Vorlesung / Übung:

Aquifer-Charakteristik: Theis-Problem

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Heutige Vorlesung

- Einführung in Theis-Problem
- Software-Installation
- Theis-Übung

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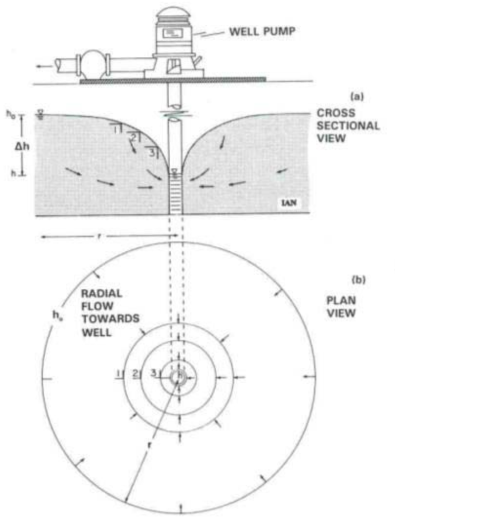
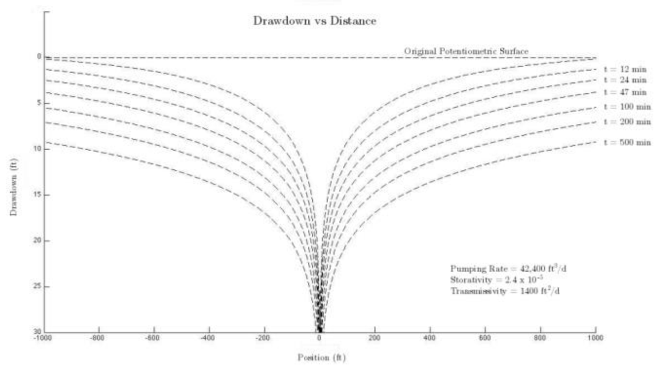
Theis-Problem: Hintergrund



Quelle: Watson & Burnett 1993

Brunnen-Hydraulik: Pumpversuch

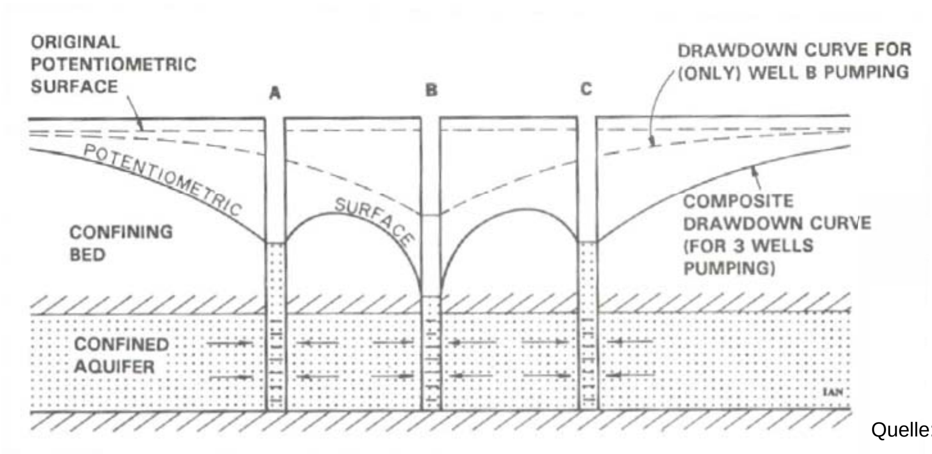
- nach Pump-Start radialer Absenktrichter an der Wasseroberfläche (……………………..) bzw. entlang Druckspiegel (…………………………)
- Trichter vergrößert sich bei anhaltendem Pumpen bis Gleichgewichtszustand erreicht ist
- Absenktrichter kann mit Kurve beschrieben werden → ………………



Theis-Problem: Pumpversuch

Pumpversuche dienen:

- Ermittlung hydrogeologischer Parameter: ……………….. K bzw.K_f, …………….. T, ……………… Porosität n, Speicherkoeffizient S
- quantitativen Nachweis einer hydraulischen Beeinflussung des Aquifers
- Wasserprobenahme → GW-Beschaffenheit und deren Veränderungen
- Gewinnung tech. Daten für Brunnenausbau



Quelle: Watson & Burnett 1993

Permeabilität

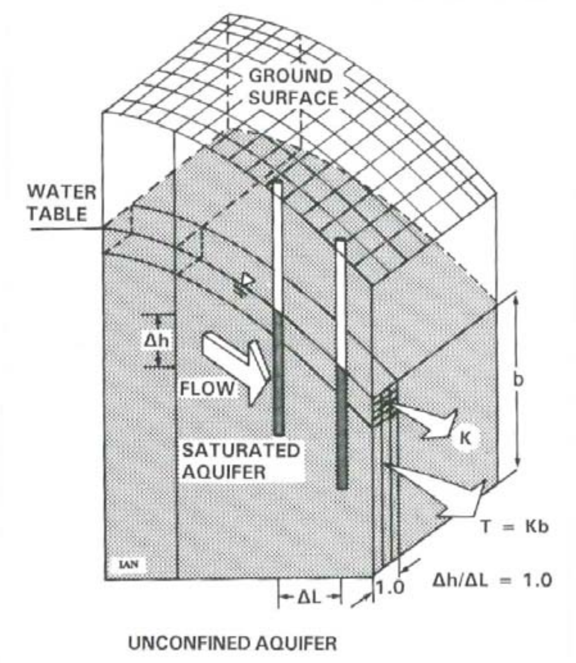


Figure 14-5 The Concepts of Permeability and Transmissivity. Permeability (K) is a measure of flow through a unit cross-sectional area of the aquifer. Transmissivity is a measure of flow through a unit width of the full saturated thickness of the aquifer (b). Both apply under a hydraulic gradient of unity. Therefore, T = Kb.

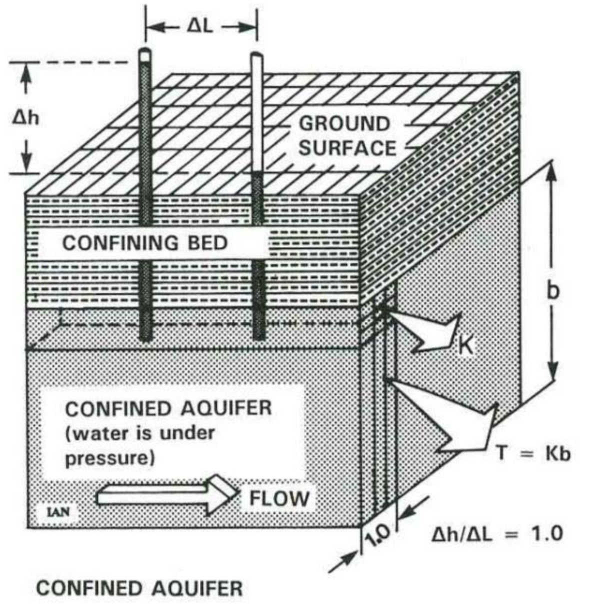


Figure 14-6 The Concepts of Permeability (K) and Transmissivity (T) in a Confined Aquifer. The established relationship between permeability and transmissivity holds for a confined aquifer (i.e., T = Kb).

Quelle: Watson & Burnett 1993

Speicherkoeffizient

spez. Speicherkoeffizient (S_s):

- Änderung des gespeicherten Wasservolumens je …………………… bei Druckänderung um ……………
- Einheit: 1/m

$$S_s = d(\alpha + n_e - \beta)$$

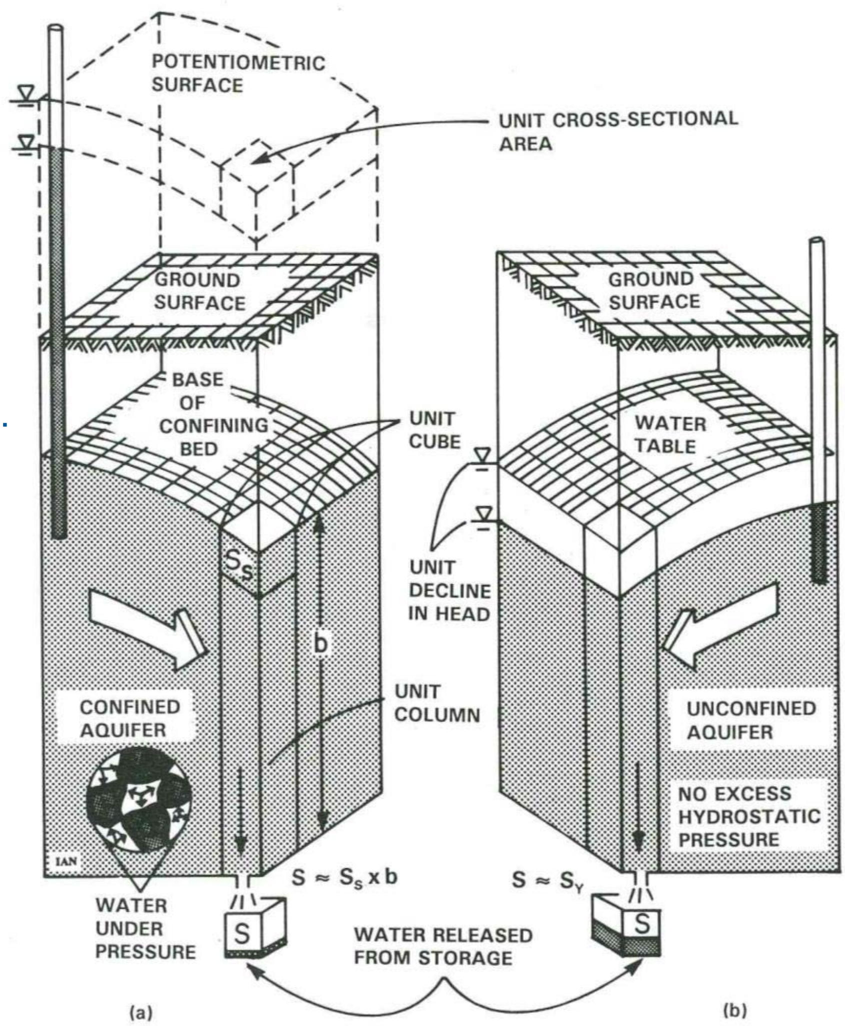
d – Dichte des Wassers

n_e- effektives Porenvolumen

α – Kompressibilität Gestein (Korngerüst)

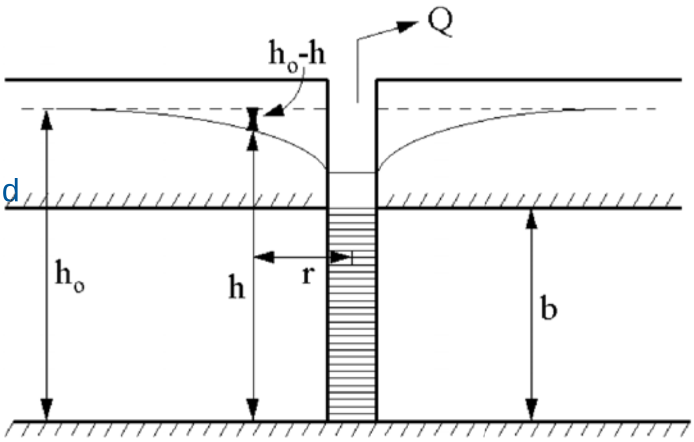
β – Kompressibilität Wasser

- ungespannt: z.B. S_s= ………
- gespannt: z.B. S_s= …………



Theissche Brunnengleichung 1D / 1.5 D

Charles Vernont Theis (1900-1987) entwickelte erstmals eine mathematische Beschreibung um Aquifereigenschaften bzw. Wasserstände während eines Pumpversuchs zu bestimmen



Ansatz: Anpassung der bereits entwickelten Wärmetransport-Gleichung auf Grundwasser-Strömung in porösen Medien

$$\alpha \cdot \left(\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2} \right) = \frac{\delta T}{\delta t}$$

……………………

Isotroper, homogener, gespannter Aquifer

$$K \cdot \left(\frac{\delta^2 h}{\delta r^2} + \frac{1}{r} \cdot \frac{\delta h}{\delta r} \right) = S_s \cdot \frac{\delta h}{\delta t}$$

………………………….. Grundwasserströmungsgleichung

Theissche Brunnengleichung 1D/ 1.5 D

$$K \cdot \left(\frac{\delta^2 h}{\delta r^2} + \frac{1}{r} \cdot \frac{\delta h}{\delta r} \right) = S_s \cdot \frac{\delta h}{\delta t}$$

Instationäre radialsymmetrische Grundwasserströmungsgleichung

Randbedingungen

$$h(t=0,r) = h_0$$

$$\lim_{r \to 0} \left(r \cdot \frac{\delta h}{\delta r} \right) = \frac{Q}{2 \cdot \pi \cdot T}$$

$$\lim_{r \to 0} \left(h(t,r) \right) = h_0$$

$$h(t,r) = h_0 - \frac{Q}{4 \cdot \pi \cdot T} \cdot W(u)$$

Theis-Formel für Absenkung

$$s(r,t) = h_0 - h(r,t) = \frac{Q}{4\pi T} * W(u)$$

$$W(u) = \int_{x=u}^{\infty} \frac{e^{-x}}{x} \, dx$$

Theis'sche Brunnenfunktion

wobei $u = \frac{S_S}{4 \cdot T} \cdot \frac{r^2}{t}$

Theis-Gleichung: Voraussetzungen für Gültigkeit

1. ……………………………………………….(vorher + nachher)
2. Grundwasserleiter ist seitlich begrenzt
3. ……………………………………..Grundwasserleiter
4. Brunnendurchmesser vernachlässigbar klein
5. Horizontale Grundwasserdruckfläche (initial)
6. Brunnen sind über gesamte wassererfüllte Mächtigkeit verfiltert
7. ……………………………………………
8. Strömung des GW zum Entnahmebrunnen lässt sich mit Darcy-Gesetz beschreiben

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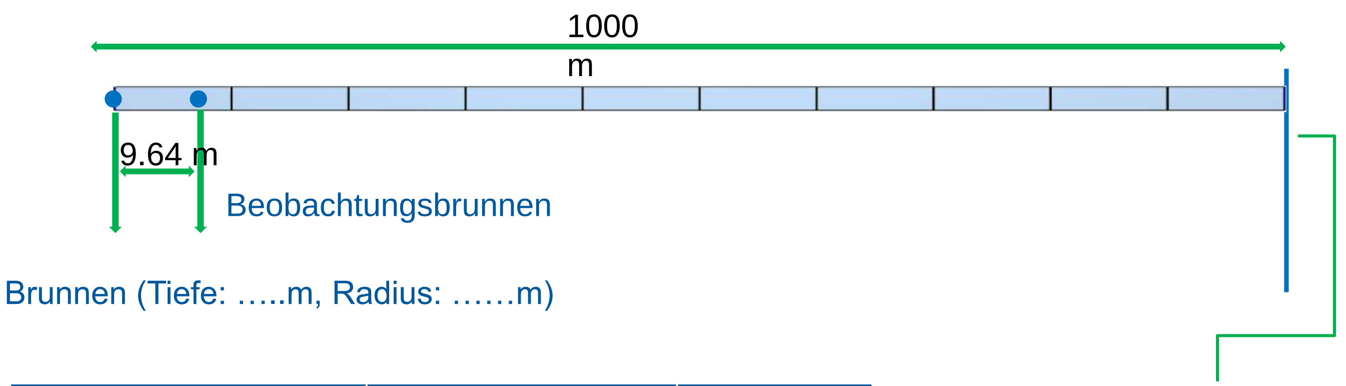
Theis: 1D



Rechte RB (r_bc)
Hydraulic head = 0 m

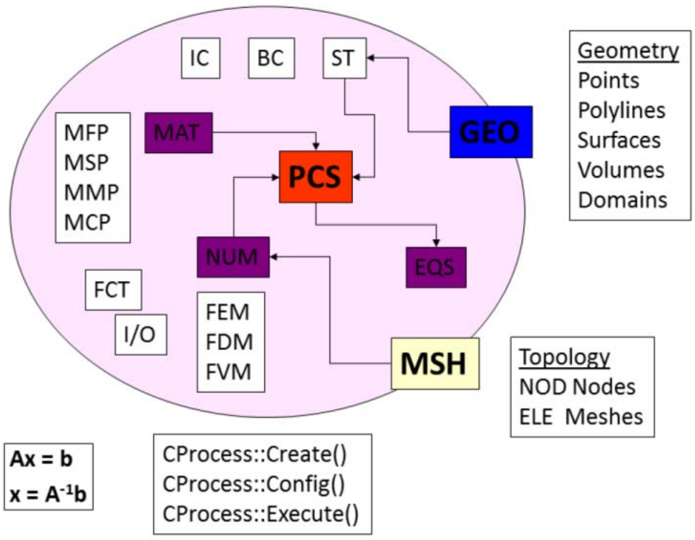
Parameter	Wert	Einheit
Pumprate	1.4158E-2	m^3/s
Spez. Pumprate	2.253E-3	m^3/s
Hydraul. Leitfähigkeit	9.2903E-4	m/s
Intrinsische Permeabilität	1.2391E-10	m^2
Spez. Speicher	1E-3	1/m

Initiale Randbedingung:

$$h(r, t_0) = 0$$

Theis: 1D

Object	File	Explanation
GEO	GWF_Theis.gli	system geometry
MSH	GWF_Theis.msh	finite element mesh
PCS	GWF_Theis.pcs	process definition
NUM	GWF_Theis.num	numerical properties
TIM	GWF_Theis.tim	time discretization
IC	GWF_Theis.ic	initi
BC	GWF_Theis.bc	boun
ST	GWF_Theis.st	sour
MFP	GWF_Theis.mfp	fluid
MMP	GWF_Theis.mmp	med
OUT	GWF_Theis.out	outp



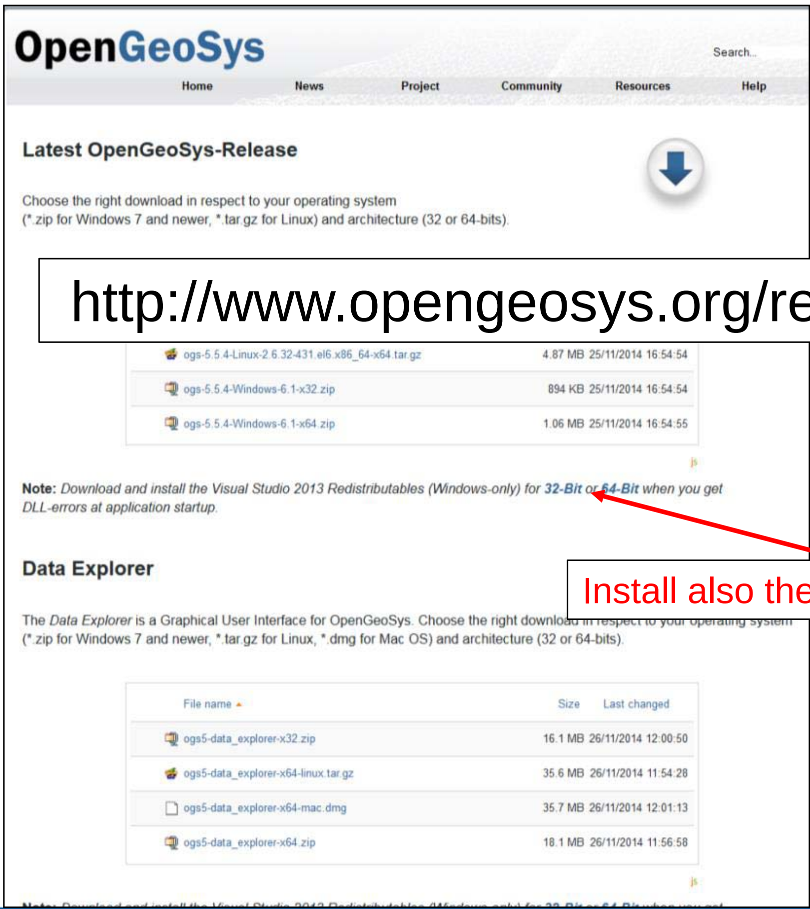
Software-Installation

Notepad++

OpenGeoSys

OpenGeoSys Data Explorer

OpenGeoSys



http://www.opengeosys.org/resources/downloads

Install also the Visual Studio Redistributable

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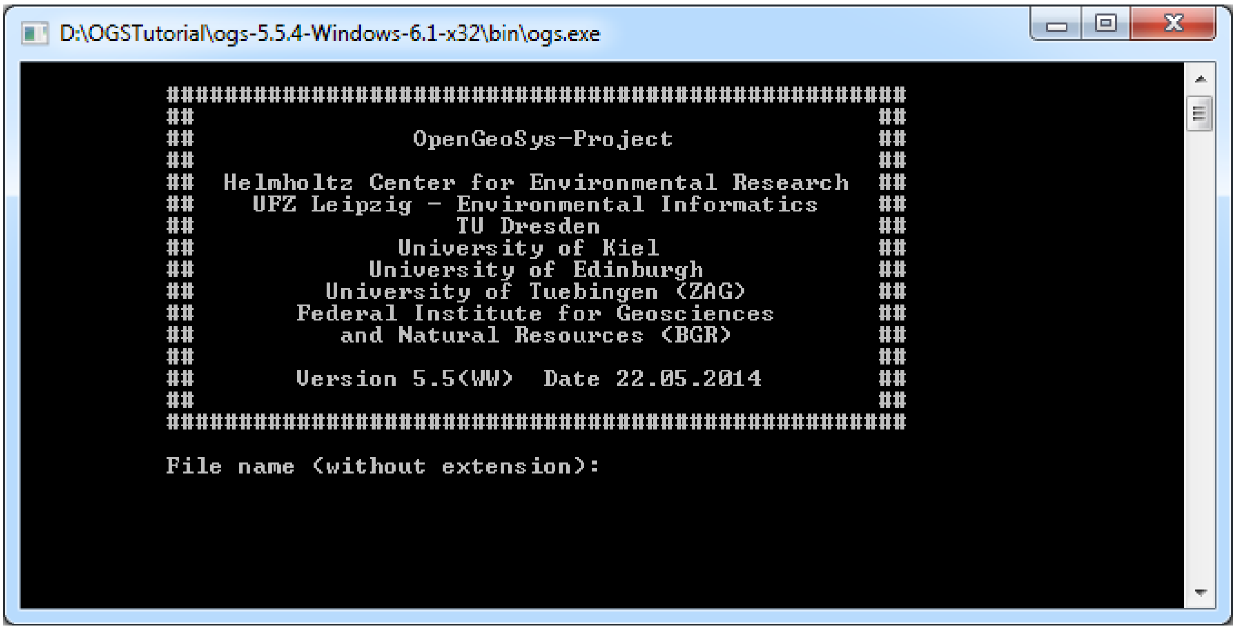
Starten von ogs.exe



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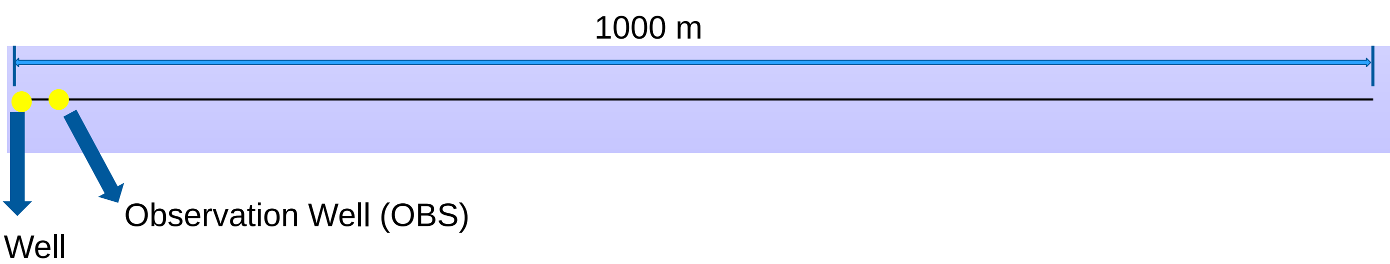
Eingabedateien

Generelle Struktur der Eingabedateien

```
# MAIN_KEYWORD1
$SUB_KEYWORD1
value value value
$SUB_KEYWORD2
value value
# MAIN_KEYWORD2
$SUB_KEYWORD1
value value
[..]
# STOP
```


Beispiel : Theis 1.5D



Benutze Notepad++, Excel (und ParaView)

Los geht's!

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Prozess-Datei (*.pcs)

Theis 1.5D

```
# PROCESS
$PCS_TYPE
GROUNDWATER_FLOW
$PRIMARY_VARIABLE
HEAD
# STOP
```

$PCS_TYPE	$PRIMARY_VARIABLE
GROUNDWATER_FLOW	HEAD
LIQUID_FLOW	PRESSURE1
RICHARDS_FLOW	PRESSURE1
AIR_FLOW	PRESSURE1, TEMPERATURE1
MULTI_PHASE_FLOW	PRESSURE1, PRESSURE2,
MASS_TRANSPORT	Varying (e.g CONCENTRATION)

Prozess-Datei (*.pcs)

```
GeoSys-PCS: Processes -------------
#PROCESS
 $PCS_TYPE
  GROUNDWATER_FLOW
 $NUM_TYPE
  NEW
$PRIMARY_VARIABLE
  HEAD
#STOP
```

→ **speichern als pds.pcs**

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Geometrie-Datei (*.gli)

```
# POINTS
0 0 0 0 $NAME WELL
1 300 0 0
2 1000 0 0 $NAME INIFINIT
3 9.639 0 0 $NAME OBS
# POLYLINE
$NAME
LEFT
$POINTS
0
1
# POLYLINE
$NAME
RIGHT
$POINTS
1
2
# STOP
```

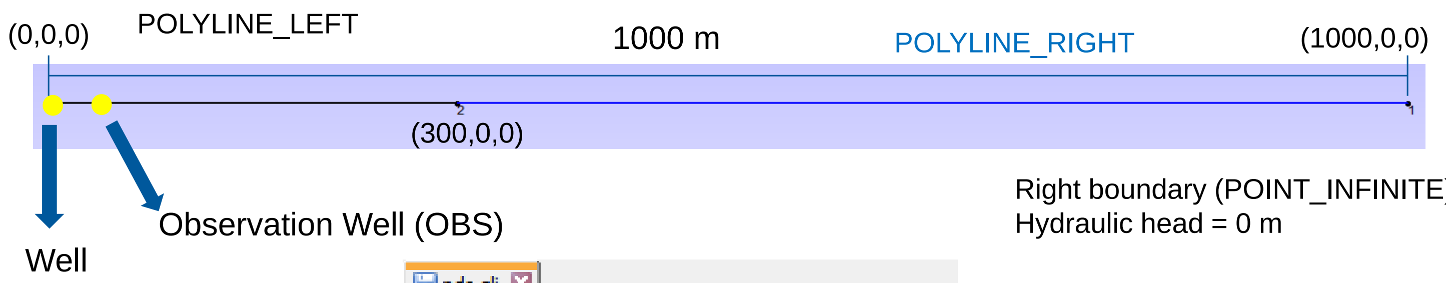
3	9.639	0	0	$NAME OBS
Punktnummer	x	y	z	Punktname

$NAME – Ein Punktname wird nur für Randbedingung, Source terms oder initiale Bedíngungen

2 Polylinien, um später ein feineres Mesh nahe des Brunnen (left polyline) und ein gröberes Mesh weiter entfernt (right polyline) zu

Keyword:	#SURFACE
Parameters:	$POLYLINE . . .

Geometrie-Datei (*.gli)



Right boundary (POINT_INFINITE)
Hydraulic head = 0 m

pds.gli

```
GeoSys-gli: geometry ----------
#POINTS
 0 0 0 0 $NAME WELL
 1 300 0 0
 2 1000 0 0 $NAME INFINITE
 3 9.639 0 0 $NAME OBS
#POLYLINE
$NAME
 LEFT
$POINTS
 0
 1
#POLYLINE
$NAME
 RIGHT
$POINTS
 1
 2
#STOP
```

→ **speichern als pds.gli**

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Mesh-Datei (*.msh)

#FEM_MSH — Header der Mesh_Dateil

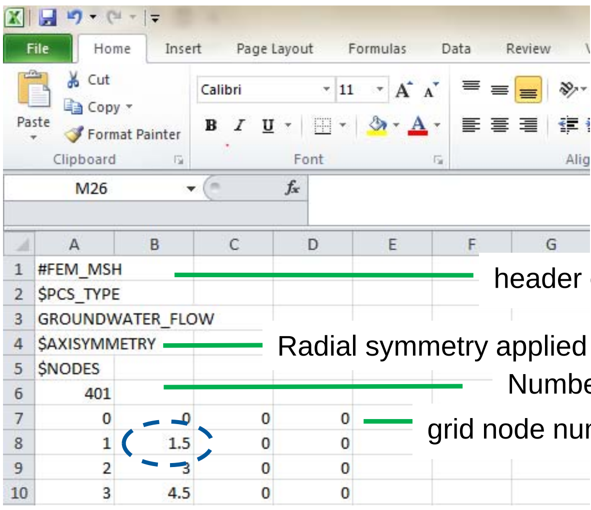
```
$AXISYMMETRY
$NODES
401
0 0 0 0
1 .57 0 0
[..]
399 996.5 0 0
400 1000 0 0
```

- $AXISYMMETRY — Radial-Symmetrie (cylindric coordinates)
- 401 — Knotenanzahl
- 0 0 0 0 — Meshknotenzahl und x; y; z Koordinaten

```
$ELEMENTS
  400
0 0 line 0 1
1 0 line 1 2
[..]
398 0 line 398 399
399 0 line 399 400
# STOP
```

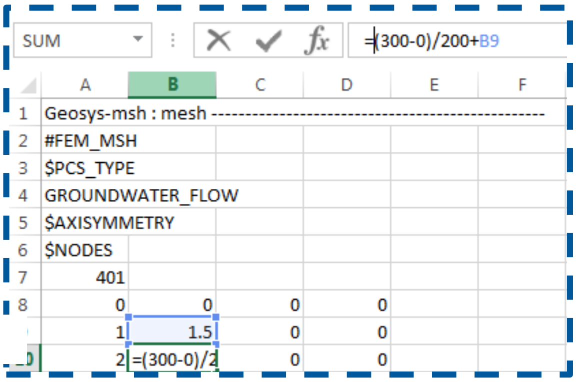
- <u>Elemente</u>
- Elementnummer mit der assoziierten Materialgruppe, Geometrietyp (Linie, Dreieck,..)

Mesh-Datei (*.msh)



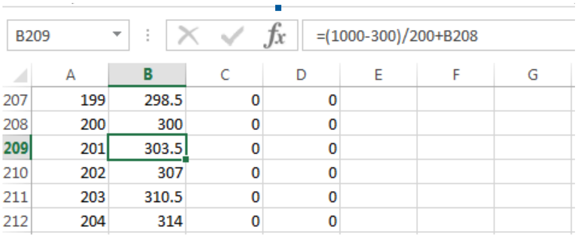
	A	B	C	D
1	#FEM_MSH			
2	$PCS_TYPE			
3	GROUNDWATER_FLOW			
4	$AXISYMMETRY			
5	$NODES			
6	401			
7	0	0	0	0
8	1	1.5	0	0
9	2	3	0	0
10	3	4.5	0	0

- #FEM_MSH — header of the mesh file
- $AXISYMMETRY — Radial symmetry applied (cylindric coordinates)
- 401 — Number of nodes
- 0 0 0 0 — grid node number and x; y; z coordinates



SUM =(300-0)/200+B9

	A	B	C	D
1	Geosys-msh : mesh --			
2	#FEM_MSH			
3	$PCS_TYPE			
4	GROUNDWATER_FLOW			
5	$AXISYMMETRY			
6	$NODES			
7	401			
8	0	0	0	0
	1	1.5	0	0
	2	=(300-0)/2	0	0



B209 =(1000-300)/200+B208

	A	B	C	D
207	199	298.5	0	0
208	200	300	0	0
209	201	303.5	0	0
210	202	307	0	0
211	203	310.5	0	0
212	204	314	0	0

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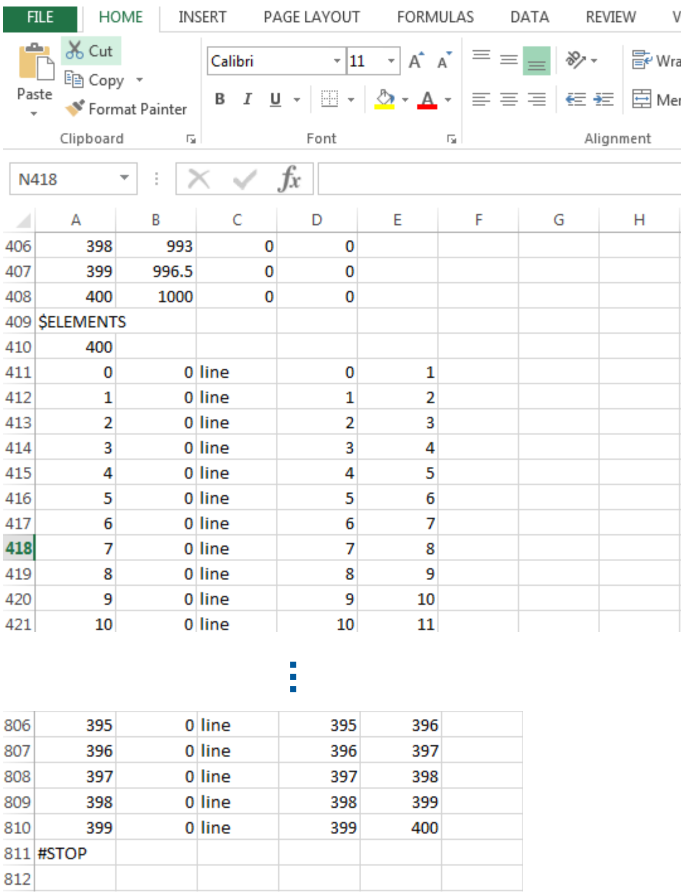
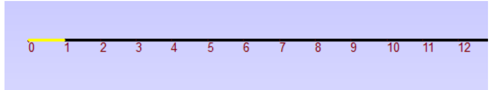
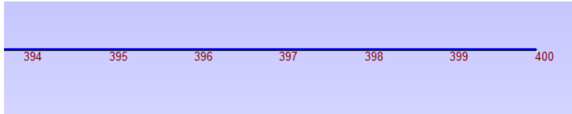
Mesh-Datei (*.msh)



	A	B	C	D	E	F	G	H
406	398	993	0	0				
407	399	996.5	0	0				
408	400	1000	0	0				
409	$ELEMENTS							
410	400							
411	0	0	line	0	1			
412	1	0	line	1	2			
413	2	0	line	2	3			
414	3	0	line	3	4			
415	4	0	line	4	5			
416	5	0	line	5	6			
417	6	0	line	6	7			
418	7	0	line	7	8			
419	8	0	line	8	9			
420	9	0	line	9	10			
421	10	0	line	10	11			
⋮								
806	395	0	line	395	396			
807	396	0	line	396	397			
808	397	0	line	397	398			
809	398	0	line	398	399			
810	399	0	line	399	400			
811	#STOP							
812								



⋮



→ **speichern als pds.txt**
→ **dann über Editor als pds.msh**

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Randbedingungen-Datei (*.bc)

GeoSys-BC: Boundary Conditions --
#BOUNDARY_CONDITION
$PCS_TYPE
 GROUNDWATER_FLOW
 $PRIMARY_VARIABLE
 HEAD
 $GEO_TYPE
 POINT INFINIT
 $DIS_TYPE
 CONSTANT 0.0
#STOP

$GEO_TYPE
POINT
POLYLINE
SURFACE
VOLUME

Dirichlet Randbedingung: $h(x_0,t) = f_1(x_0,t)$

$DIS_TYPE	Description
CONSTANT	Dirchlet boundary condition
DIRECT	BC. assign to element nodes directly
FUNCTION	A linear function is given
LINEAR, GRADIENT, **...**	**...**

$TIME_TYPE
CURVE

Defined by *.rfd file.

$...
...

Randbedingungen-Datei (*.bc)

pds.bc

```
GeoSys-BC: Boundary Conditions ----------------------------
#BOUNDARY_CONDITION
$PCS_TYPE
 GROUNDWATER_FLOW
$PRIMARY_VARIABLE
 HEAD
$GEO_TYPE
 POINT INFINITE
$DIS_TYPE
 CONSTANT 0.0
#STOP
```

→ **speichern als pds.bc**

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Quellterm-Datei (*.st)

```
GeoSys-ST: Source Terms
-----------------------------------------------

#SOURCE_TERM
 $PCS_TYPE
  GROUNDWATER_FLOW
 $PRIMARY_VARIABLE
  HEAD
 $GEO_TYPE
  POINT WELL
  $DIS_TYPE
  CONSTANT_NEUMANN -2.253E-3
#STOP
```

Neumann Randbedingung: $q_r \cdot v = f_2(x,t)$

$DIS_TYPE	Description
CONSTANT	Neumann boundary condition
CONSTANT_NEUMANN	Neumann boundary condition
LINEAR, LINEAR_NEUMANN …	…

$PCS_TYPE	$PRIMARY_VARIABLE	Unit
GROUNDWATER_FLOW	HEAD	m
LIQUID_FLOW	PRESSURE1	Pa
RICHARDS_FLOW	PRESSURE1	Pa

Quellterm-Datei (*.st)

```
GeoSys-ST: Source Terms ----------------
#SOURCE_TERM
 $PCS_TYPE
 GROUNDWATER_FLOW
 $PRIMARY_VARIABLE
  HEAD
 $GEO_TYPE
 POINT WELL
 $DIS_TYPE
 CONSTANT_NEUMANN -194.69
#STOP
```

→ **speichern als pds.st**

Initiale Randbedingungen-Datei (*.ic)

```
GeoSys-IC  Initial Conditions
------------------------------------
#INITIAL_CONDITION
 $PCS_TYPE
  GROUNDWATER_FLOW
 $PRIMARY_VARIABLE
  HEAD
 $GEO_TYPE
  DOMAIN
 $DIS_TYPE
  CONSTANT 0.0
#STOP
```

$GEO_TYPE
DOMAIN
POINT
POLYLINE
SURFACE

$$h(x, y, z, 0) = f(x, y, z)$$

$PCS_TYPE	$PRIMARY_VARIABLE	Unit
GROUNDWATER_FLOW	HEAD	m
LIQUID_FLOW	PRESSURE1	Pa
RICHARDS_FLOW	PRESSURE1	Pa

Meist als konstanter Wert;
Oder mittels „Reload function“

Initiale Randbedingungen-Datei (*.ic)

```
GeoSys-IC  Initial Conditions ------
#INITIAL_CONDITION
$PCS_TYPE
GROUNDWATER_FLOW
$PRIMARY_VARIABLE
HEAD
$GEO_TYPE
DOMAIN
$DIS_TYPE
CONSTANT 0.0
#STOP
```

→ speichern als pds.ic

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Materialeigenschaften-Datei (*.mmp)

```
GeoSys-MMP  Material Medium
Properties --------------------

#MEDIUM_PROPERTIES
 $GEOMETRY_DIMENSION
  1
 $GEOMETRY_AREA
  1
 $STORAGE
  1  1e-3
 $PERMEABILITY_SATURATION
  1 1.0
 $PERMEABILITY_TENSOR
  ISOTROPIC  9.29036E-4
#STOP
```

GROUNDWATER_FLOW

Keyword	Definition	Unit
$STORAGE	Specific storage	-
$PERMEABILITY_SATURATION	Relative permeability	-
$PERMEABILITY_TENSOR	Hydraulic conductivity	m/s

Bitte beachten: Für Grundwasserströmung:
Permeabilität = hydraulische Leitfähigkeit

Isotrop

$$K_x = K_y = K_z = K$$

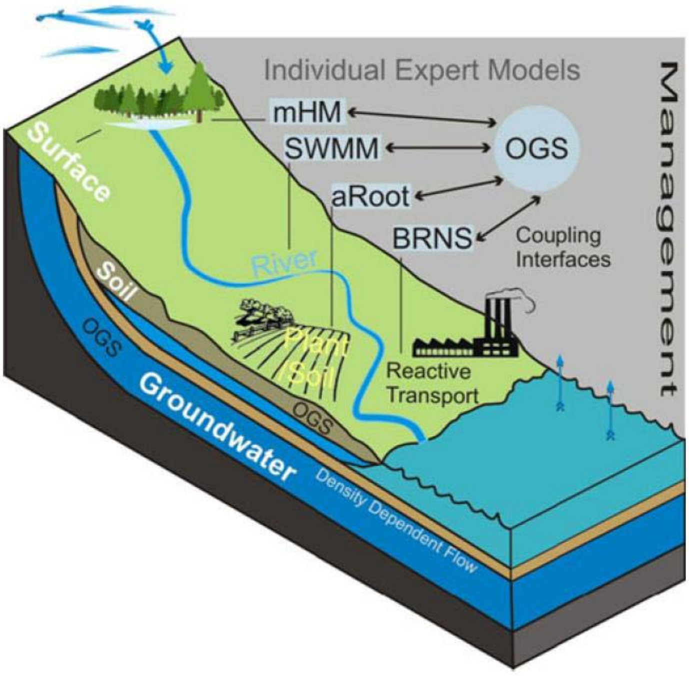
Orthotrop

$$K = \begin{pmatrix} K_x \\ K_y \\ K_z \end{pmatrix}$$

Anisotrop

$$K = \begin{pmatrix} K_{xx} & K_{xy} & K_{xz} \\ K_{yx} & K_{yy} & K_{yz} \\ K_{zx} & K_{zy} & K_{zz} \end{pmatrix}$$

Materialeigenschaften-Datei (2)



Kalbacher et al. (2012)

Process	Addtional keywords
RICHARDS_FLOW	$CAPILARY_PRESSURE $TRANSFER_COEFFICIENT ...
OVERLAND_FLOW	$SURFACE_FRICTION $CHANNEL $WIDTH ...
MASS_TRANSPORT	$POROCITY $TORTUOSITY $MASS_DISPERSION ...
...	...

Materialeigenschaften-Datei

```
GeoSys-MMP  Material Medium Properties ------
#MEDIUM_PROPERTIES
$GEOMETRY_DIMENSION
1
$GEOMETRY_AREA
1
$STORAGE
1 1.0e-3
$PERMEABILITY_SATURATION
1 1.0
$PERMEABILITY_TENSOR
ISOTROPIC 9.29036e-4
#STOP
```

→ **speichern als pds.mmp**

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Fluid-Eigenschaften-datei (*.mfp)

```
GeoSys-MAT-FP: Fluid Properties
------------------------------------
#FLUID_PROPERTIES
 $FLUID_TYPE
  LIQUID
 $PCS_TYPE
  HEAD
 $DENSITY
  1 0.000000e+0
 $VISCOSITY
  1 1E-3
#STOP
```

Keywords	Available options
$FLUID_TYPE	1) LIQUID 2) GAS
$DENSITY	**1**: constant fluid density **2**: fluid density model (pressure dependent) **4**: fluid density model (temperature dependent) …
$VISCOSITY	**1**: constant fluid viscosity **2**: fluid viscosity model (pressure dependent) **3**: fluid viscosity model (temperature dependent) …
…	…

Fluid-Eigenschaften-datei (*.mfp)

```
GeoSys-MAT-FP: Fluid Properties ---------
#FLUID_PROPERTIES
$FLUID_TYPE
LIQUID
$PCS_TYPE
HEAD
$DENSITY
1 0.0e+0
$VISCOSITY
1 1.0
#STOP
```

→ speichern als pds.mfp

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Numerik (*.num)

```
GeoSys-NUM: Numerical Parameter
-----------------------------------
#NUMERICS
 $PCS_TYPE
  GROUNDWATER_FLOW
 $LINEAR_SOLVER
; method  error method error_tolerance max_iterations theta precond storage
  2      5          1.e-014          1000            1.0      100       4
 $RENUMBER
  2 -1
#STOP
```

Other keywords
$COUPLING_CONTROL
$EXTERNAL_SOLVER_OPTION
$ELE_GAUSS_POINTS
$ELE_UPWINDING

$LINEAR_SOLVER	Available options
1	SpGAUSS, direct solver
2	SpBICGSTAB
3	SpBICG
4	SpQMRCGSTAB
	...
10	SpSOR

$NON_LINEAR_SOLVER	Available options
1	NEWTON
2	PICARD
...	…

Numerik (*.num)

```
GeoSys-NUM: Numerical Parameter ------------------------------------------
#NUMERICS
$PCS_TYPE
GROUNDWATER_FLOW
$LINEAR_SOLVER
; method error method error_tolerance max_iterations theta precond storage
  2       5              1.e-014        1000            1.0    100      4
 $RENUMBER
  2 -1
#STOP
```

→ **speichern als pds.num**

Zeitschritt-Datei (*.tim)

```
GeoSys-OUT: Output
-----------------------------------------------
#TIME_STEPPING
 $PCS_TYPE
  GROUNDWATER_FLOW
$TIME_STEPS
  10 0.864
  10 7.776
  10 77.76
  10 777.76
  10 7776
  10 77760
 $TIME_END
  864000
 $TIME_START
  0.0
 $TIME_UNIT
 SECOND
#STOP
```

```
$TIME_STEPS
 10  0.00001
```

Time steps   Time step size

Default value:
SECOND

Zeitschritt-Datei (*.tim)

```
GeoSys-TIM: time stepping ----------------
#TIME_STEPPING
 $PCS_TYPE
  GROUNDWATER_FLOW
 $TIME_STEPS
  10 0.00001
  10 0.00009
  10 0.0009
  10 0.009
  10 0.09
  10 0.9
 $TIME_END
  10
 $TIME_START
  0.0
 $TIME_UNIT
  DAY
#STOP
```

→ speichern als pds.tim

Ausgabe-Datei (*.out)

```
GeoSys-OUT: Output
 ------------------------------------------------
#OUTPUT
 $PCS_TYPE
  GROUNDWATER_FLOW
 $NOD_VALUES
  HEAD
 $GEO_TYPE
  DOMAIN
 $DAT_TYPE
  TECPLOT
 $TIM_TYPE
  STEPS 1

#OUTPUT
 $PCS_TYPE
  GROUNDWATER_FLOW
 $NOD_VALUES
  HEAD
 $GEO_TYPE
  POINT OBS
 $DAT_TYPE
  TECPLOT
 $TIM_TYPE
  STEPS 1
#STOP
```

	Values
$NOD_VALUES	Head, pressure concentration ...
$ELE_VALUES	Velocity...
...	...

$DAT_TYPE
TECPLOT
VTK
PVD
...

Frequency of the generation of output files

Ausgabe-Datei (*.out)

```
GeoSys-OUT: Output -------------------
#OUTPUT
 $PCS_TYPE
  GROUNDWATER_FLOW
 $NOD_VALUES
  HEAD
 $GEO_TYPE
  DOMAIN
 $DAT_TYPE
  TECPLOT
 $TIM_TYPE
  STEPS 1
#OUTPUT
 $PCS_TYPE
  GROUNDWATER_FLOW
 $NOD_VALUES
  HEAD
 $GEO_TYPE
  POINT OBS
 $DAT_TYPE
  TECPLOT
 $TIM_TYPE
  STEPS 1
#STOP
```

→ **speichern als pds.out**

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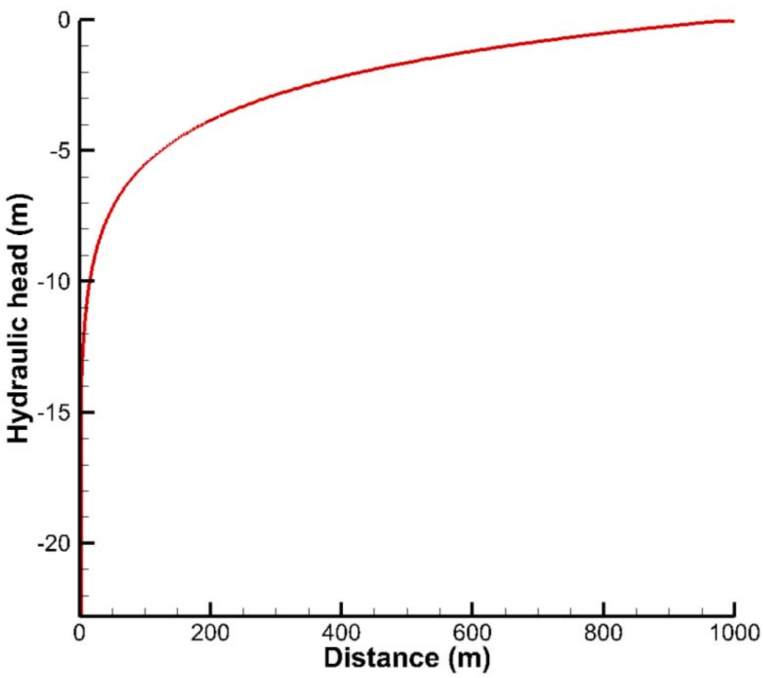
Simulation

```
1  ogs.exe pds >pds.txt
2
```

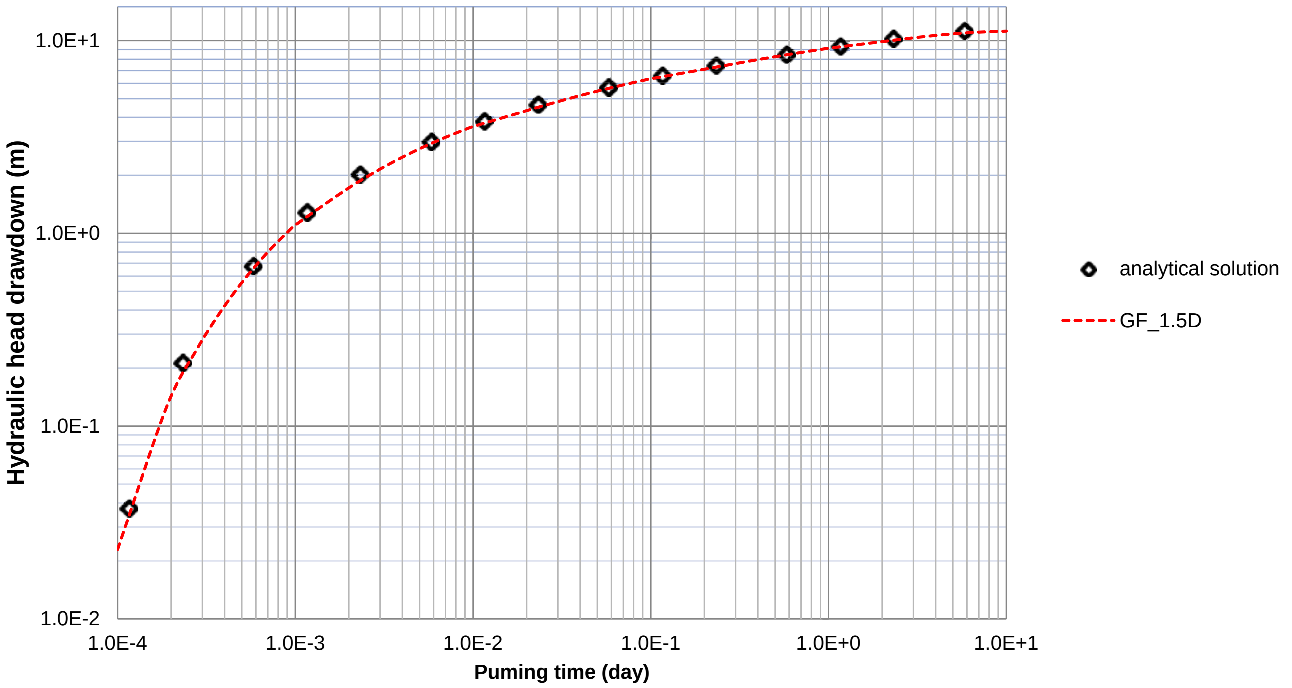
→ **speichern als run.bat**

Simulationsergebnisse (1)



Hydraulic head distribution at the end of the simulation

Simulationsergebnisse (2)



berechneter Absenktrichter am Beobachtungsbrunnen

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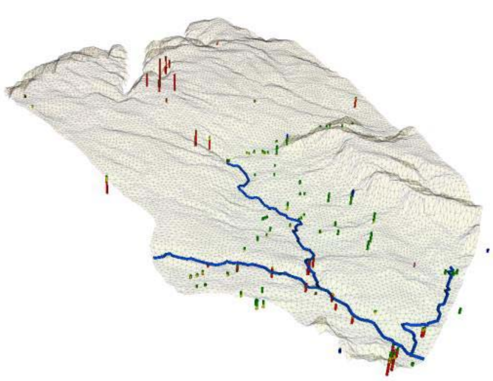
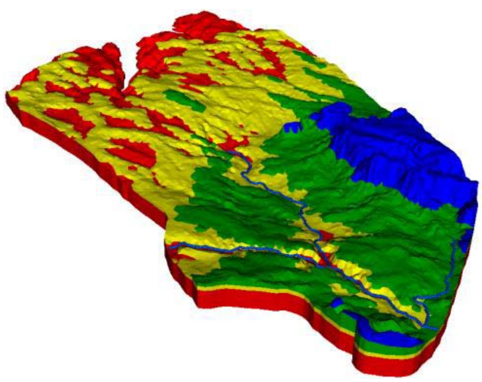
Vorschau

Vorlesung am 12.06.2015

OpenGeoSys: Ammer Einzugsgebiet → Computer mitbringen!





Quelle: K. Rink et al.

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