2016 CWEMF Annual Meeting Notice
Modeling Extremes: Drought to Flood and In-Betweens

Interaction of surface water and groundwater under highly dynamic conditions

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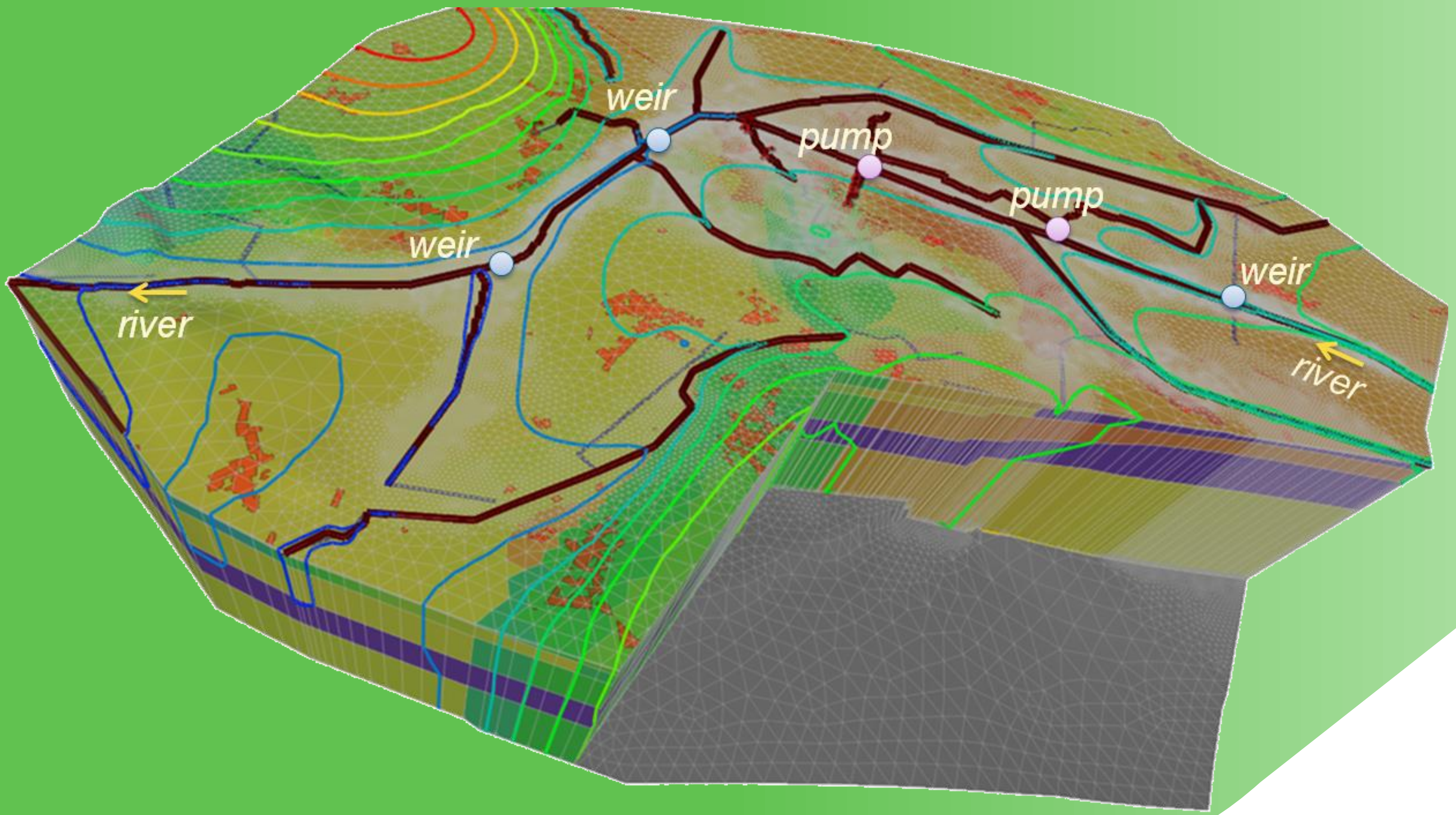
DHI

Interaction of surface water and groundwater under highly dynamic conditions

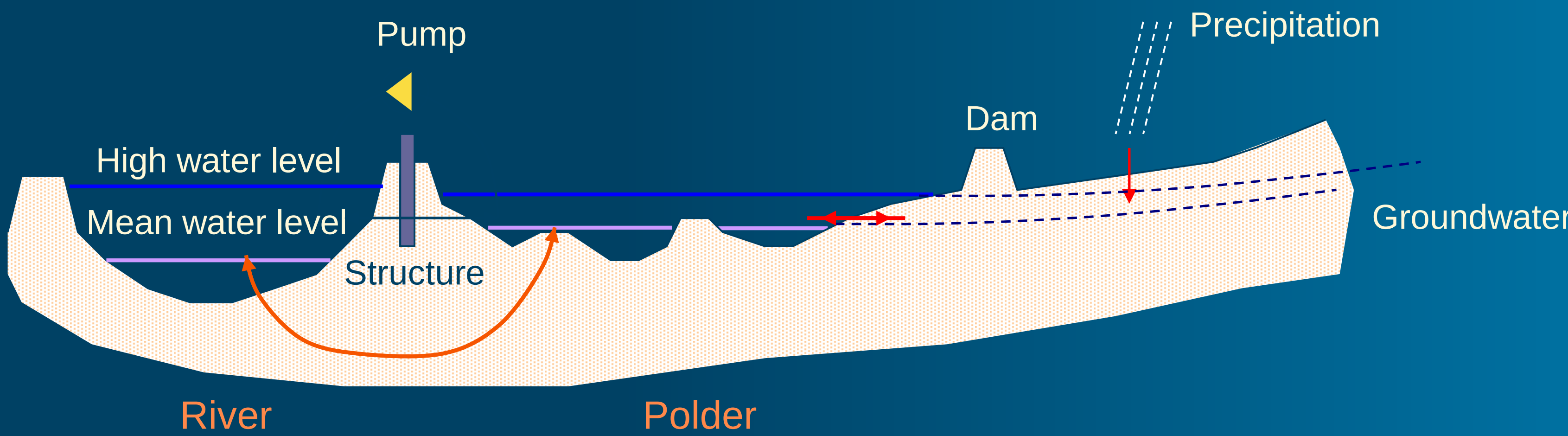
- Rational for coupling FEFLOW and MIKE 11
- Brief introduction to FEFLOW
- Short description of IfmMIKE11

- Examples
  - Managed aquifer recharge and seawater intrusion – Chennai, India
  - Balancing interests along the Odra River, Germany
  - Flood retention along the Elbe River, Germany

Introduction & short description of FEFLOW



Introduction of coupled dynamics: Polder example



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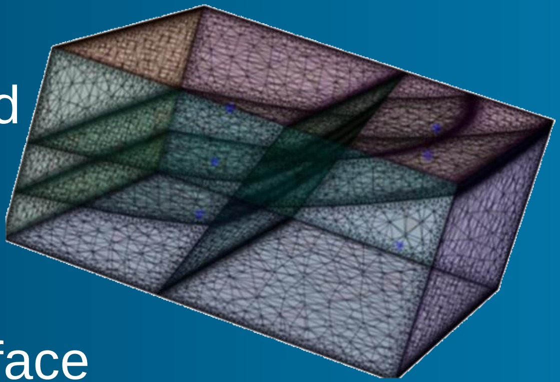
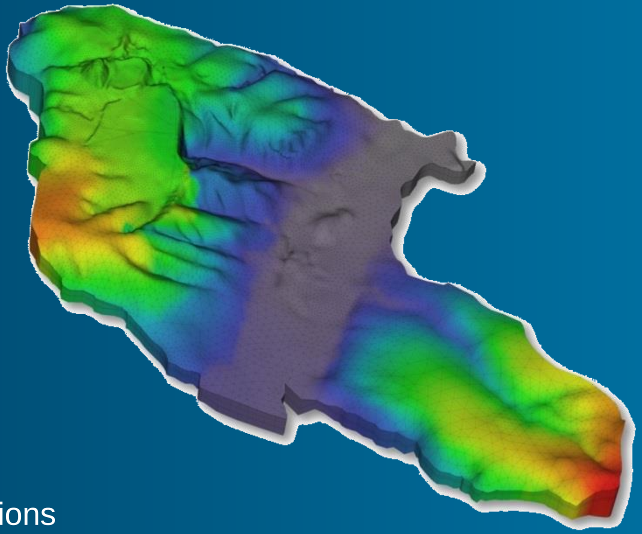
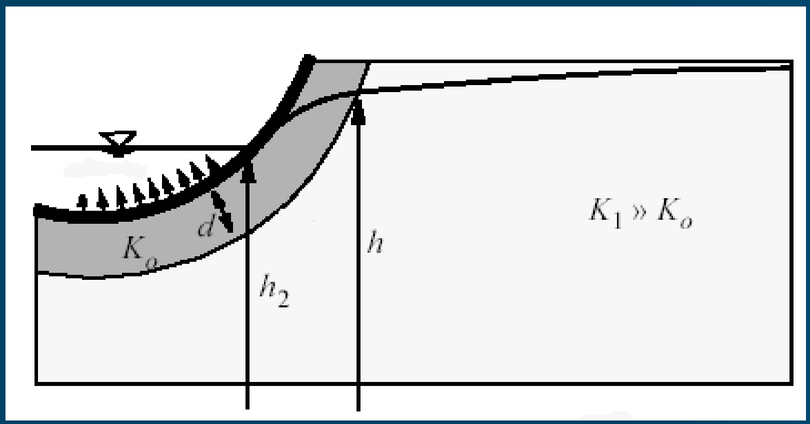
FEFLOW

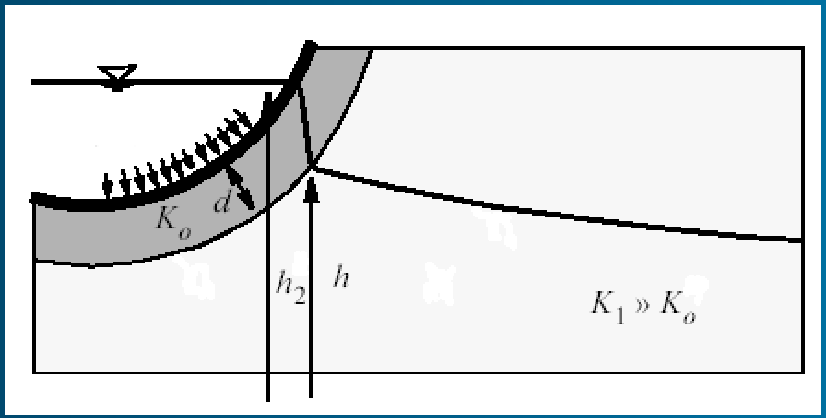


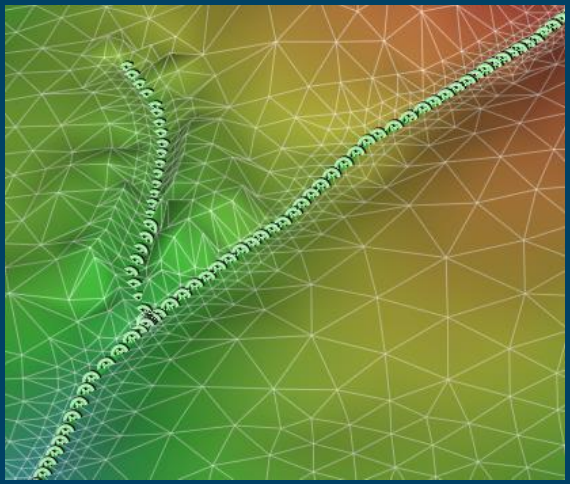
- Flexible mesh generation by finite element method
  - 3D- and 2D- models
  - Unstructured meshes
- Models for groundwater flow
  - Saturated flow (Darcy- Law) incl. phreatic surface
  - Unsaturated (partly saturated flow (Richards'- equation))
- Modelling of transport processes
  - Mass transport (advection, dispersion, diffusion, density dependent)
  - Heat transport
- Chemical and physical processes
  - Sorption
  - Chemical reaction processes
- Add-ons
  - Open programming interface by IFM
    - Coupling to MIKE 11
    - Coupling to PHREEQC



Type 3 boundary condition (River BC in FEFLOW)







$$q_{n_h} \approx -K_o \frac{\Delta h}{\Delta l} = -K_o \frac{h_2 - h}{d}$$

Transfer rate $\Phi_h \approx \frac{K_o}{d} \quad \text{in} \quad [d^{-1}]$

$$Q = A * \phi_h (h_r - h_{gw})$$

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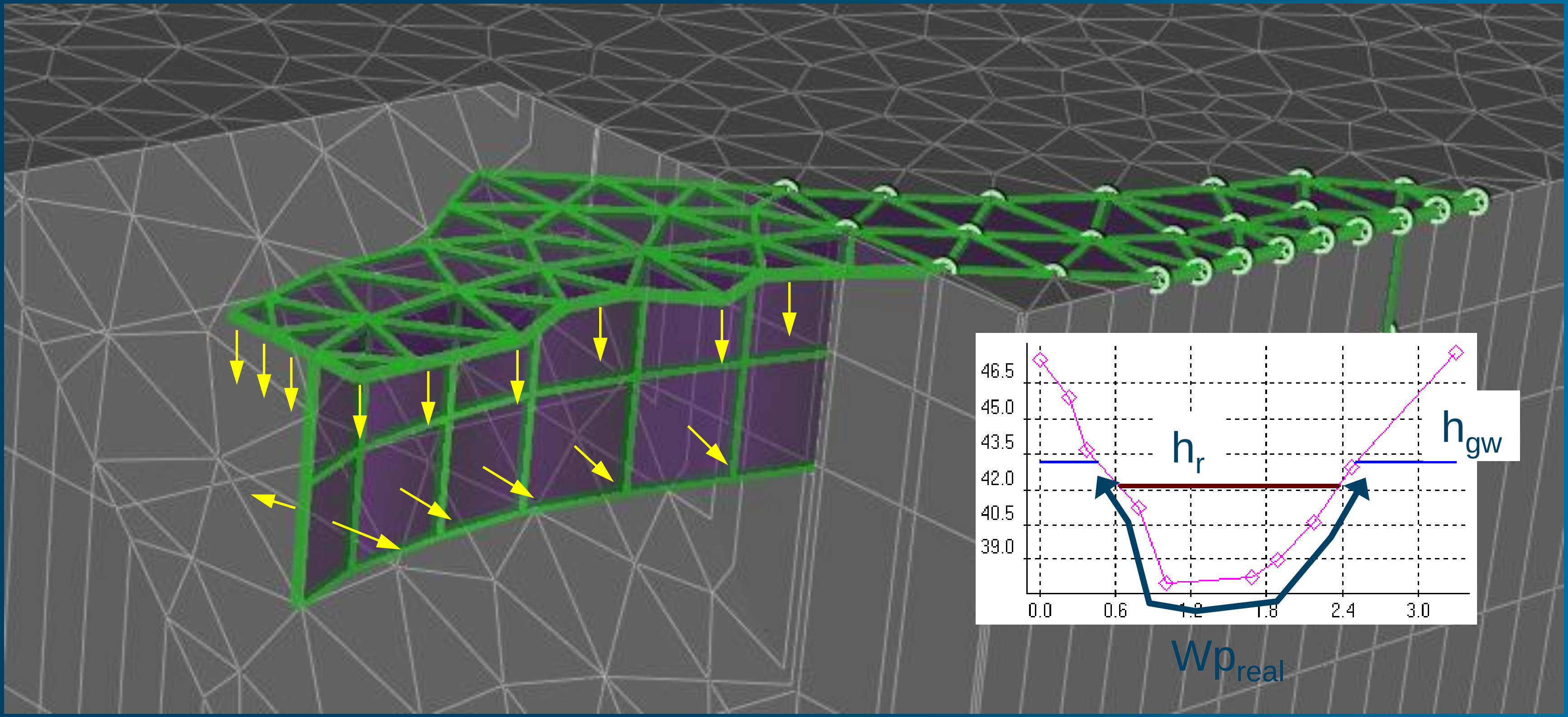
Type 3 boundary condition (con't)

Combined or T-Infiltration

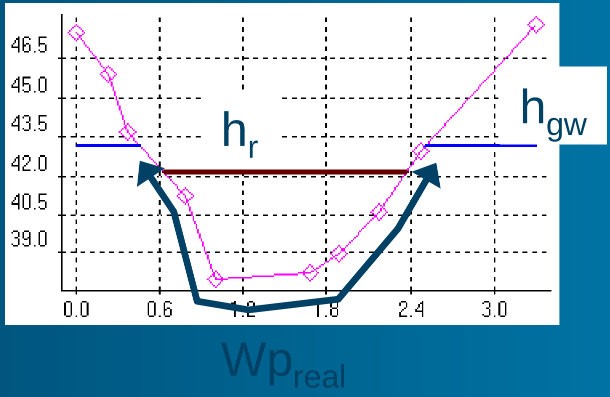


Horizontal/ lateral infiltration

Vertical/ surface infiltration

Vertical/ surface infiltration or T-infiltration?

$$Q = Wp * L_{rep} * \phi_h (h_r - h_{gw})$$

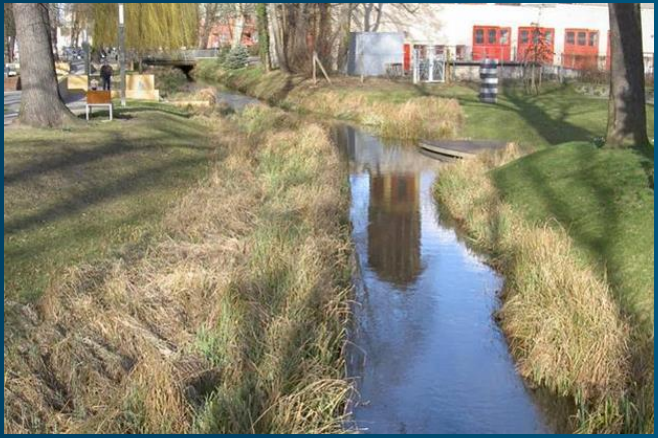


Vertical infiltration

Wp = B

Lateral infiltration

Wp = 2*H

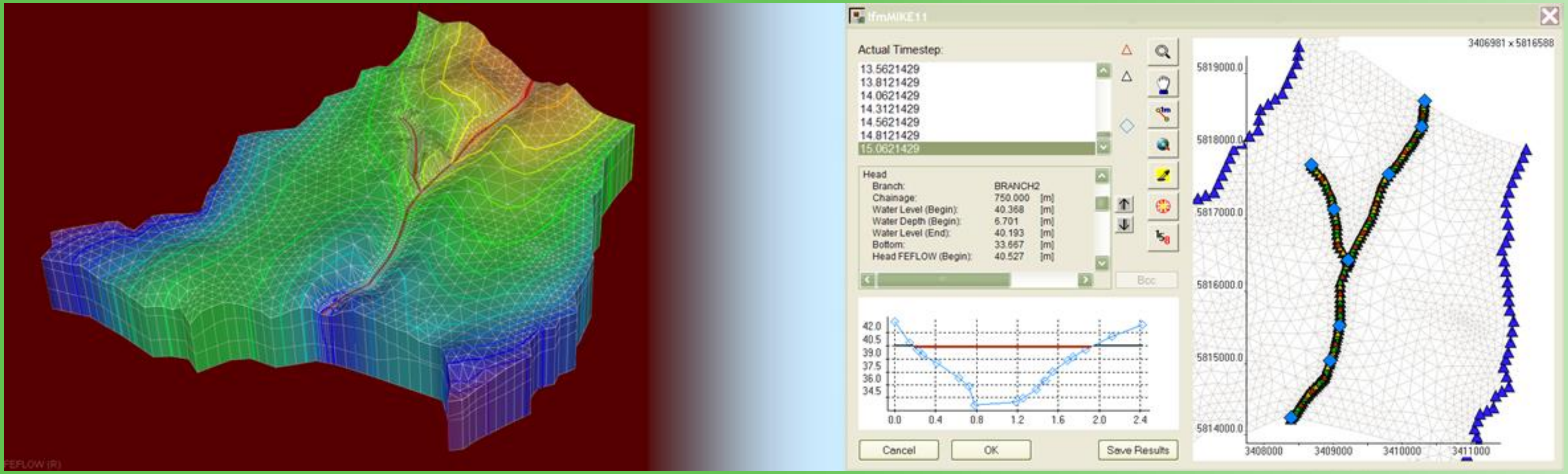


T-infiltration

Wp = 2*H + B

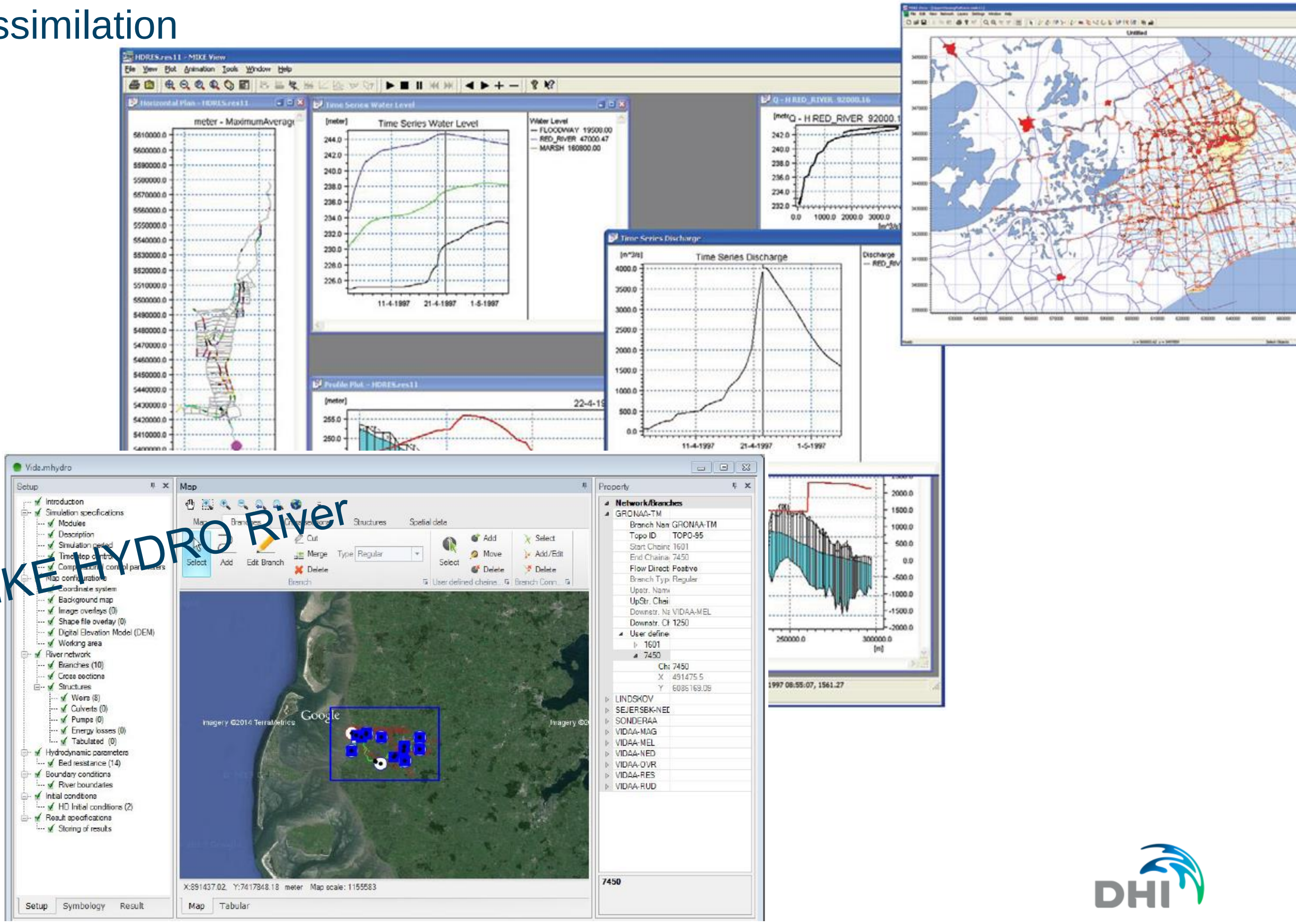
Better representation, but more complicated geometries cannot be represented.
Furthermore, dynamically flooded areas cannot be represented by standard Feflow BCs

Short description of IfmMIKE11



1D Hydrodynamics with MIKE 11

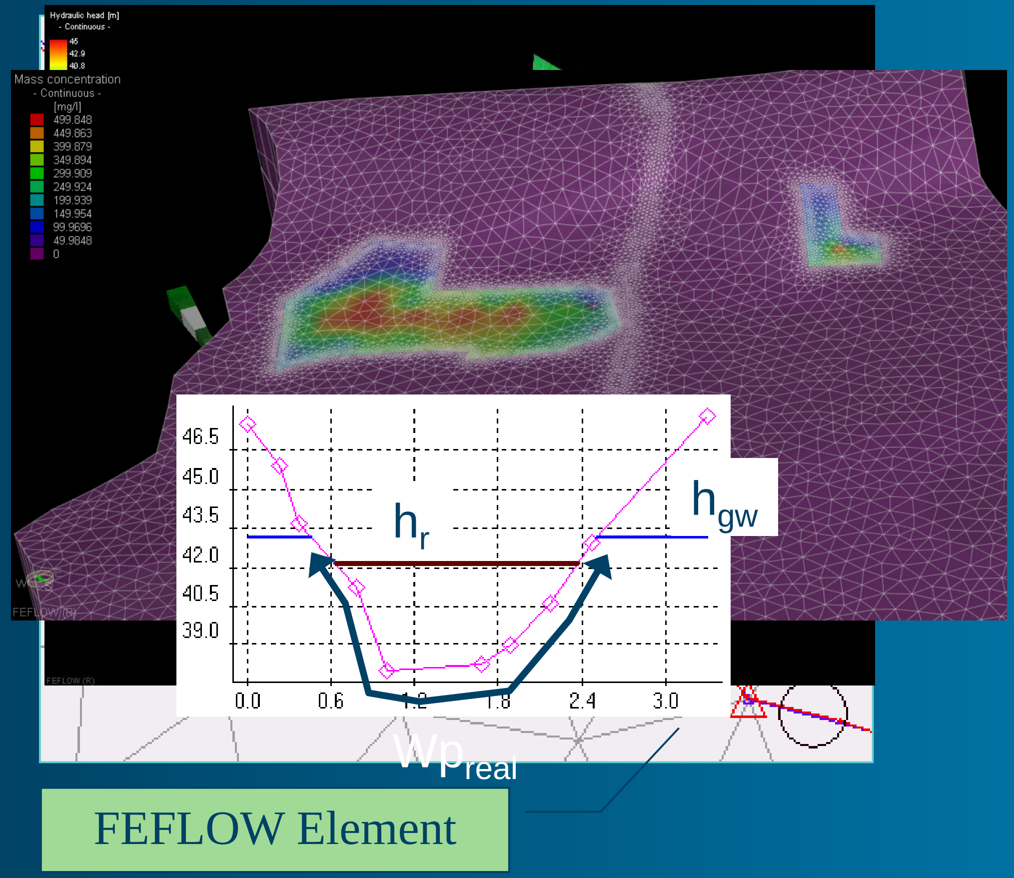
- Rainfall run-off
- 1D St. Venant equations
- Forecasting and data assimilation
- Sediment transport
- Ecological modelling
- Stationary / instationary
- Control structures
- Looped networks

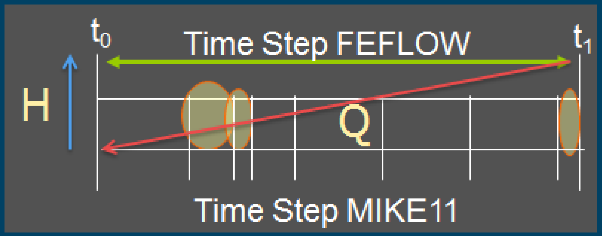


in 2016 integrated in MIKE HYDRO River

IfmMIKE11: Integrated coupling with the hydrodynamic 1D System MIKE11

- Dynamic coupling
- Adaptive time step control
- Rivers, polders and low lands
- Groundwater pumping on surface flows
- Wetted area in relation to the real river cross sections
- Mass transport



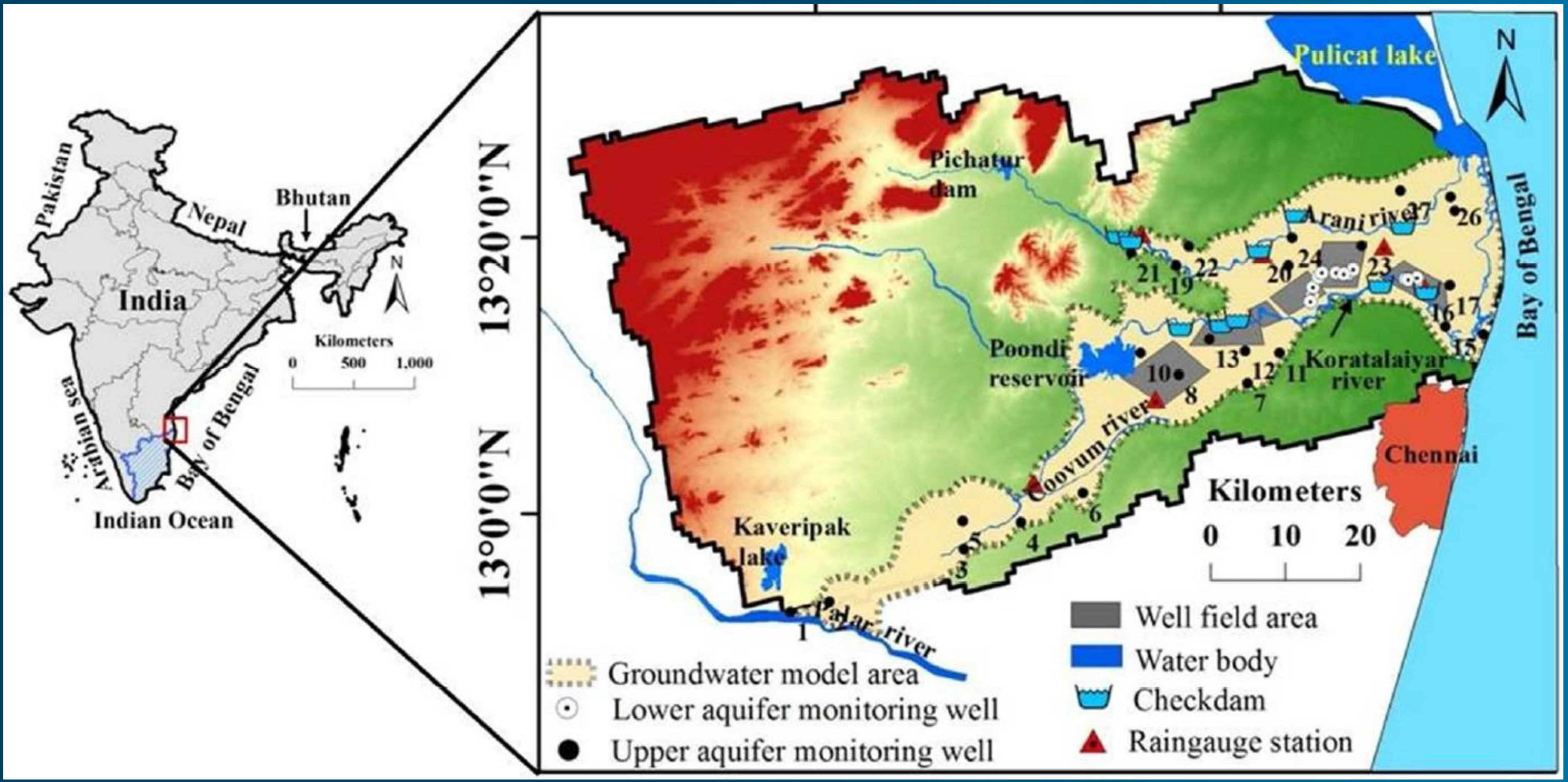


Interaction of surface water and groundwater under highly dynamic conditions

Saphpani, Chennai / India

Co-funding of the project by the European Commission within the 7th Framework Programme under Grant agreement number: *282911* is kindly acknowledged

Chennai – Aranai & Koratalaiyar Rivers (AK-Basin)

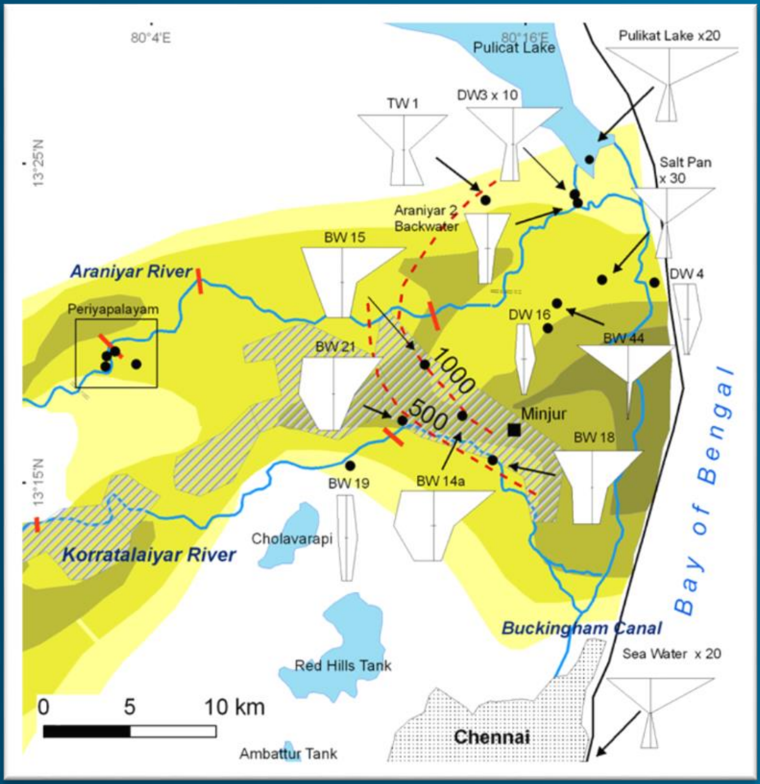


Interaction of surface water and groundwater under highly dynamic conditions

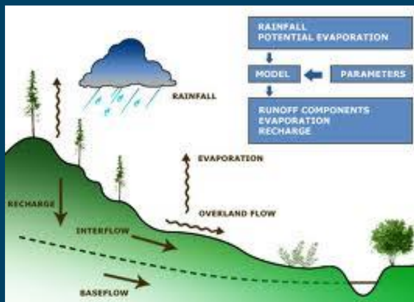
Objectives

- Chennai is the 4th largest metropolitan city in India.
- Seawater intrusion up to a distance of 13 km since 1969 due to extensive extraction

- To create a model concept for the Chennai case site representing:
  - surface-groundwater interactions
  - freshwater-seawater dynamics
- To create a tool to simulate MAR measures
- Simulation of MAR measures (check dams) counteract:
  - Seawater intrusion
  - Groundwater overexploitation



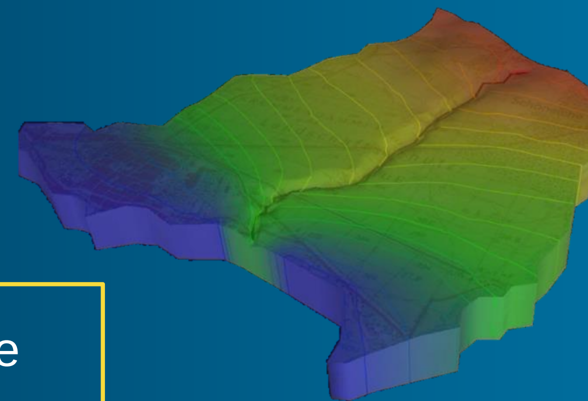
Modelling methodology



Climate Data

Rainfall Runoff (MIKE 11 - RR)

Recharge



Land Use Map
Soil Map
Stream Flow

Inflow

Q

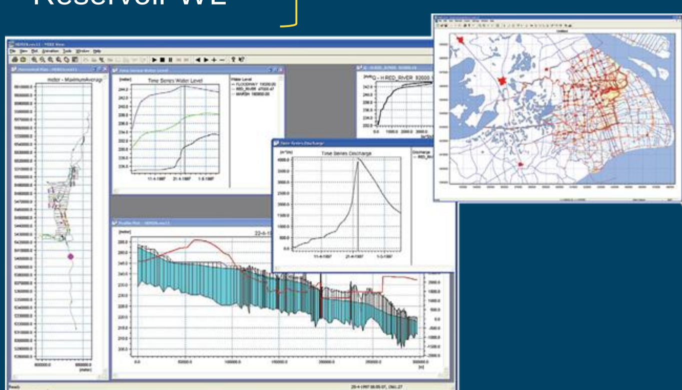
H

Surface Water (MIKE 11)

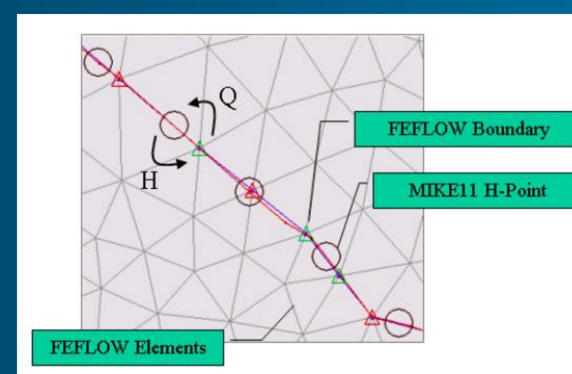
Groundwater (FEFLOW)

River Profile
Structures
SW Extraction
Reservoir Storage
Reservoir WL

Geologic Map
GW Extraction



Coupling Interface (IfmMike11)



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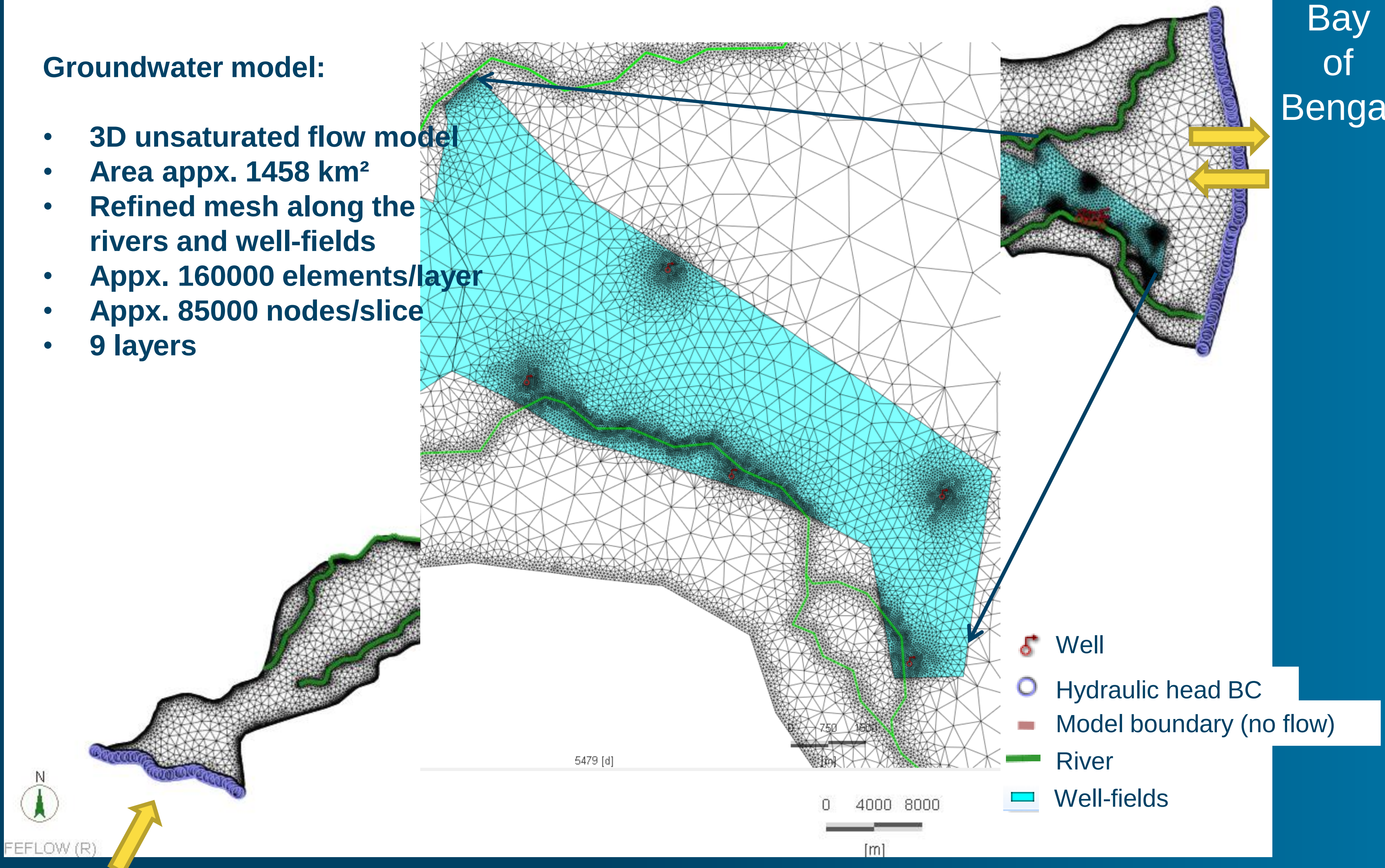
Groundwater model

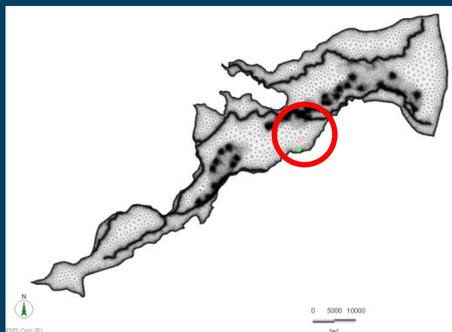
Groundwater model:

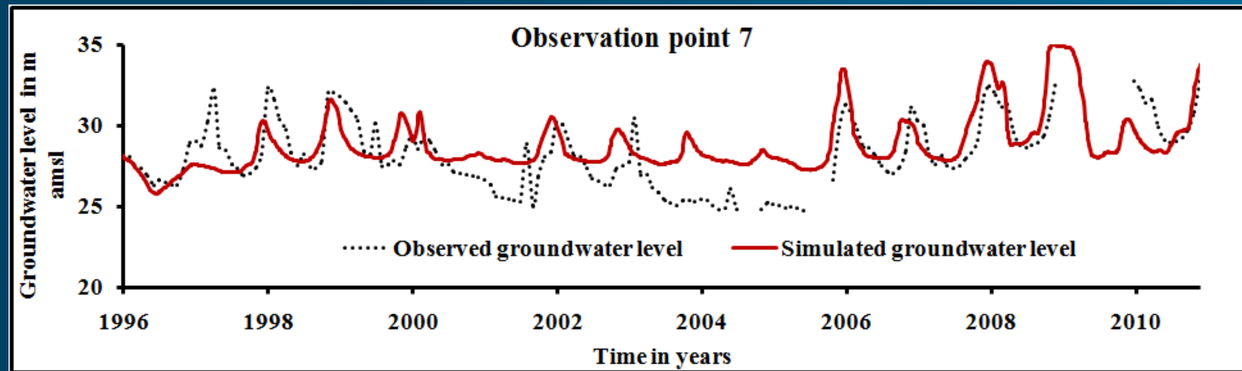
- **3D unsaturated flow model**
- **Area appx. 1458 km²**
- **Refined mesh along the rivers and well-fields**
- **Appx. 160000 elements/layer**
- **Appx. 85000 nodes/slice**
- **9 layers**



Interaction of surface water and groundwater under highly dynamic conditions

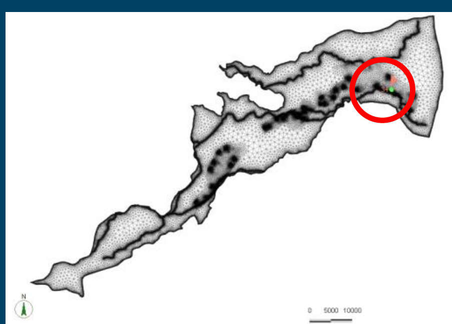
Calibration

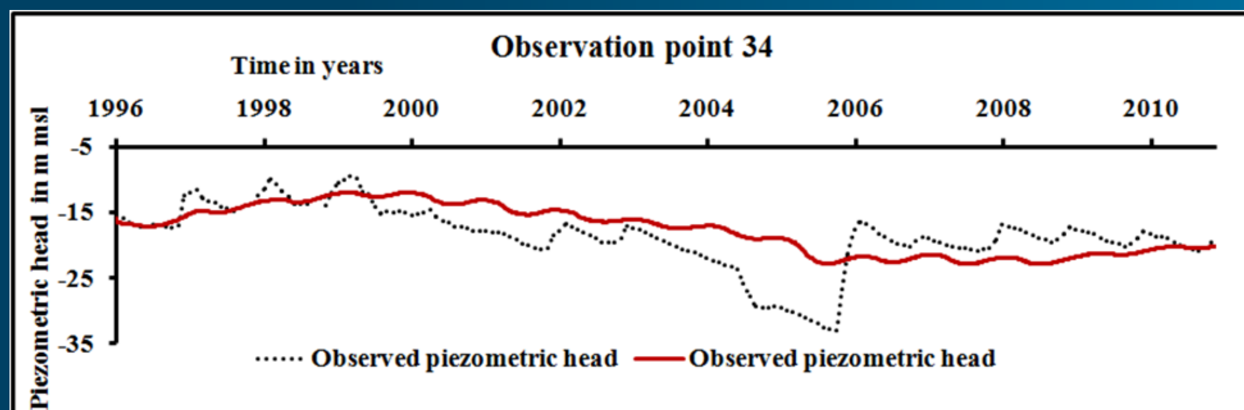




ObsPoint 7 in Slice 1

Observed vs simulated groundwater level in single aquifer system



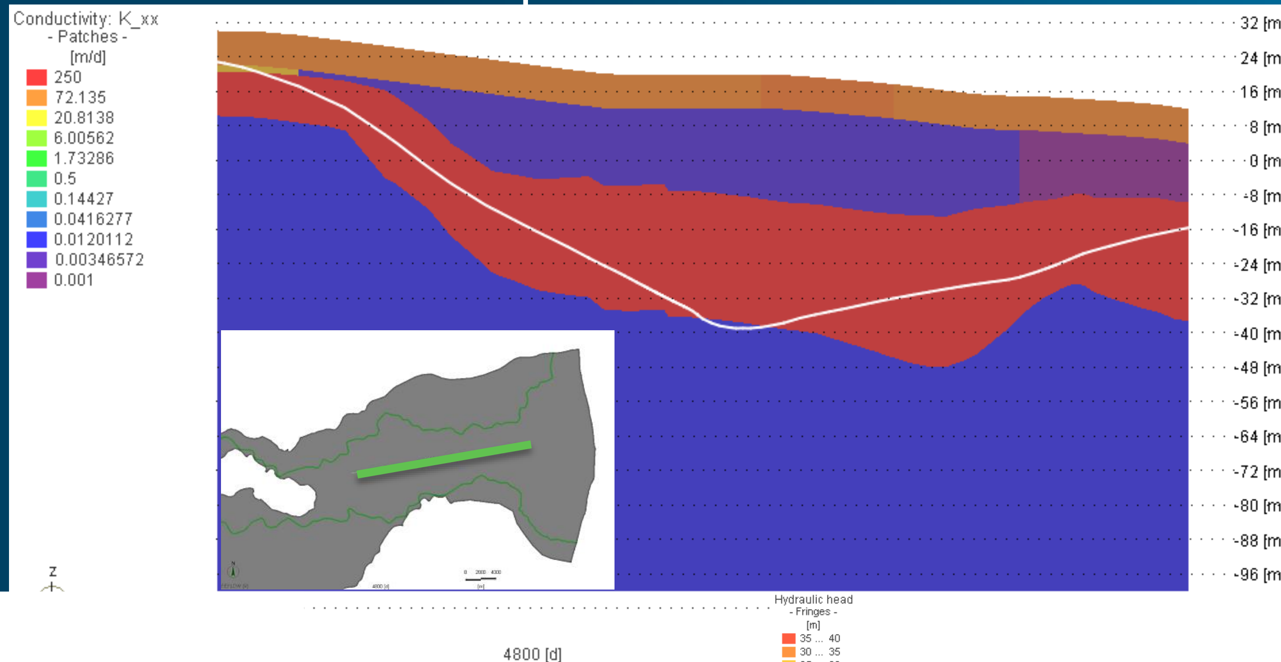


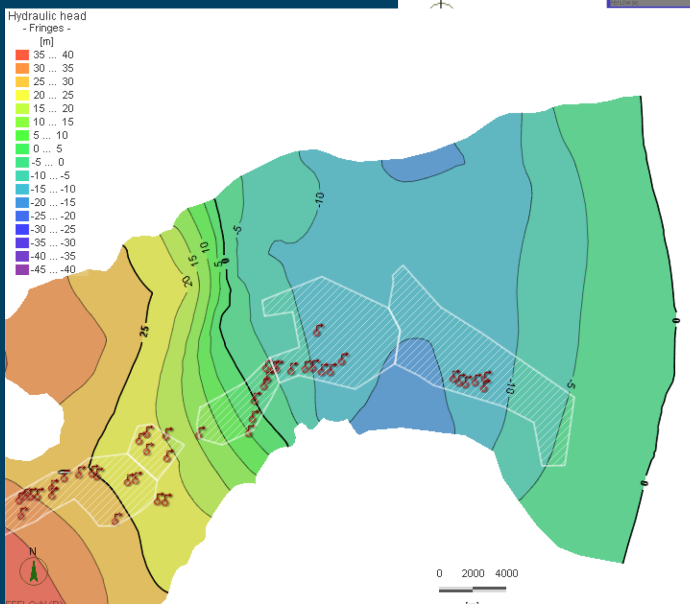
ObsPoint 34 in Slice 6

Observed vs simulated piezometric head in bottom aquifer (Minjur well field)

Results

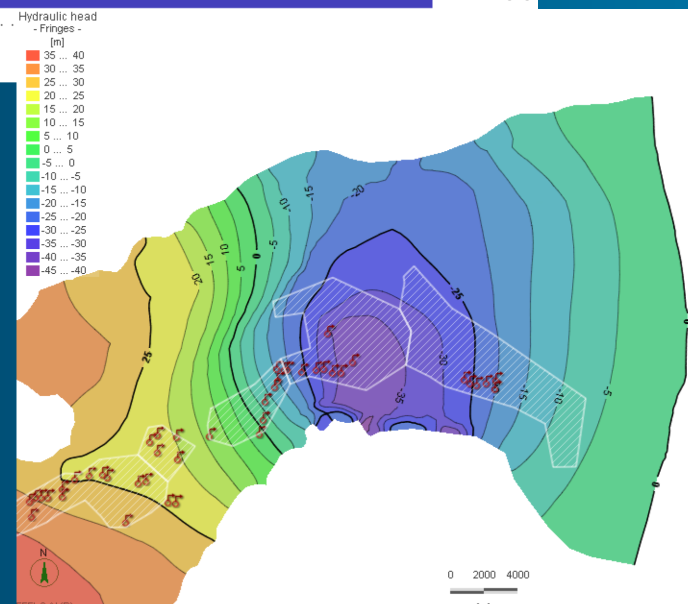
Cone of depression due to abstraction





January 1998

January 2009



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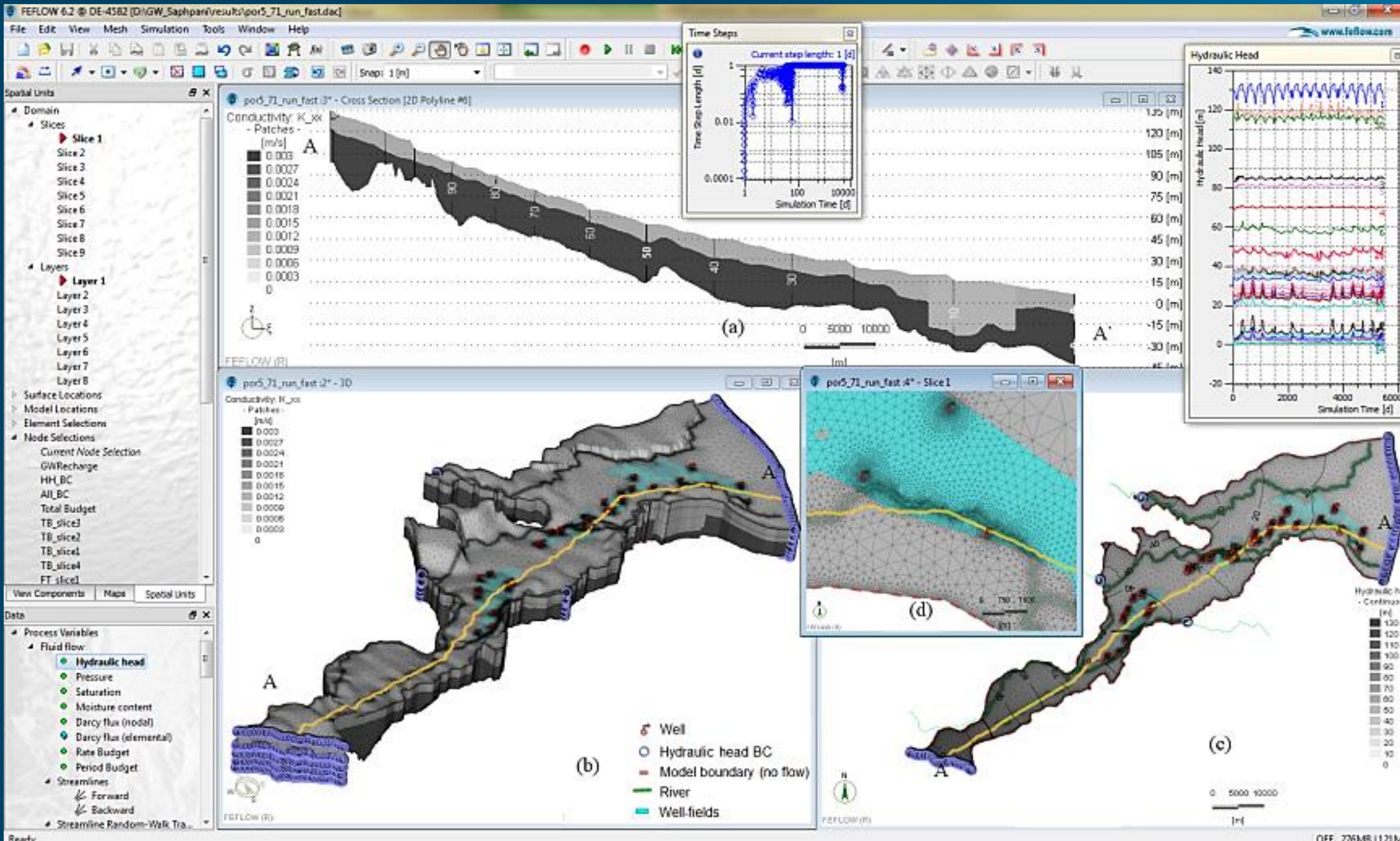
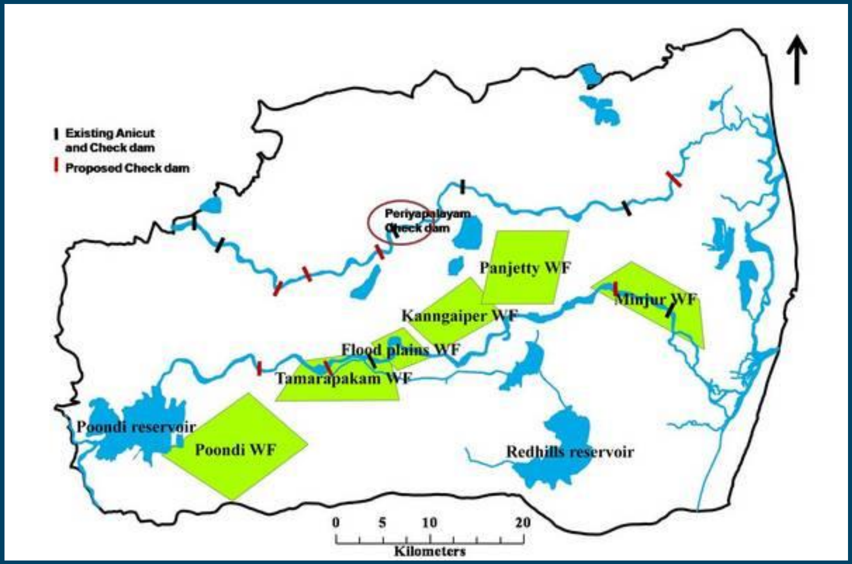
Coupling to MIKE 11 by IfmMIKE11



Interaction of surface water and groundwater under highly dynamic conditions

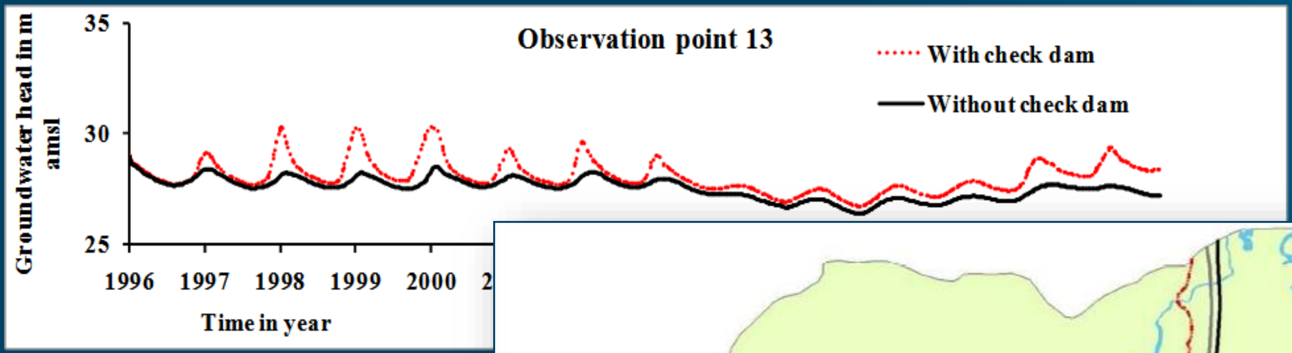
MAR measure – Check dams

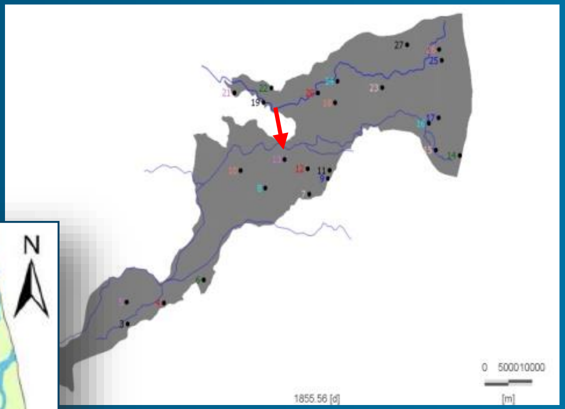


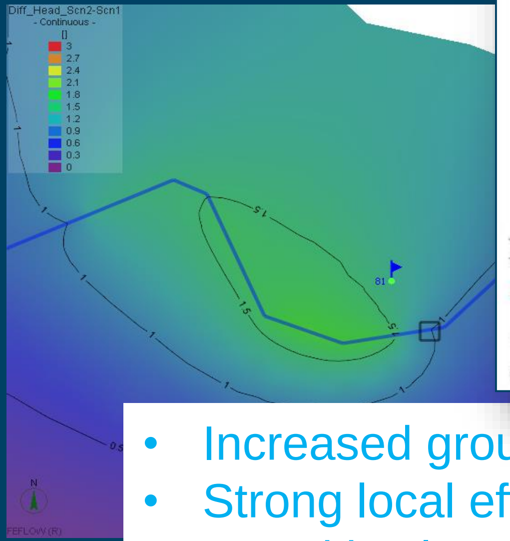
Interaction of surface water and groundwater under highly dynamic conditions

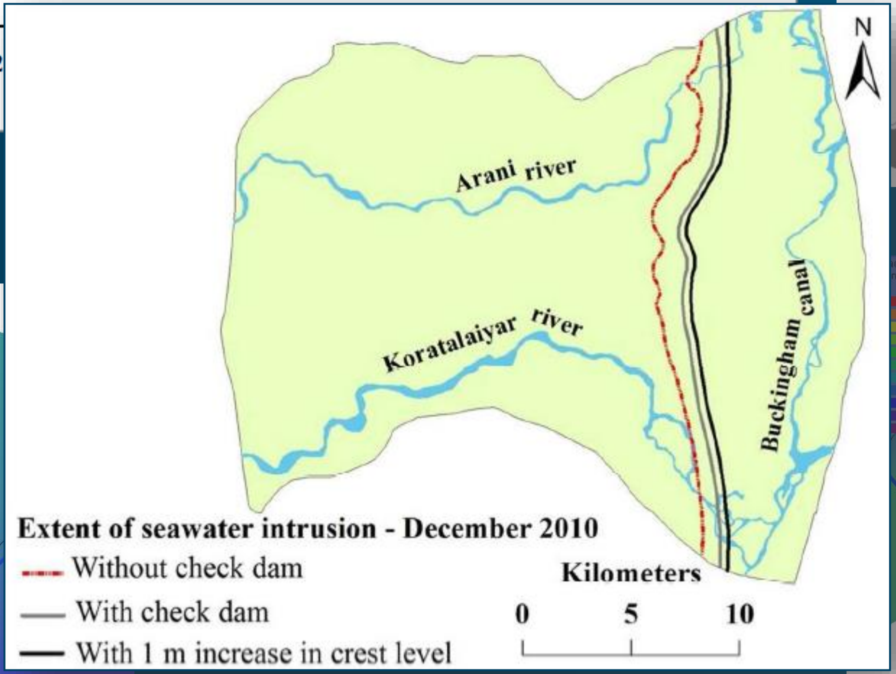
MAR Measure – Check dams

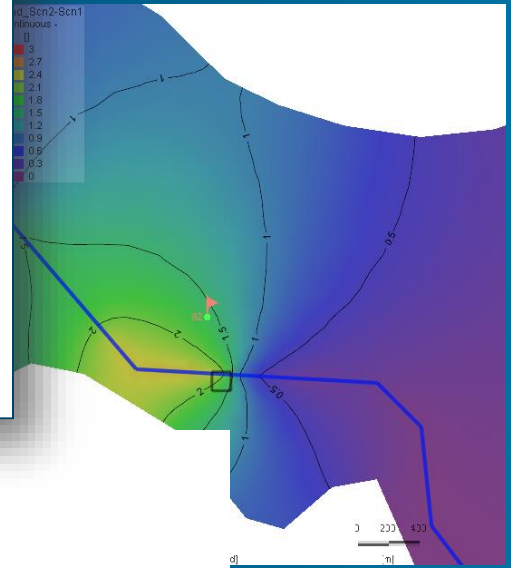
Groundwater head with and without existing check dams











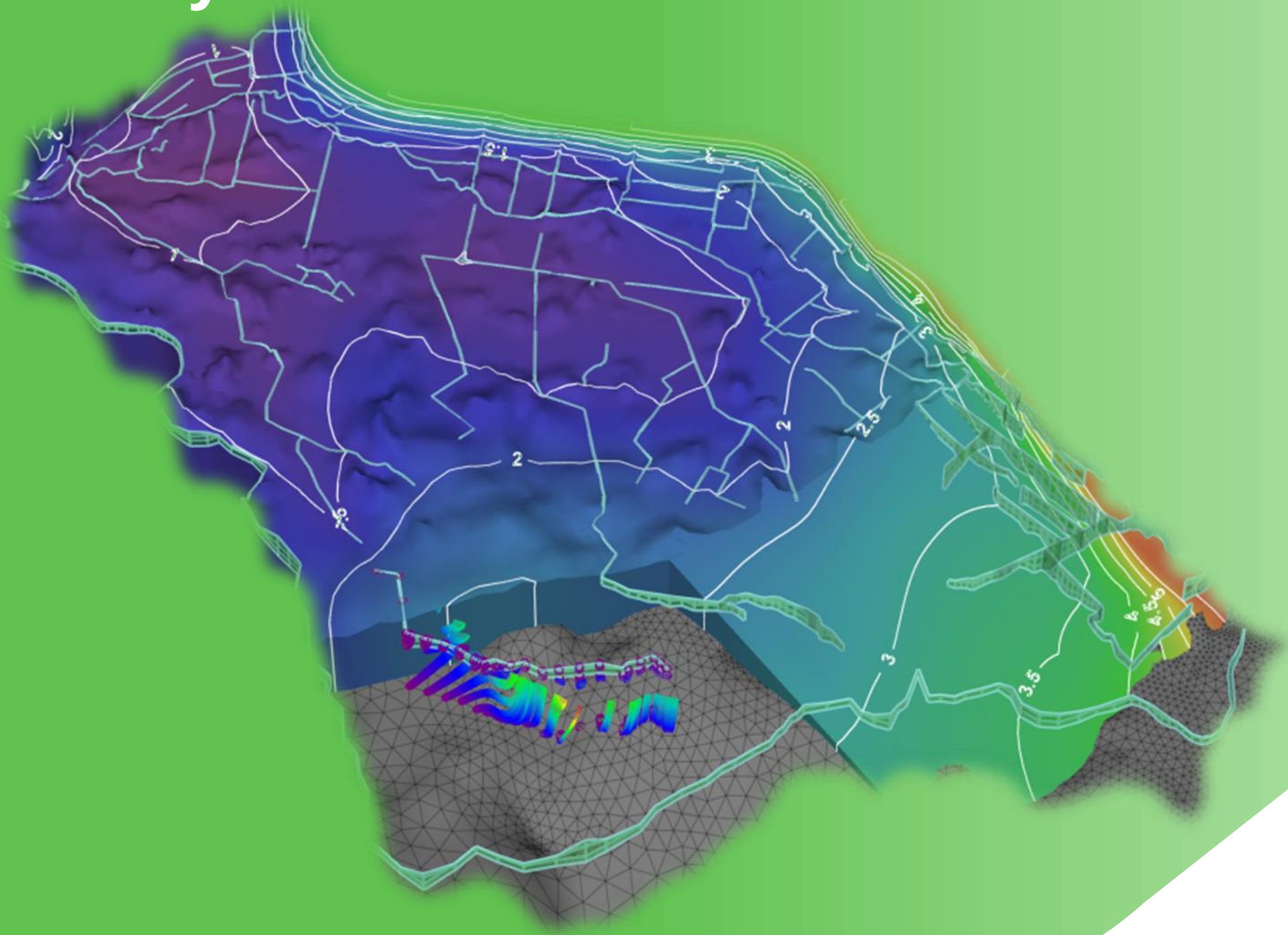
- Increased groundwater levels due to check dams
- Strong local effect on heads
- A positive longterm effect on the salinities

Interaction of surface water and groundwater under highly dynamic conditions

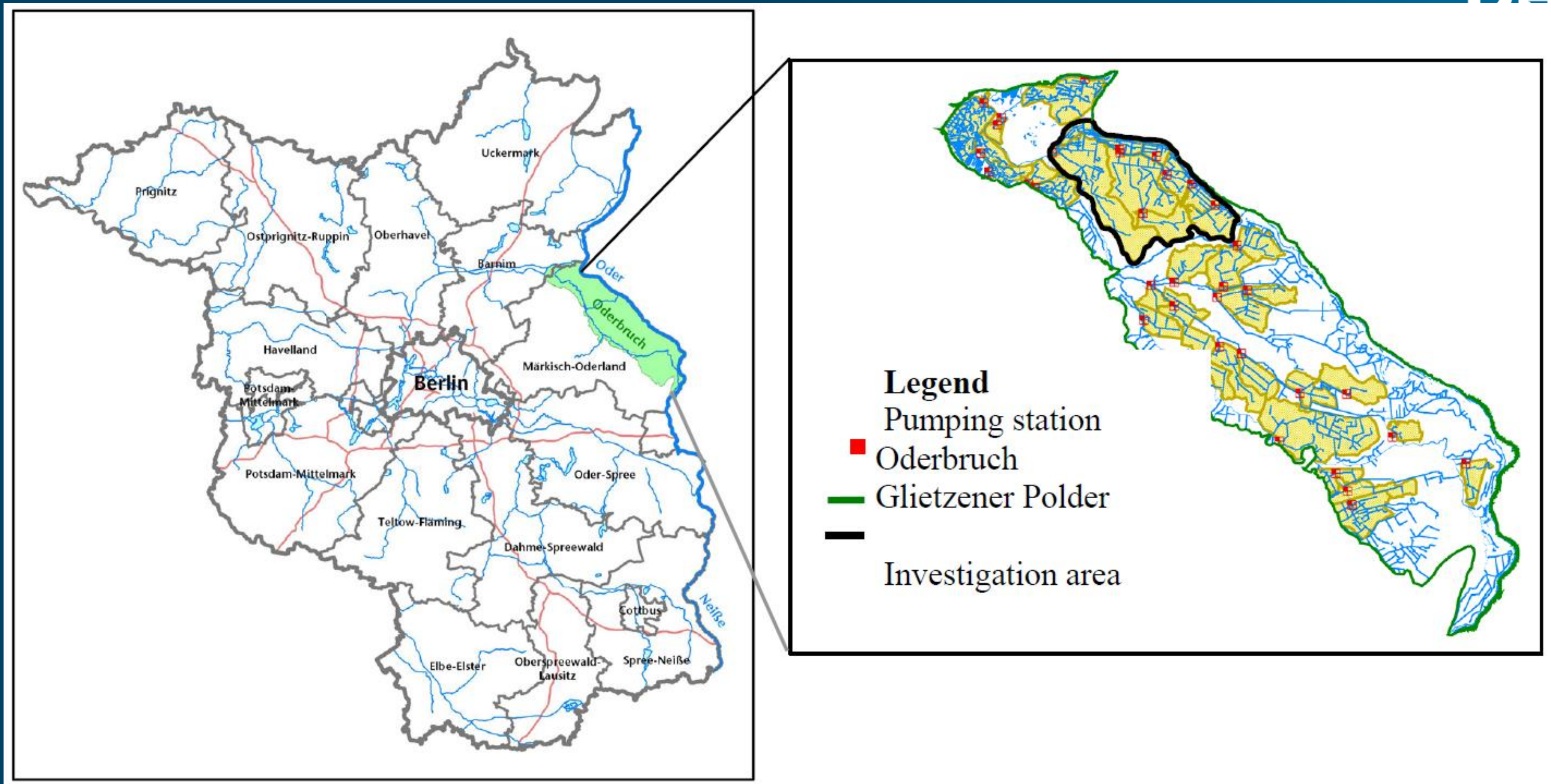
Conclusions

- Calibrated integrated surface and groundwater model (MIKE11 and FEFLOW)
- Successful surface and groundwater modelling coupling (IfmMIKE11)
- Salinity transport could be modelled
- MAR scenarios indicate a positive but relatively slow effect
- The existing tool can be used for
  - running more specific MAR scenarios
  - optimizing well extraction schemes and locations
  - identifying drinking water protection zones
  - geothermal feasibility studies
  - Environmental Impact Assessments

Balancing interests along the Odra River, Germany

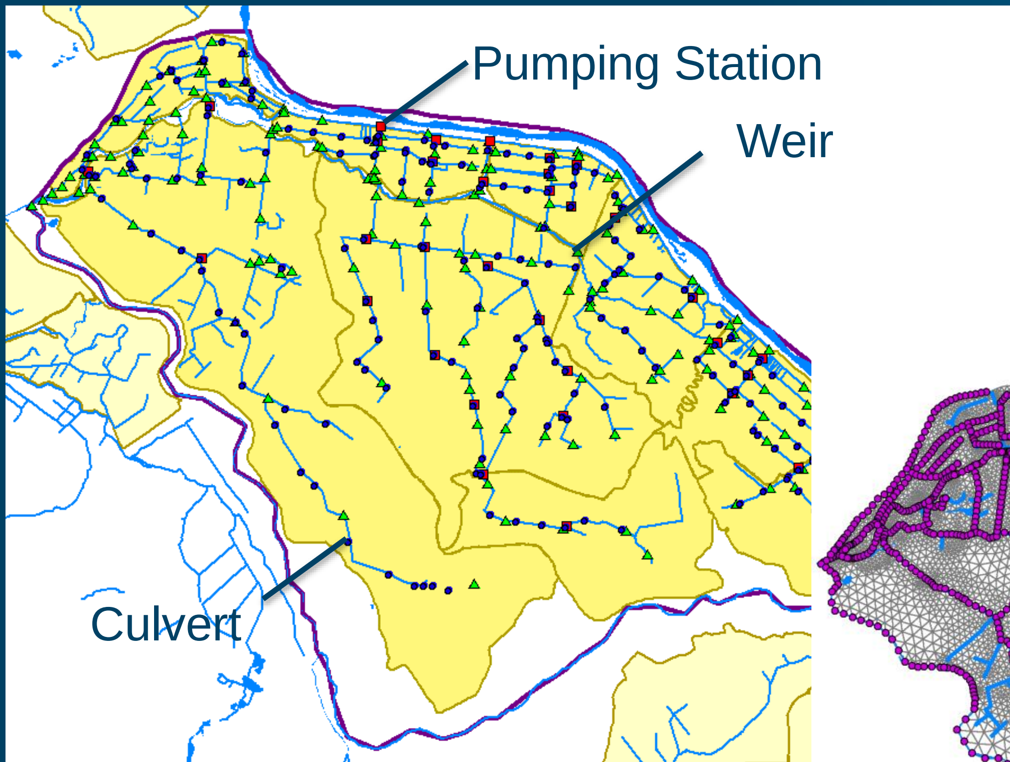


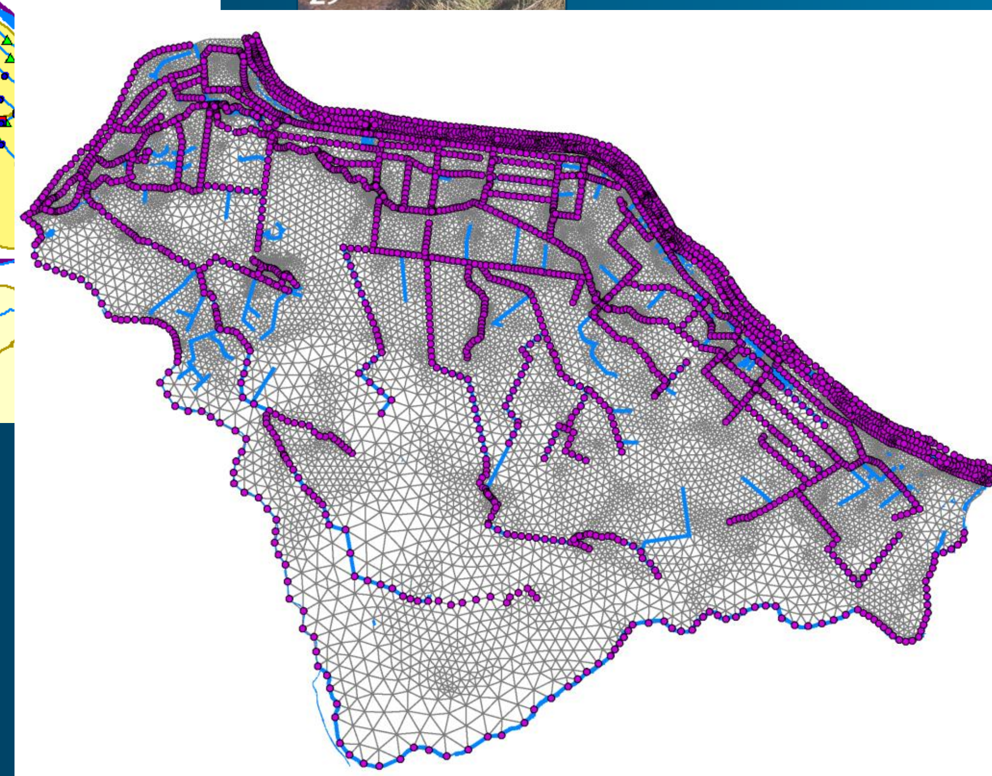
Oderbruch (low lands along Odra)



- Intensive agriculture, low lands dewatering, ecologically important habitats
- Ditches, drains, pumping stations, weirs
- Objective: Optimize water management to achieve acceptable groundwater levels for various stakeholders and maximize storage

Oderbruch (low lands along Odra)

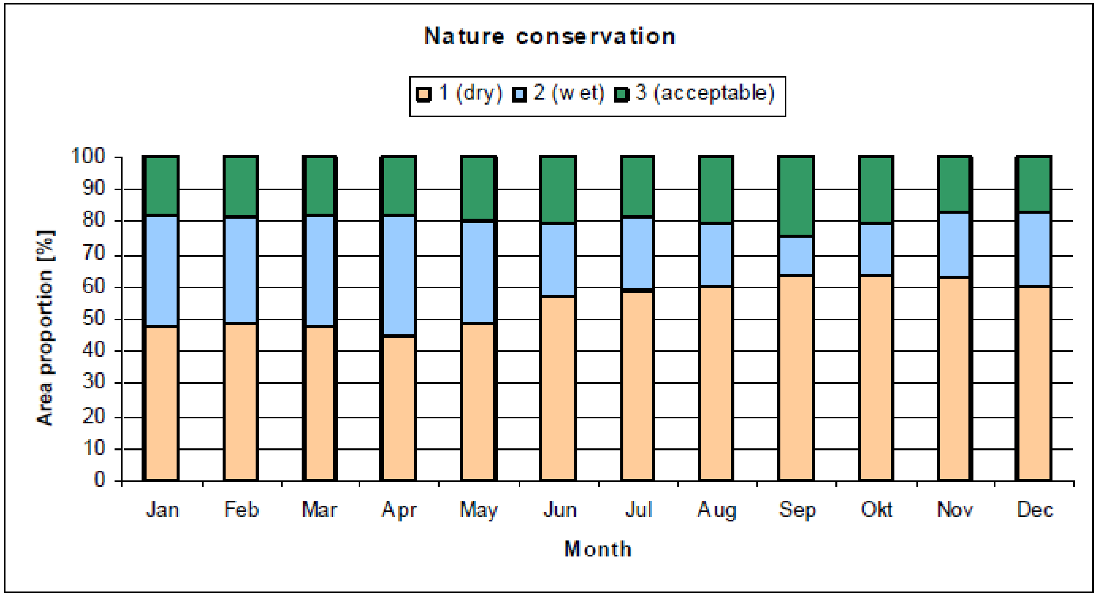




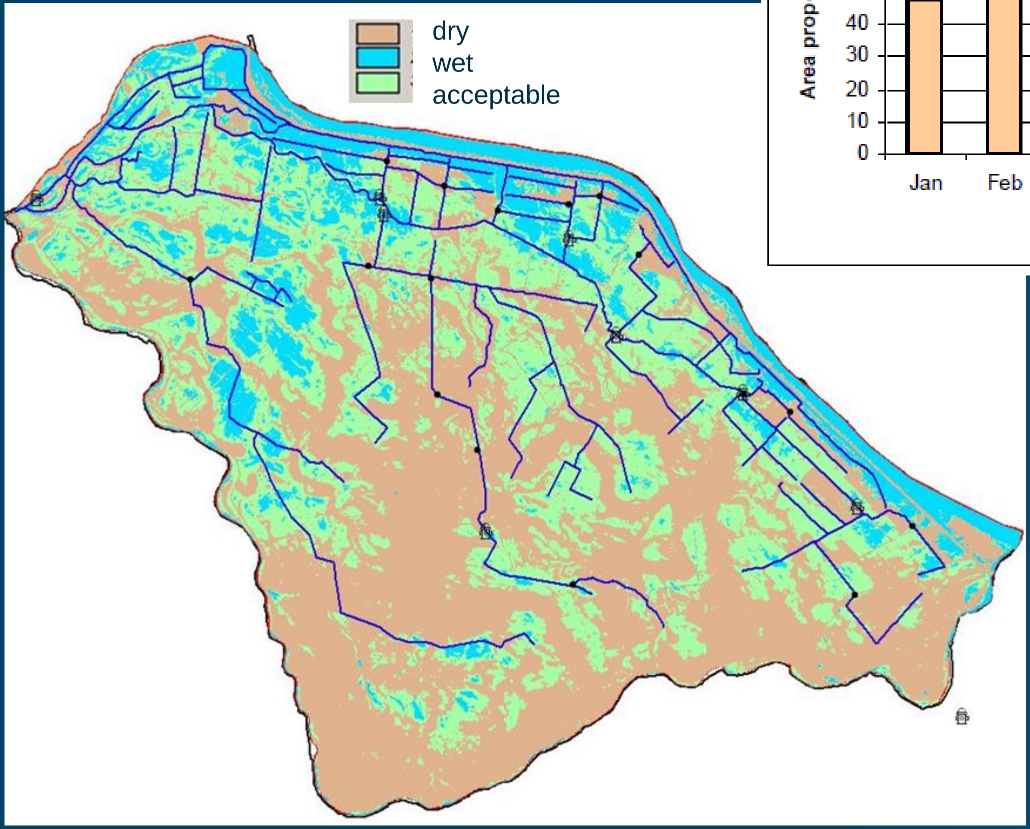
Interaction of surface water and groundwater under highly dynamic conditions

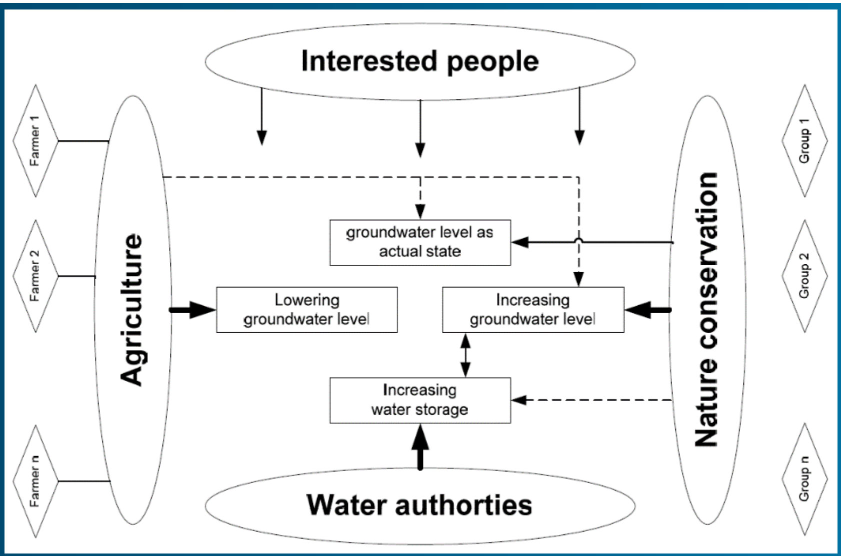
Balancing interests on a monthly basis

Statistical analyses for current state for nature conservation



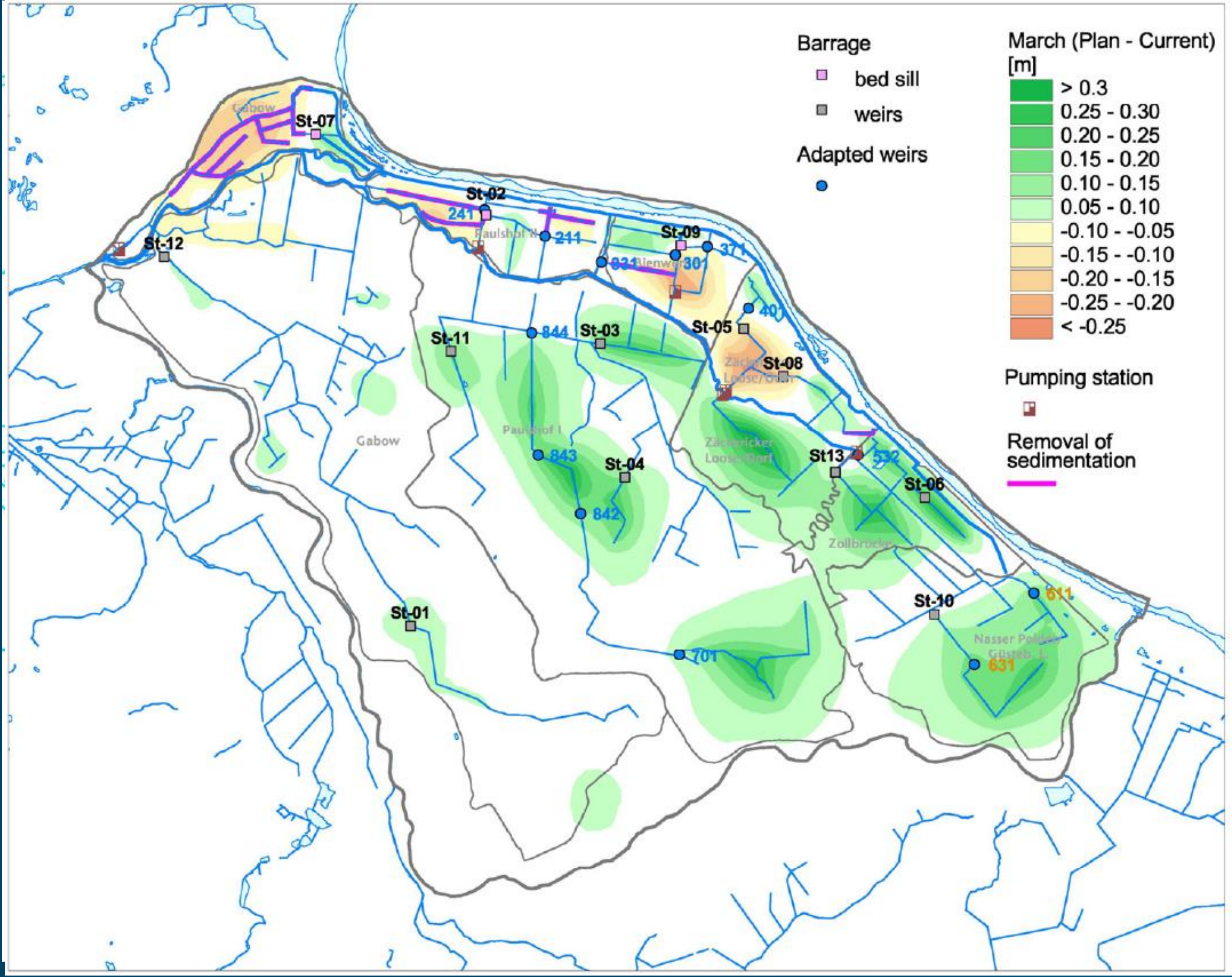
current state in March for agriculture





Interaction of surface water and groundwater under highly dynamic conditions

Balancing interests on a monthly basis



Proposed measures

Resulting groundwater differences in March

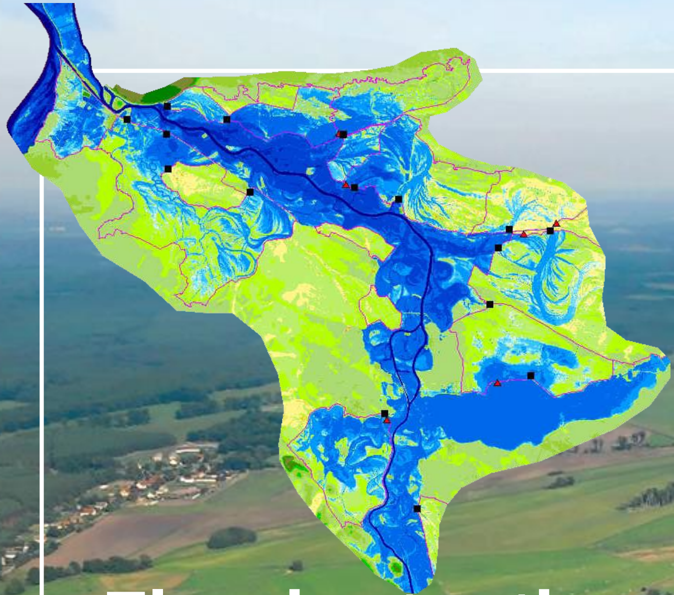
Interaction of surface water and groundwater under highly dynamic conditions

Conclusions

- By:
  - Changing of the target water levels of the pumping stations
  - Demolition of several pumping station
  - New construction or demolition of weirs
  - Removal of sedimentation in several ditches (clearing of mud)
  - New construction or demolition of several ditches
  - Changing connection of the dewatering ditch of the dam (Odra)

- Following main objectives for the lowlands along the river Odra could be reached:
  - Maximum water storage within the area
  - Achievement of acceptable groundwater levels for all parties (stakeholders) concerned.
  - Reduction of energy (pumping) and maintanance costs

- This could only be achieved by a fully coupled surface water and groundwater model (FEFLOW/MIKE11)!



http://de.wikipedia.org/wiki/Elbehochwasser_2002

Foto: NABU

Flood retention along the Elbe River, Germany

LAND BRANDENBURG

SACHSEN-ANHALT

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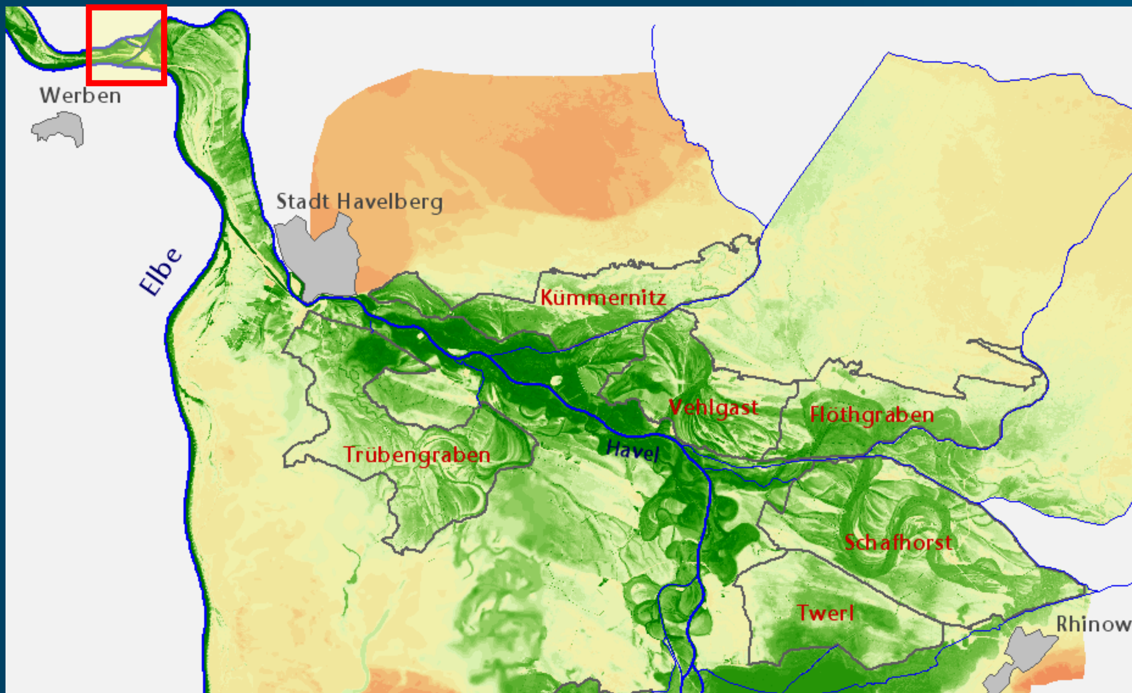
Optimization of fooding the River Havel to minimize flood damages along the River Elbe (Flood 2002)



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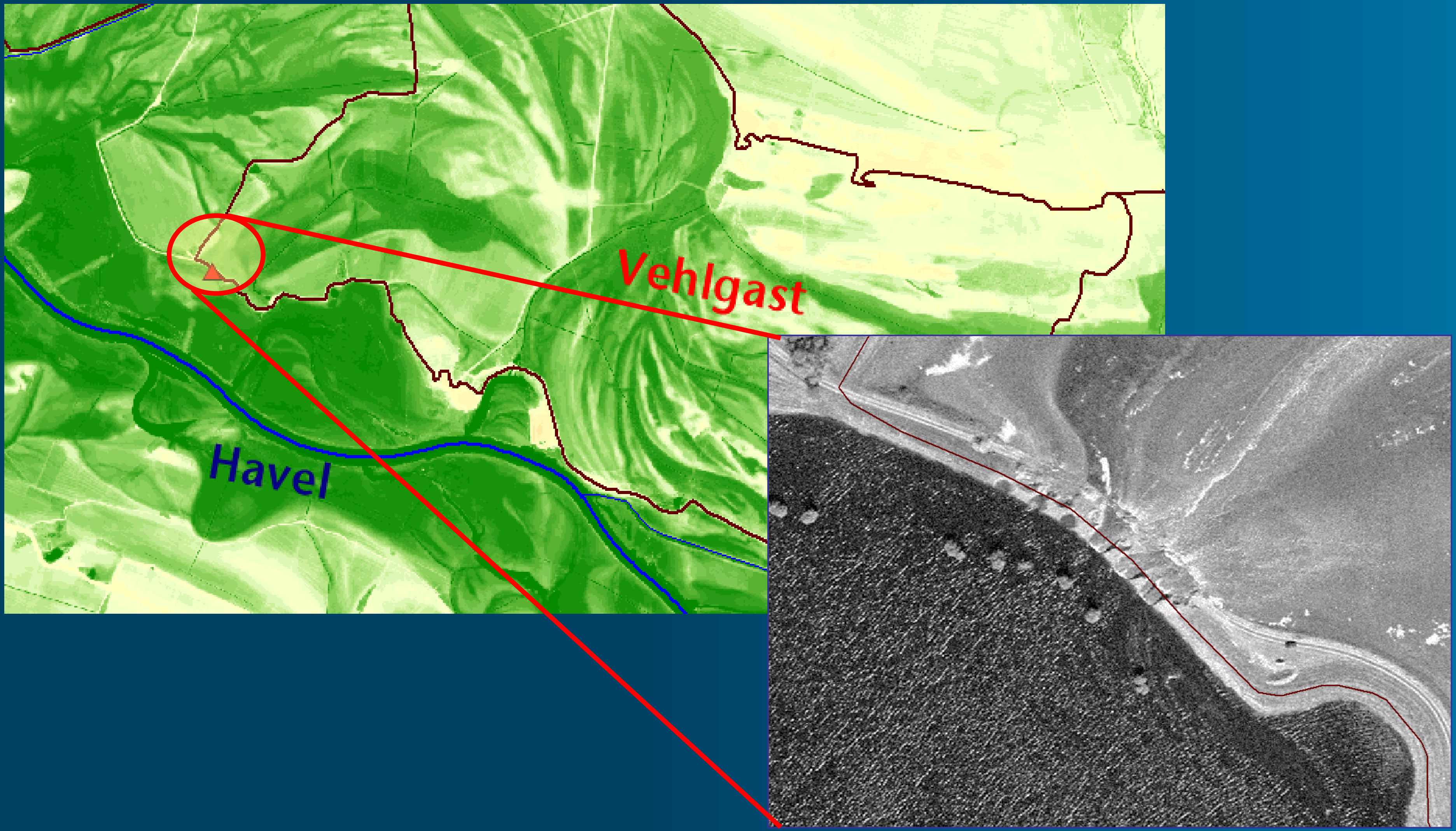
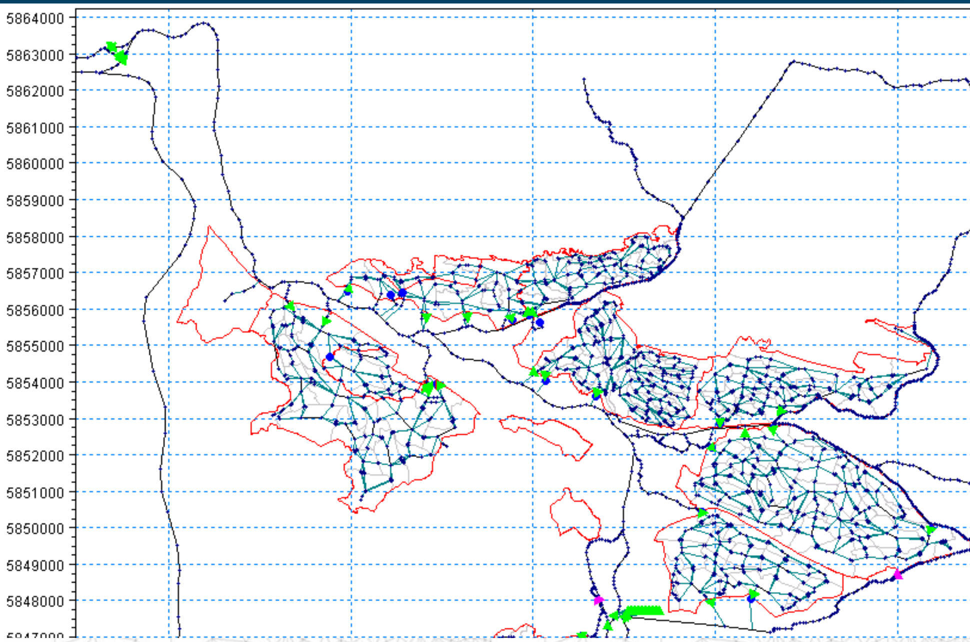
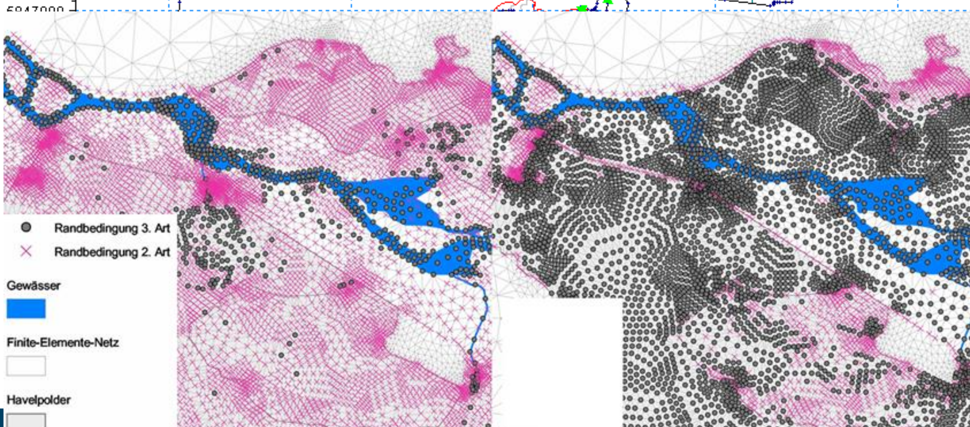
Polder floding

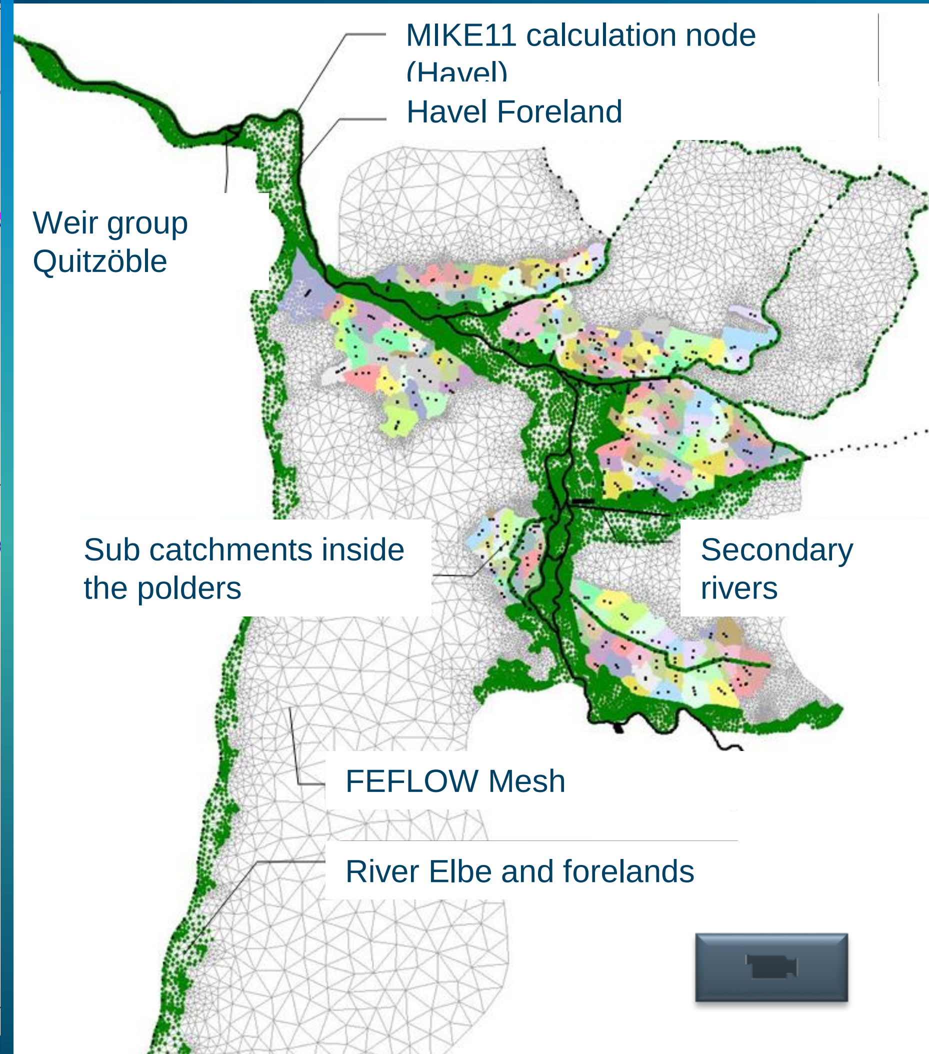


Interaction of surface water and groundwater under highly dynamic conditions

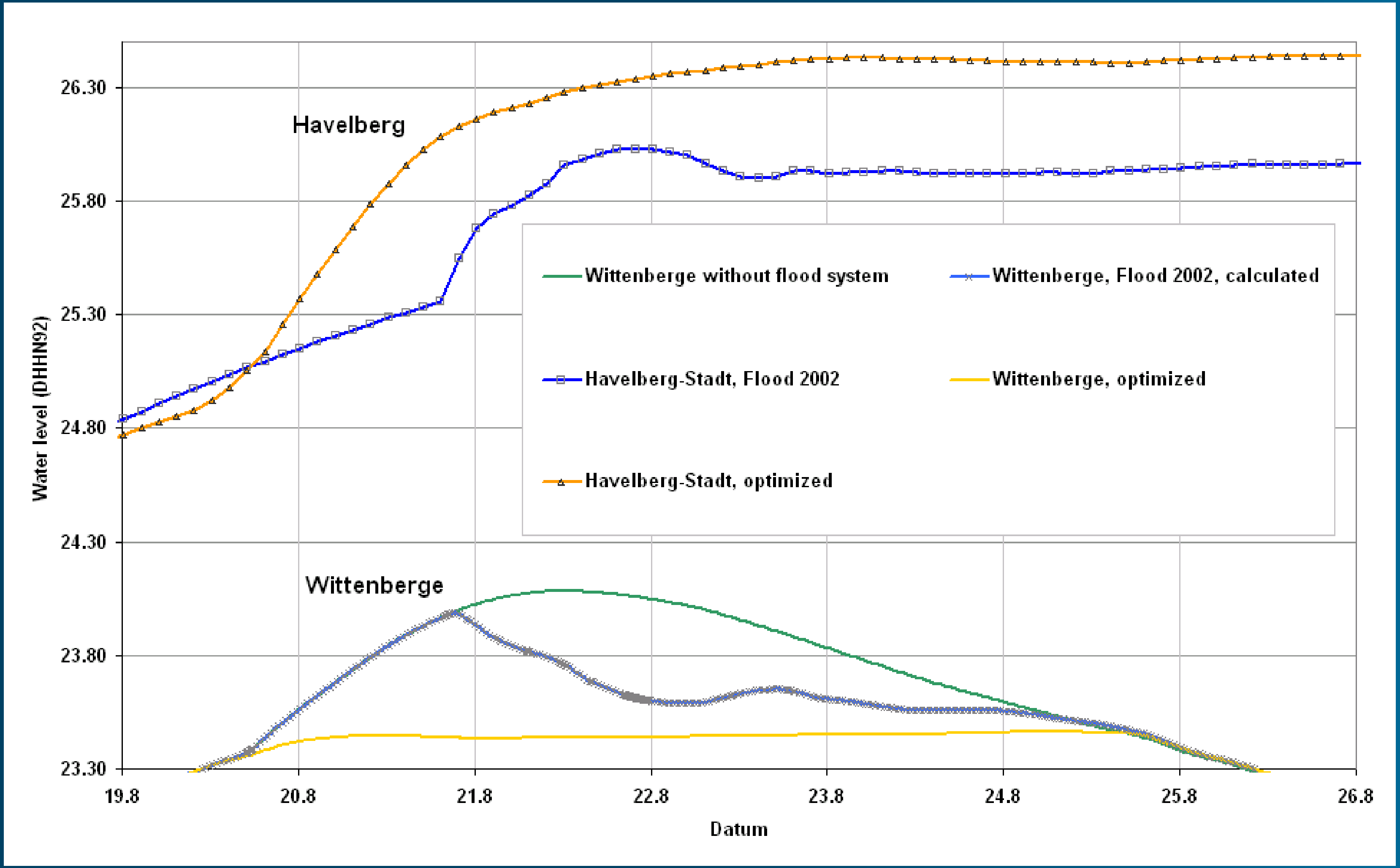
Model overview





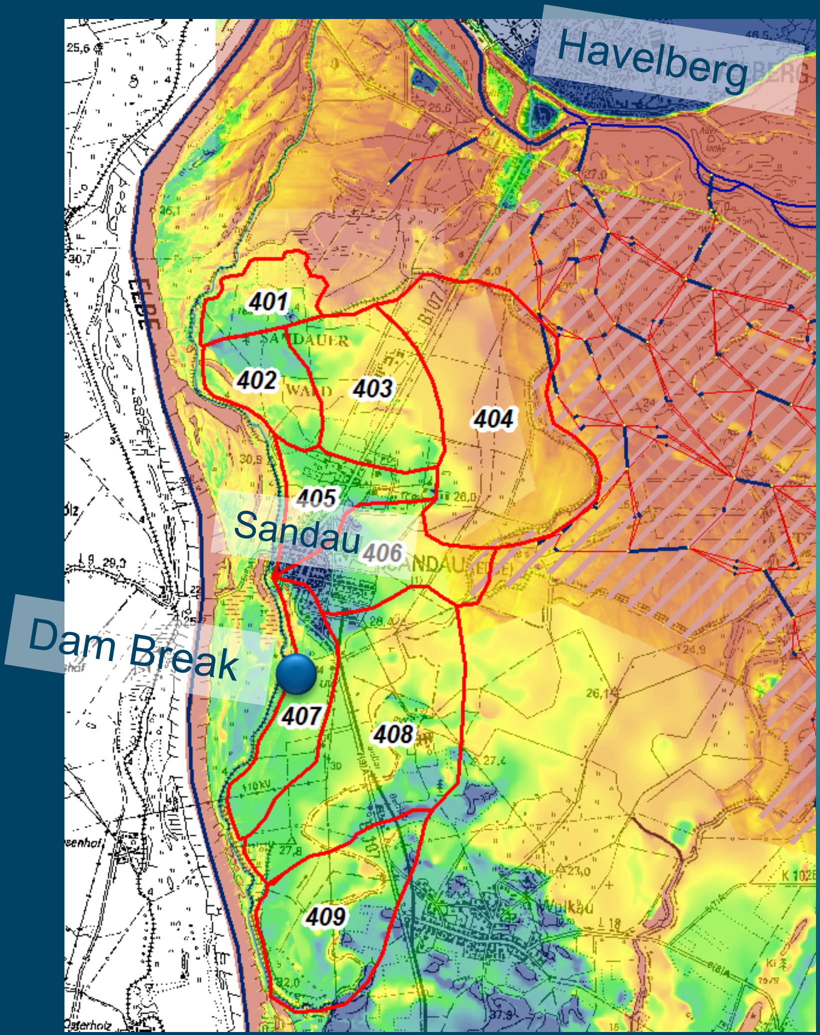


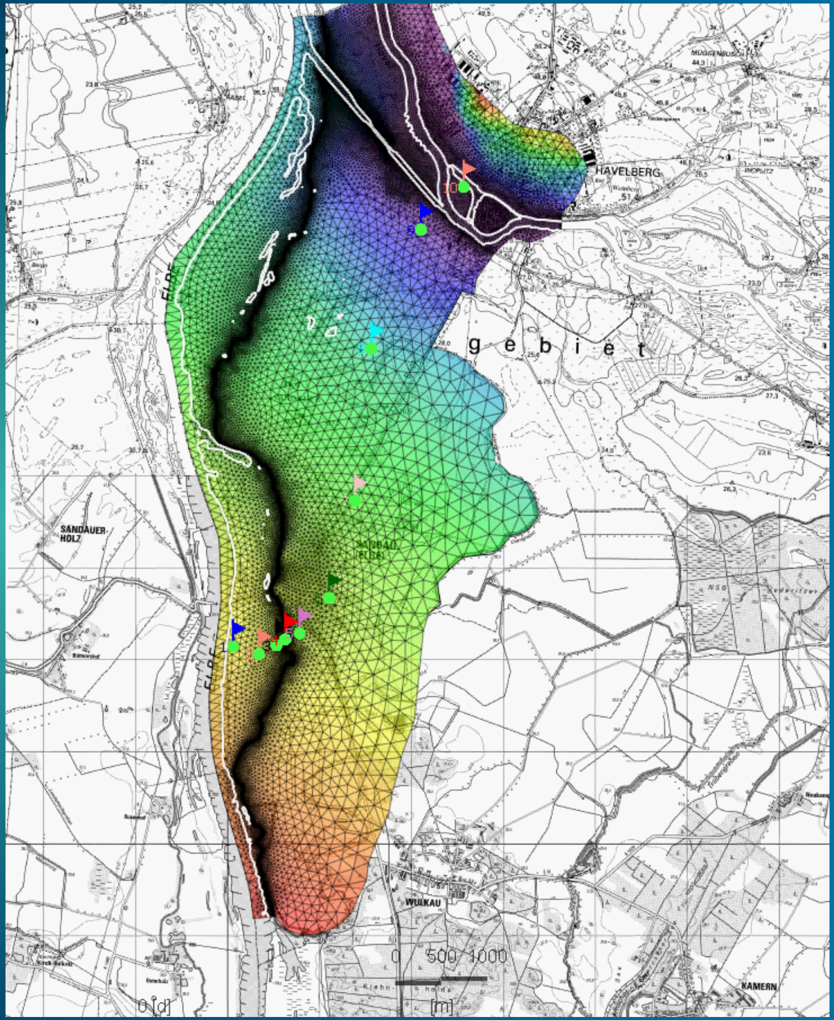
Optimized Results



Interaction of surface water and groundwater under highly dynamic conditions

Examples for dam break scenarios "*Island Sandau*"





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Conclusions and Outlook

- IfmMIKE11 is a well working tools for FEFLOW, offering integrated surface- and groundwater analyses for operational use.
- The tool can (for example) be used for:
  - meeting BO driven target flows;
  - managed aquifer recharge;
  - polder management;
  - groundwater flooding;
  - mine water management and many other applications.
- The tool is ready to use and was tested successfully on numerous projects
- Further developments will include a bidirectional 2D- surface water coupling (MIKE21), time varying import filters for other 2D surface water models and an integrated coupling to sewer systems (MIKE URBAN)

Thank you for your attention

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