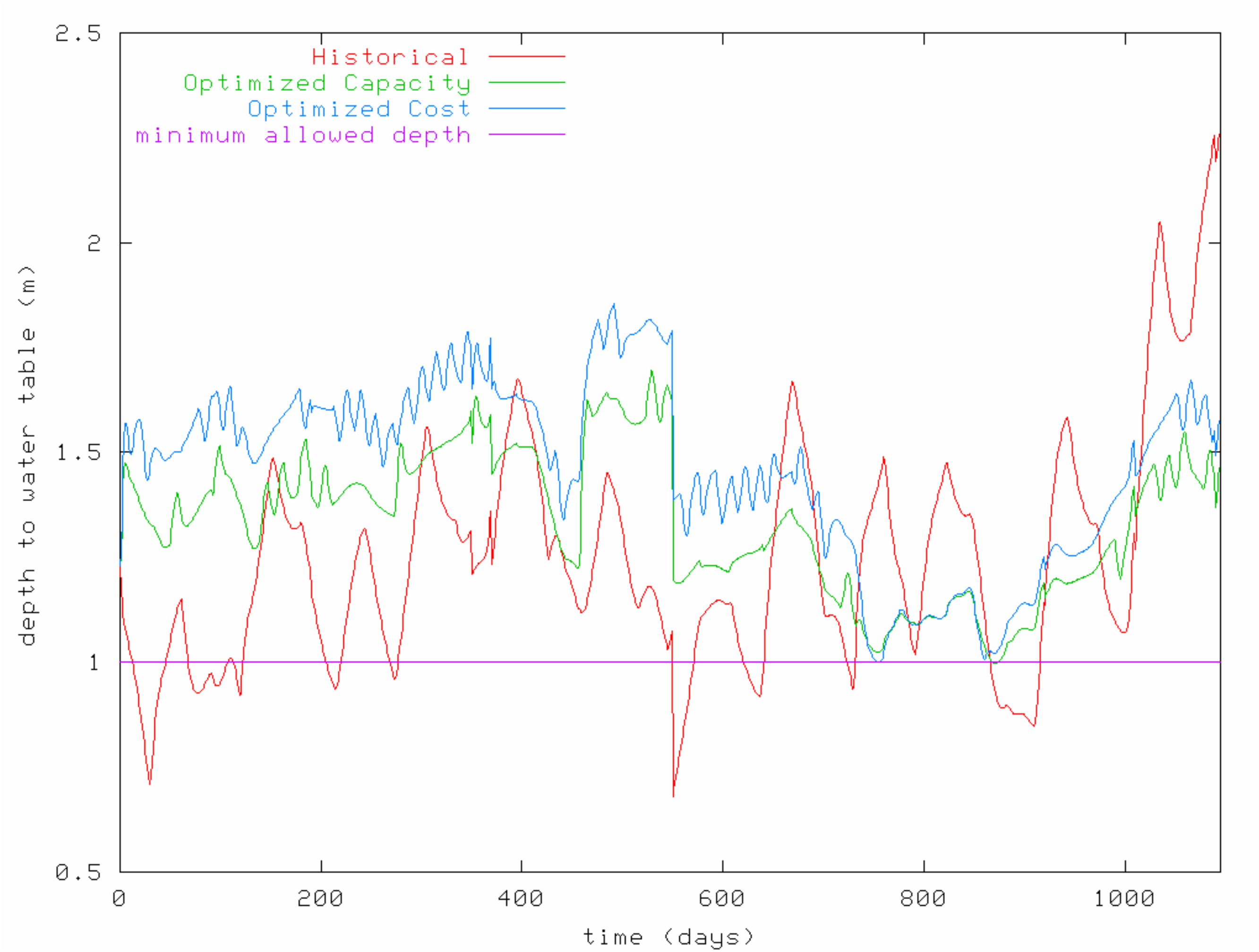
- ⇨ Fixed contract
- ⇨ Adaptive contract:
  - ➢ first year is given, for following years calculating max. rate for new contract using:
    maxpower p = consumption first year / rel. minimum amount
    (i.e. minimum amount for following years is exactly consumption of first year)

Results – operational cost

Normalized results of the various optimization approaches, taking overall pump capacity and the costs into consideration.

	Pump Capacity [%]	*Cost for fixed contract [%]*	*Cost for adaptive contract [%] (100 % means: equivalent to cost of fixed contract, historical approach)*
Historical approach (Realized pump control)	**100**	**100.0**	**109.7**
Optimization of overall pump capacity	**101.6**	**100.1**	**96.3**
Optimization of cost	**106.4**	**89.7**	**89.4**

Results – depth to water table



Depth to water table at observation point 6, taking various target functions into consideration

Results – operational cost

Composition of costs – comparison between historical and cost-optimized solution, adaptive contract

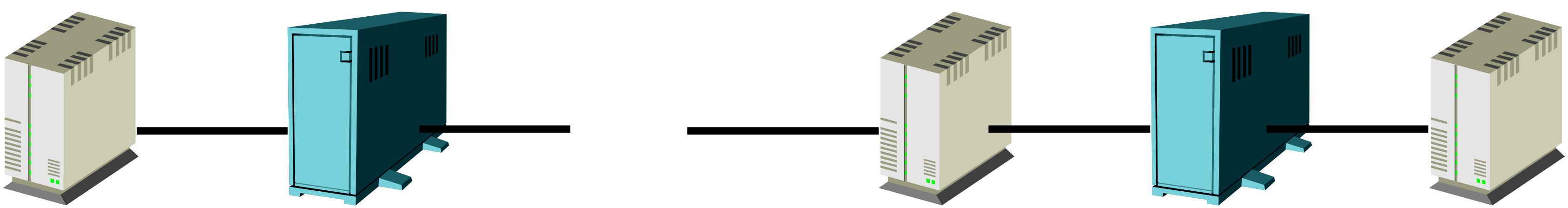
station	maxpower (normalised) hist	opt cost	unutilised expenses (normalised) hist	opt cost	excess charges (normalised) hist	opt cost
1	1,00	0,36	1,000	0,907	0,266	0,637
2	0,38	0,99	1,001	0,000	0,203	0,004
3	0,08	0,19	0,301	0,018	0,044	0,093

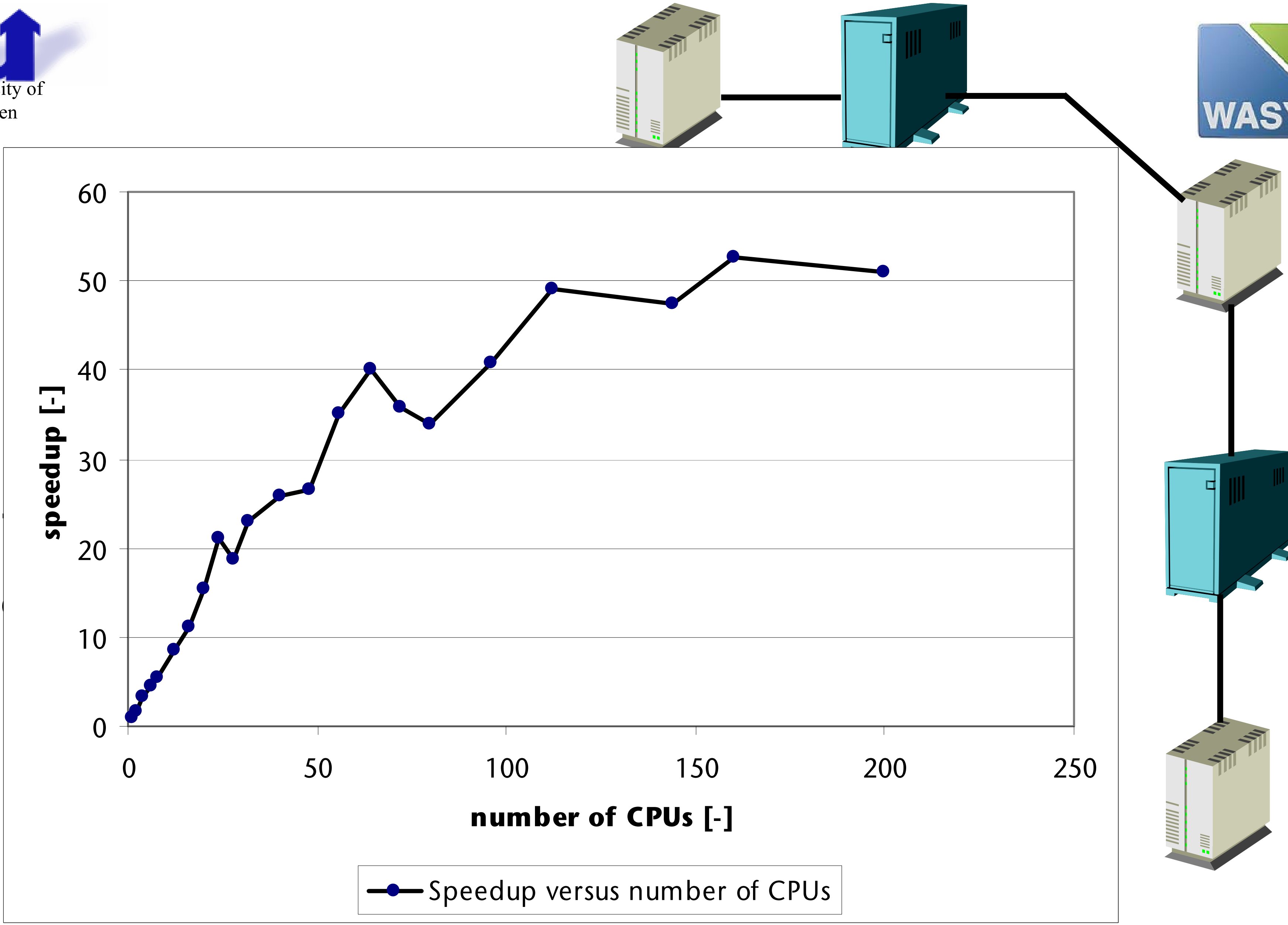
⇨ **Changes in major load situation from station 1 to 2**

⇨ **Optimum utilization of the station with main load**

Computing duration

- ⇨ Workstation-Pool (max. 16 P4, 1.8GHz): approx. 13-17 hours
- ⇨ Opteron single CPU: approx. 30 hours
- ⇨ Cluster (max. 256 Opteron, 2GHz): approx. 50 minutes using 64 CPUs
- ⇨ Duration for one model call:
  - ➢ P4: 7-10 minutes
  - ➢ Opteron: 2-3 minutes (without recompiling)




60
50
40
30
20
10
0
speedup [-]
0
50
100
150
200
250
number of CPUs [-]
Speedup versus number of CPUs
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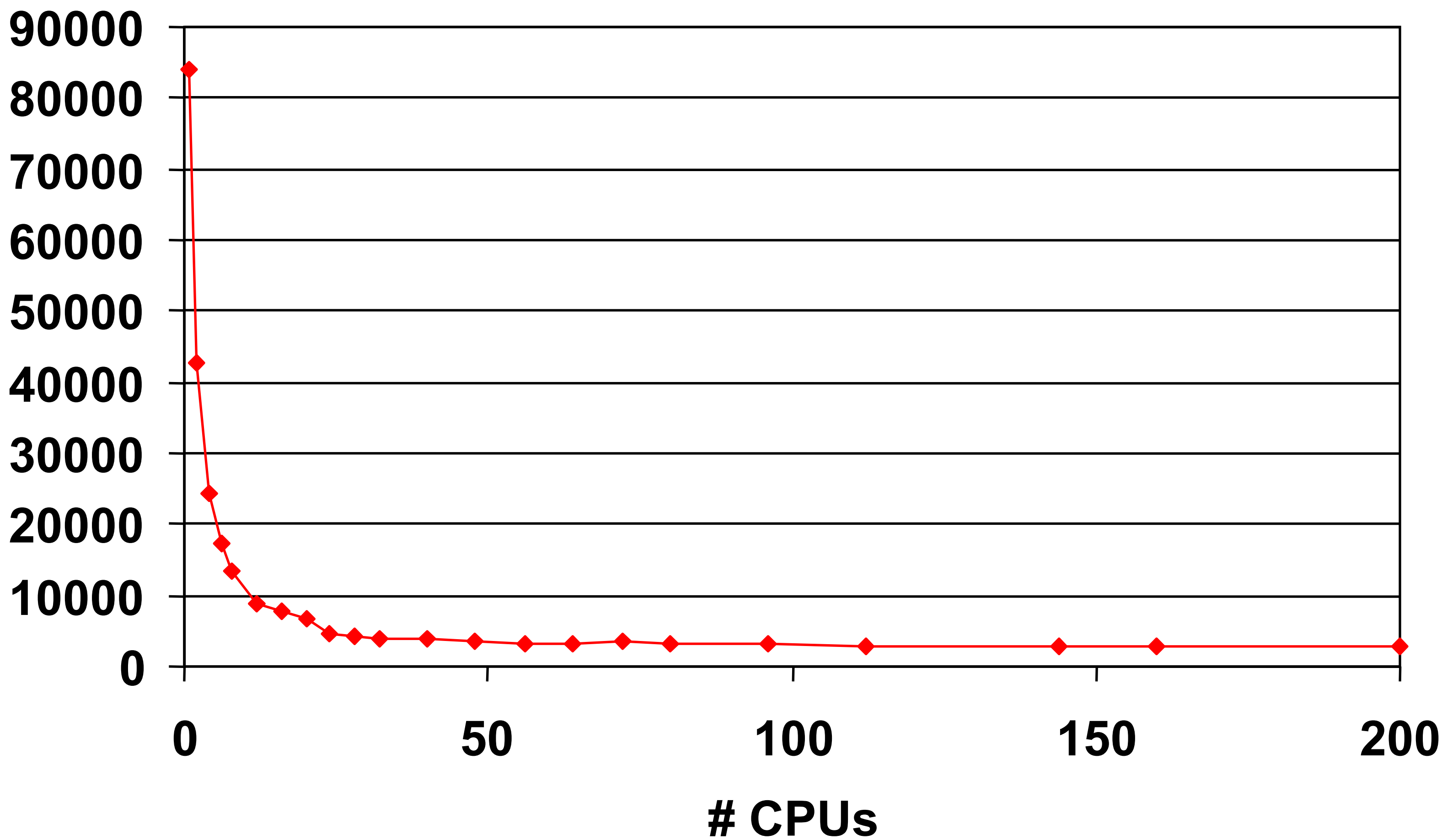
Groundwater Problem (Binsheim, 22 variables)



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Outlook

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- ⇨ Sensitivity of effects from experience-gathering phase
- ⇨ Consideration of a wider timeframe
- ⇨ Analysis of worst-case scenarios
- ⇨ Consideration of a wider area of interest incl. consideration of additional pumping stations
- ⇨ Application for different optimization tasks

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Thank You!