Mathematical modeling of environmental isotope data to estimate the catchment area of drinking water supply

Case study Lake Leis
(Rhine valley)

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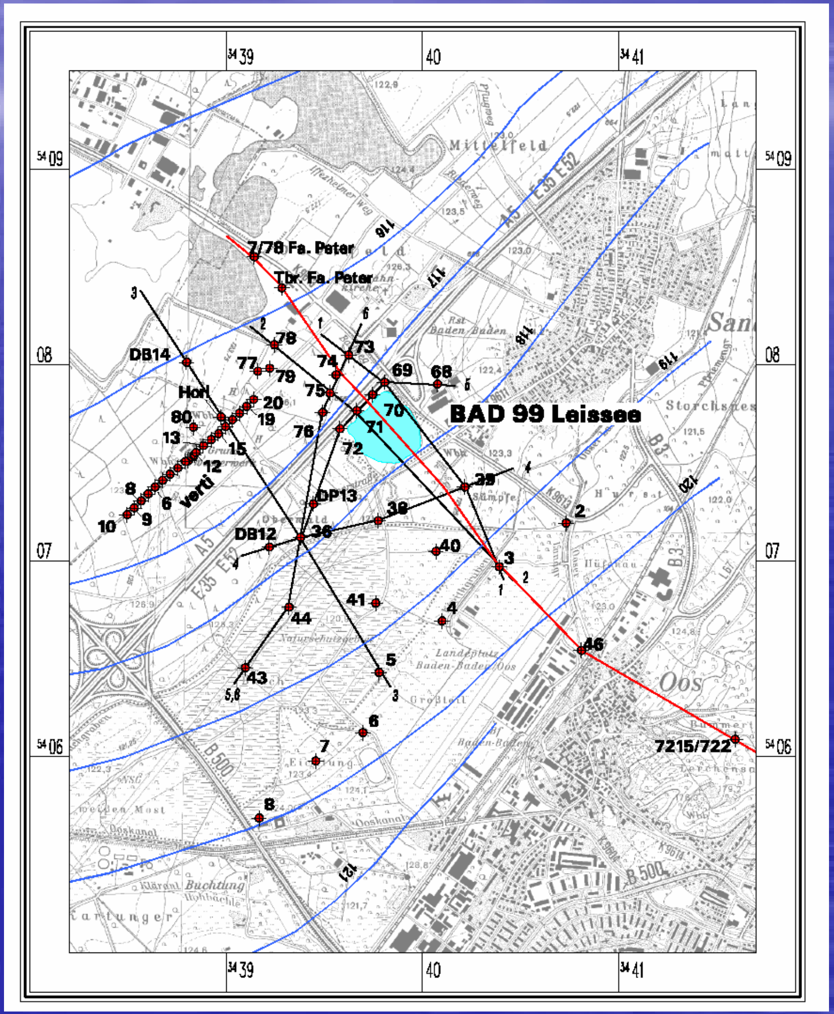
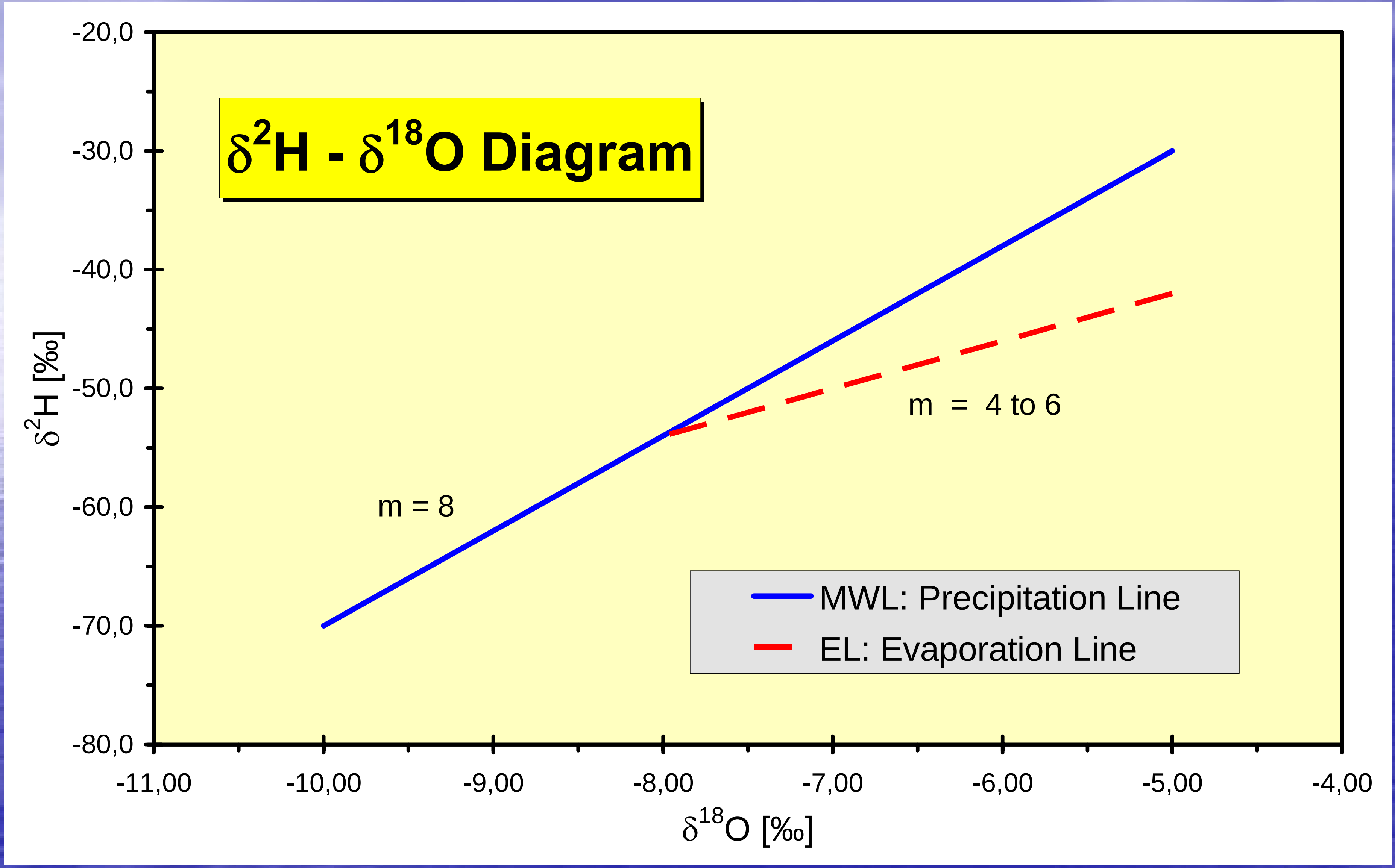
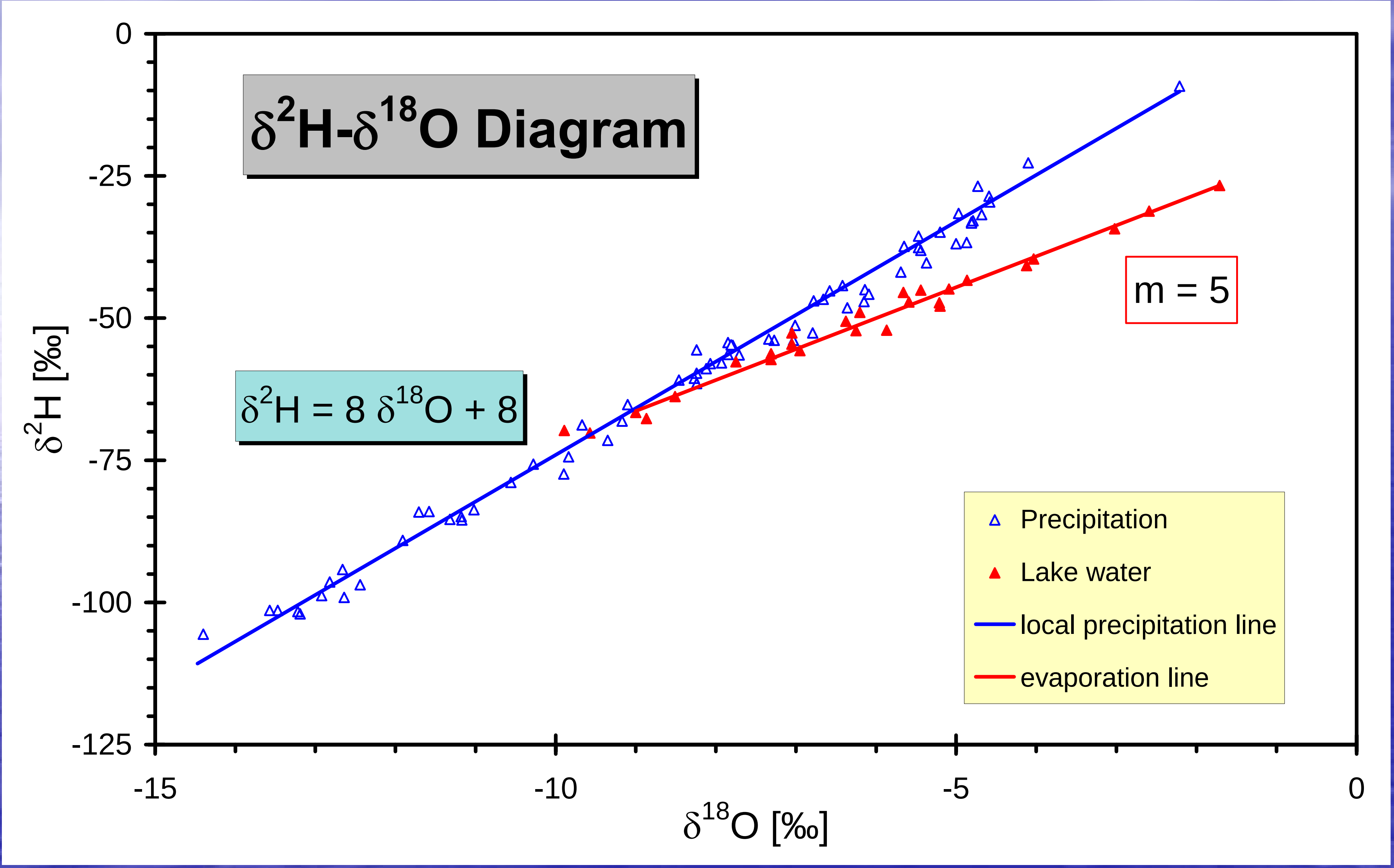
Interaction surface water – ground water

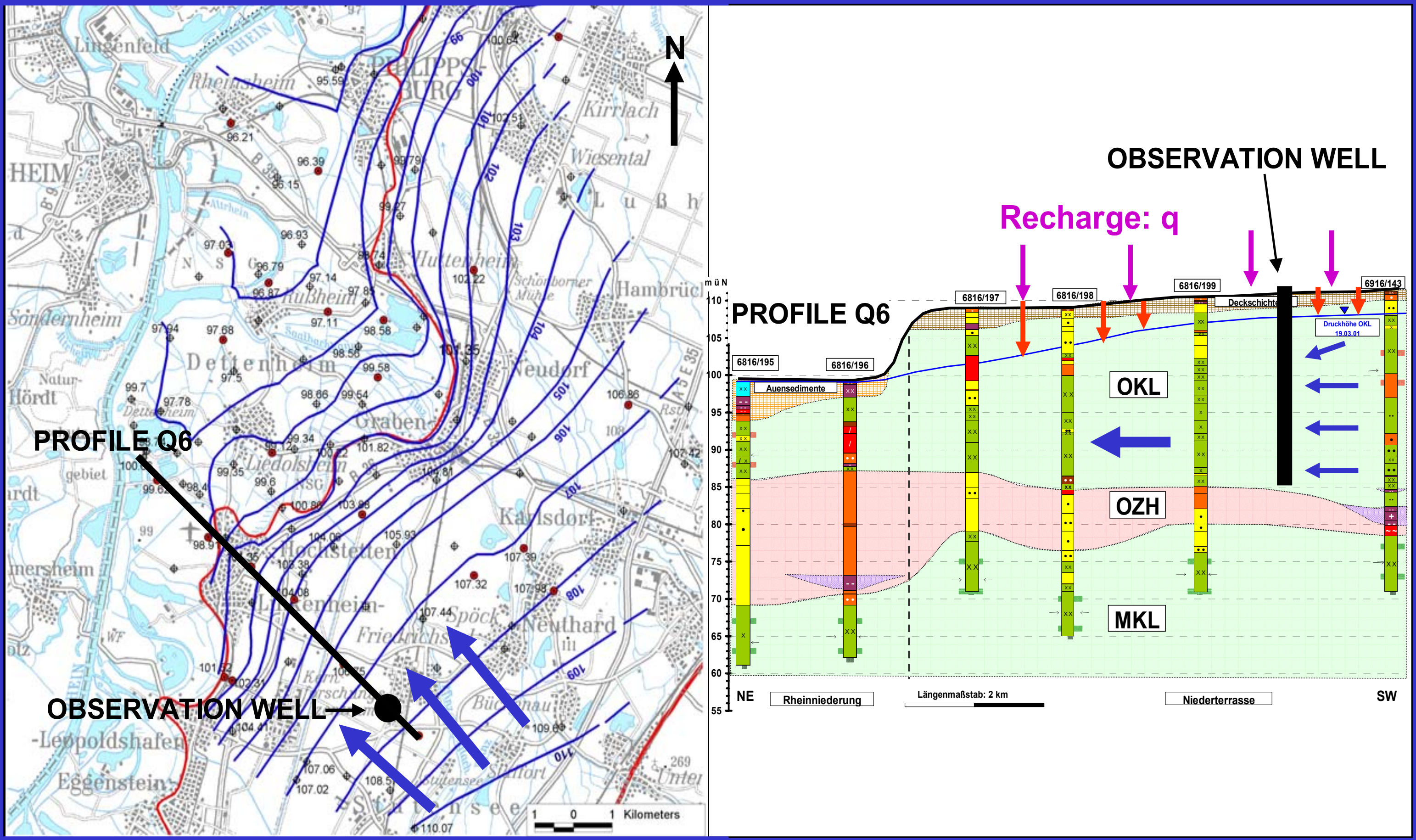




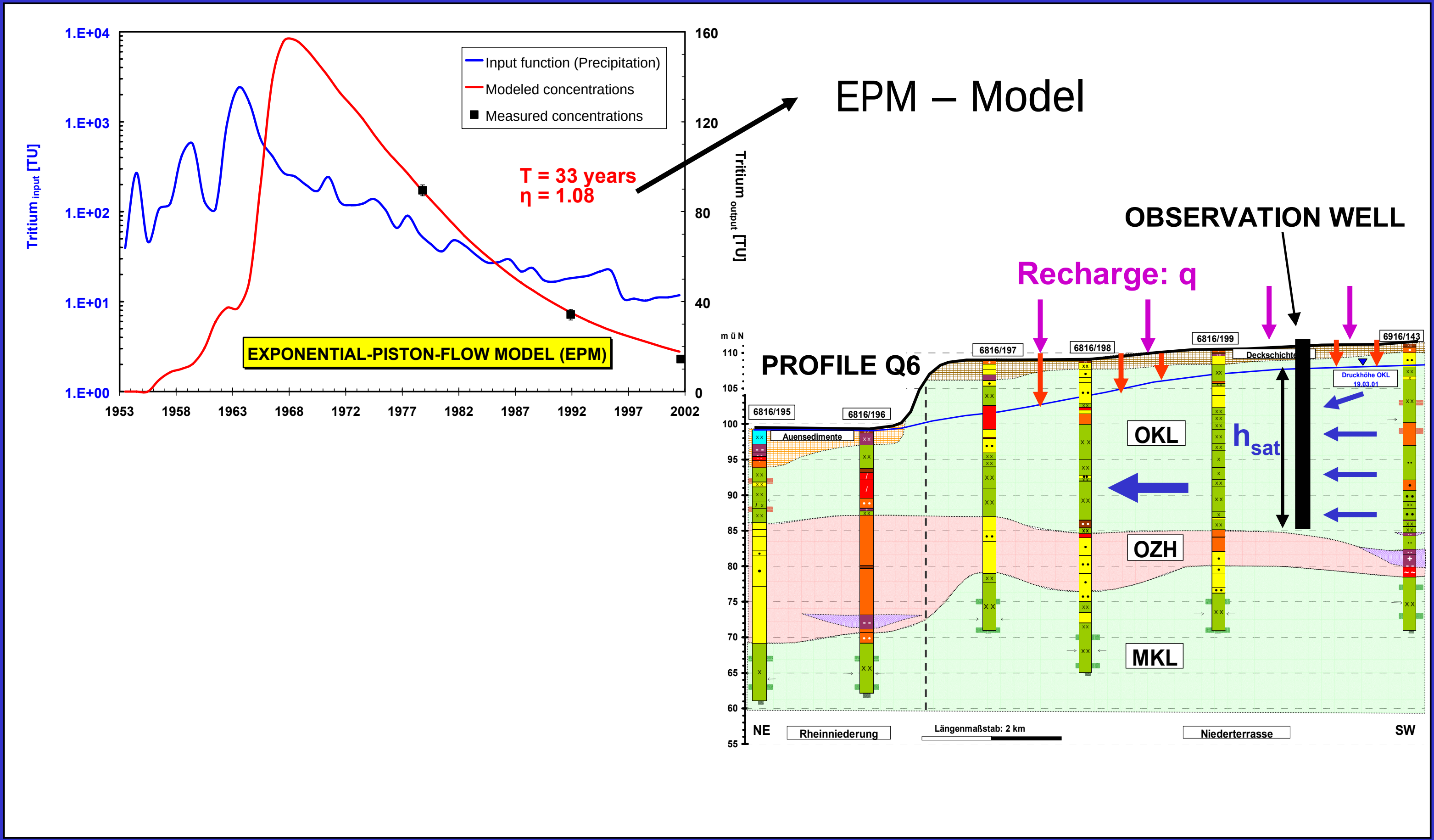
δ²H - δ¹⁸O Diagram
-20,0
-30,0
-40,0
-50,0
-60,0
-70,0
-80,0
δ²H [‰]
-11,00
-10,00
-9,00
-8,00
-7,00
-6,00
-5,00
-4,00
δ¹⁸O [‰]
m = 8
m = 4 to 6
MWL: Precipitation Line
EL: Evaporation Line


δ²H-δ¹⁸O Diagram
δ²H = 8 δ¹⁸O + 8
m = 5
Precipitation
Lake water
local precipitation line
evaporation line
0
-25
-50
-75
-100
-125
-15
-10
-5
0
δ²H [‰]
δ¹⁸O [‰]

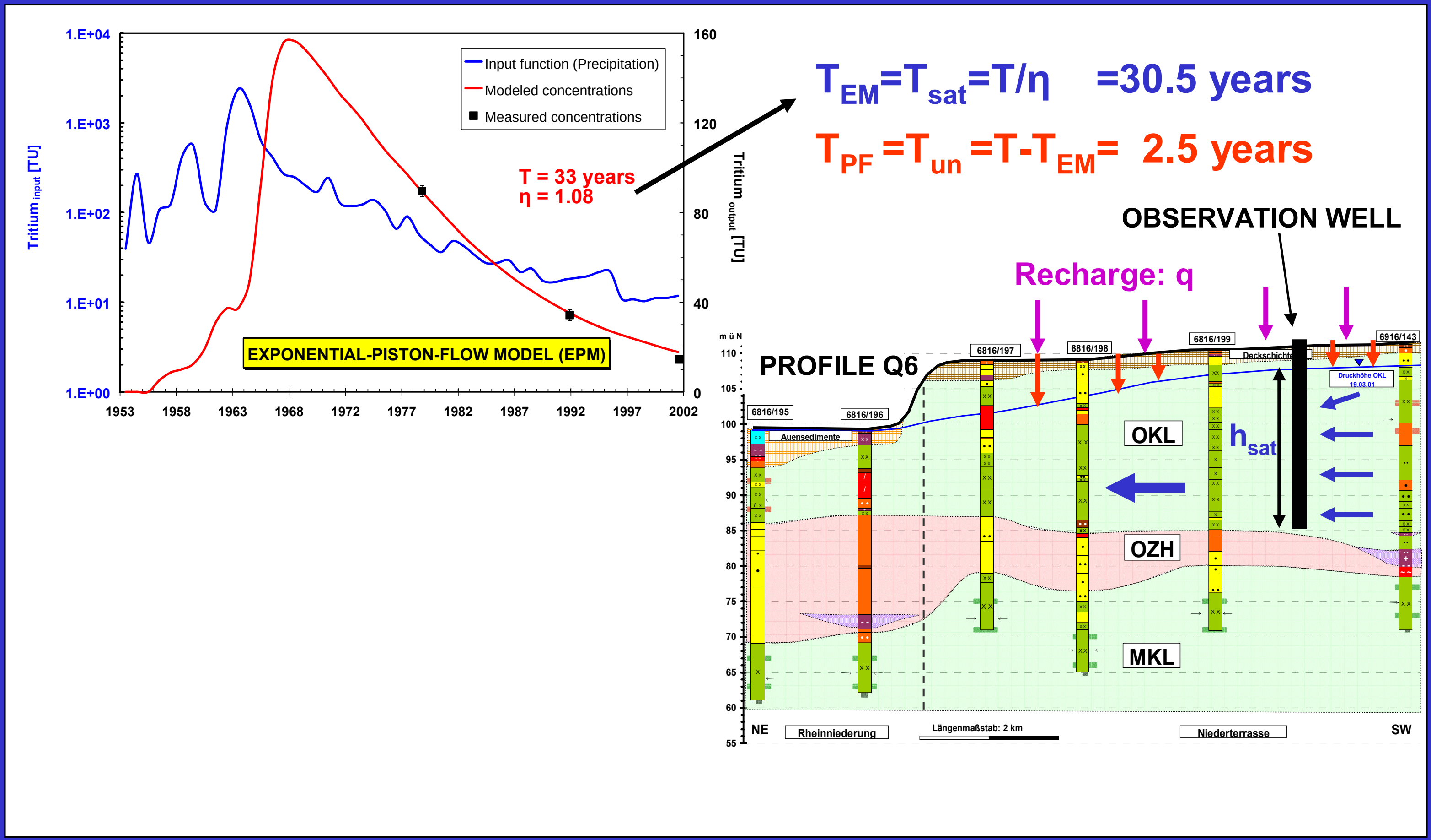
Estimation of local recharge



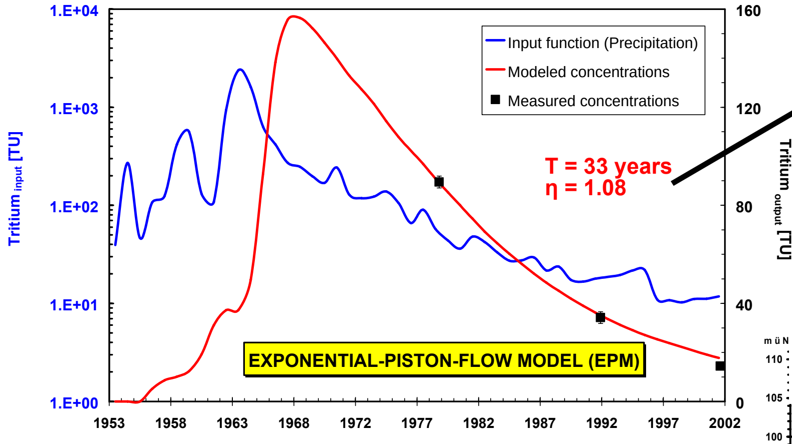
Estimation of local recharge



Estimation of local recharge

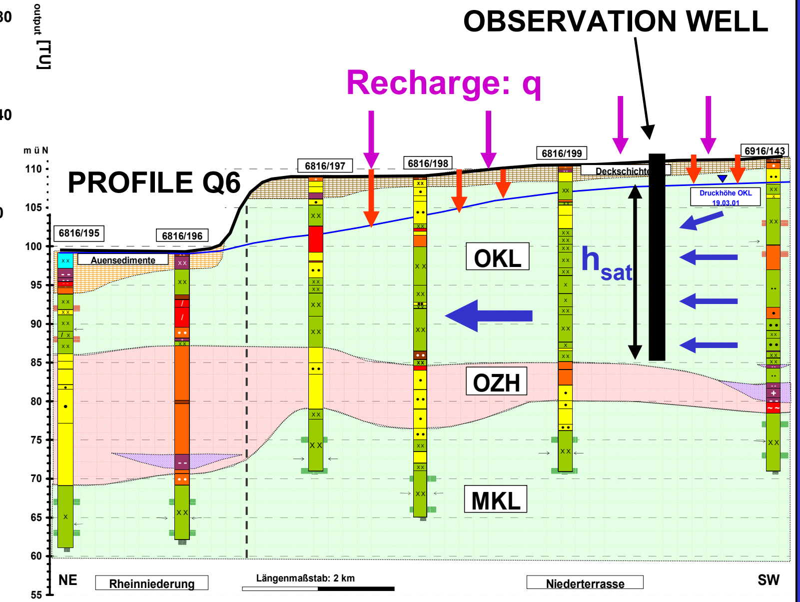


Estimation of local recharge



$T_{EM} = T_{sat} = T/\eta \quad = 30.5$ years

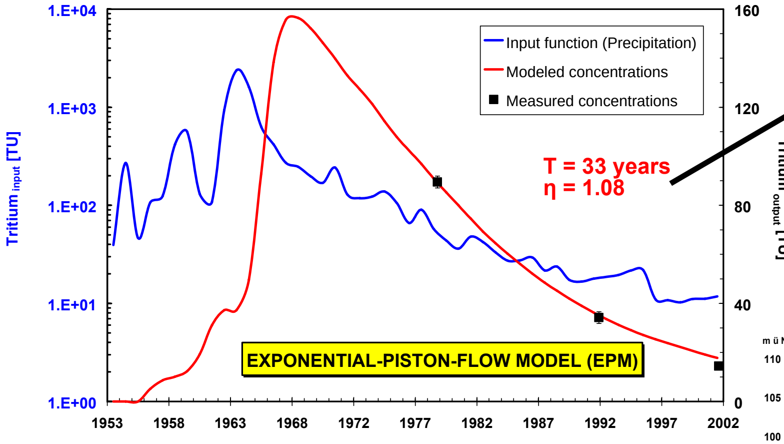
$T_{PF} = T_{un} = T - T_{EM} = 2.5$ years



(1) knowing $\Theta = 0.08$, $h_{un} = 3.2$ m

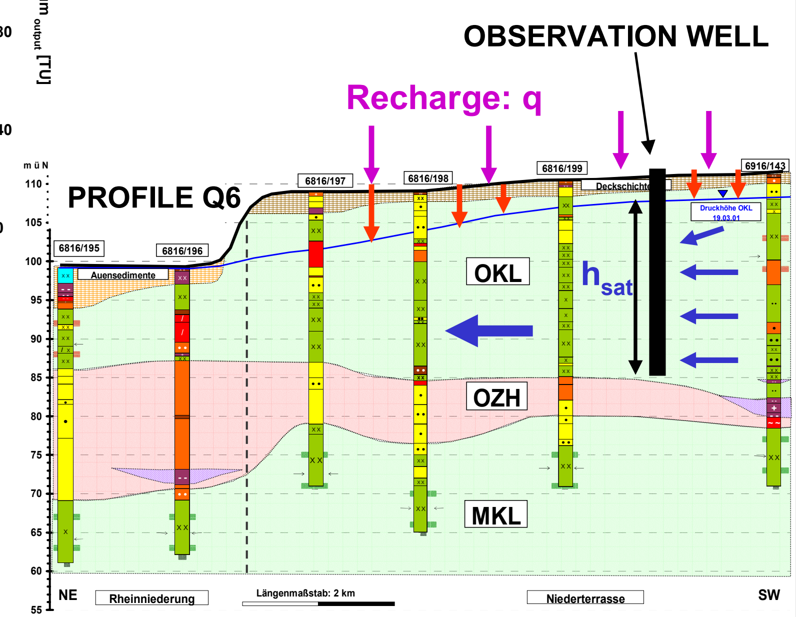
$q = h_{un} \cdot \Theta / T_{PF} = 105$ mm/a

Estimation of local recharge



$T_{EM}=T_{sat}=T/\eta \quad =30.5$ years

$T_{PF}=T_{un}=T-T_{EM}= \; 2.5$ years

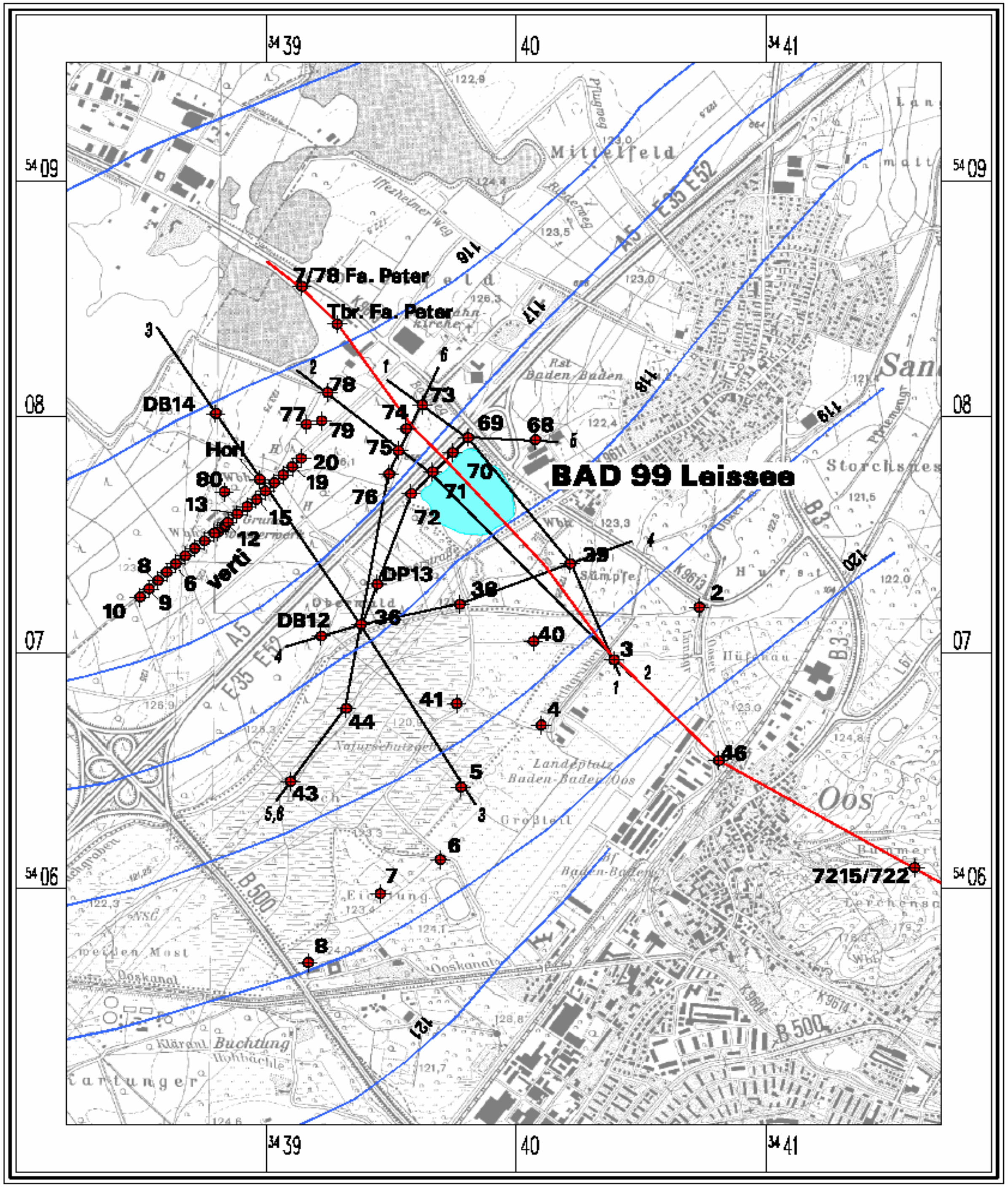


(1) knowing $\Theta=0.08$, $h_{un}=3.2$ m

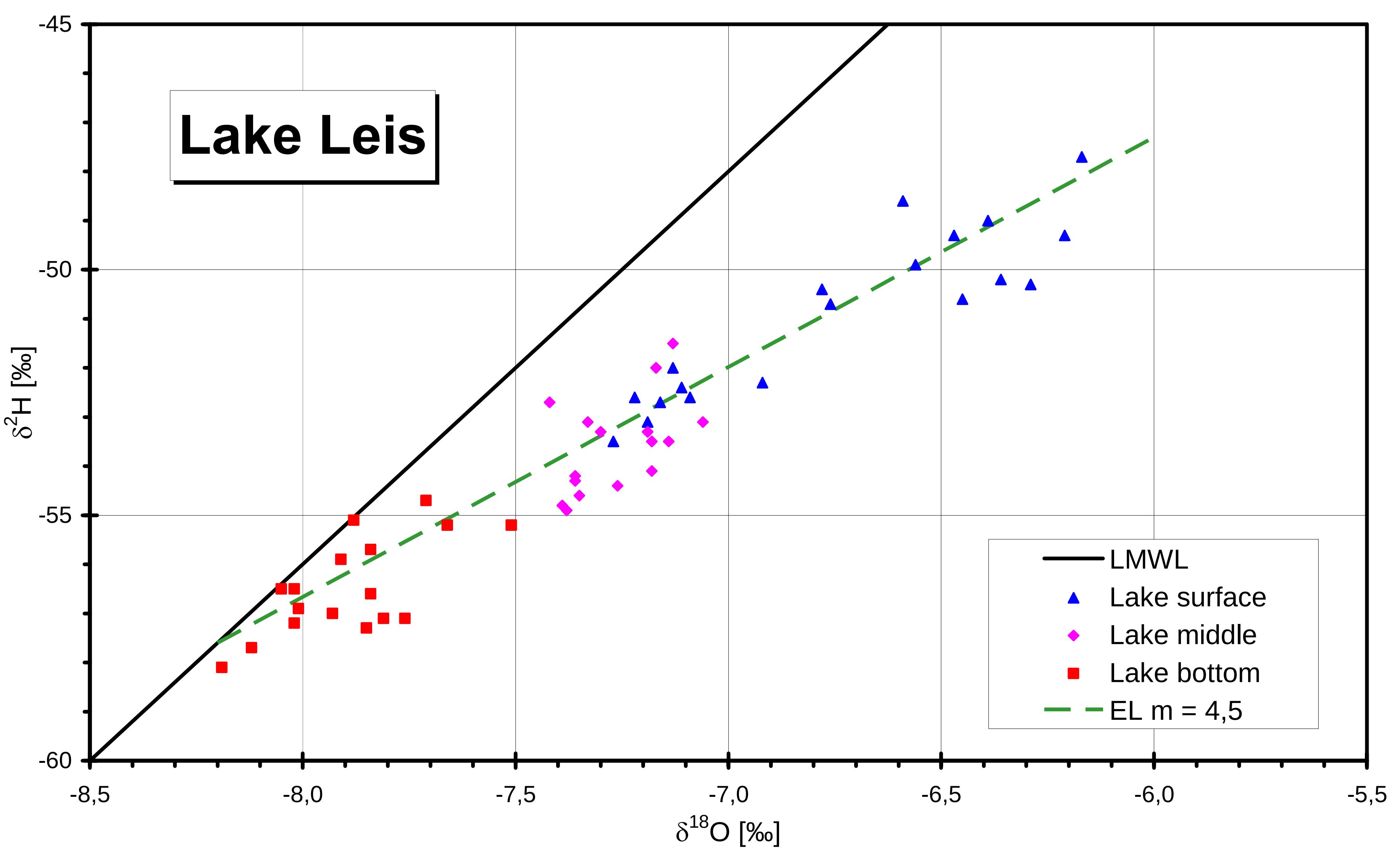
$q = h_{un}\cdot\Theta \,/\, T_{PF} = 105$ mm/a

(2) estimating $n=0.2$

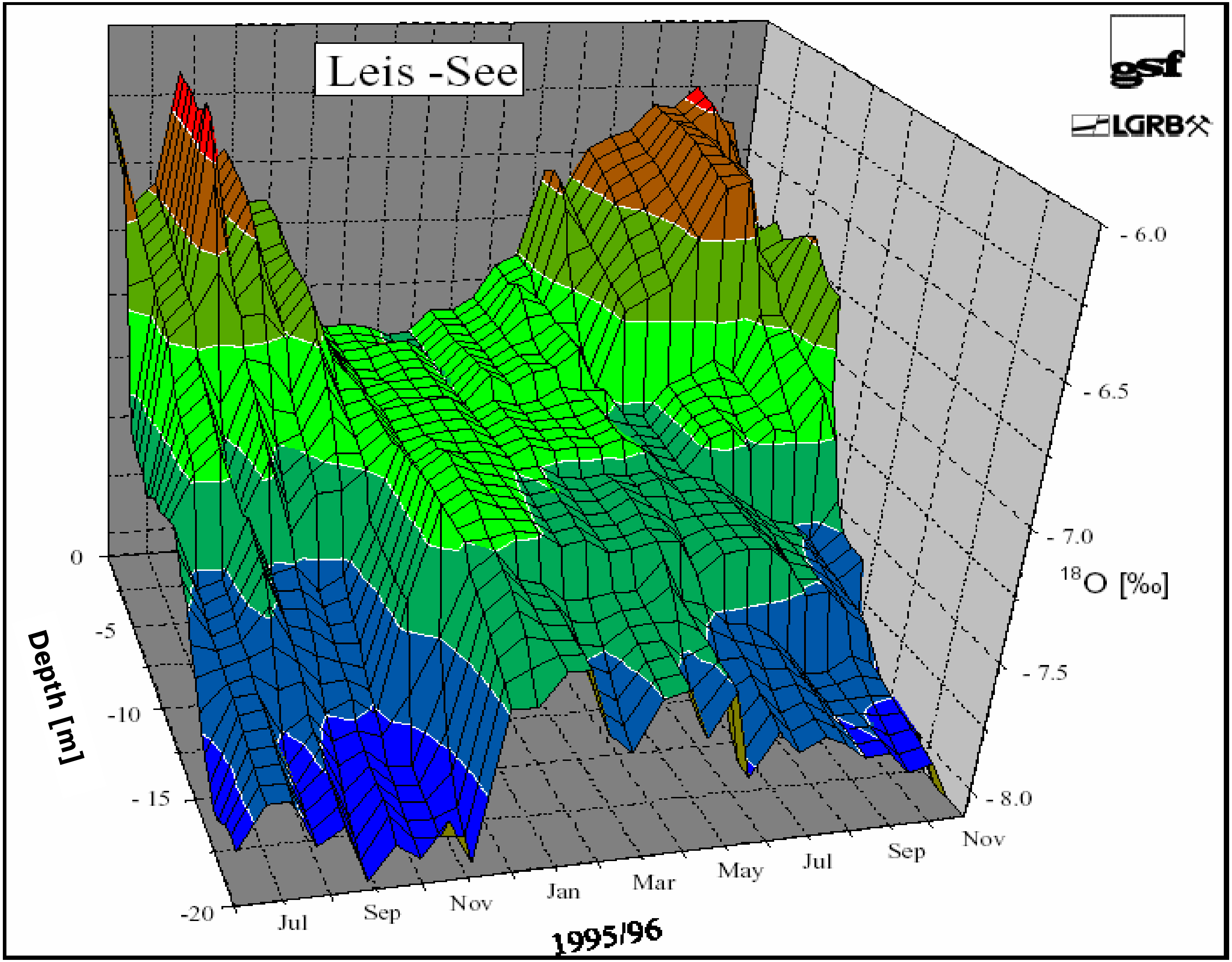
$h_{sat}= q\cdot T_{EM} \,/\, n = 16$ m

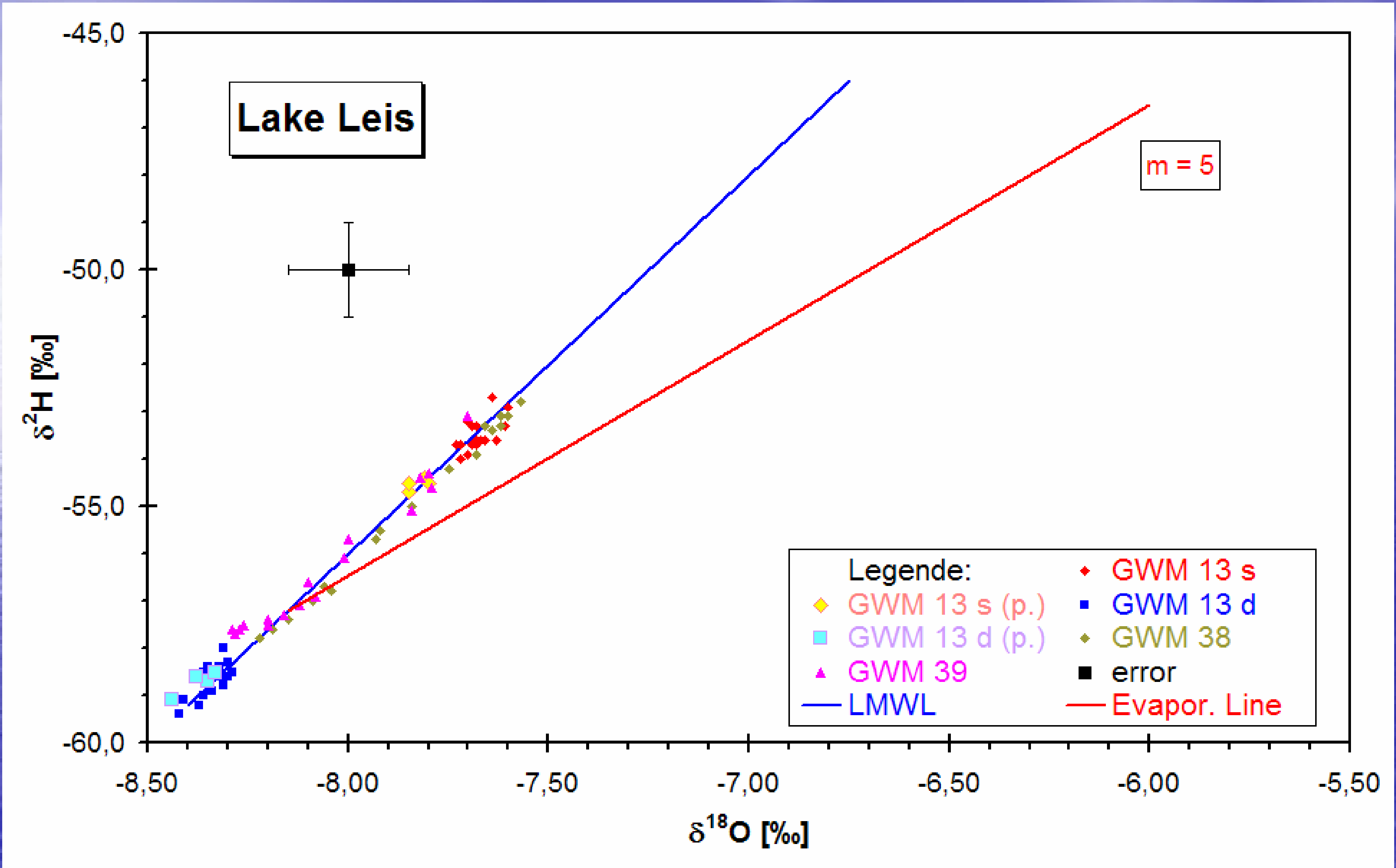


BAD 99 Leissee
7/78 Fa. Peter
Tbr. Fa. Peter
DB14
DB12
DP13
verti
7215/722
Mittelfeld
Landeplatz Baden-Baden Oos
Oos
Ooskanal
Naturschutzgebiet
B 500
A5 E35 E52
B3
34 39
40
34 41
54 09
08
07
54 06

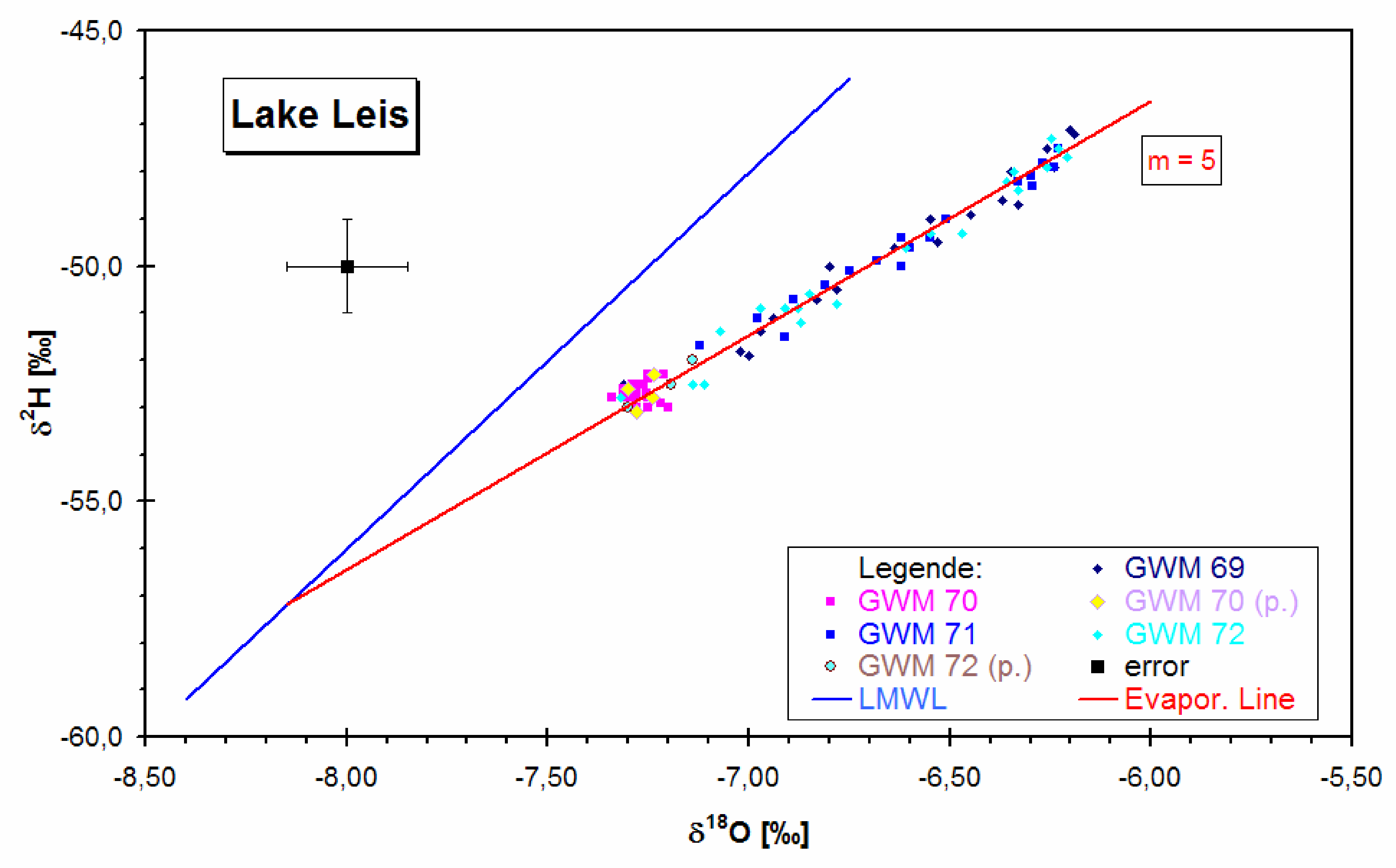


Lake Leis
-45
-50
-55
-60
-8,5
-8,0
-7,5
-7,0
-6,5
-6,0
-5,5
δ2H [‰]
δ18O [‰]
LMWL
Lake surface
Lake middle
Lake bottom
EL m = 4,5

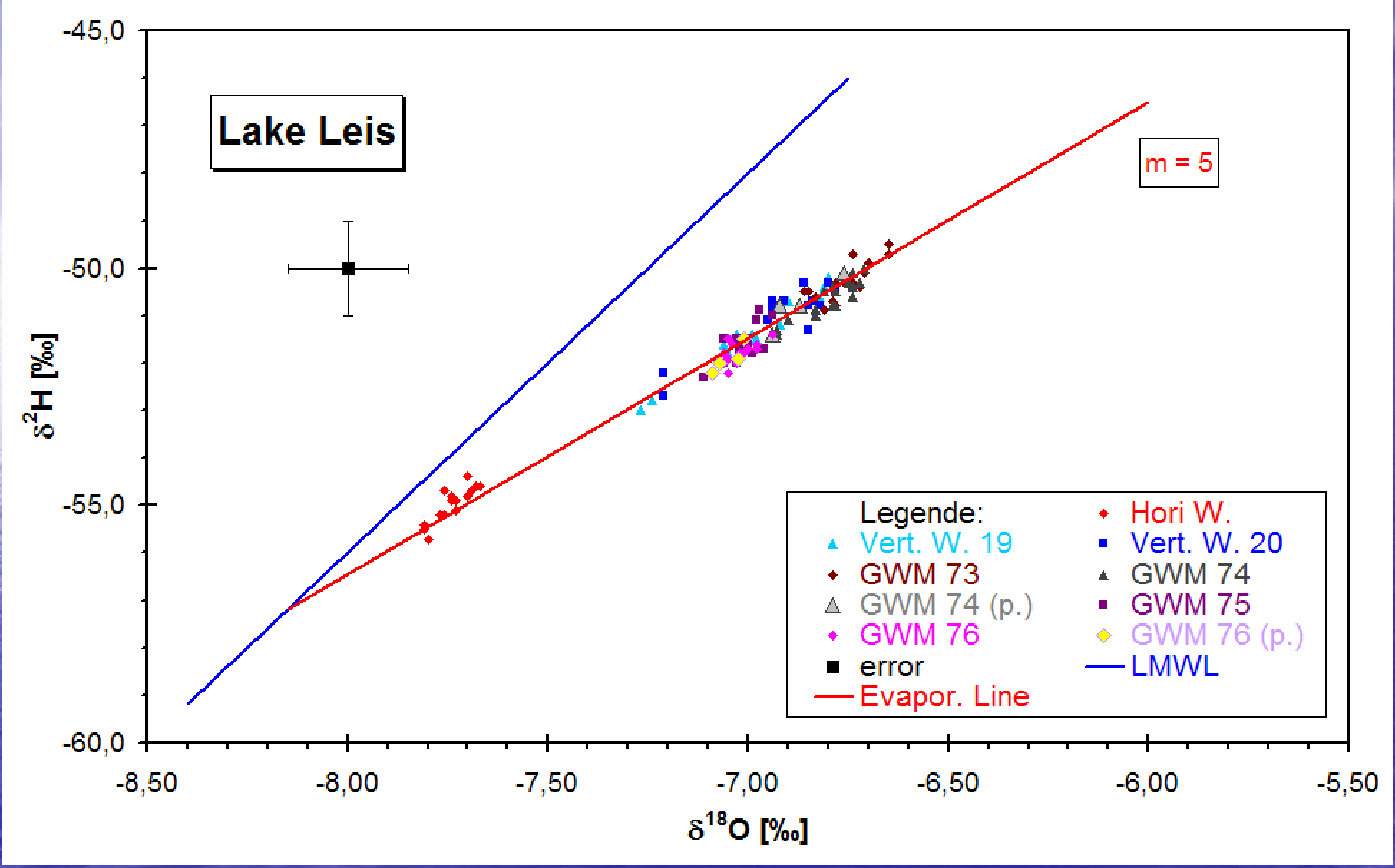

Leis -See
gsf
LGRB
- 6.0
- 6.5
- 7.0
- 7.5
- 8.0
18O [‰]
0
-5
-10
- 15
-20
Depth [m]
Jul
Sep
Nov
Jan
Mar
May
Jul
Sep
Nov
1995/96



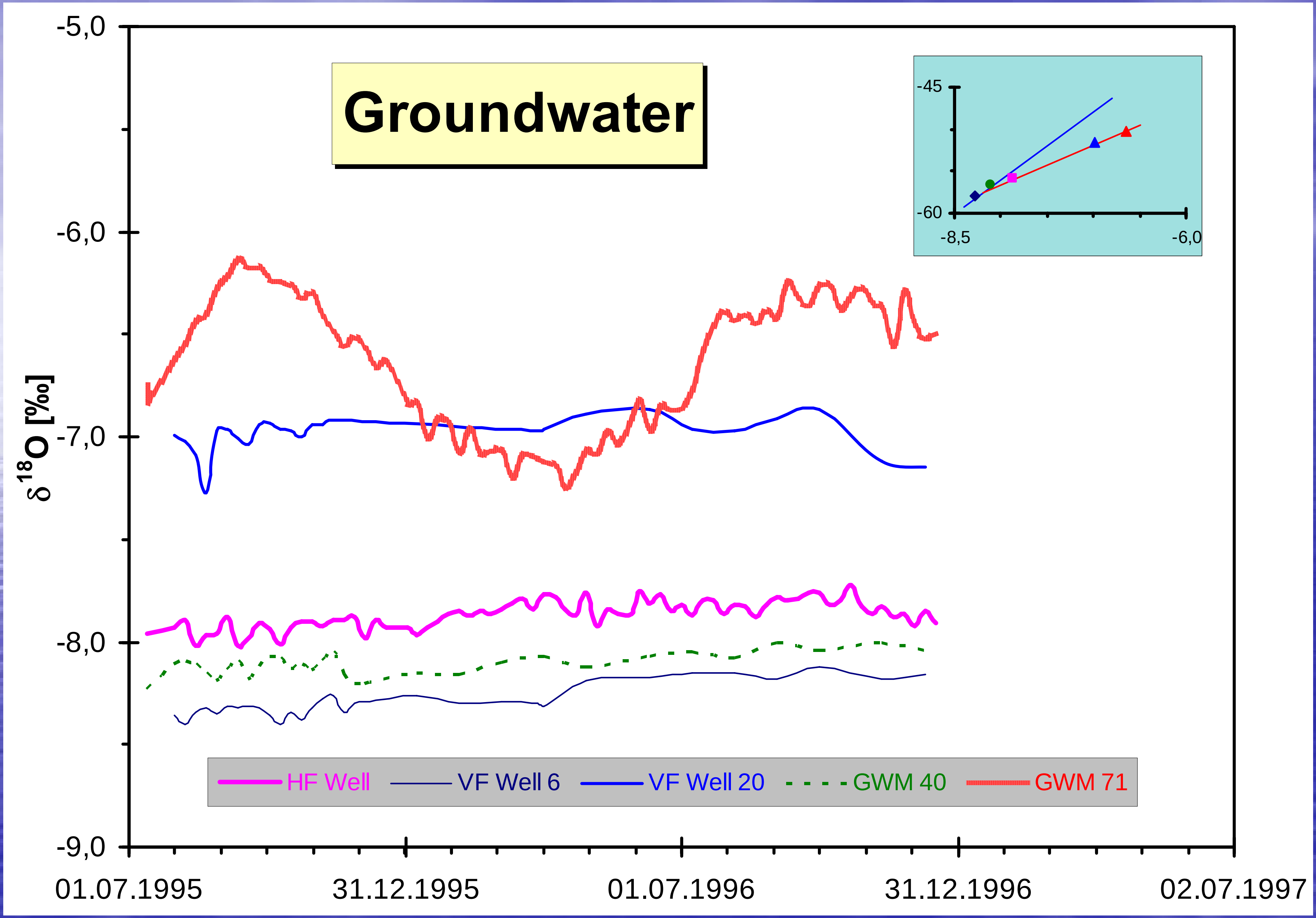
Lake Leis
m = 5
-45,0
-50,0
-55,0
-60,0
δ²H [‰]
-8,50
-8,00
-7,50
-7,00
-6,50
-6,00
-5,50
δ¹⁸O [‰]
Legende:
GWM 13 s (p.)
GWM 13 d (p.)
GWM 39
LMWL
GWM 13 s
GWM 13 d
GWM 38
error
Evapor. Line



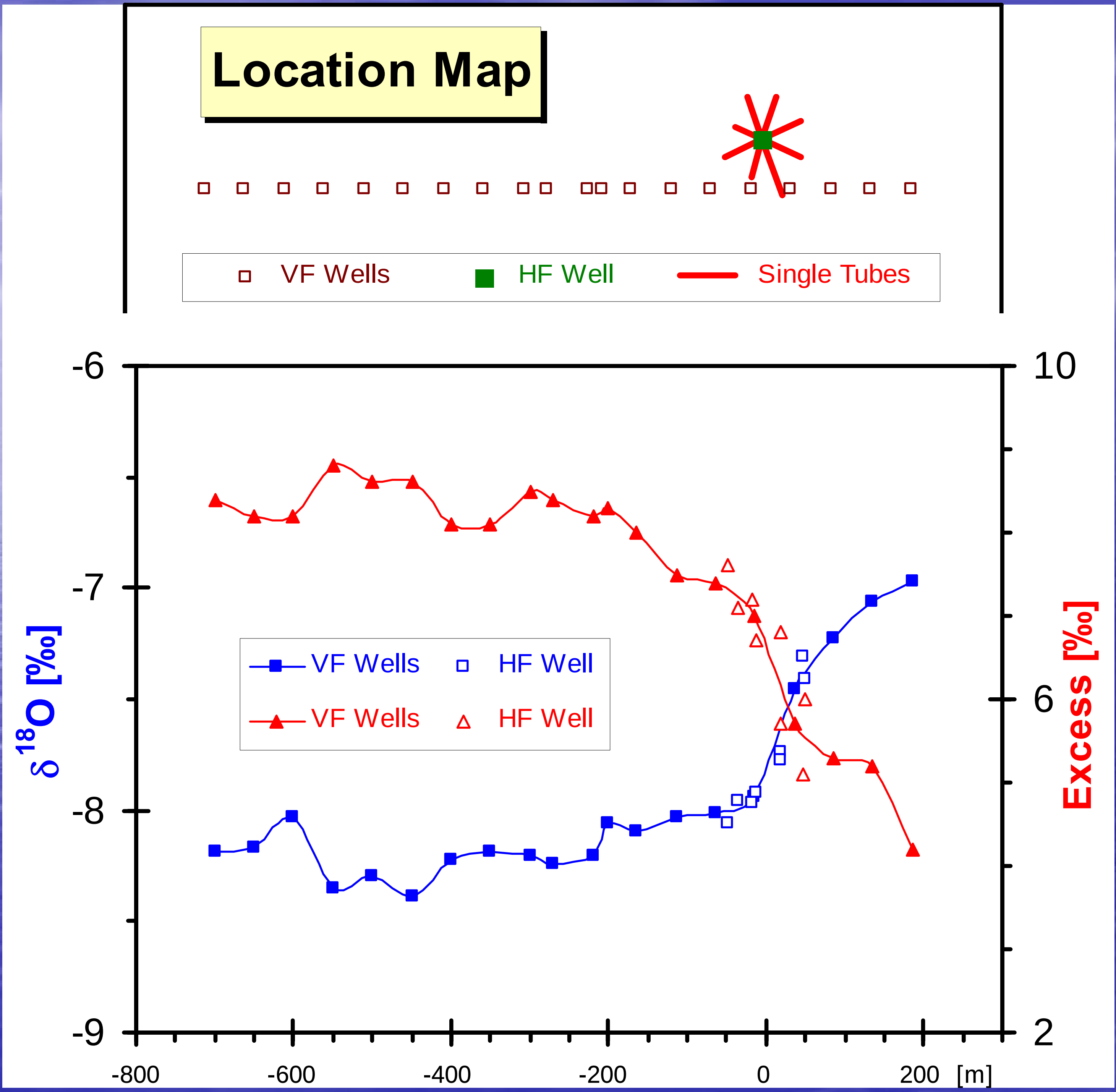
Lake Leis
m = 5
-45,0
-50,0
-55,0
-60,0
δ²H [‰]
-8,50
-8,00
-7,50
-7,00
-6,50
-6,00
-5,50
δ¹⁸O [‰]
Legende:
GWM 69
GWM 70
GWM 70 (p.)
GWM 71
GWM 72
GWM 72 (p.)
error
LMWL
Evapor. Line



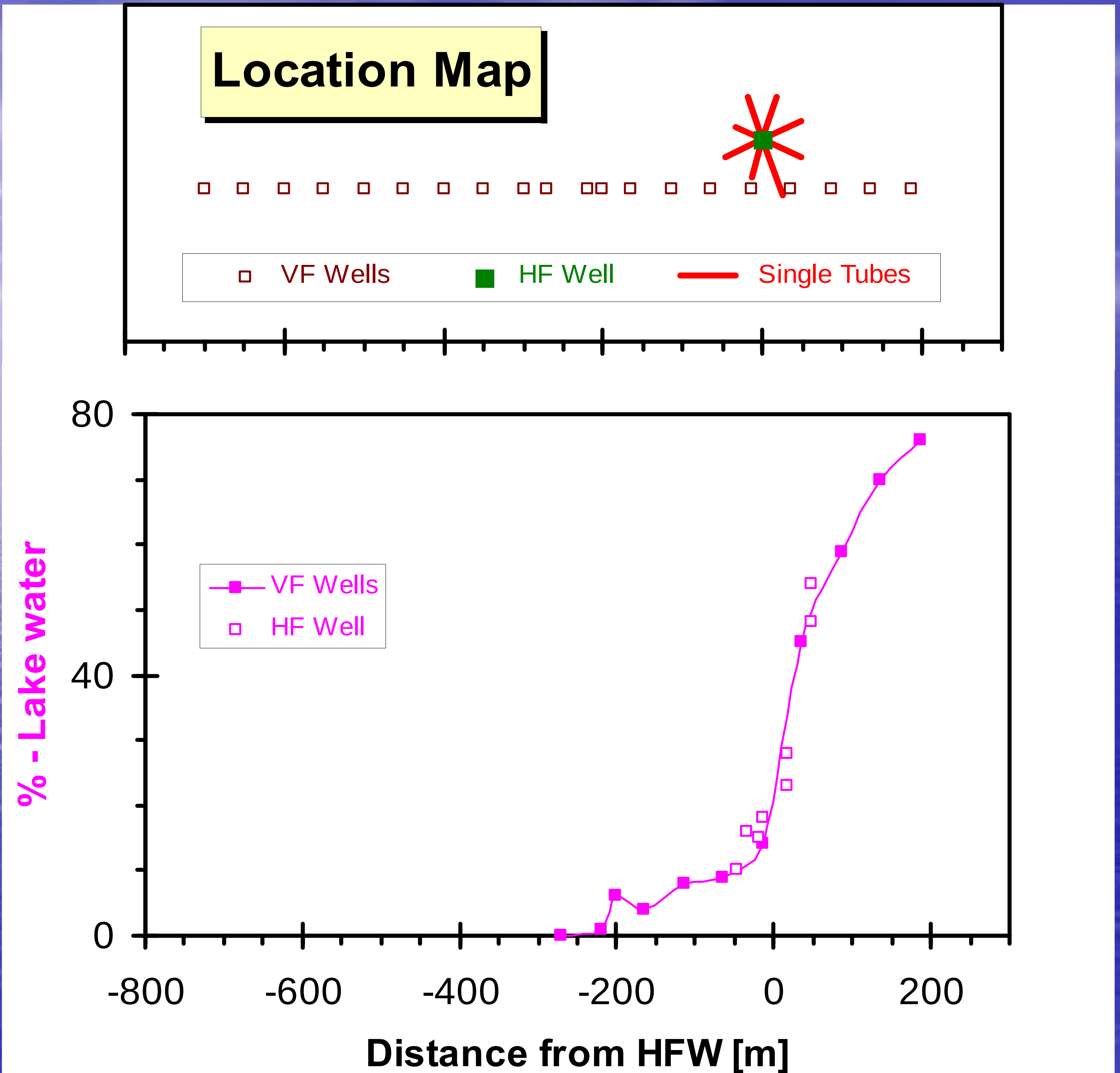
Lake Leis
m = 5
-45,0
-50,0
-55,0
-60,0
δ²H [‰]
-8,50
-8,00
-7,50
-7,00
-6,50
-6,00
-5,50
δ¹⁸O [‰]
Legende:
Hori W.
Vert. W. 19
Vert. W. 20
GWM 73
GWM 74
GWM 74 (p.)
GWM 75
GWM 76
GWM 76 (p.)
error
LMWL
Evapor. Line



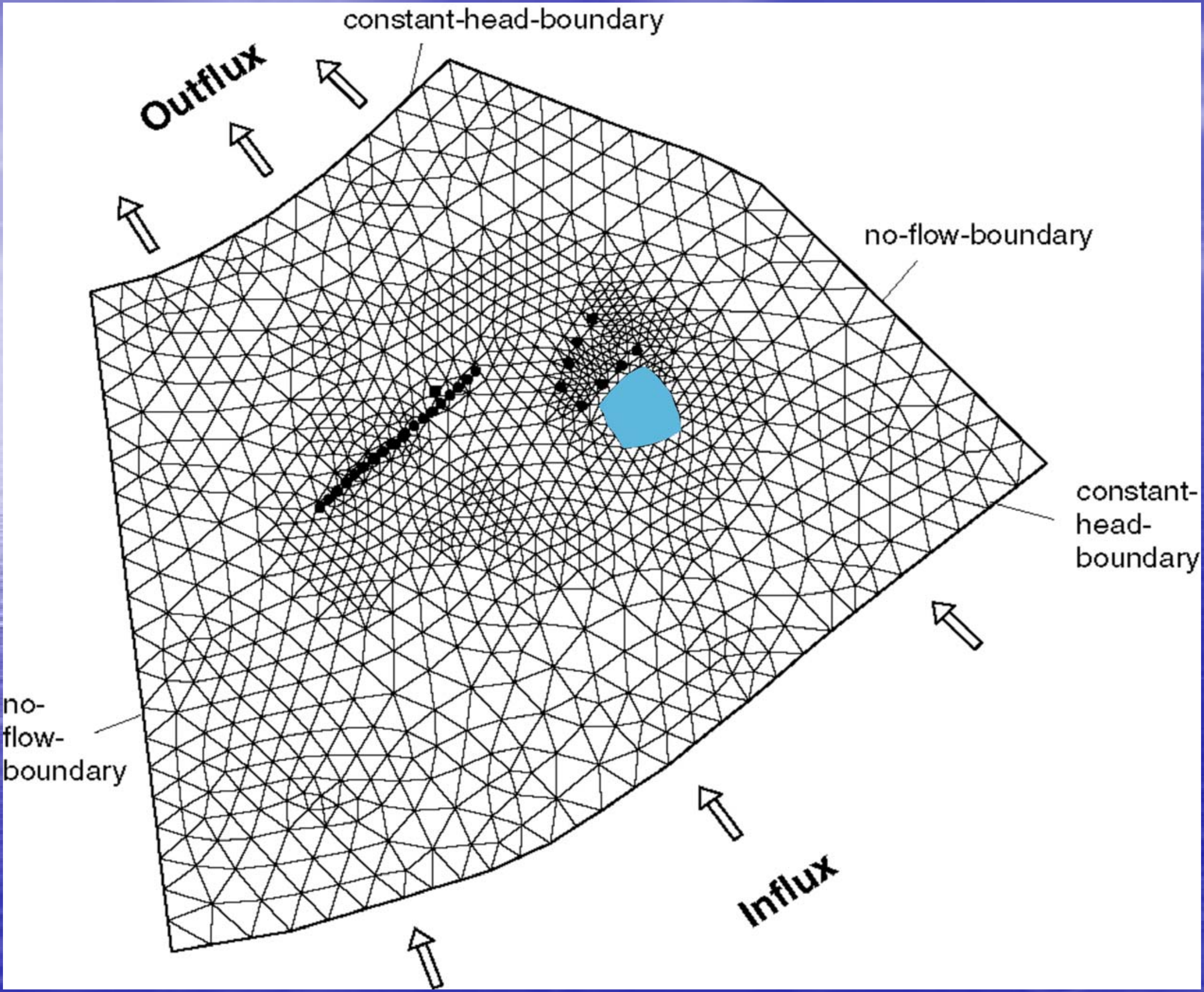
Groundwater
δ18O [‰]
-5,0
-6,0
-7,0
-8,0
-9,0
01.07.1995
31.12.1995
01.07.1996
31.12.1996
02.07.1997
HF Well
VF Well 6
VF Well 20
GWM 40
GWM 71
-45
-60
-8,5
-6,0

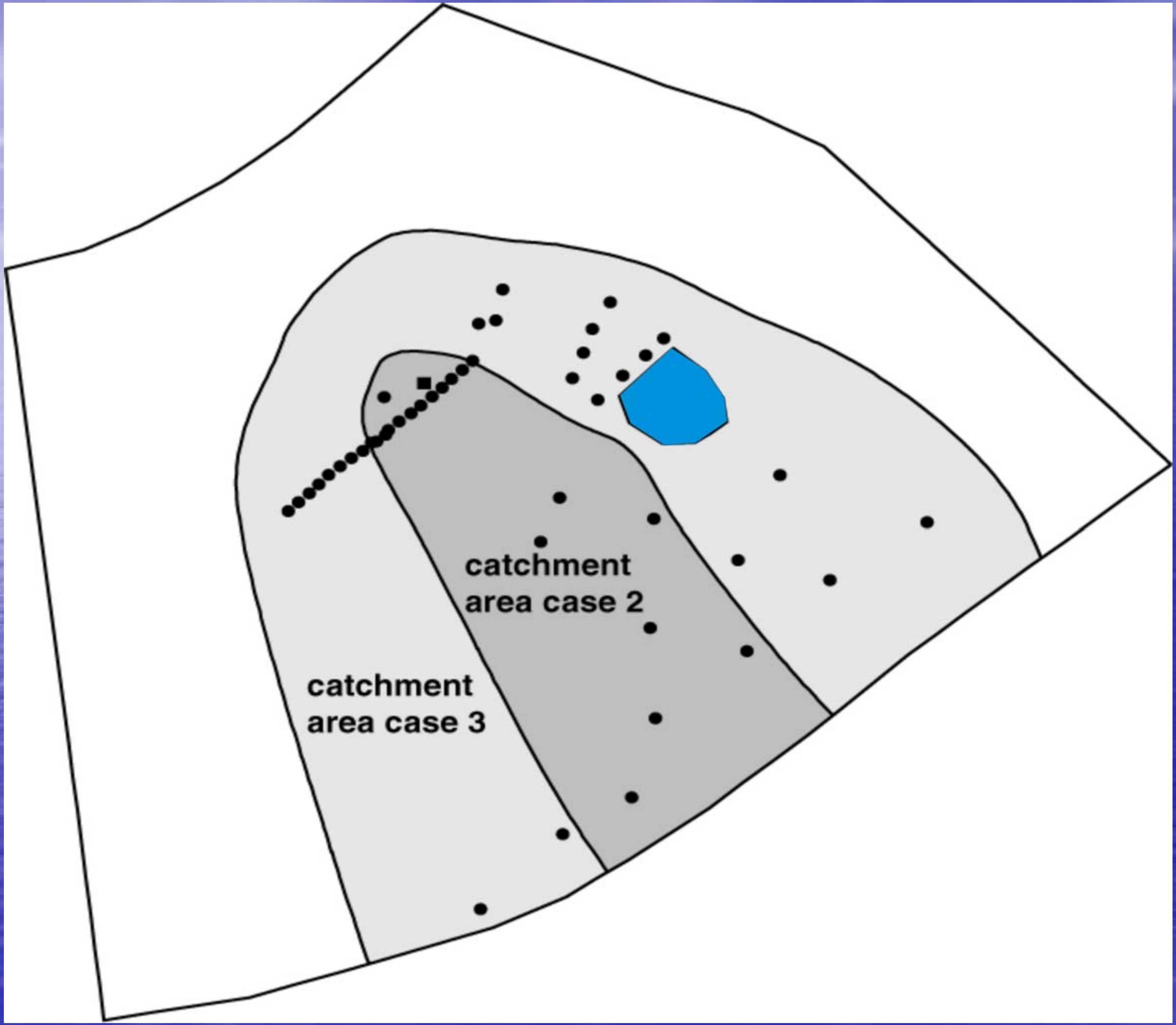


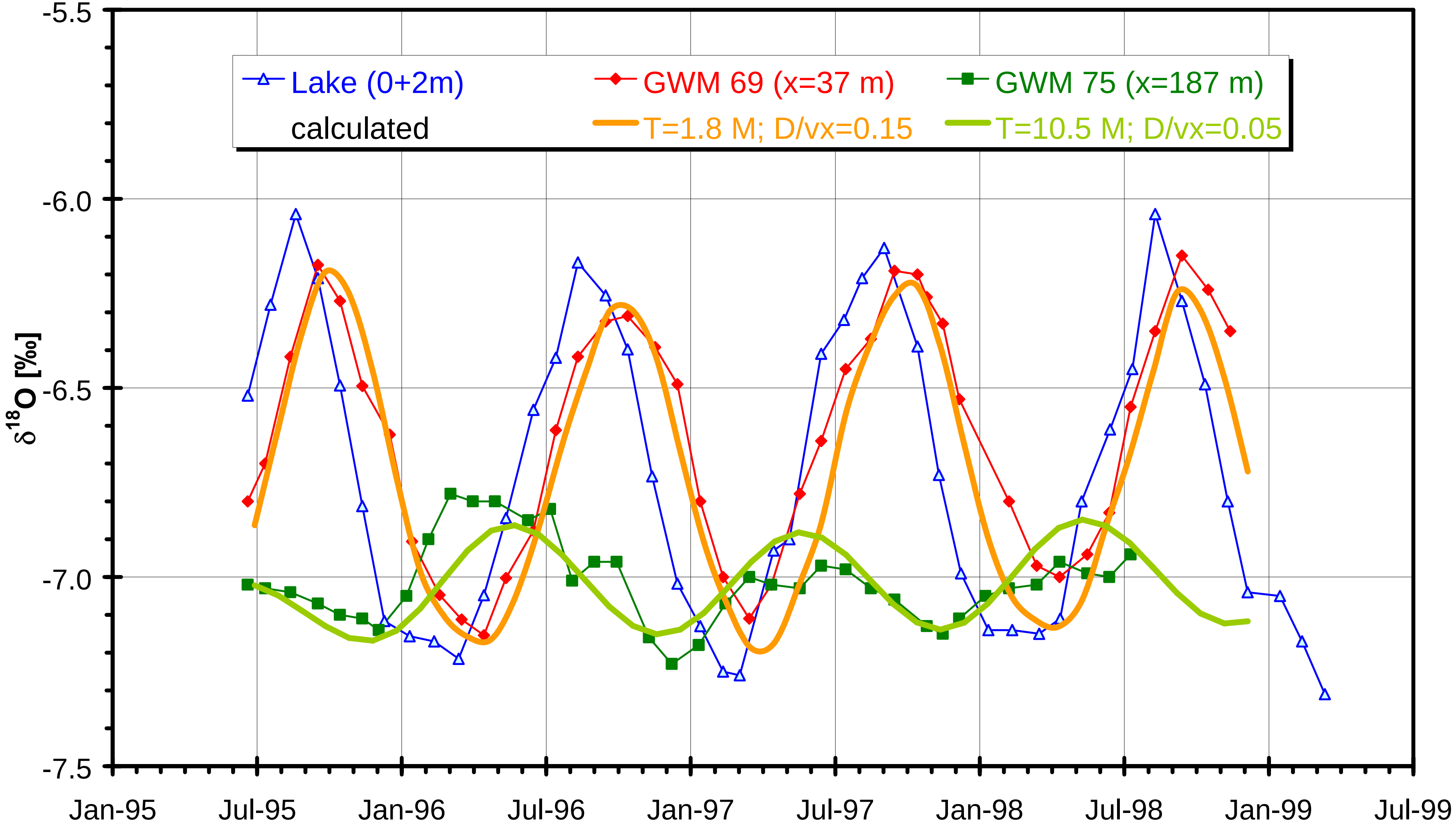
Location Map
VF Wells
HF Well
Single Tubes
-6
-7
-8
-9
10
6
2
δ18O [‰]
Excess [‰]
VF Wells
HF Well
VF Wells
HF Well
-800
-600
-400
-200
0
200 [m]



Location Map
VF Wells
HF Well
Single Tubes
80
40
0
% - Lake water
VF Wells
HF Well
-800
-600
-400
-200
0
200
Distance from HFW [m]


constant-head-boundary
Outflux
no-flow-boundary
constant-
head-
boundary
no-
flow-
boundary
Influx


catchment
area case 2
catchment
area case 3



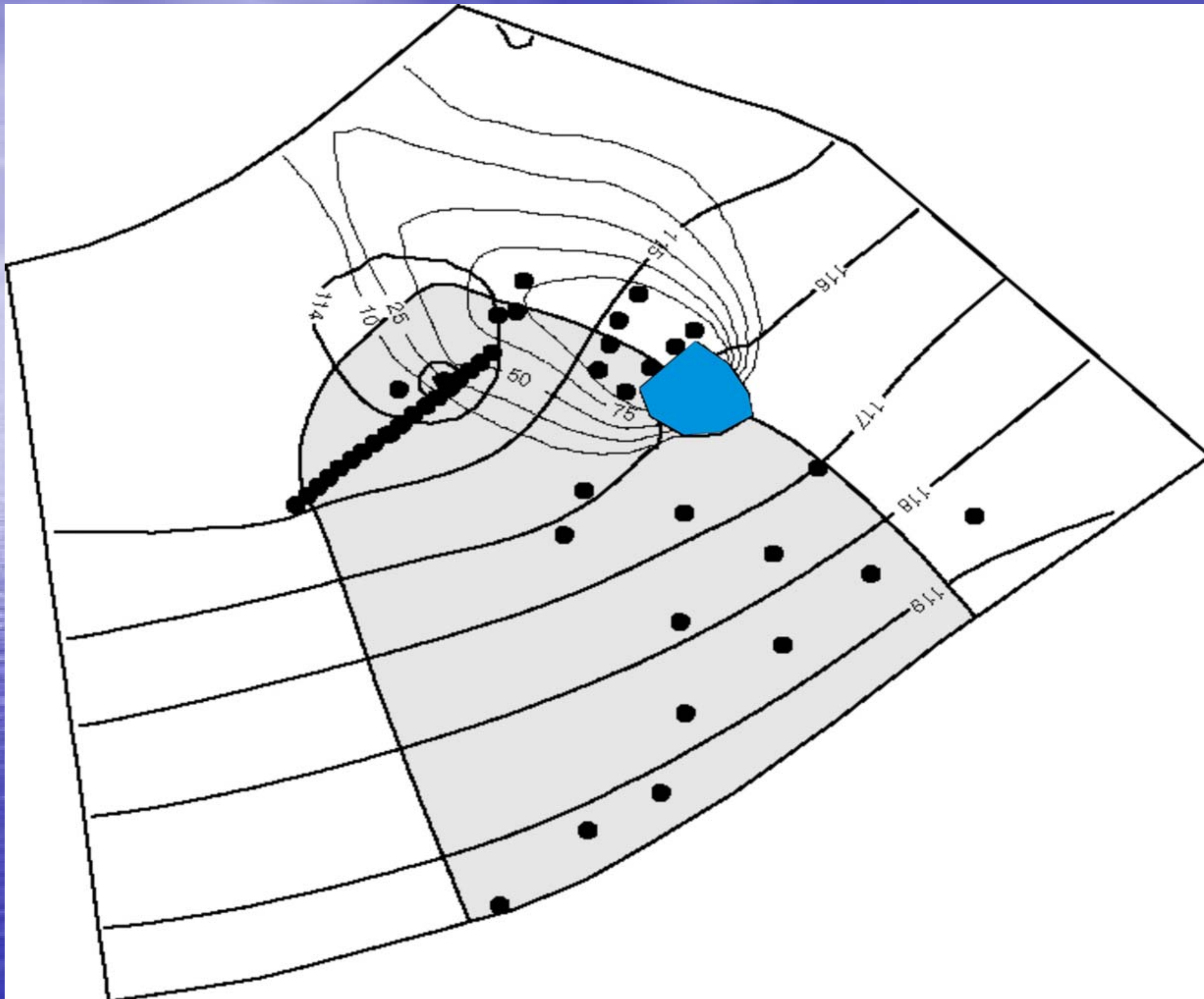
Lake (0+2m)
GWM 69 (x=37 m)
GWM 75 (x=187 m)
calculated
T=1.8 M; D/vx=0.15
T=10.5 M; D/vx=0.05
δ18O [‰]
-5.5
-6.0
-6.5
-7.0
-7.5
Jan-95
Jul-95
Jan-96
Jul-96
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99

MEAN δ^{18}O-VALUES OF WATER SAMPLES AND VALUES OF MODEL PARAMETERS OBTAINED BY CALIBRATION OF A TWO-DIMENSIONAL ANALYTICAL DISPERSION MODEL USING THE ISOTOPE DATA

Sampling point	Distance from the lake	Mean isotope content	Portion of lake water	Mean transit time of water	Dispersion parameter
-	x (m)	δ^{18}O (‰)	p (%)	T (d)	P_D (-)
Ground water	-	- 8.22	0	-	-
Lake water	0	- 6.59	100	0	0
P 69	37	- 6.63	98	37 ± 3	0.15 ± 0.02
P 70	46	- 7.22	60	n.d.	n.d.
P 71	34	- 6.63	98	42 ± 4	0.18 ± 0.02
P 72	47	- 6.57	100	70 ± 4	0.20 ± 0.02
P 73	258	- 6.84	90	330 ± 30	0.05 ± 0.01
P 74	237	- 6.73	99	360 ± 30	0.10 ± 0.03
P 75	187	- 7.00	85	300 ± 30	0.05 ± 0.01
P 76	141	- 7.08	80	300 ± 30	0.10 ± 0.03

MEAN VALUES OF HYDRAULIC PARAMETERS CALCULATED FOR THE FLOW DISTANCE BETWEEN LAKE BANK AND OBSERVATION WELLS

Sampling point	Distance from the lake	Mean ground water velocity	Longitudinal dispersivity	Mean hydraulic conductivity
-	*x* (m)	*v* (m/d)	α_L (m)	*k* (m/s)
P 69	37	1.00 ± 0.10	5.5 ± 0.5	$7.2 \pm 0.7 \cdot 10^{-4}$
P 71	34	0.81 ± 0.08	6.1 ± 0.6	$5.9 \pm 0.6 \cdot 10^{-4}$
P 72	47	0.67 ± 0.05	9.4 ± 0.9	$4.8 \pm 0.5 \cdot 10^{-4}$
P 73	258	0.78 ± 0.08	12.9 ± 2.5	$5.7 \pm 0.5 \cdot 10^{-4}$
P 74	237	0.66 ± 0.06	23.7 ± 7.7	$4.8 \pm 0.4 \cdot 10^{-4}$
P 75	187	0.62 ± 0.10	9.4 ± 1.8	$4.5 \pm 0.7 \cdot 10^{-4}$
P 76	141	0.67 ± 0.07	14.1 ± 4.2	$4.8 \pm 0.5 \cdot 10^{-4}$



114
10
25
50
75
115
116
117
118
119

Conclusions:

- The results of isotope studies facilitate the description of lake - ground water interaction in a qualitative and quantitative way.
- The quantification of lake water portions in the surrounding aquifer is also basis for the evaluation of possible changes in ground water quality.
- The use of isotope data reduces parameter uncertainty in numerical ground water modelling on a local scale.
- The combination of isotope and modelling techniques provides the unique possibility for the delineation of a ground water protection area.

Thank you for your attention