Deltares
Enabling Delta Life

# Regional Modelling with iMOD

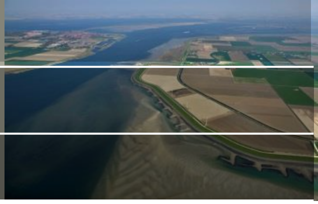
*Unravelling the complex link between geology and groundwater flow - application to the Visp basin*

Peter Vermeulen
*Deltares, Subsurface and Groundwater Systems, Utrecht, the Netherlands*

22 june 2017


# Content

- DELTARES
- INTRODUCTION OF IMOD
- SOME CASE STUDIES
- VISP MODEL



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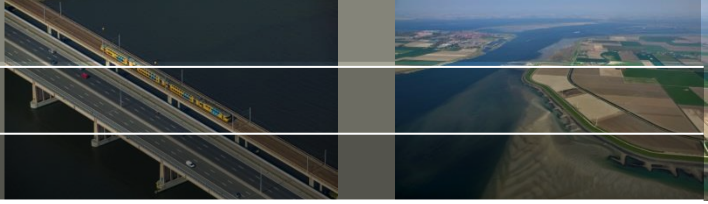
**Independent institute for applied research in the field of water, subsurface and infrastructure**

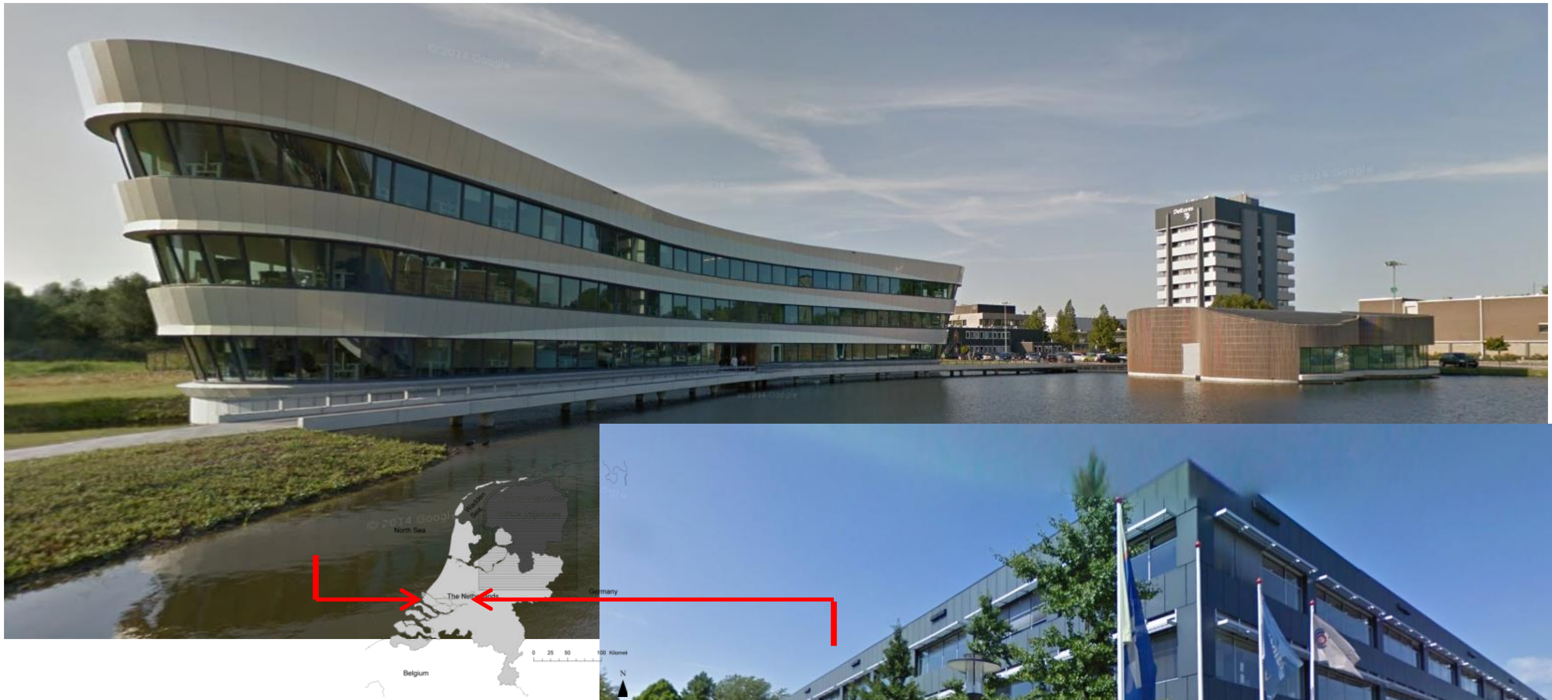
## Our Mission

**The top-level development and practical application of expertise in the area of water, subsurface and infrastructure for people, environment and society.**



# Locations

Delft
(85%)





Workforce: 840
Number of nationalities: 28
Annual turnover 113 million euros
National and international activities

Utrecht (15%)

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# Societal themes


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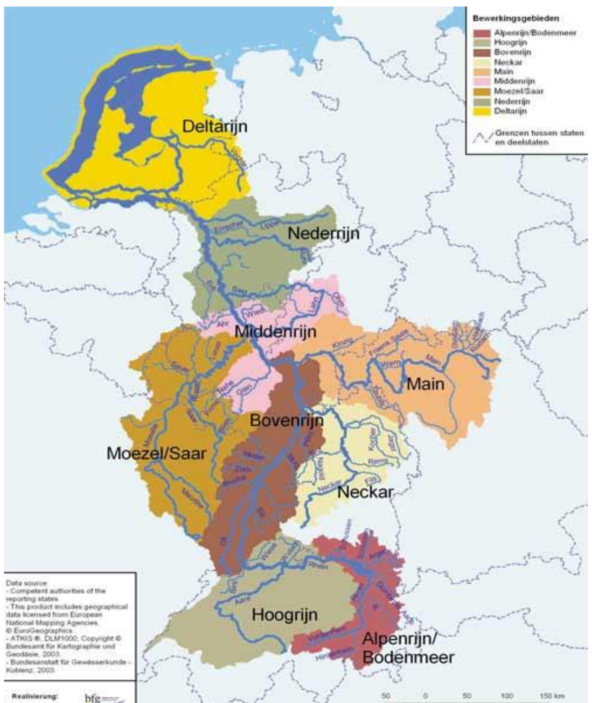
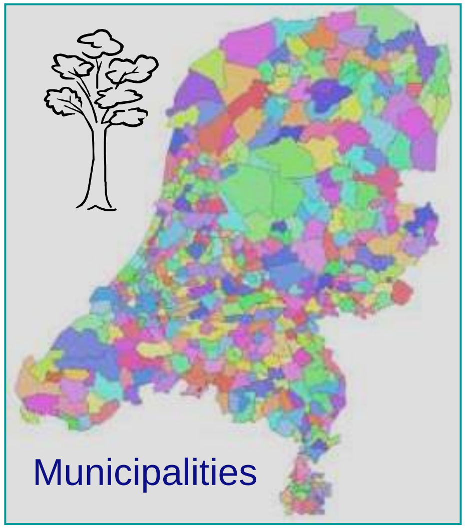
# Regional High Resolution Modelling

**WHY ?**

Groundwater disregards administrative boundaries forcing neighboring stakeholders to co-operate / build a groundwater model covering the area of all these stakeholders







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# Regional High Resolution Modelling

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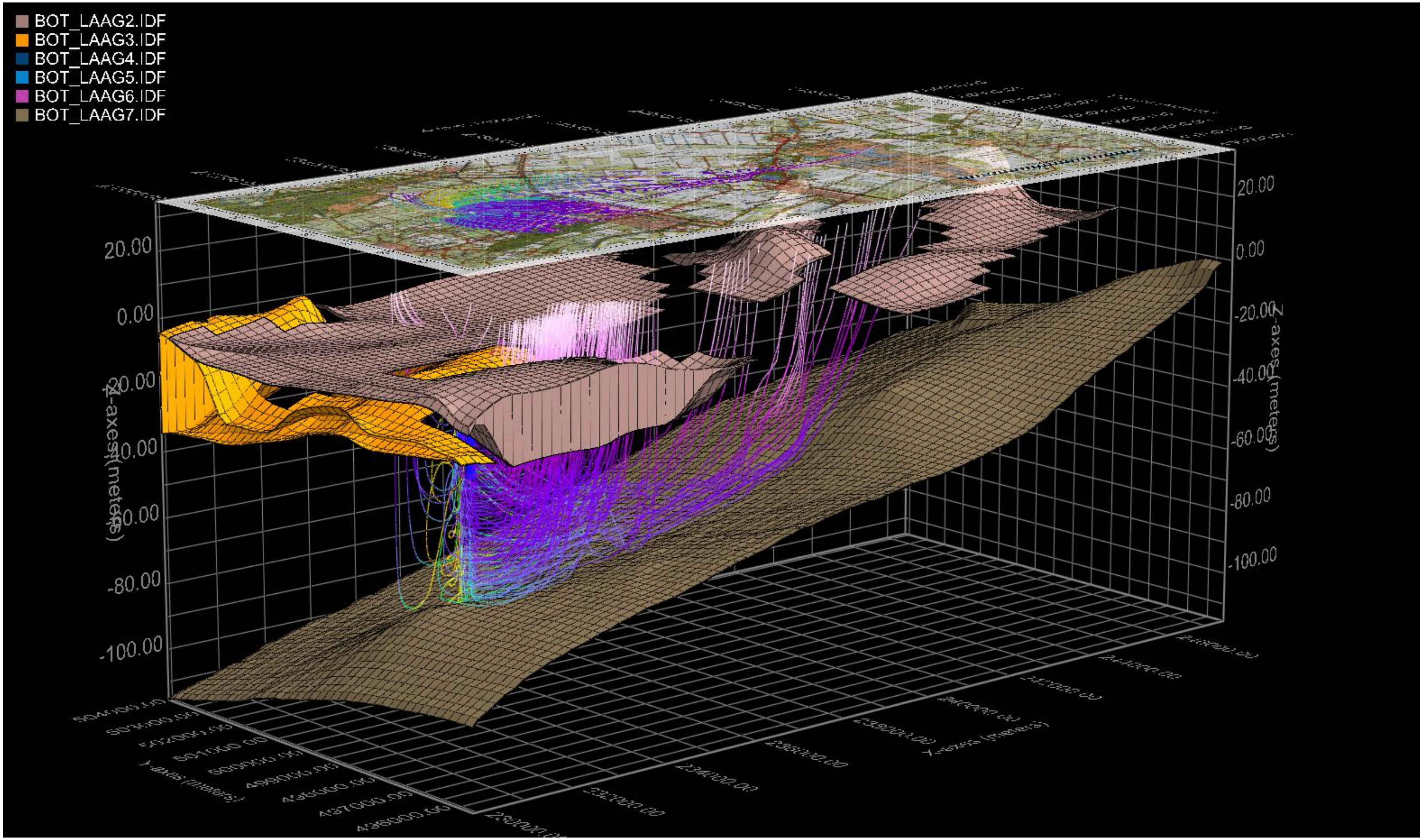
# Regional High Resolution Modelling

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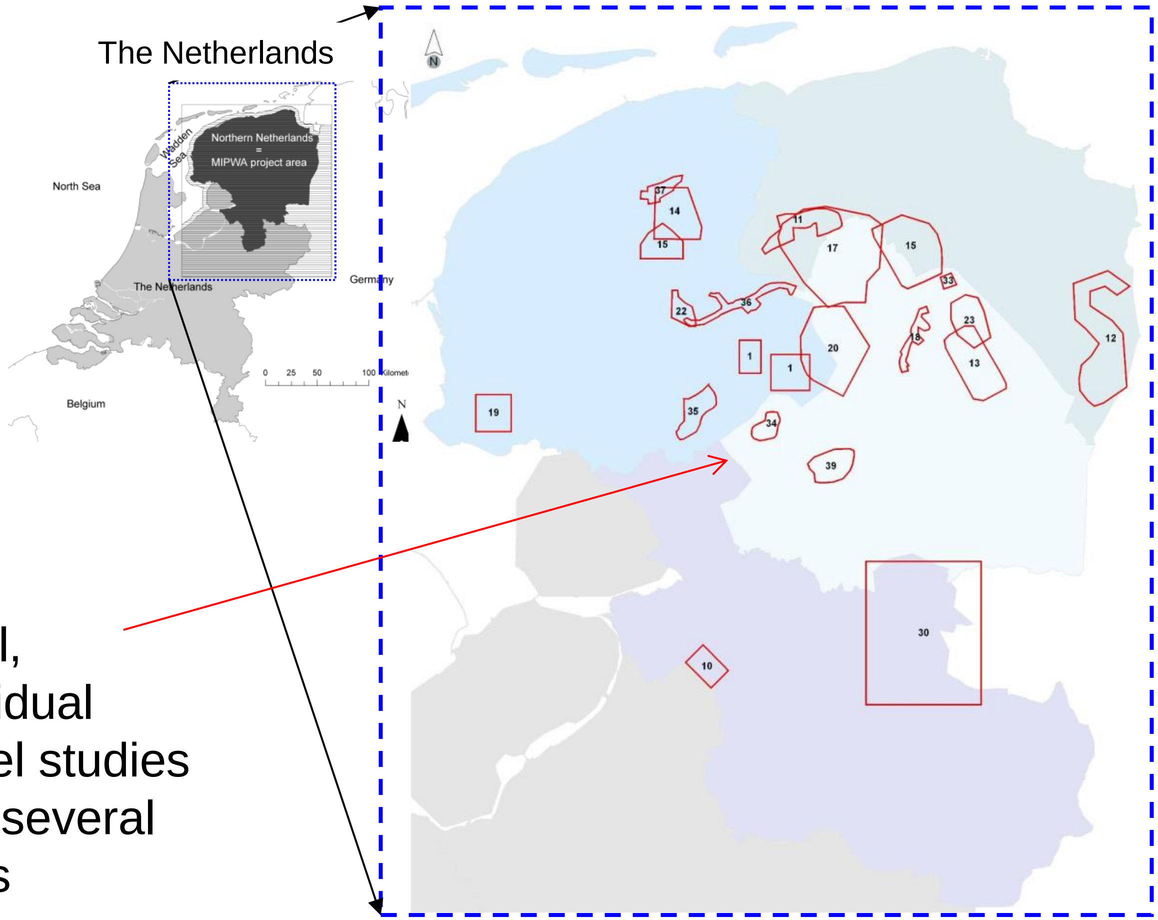
# Regional High Resolution Modelling

2005




Local, individual model studies over several years

***"Leaving the Era of series of Individual Models behind"***

***D. Palombi – AGS, Alberta***



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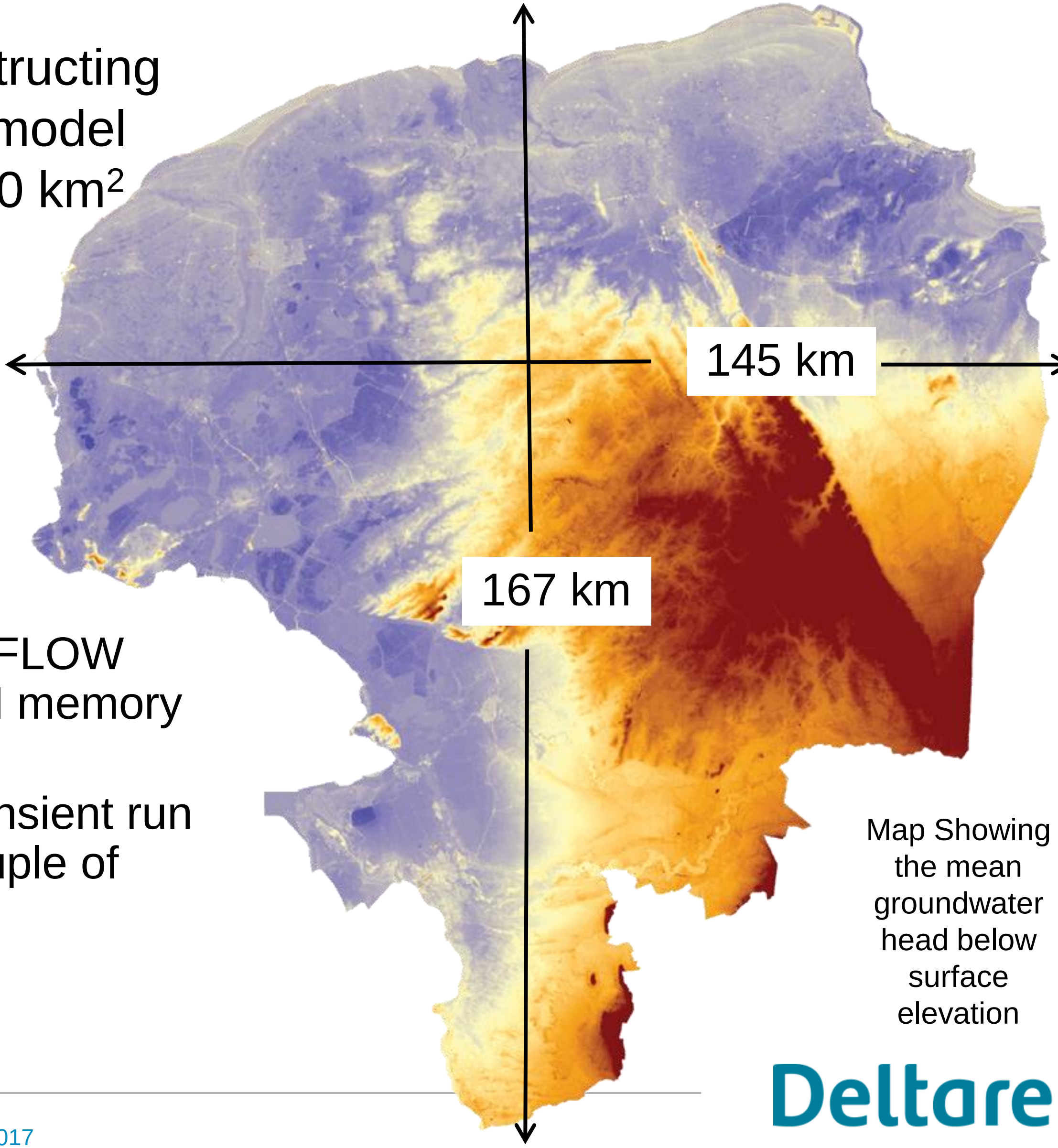
# Regional High Resolution Modelling

**Challenge in 2005:** Constructing a numerical groundwater model for a very large area 24000 $km^2$

Dimensions 3D-model:

- 7 layers
- resolution: 25 x 25 meter
- 271 million nodes

- Maximum size of a MODFLOW model on a 2 Gbyte RAM memory pc: ~ 50 million cells
- Estimated runtime for transient run (4000 stressperiods): couple of years !
- Runtime : $f(n^{1,5-2})$




Map Showing the mean groundwater head below surface elevation

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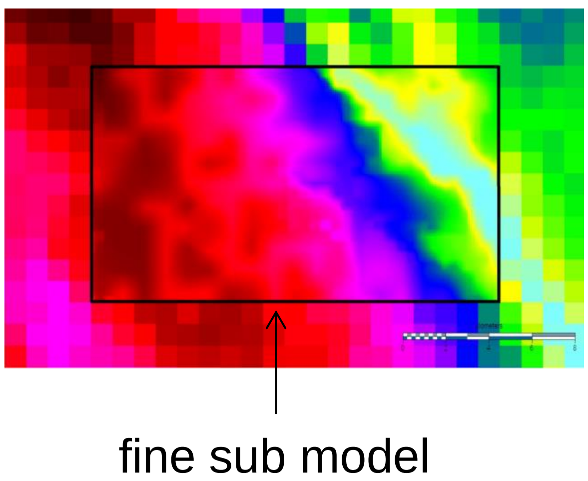
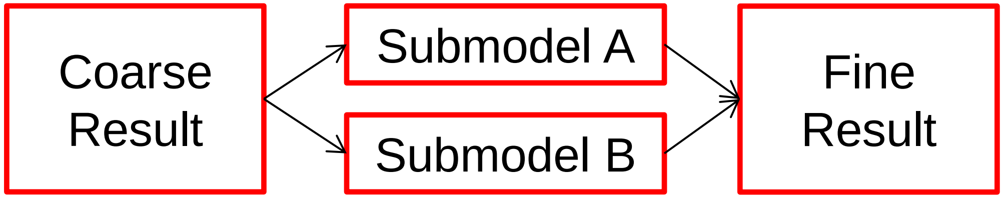
# Regional High Resolution Modelling

**iMOD-approach:**

- Georeferenced input- and output files;
- Facilitate an interactive and ad hoc generation of sub-models with user-defined cell size and model domain geometry;
- Consistency between different resolutions via applied up- and downscaling of original input data set.

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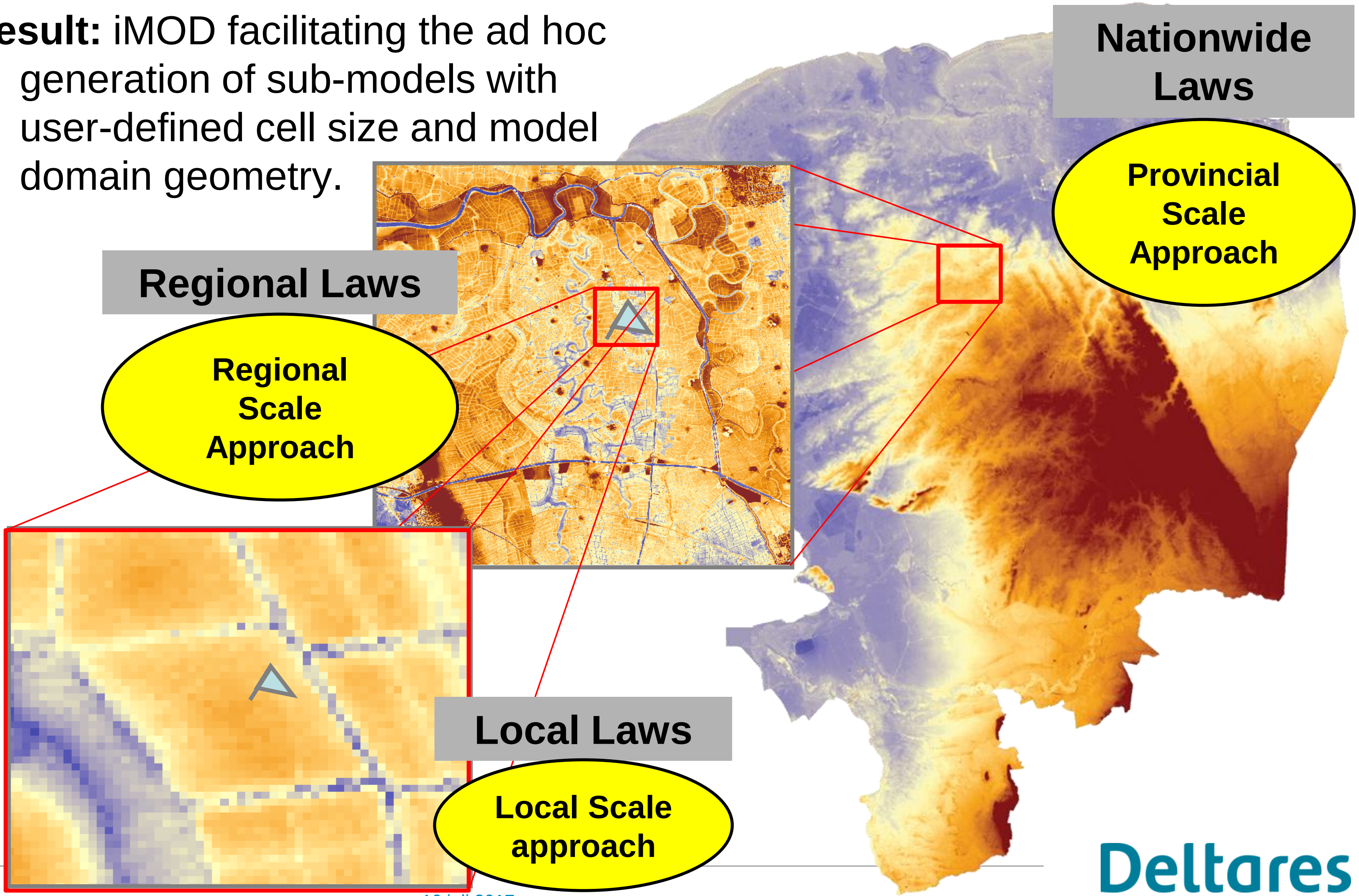
# Regional High Resolution Modelling

**Result:** iMOD facilitating the ad hoc generation of sub-models with user-defined cell size and model domain geometry.

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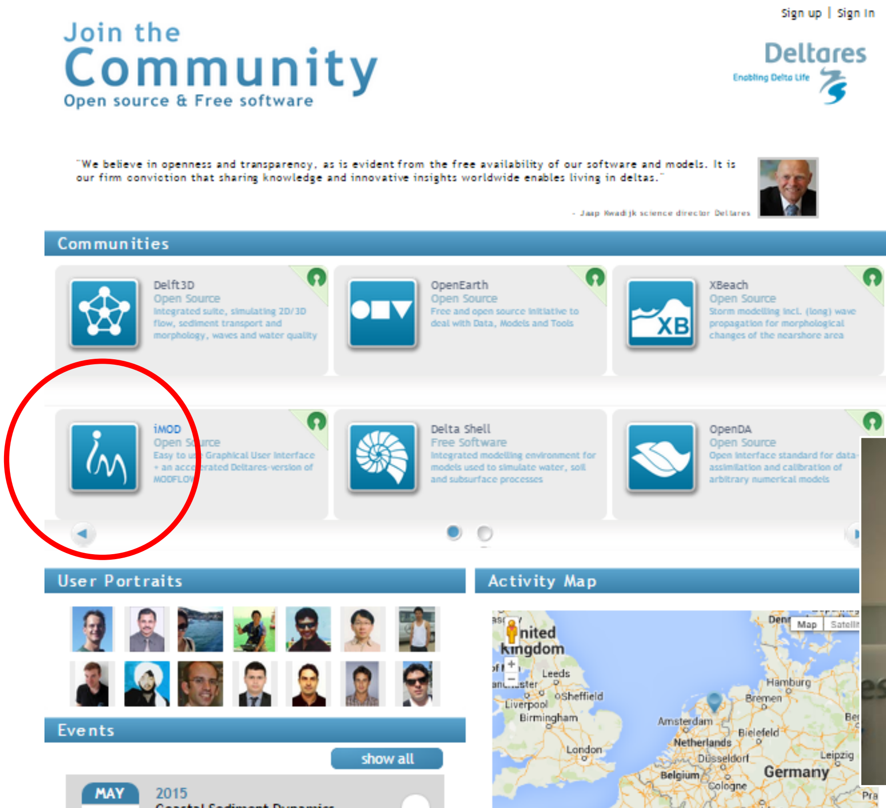
# Regional High Resolution Modelling

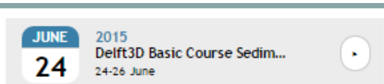
**The iMOD-approach:** a large scale high resolution-approach allows working from one expandable data set covering all possible future areas of interest.

- In practice, this proves to be very efficient and transparent;
- Minimizes the risk that future subdomain model applications are limited by nearby model boundaries;
- Reduces the costs for maintenance and offers a single platform to improve the model – “living models”

# iMOD Open-Source / free of Charge




| Start development | Open Source | Exe free of charge |
|---|---|---|
| 2006 | 2014 | 2016 |



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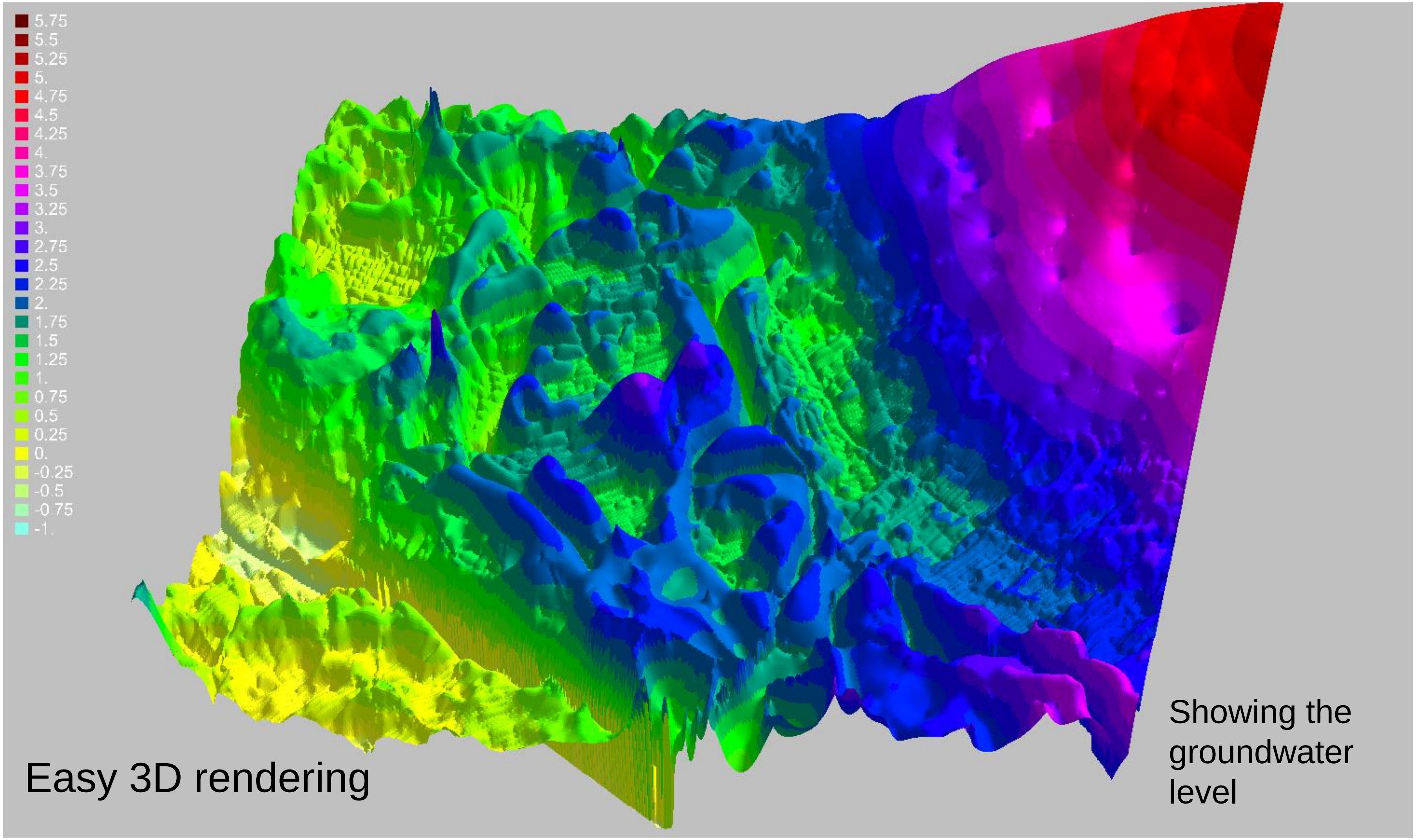
# IMOD VISUALISATION




Easy 3D rendering

Showing the groundwater level

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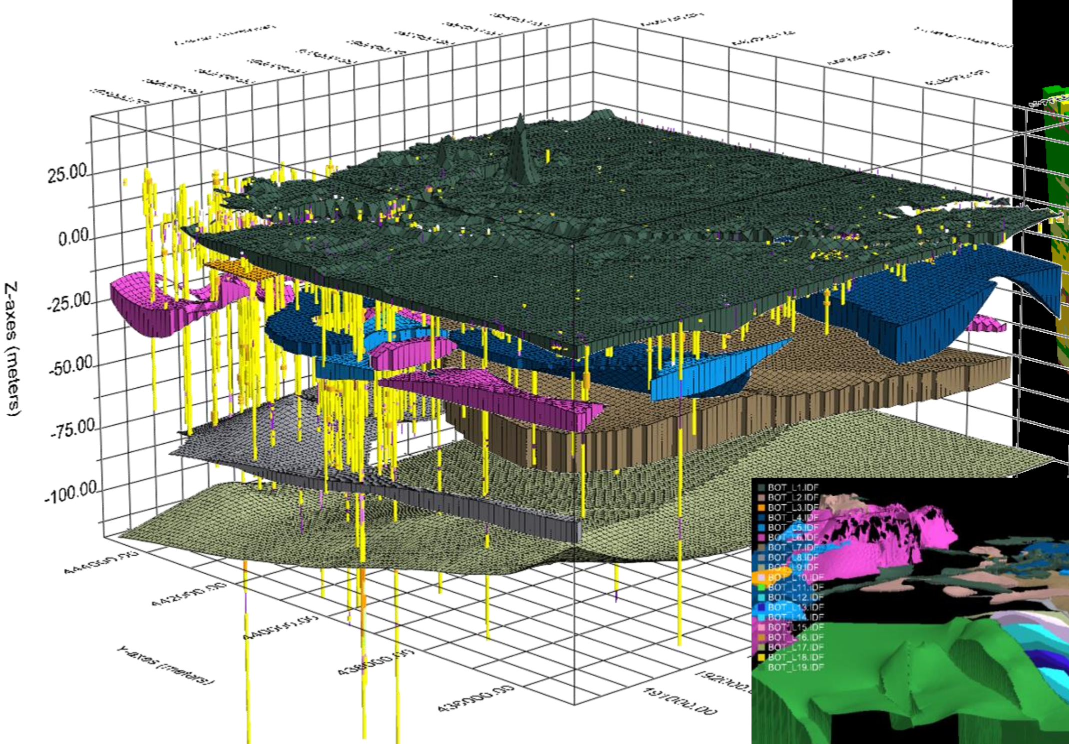
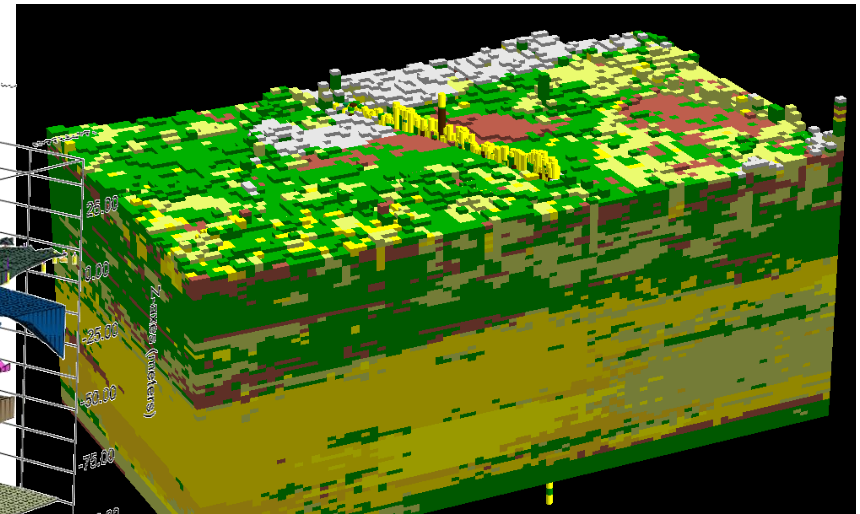
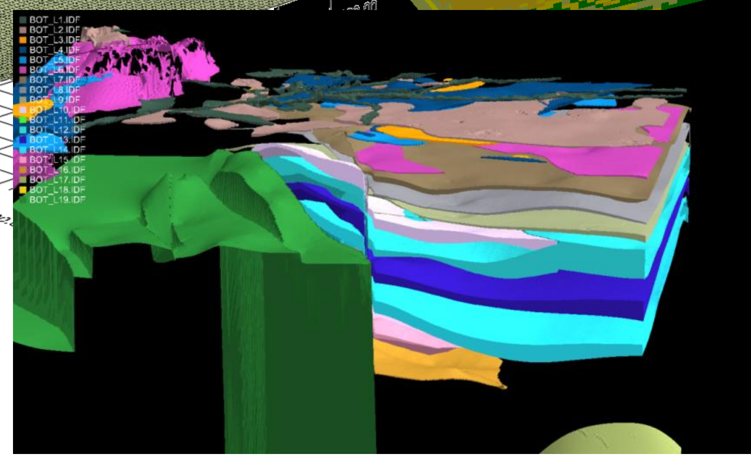
# IMOD VISUALISATION

*Excellent visualisation of geological data in infrastructural or scientific projects: Cores; Cone penetration tests; 3D geological models*




Showing Permeability in voxels of 100x100x0.5m



Showing Subsoil with aquitards and boreholes in the neighborhood of Arnhem

Showing the Subsoil in the Central Graben (Limburg)

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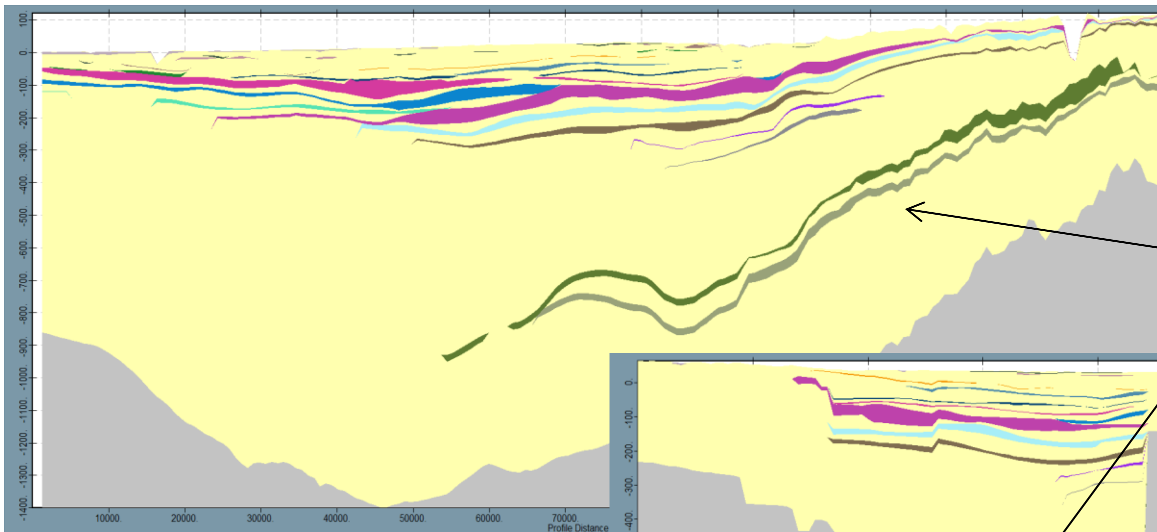
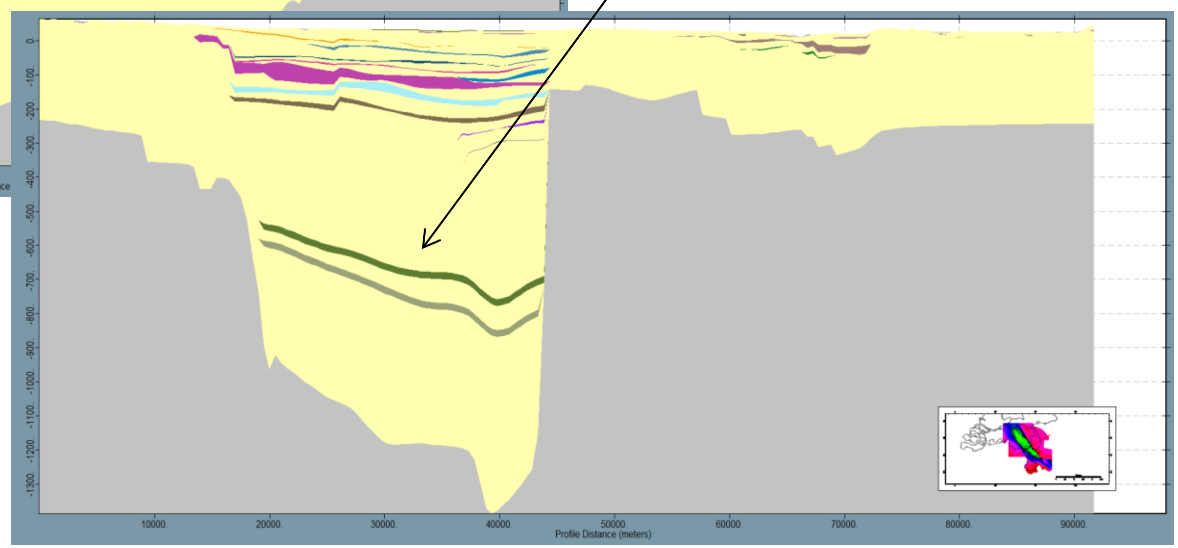
# IMOD VISUALISATION

*Drawing cross sections interactively in any direction and with/without extra intermediate knick points*




Showing a cross section along the Central Graben (Limburg) from DenBosch (left) to Inden (right)

Browncoal (Frimmersdorf/Morken)




Showing a cross section perpendicular to the Central Graben (Limburg) from Belgium (left) to Niersverband (right)

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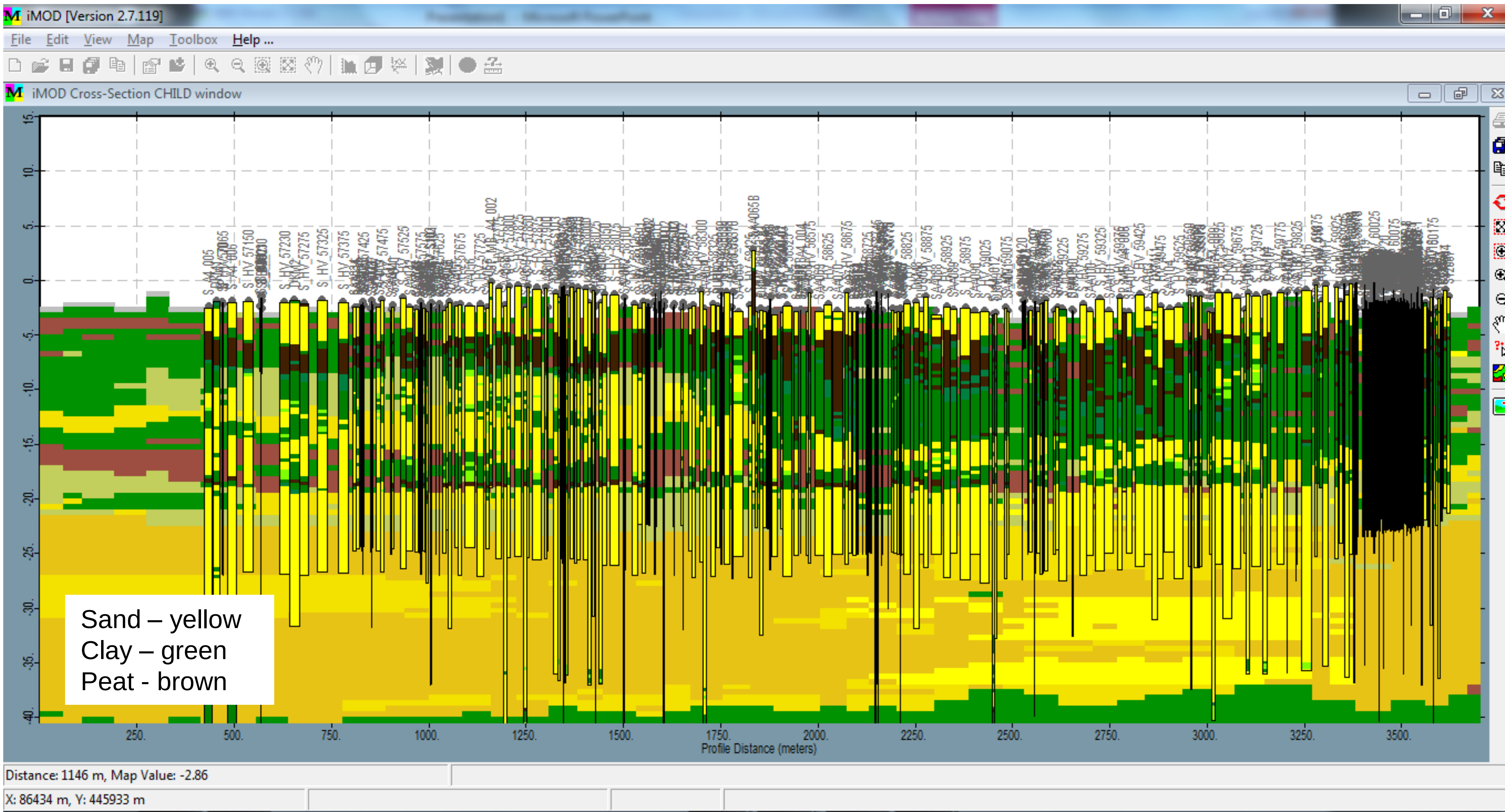
# IMOD VISUALISATION

*No problem handling large datasets with boreholes* >150,000 cores



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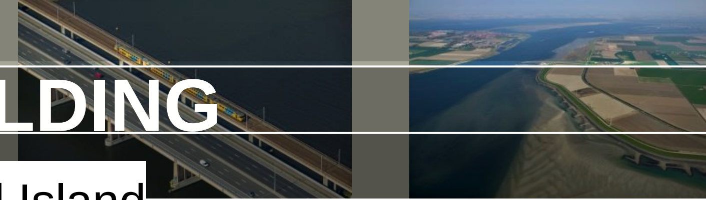
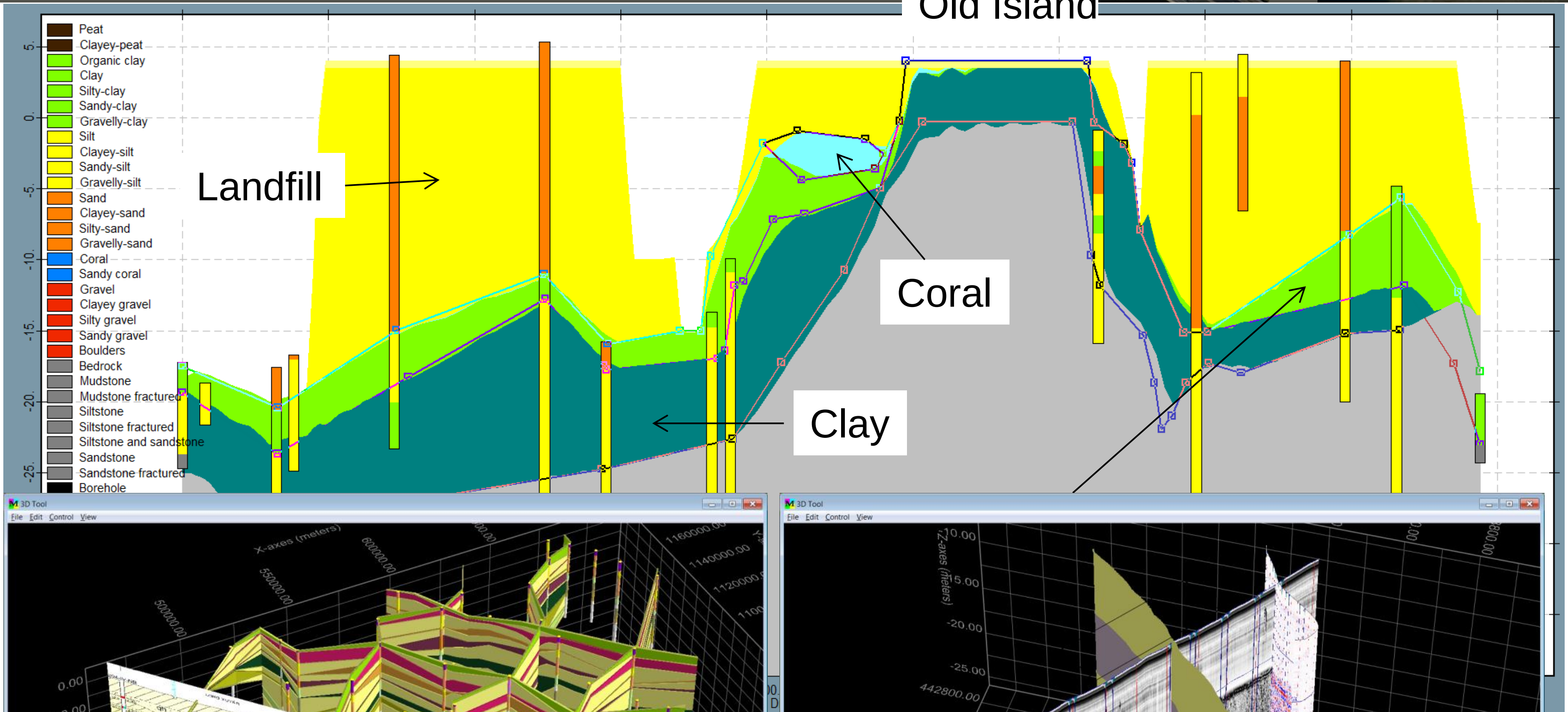
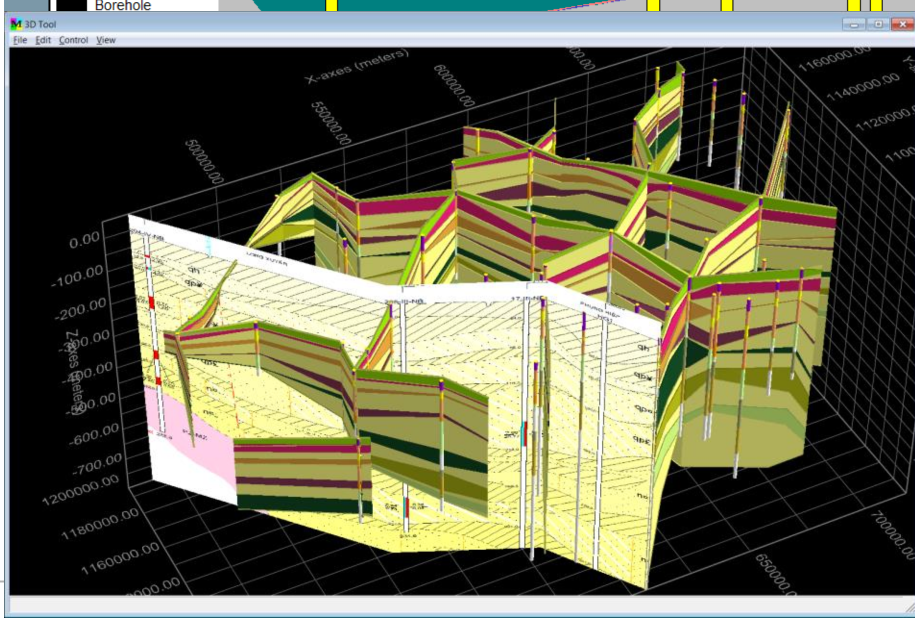
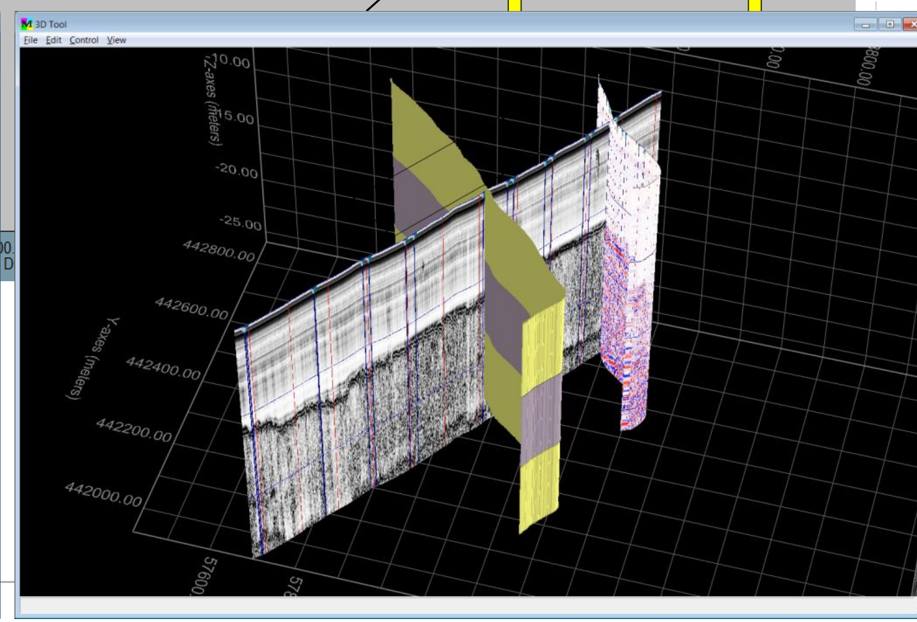
# iMOD SOLID BUILDING



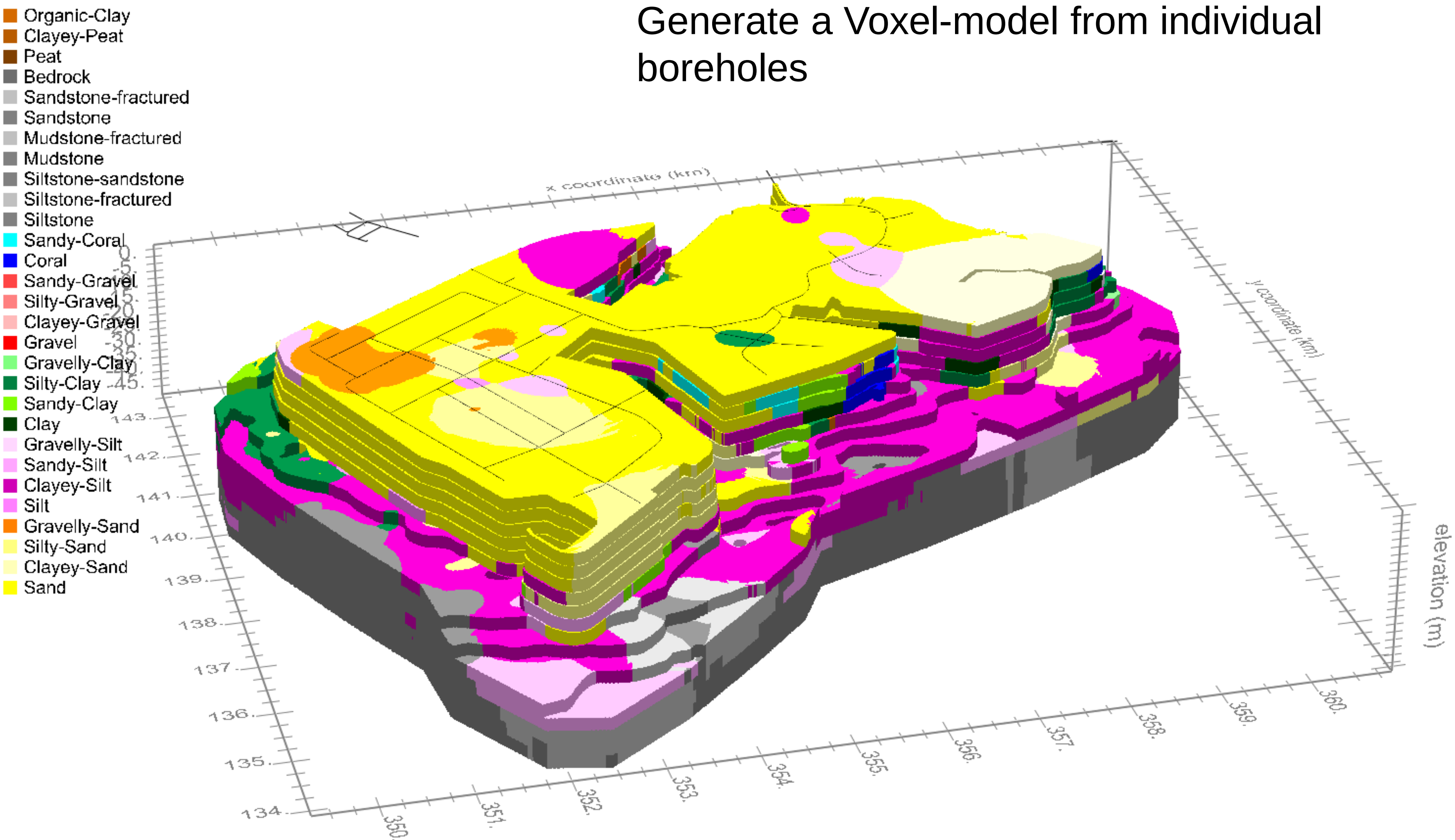


# iMOD SOLID BUILDING

Generate a Voxel-model from individual boreholes

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# iMOD – Who uses it ?

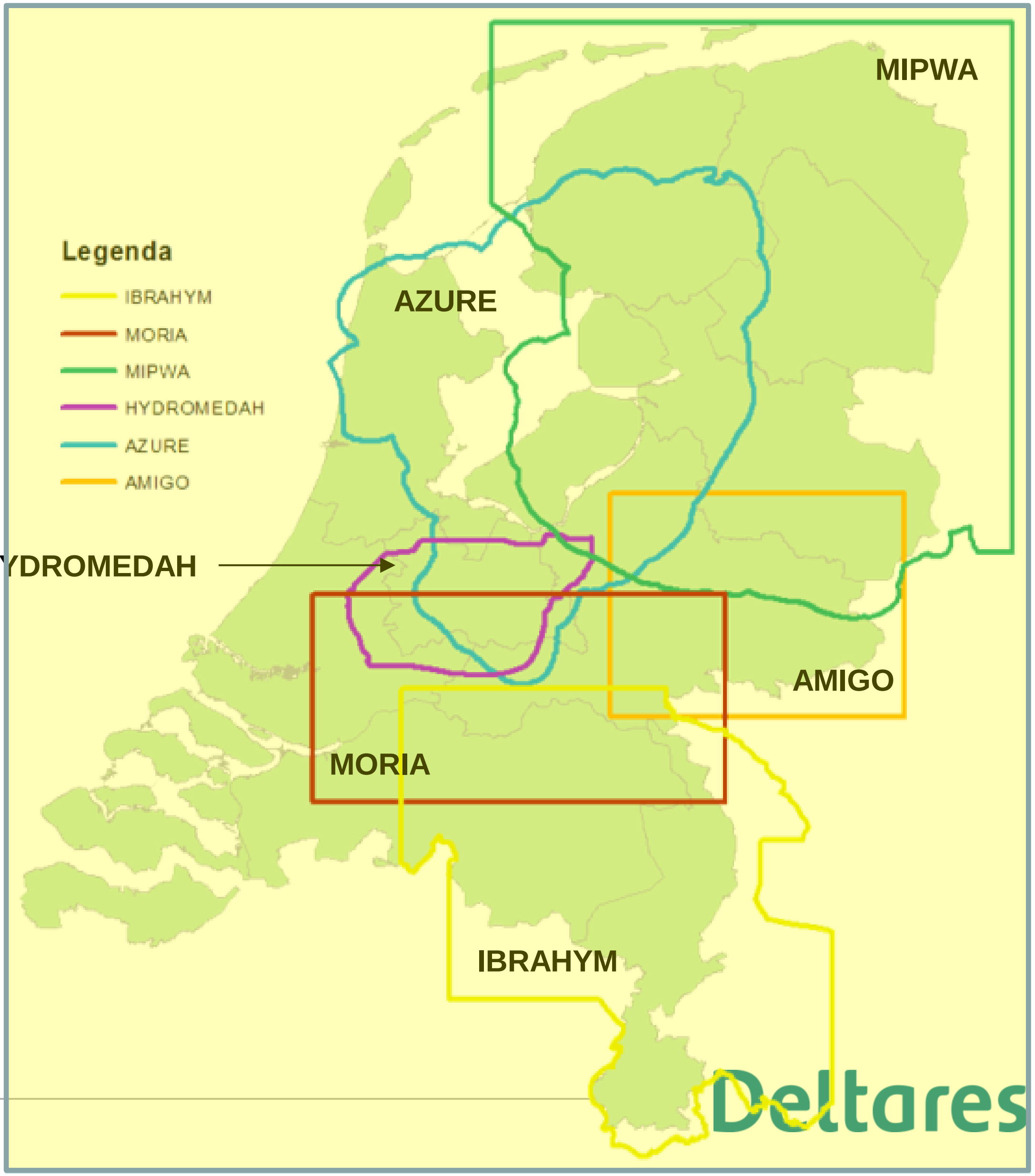
iMOD-consortia* in the Netherlands with:

- supra-regional groundwater flow models: all 25x25 meter resolution;
- daily stressperiods for at least 15 years

*consortia consists out of Provinces, Drinkingwater Companies and Waterboards

**NHI**

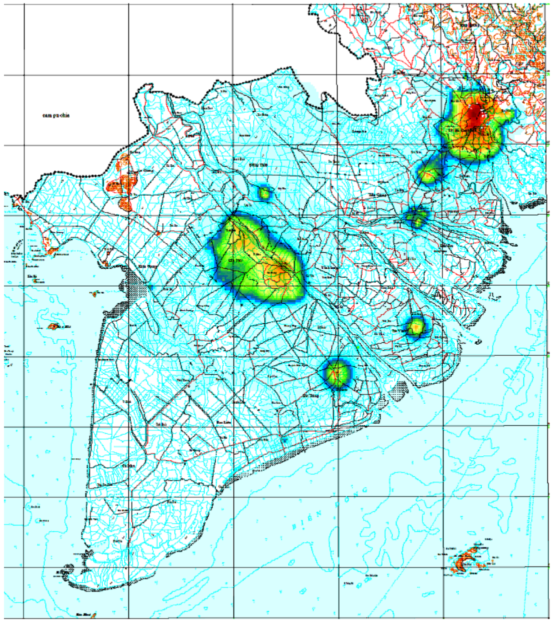
*Netherlands – Hydrologic Instrument*



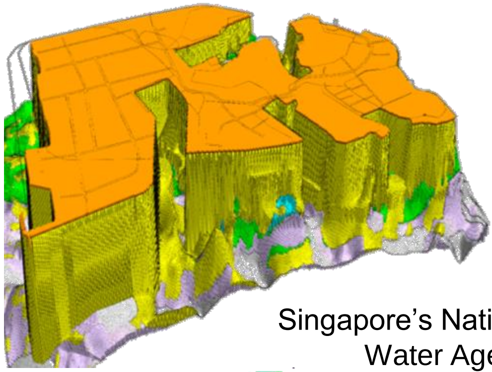
# iMOD – Who uses it ?

Internationally:

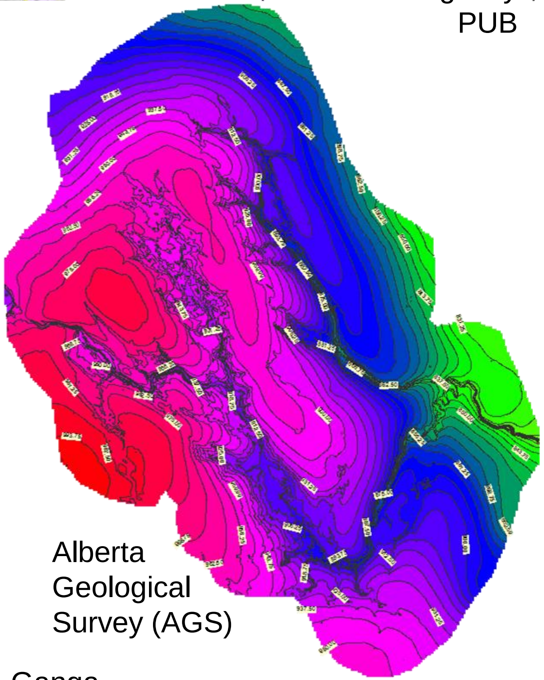
- Vietnam – Mekong Delta
- Alberta Geological Survey, Canada
- Germany:
    1. Geologischer Dienst Schleswig-Holstein
    2. Wasserverband Niersverband
    3. Hessisches Landesamt für Naturschutz, Umwelt und Geologie
- Switzerland Canton Valais
- Singapore National University
- Kenya – Lake Naivasha
- Colombia
- India – Ganga Basin



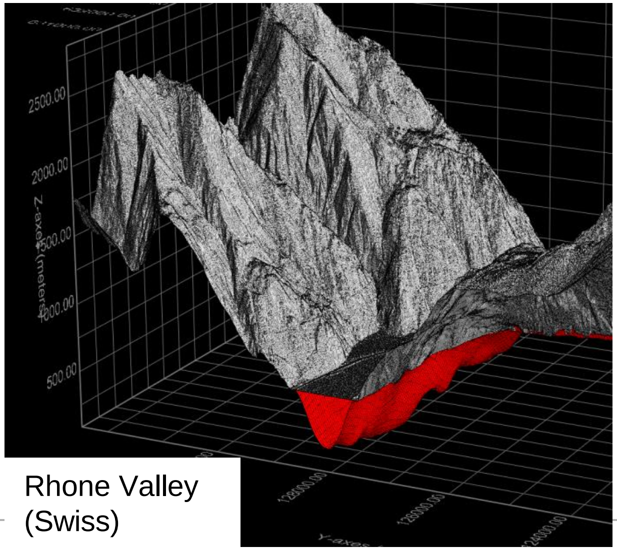
Vietnam – University of Ho Chi Minh City



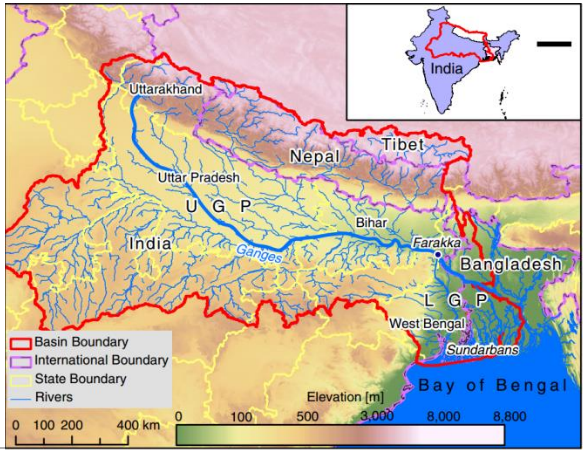
Singapore's National Water Agency PUB



Alberta Geological Survey (AGS)




Rhone Valley (Swiss)




India – Ganga Basin

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# iMOD Developments

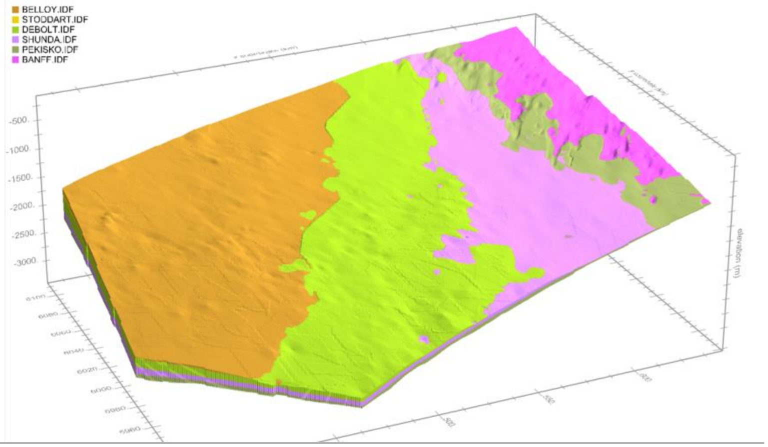
Philosophy:

**All features and developments are available to all iMOD users.**

- Paid by Deltares
- Paid by iMOD Consortia
- Paid by national and international projects

*Entwicklung und Bereitstellung von speziellen Tools für die Modellsoftware iMOD für das Hessische Landesamt für Naturschutz, Umwelt und Geologie*


*Enhance 3D Visuals of iMOD for the dissemination of the AGS Geological Models*

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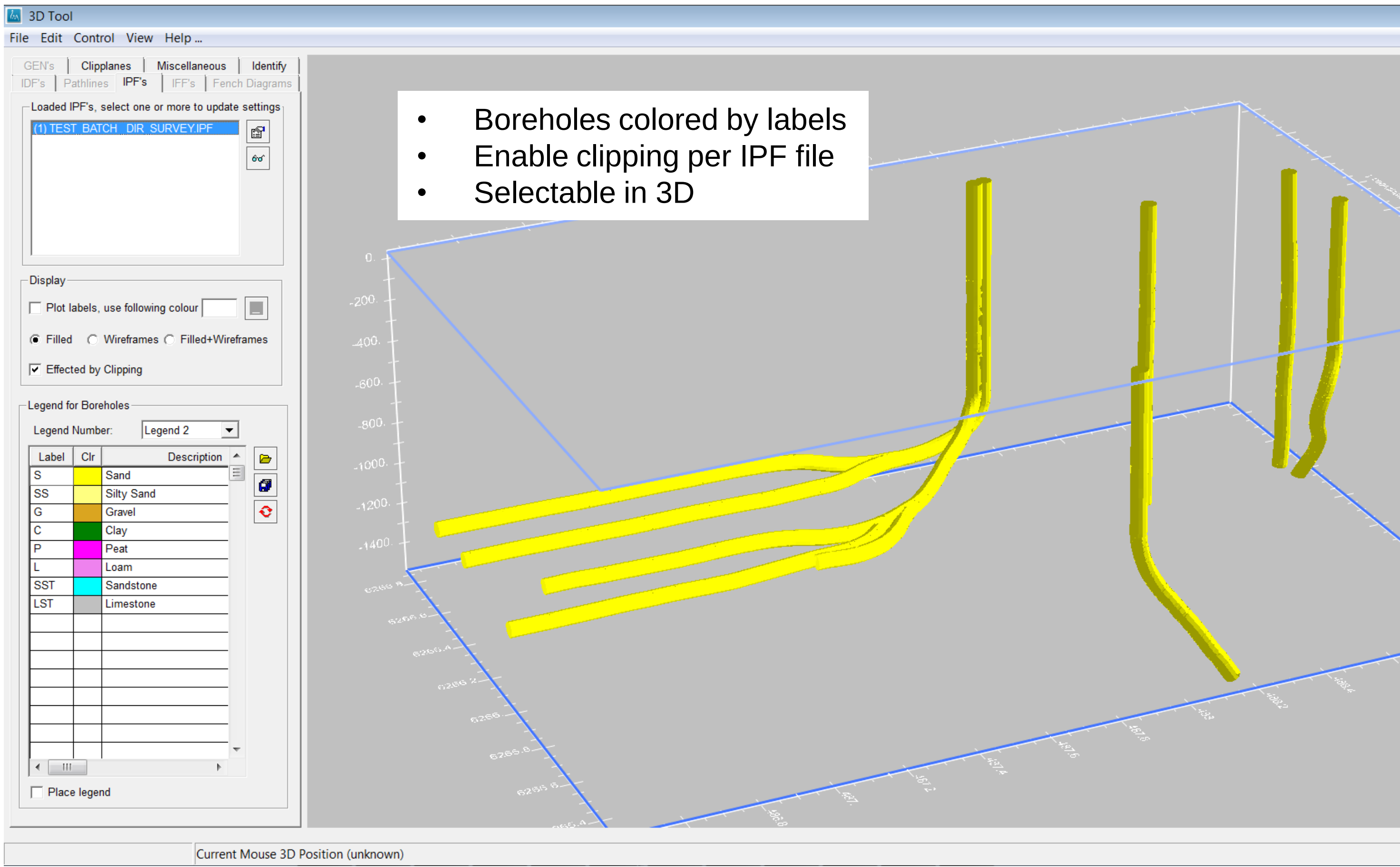
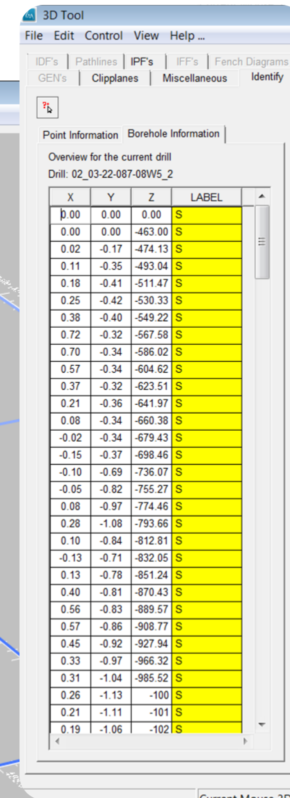
# Developed for AGS

*Display deviated wells in 3D and cross-sections*

- Boreholes colored by labels
- Enable clipping per IPF file
- Selectable in 3D

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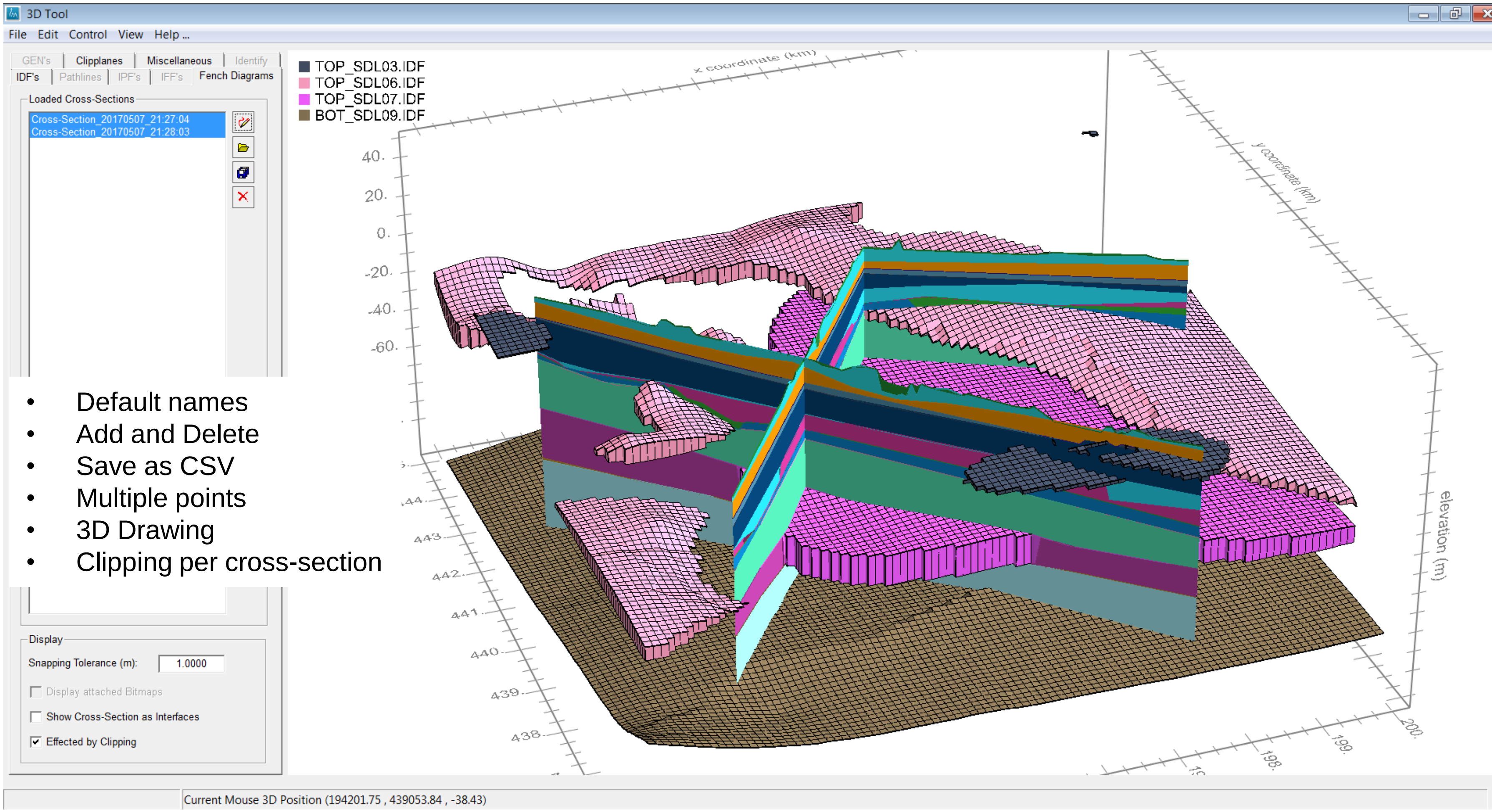
# Developed for AGS

*Defines Cross-sections in 3D to generate fence-diagrams*




- Default names
- Add and Delete
- Save as CSV
- Multiple points
- 3D Drawing
- Clipping per cross-section



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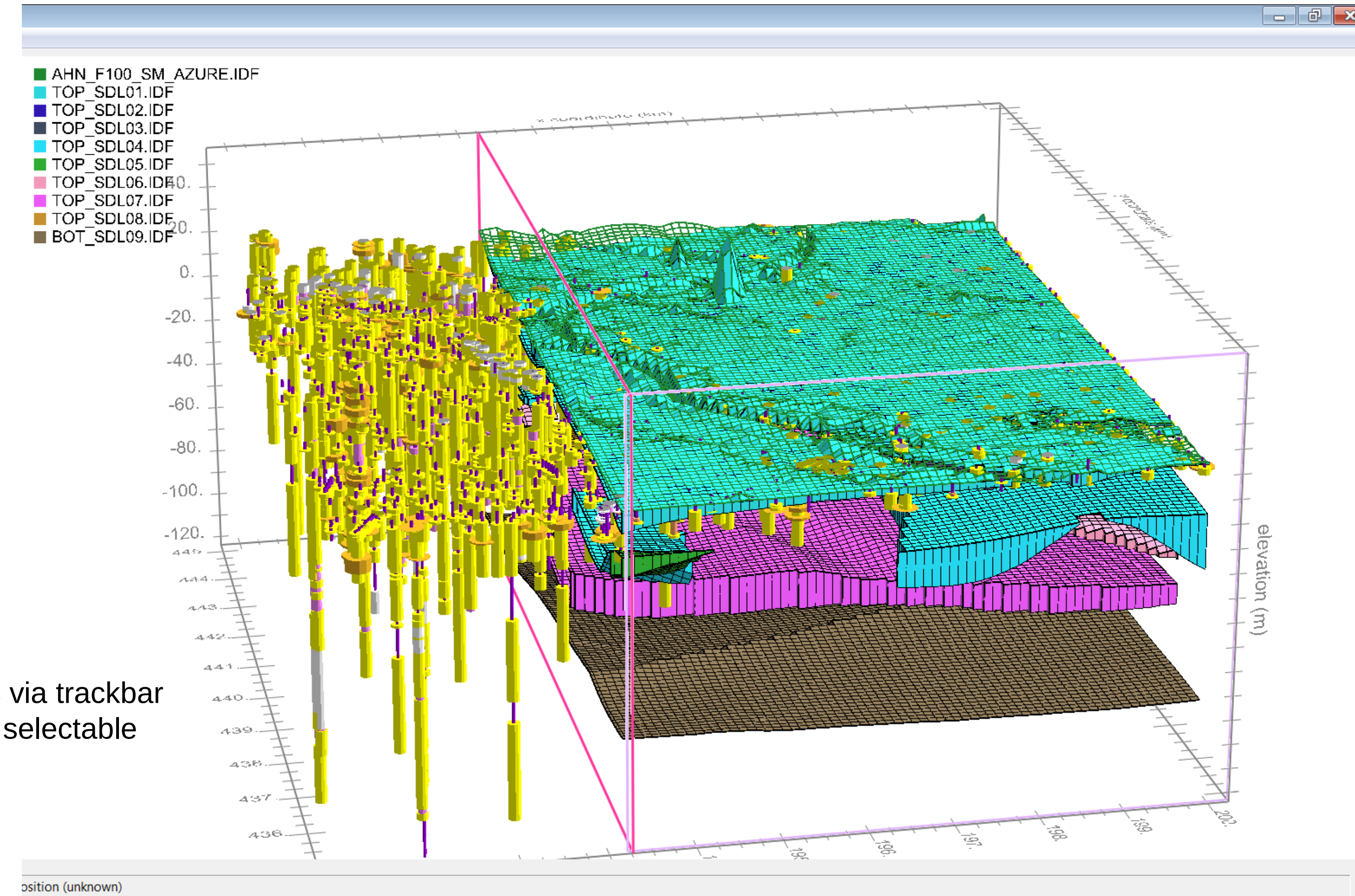
# Developed for AGS

*Define clipping planes to slice the model*




- Clipping per axes via trackbar
- Clipping per item selectable

# Example Projects

Supra-Regional model: State-of-California model, USA

Rhone-Valley - *Switzerland*



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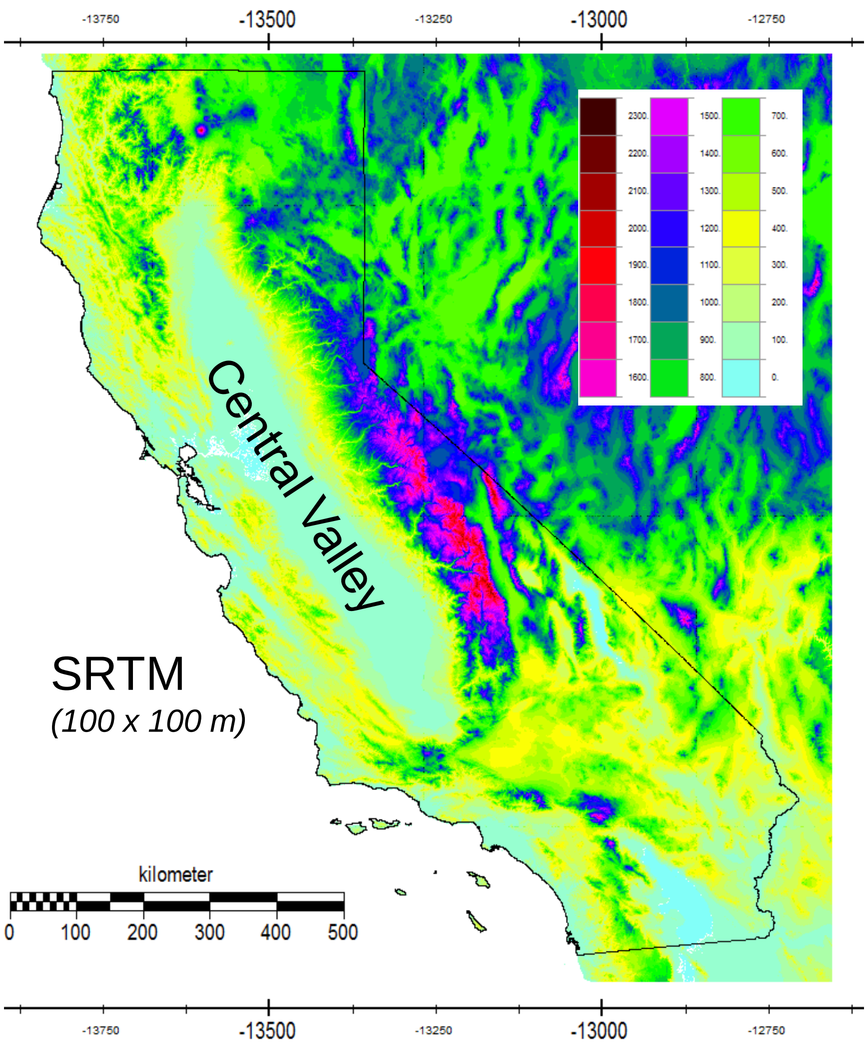
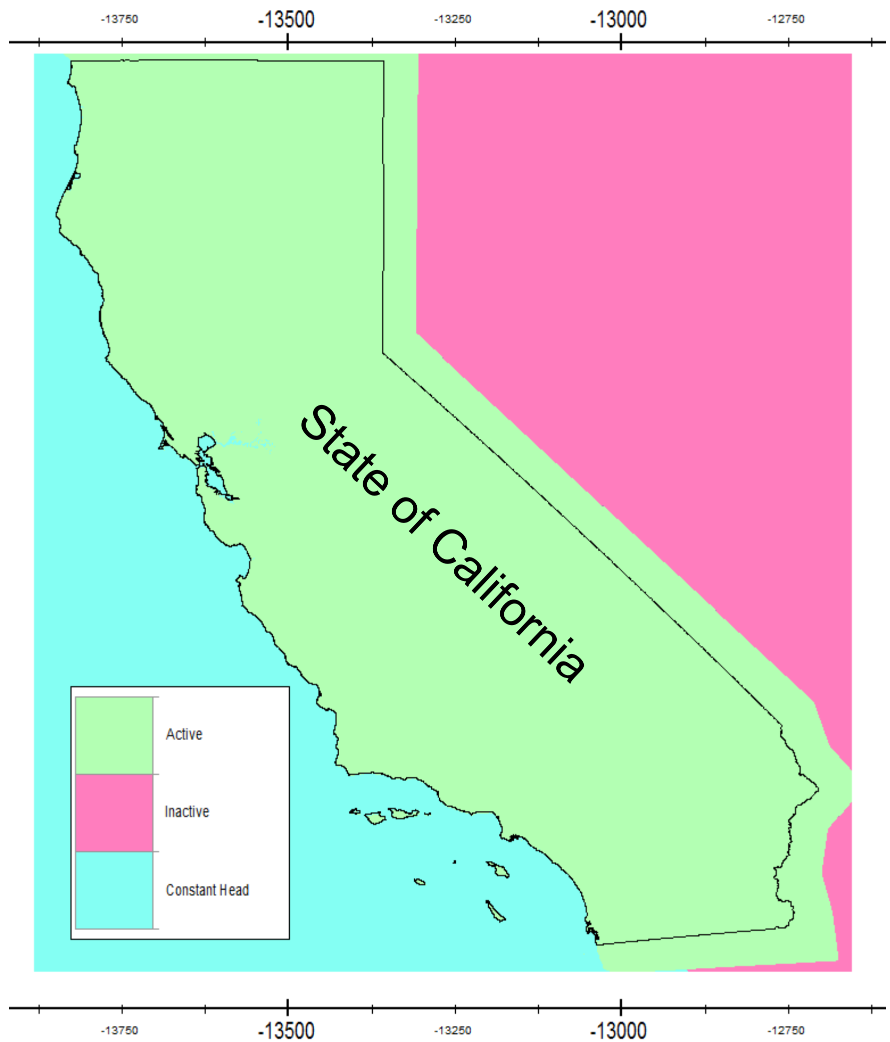
# Model of the State of California

**Demonstration:**

- Area: State of California;
- Just a Proof of Concept: we do not claim to have any knowledge of the real geohydrology of the State of California!
- Illustrative purpose only;
  - Transmissivity 100 m2/day – ability to include local more detailed data;
  - Recharge 0.1 mm/day
  - Model input SRTM (100 meter resolution)
  - Drainage network based on SRTM and local drainage direction

# Model of the State of California




USGS science for a changing world



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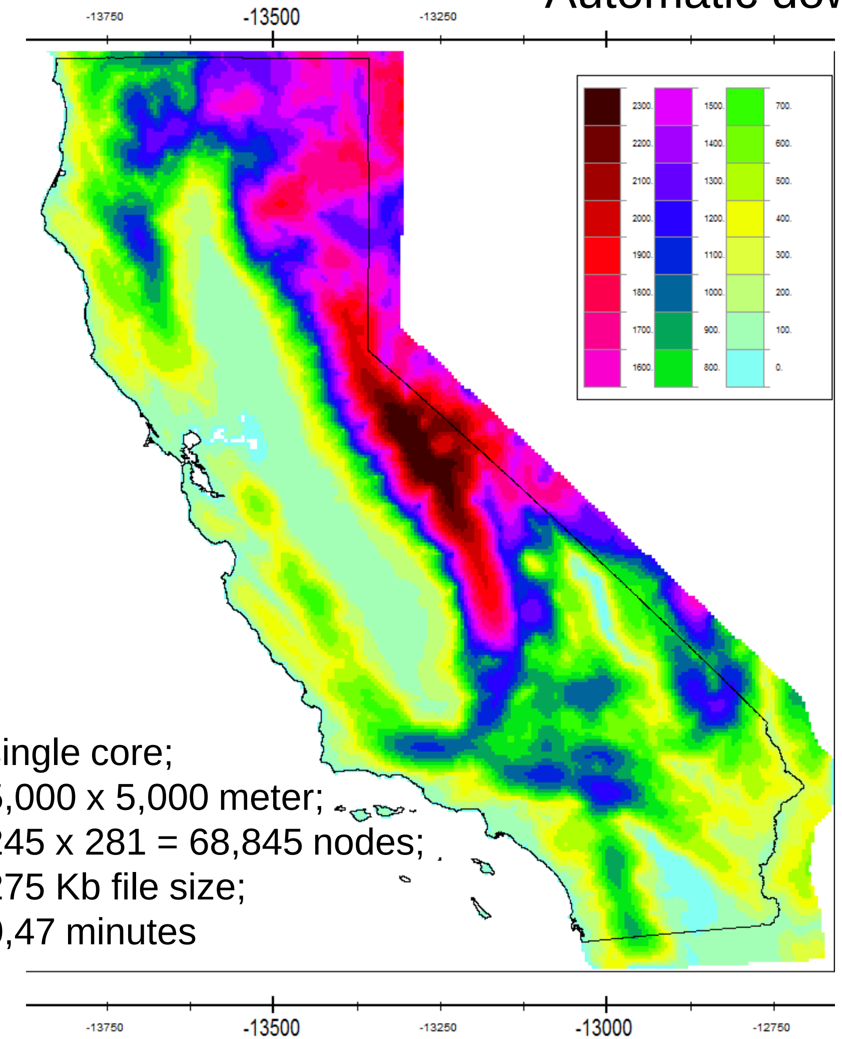
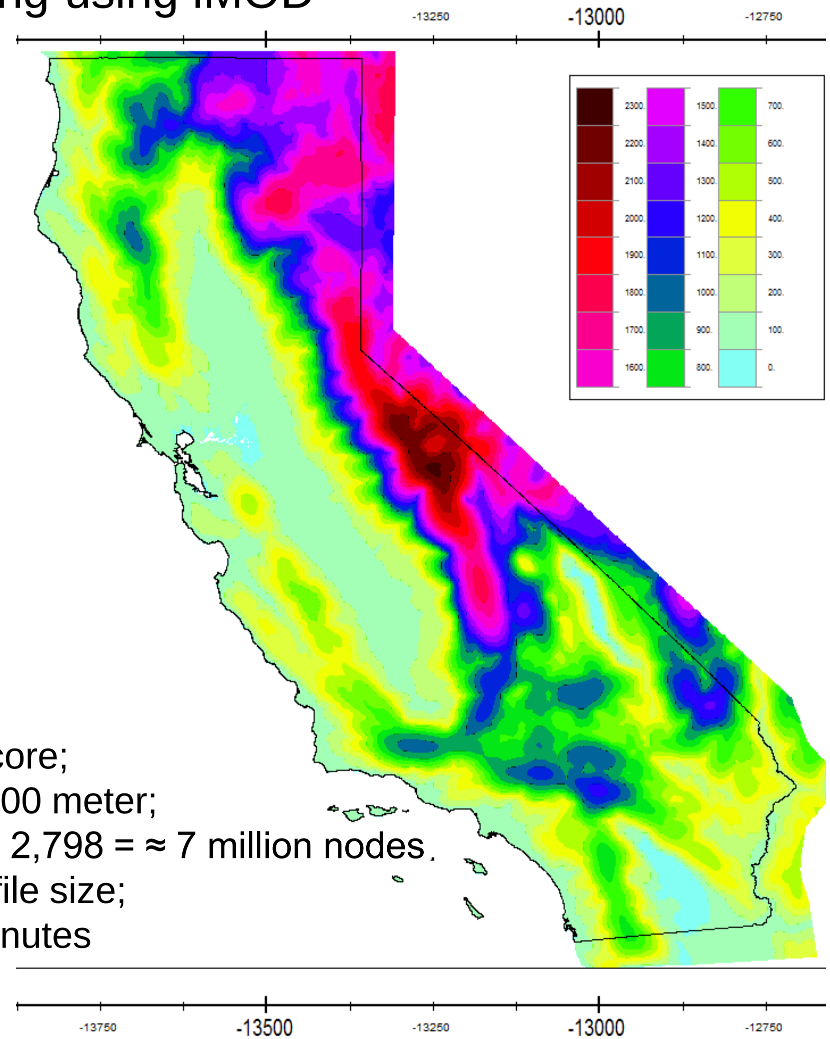
# Model of the State of California

## Automatic downscaling using iMOD




single core;
5,000 x 5,000 meter;
245 x 281 = 68,845 nodes;
275 Kb file size;
0,47 minutes




single core;
500 x 500 meter;
2,454 x 2,798 = ≈ 7 million nodes.
27 Mb file size;
2,37 minutes

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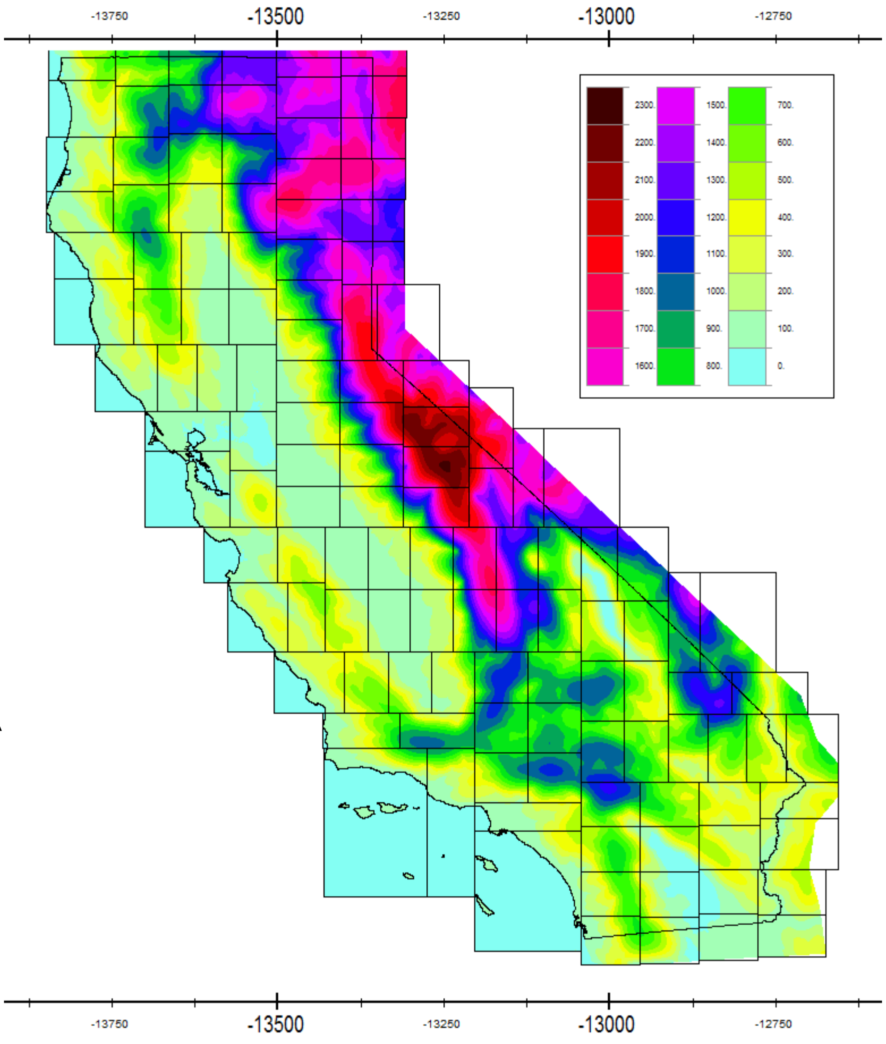
# Model of the State of California

Automatic sub model allocation (128) through an algorithm that takes into account an even distribution of load (active nodes) within each sub model




128 core (245 Gb RAM)*;
50 x 50 meter;
23,897 x 27,974 ≈ 335 million active nodes
2,6 Gb file size;
16:34 minutes#

* Simulated on the Dutch National Super Computer SARA
# On a single node estimated to consume 12 hours

*J. Verkaik & J.D. Hughes & E.H. Sutanudjaja & P.E.V. van Walsum, ***First Applications of the New Parallel Krylov Solver for MODFLOW on a National and Global Scale***, AGU Fall Meeting, December 2016

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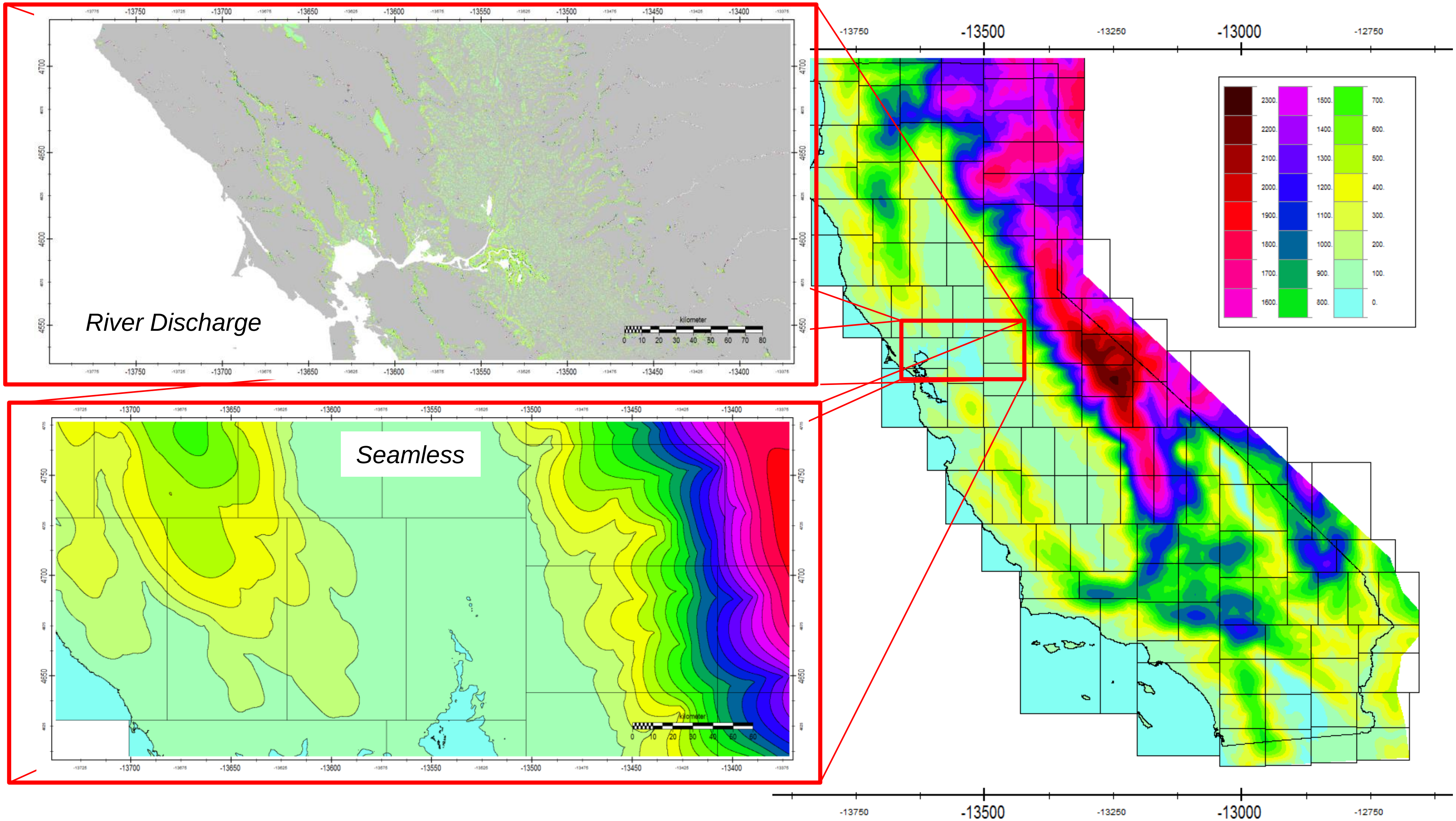
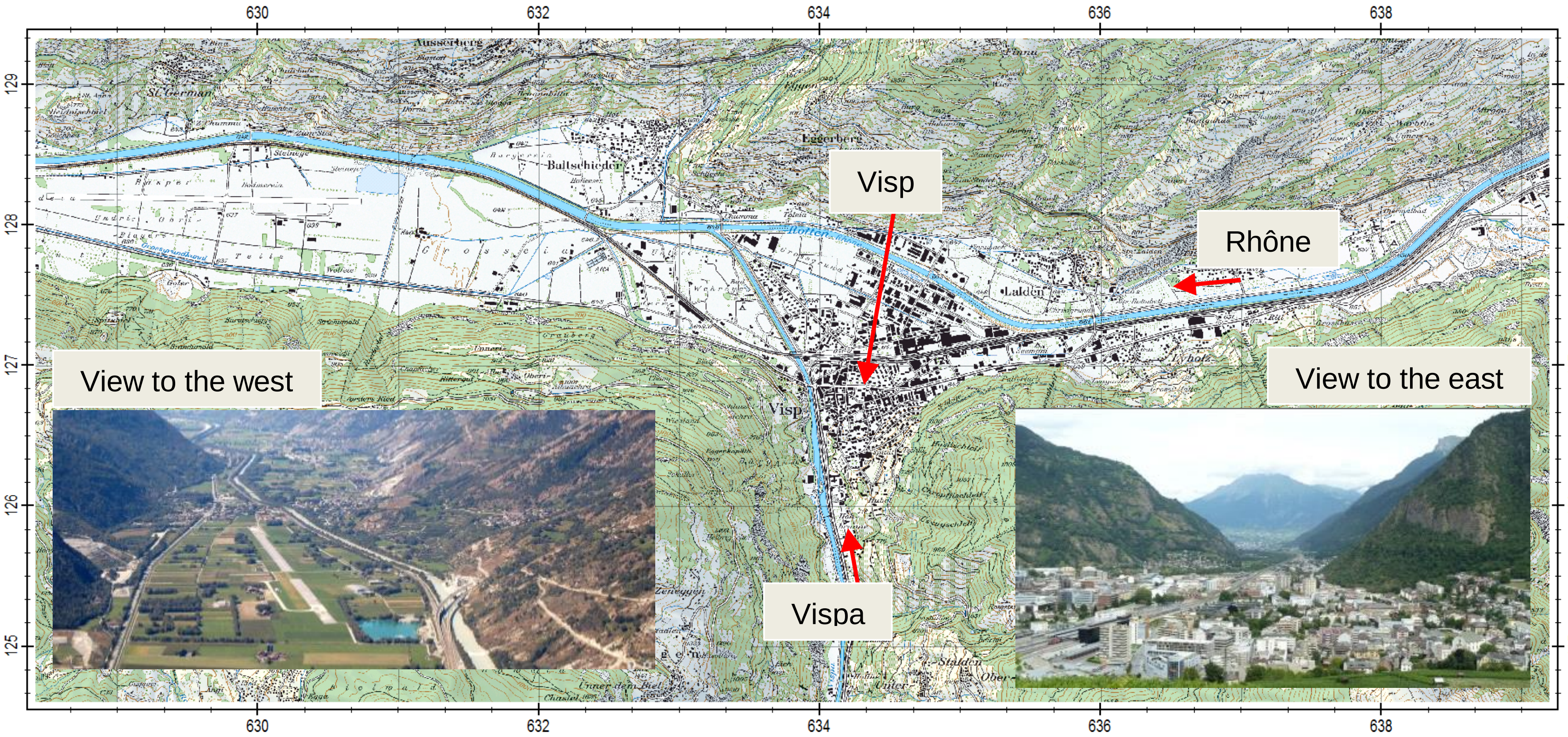
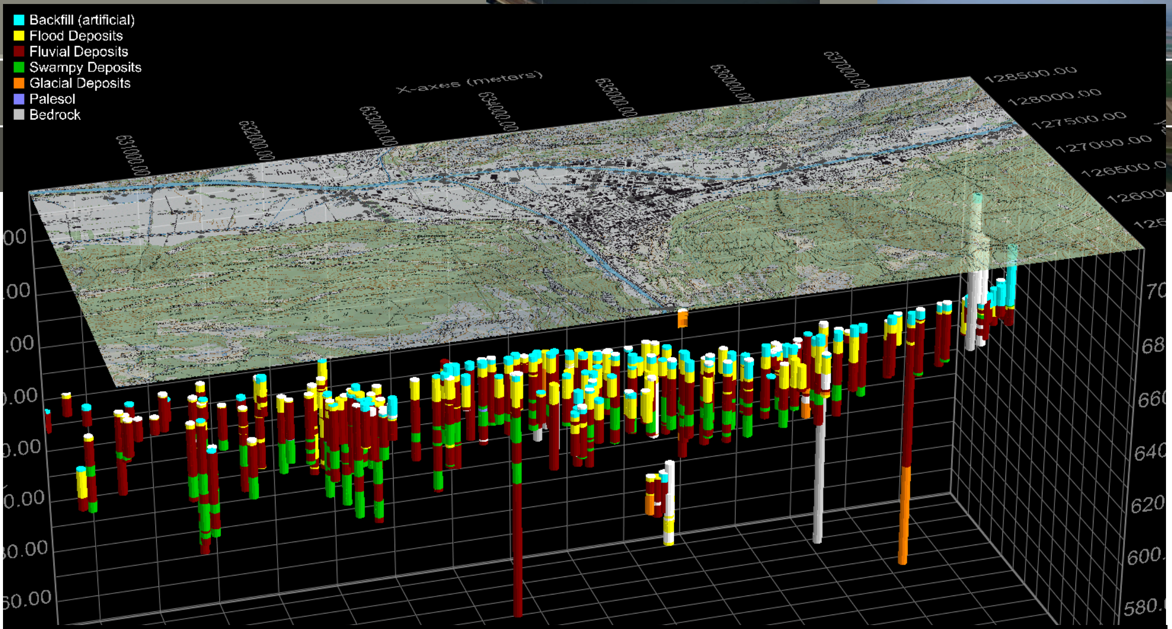
# Model of the State of California



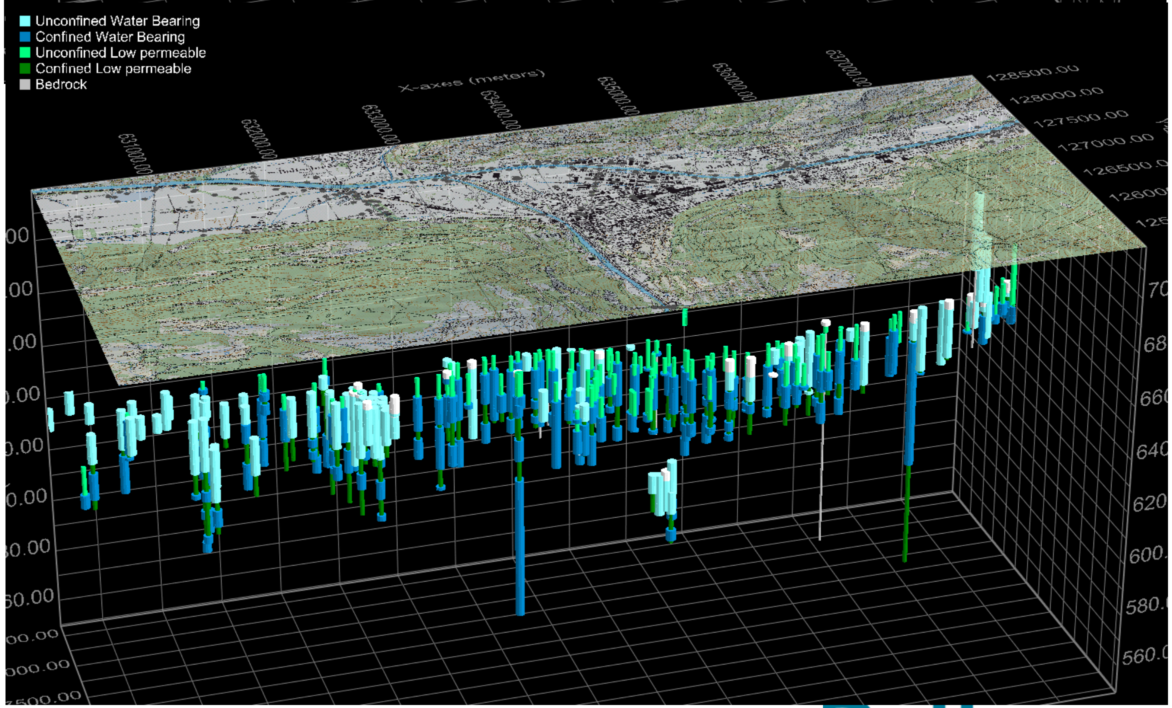
# Model of Visp



# Boreholes



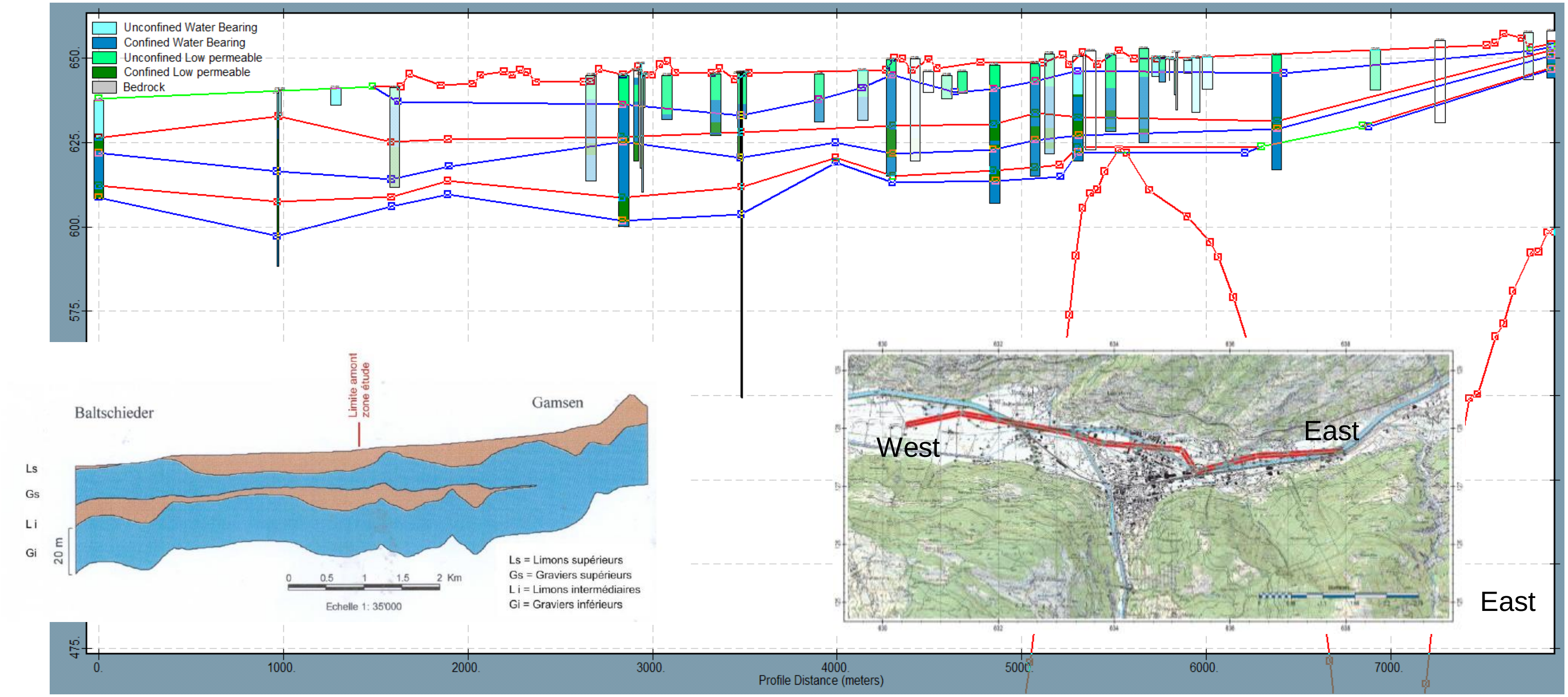

**Main Lithologies:**
Flood, Fluvial, Swampy and Glacial deposits




**Main Hydro Units:**
High permeable materials (blue)
Low permeable material (green)

# Model of Visp

**3D Model layering consisting out of:**
Layers determined by the hydro units present in the boreholes



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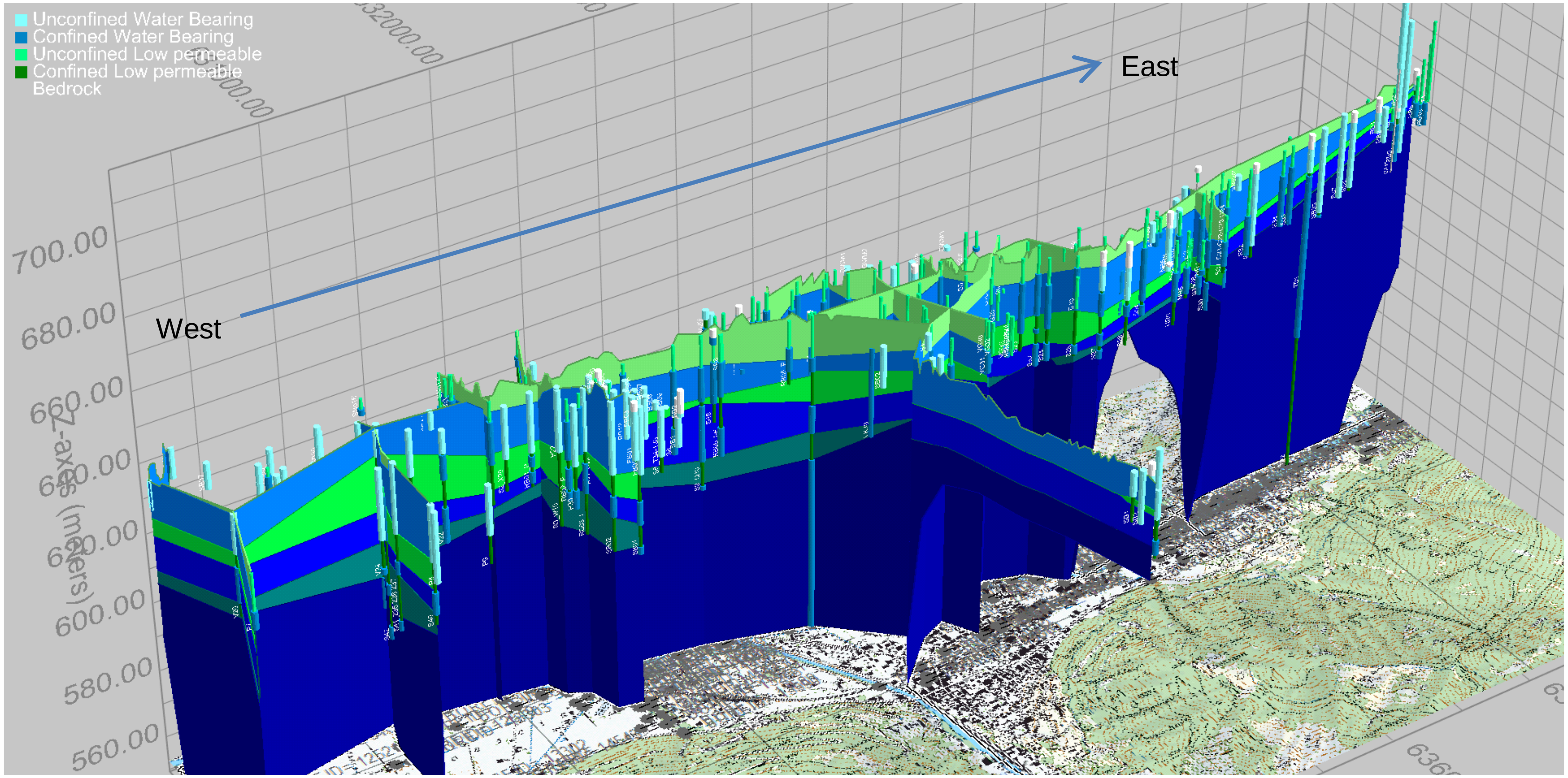
# Model of Visp

**3D Model layering consisting out of:**
10 cross-sections were used to capture the subsoil near Visp

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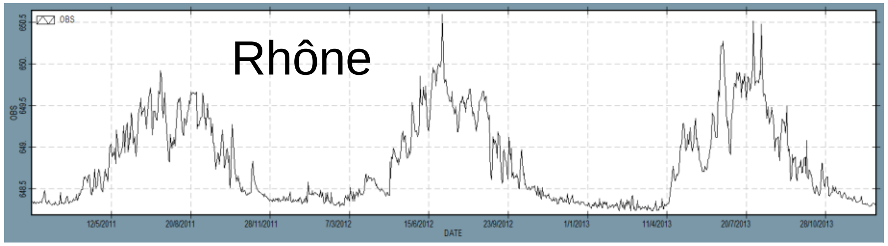
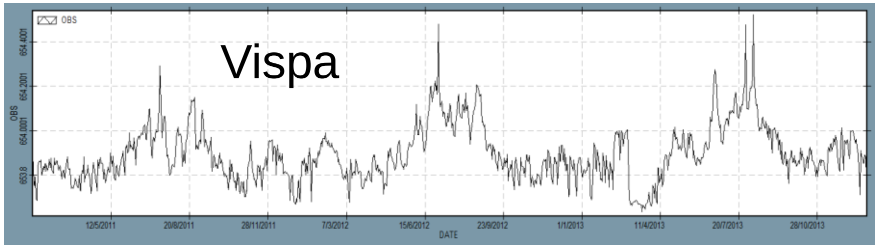
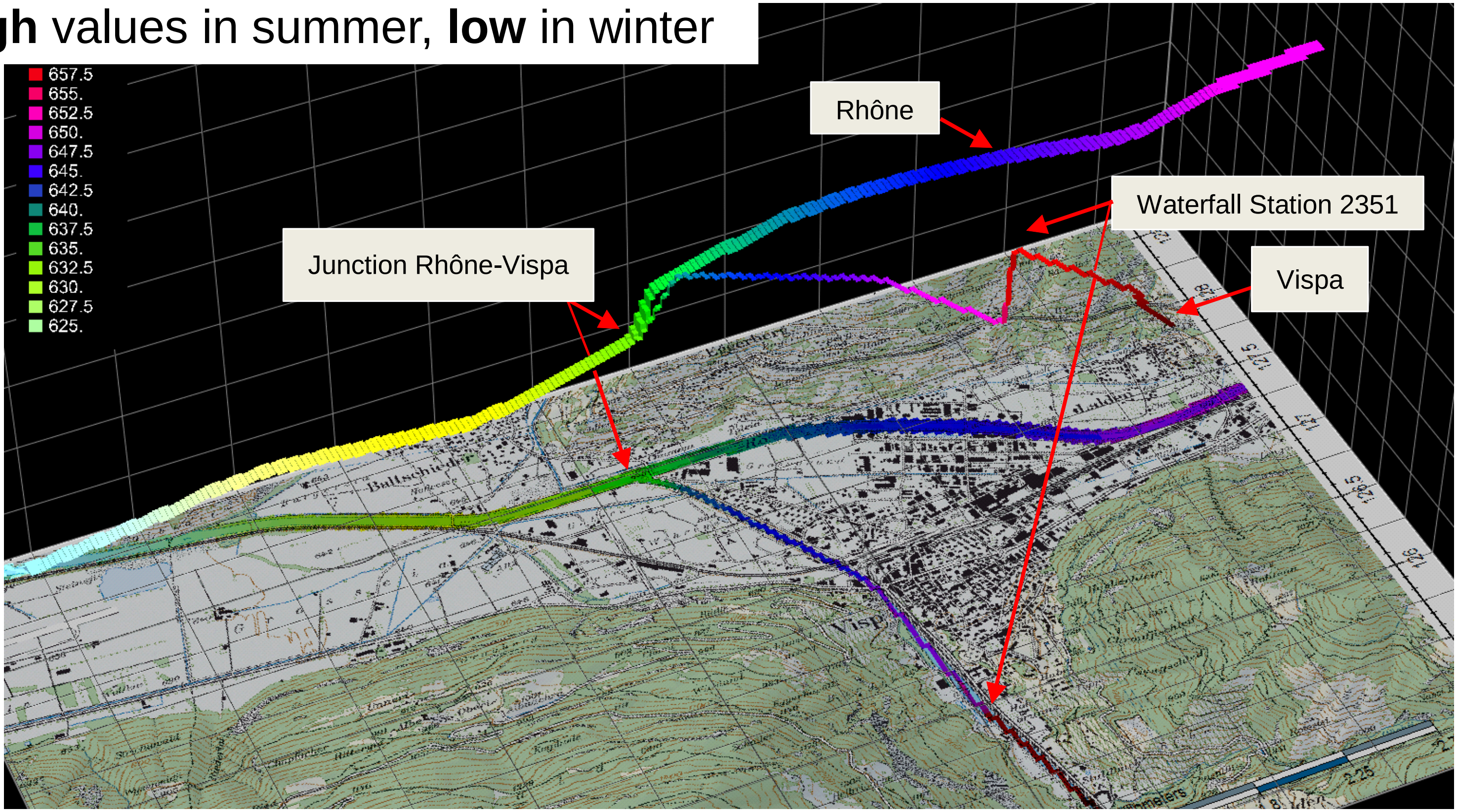
# Model of Visp




**High** values in summer, **low** in winter

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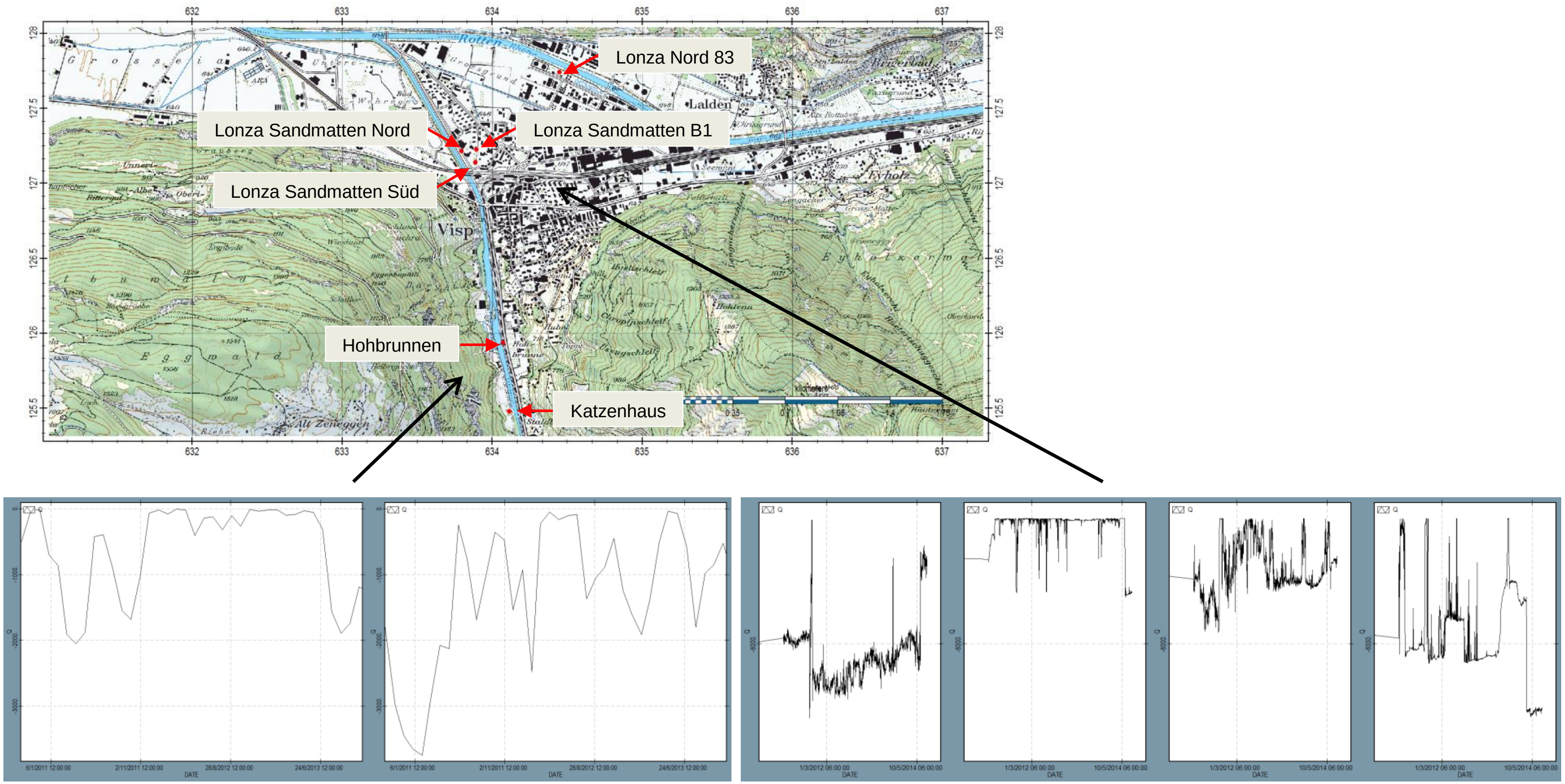
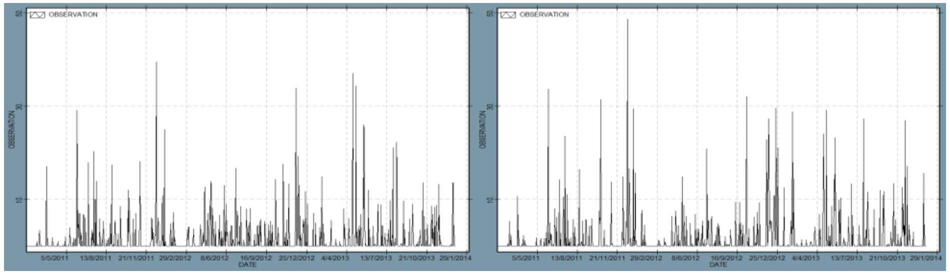
# Model of Visp



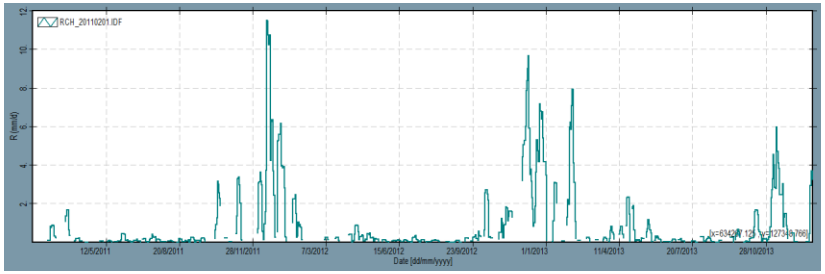

Drinking water purposes

Industrial and drinking water purposes

# Model of Visp




Measured Precipitation (Visp/Grachen)




Computed net recharge – rural areas using average infiltration factors per month and a 5 days moving average – summers extremely dry – 0.1mm/d

- Fixed potential boundaries
- Closed model boundaries
- Fixed flux boundaries

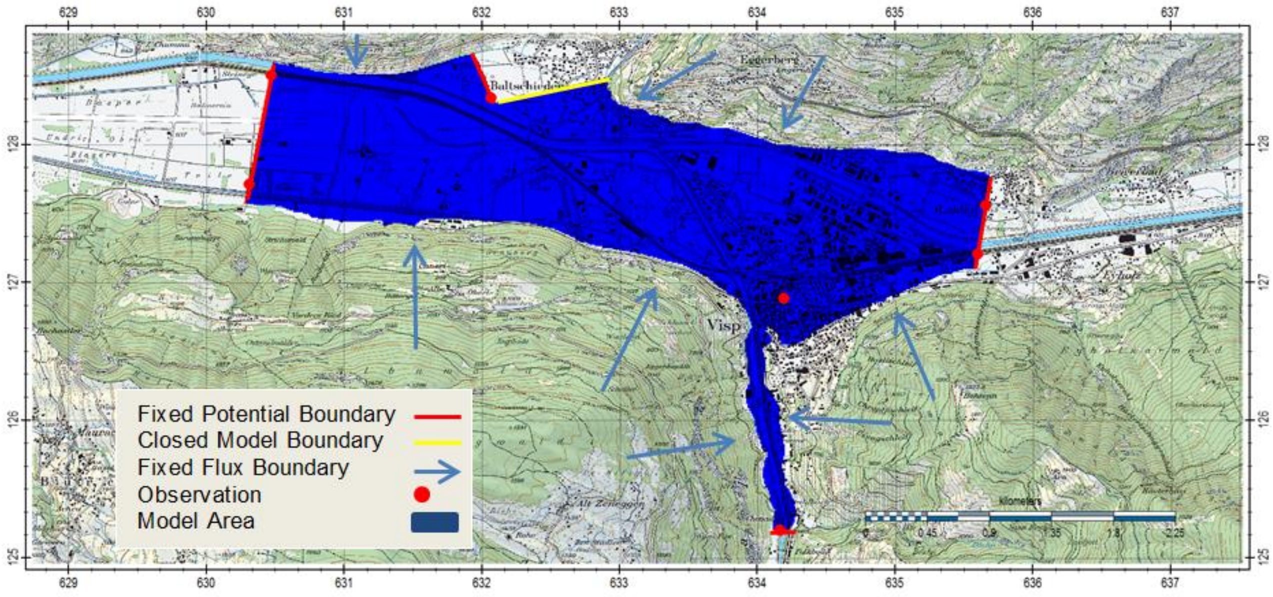
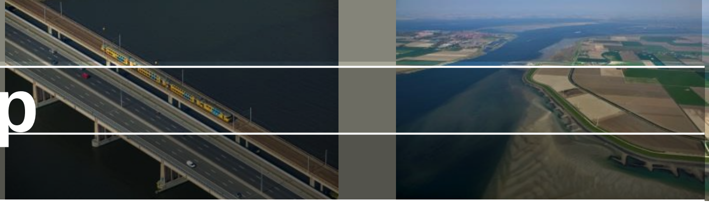



*Figure 3.4 Model area and the layout of the chosen model boundaries.*



# Model of Visp

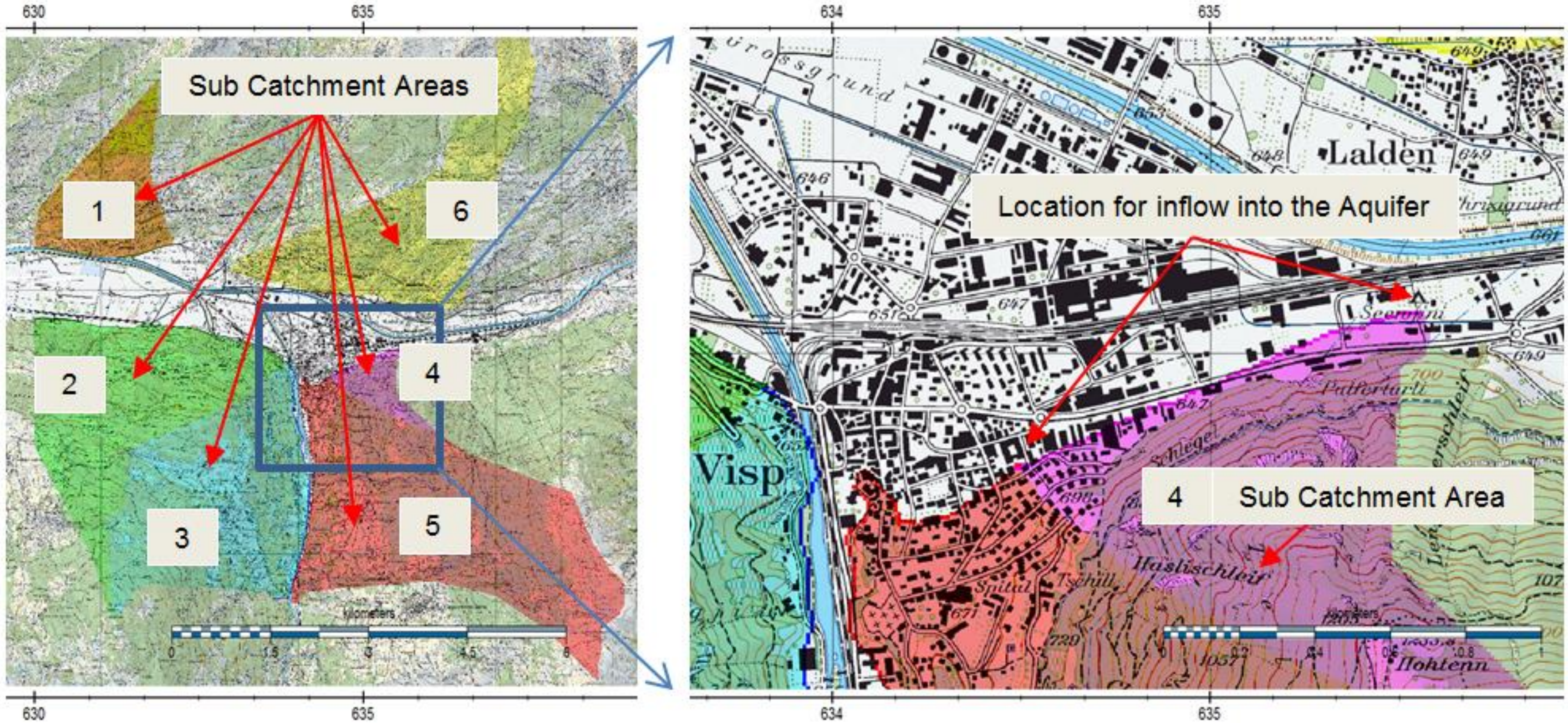



*Figure 3.8 Layout of the six sub catchment areas that discharge directly into the aquifer of the Rhône valley.*

Precipitation and snow melt water flow from the mountain hills into the valley and determine a part of the total inflow in the aquifers of the Rhône valley – found that a moving average of 210 days gave a realistic inflow*.

**Geotechnisches Institut, June 2015*

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# Model of Visp

Cellars have an obstructing effect for groundwater flow, especially when fully penetrating a water bearing layer

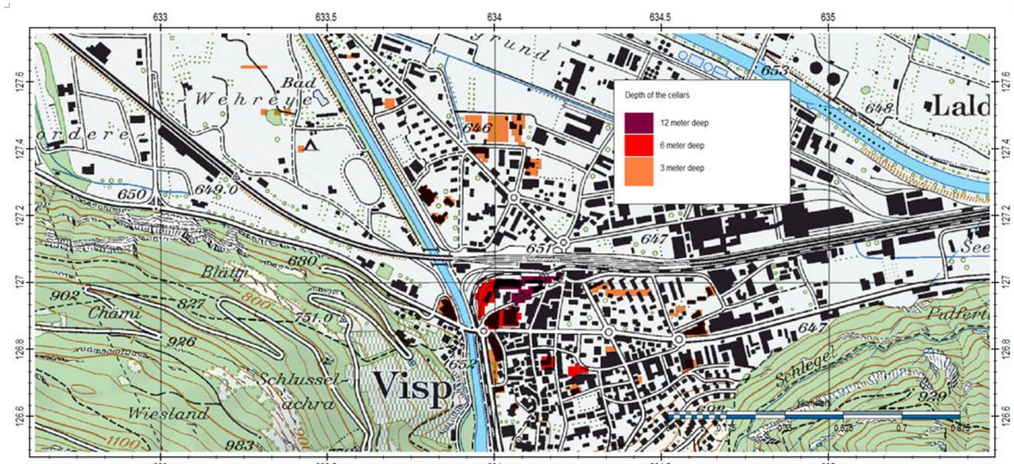


*Figure 3.19 Overview of the major underground infrastructures ("elements") in the city of Visp, coloured by their estimated depth in meter below surface level (source: Municipality of Visp)*

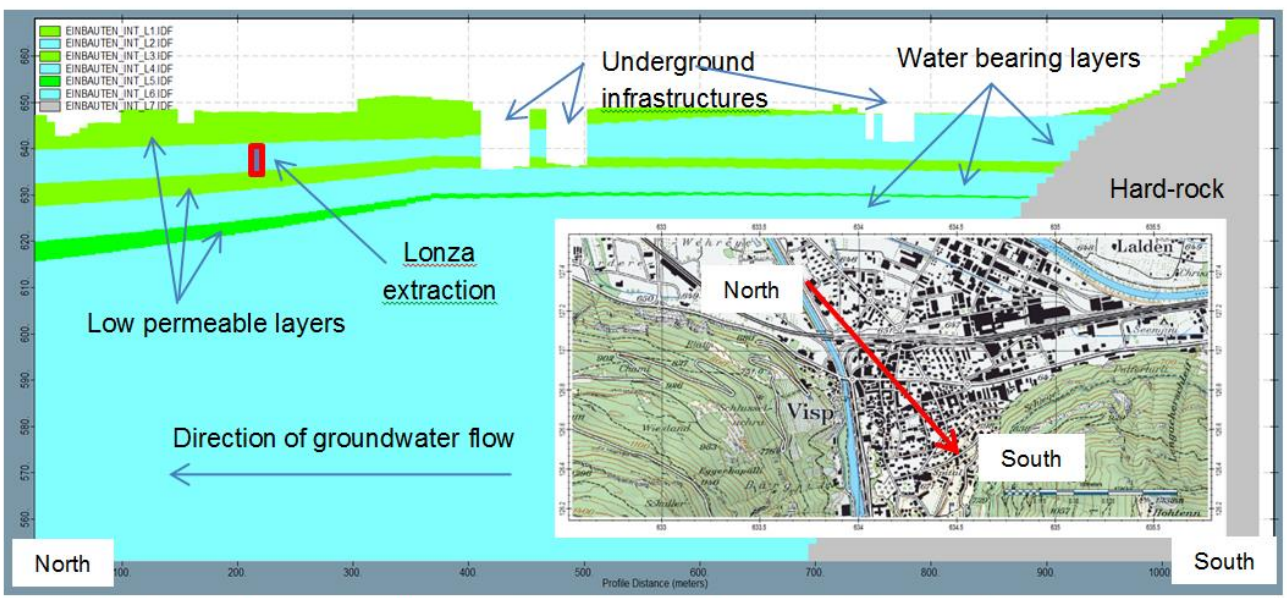


*Figure 3.20 Cross-section showing the penetration of the elements depicted in Figure 3.19.*

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# Model of Visp

Automatic Parameter Optimization by:

- Permeability's
- Inflow from Mountains Rhone/Vispa
- Leakage factor of Rhone/Vispa
- Porosity and specific storage

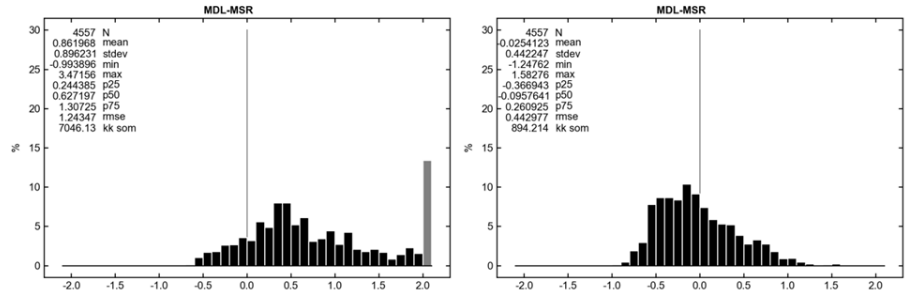


*Figure 4.3 Computed statistics (left) before the parameter optimization and (right) thereafter.*

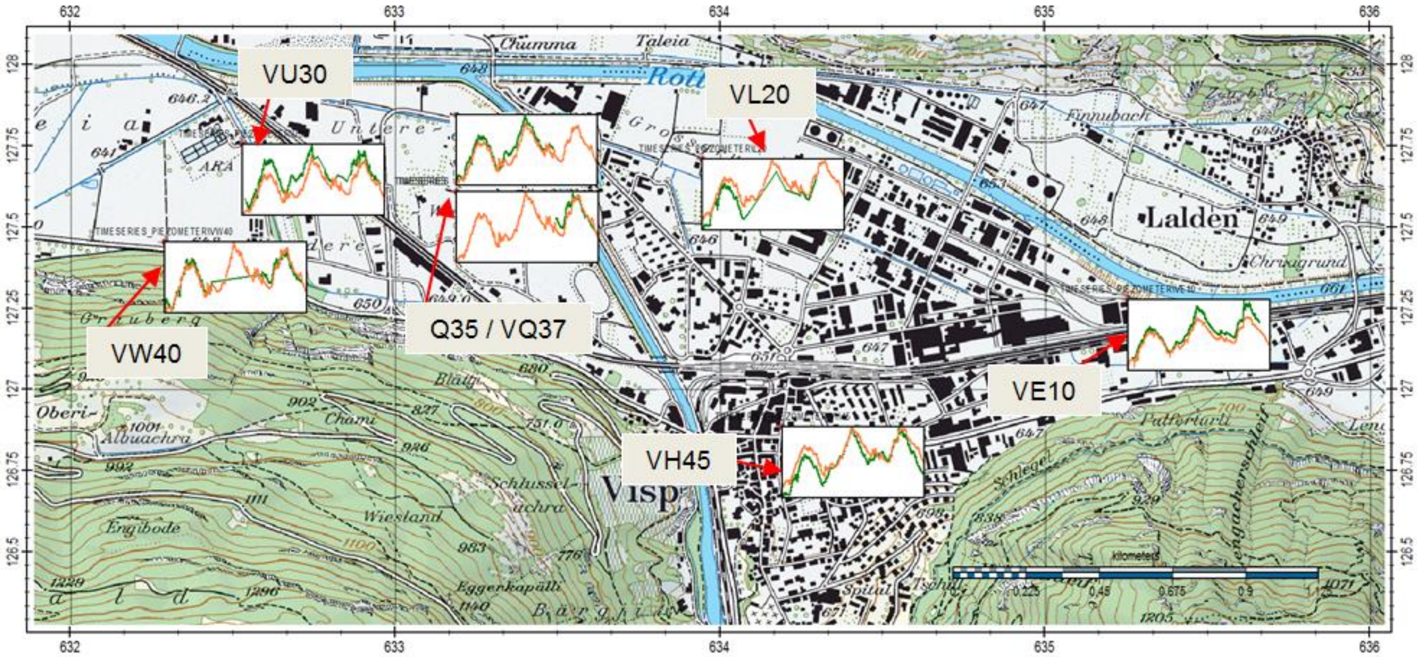


*Figure 4.2 Computed (orange) and measured (green) groundwater levels for all observation wells.*

Mean residual:
Before: 0.890m
After: 0.025m

**Bandwidth of parameter uncertainty**



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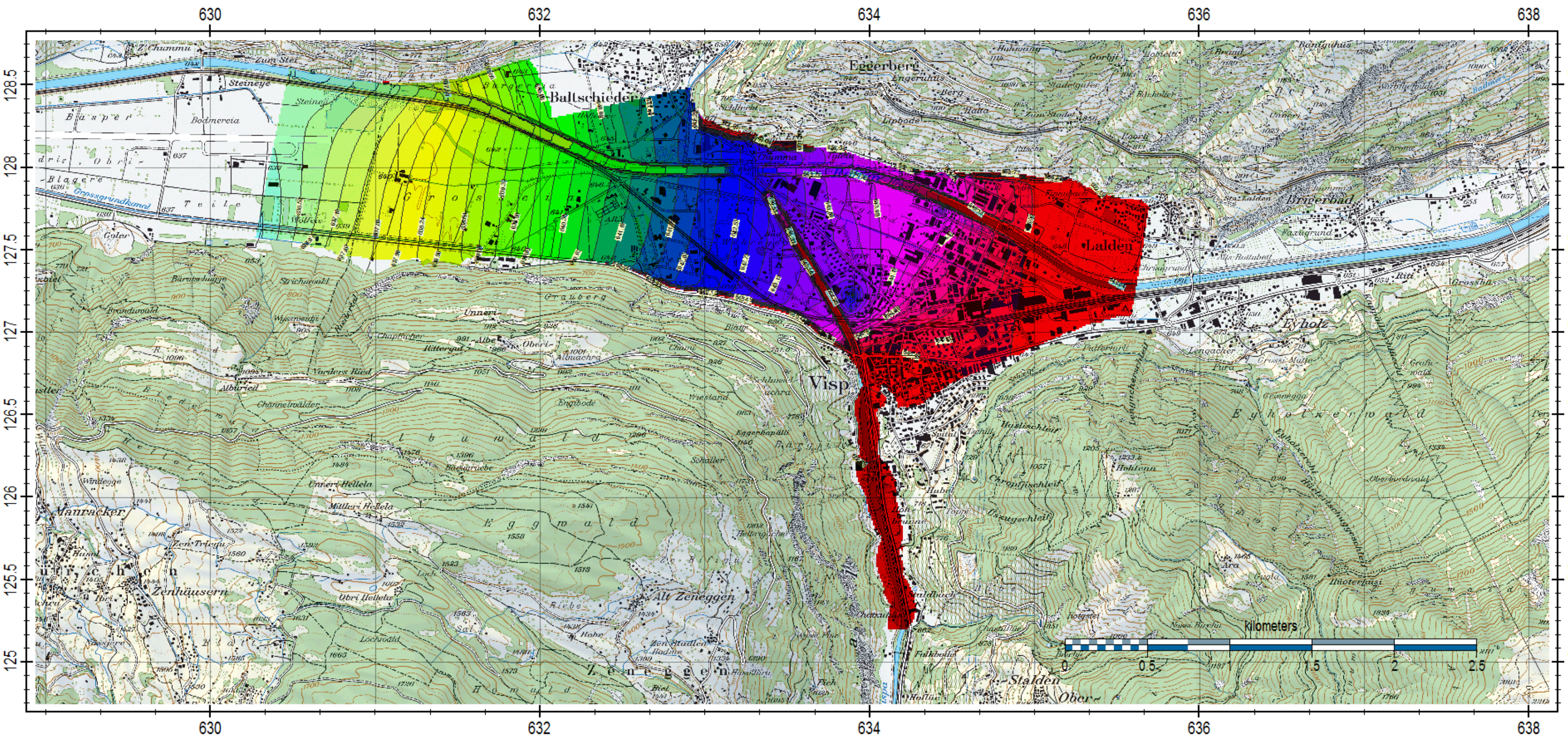
# Model of Visp




Computed isohypses for model layer 1 (groundwater level). Model simulated for 2011-2013 year on a daily time step (1065 time steps) on a resolution of 10 x 10 meter



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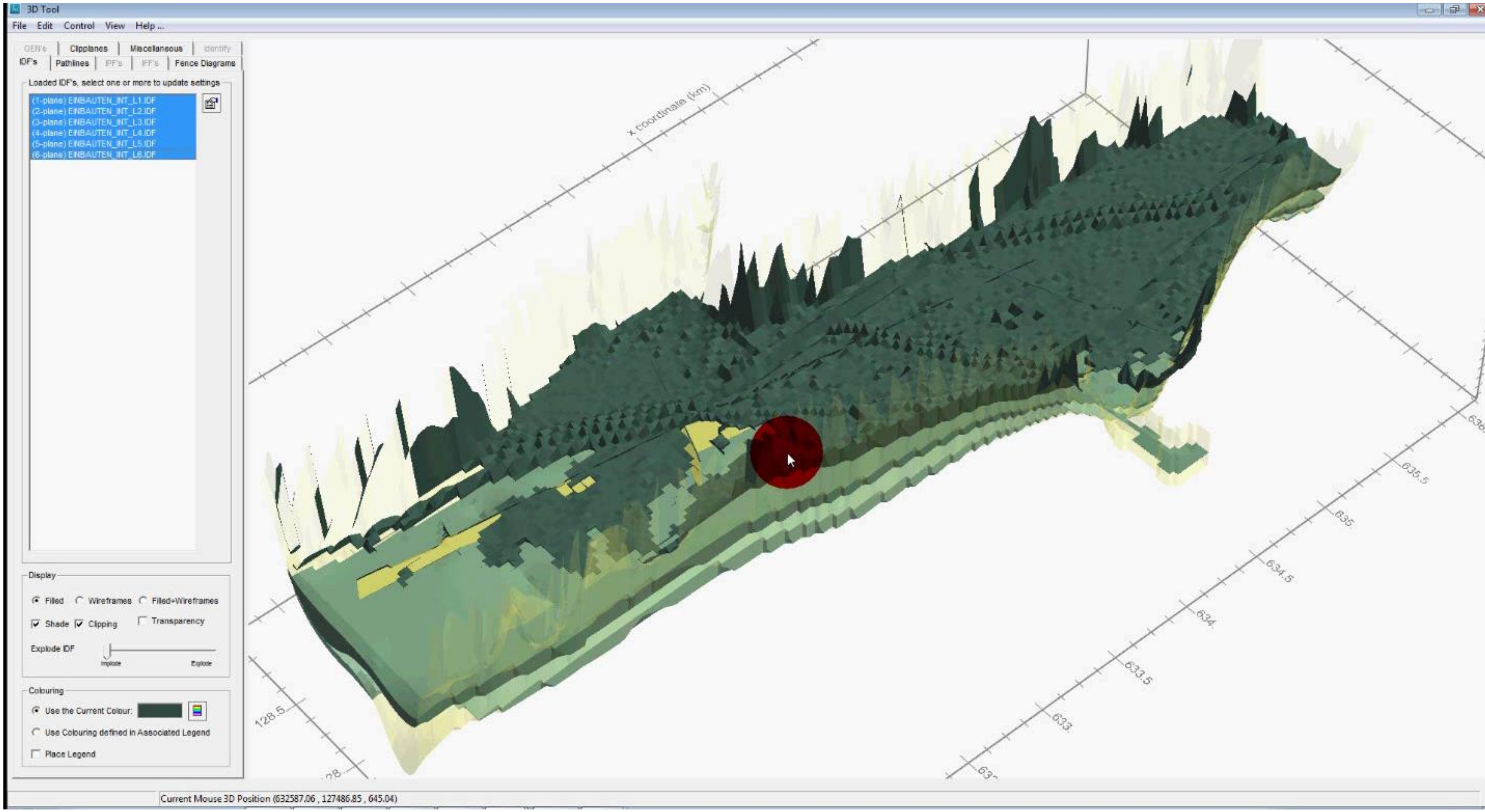
# Model of Visp



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