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Overview and experiences of the Swiss soil monitoring network over 25 years - Focus on forest soils -

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NABO
Nationale Bodenbeobachtung
Observatoire national des sols
Osservatorio nazionale dei suoli
Swiss Soil Monitoring Network

www.nabo.admin.ch

Acknowledgements

Swiss soil monitoring network

Current collaborators:	Former collaborators:
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Stefan Ammann (7)	Hans Vogel (5)
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Armin Keller (5)	Konrad Studer (10)
Reto Meuli (1)	Thomas Keller (6)
	Hans Brunner (6)
	Nicolas Rossier (2)

(7) = years of activity

The acknowledgements reveal that soil monitoring is laborious and many persons and changes are involved. The major challenge in long-term soil monitoring is thus to cope with changes of relevant boundary conditions as persons but also methodologies and site conditions.

Outline

- The Swiss soil monitoring network (NABO)
- Results and findings:
  - Inorganic pollutants: three sampling campaigns
  - Organic pollutants: status study
- Lessons learnt
- Basic challenges of soil monitoring
- References

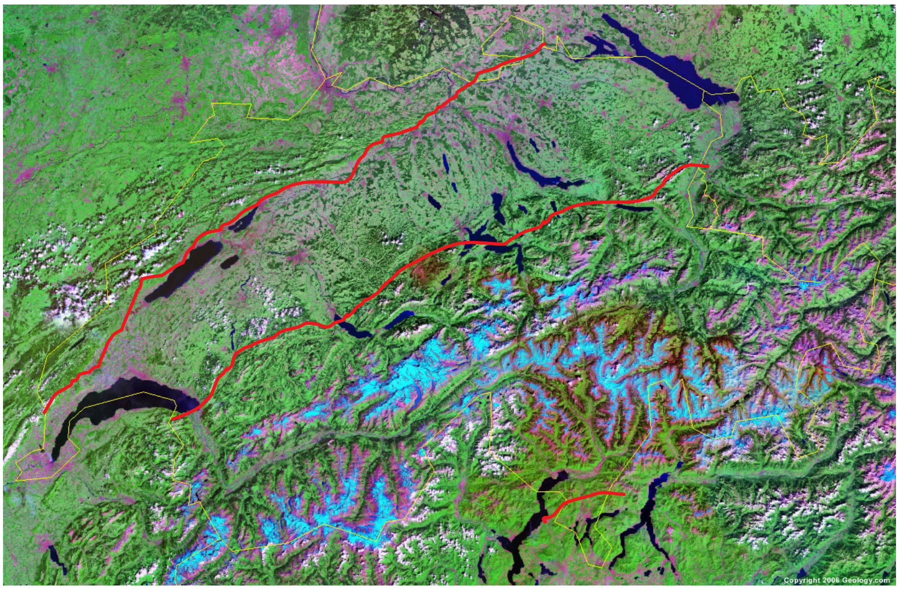
Objectives and mandate

Monitoring and assessment of the countrywide status and long-term trend of impacts on soils in Switzerland.

Federal law of 7 October 1983 relating to the protection of the environment (art. 44)

Ordinance of 1 July 1998 relating to impacts on the soil (art. 3)

Switzerland (1) : Satelite photo



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The major landscapes and settlement areas from N to S:

Jura (tabular and folded Jura): approx. 2‘000 to 5‘200 ft

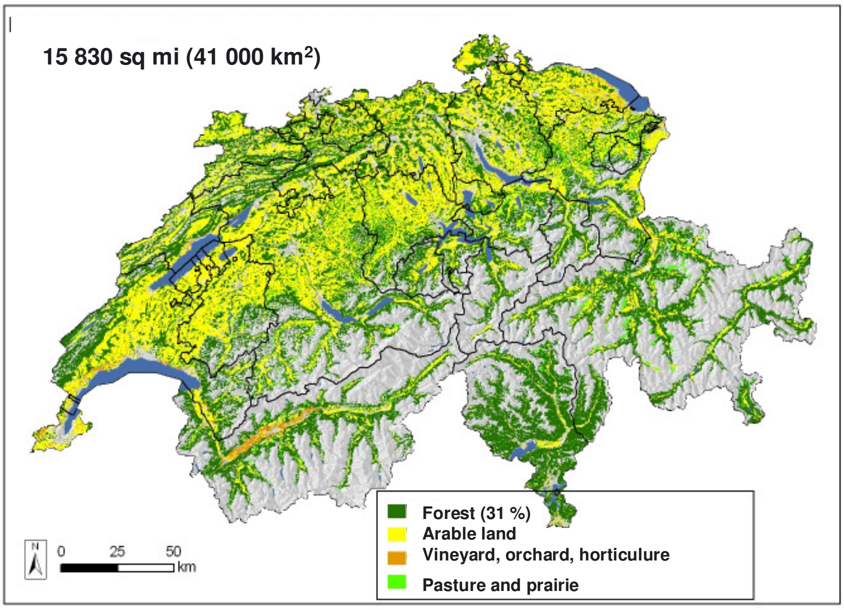
Plateau (lower and upper plateau): 950 to 3‘000 ft

Alps (northern prealps, central alps and southern alps): 4‘000 to 14‘000 ft

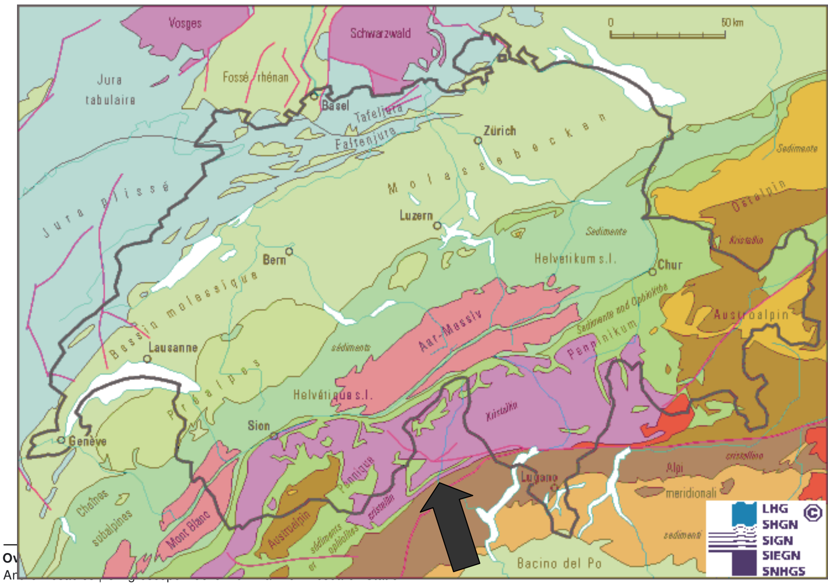
Southern Ticino: 800 to 2‘700 ft

Settlement concentrations (dark pink areas at lower elevations): Basel, Geneva, Lausanne, Bern, Zurich, Lugano,

Switzerland (2) : Land use



Switzerland (3) : Geology



Arrow: direction of tectonic movement (S to N)

Pink: cristalline basement outcrops (Central alps, Black forest/Vosges)

Yellow and brownish: nappes of cristalline and southern alpine sediments

Light green and blue: northern alpine and jurassic lime stones and marls

Bright brown: alpine sediment basins

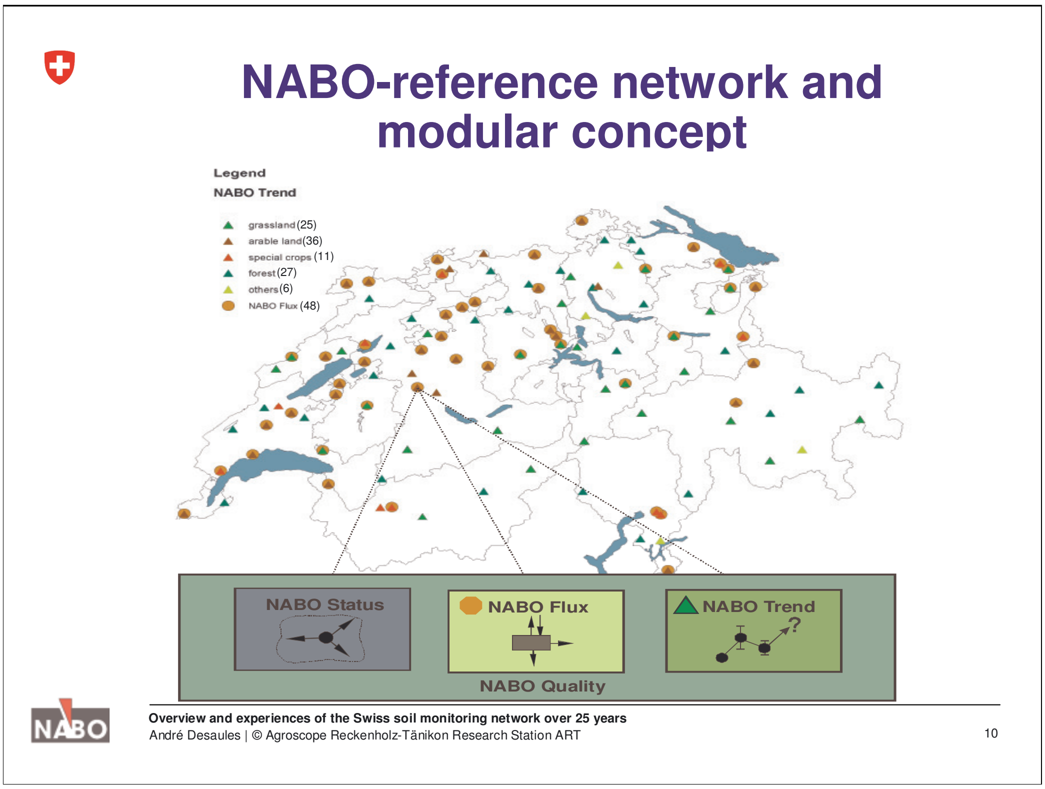
Switzerland (4): Basic data

- Surface area: 15 830 sq mi (41 000 km^2): unproductive 25%, forested 31%, agriculture 37%, settled 7%)
- Elevation: min. 640 ft to max. 15 210 ft
  - Jura: 2 000 to 5 200 ft
  - Plateau: 950 to 3 000 ft
  - Alps: 4 000 to 14 000 ft
  - Southern Ticino: 800 to 2 700 ft
- Annual temperature: approx. 27 to 52°F (mean 42°F)
- Annual precipitation: 24 to 71 in (mean 43 in)
- Population: 7.6 millions (480 pers/sq mi)

NABO reference network characteristics

- Up to 105 long-term observation sites of all relevant land-use types
- The current periodicity of sampling campaigns is 5 years: 1985/89, 1990/94, 1995/99, [2000/04, 2005/09]
- Soil pollutants:
  Inorganics: Cd, Zn, Pb, Cu, Hg, Ni, Cr, Co (2M HNO_3) and F
  Organics: PAH, PCB, [PCDD/F]

The work for the Swiss soil monitoring network started in August 1984 and is still continuing after almost 25 years and several administrative restructurations. Results will be presented of the first three sampling campaigns. Currently the 5th sampling campaign is running.



The NABO reference network comprises currently 105 long-term monitoring sites of all characteristic land use types:

Forests: 27 (deciduous 12, coniferous 15)

Conservation sites: 4

Grassland: 25

Arable: 36

Special crops: 11

Urban parks: 2

At 48 agricultural sites fluxes of pollutants are recorded additionally.

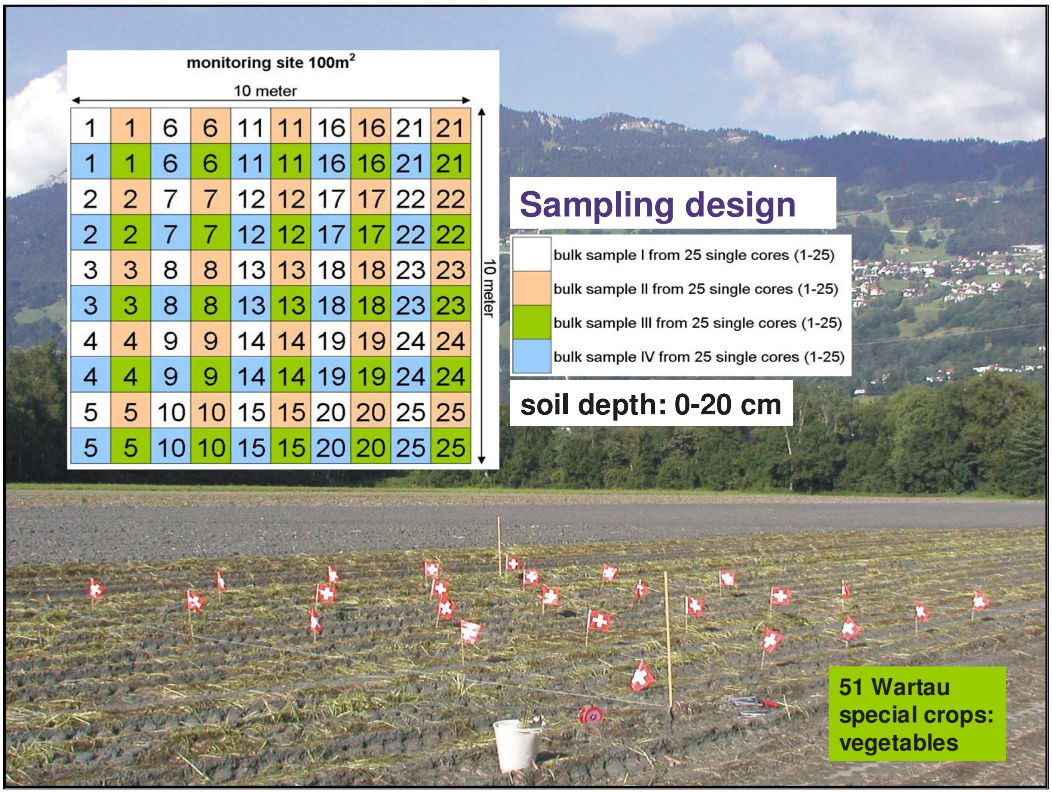
The conceptual framework consists of 4 modules:

•**NABO-Quality** is the foundation of reliability of the results and their interpretation.

-**NABO-Status** records soil pollution levels and assesses them over space.

-**NABO-Flux** records pollutant fluxes as indicators for soil pollution forecasts (indirect monitoring).

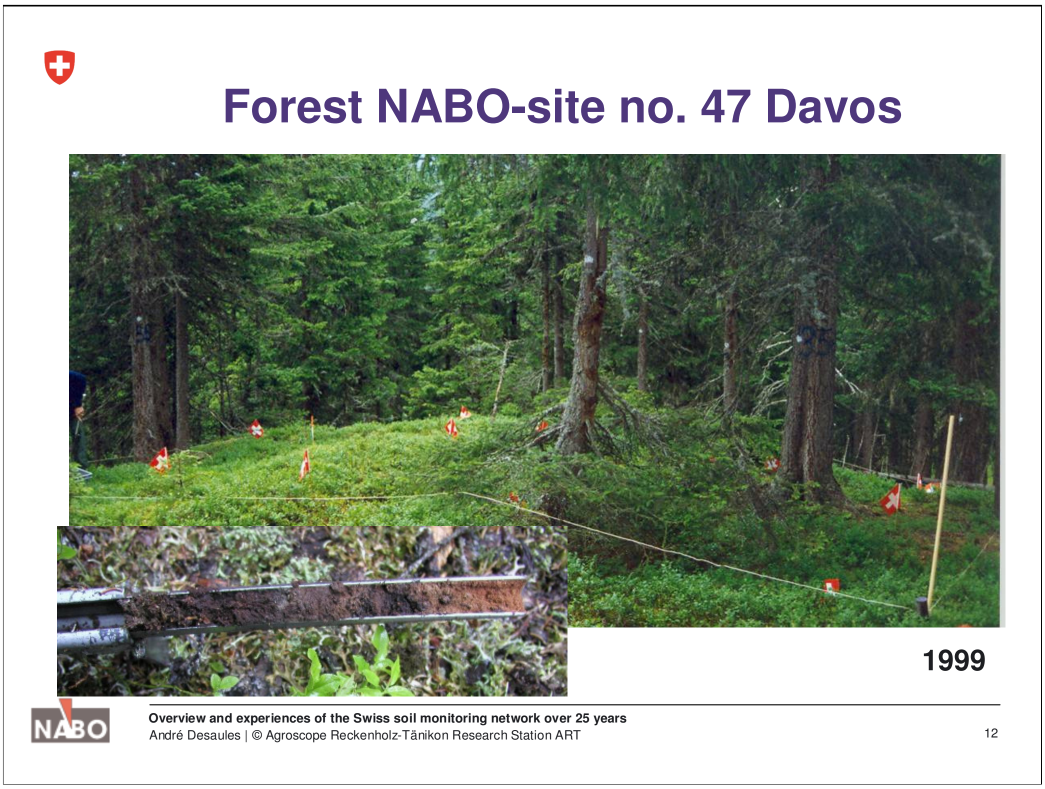
-**NABO-Trend** measures and assesses changes of soil pollution over time (direct monitoring) and is the focus of this presentation.



Special crop NABO-site no 51 Wartau (inner alpine Rhine valley 1 500 ft)

The sampling design and support consists of 4 parallel stratified composite samples of 25 increments each from a sampling site of 10 by 10 m.

The reference sampling depth is 20 cm from the surface.



Site: central alps 5 430 ft (less than 1 mi from the Davos World Economic Forum)

Sampling auger: diameter 1.18 in, organic-mineral soil core 7.87 (20 cm)

NABO-site no. 58 Mels

1988 (1)

1993 (2)

‚Vivian' storm
Feb. 1990

Site: Northern prealps 3 000 ft

Windthrow: The only one out of 27 forest sites which was affected.

NABO-site no. 42 Galmwald

1987 (1)

‚Lothar'
storm
Dec. 1999

2003 (4)

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Site: Plateau 1 900 ft

Windthrow: 3 out of 27 forest sites were affected.

Inorganic pollutants:
Three sampling campaigns 1985-1999

Frequent concentration levels and guide values (depth 0-20 cm, n = 102)

Element	Guide value*	Frequent conc. (10-90th perc.)	Guide value exceedance
	[mg/kg]	[mg/kg]	[n]
Cd	0.8	0.11-0.49	5
Zn	*200*	35-89	*0*
	150		0
Pb	50	16-38	6
Cu	*50*	6-35	*6*
	40		10
Hg	*0.8*	0.06-0.19	*0*
	0.5		0
Ni	50	6-40	5
Cr	50	13-38	1
Co	*25*	3-10	1
F	*400*	234-715	*57*
	700		13

* *VSBo 1986*, VBBo 1998

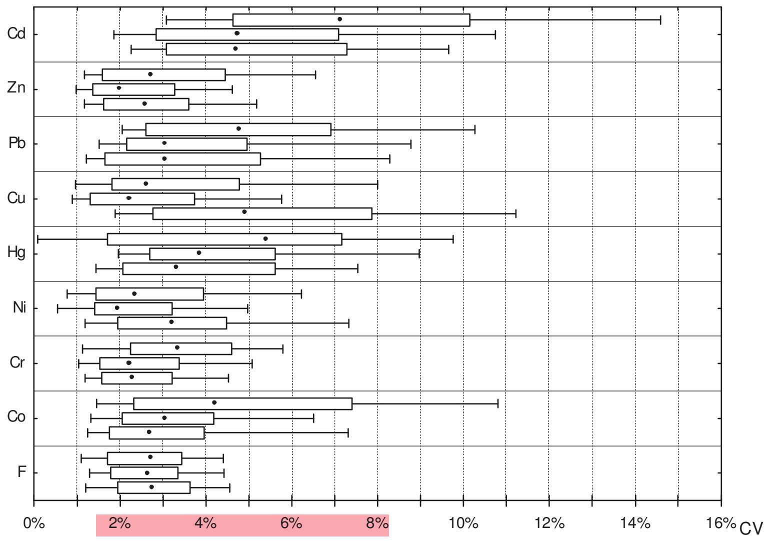
(Desaules et al.1993)

The frequent concentration levels of the 1st campaign (1985/89) are below the respective guide values - except for F.

The revision of the guide values in 1998 (normal characters) partly changed the number of exceeded guide values – especially for F.

The guide values are legally based soil quality benchmarks, considered as precautionary general upper limits of negligible risks.

Data Quality (1): Site precision (n = 4)

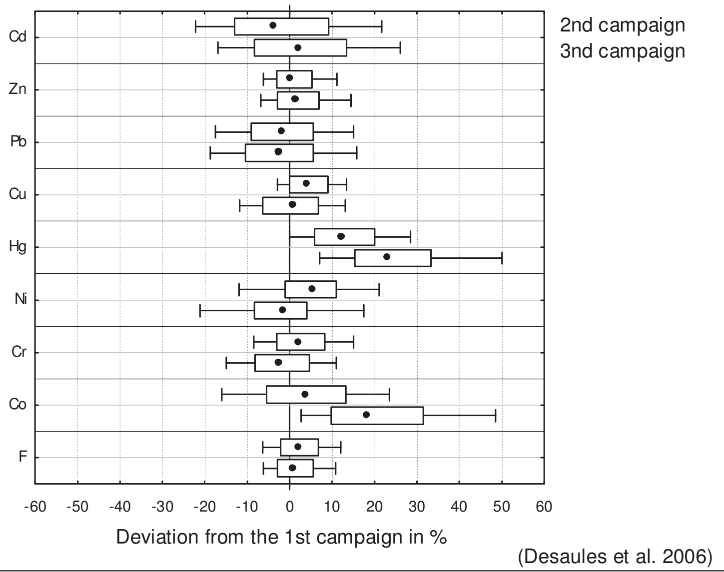


Measurement campaigns 1 to 3 from top to bottom (Desaules et al.2006)

Site precision def.: repeatability conditions for sampling, sample preparation and chemical analysis of 4 replicate composite soil samples

Note: Site precision varies with elements and **with time**!

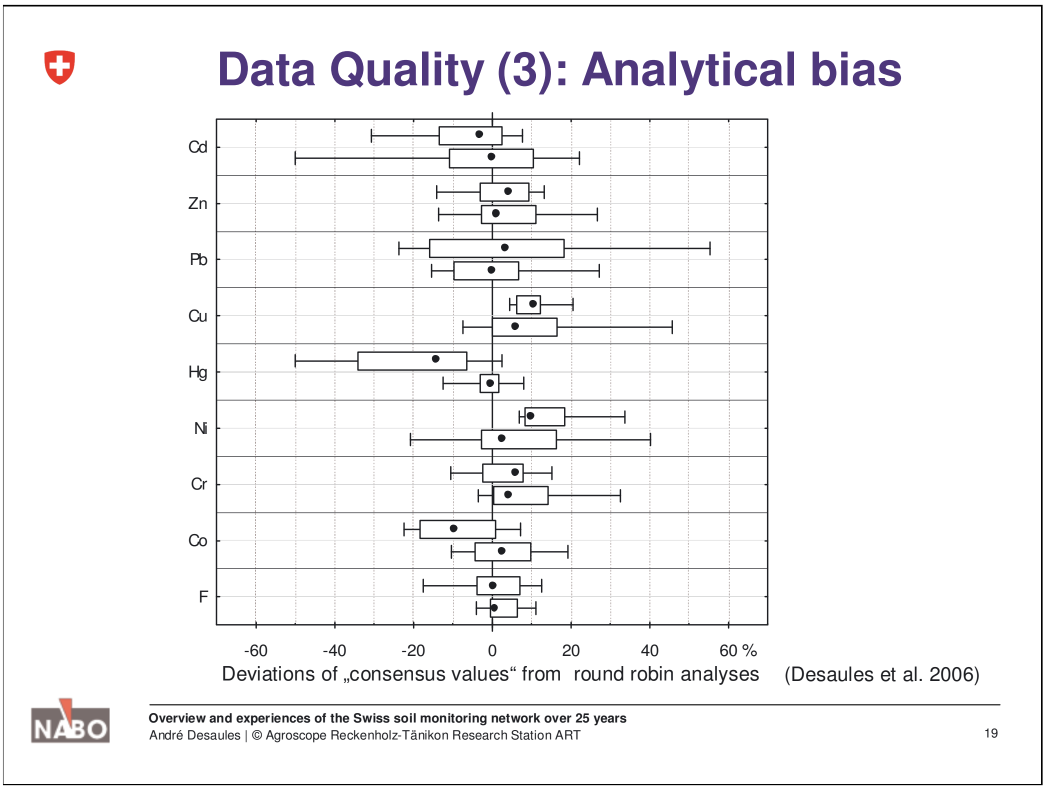
Data Quality (2): Analytical stability



(Desaules et al. 2006)

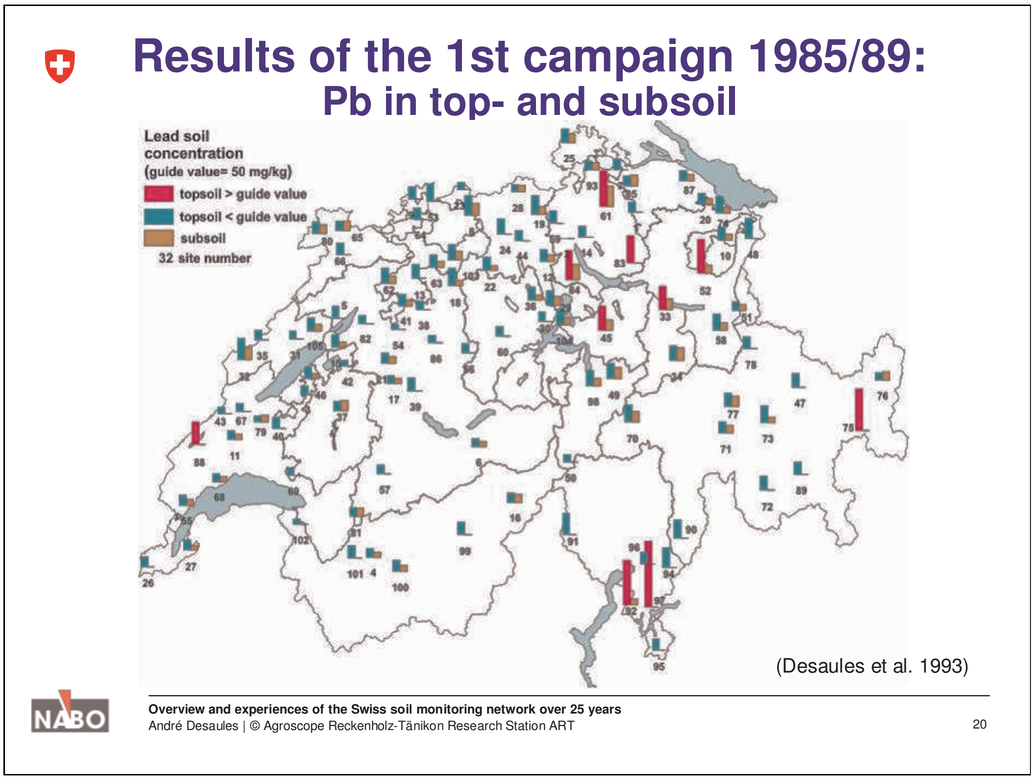
Analytical stability (chemical preparation and analysis of the same sample after 5 years) is just one component of measurement stability it excludes sampling and physical sample preparation stability

Note: There is always an inherent analytical variation in analytical stability which is generally not constant over time (see esp. Hg and Co).



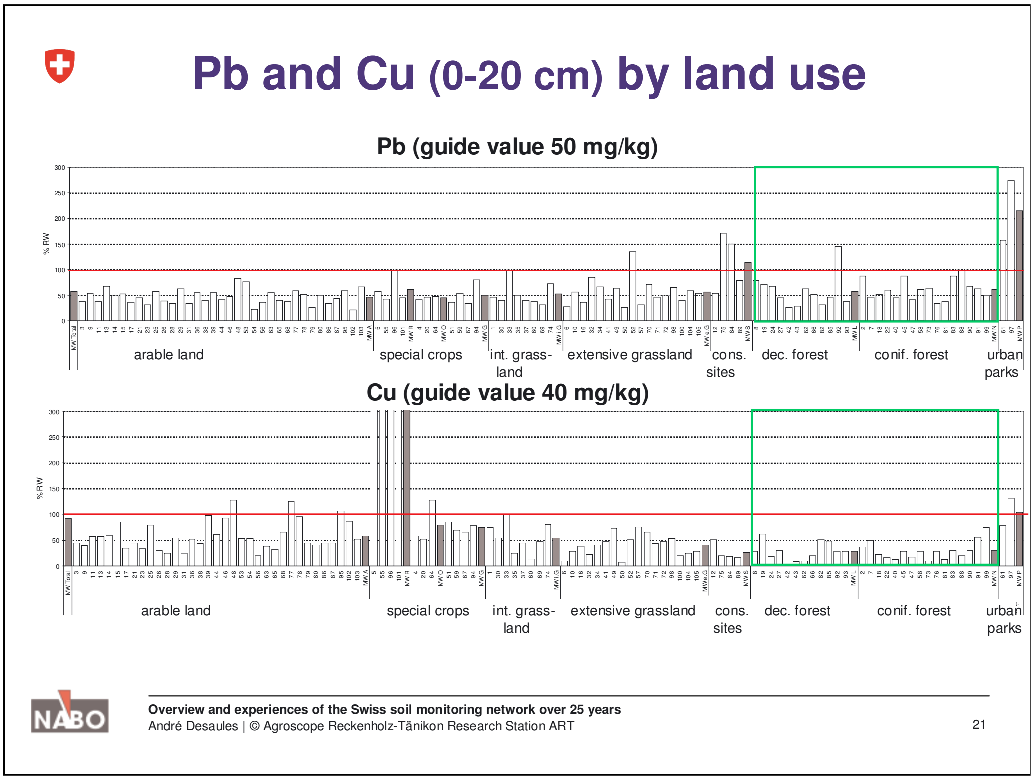
There is nothing like a constant analytical bias (systematic error) in chemical analysis as often believed and it may change over time.

The 3 presented slides of the quality parameters (site precision, analytical stability and analytical bias) give evidence of temporal fluctuations and the necessity of a continuous quantitative control of the data quality.



The topsoil levels of Pb exceed with few exceptions the subsoil levels, which usually indicates soil pollution. The figures with bars should prevent spatial extrapolation, but it appears that in the NE of Switzerland and S of the Alps exceeding guide values seem to be more frequent.

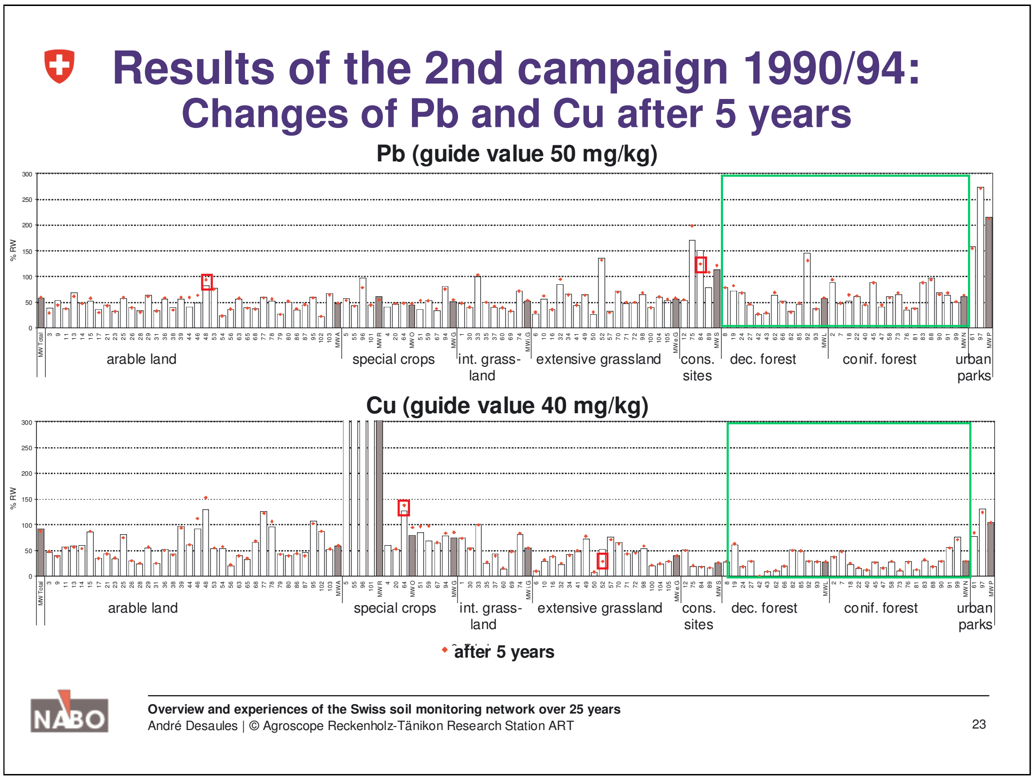
Note: for reasons of relative and ecotoxic comparability the further presented concentrations and their changes are normalized in percent of the respective guide values set as 100 %.



The concentration levels of Pb and Cu for all sites reveal that the variablity within land use type (white bars) generally exceeds variability between land use types (grey bars) and puts the common classification by land use into question. Striking exceptions are the high Cu levels of the 4 vineyard sites (223-860 mg/kg) and to some extent the Pb concentrations in the two urban parks. **Forest sites show generally greater variations but similar Pb concentrations and a tendency of lower Cu concentrations**

Findings from the 1st campaign 1985/89

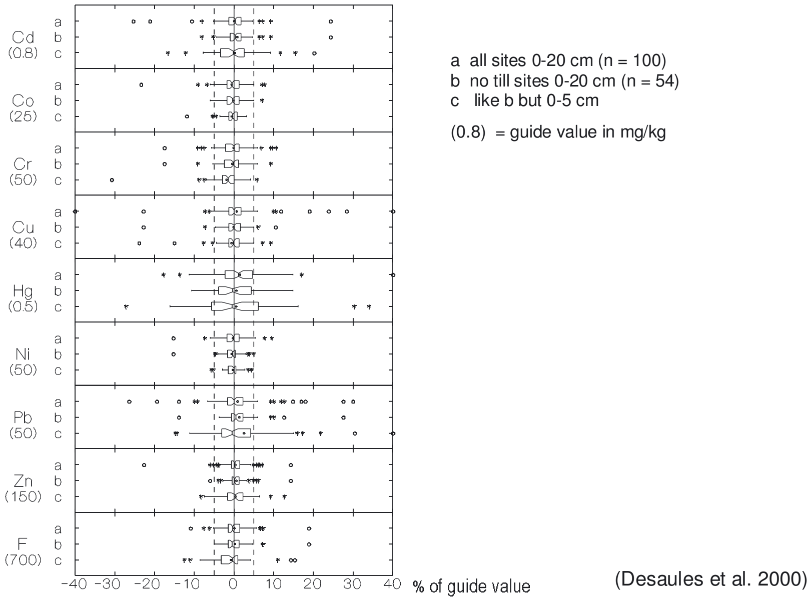
- All soils of Switzerland – even in remote areas – are to some extent polluted but the level is generally low.
- The rank order of general soil pollution relative to the guide values is Pb > Cu > Cd for the 9 investigated elements.
- The guide values are often exceeded for F > Ni > Cr but also for Cd due to natural causes as parent material concentrations.
- Except for Cu in vineyards land use is not a reliable indicator for soil pollution.



The concentration changes of Pb and Cu after 5 years (red symbols) show, that positive as well as negative changes occur which are sometimes significant. However, the mean changes (grey bars) are hardly significant.

No clear differences of changes are apperent on forest sites.

Changes for all elements after 5 years



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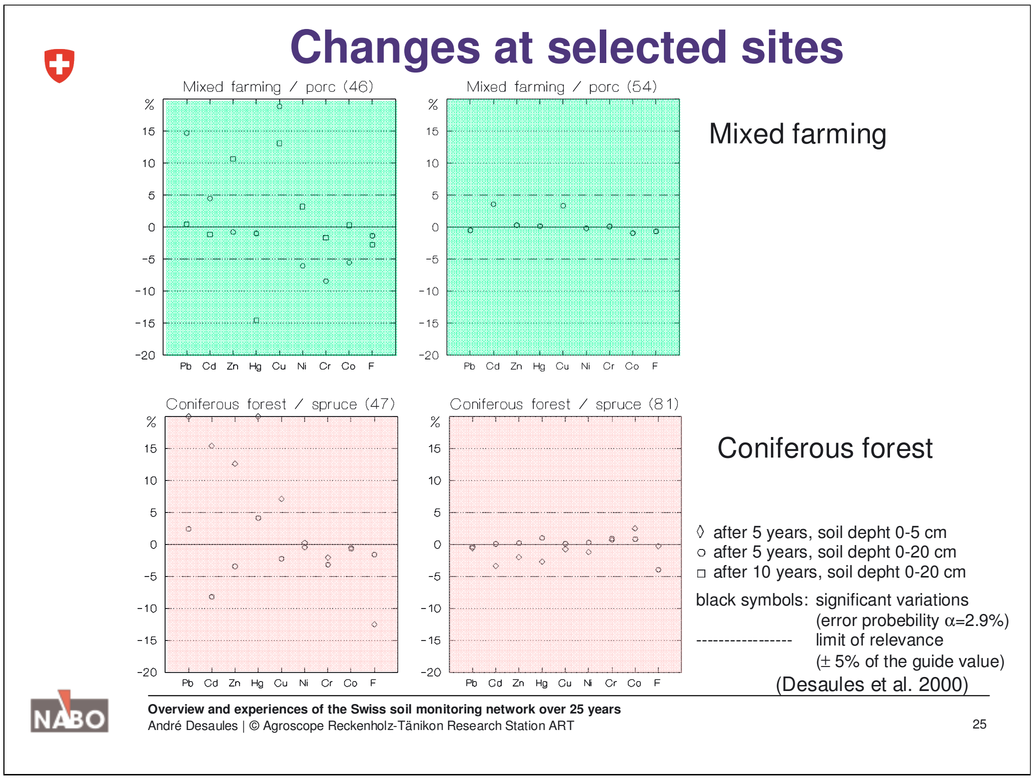
a) For all sites 0-20 cm: The changes are mostly below 5% of the respective guide values and quite symmetric.

b) For no till sites 0-20 cm: No greater changes due to no tillage could be observed.

c) For No till sites **0-5 cm**: No greater positive changes due to less dilution effect of inputs could be observed either. Hypothesis: **Sampling at shallow soil depth is not robust.**

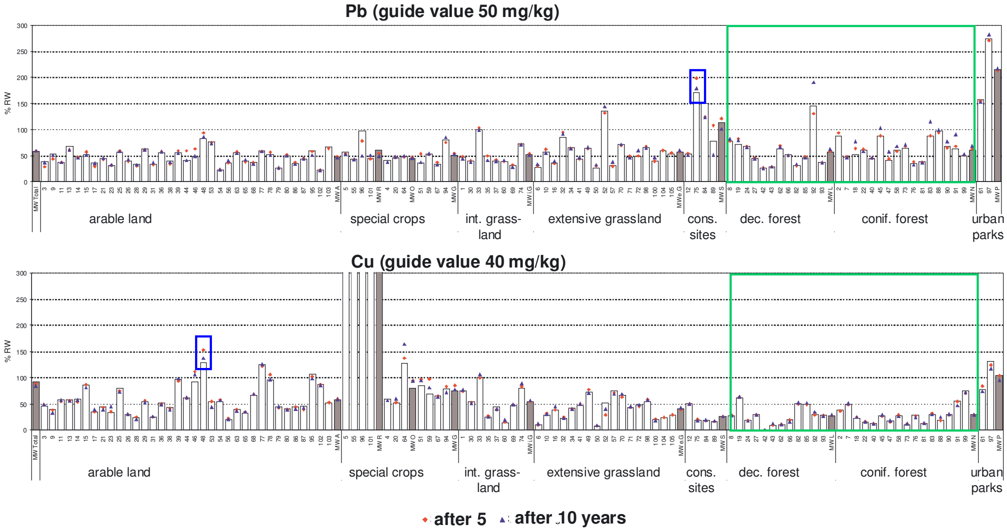


Quite different patterns of changes for all 9 investigated elements can be observed for the same types of land use. This is an indication that further factors influence soil concentration changes.

Findings from the 2nd campaign 1990/94

- The changes were as well positive as negative.
- After 5 years the majority of the sites (87 %) showed already at least one significant change for one of the 9 investigated elements.
- The changes are therefore not only a result of inputs. There must be other causes.

Results of the 3rd campaign 1995/99:
Changes of Pb and Cu after 5 and 10 years



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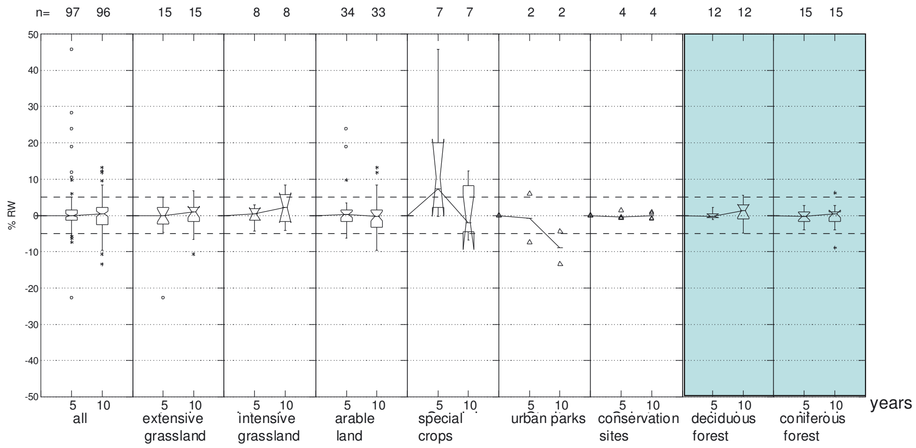
The changes after 10 years (blue symbols) are not always greater than after 5 years (red symbols) as expected. To analyse this, the bar figures are no more appropriate.

Changes of Cu concentrations after 5 and 10 years by land use

Cu guide value (RW) = 40 mg/kg



(Desaules et al. 2006)

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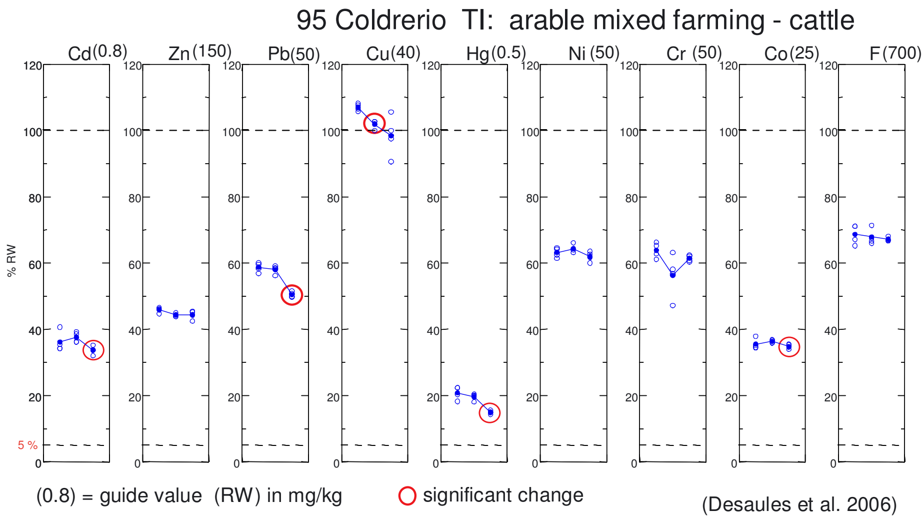
•At first sight the important zigzag changes with a great variability for Cu under special crops (4 vineyards) are striking. The reasons must be closer investigated (sampling, deep tillage, stage migration)

•Note further the general mean tendency of increase under grassland and deciduous forest. For the intensive grassland the reason is mainly attributed to Cu additives in the fodder for porcs.

•For all sites the Cu changes almost neutralise themselves. Sense to express mean changes?

No clear differences of Cu changes are apperent on forest sites

Changes at an arable site after 5 and 10 years



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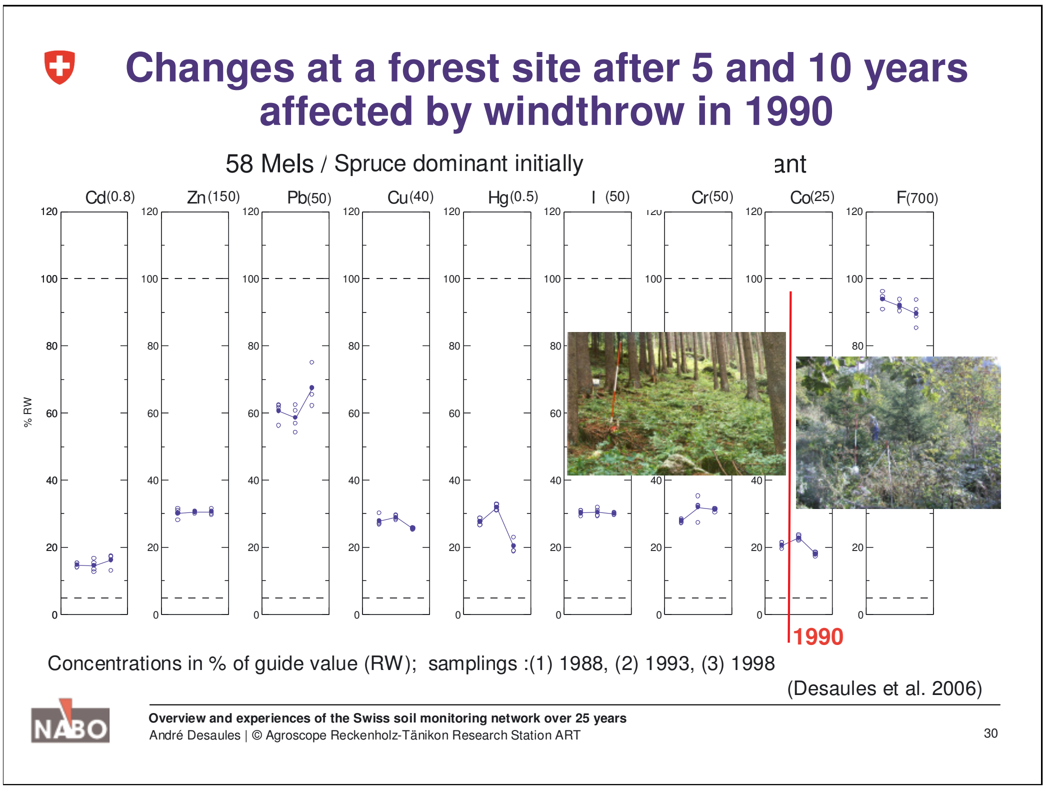
The overview of changes for all 9 investigated elements at one site gives an example of their different levels relative to the guide values (e.g. Cu and Hg) and their different evolutions of change.

Zigzag evolutions are common as it is characteristic for environmental time series (e.g. global temperature).

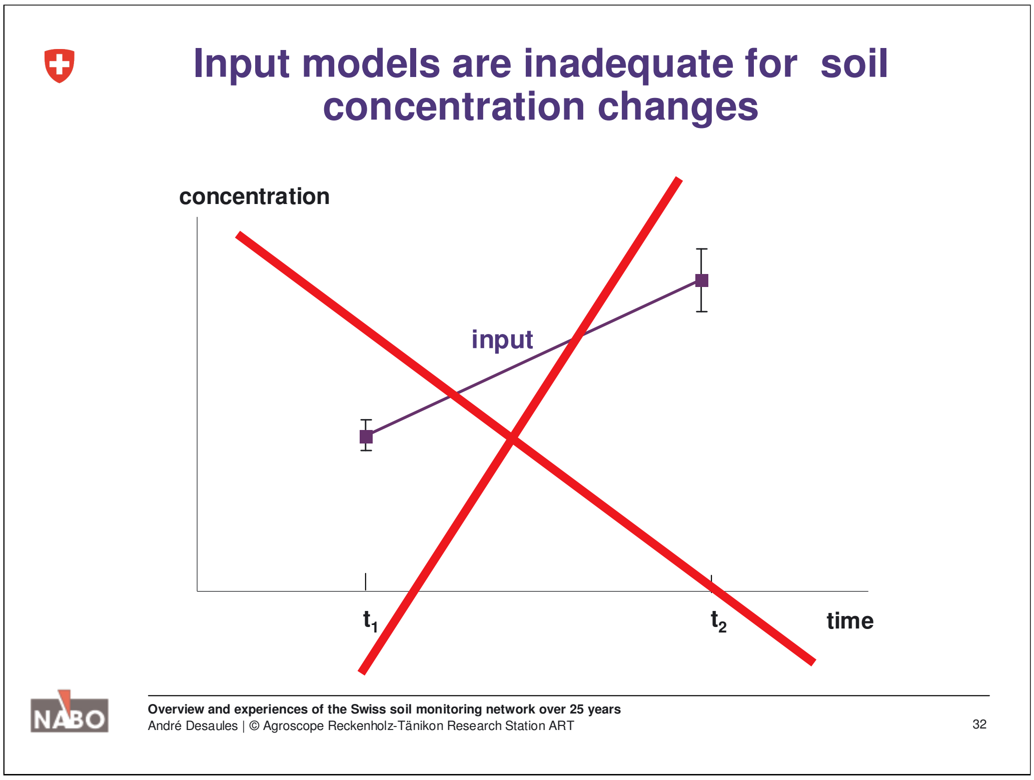
Only 5 changes were significant and/or relevant (>5% of guide value) which are indicated by red circles.



Surprisingly no effect of windthrow was observed.

Findings from the 3rd campaign 1995/99

- Zigzag evolutions of changes are common.
- Therefore trend statements after 3 campaigns in 10 years are not yet possible.
- The dynamics of changes can vary with time.
- The causes of measured changes are complex (real and artefacts).
- Varying site numbers (n) influence mean changes (Will Rogers phenomenon or stage migration).



View to the frequently measured zigzag evolutions, (black box) input models are inadequate for soil monitoring.

Organic pollutants:
Status study

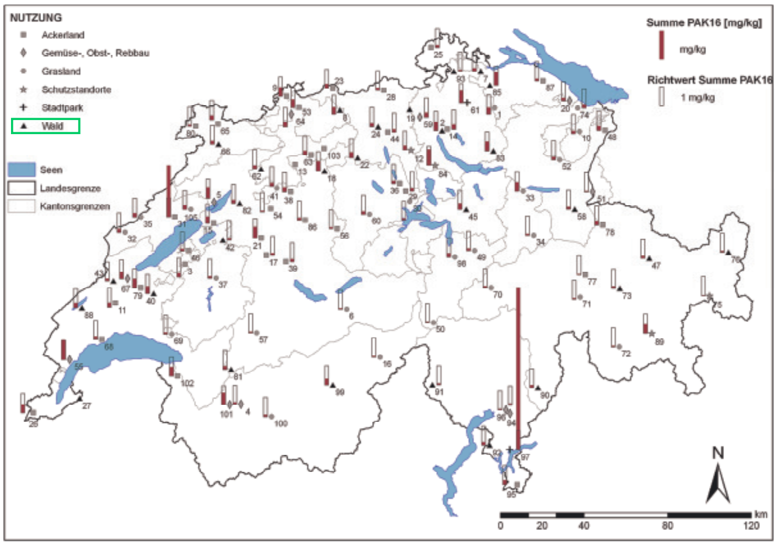
Data Quality:
Estimation of the analytical and measurement uncertainty

Compound		Concentrations	Analytical uncertainty (AU)	Measurement uncertainty	
				Soil conditions:	
		(mg/kg)	(2 RSD)	similar (2 AU)	different (5 AU)
PAH_{16}	Minimum	0.032	±54 %	±108 %	±270 %
	10. Perzentil	0.072	±48 %	±96 %	±240 %
	Median	0.163	±44 %	±88 %	±220 %
	Richtwert[2]	*1*	±41 %	±82 %	±205 %
	Maximum	8.46	±37 %	±74 %	±185 %
BaP	Minimum	0.0005	±100 %	±200 %	±500 %
	10. Perzentil	0.003	±77 %	±154 %	±385 %
	Median	0.013	±45 %	±90 %	±225 %
	Richtwert[2]	*0.02*	±37 %	±74 %	±185 %
	Maximum	1.13	±33 %	±66 %	±165 %
PCB_7	Minimum	0.005	±100 %	±200 %	±500 %
	10. Perzentil	0.008	±94 %	±188 %	±470 %
	Median	0.0016	±48 %	±96 %	±240 %
	Maximum	0.012	±46 %	±92 %	±230 %

The extended analytical uncertainty (p = approx. 95%) is much concentration dependent and reaches partly 100% at the minimum concentrations.

Since no data for the whole measurement process including sampling are available, its estimate is based here on the analytical uncertainty and soil conditions as an estimate of the sample materialisation error.

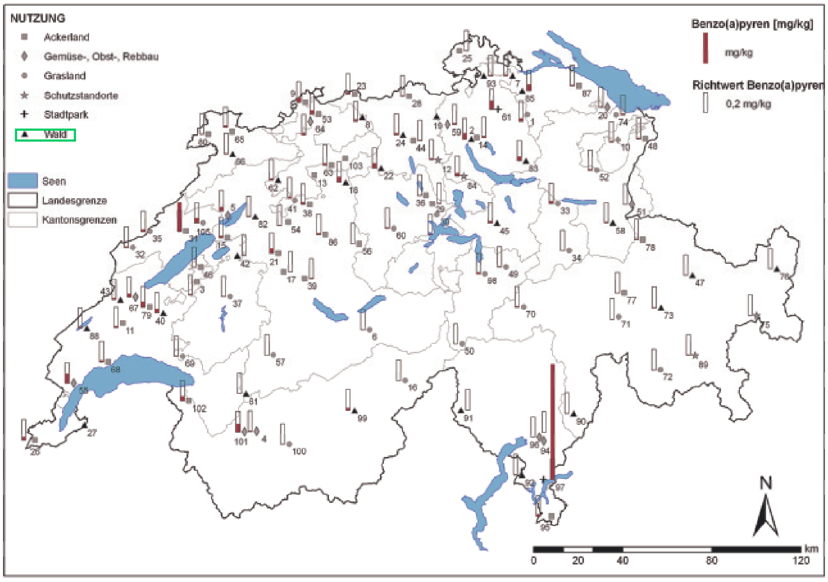
PAH-concentrations (top 20 cm)



(Desaules et al. 2008)

PAH16 concentrations only twice exceed the respectivew guide value of 1 mg/kg. There is a tendency of higher levels under forests and settlement areas

BaP-concentrations (top 20 cm)



(Desaules et al. 2008)

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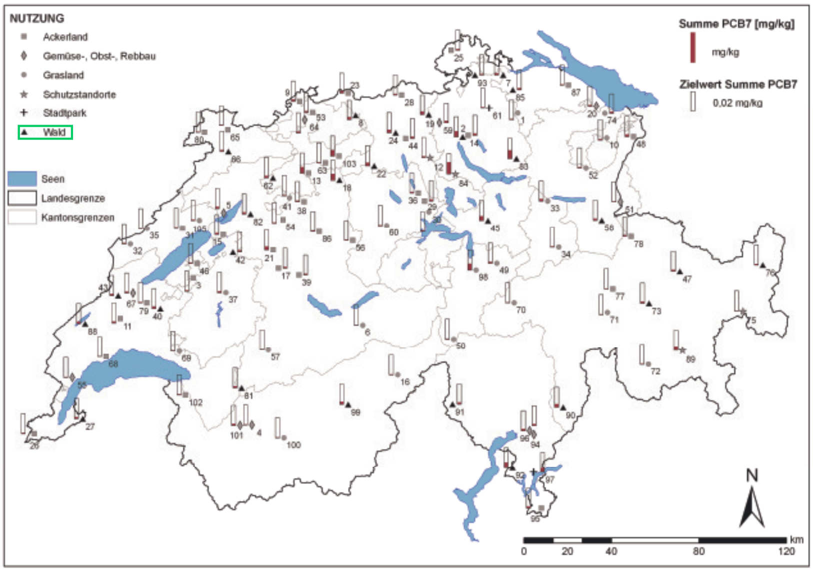
The same holds for benzo(a)pyrene

PCB-concentrations (top 20 cm)



(Desaules et al. 2008)

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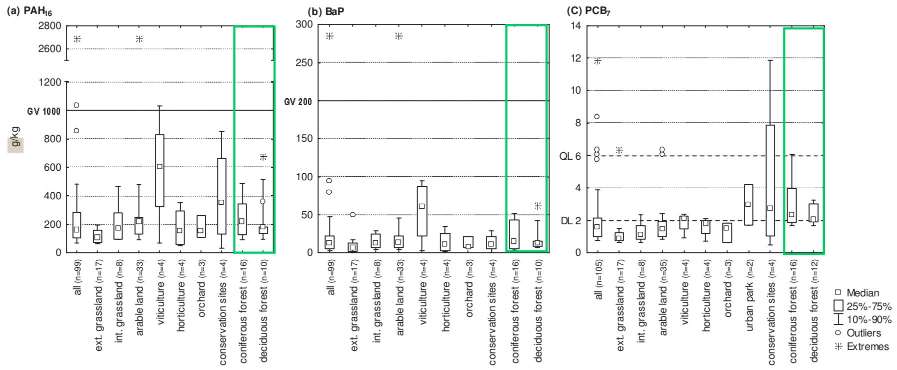
The measured PCB7-concentrations are all much below the quality benchmark of 0.02 mg/kg. Again a slight tendency to higher values under forest are observed which may, however, be attributed to the lower bulk density of forest topsoils.

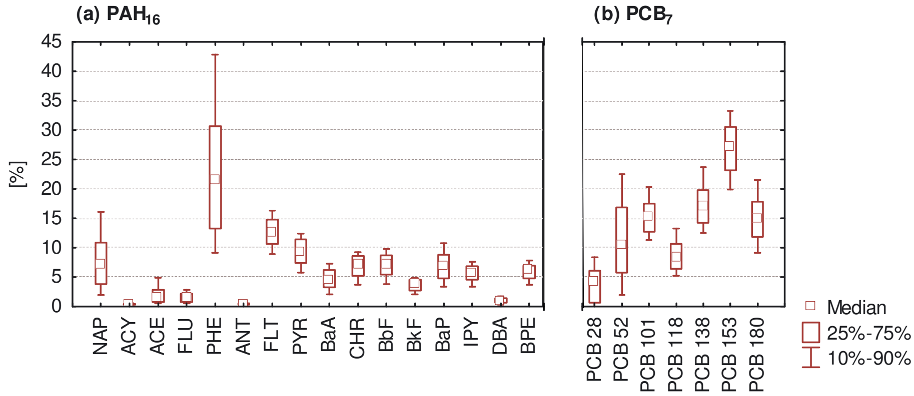
PAH- and PCB- concentrations by land use



(Desaules et al. 2008)

Compared to all sites and the bulk of other land use types the forest sites show no distinct differences. Only the PCB7 concentrations seem a little higher. And relative to deciduous forest, the concentrations are generally higher under coniferous forest.

PAH- und PCB-profiles



(Desaules et al. 2008)

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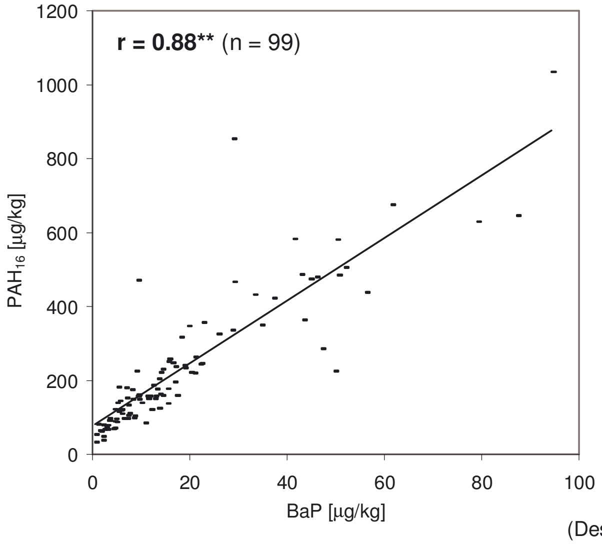
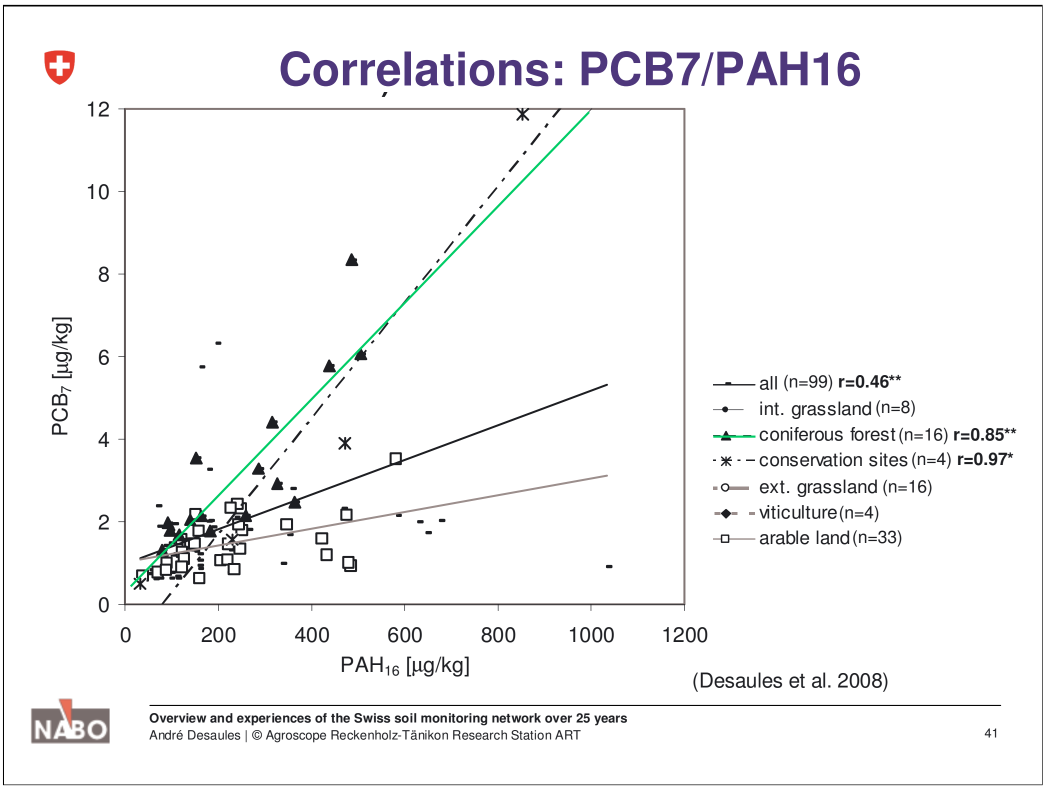
Over all sites the prevailing compounds are phenanthrene and PCB 135 with little variations between sites.

Correlations: PAH16/BaP



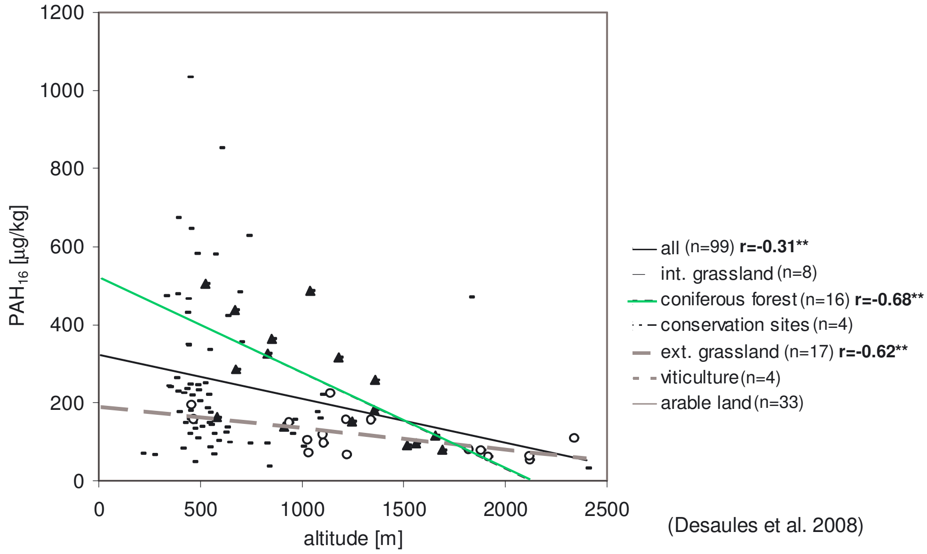
(Desaules et al. 2008)

BaP is a fairly good indicator for PAH16.



The correlation among PCB7 and PAH16 is promising on coniferous and perhaps conservations sites.

Correlations: PAH/altitude



(Desaules et al. 2008)

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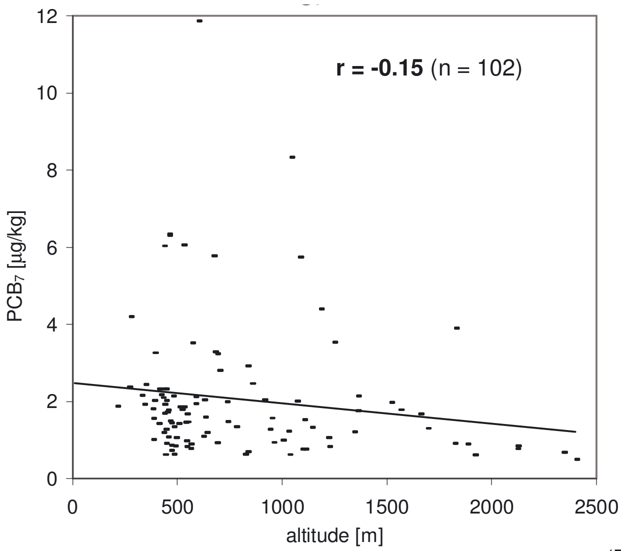
The positive correlation of PAH16 with increasing altitude found in literature could not be confirmed.

Correlations: PCB/altitude



(Desaules et al. 2008)

The situation is still worse for PCB7

Methodological comparability of the NABO-study with other studies

PAH-studies (1989-2008)

Studies	Congeners	Sample depth (cm)	Laboratory
1 NABO	16	20	ART
2	(16)	?	
3	7	0-6/6-12	
4	16	10	
5	16	5	
6	16	10	ART
7	14	8	
8	14	3-10	
9	27	5	
10	(16)	?	
11	16	3	
12	20	10	
13	21	A-horizon	
14	12	5/20	
15	18	5	
16	17	15.24	
17	16	10	
18	15	10	
19	6	10	
20	14	5	
Comparable:	**8/20**	**1/20**	**2/20**

PCB-studies (1994-2008)

Studies	Congeners	Sample depth (cm)	Laboratory
1 NABO	7	20	ART
2	(7)	?	
3	51	20	
4	7	10	
5	17	A-horizon	
6	33	8	
7	6	Ap-horizon	
8	6	5	
9	7	3-10	
10	7	3	
11	6	humus layer	
12	6	5	
13	14	10	
14	7	10	EMPA
Comparable:	**6/14**	**2/14**	**1/14**

(Computed from Desaules et al. 2008)

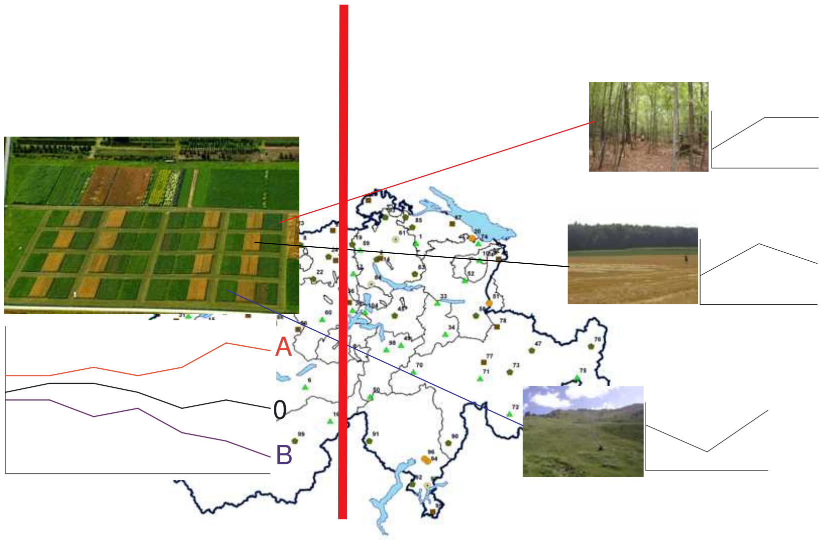
There is a flagrant lack of harmonization among published studies, thus comparisons of concentration values are mostly ill founded.

Findings: organic compounds

1. The PAH- and PCB concentrations of the NABO-network are low compared to the precautionary guide values.
2. Relatively high concentrations are partly found in soils under special cultures, urban areas, and surprisingly conservation sites.
3. The low degree of methodological harmonization hampers the comparability of different studies.
4. View to considerable measurement uncertainties and low correlations interpretations are difficult.
5. Only a correct and meaningful methodological harmonization of the whole measurement chain from sampling to chemical analysis allows improvements of comparability and interpretation.

Lessons learnt
and
challenges of soil monitoring

1) Site specific interpretation



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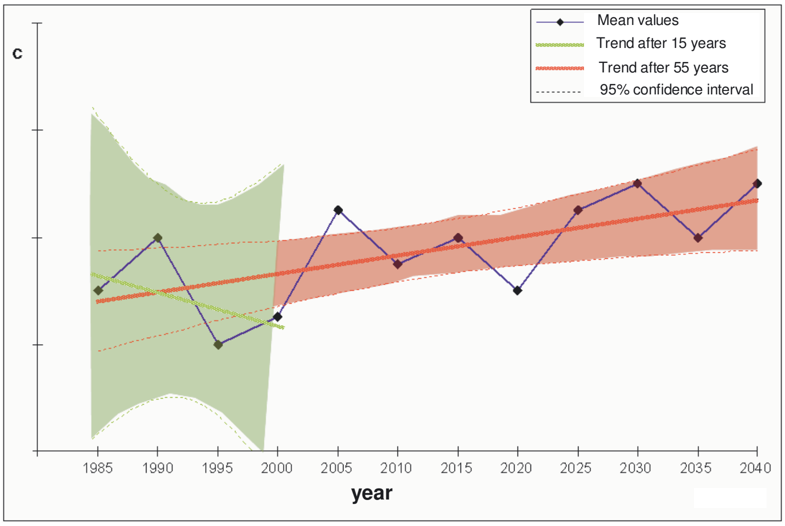
So far we can summarise the consequences of our findings by 6 lessons:

Lesson 1: Methodology, evaluation and interpretation of soil monitoring are so far still too strongly influenced by agronomic field trials.

Each soil monitoring site is an individual case, the sites cannot be treated like a field trial with the same or similar boundary conditions. Pooling of sites with different boundary conditions is a considerable source of artefacts.

Therefore the „relevant“ boundary conditions of the individual soil montioring sites must be much more carefully recorded and considered.

2) Increasing measuring periodicity



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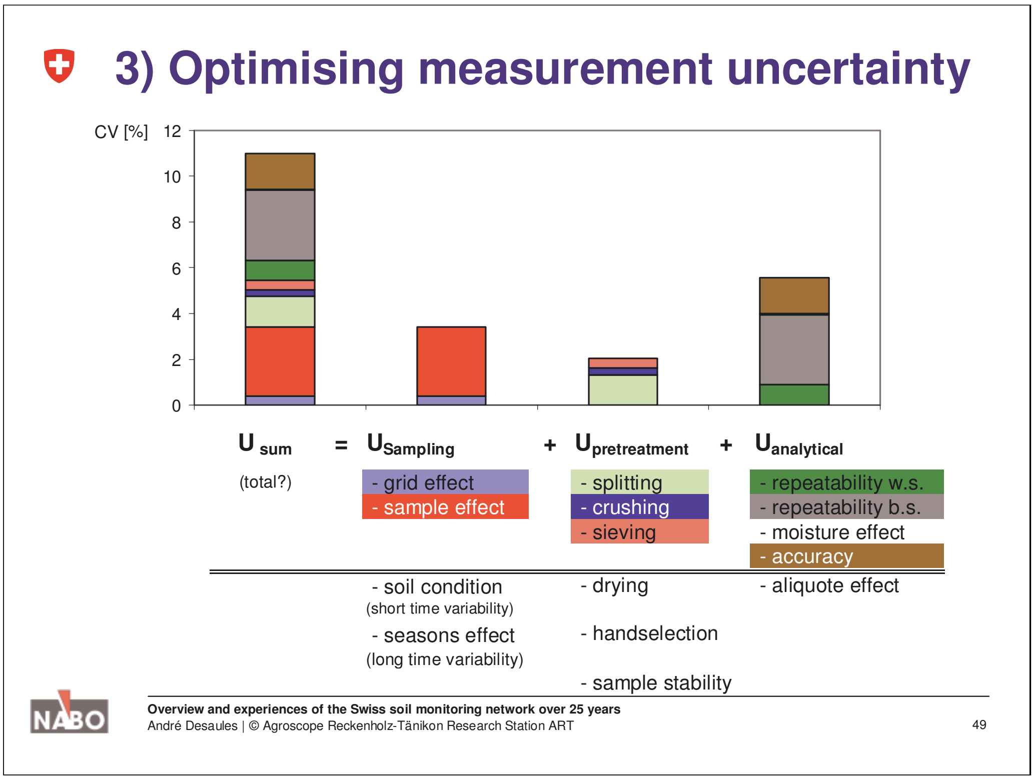
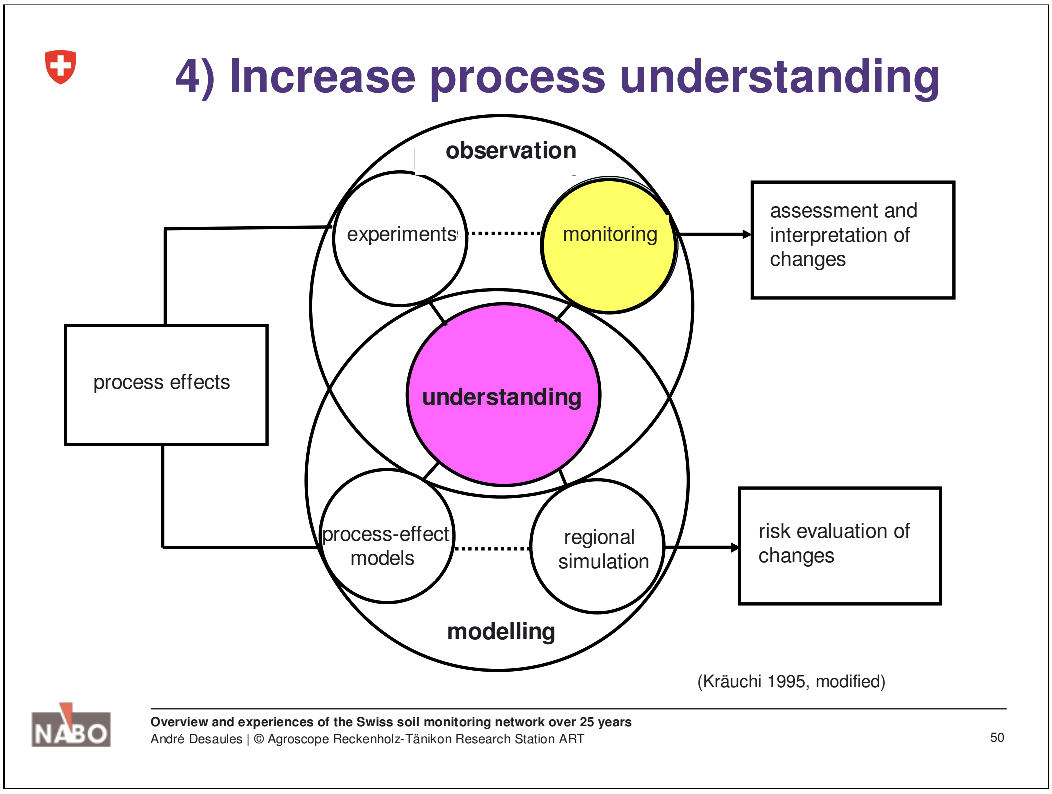
Lesson 2: Trends can be identified and certified only after sufficiently intense and long measurement series. Measurements within the noise cannot be interpreted. With increasing number of measurements and accurracy noise can be reduced and trends earlier detected. This is the foundation of pleading for increasing measurement periodicity in soil monitoring as well.



Lesson 3: One measure to reduce the noise of trends is to increase measurement accuracy by opitimising measurement uncertainty.

The given example of an uncertainty budget for Zn of a grassland soil under repeatability conditions shows optimising potential in sampling, splitting and analytical repeatability between series.



Lesson 4: Measured changes of concentrations can only be correctly assessed and evaluated if their processes (causes and effects) are sufficiently understood. Soil monitoring is therefore a basic element in ecosystems research and understanding.

5) Control changes of boundary conditions

Example: Temporal changes of measured Cu concentrations at four vineyard sites.

sampling campaign	mean n = 4 (mg/kg)	vineyard sites				
		5 (mg/kg)	55 (mg/kg)	96 (mg/kg)	101 (mg/kg)	106 (mg/kg)
t1	**433**	314	244	654	520	nd
t2	**301**	313	223	456	nd	*213*
changes	**-132**	-1	-21	-198	-307	

Sampling effect

Tillage effect

Grouping effect (Will Rogers phenomenon)

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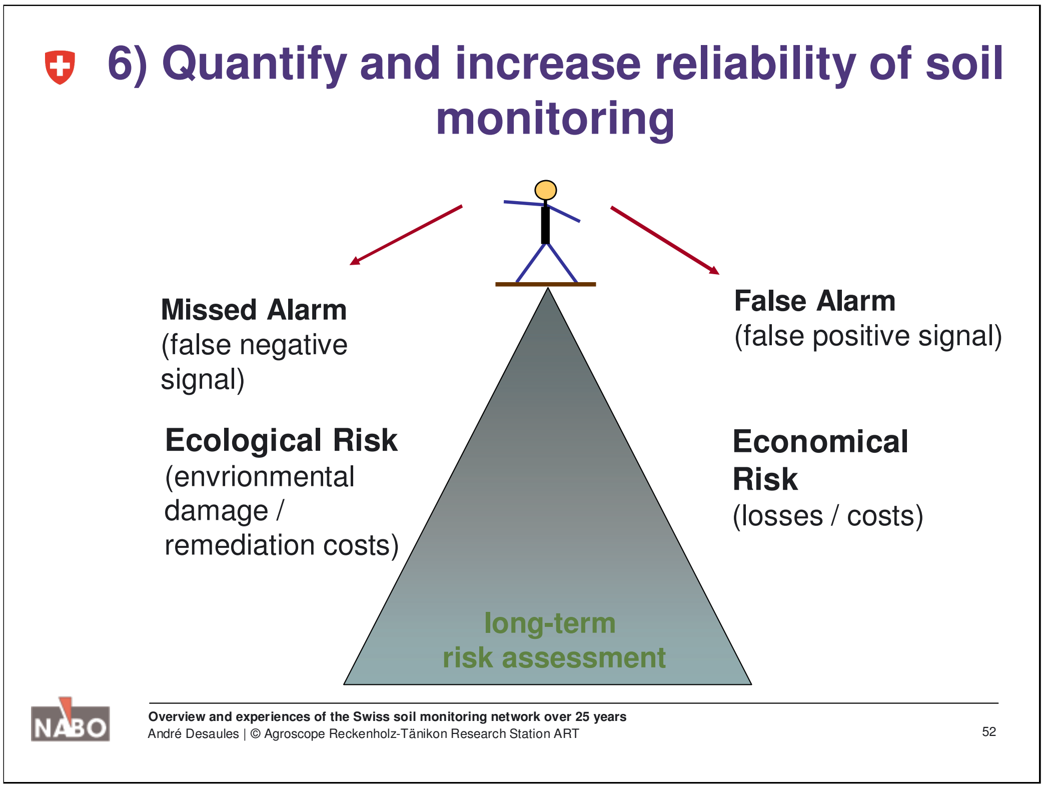
Lesson 5: The temporal change of relevant boundary conditions as sampling depth, pedoturbation, analytical conditions, number of sites etc. may affect the measured soil concentrations or mean values.

The influence of changing number of monitoring sites on the mean value is known as Will-Rogers phenomenon or stage migration.

Time series in environmental monitoring should therfore be consistent and rely on the same sites.



Lesson 6: View to the enormous possible damages and costs due to false monitoring signals, the best possible reliable soil monitoring is a very cost saving public investment in the long-term. The required degree of reliability is determined by the politically accepted risks.

Environmental monitoring networks which are not able to adequatly assess their degree of reliability are threfore not fit for taking political decisions.

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Basic challenges of soil monitoring

- Assurance of long-term continuity and consistency under changing boundary conditions as site conditions, methodologies, etc.
- Assessment of reliability by adequate quantification of long-term bias, variance and confidence intervals.
- All changes of potentially relevant boundary conditions must be documented by appropriate metadata.

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The basic challenges are as well requirements for a ‚good soil monitoring practice' GSMP

References

This presentation is based on a presentation held at EUROSOIL 2008 Conference, 25-29 August in Vienna, Austria available in English under:

www.nabo.admin.ch >**Presentations**: NABO-Trend: T009

For references see: www.nabo.admin.ch >**Bibliography**