Belgian Nuclear Research Centre

Diederik Jacques - 10/10/2023

cAt – Hydrogeological aspects

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Discussion and input form IMDC – Jan Walravens

....

Introduction – Geotransfer factor

Knowing the environment

Ground water modelling

- Local Model
- Site Model
- Wetland model

Conclusions & Future work

INTRODUCTION: GeoTransfer Factor

Why do we need a Geo Transfer factor (GTF)

- To estimate the radiological impact of the disposal
- **Definition:** The ratio of the RN concentration in a biosphere receptor to the RN flux from disposal facility
- Higher GTF means there is a lower dilution in the geosphere
- Different biosphere receptors (pathways):
  - Private well
  - Wetlands

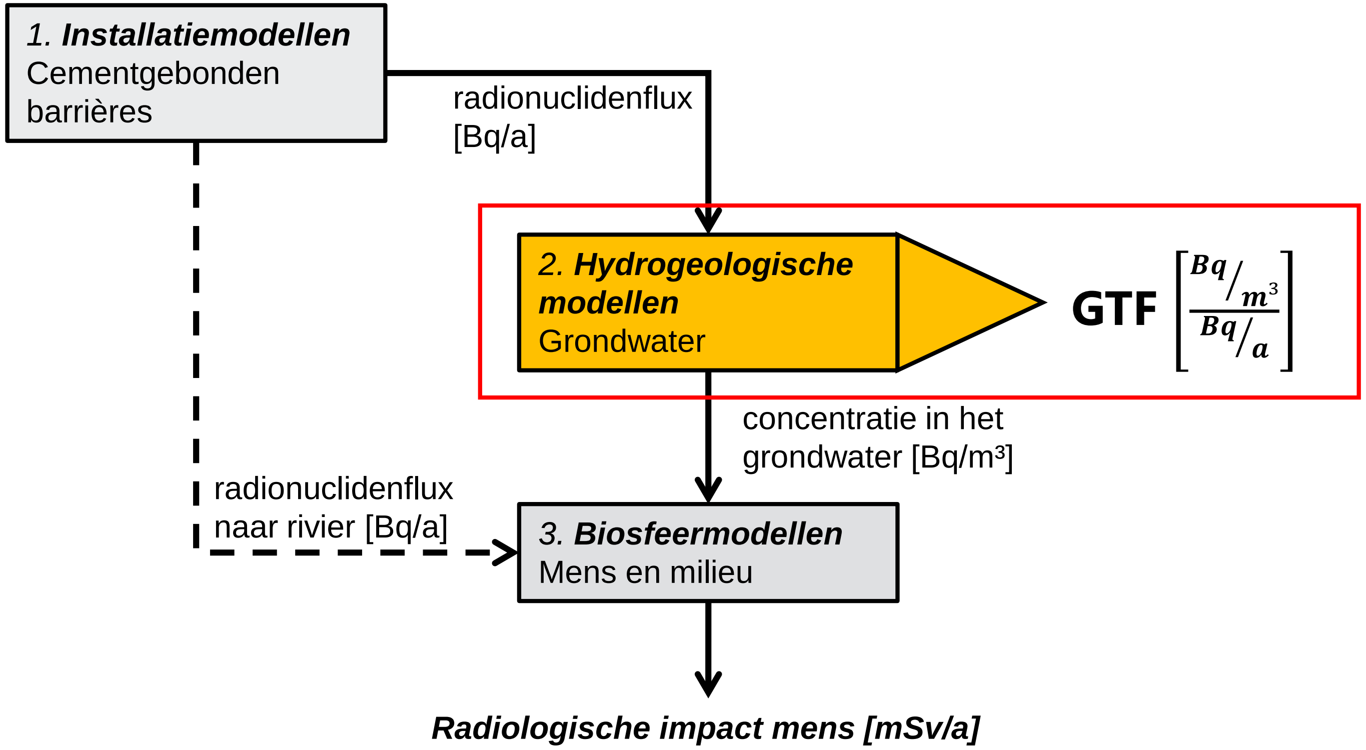
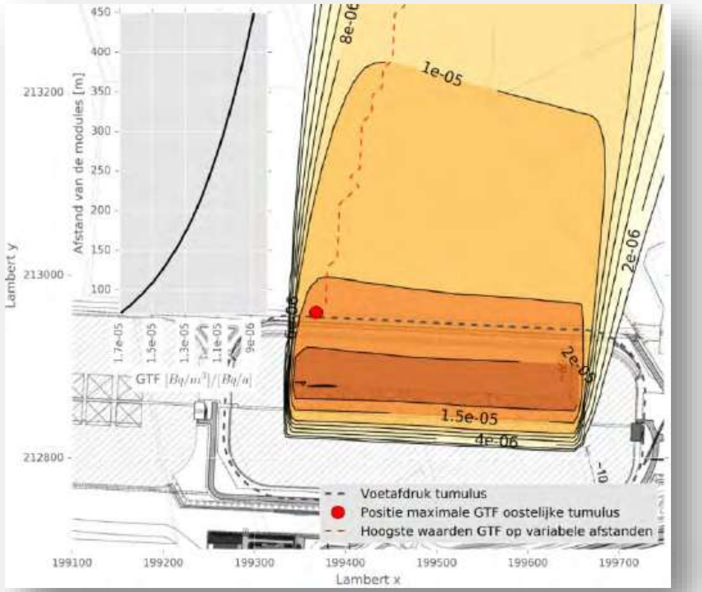
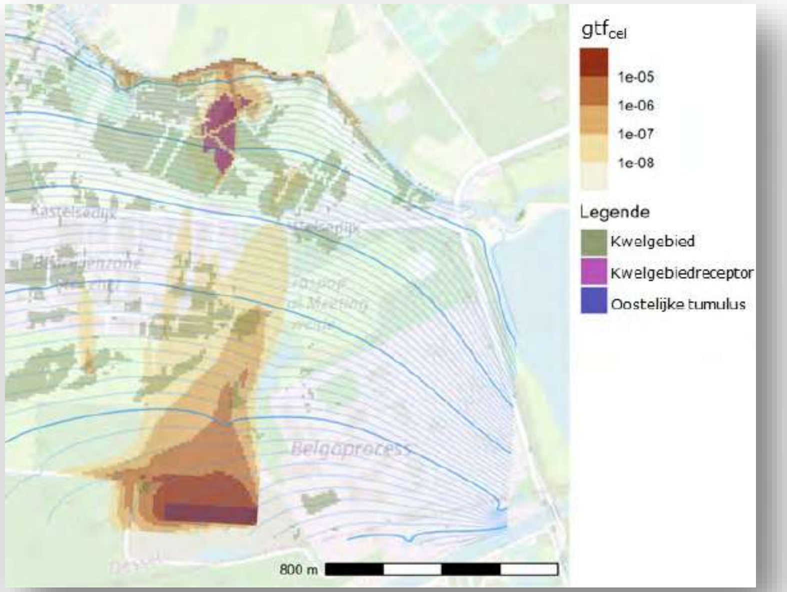


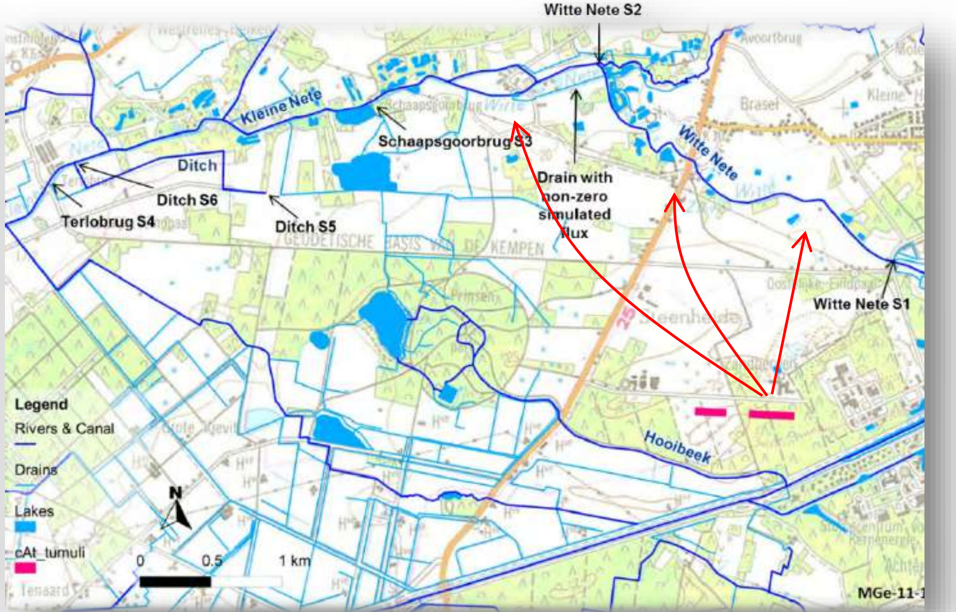
Figure adapted from the Safety file

Why different GTFs?

- GTF is calculated for different biosphere receptors:
  - Private well: at the most adverse location at the foot of the tumuli
  - Wetlands: areas where (contaminated) groundwater reaches the roots of plants and a RN transfer can take place
  - River: drainage of (contaminated) groundwater to river network

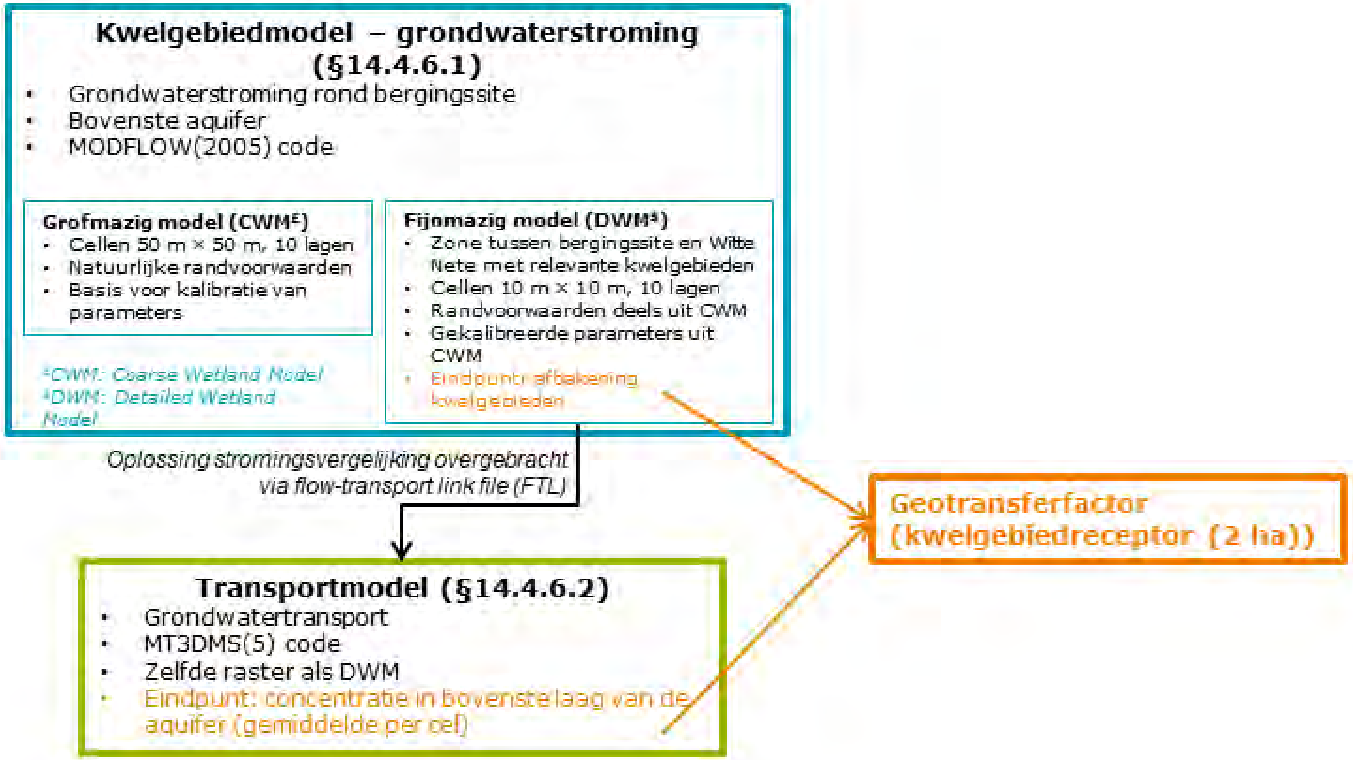






How do we obtain GTFs?

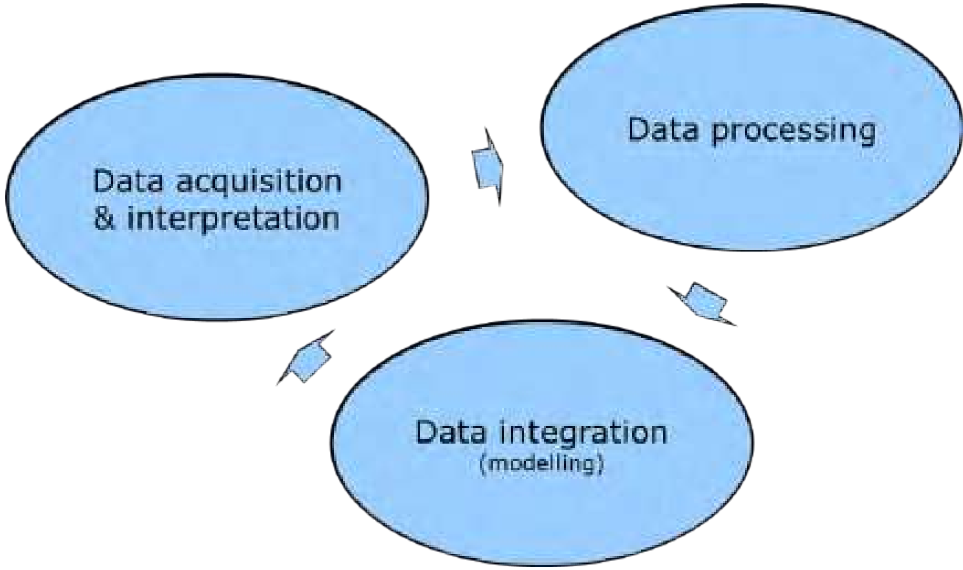
- Hydrogeological modelling
  - Groundwater flow model
    - Often using nested models to combine the natural boundary conditions with need for precision
  - Groundwater transport model
    - Using results from the flow model
    - Simulating constant activity flux through disposal tumulus
    - RN independent



KNOWING THE ENVIRONMENT

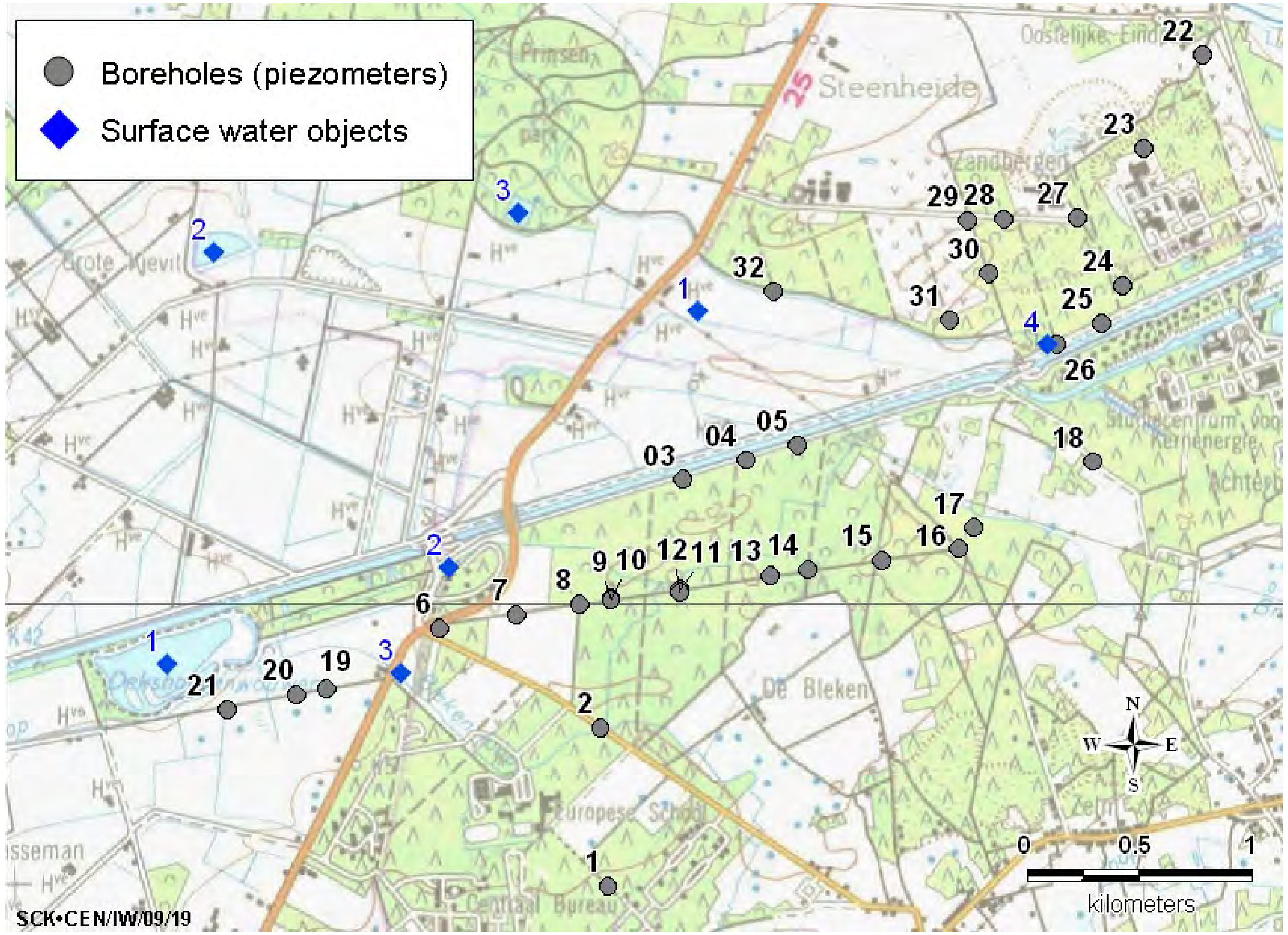
The characterization of the environment

- Long-term: starting in 1999 and lasting to date
- Stepwise iterative approach
  - Every site characterization campaign is followed by modelling
  - Every modelling is evaluated & then reviewed by the Safety Authority
  - This leads to further characterization
    to answer the raised questions
- Gradually focusing the site-characterisation efforts on building a solid safety-relevant scientific basis



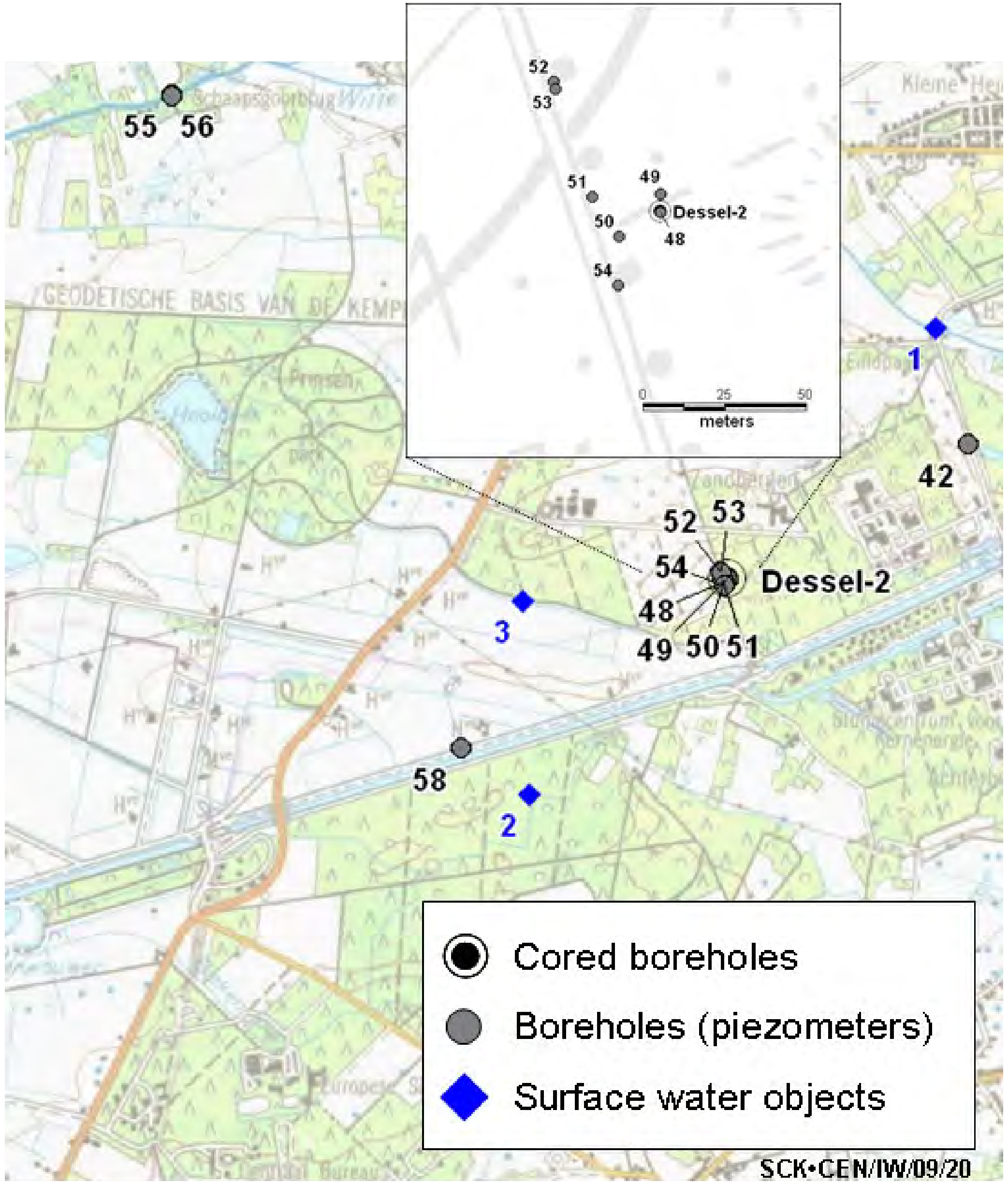
Campaign 1999 – 2000

- Focused on piezometry and surface water level observations
- Basis for the local piezometric network
- One pumping test L-11
  - South of the canal
- Initial modelling
  - *Role of Kasterlee Clay?*
  - *Boundary conditions?*



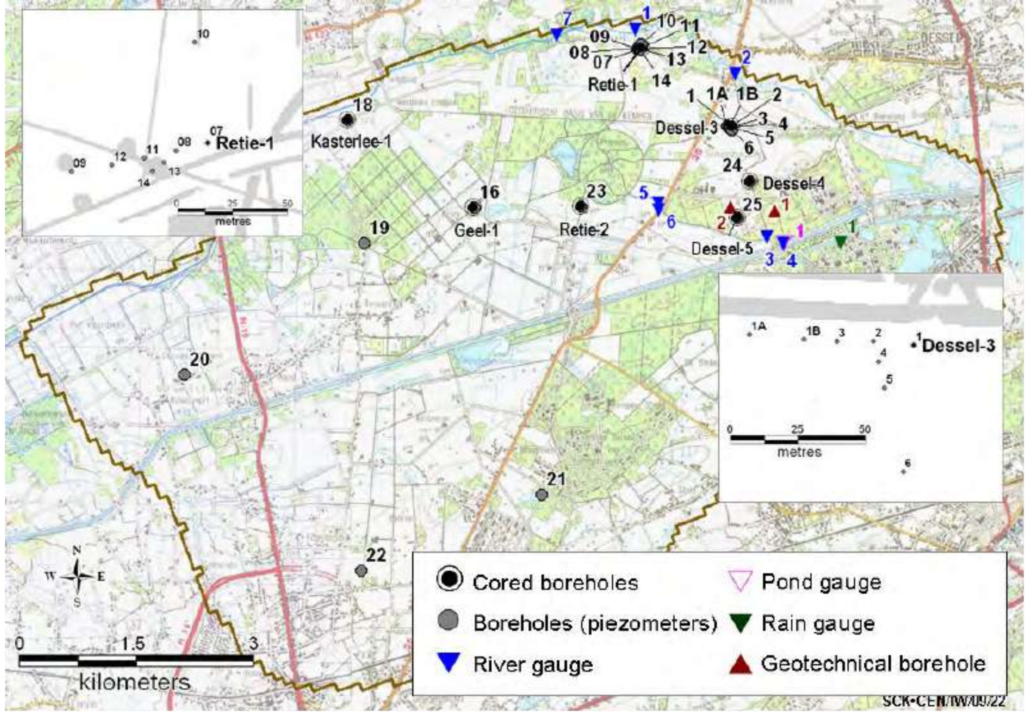
Campaign 2002

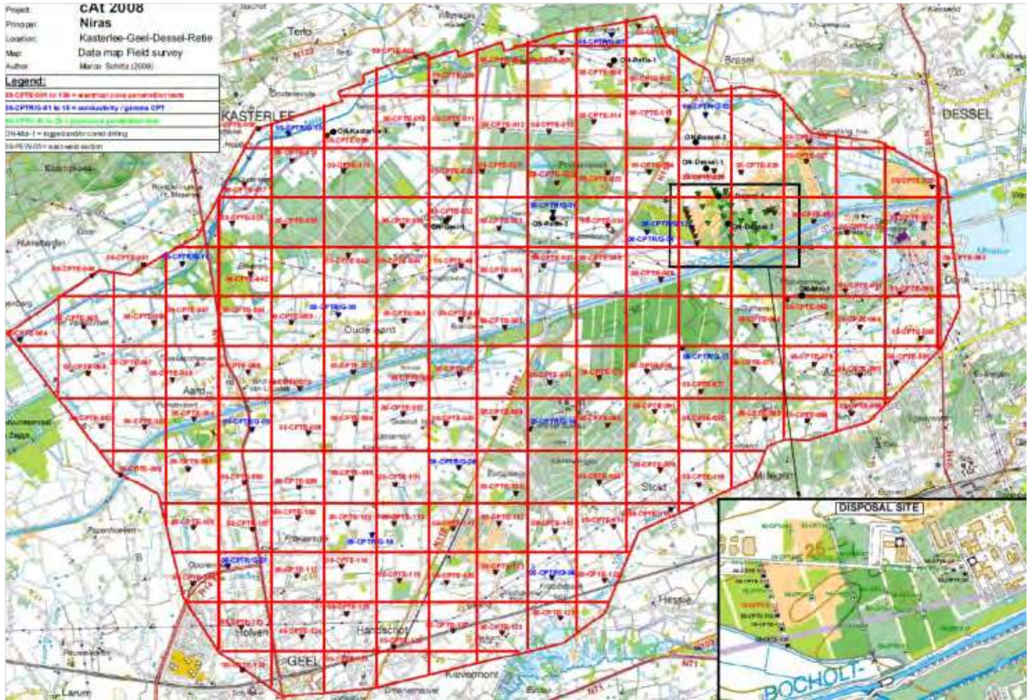
- Focused on hydraulic parameters at the cAt site
- Verification of the Kasterlee Clay (im)permeability
- Dessel-2 borehole cluster
  - 2 pumping tests
  - Core sample analyses
- Few extra piezometers and surface observations points
  - Focused on the boundary conditions (Nete, Hooibeek, sand pit, canal)
- Local model 1st iteration:
  - *Is Kasterlee Clay (dis)continuous?*
  - *Spatial coverage of observations?*



Campaign 2008

- Focus on the entire Local model area
  - Filling the white spots
  - Focus on the principal pathway
    - Piezometry
    - Pumping tests
    - Core sample analyses
- Kasterlee Clay continuity verification
  - **C**one **P**enetration **T**esting
    - Performed on a regular grid
    - More precise stratigraphy
    - Detailed geometry of the Kasterlee Clay
- Local model 2nd iteration (SC 2013)
  - *Can we validate the flow direction and velocity?*

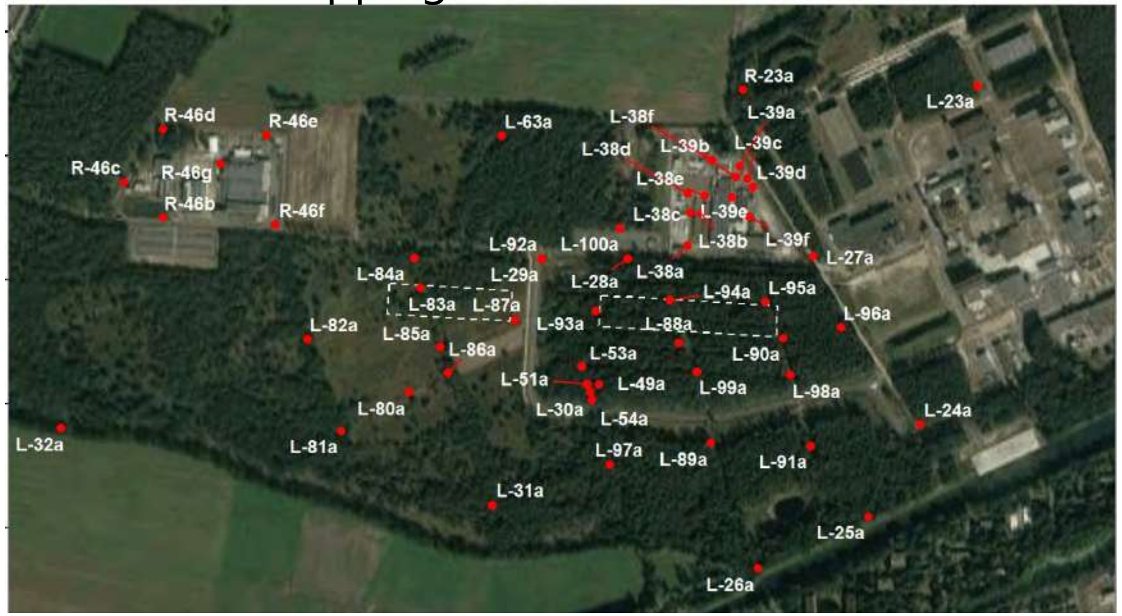




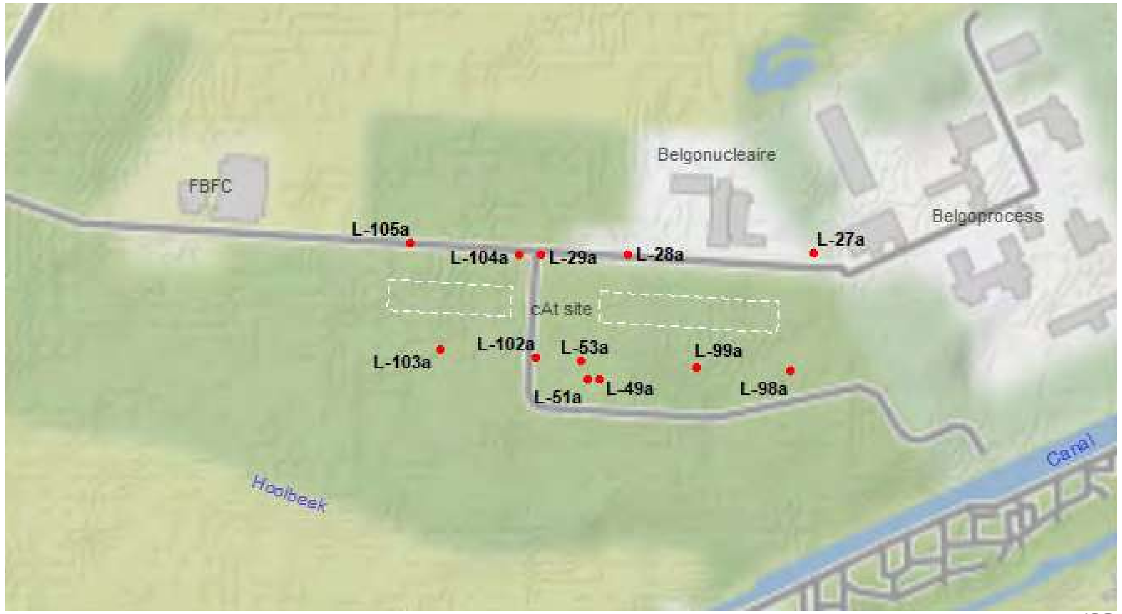
Campaign 2016 – 2019

- Focused on validation of the flow direction and velocity
  - New temporary piezometers at the cAt site
    - monthly measurements -> daily interpolated maps
    - summary plots for flow direction under the tumuli
  - Dilution tests
    - Existing and new piezometers
      - Long filters and minimizing the excavation disturbed zone
- Answers to the Safety authority
  - *Steady-state flow confirmed for the eastern tumulus*

Water table mapping



Dilution tests



GROUNDWATER MODELLING

Three models

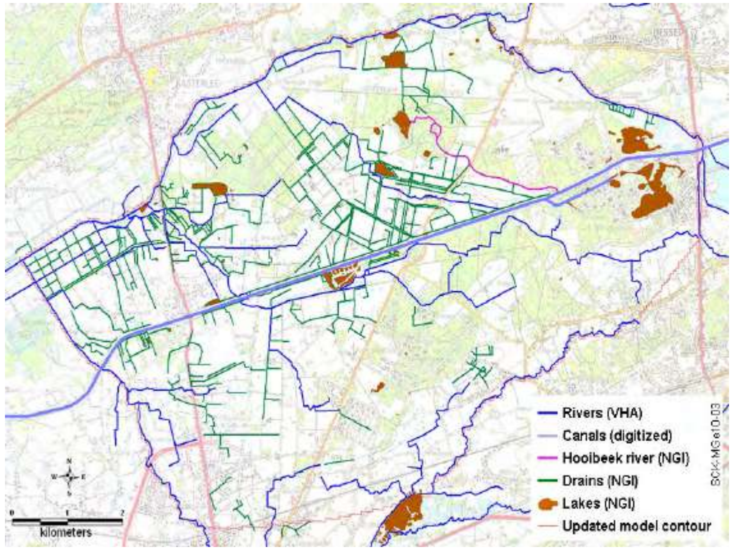
- Private well Eastern tumulus
  - Steady-state model
  - Approved in 2019
- Private well Western tumulus
  - Transient model
  - Unfortunately, insufficient data for validation (see further)
- Wetland Eastern tumulus
  - Transient model with more details in wetland areas
  - Approved in 2023

Steady-state Local model

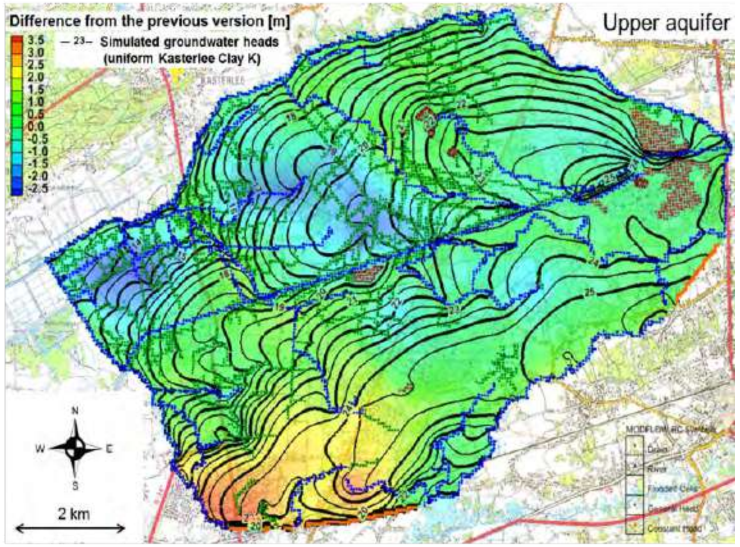
Steady-state model – Local model (safety case 2013)

- Constant boundary conditions lead to time-invariant flow and velocity field

Constant recharge flux; river, lake, drain levels

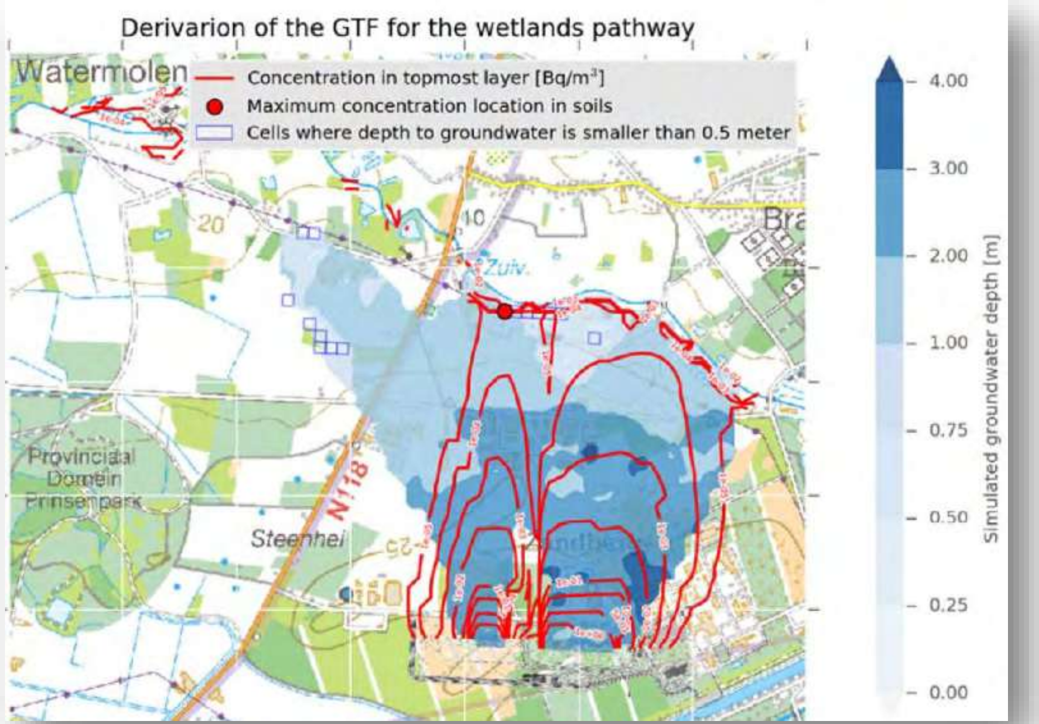


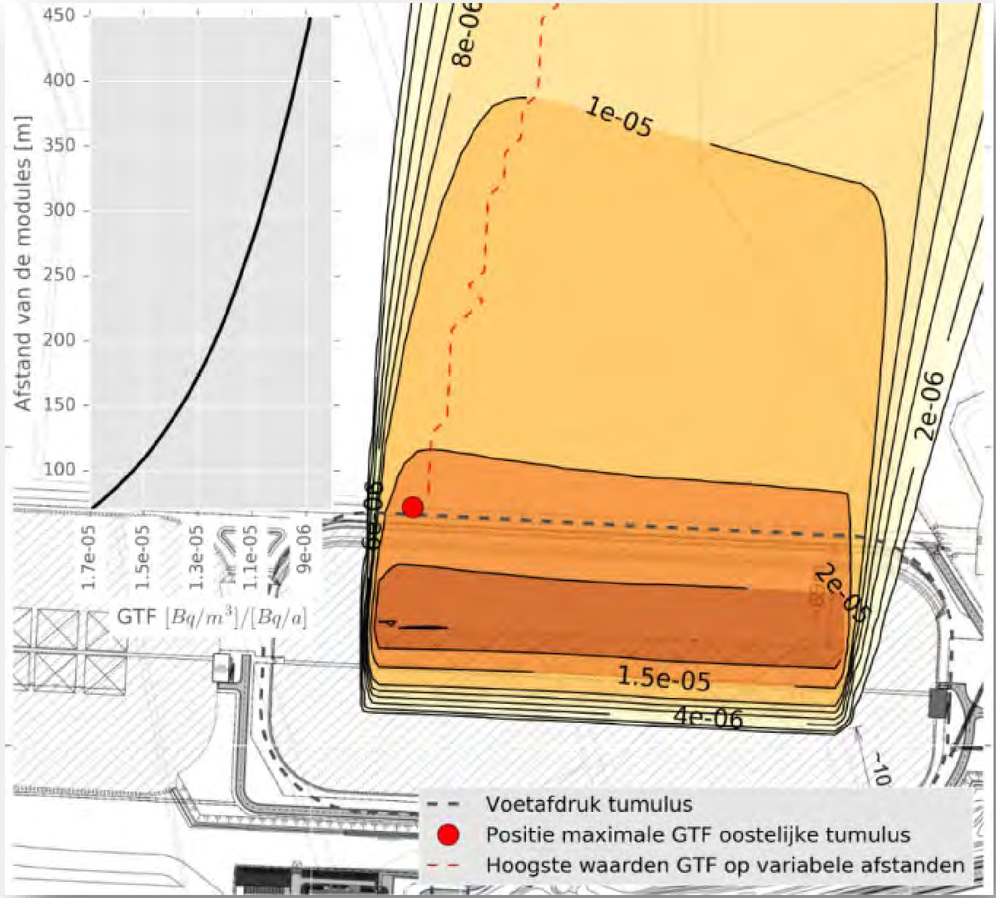
Single (equilibrium) flow-field representation



GTFs calculated

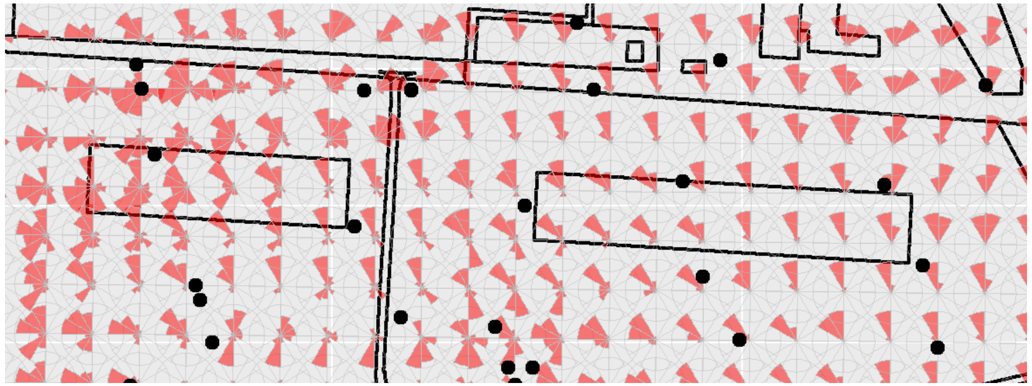
- The GTF was calculated for three receptors:
  - Eastern tumulus private well (1.7×10^{-5} a/m^3)
  - Wetlands: 4.7×10^{-9} a/m^3 (<<< GTF_{well})
  - Rivers ($Flux_{rivers} = Flux_{source}$)

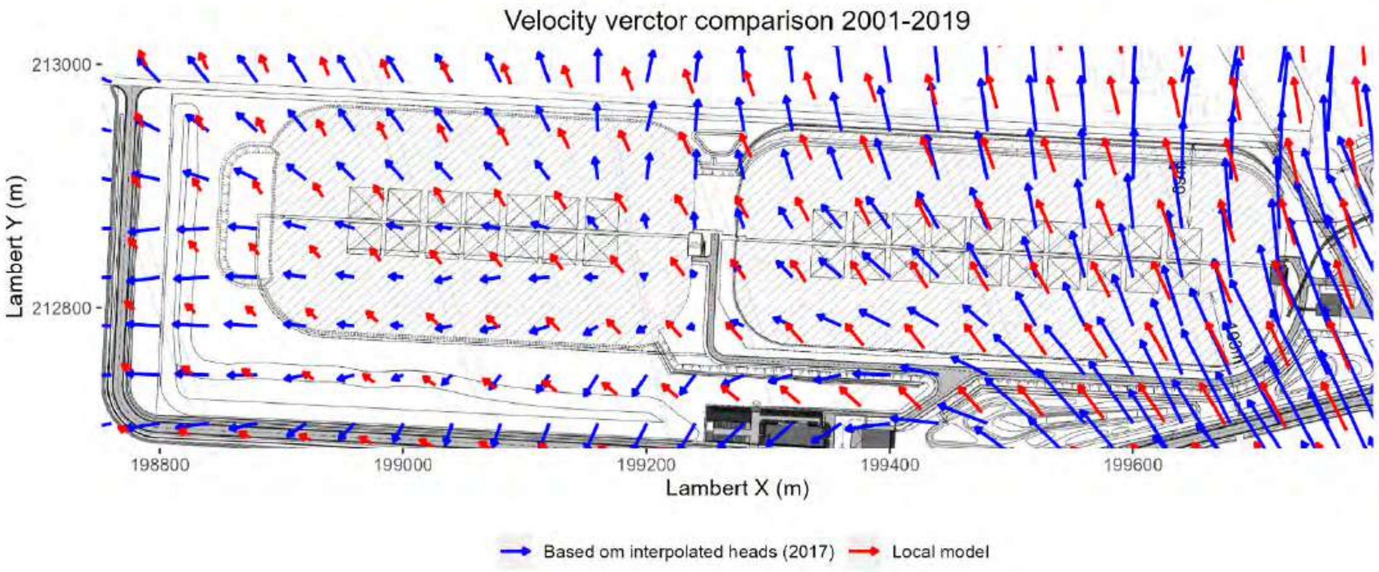




Invariant flow field is validated (for Eastern tumulus)

- Comparison between the single model result and daily interpolated heads
  - Eastern tumulus: reasonable fit & low variability (steady-state OK!)
  - Western tumulus: poor fit due a.o. to high temporal (seasonal) variability





Hence – the safety authority requested

- To confirm the hydrogeological at the Western tumulus based on field data
- To develop a new hydrogeological model that:
  - correctly describes the actual conditions at the disposal site and its surroundings
  - allows to provide conservative estimates of the GTF for the Western tumulus
- To validate the model for the identification of wetland areas and the estimation of dilution in the upper part of the aquifer (eastern & western tumulus)

New data revealed the complex situation at the Western tumulus

- New data (see before) and new statistical data analysis revealed that a steady-state model with invariant flow fields (and velocities) is not representative for the Western tumulus

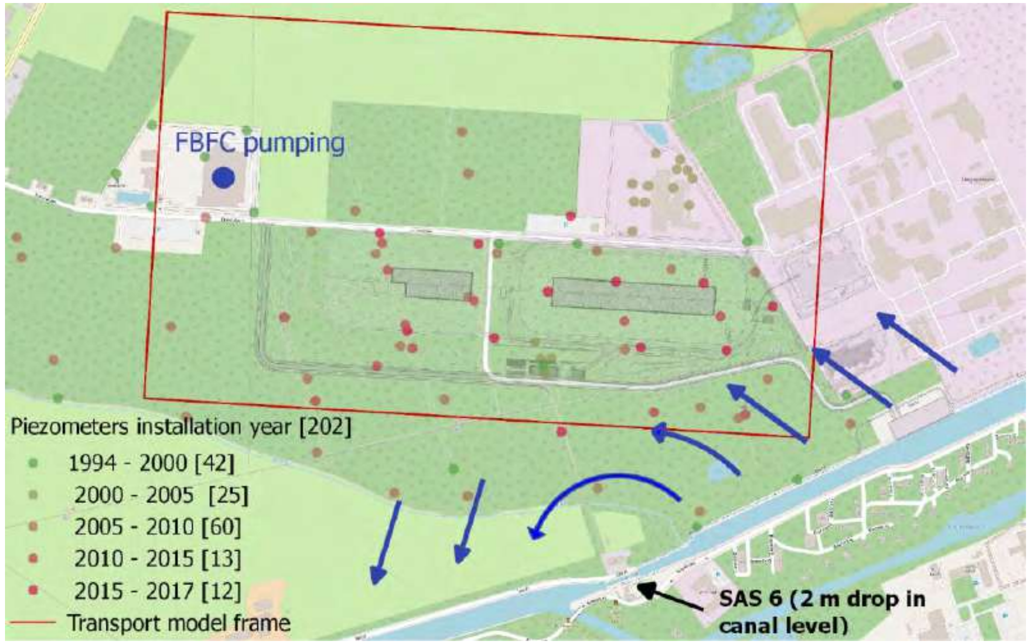
- Therefore, a model with variable boundary conditions (recharge, river levels) is required.

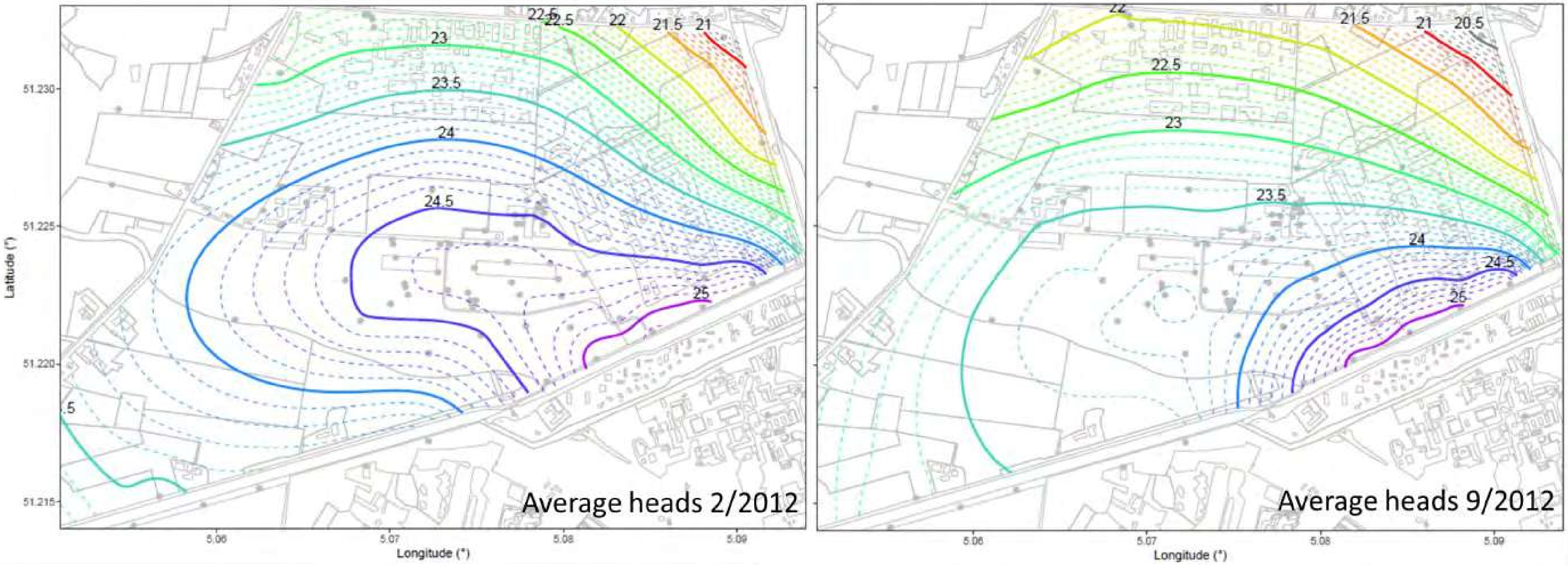
Transient Site model

GTF for the western tumulus

Hydrogeology at the western tumulus

- Flat groundwater table
- Influenced by
  - the leaking canal
  - seasonal recharge
  - pumping operations



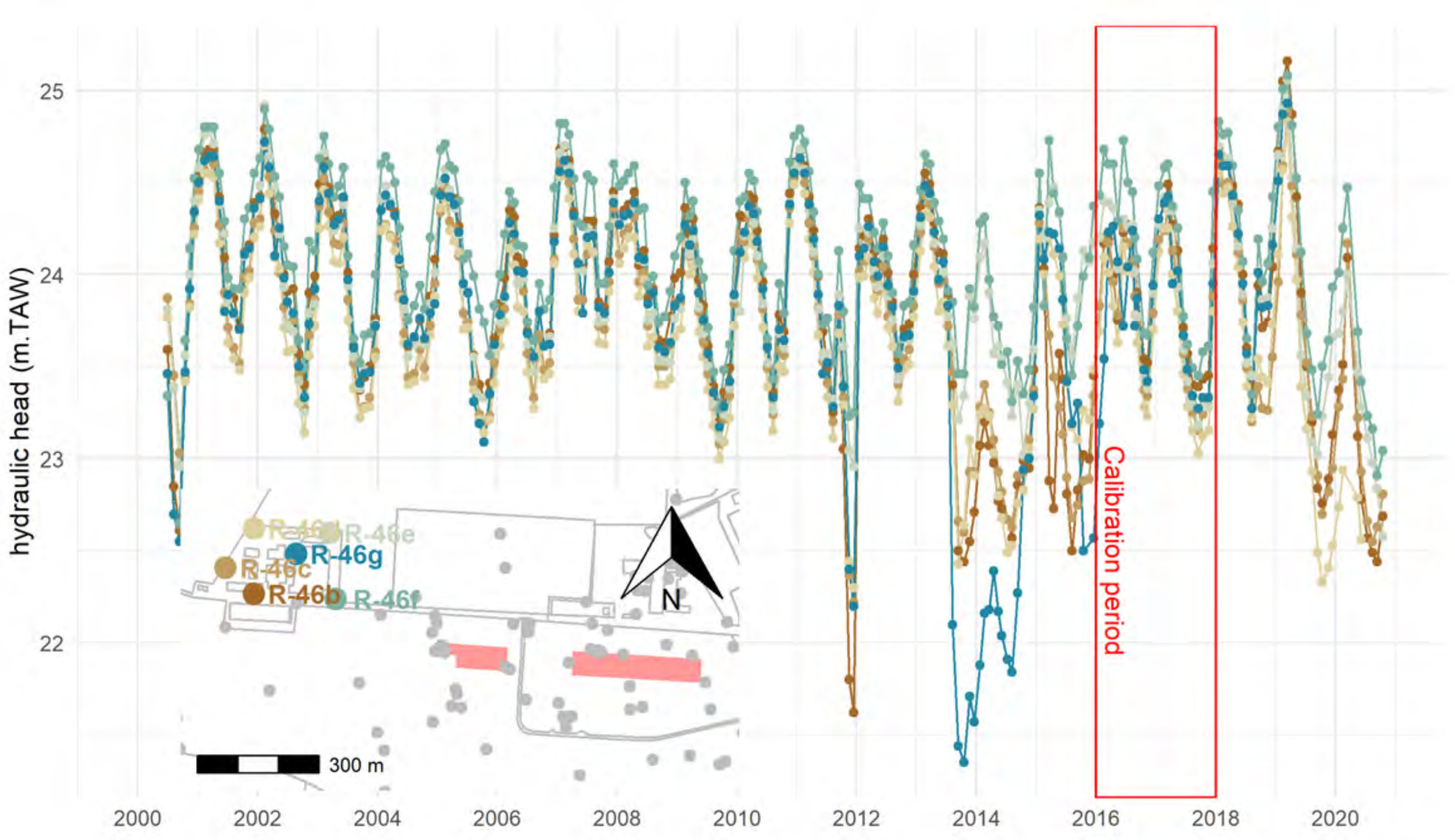


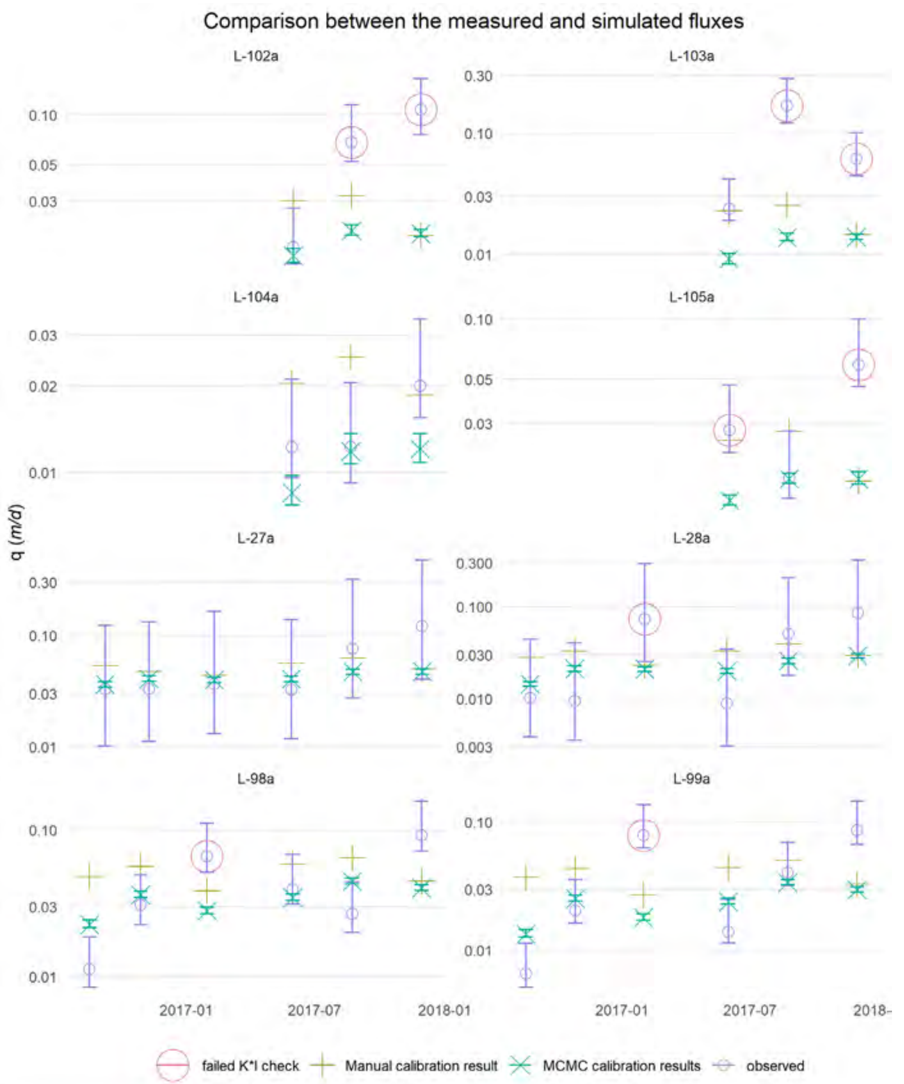
Site model

- Transient groundwater model
  - Extent focused on the upper aquifer
  - Grid refinement (child model) to increase the resolution of transport
  - Recharge dependent on transient precipitation, soil properties and land-use
  - Hydraulic parameters from site characterization and best knowledge

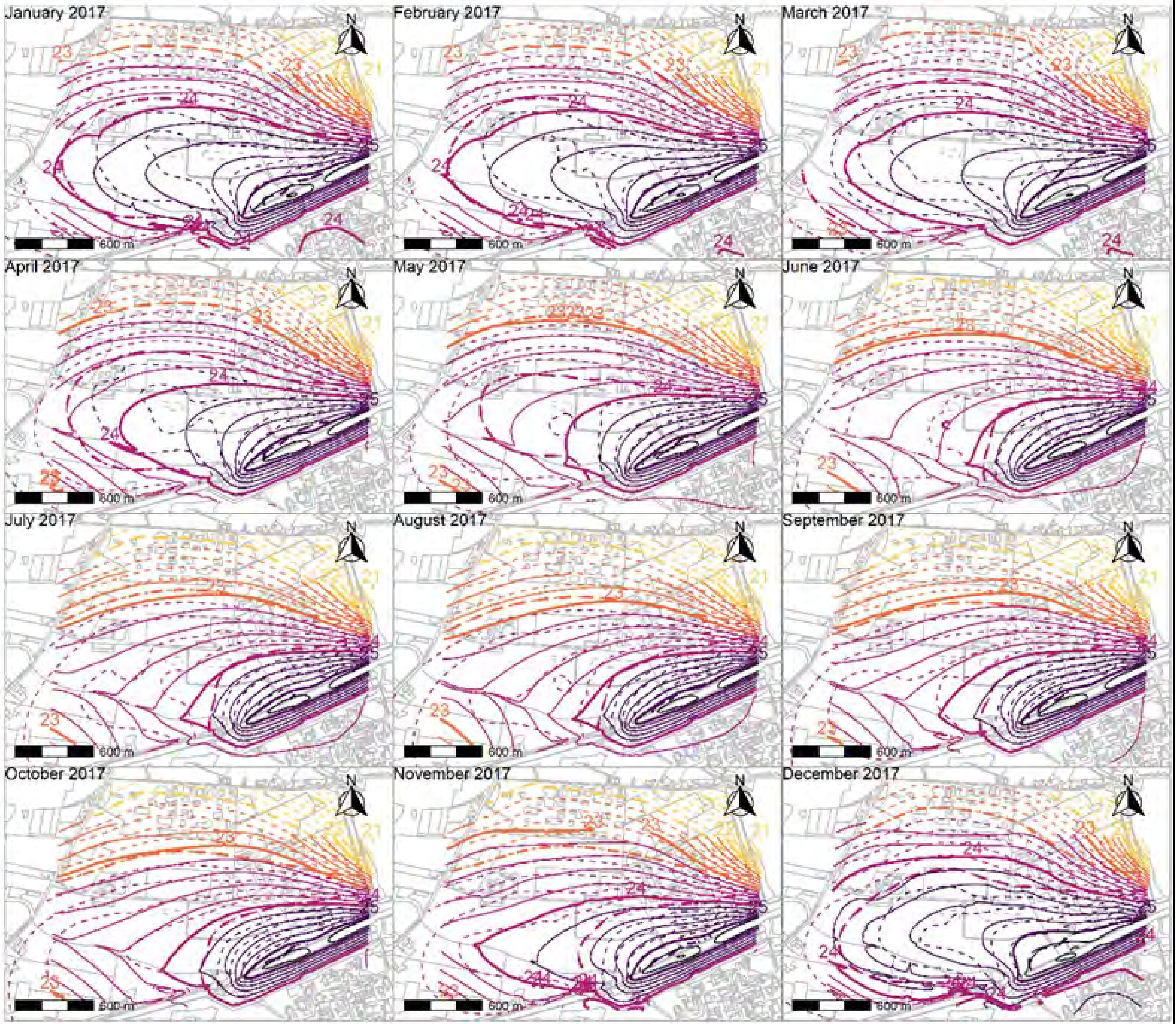
Calibration

- Calibration using the observed heads and fluxes
- Selecting period with limited influence of pumping (at FBFC, BP, NIRAS cAt)
- Manual and automated calibration





Parameters calibrated using MCMC

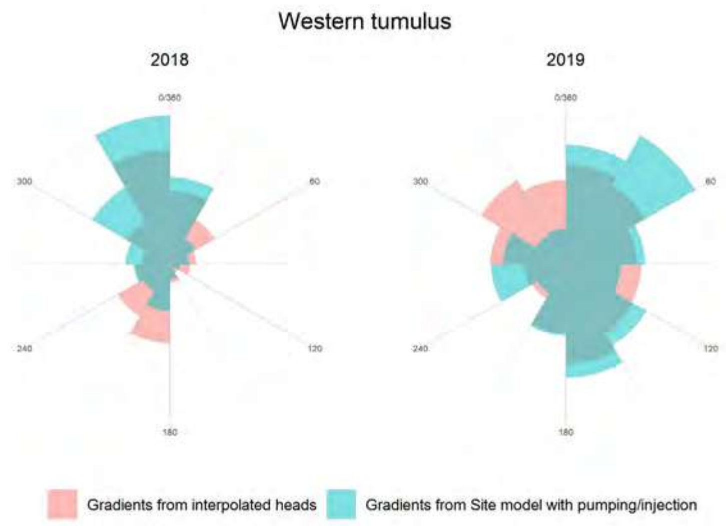


Validation

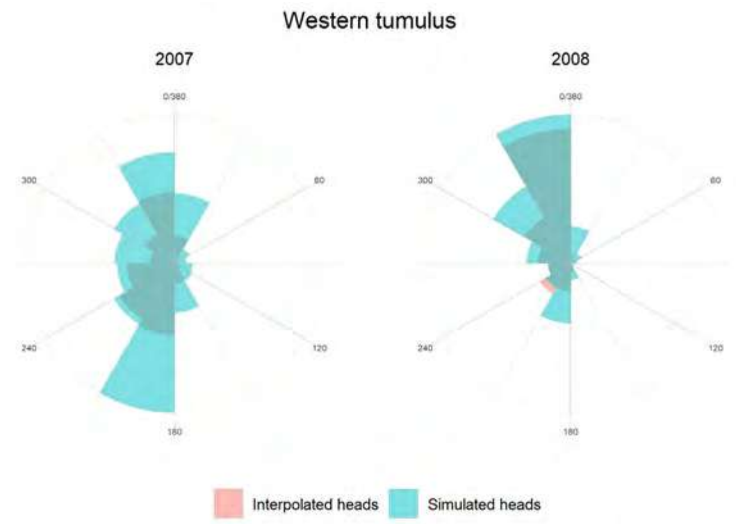
- Comparison of simulated with observed heads outside of the calibration period, turned out to be problematic, because:
  - The detailed observations period 2016 – 2019 influenced by pumping
  - Earlier periods not detailed enough
- Possibility to: either include pumping (no data available), or use less observations
- No good solution available…

Comparison between the hydraulic gradients from interpolated maps and the model

With arbitrary pumping



Period with less detailed data



Conclusions (Site model)

- The model cannot be satisfactorily validated
  - Need for a sufficiently long period of detailed observations without external influences (pumping)
- The GTF for the western tumulus cannot be calculated (for the moment…)
- Site characterization is entering a new phase:
  - Detailed piezometric measurements at the western tumulus using data loggers for a higher measurement frequency
  - Continuing the flux measurements

Validation of the wetlands positions and GTF of wetlands

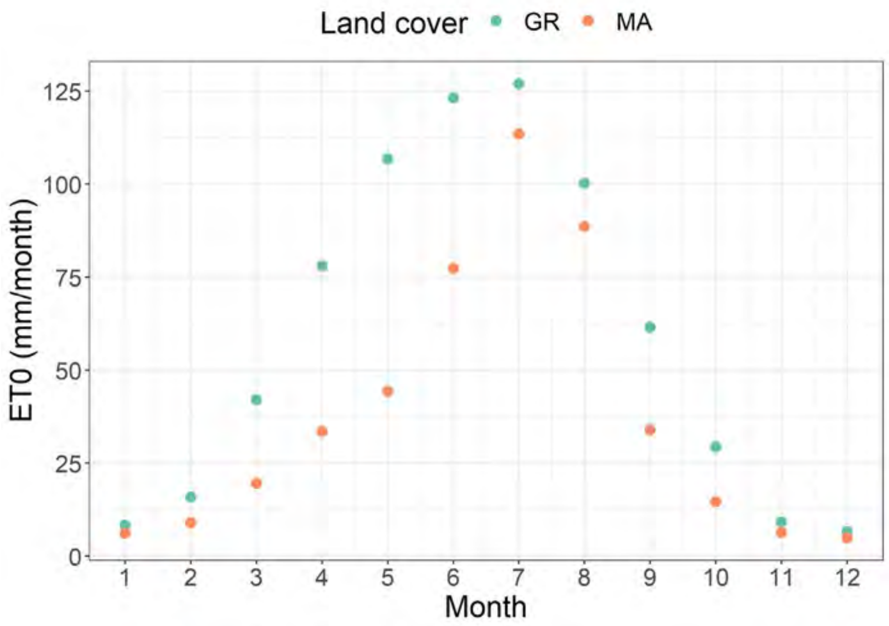
But… what are “Wetlands”?

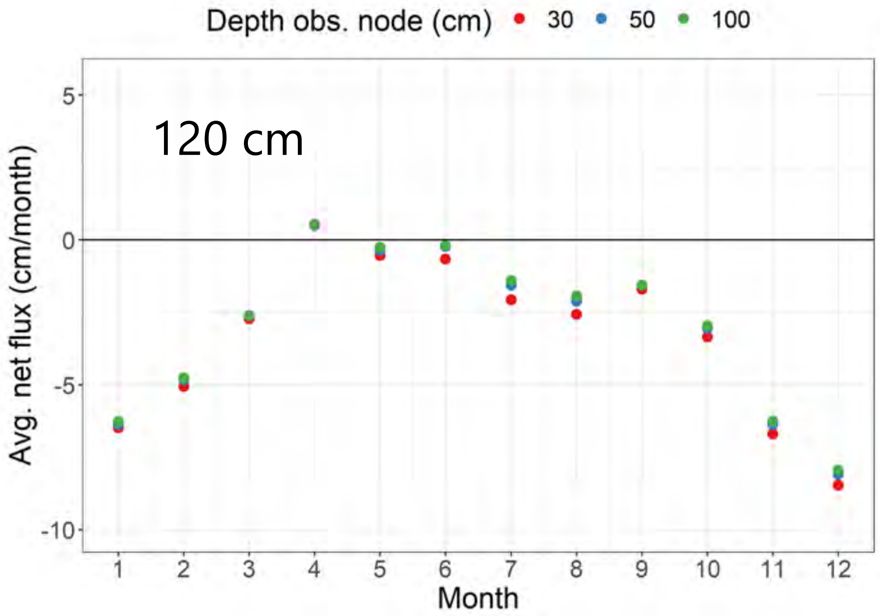
- Not in ecohydrological sense

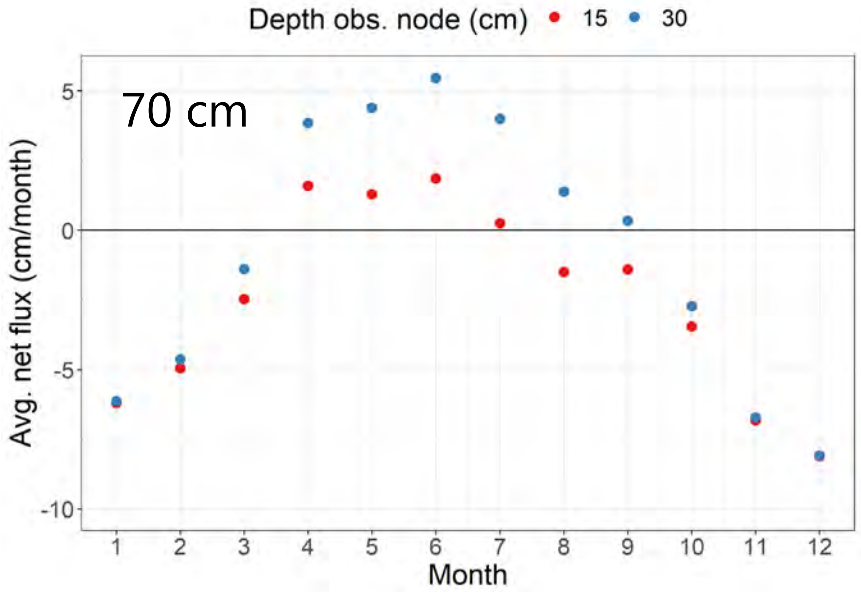
- Entrance point of radionuclide in the soil and crop compartment (30 cm topsoil) via groundwater and upward fluxes

Delineation criterium

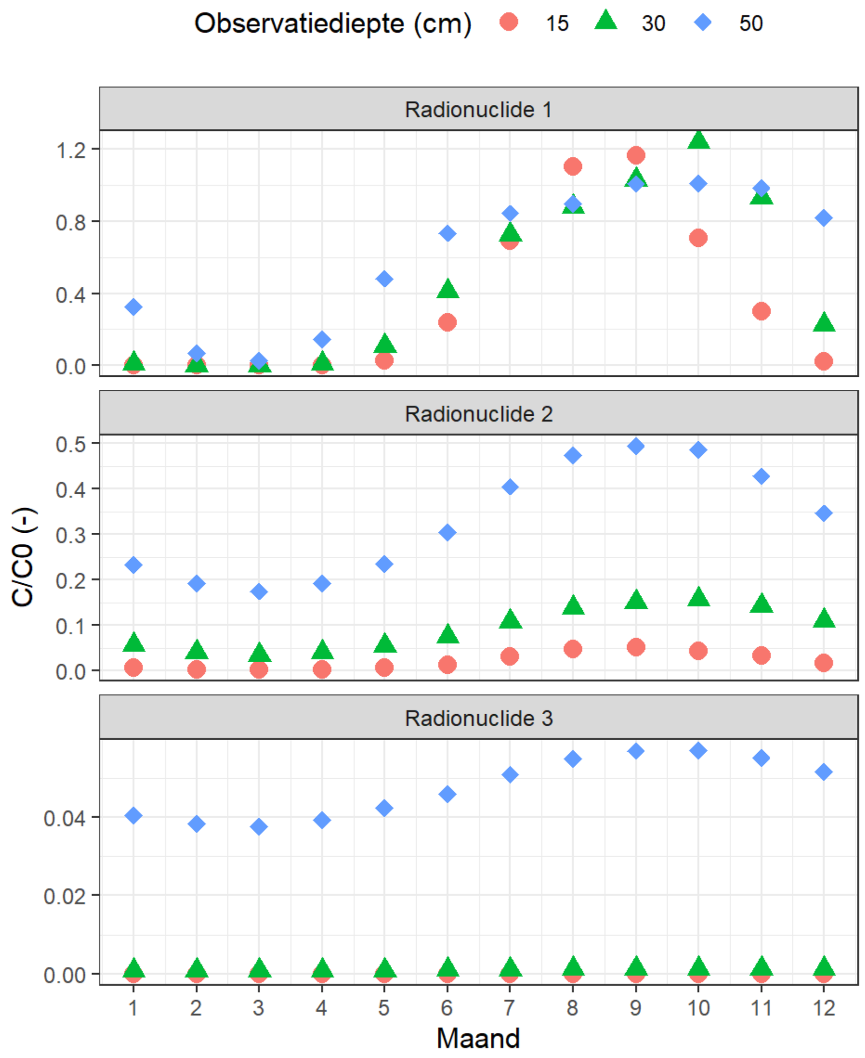
- Transient model – time of highest groundwater level does not coincide with time of highest upward flux.







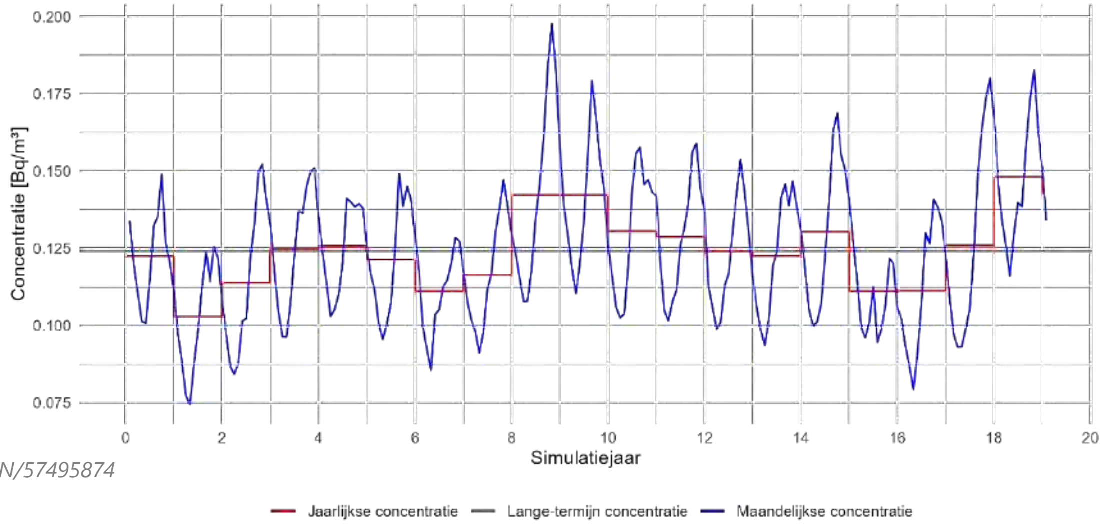
Delineation criterion



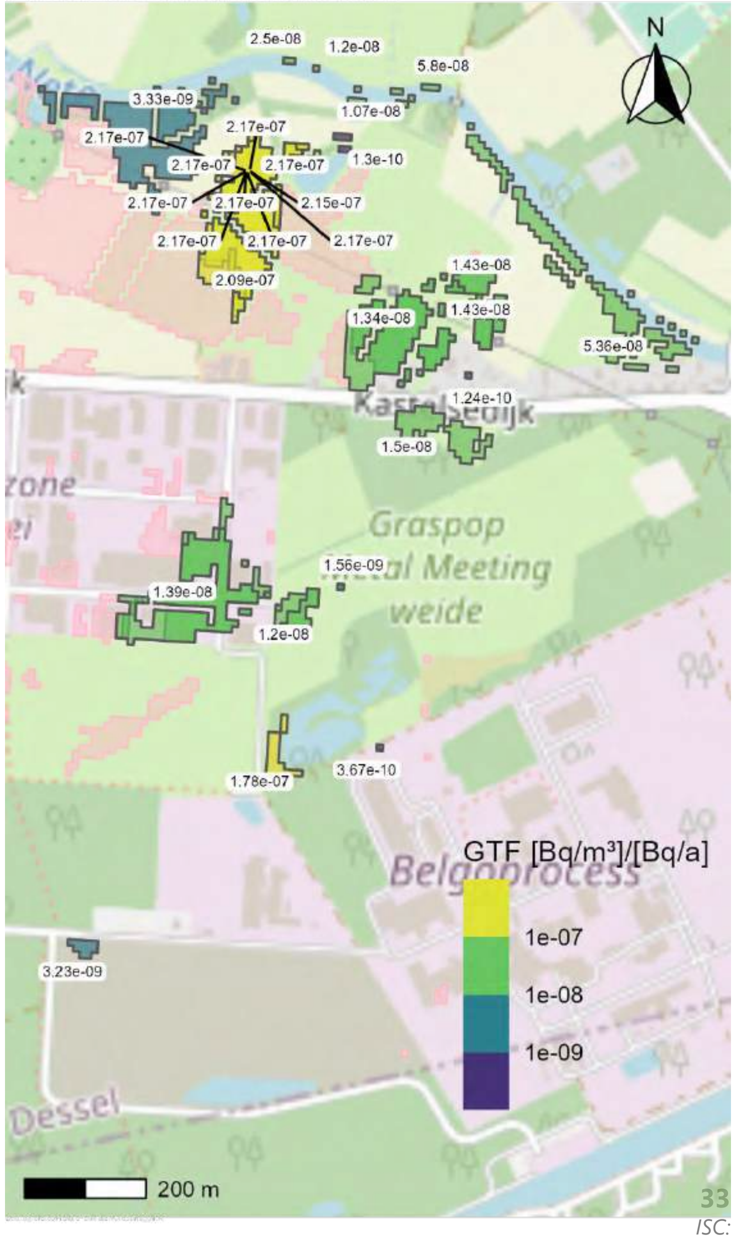
- Based on stylized scenarios: long-term average ground water level less than **70 cm** below surface in **April or May**.

Wetland receptor definition

- Wetland receptor is defined in several steps:
  1. Calculate the cell GTF
     - Based on long-term average concentration and source flux
  2. Overlay with map of wetlands
  3. Lookup all 2 ha areas (200 cells of 10×10 m) – potential wetland receptors
     - Selecting the highest value – wetland receptor

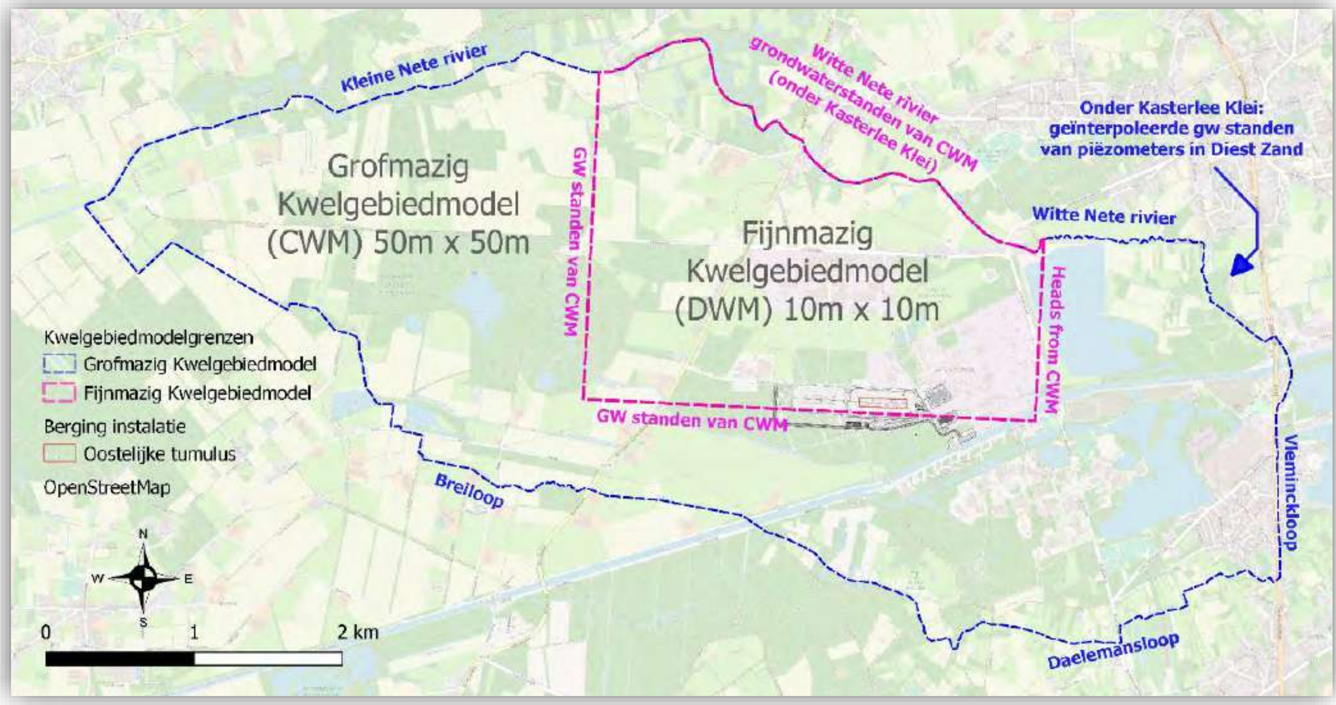


Klimaat: CCI HYDR hoog/nat
Landgebruik: uniforme gras
Concept: geen kanaal & hooibeek
Paremeterset: Manulele kalibratie



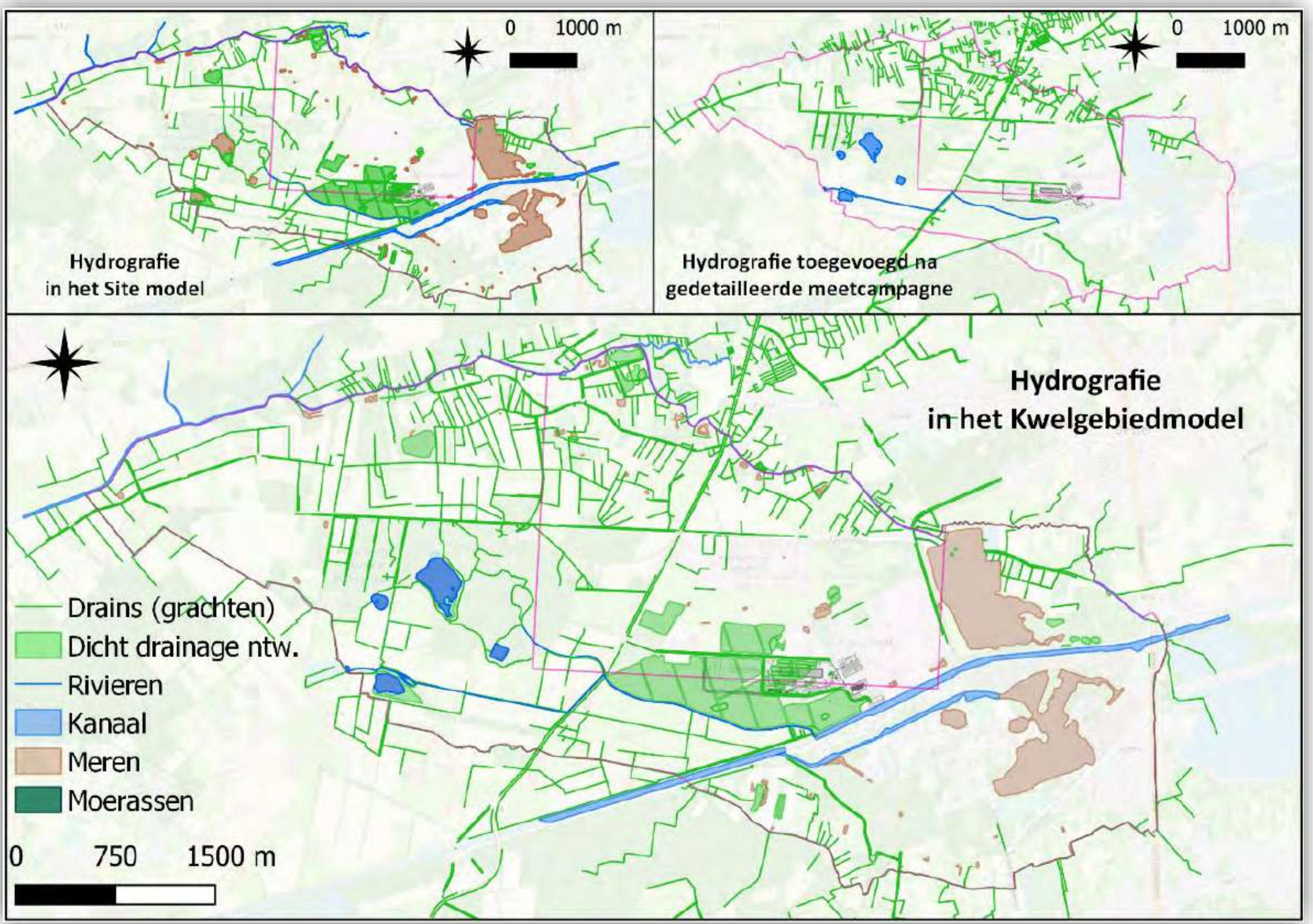
Building the flow model for the wetlands

- Largely based on the Site model:
  - Extent of the parent (coarse) model
  - Hydraulic parameters
  - Recharge
- Different focus:
  - Pathways of RN from the Eastern tumulus
  - Not in the immediate vicinity of the disposal site (relatively deep groundwater level)
  - Hydrology important, especially in the agricultural zone close to Nete River level dynamics



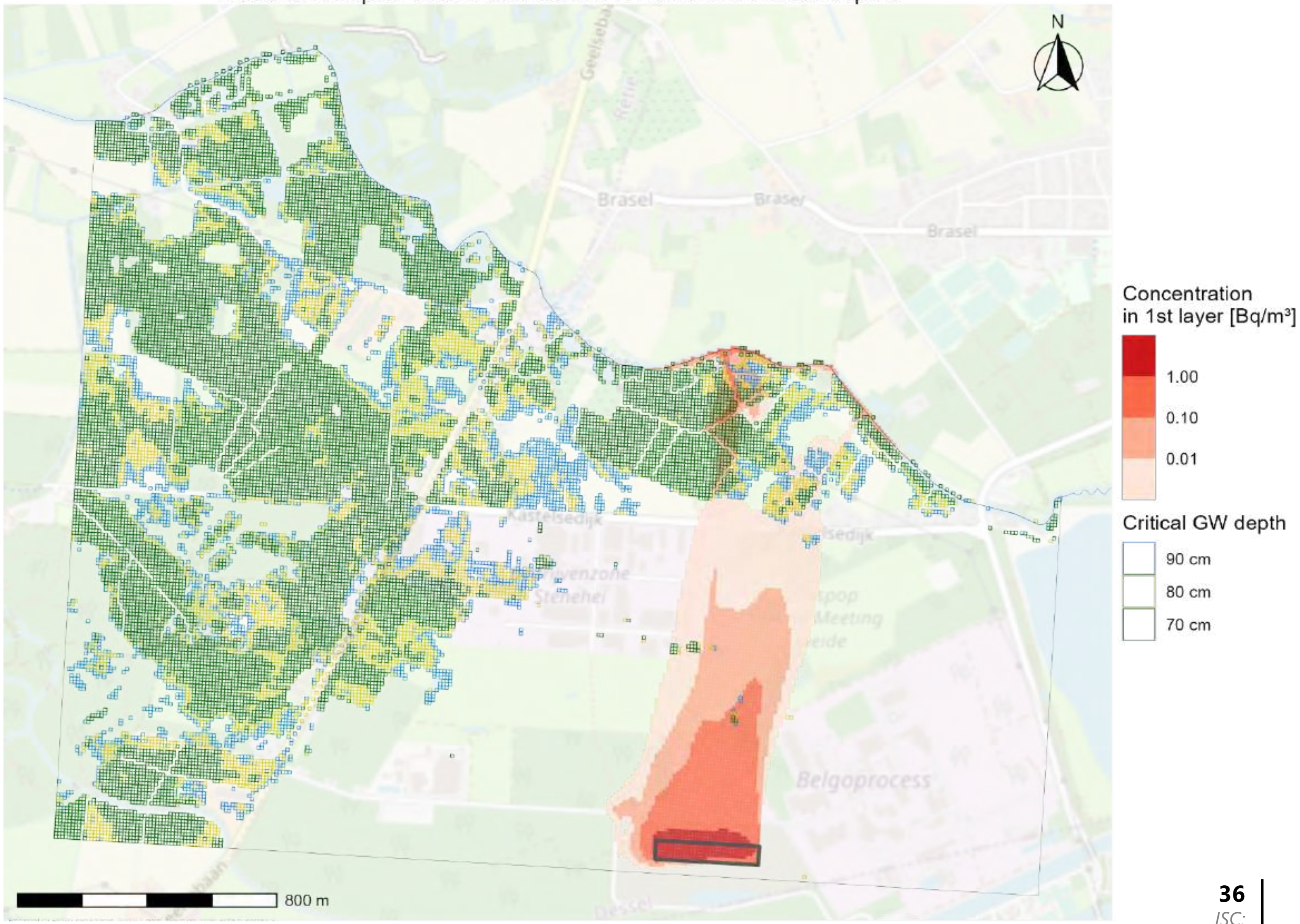
Wetland model detailed hydrography

- Field survey (IMDC)
  - Mapping & measuring the levels
- River hydraulic modelling
  - dynamic river stages

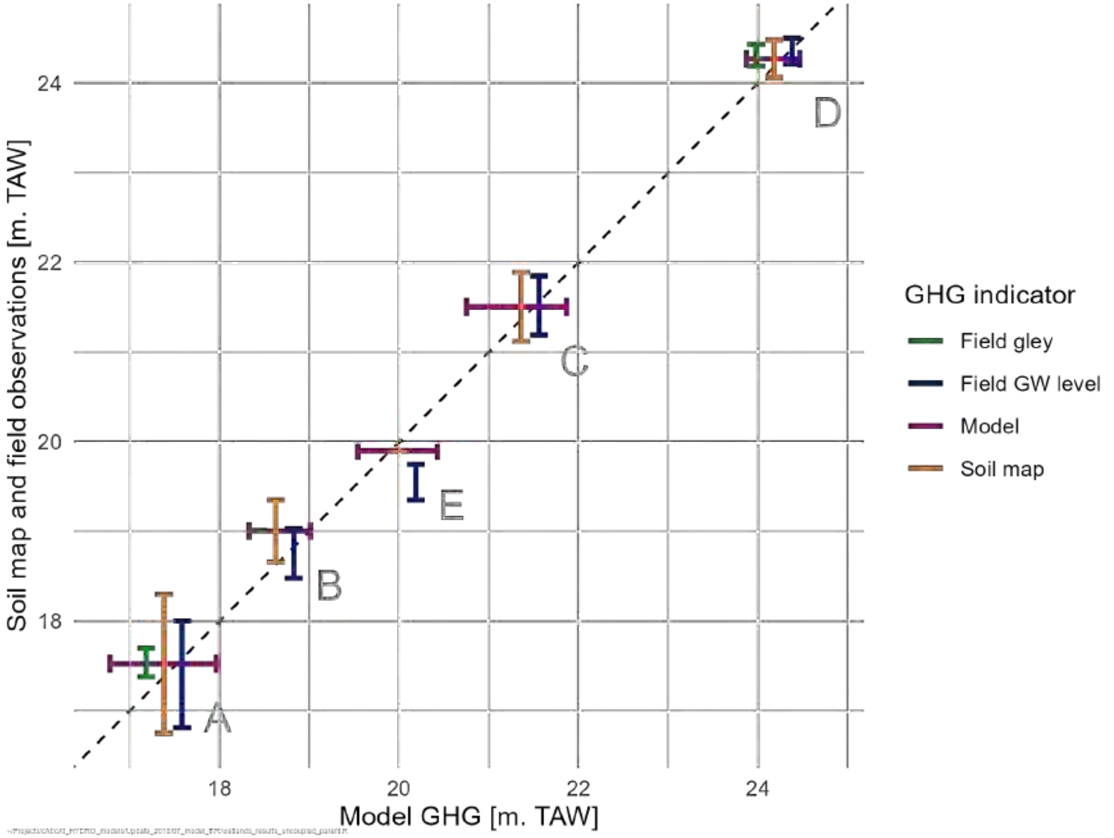


Wetland delineation

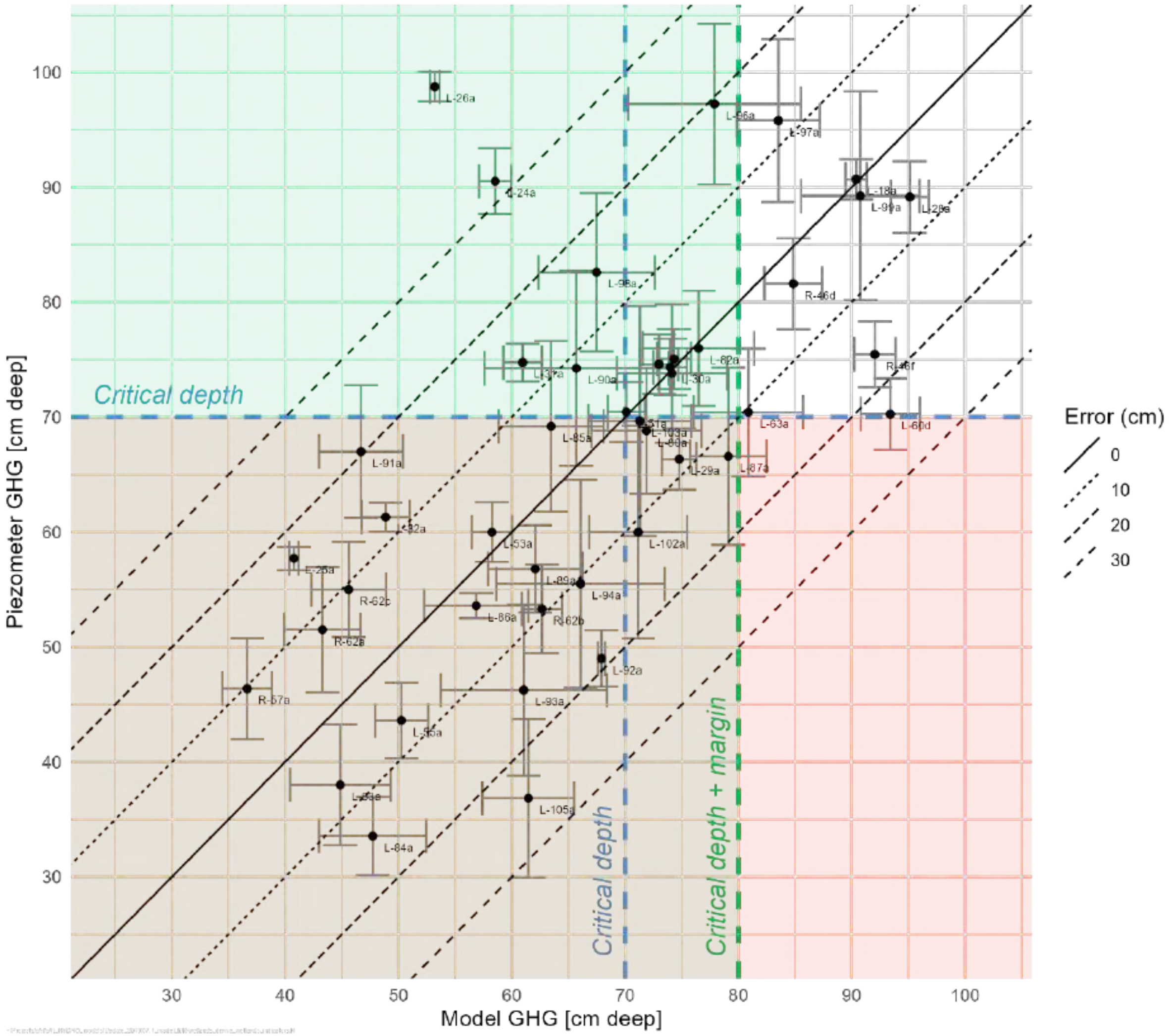
Wetland receptor extent delineation for different critical depths



Validation of Wetland locations
Soil map information and field work



Validation of Wetland locations
Averaged groundwater levels



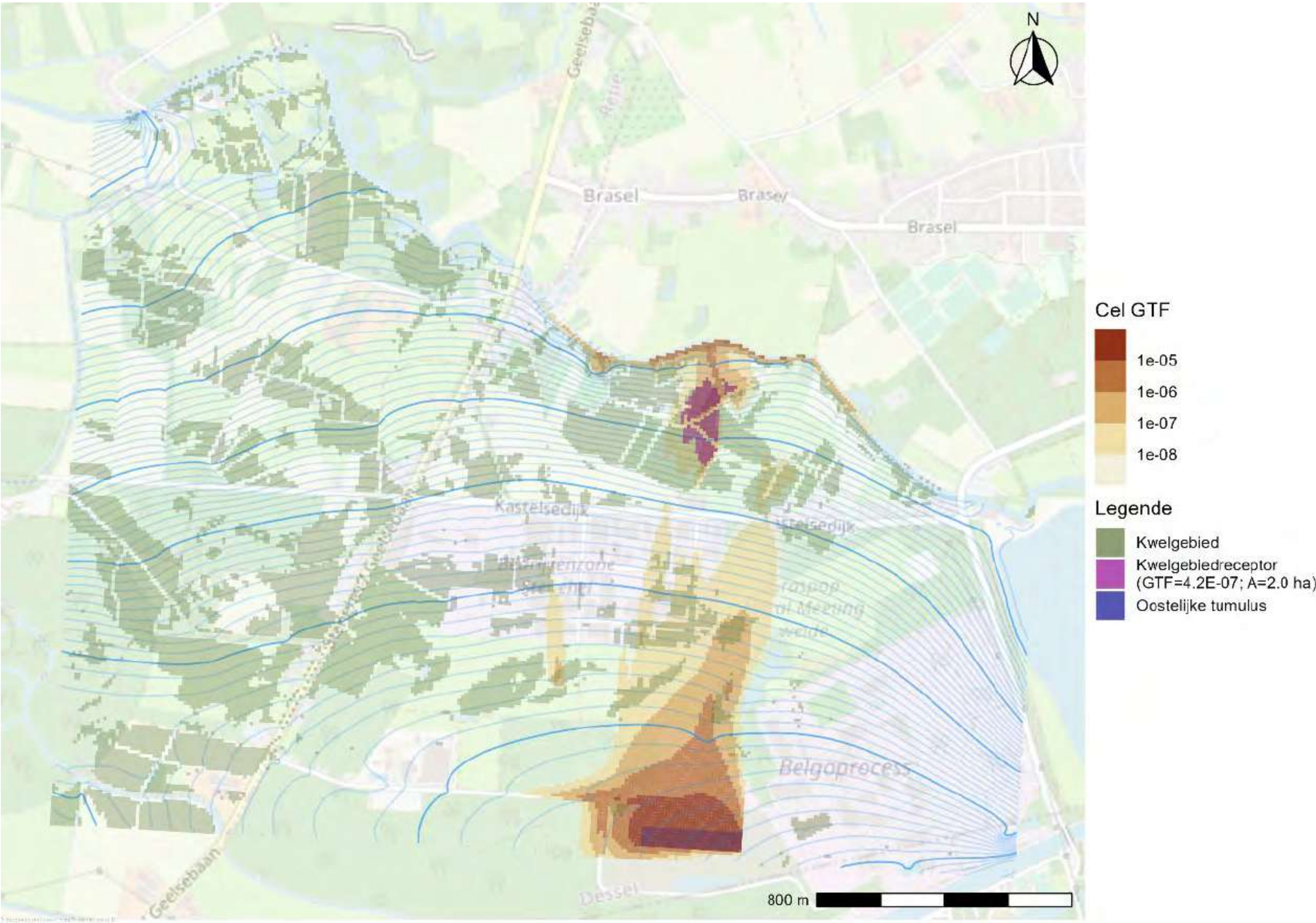
Towards a conservative estimate of the GTF

Consideration of possible future changes

- Step-wise approach
  - Variant 0 – application of the reference future climate on current land-use
  - Variant 1 – model adapted for the future climate simulations
    - Recharge excess eliminated: solved by in an iterative procedure
  - Reference variant – stylized model using a number of assumptions:
    - Uniform land-use
    - Reference climate scenario
    - Presence of the canal
    - Parameter set
  - GTF sensitivity:
    - Consequences of alternative choices & scenarios

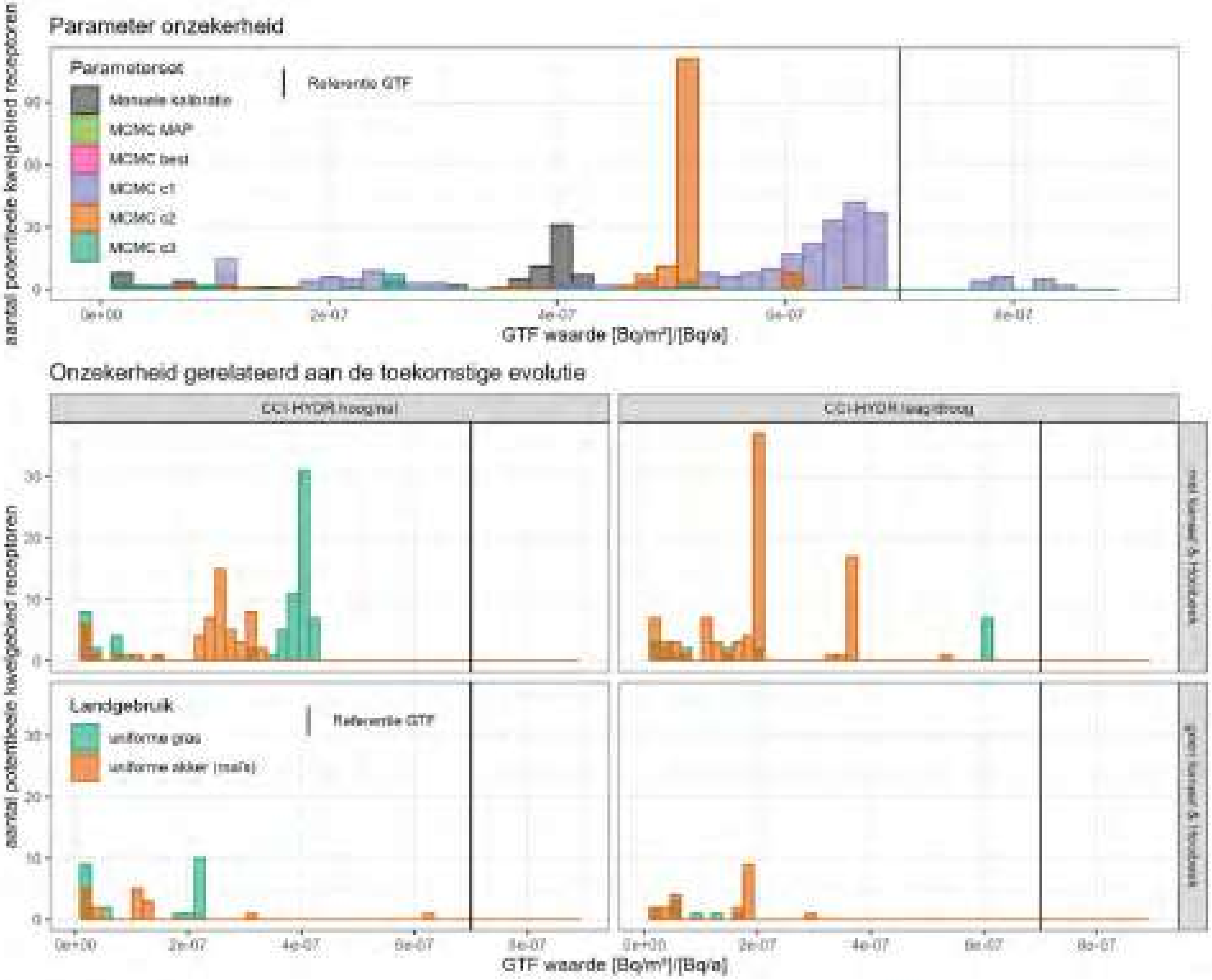
Results: reference variant

- Reference variant:
  - CCI-HYDR high/wet climate
  - Manually calibrated parameters
  - Uniform grass land-use
  - Canal exists
- GTF = 4.2×10^{-7} a/m^3



GTF sensitivity & selection of the reference GTF

- Reference $GFT_{wetl}=7\times10^{-7}$ a/m^3



Conclusions

- New hydrogeological model based on newest field measurements
- Validation of the model for:
  - the delineation of wetlands in the environment of the disposal site
  - the estimation of the dilution in the uppermost aquifer
- New & higher (larger impact) GTF for the wetland receptor

- **Confirmation** – radiological impact for private well receptor is the highest

Conclusions & Future work

Conclusion

- Eastern tumulus
  - Private well receptor – steady-state flow model approach
  - Wetland receptor
    - Detailed model in the area of wetlands
    - Transient flow model

- Western tumulus – Private well receptor
  - Detailed model in the area of the disposal facility
  - Transient flow model

  - Model calibration OK
  - Model validation – lack to sufficient high-quality data

Future work - Continuous monitoring

- Extended and more in-depth monitoring of the area surrounding the Western tumulus
  - Coverage
  - More permanent structures
  - DAQ
  - Reducing the error

- Further monitoring of Eastern tumulus
  - Associated with the exploitation phase of the disposal facility
  - Radiological and chemical conditions in the vicinity of the disposal facility to detect any abnormal situation

Future work - Modelling work

- Validated model (Site model) for Western tumulus based on the new data
- Confirmation of GTF values used in the safety assessment

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