Aalto University
School of Engineering

DTU

Risk assessment of Pursiala groundwater area in poor chemical state

Master's Thesis – Nordic Master Program in Environmental Engineering

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Contents

- Overview of the case study
- Methods
- Results
- Discussions
- Conclusions and recommendations

Overview – Workflow

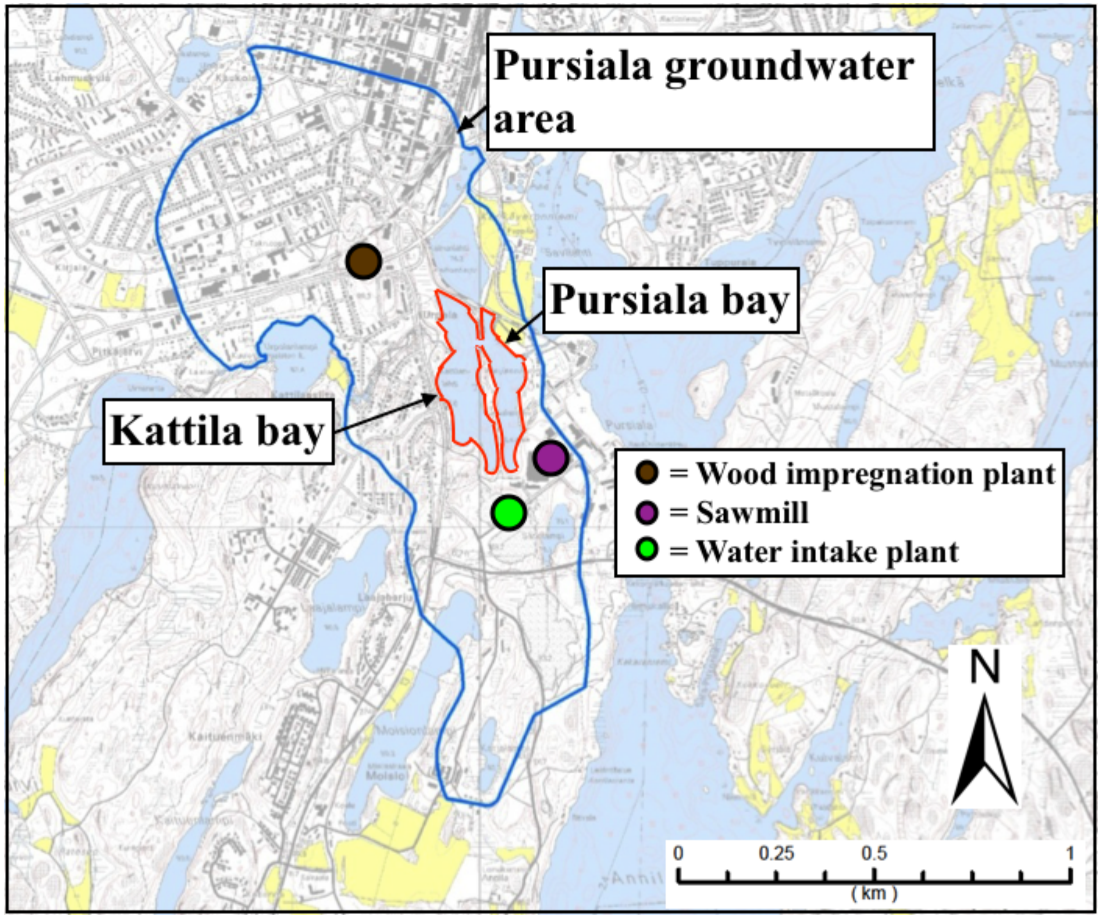
The Master’s Thesis is divided in 3 phases:

1. Literature review:
   I. Pursiala area
   II. Chemicals of interest
2. Groundwater analysis:
   I. Aquifer vulnerability
   II. Contaminants’ dispersion in the Pursiala aquifer
3. Human health risk assessment

Overview – Objective of the Master's Thesis

- Provide information for the risk management of the **Pursiala groundwater area**
- Understand the **reliability of the procedure** for future groundwater applications
- Determine the **health risks** for the local people

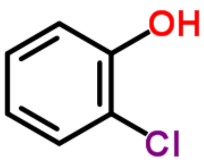
Overview – Pursiala groundwater area



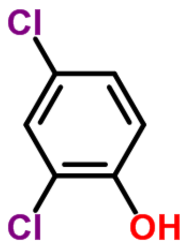
Source 1

- It is classified as the **most important resource** for potable water in the city of of Mikkeli[1]
- The analysis was focused in two activities:
  - A **sawmill**, which caused a contamination by **Chlorophenols (CPs)**
  - A **wood impregnation plant**, which brought to a release of **Polycylic Aromatic Hydrocarbons (PAHs)**

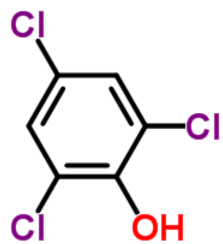
Overview – Chlorophenols



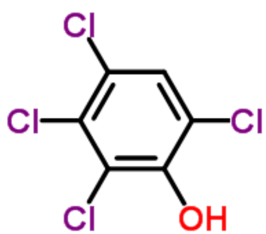
2-CP



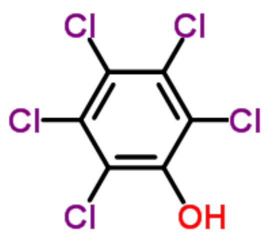
2,4-DCP



2,4,6-TCP



2,3,4,6-TeCP



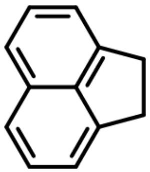
PCP

Source 4

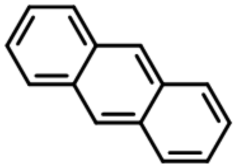
- Chlorophenols (CPs) are the result of the addition of chlorines's atoms to phenol
- They can be present in **drinking water** → the disinfection of phenols through chlorination can bring to CPs as a final result[2]
- Between the 19 types of chlorophenols, **5** were sampled in the area affected by the sawmill
- The **exposure** to CPs can cause different damages, especially on kidneys and lungs[3]

Chemical	2-CP	2,4-DCP	2,4,6-TCP	2,3,4,6-TeCP	PCP
Groundwater guideline [μg/l][5]	40	20	1	200	0.3

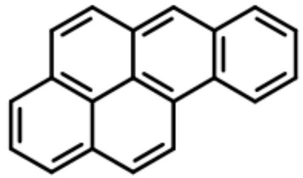
Overview – Polycyclic Aromatic Hydrocarbons (1)



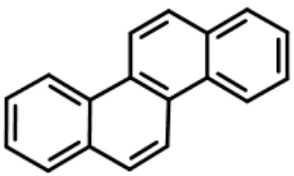
Acenaphthene



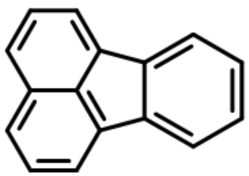
Anthracene



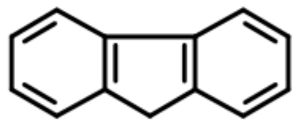
Benzo(a)pyrene



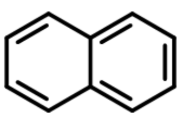
Chrysene



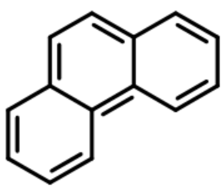
Fluoranthene



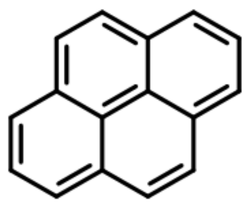
Fluorene



Naphthalene



Phenanthrene



Pyrene

Source 4

- Polycyclic Aromatic Hydrocarbons (PAHs) are formed due to the incomplete degradation of organic materials
- PAH concentrations in water are **quite low** → they have a high affinity for particulate matter and a low solubility[6]
- **9** different PAHs were detected in the source area in the aquifer
- **Cancer risk** is associated to PAHs but data on human beings are missing[7]

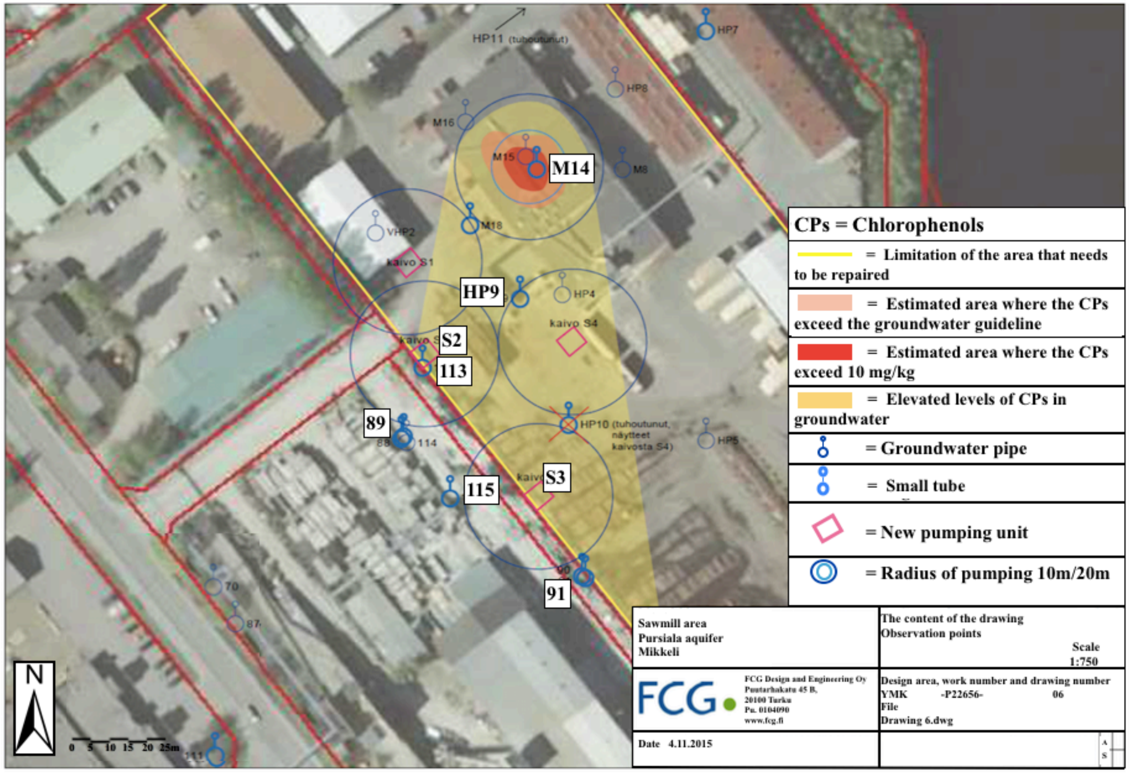
Overview – Polycyclic Aromatic Hydrocarbons (2)

Chemical	Acenaphthene	Anthracene	Benzo(a)pyrene
Groundwater guideline [μg/l][5]	400	2000	0.005

Chemical	Chrysene	Fluoranthene	Fluorene
Groundwater guideline [μg/l][5]	5	300	300

Chemical	Naphthalene	Phenanthrene	Pyrene
Groundwater guideline [μg/l][5]	300	100	200

Methods – Chlorophenol concentrations



Source 8

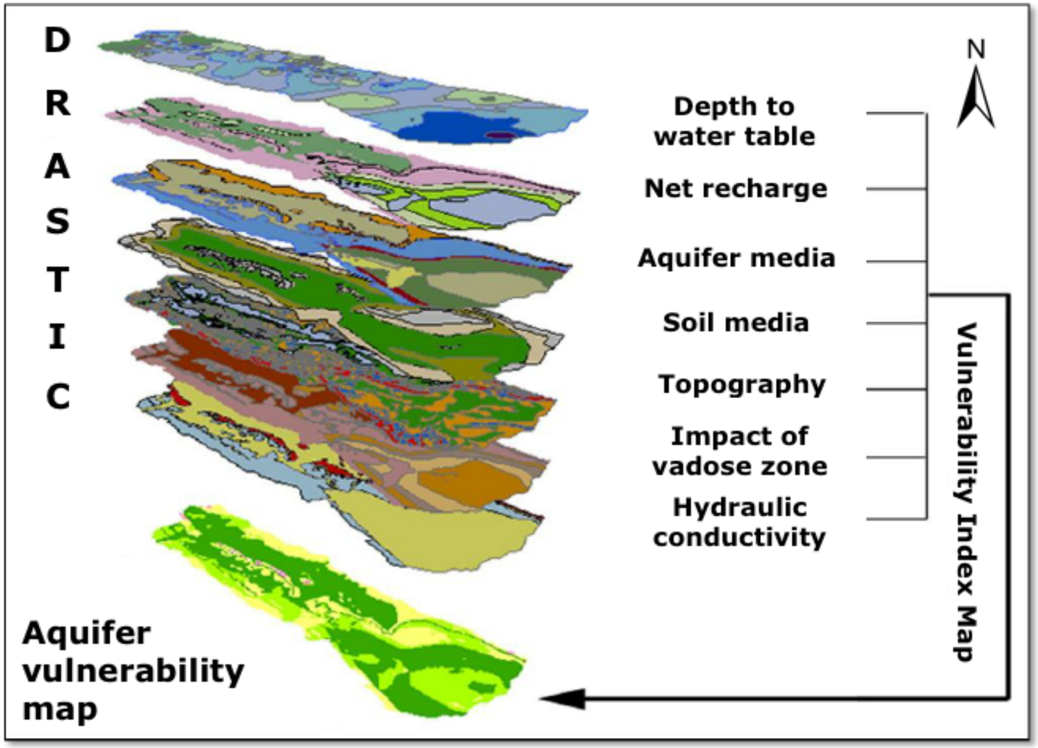
- The concentrations in the groundwater area around the sawmill were compiled in wells installed by the **Finnish Consulting Group (FCG)**

Chemical	Groundwater guideline [µg/l]	Concentration [µg/l]
2-CP	40	3.9E+02
2,4-DCP	20	2.9E+02
2,4,6-TCP	1	3.1E+03
2,3,4,6-TeCP	200	1.0E+05
PCP	0.3	2.4E+03

Source 8

- All the concentrations **exceed the groundwater guideline** → it is necessary to perform a **human health risk assessment** on these chemicals

Methods – DRASTIC



Source 10

- It is able to estimate the aquifer vulnerability through a linear combination of **seven hydrogeological parameters**[9]
- Each paratemeters has a **weight** and a **rating**

- The DRASTIC index DVI is therefore generated:

$$DVI = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$$

Methods – Sensitivity analysis in DRASTIC

- **Two sensitivity analyses** are conducted in order to understand the role the played by the parameters in the aquifer vulnerability:
  - **Map removal sensitivity analysis** → the DVI sensitivity, expressed with the sensitivity index SI [%] is calculated by removing one or more parameters on the DVI value[11]:

$$SI = \frac{\left| \frac{DVI}{N_p} - \frac{DVI'}{N'_p} \right|}{DVI} \times 100$$

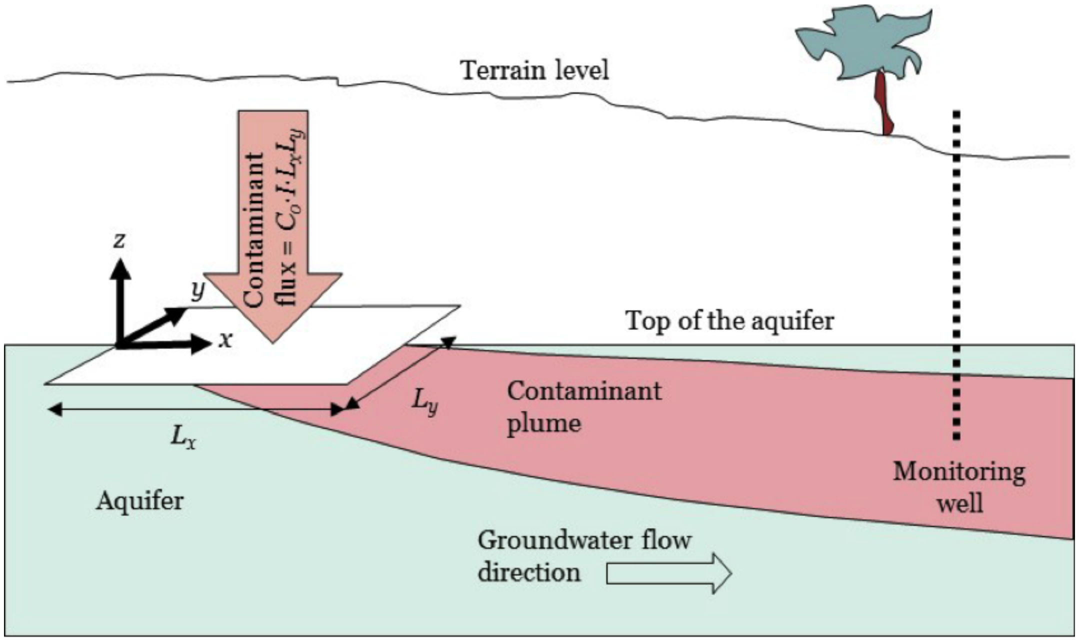
- **DVI'** is the index obtained by **excluding** one or more parameters
- **N_p and N'_p** are the number of parameters used for calculating the indexes

  - **Single parameter sensitivity analysis** → the effective weight W [%] of the parameter in the DVI index is calculated[12]:

$$W = \frac{P_r \times P_w}{DVI} \times 100$$

- **P_r and P_w** are the rating and the weight of the parameters

Methods – GrundRisk



Source 13

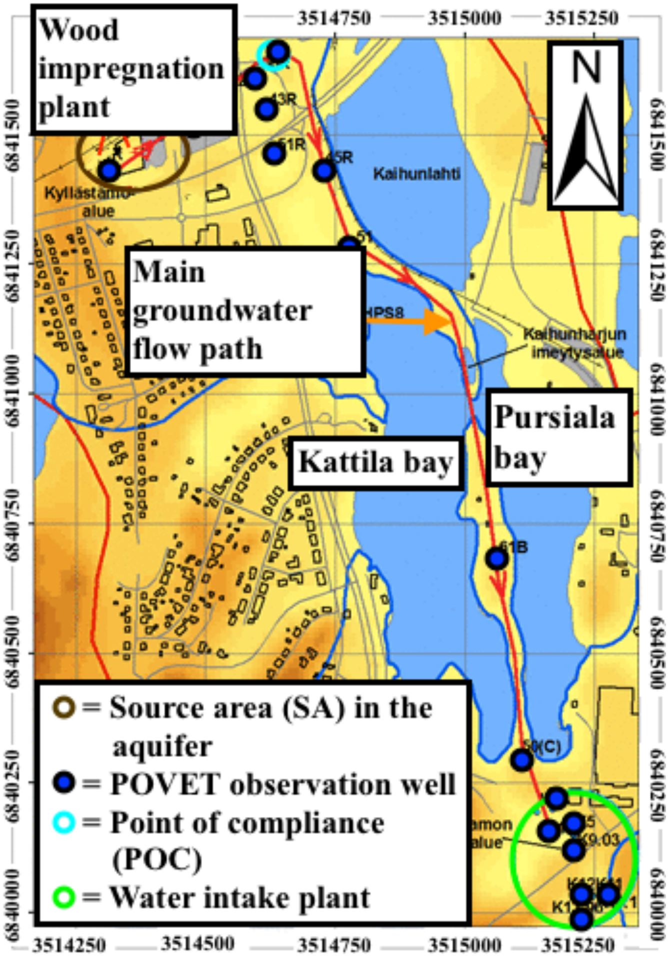
- It is based on **five assumptions**[13]:
  - The soil is homogeneous
  - Sorption processes are linear and reversible
  - Advection occurs at constant velocity
  - The first order kinetic describes the degradarion
  - The contaminant mass discharge and the contaminant source are constant

- The dispersion of the contaminants in Pursiala aquifer is described by using **GrundRisk model number V**

↓

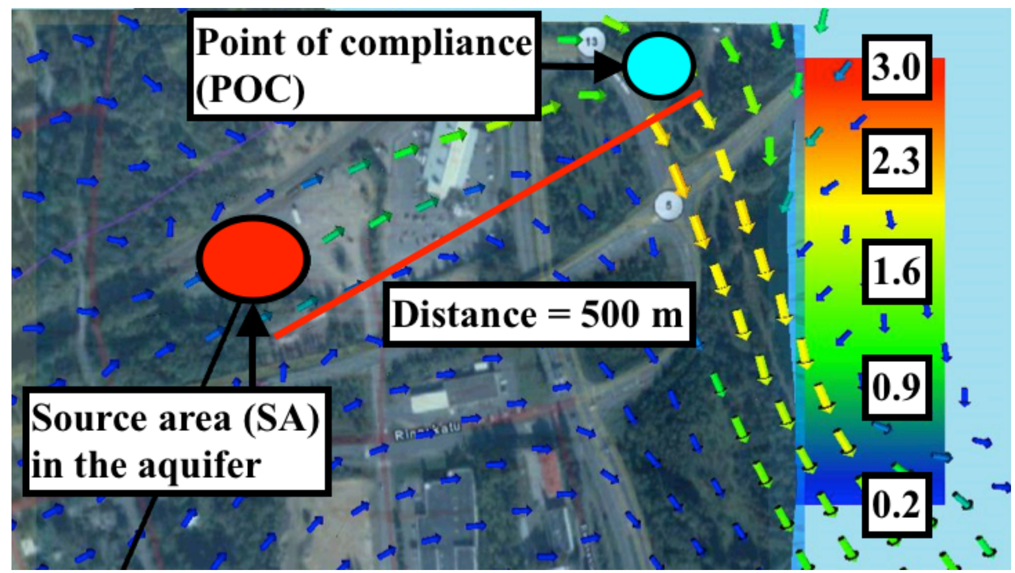
Direct input from the contaminant source to the groundwater aquifer

Methods – Set-up of the simulations (1)



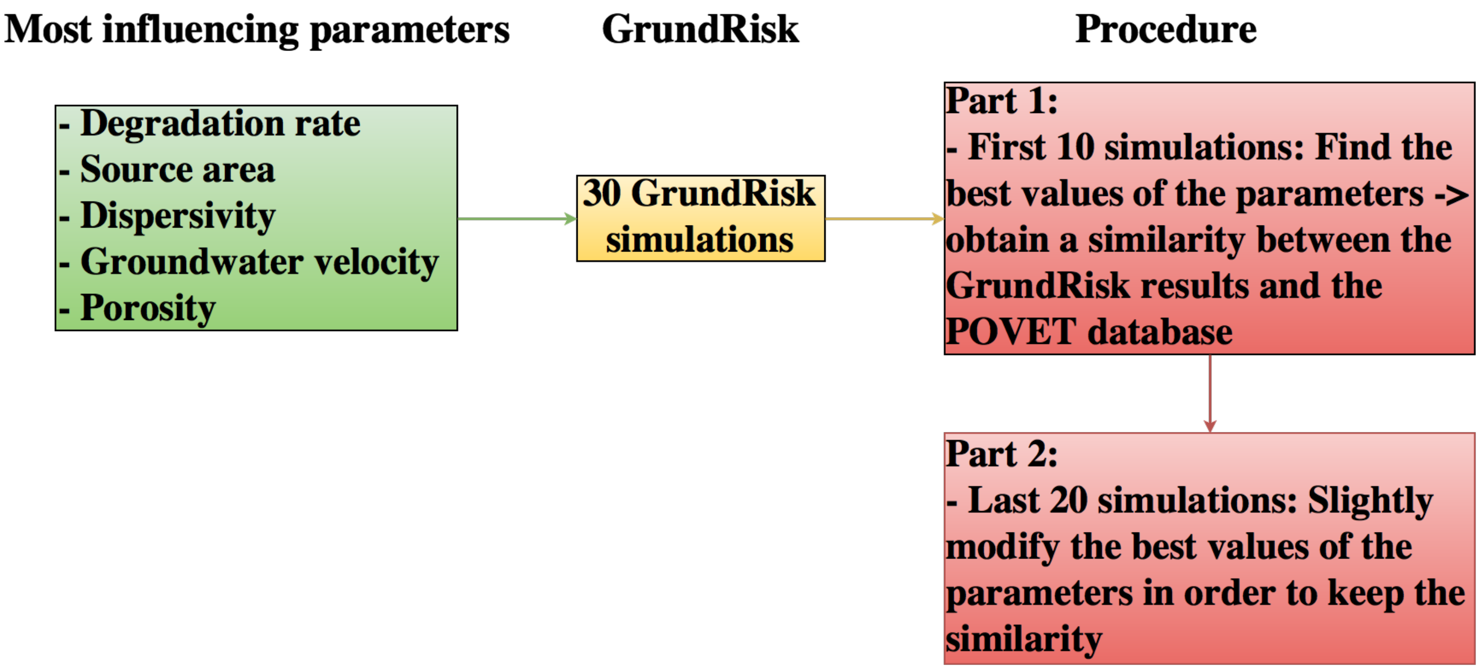
Source 14

- The GrundRisk analysis was only executed on the polycyclic aromatic hydrocarbons (PAHs)
- The simulations on the PAHs were run only in the pathway next to the wood impregnation plant



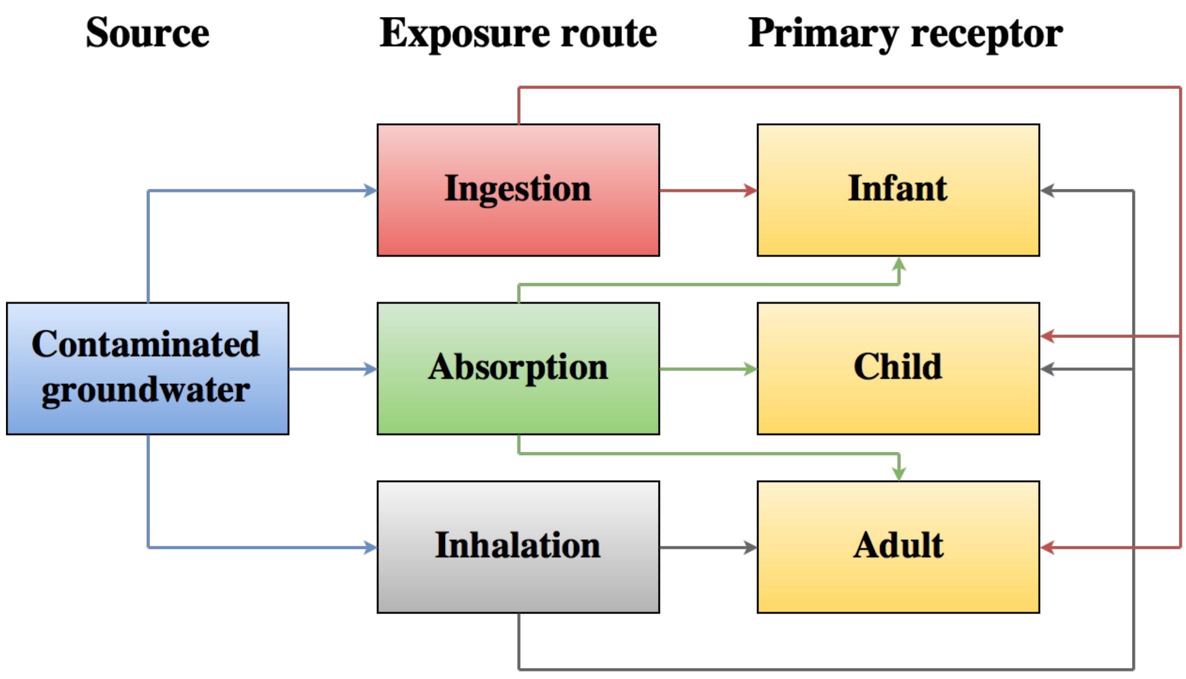
Source 14

Methods – Set-up of the simulations (2)



- **Calibration** of the GrundRisk parameters in order to obtain **similarities** between GrundRisk and the POVET database (Finnish groundwater database)

Methods – Human health risk assessment (1)



- The human health risk assessment aimed to understand the **potential risks** for the local people of Mikkeli
- **Inhalation** was not considered an important exposure route → the concentrations in the source area in the aquifer were **not so high**

Methods – Human health risk assessment (2)

- **Ingestion exposure route[15]:**

$$D_{Ingestion} = \frac{C_C \times IR \times EF}{BW}$$

- **C_C = Chemical concentration [mg/l]**
- **IR = Intake rate [l/day]**
- **EF = Exposure factor [-]**
- **BW = Body weight [kg]**

- **Dermal exposure route[15]:**

$$D_{Dermal} = \frac{C_C \times P \times BSA \times ET \times CF \times EF}{BW}$$

- **P = Dermal permeability coefficient [cm/hour]**
- **BSA= Body surface area [cm²]**
- **ET = Exposure time [hour/day]**
- **CF = Conversion factor [1 l/1000 cm³]**

- The doses obtained from these exposure routes are compares to the **reference dose RfD** (taken from the **IRIS database[16]**)
- The **Hazard Quotient & Hazard Index** are used to evaluate the non-carcinogenic risks[17]:

$$HQ = \frac{D}{RfD} \rightarrow HI = \sum HQ_{Chemical} \rightarrow HI_{Cumulative} = \sum HI_{Exposure}$$

Results – DRASTIC method (1)

- **Initial situation:** $$DVI = D_r \times D_w + R_r \times R_w + A_r \times A_w + S_r \times S_w + T_r \times T_w + I_r \times I_w + C_r \times C_w$$

Area	Maximum DVI index
Wood impregnation plant	152
Sawmill	168

- **Map removal sensitivity analysis:** $$SI = \frac{\left| \frac{DVI}{N_p} - \frac{DVI'}{N'_p} \right|}{DVI} \times 100$$

	Area around the wood impregnation plant	Area around the sawmill
Removed parameter	SI [%]	SI [%]
D	1.8	0.1
R	1.6	1.2
A	0.9	0.6
S	0.6	0.6
T	1.3	1.4
I	2.1	1.6
C	0.7	1.5

Results – DRASTIC method (2)

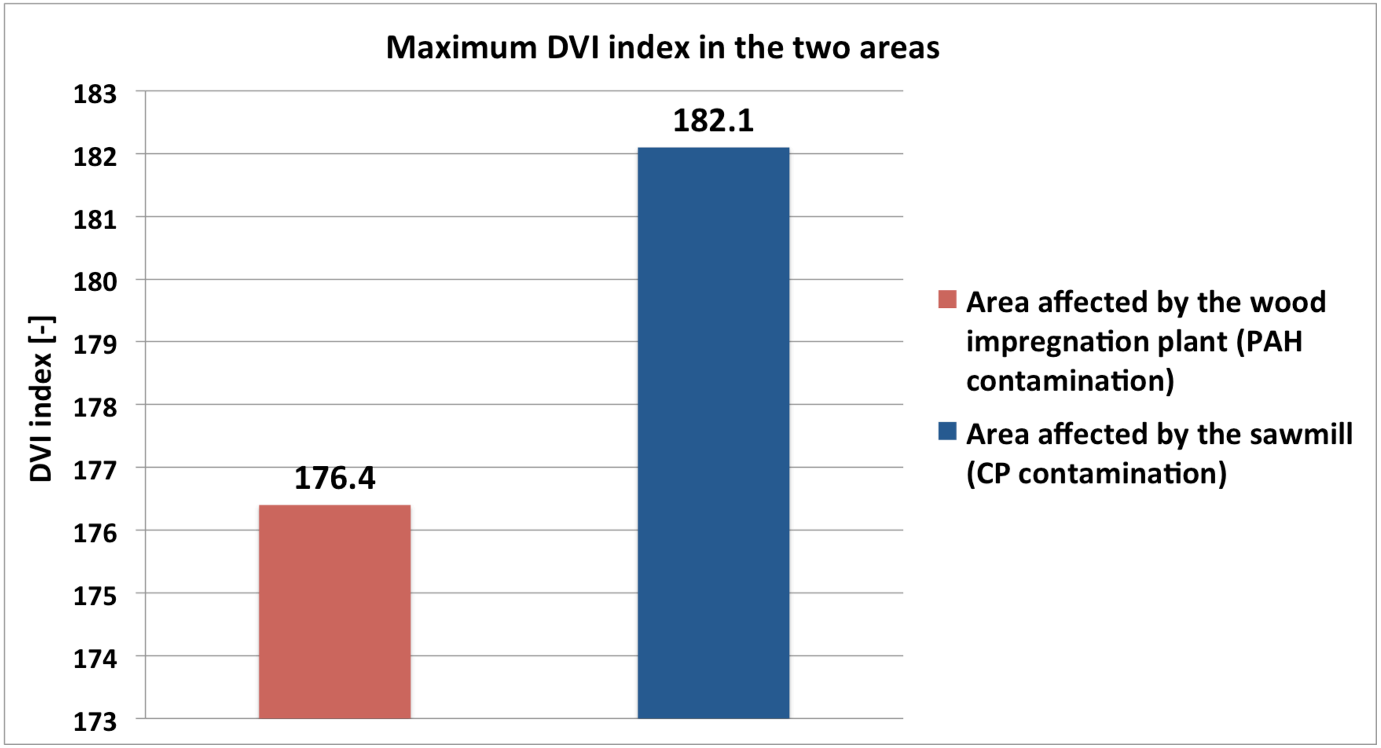
- **Single parameter sensitivity analysis:** $$W = \frac{P_r \times P_w}{DVI} \times 100$$

		Area around the wood impregnation plant	Area around the sawmill
Parameter	Theoretical W [%]	Effective W [%]	Effective W [%]
D	21.7	3.3	14.9
R	17.4	23.7	21.4
A	13.0	19.7	17.9
S	8.7	10.5	10.7
T	4.3	6.6	6.0
I	21.7	26.3	23.8
C	13.0	9.9	5.4

$$ParamaterWeight_{Effective} = \frac{ParamaterWeight_{Theoretical} \times W_{Effective}}{W_{Theoretical}}$$

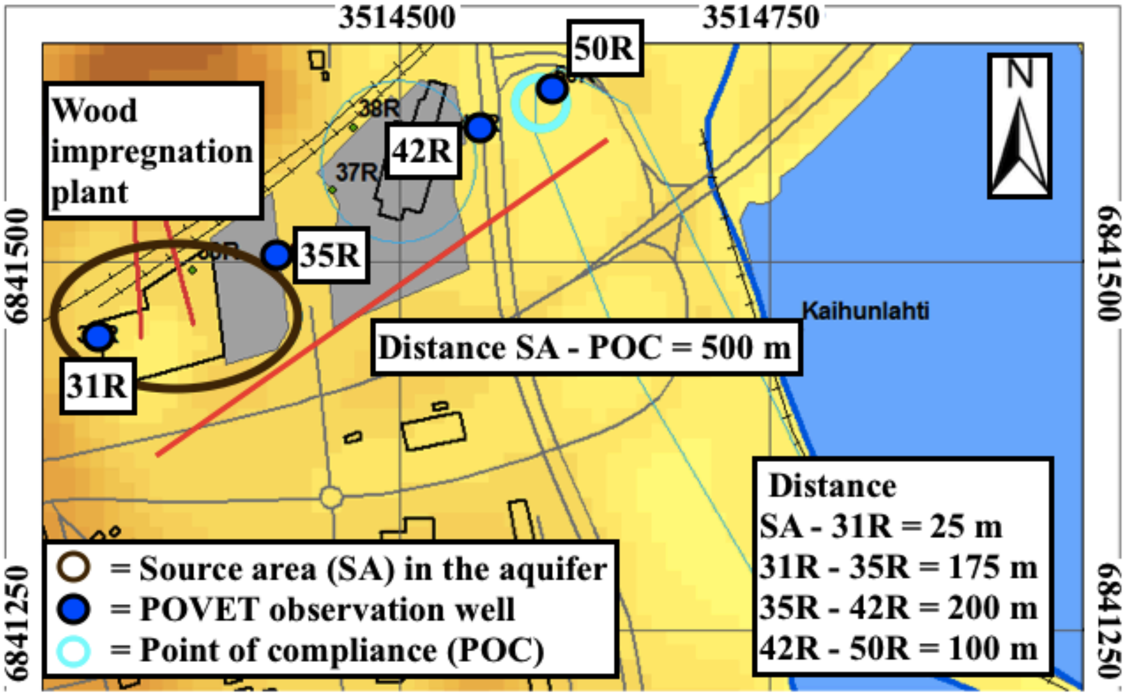
- The values of the DRASTIC parameters changed → new values of the DVI drastic indexes

Results – DRASTIC method (3)



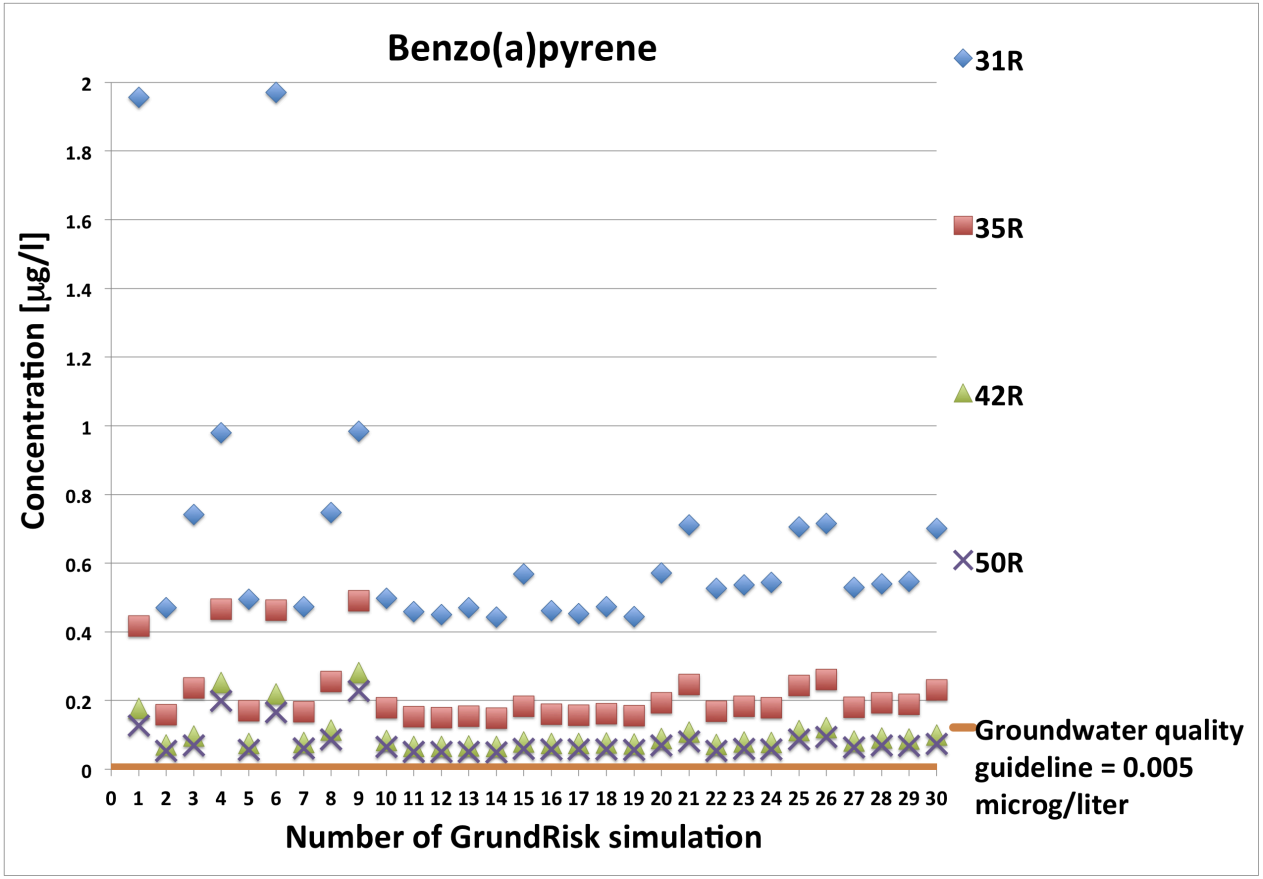
- The sensitiviy analysis caused an **increase** of the vulnerability
- The area affected by the **sawmill** has a higher vulnerability than the area affected by the wood impregnation plant

Results – GrundRisk simulations (1)



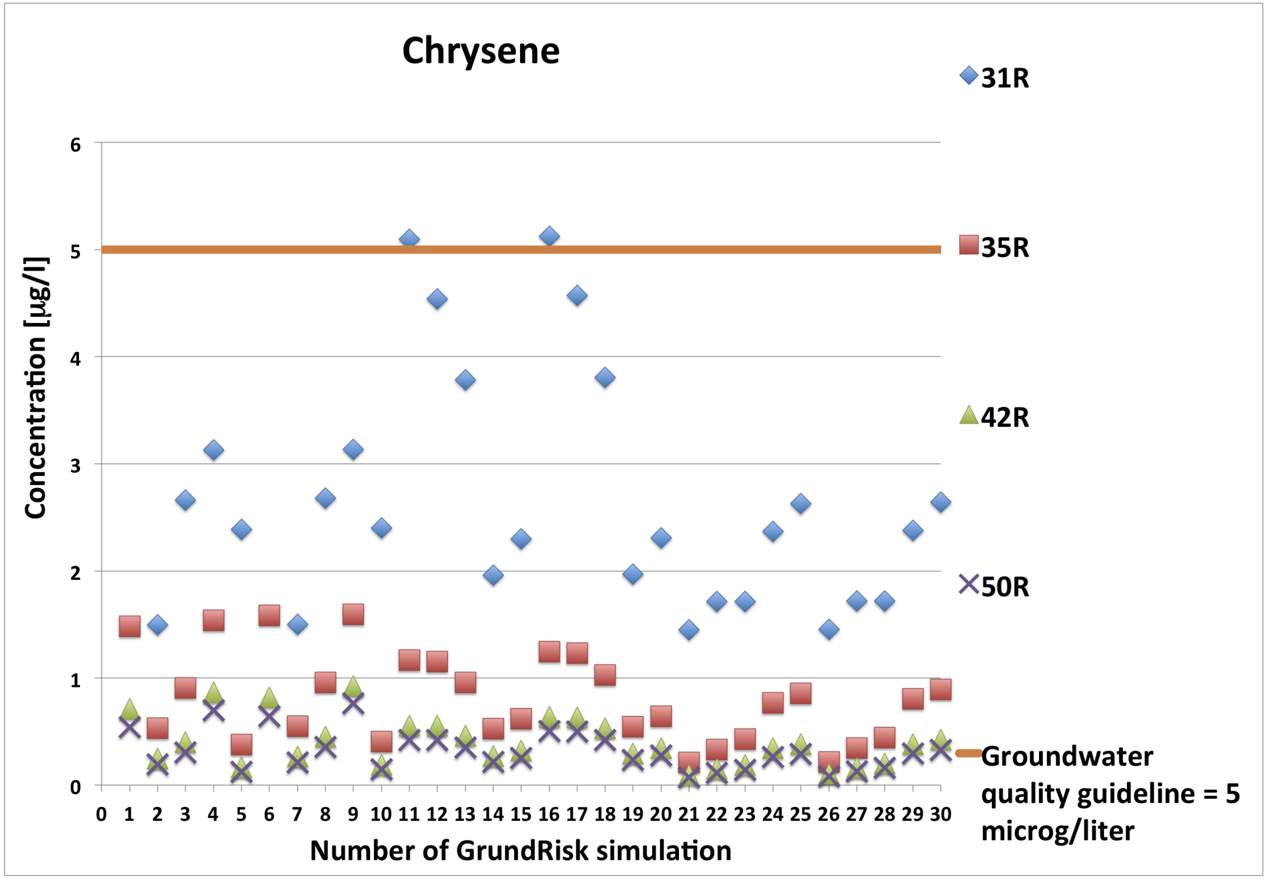
- Information on the POVET database was only available for Well 31R, 35R, 42R and 50R
- Only the concentrations of **Benzo(a)pyrene and Chrysene** were above the groundwater guidelines

Results – GrundRisk simulations (2)



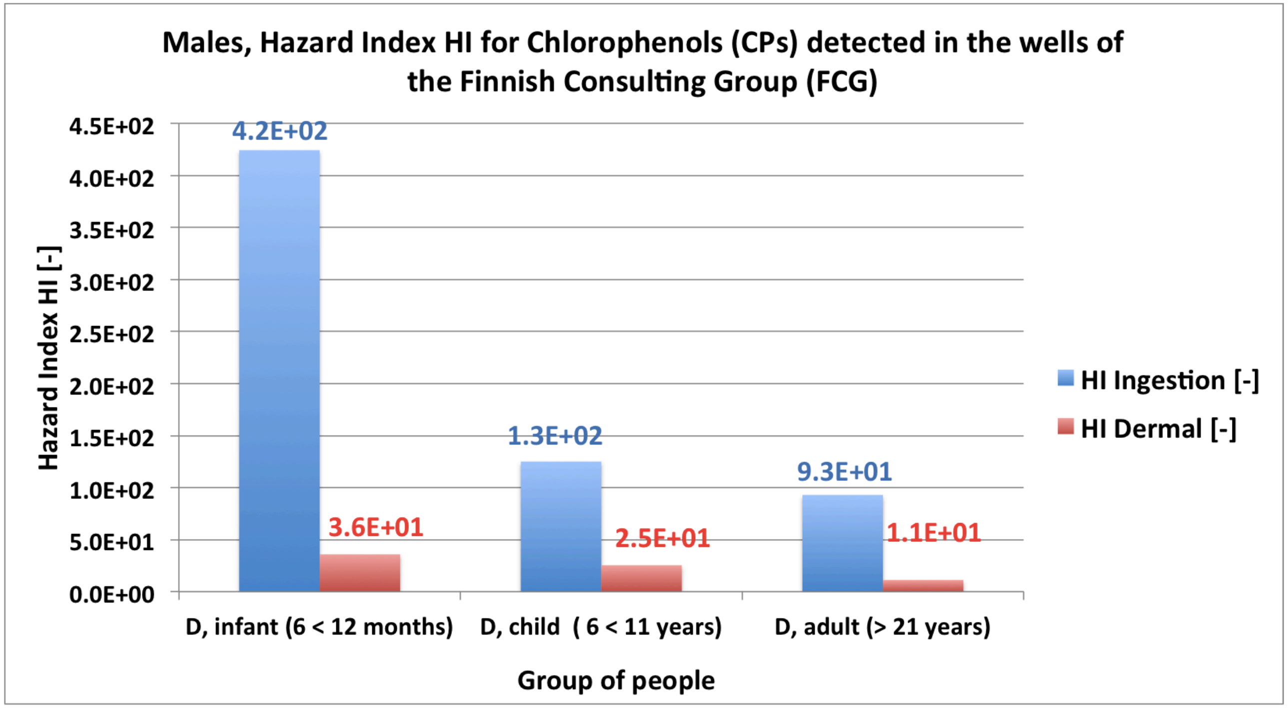
- The concentrations are **always above** the groundwater guideline

Results – GrundRisk simulations (3)



- The concentrations are above the groundwater guideline **only for well 31R**

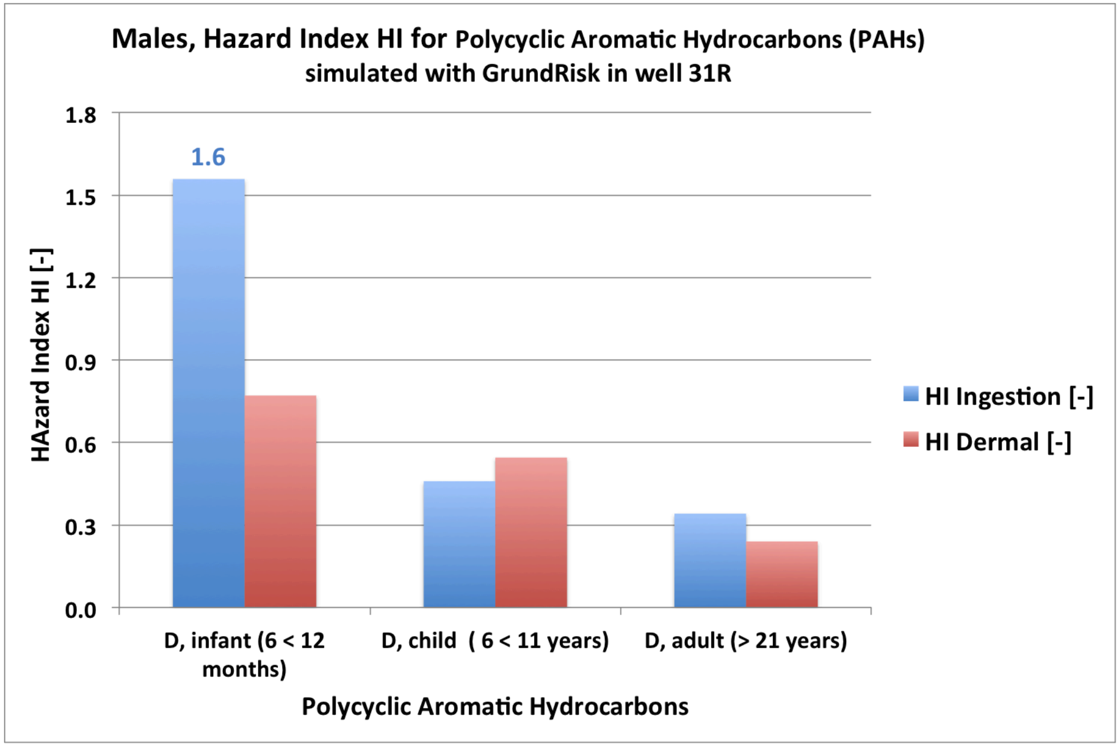
Results – Human health risks, CPs



- The hazard indexes HI are above the acceptable level of 1 for **all the groups**

Group of people	Cumulative HI [-]
D, infant (6 < 12 months)	4.6E+02
D, child (6 < 11 years)	1.5E+02
D, adult (> 21 years)	1.0E+02

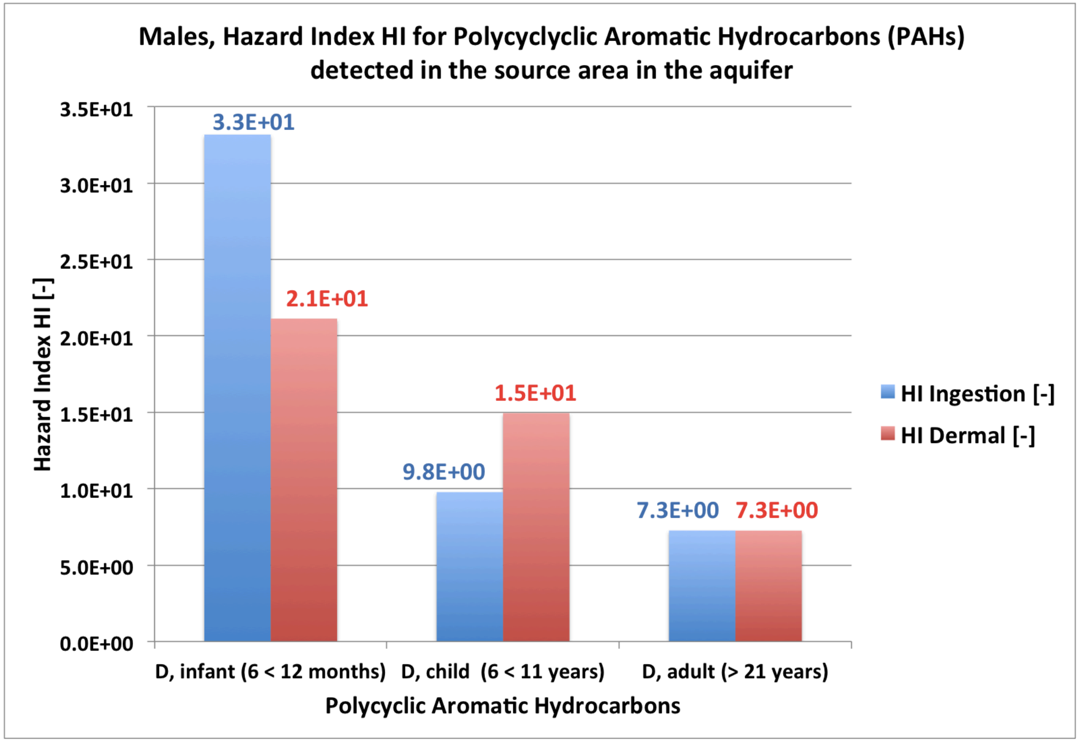
Results – Human health risks, PAHs (1)



- The hazard index HI is above the acceptable level of 1 for only the **group of infants**

Group of people	Cumulative HI [-]
D, infant (6 < 12 months)	2.3
D, child (6 < 11 years)	1.0
D, adult (> 21 years)	0.6

Results – Human health risks, PAHs (2)



- The hazard indexes HI are above the acceptable level of 1 for **all the groups**

Group of people	Cumulative HI [-]
D, infant (6 < 12 months)	5.4E+01
D, child (6 < 11 years)	2.5E+01
D, adult (> 21 years)	1.4E+01

Discussion – Aquifer vulnerability

- The DRASTIC method had some limitations:
  - It could not be used together with **geo-referential tools**
  - **No comparison** was done between the field data and the DVI indexes
- No further comments are necessary for the DRASTIC method → the **method is very simple** to use

Discussion – Modelling tool

- In the real case, the contaminants are **already in the aquifer** → Model number V considers a direct input from the contaminant source **on top of the aquifer**
- The mixture of the chemicals, which could not be considered in GrundRisk, might bring to an **excess** of the groundwater guidelines
- GrundRisk is never calibrated → it was necessary in this thesis in order to study its applicability to the **Finnish conditions**
- **Similarities** were found between GrundRisk and the POVET database → the analysis with this modelling tool is **satisfactory**

Discussion – Human health risk assessment

- The missing calculations on the doses through the inhalation exposure **did not affect** the final results
- No analysis was executed on the **cancer risks** → slope factors were available only for a limited number of chemicals
- The human health risk assessment did not consider any joint toxic actions, which might bring to an **excess** of the acceptable levels

Conclusions

- The DRASTIC method revealed a **high vulnerability** of the Pursiala aquifer
- It is possible to apply GrundRisk in **future groundwater applications**
- The results of the human health risk assessment confirmed the **emergency state** of the area around Pursiala

Recommendations

- The availability of hydrogeological parameters for the **whole aquifer** will allow to conduct a complete analysis on Pursiala
- The calculation of the **carcinogenic effects** will give a more complete vision of the risks for the local people of Mikkeli
- It is highly recommended to increase the impact of the **remediation technologies** in the Pursiala area
- The **limitations and the simplifications** of GrundRisk must be clarified in order to produce reliable results

Thank you very much for the attention!

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