A comprehensive approach to assessing and managing health risks from cyanotoxins, applicable under a wide range of conditions

Ingrid Chorus

Until 2019 Federal Environmental Agency, Germany /

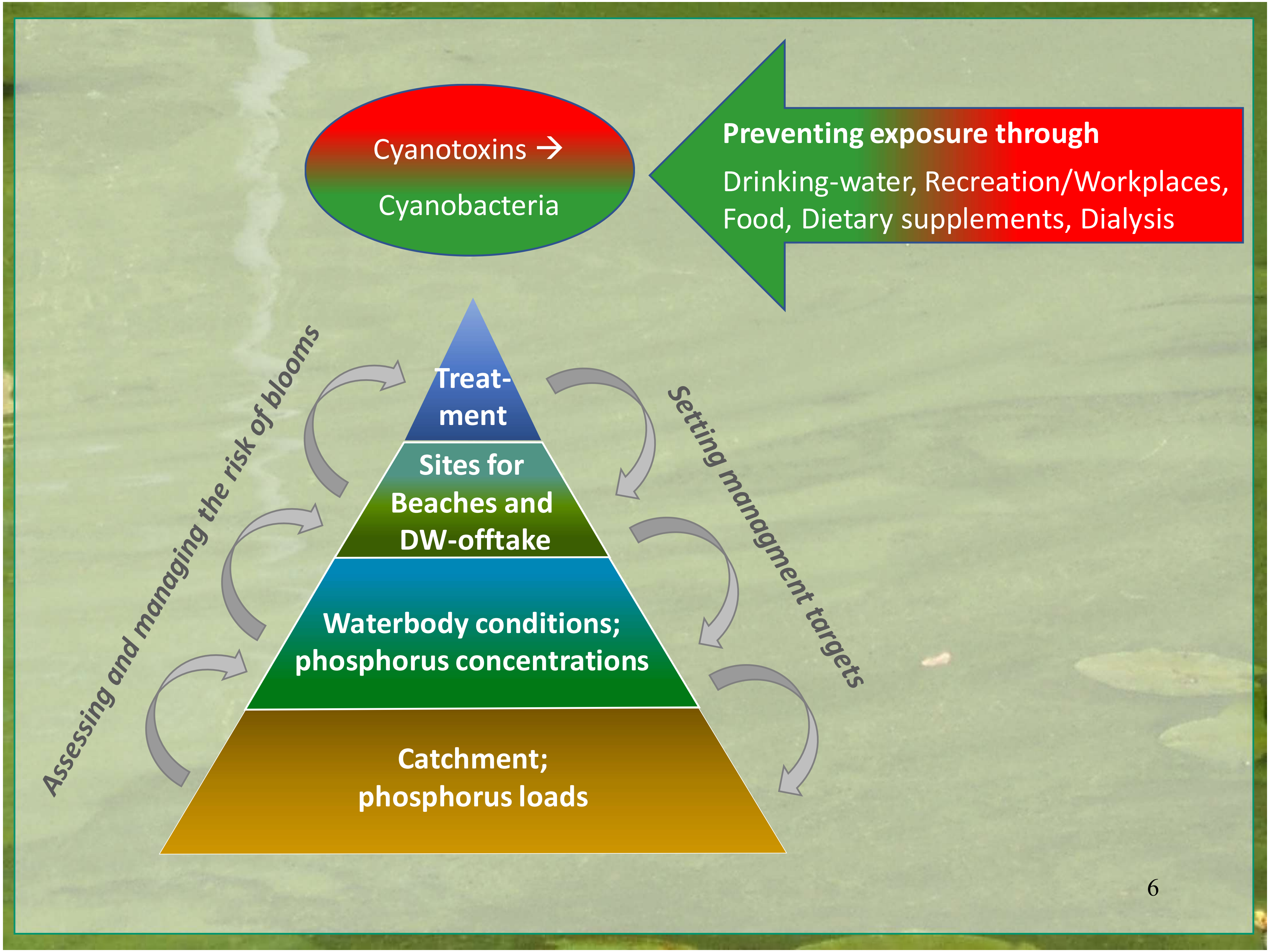
WHO Collaborating Centre for research on drinking-water hygiene

White death dap

- acutely lethal dose: ≥ 50 g biomass

Cyanobacteria

- acutely lethal dose: ≥ 50 g biomass


Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces,
Food, Dietary supplements, Dialysis
Treat-
ment
Sites for
Beaches and
DW-offtake
Waterbody conditions;
phosphorus concentrations
Catchment;
phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

GOV ← **Define health-based targets**

↓

System assessment:
can the supply chain, ***<u>from catchment to consumer</u>***, meet the health-based targets at all times ?

↓

Monitoring
the measures critical for controlling the system

↓

Management and communication plans
for normal operations and incidents

Water Safety Plans (System assessment, Monitoring, Management and communication plans)

↓

GOV ← **Independent surveillance**
to verify the functioning of the system

7


Cyanotoxins →
Cyanobacteria

Cyanotoxins →
Cyanobacteria

Defining targets

WHO Guideline values and backround documents on the web since 24 November **for YOUR review** by 12th January:

https://www.who.int/water_sanitation_health/water-quality/guidelines/chemicals/chemicals-information/en/

	Drinking-w lifetime	Drinking-w short-term	Drinking-w acute	Health-based* reference	Recreation
MC-LR (applicable to sum MC)	1 µg/L	?			?
CYNs	0.7 µg/L	3 µg/L			6 µg/L
ATXs				30 µg/L	60 µg/L
STXs			3 µg/L (5 kg baby)		30 µg/L (15 kg kid)

*HBR = "unlikely to cause adverse effects in exposed adults"

Cyanotoxins → Cyanobacteria

„Translating“ cyanotoxin targets to targets for cyanobacteria:

parameter	Biovolume	Chlorophyll a	Cell counts*
worst-case estimates:	MC/BV ≤ 3/1 [µg/mm³]	MC/Chl.a ≤ 1:1 [µg/µg]	cell quota ≤ 200 fg MC/cell or ≤ 0.2 µg/10^6 cells

<u>Visual assessment</u>: scums and turbidity:

Cyanotoxins → Cyanobacteria

„Translating“ cyanotoxin targets to targets for cyanobacteria:

parameter	Biovolume	Chlorophyll a	Cell counts*
worst-case estimates:	MC/BV ≤ 3/1 [µg/mm³]	MC/Chl.a ≤ 1:1 [µg/µg]	cell quota ≤ 200 fg MC/cell or ≤ 0.2 µg/10^6 cells

Visual assessment: scums and Secchi Disc reading > 1-2 m:

Reasons:

1. Biomass includes unspecific effects of cyanobacterial blooms (e.g from unknown metabolites; associated pathogens)
2. Easier (cheaper) access to microscopy and/or pigment analyses (including on-site probes or remote sensing)
3. Turbidity and scum-scouting allow low-cost estimate of probability

Cyanotoxins → Cyanobacteria

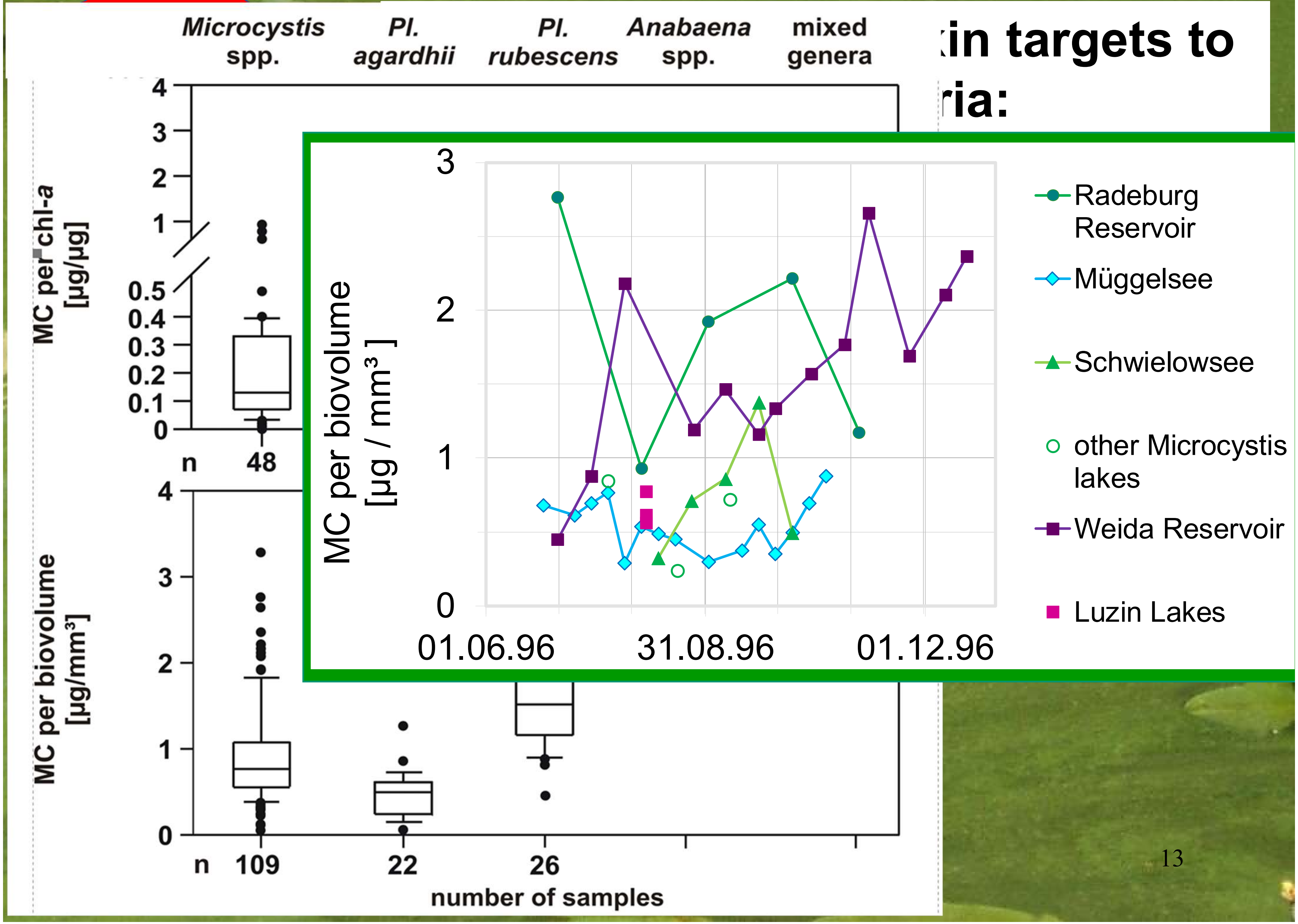
„Translating“ cyanotoxin targets to targets for cyanobacteria:

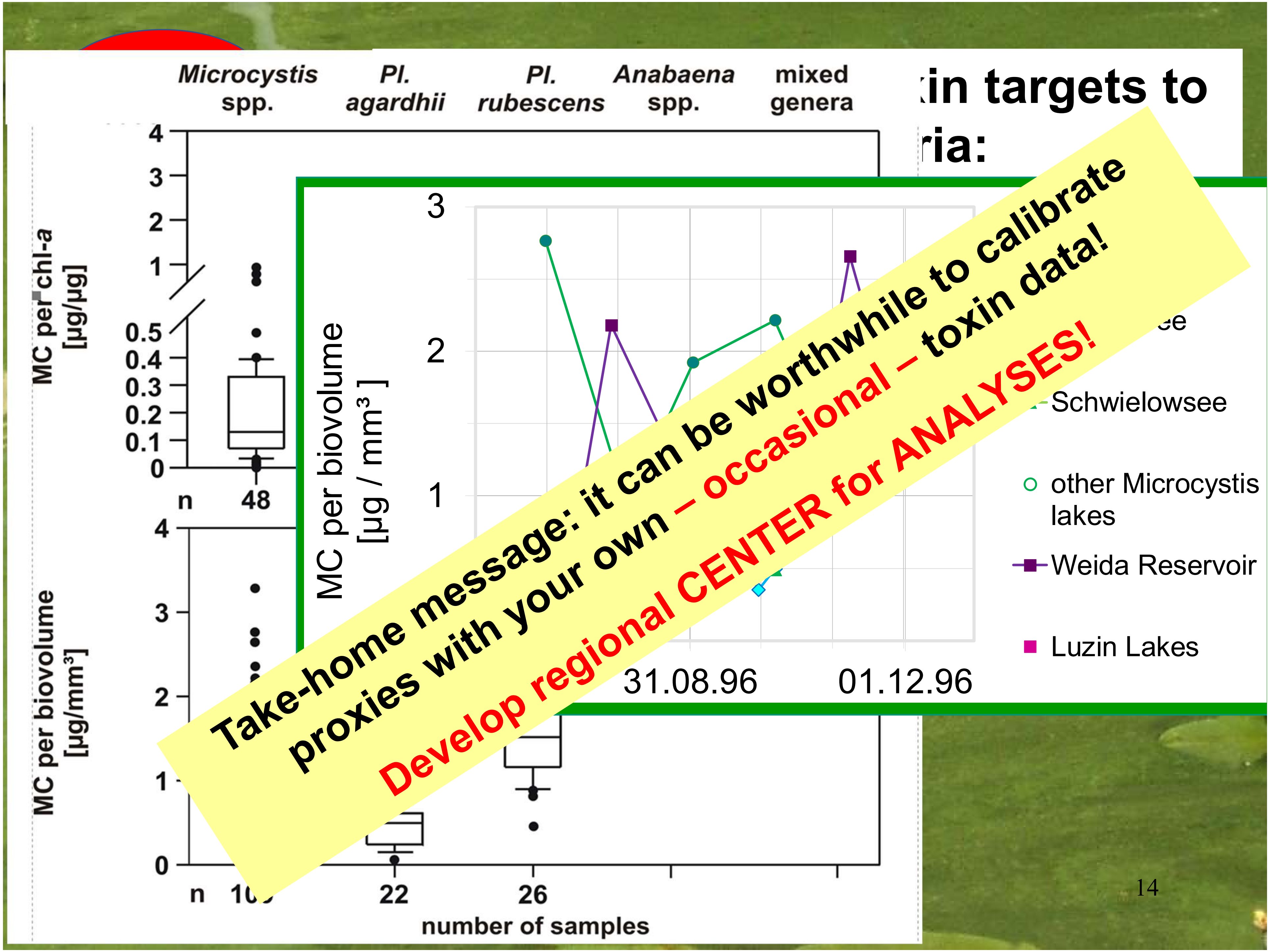
parameter	Biovolume	Chlorophyll a	Cell counts*
worst-case estimates:	MC/BV ≤ 3/1 [µg/mm³]	MC/Chl.a ≤ 1:1 [µg/µg]	cell quota ≤ 200 fg MC/cell or ≤ 0.2 µg/10^6 cells

Visual assessment: scums and Secchi Disc reading > 1-2 m:

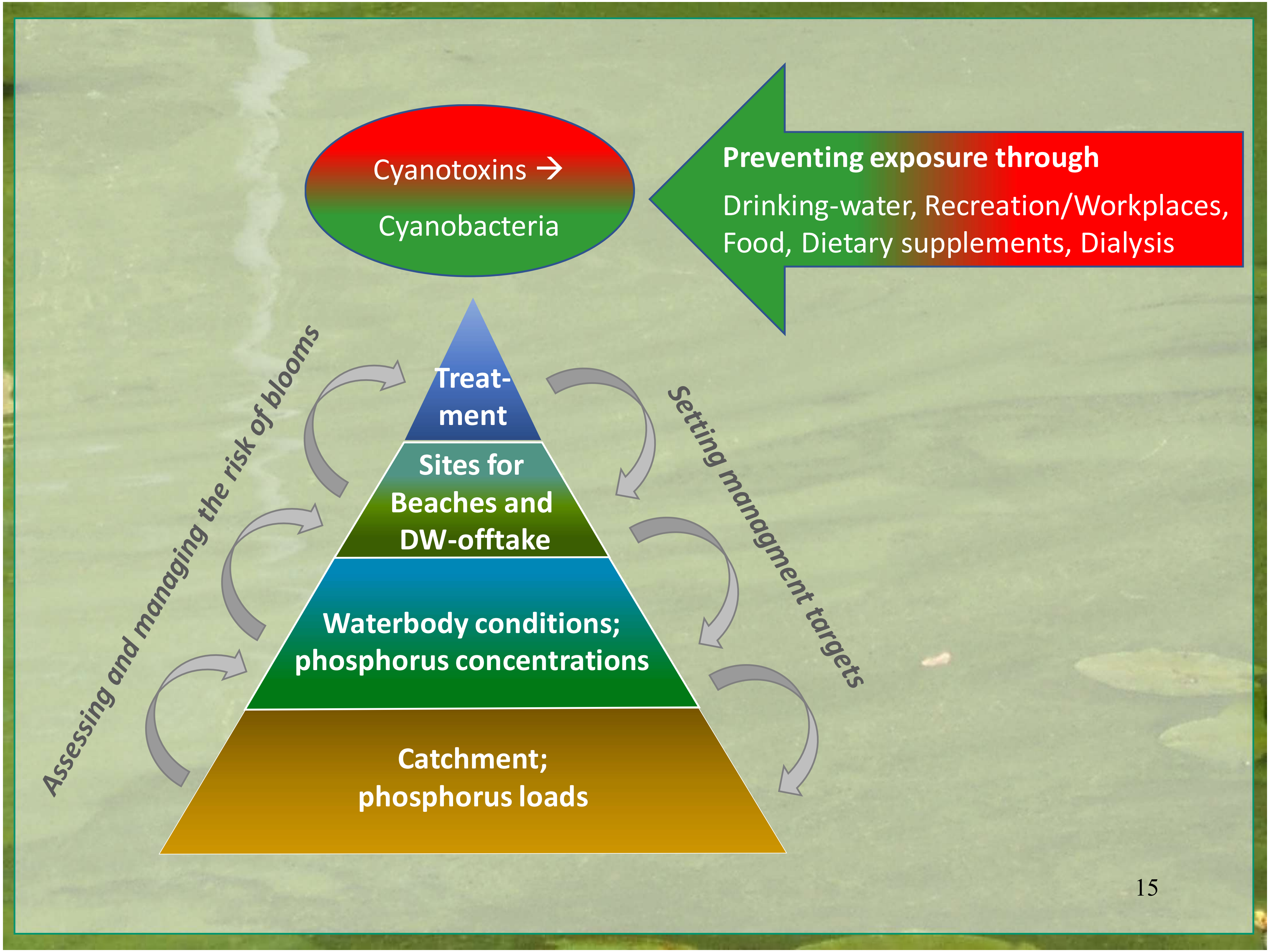
Are these ratios appropriate for Uruguay / Argentina?

…in targets to
…ria:





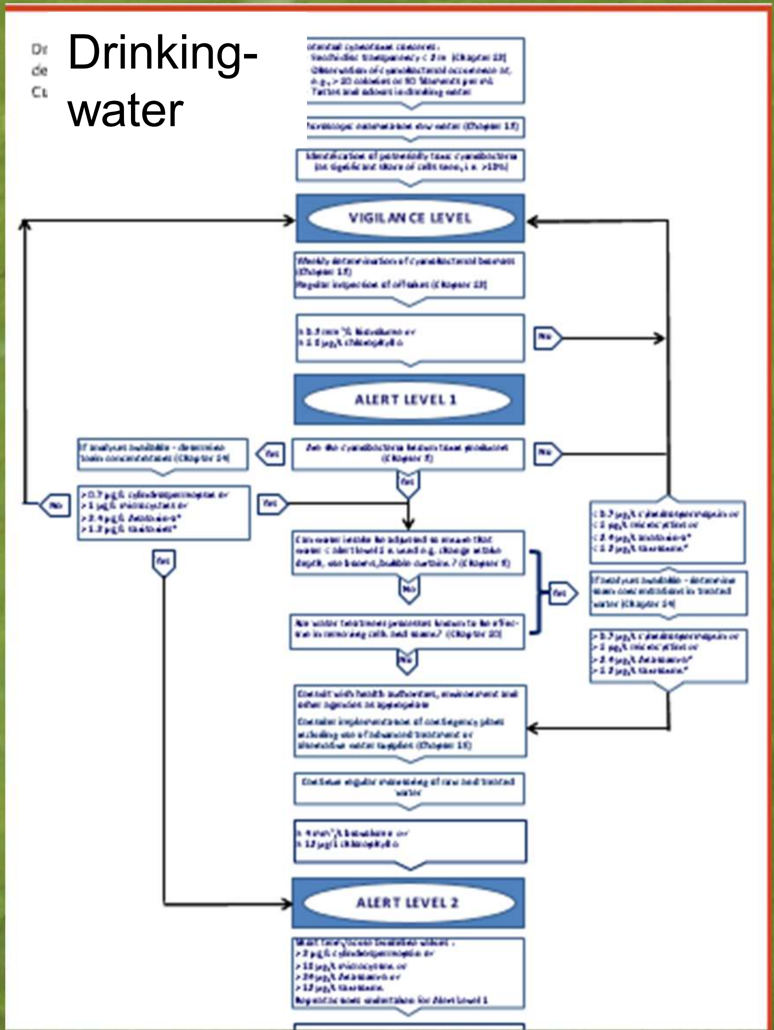
…in targets to
…ria:
Microcystis spp.
Pl. agardhii
Pl. rubescens
Anabaena spp.
mixed genera
MC per chl-a [µg/µg]
MC per biovolume [µg/mm³]
n 48
n 22 26
number of samples
MC per biovolume [µg / mm³]
31.08.96
01.12.96
Schwielowsee
other Microcystis lakes
Weida Reservoir
Luzin Lakes
Take-home message: it can be worthwhile to calibrate proxies with your own – occasional – toxin data!
Develop regional CENTER for ANALYSES!

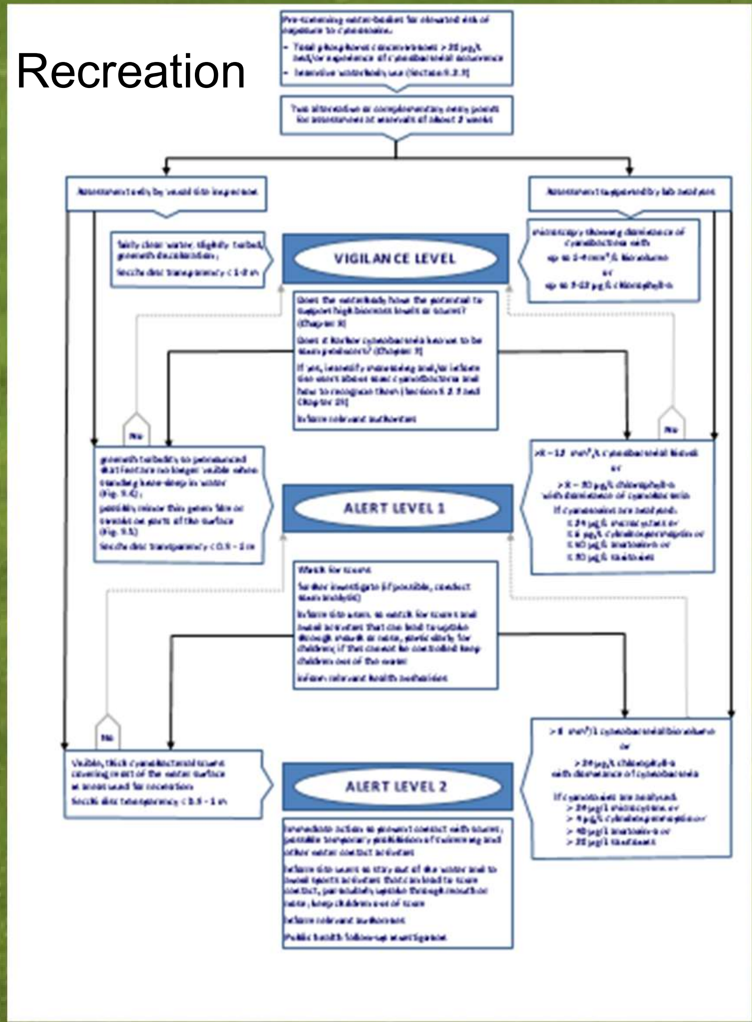

Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis
Treat-ment
Sites for Beaches and DW-offtake
Waterbody conditions; phosphorus concentrations
Catchment; phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

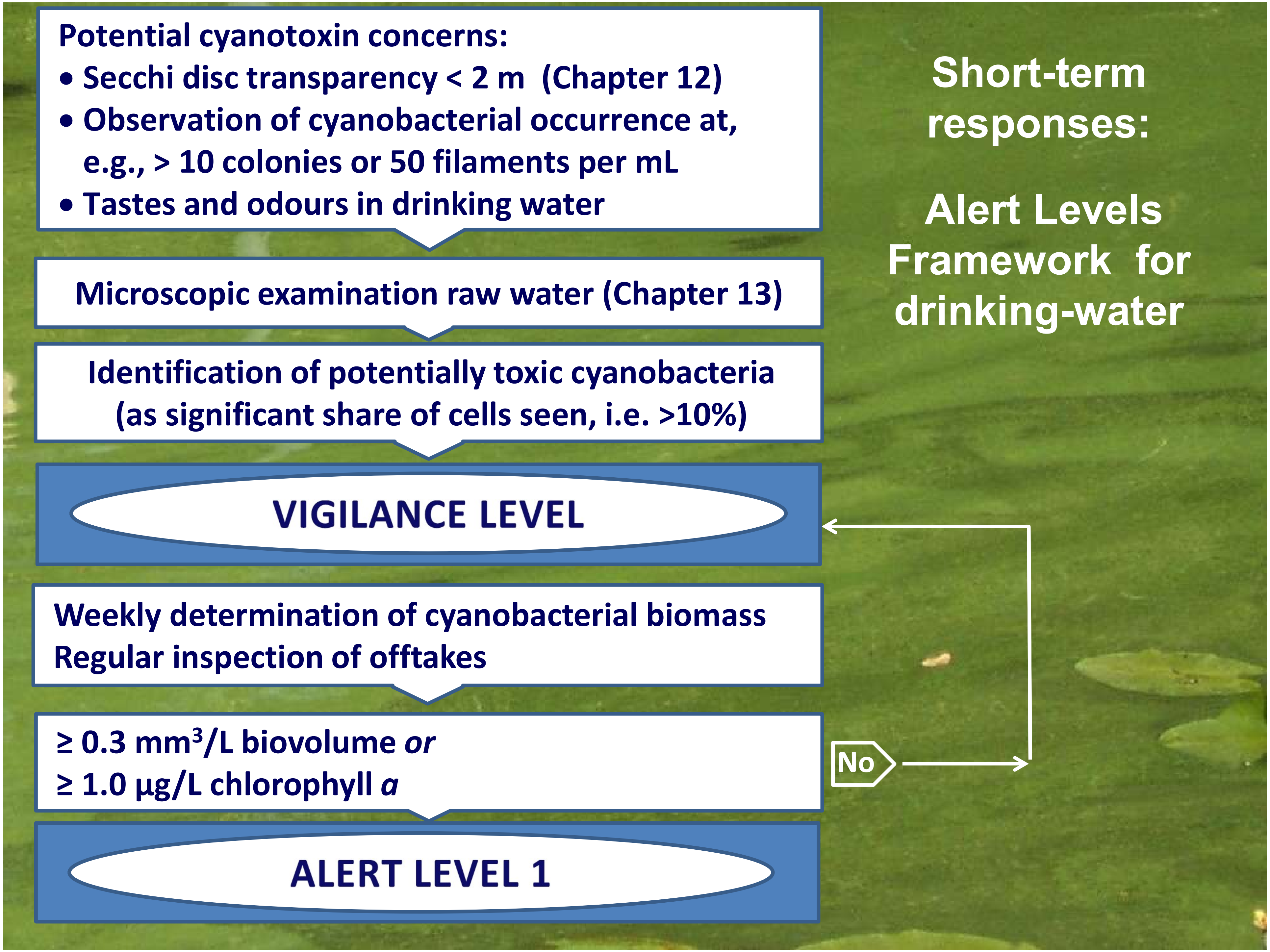
Short-term responses to blooms: Alert Levels Frameworks for drinking-water and for recreational waterbody use

Preventing exposure through

Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis






Short-term responses:
Alert Levels Framework for drinking-water
Potential cyanotoxin concerns:
• Secchi disc transparency < 2 m (Chapter 12)
• Observation of cyanobacterial occurrence at, e.g., > 10 colonies or 50 filaments per mL
• Tastes and odours in drinking water
Microscopic examination raw water (Chapter 13)
Identification of potentially toxic cyanobacteria (as significant share of cells seen, i.e. >10%)
VIGILANCE LEVEL
Weekly determination of cyanobacterial biomass
Regular inspection of offtakes
≥ 0.3 mm³/L biovolume *or*
≥ 1.0 µg/L chlorophyll *a*
No
ALERT LEVEL 1

Alert Levels Framework for drinking-water

ALERT LEVEL 1

Are the cyanobacteria known toxin producers?

Yes

Can water intake be adjusted to avoid them?

No

Are treatment processes effective?

No

≥ 4 mm³/L biovolume *or* ≥ 12 µg/L chlorophyll *a*

Yes (to either of the two questions above):

< 0.7 µg/L cylindrosp. *or*
< 1 µg/L microcystins *or*
< 2.4 µg/L anatoxin-a*
< 1.2 µg/L saxitoxins*

ALERT LEVEL 2

Short term/acute Guideline values :
> 2 µg/L cylindrospermopsin *or*
> ? µg/L microcystins *or*
> 24 µg/L Anatoxin-a *or*
> 12 µg/L saxitoxins

Elevated risk to human health unless alternative supplies or advanced treatment are used

Short-term responses:

Alert Levels Framework for recreation

Two alternative or complementary entry points for assessment at intervals of about 2 weeks

Pre-screening water-bodies for elevated risk of exposure to cyanotoxins:

- Total phosphorus concentrations > 20 µg/L and/or experience of cyanobacterial occurrence
- Intensive waterbody use

Assessment only by visual site inspection

fairly clear water, slightly turbid, greenish discoloration;
Secchi disc transparency < 1-2 m

Assessment supported by lab analyses

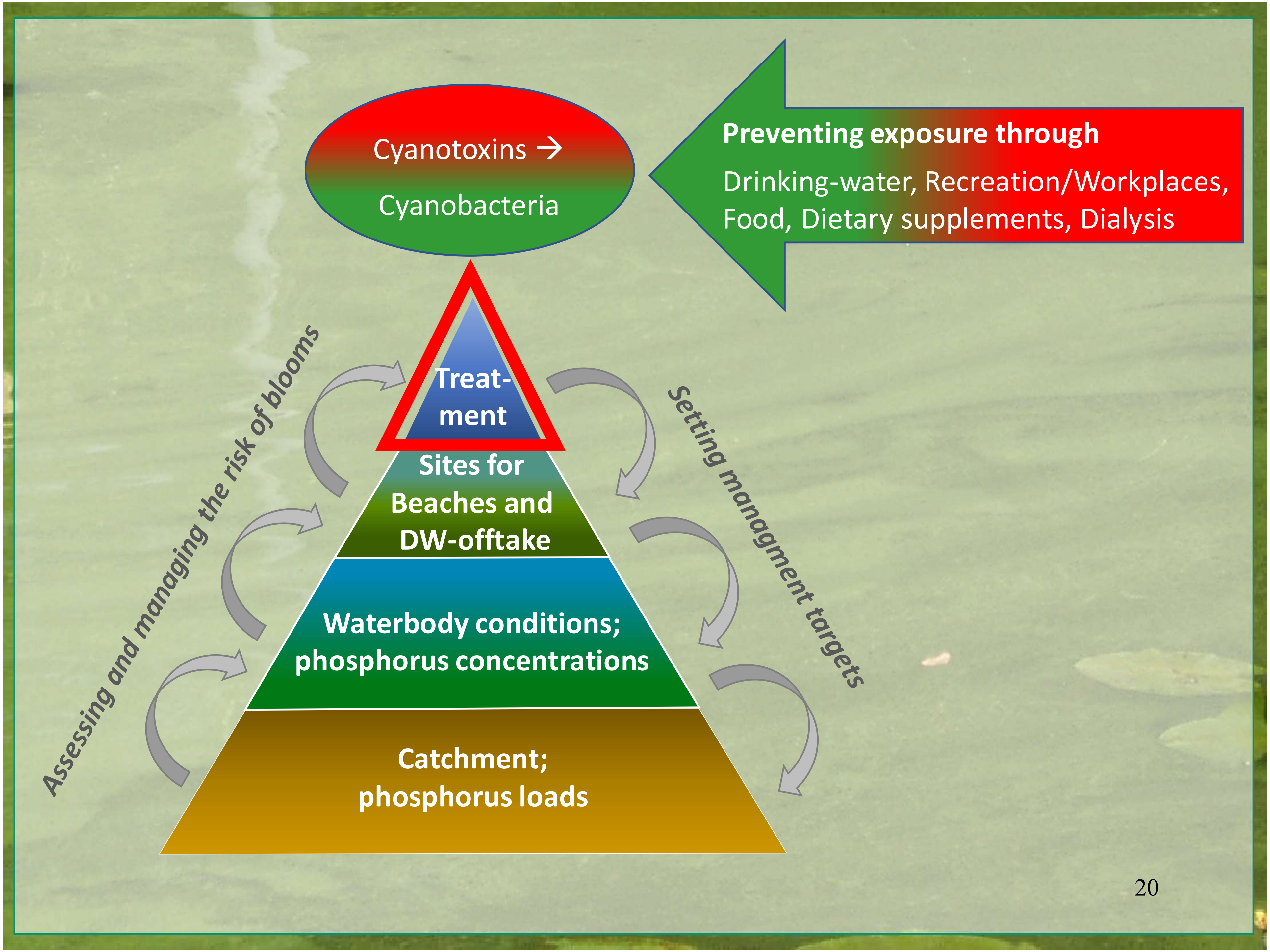
dominance of cyanobacteria
≤ 1-4 mm³/L biovolume
or
≤ 3-12 µg/L chlorophyll-a

VIGILANCE LEVEL

If potential to support high biomass (TP > 20 µg/L or known toxin producers, intensify monitoring and/or inform site users and relevant authorities

If turbid or scums…

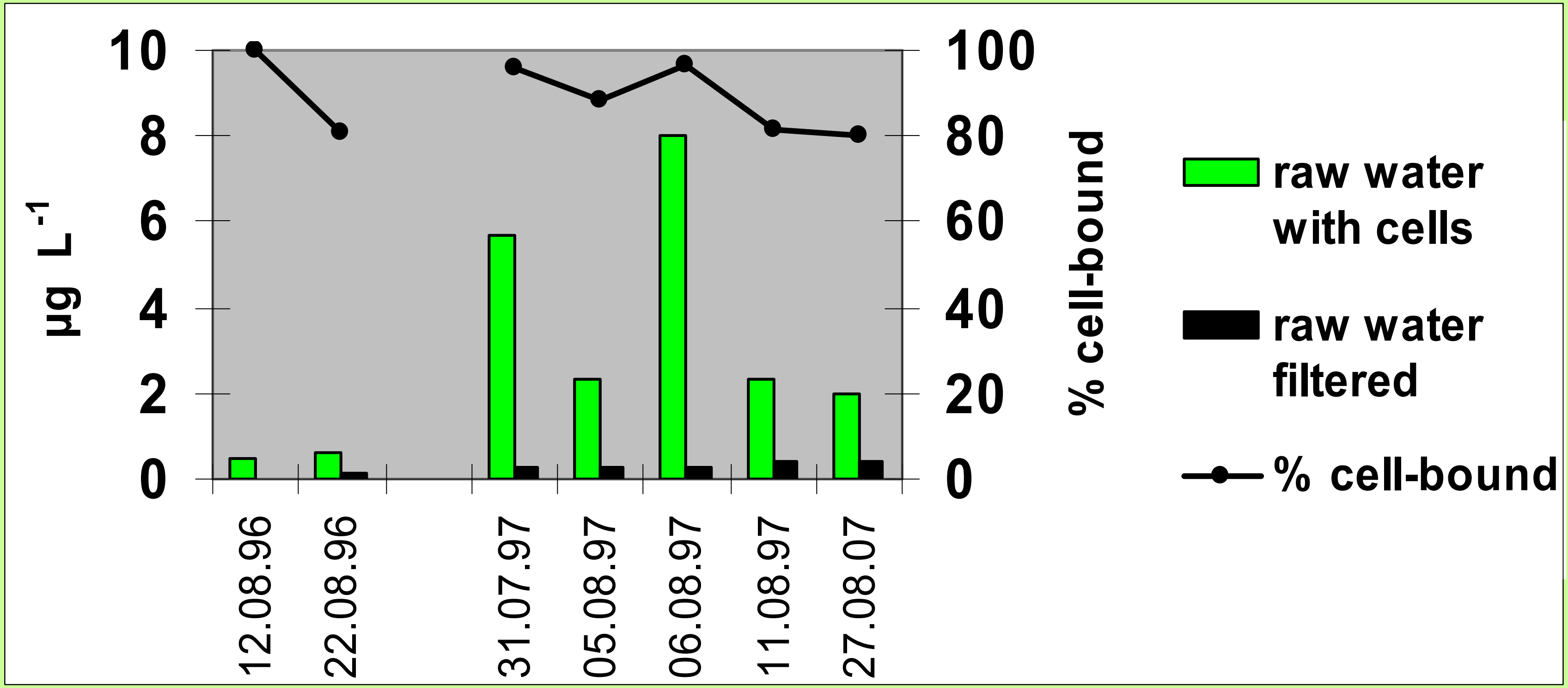
>8 – 12 mm³/L cyanobacterial biovol. or
> 8 – 30 µg/L chlorophyll-a or toxin > …


Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis
Treat-ment
Sites for Beaches and DW-offtake
Waterbody conditions; phosphorus concentrations
Catchment; phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

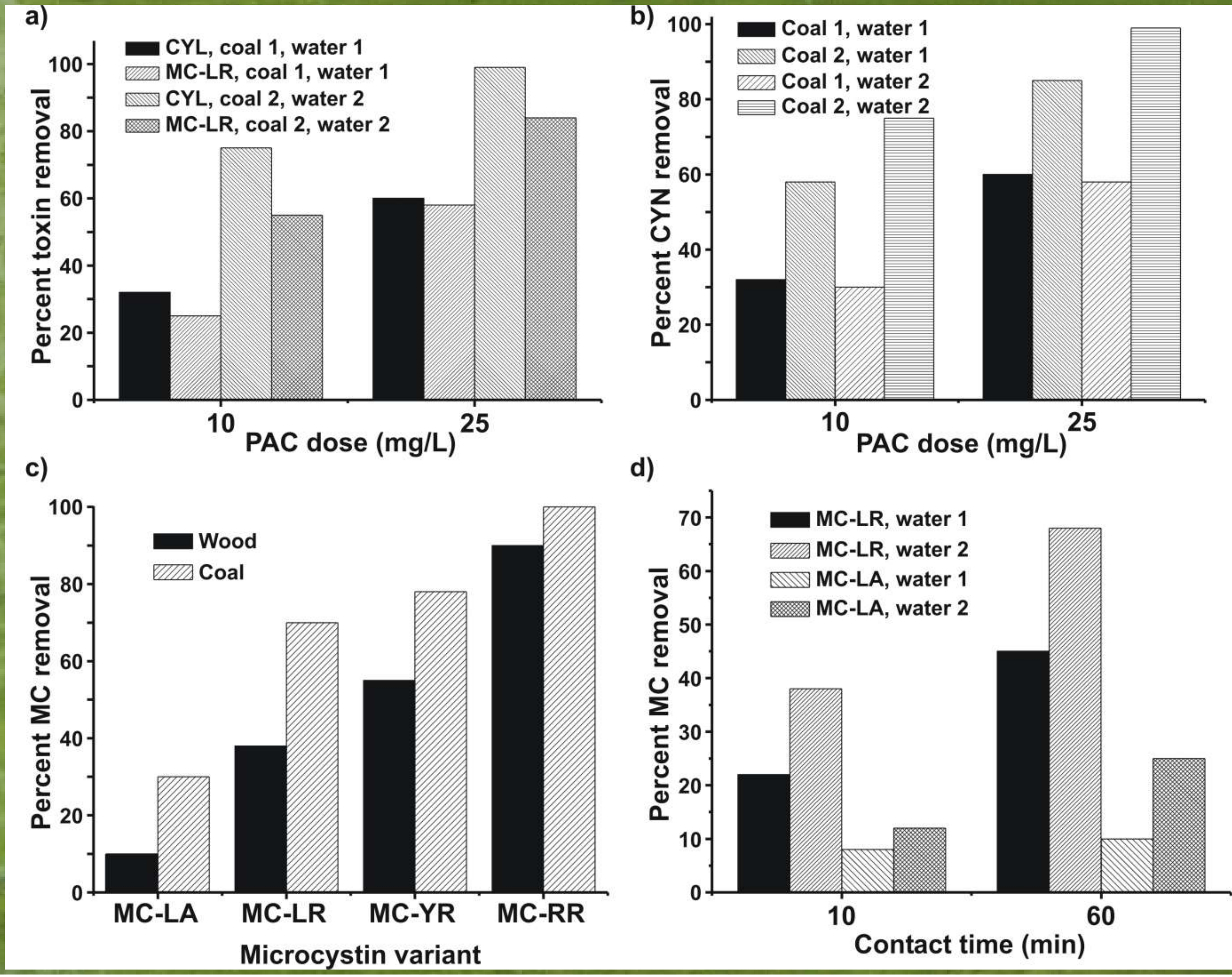
Treat-
ment

Example treatment: Rostock treatment plant – microcystin in raw and filtered water

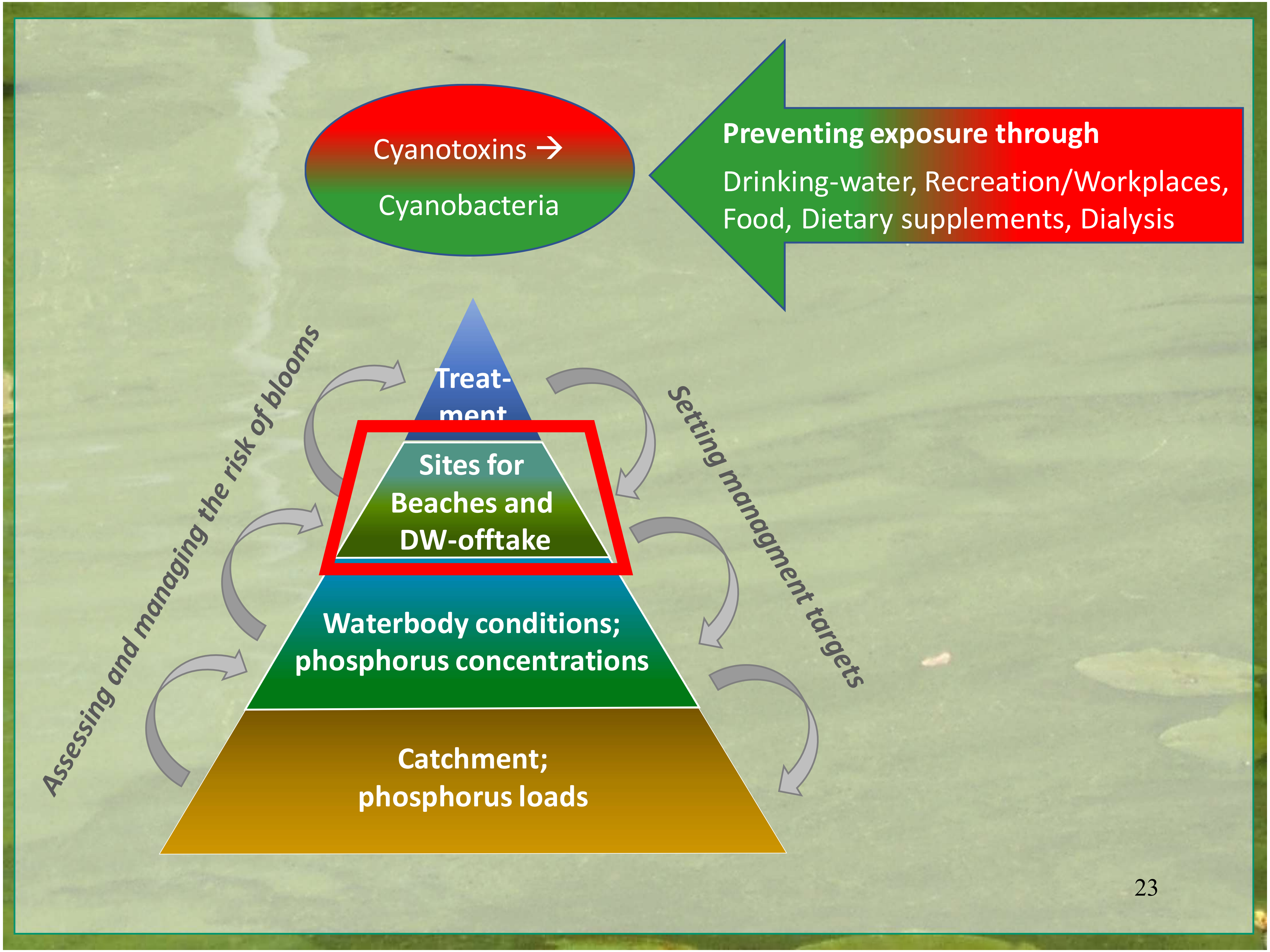
***Microcystis* or *Planktothrix agardhii* in raw water (biovol. 19 mm³/L in one case, otherwise < 2 mm³/L; locculation and rapid filtration**



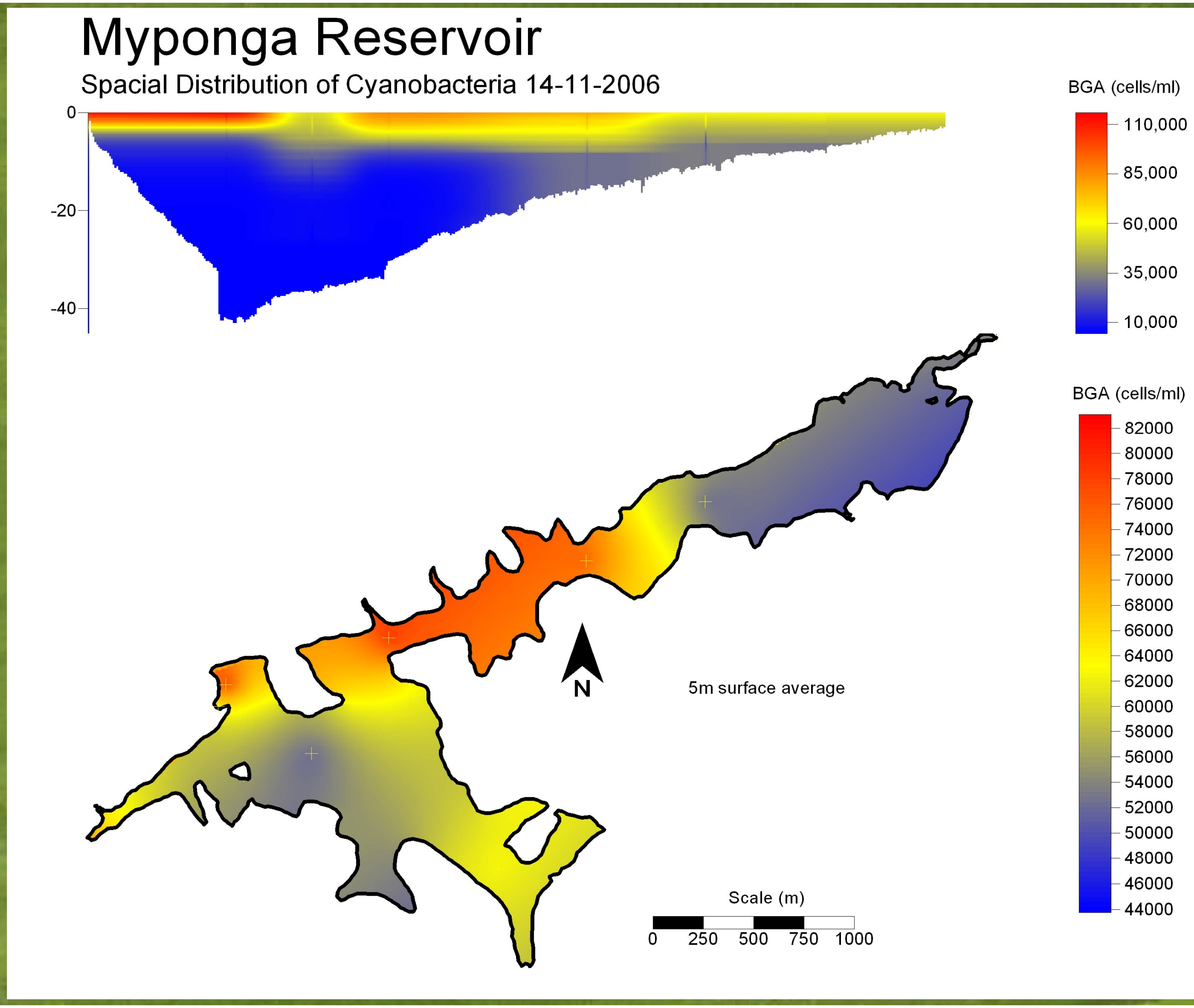
Chorus (ed.) 2001



Newcombe, Ho & Neto in: Toxic Cyanobactera in Water, 2nd edition (in prep.)
Figure 10.1: **Cyanotoxin removal effectiveness through types of PAC**

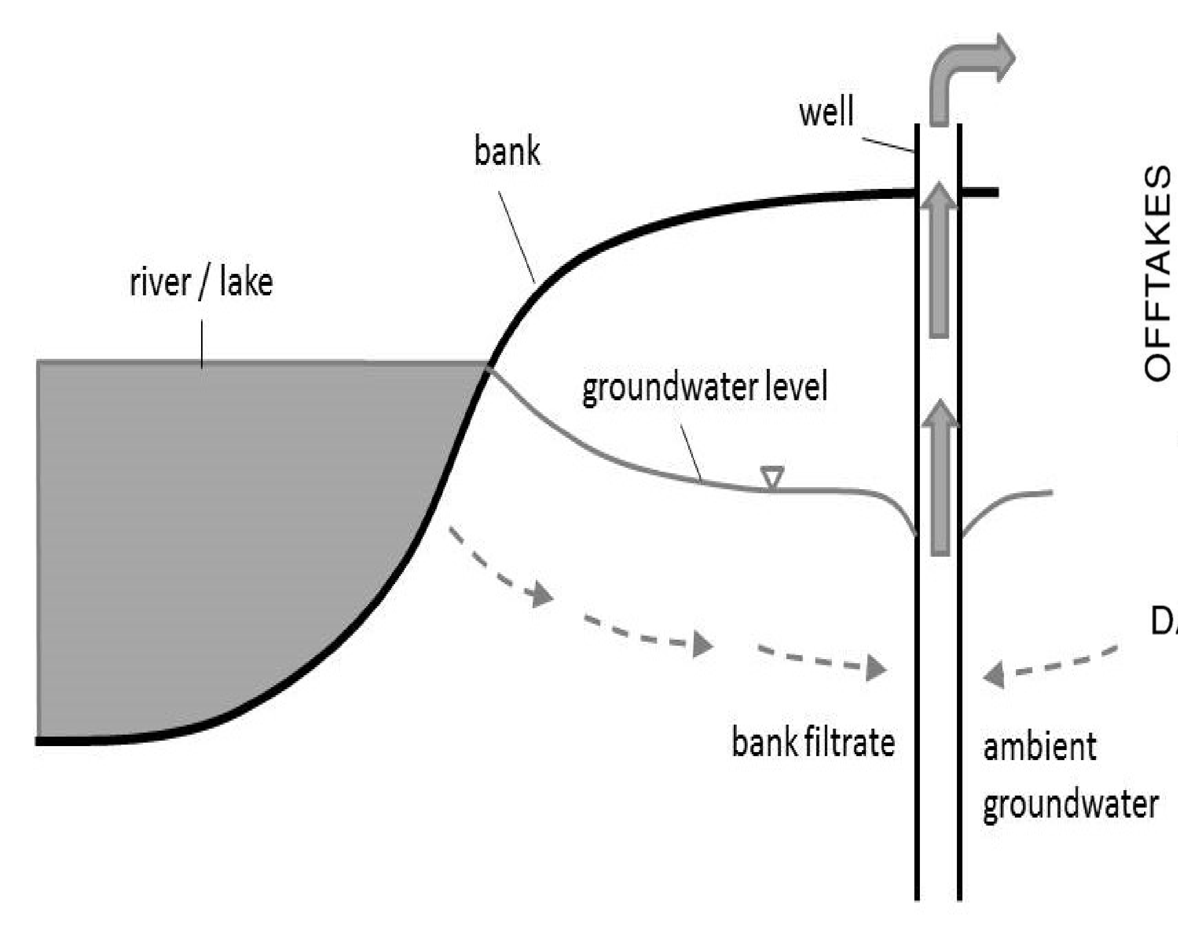

Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis
Treat-ment
Sites for Beaches and DW-offtake
Waterbody conditions; phosphorus concentrations
Catchment; phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

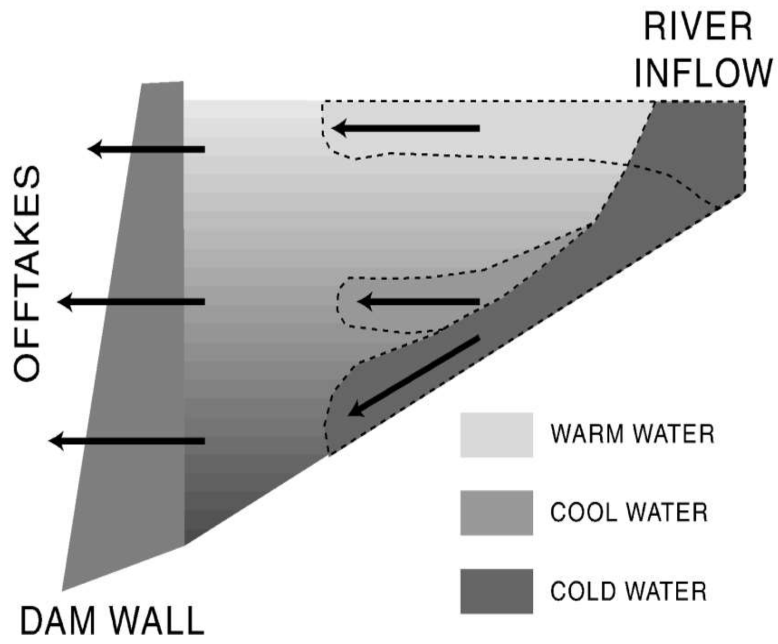
Sites for Beaches and DW-offtake



Burch et al. in Toxic Cyanobactera in Water, 2nd edition (in prep.)
Figure 9.1: **Vertical profiles and horizontal variability of *Dolichospermum circinalis* in a reservoir in South Australia** (phycocyanin fluorescence, converted to cells per mL)

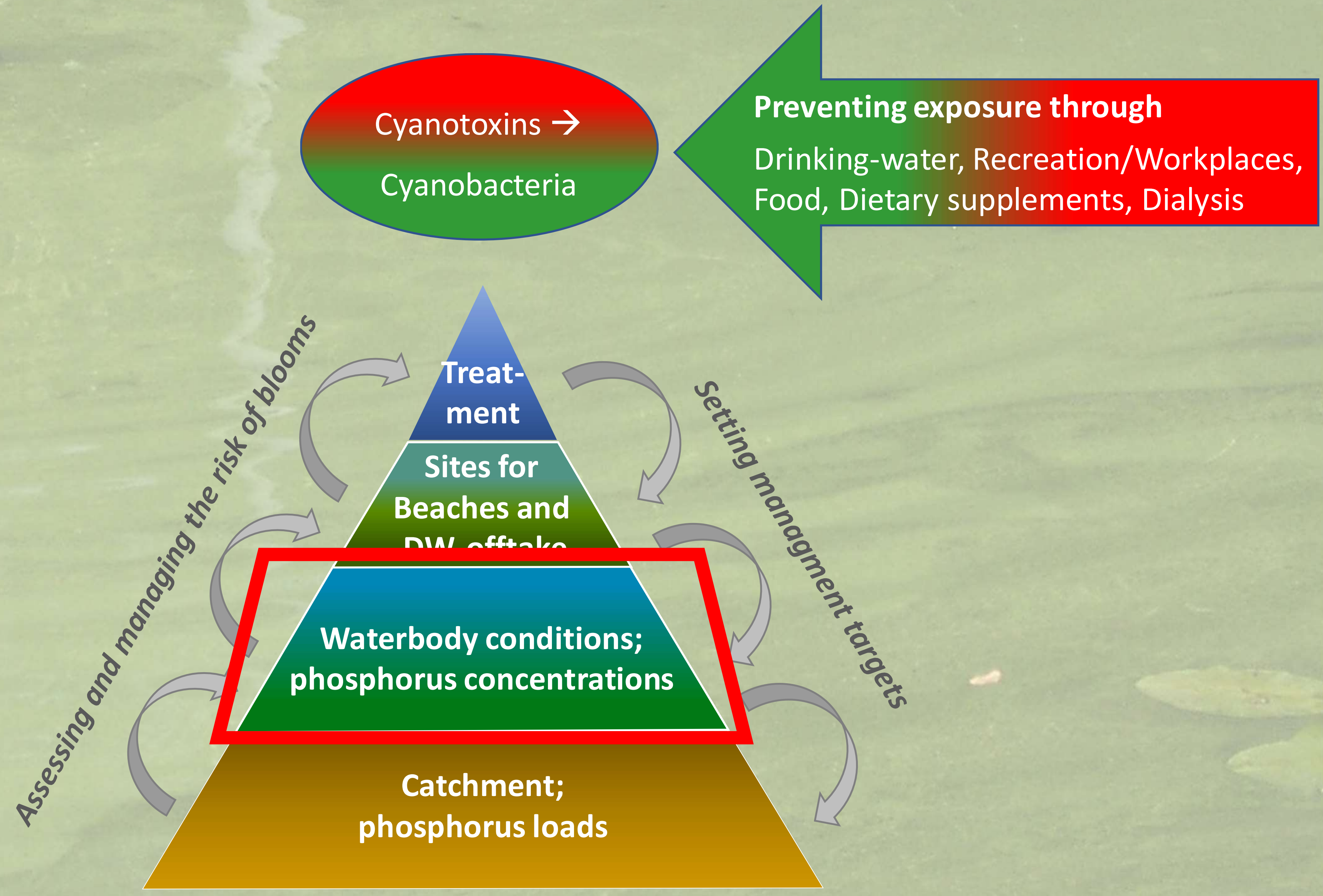
Sites for Beaches and DW-offtake





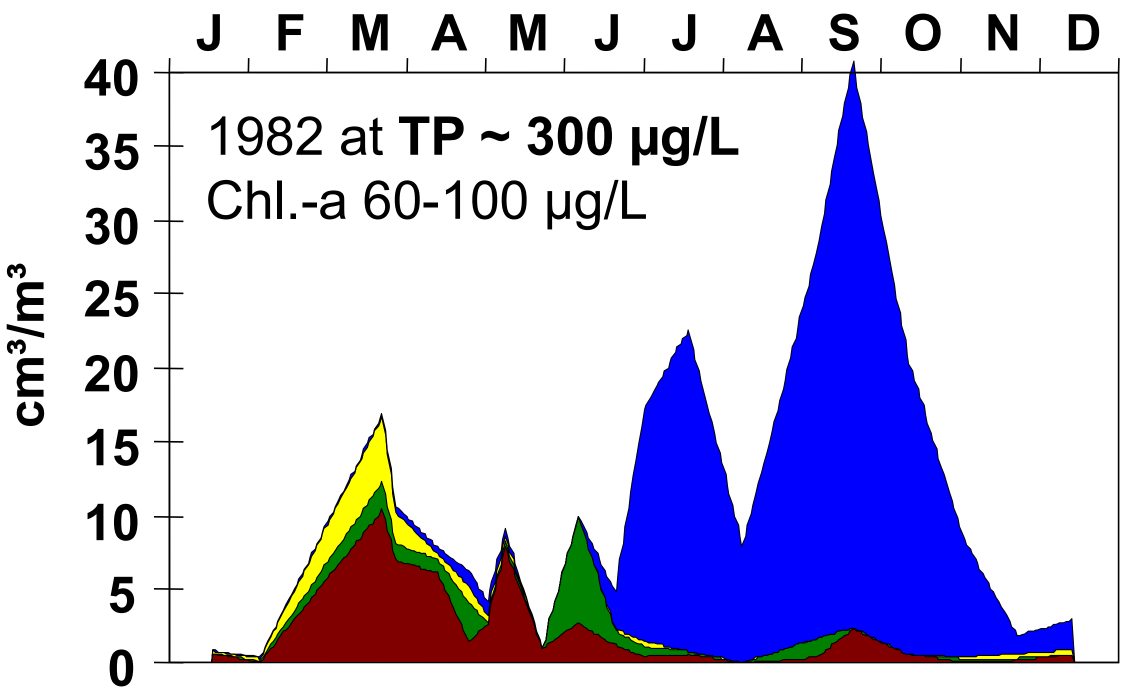
From Burch et al, TCiW, 2nd edition:

- For reservoirs: variable offtake depths can avoid blooms effectively
- For rivers: riverbank filtration as highly effective treatment method


Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis
Treat-ment
Sites for Beaches and DW offtake
Waterbody conditions; phosphorus concentrations
Catchment; phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

Waterbody conditions; phosphorus concentrations

Example nutrient loading: Restoration Schlachtensee

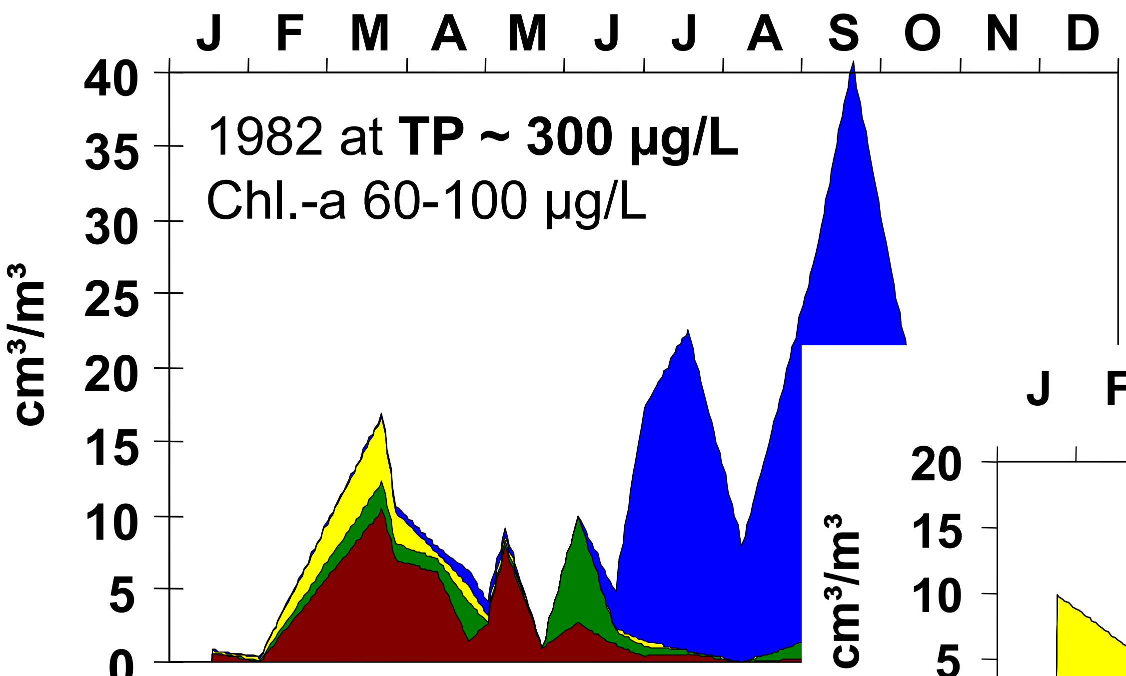


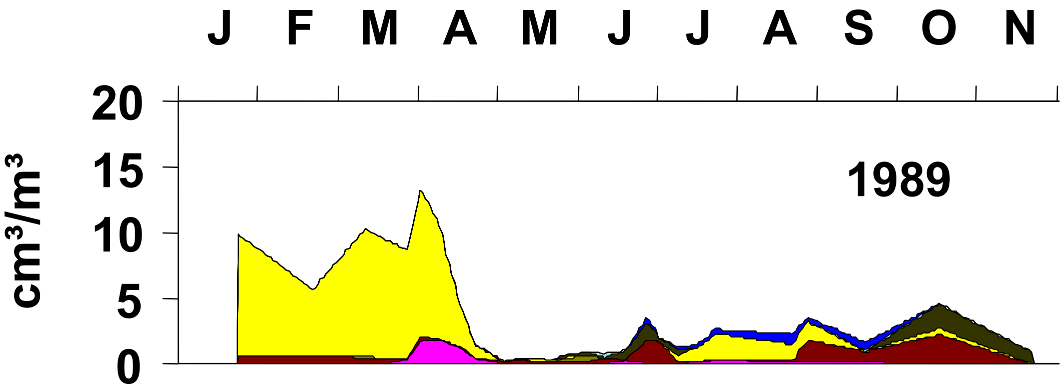
Before restoration

.

Waterbody conditions; phosphorus concentrations

Example nutrient loading: Restoration Schlachtensee



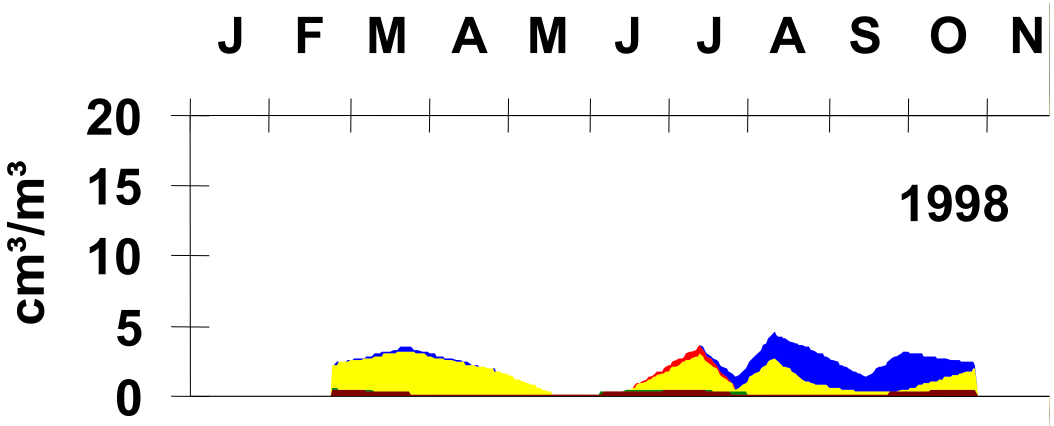


After restoration (for details, see
https://www.umweltbundesamt.de/publikationen/oligotrophication-of-lake-tegel-schlachtensee)

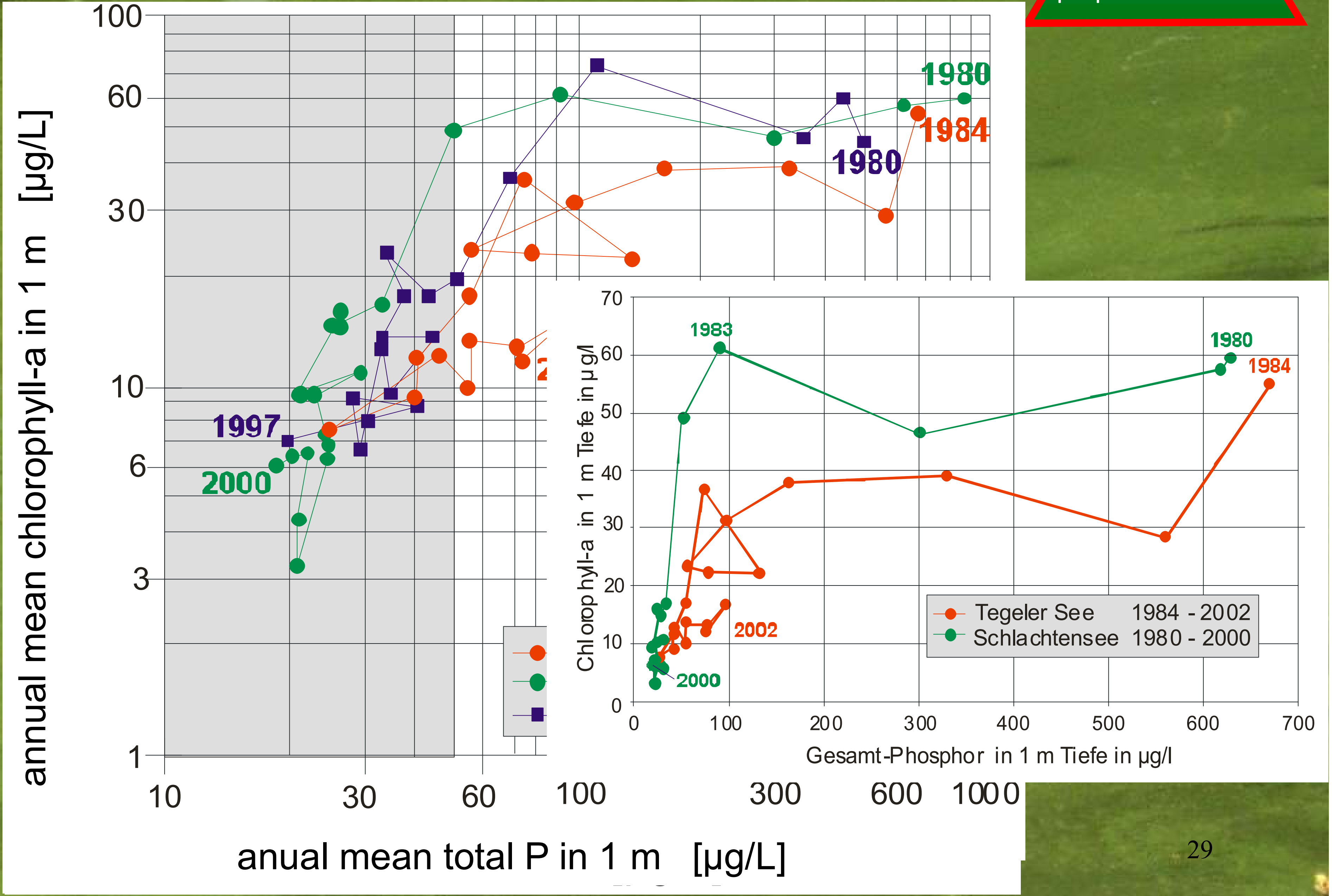
1989, 1998 at

TP ~ 20 µg/L

Chl.a 10-20 µg/L and



Waterbody conditions; phosphorus concentrations



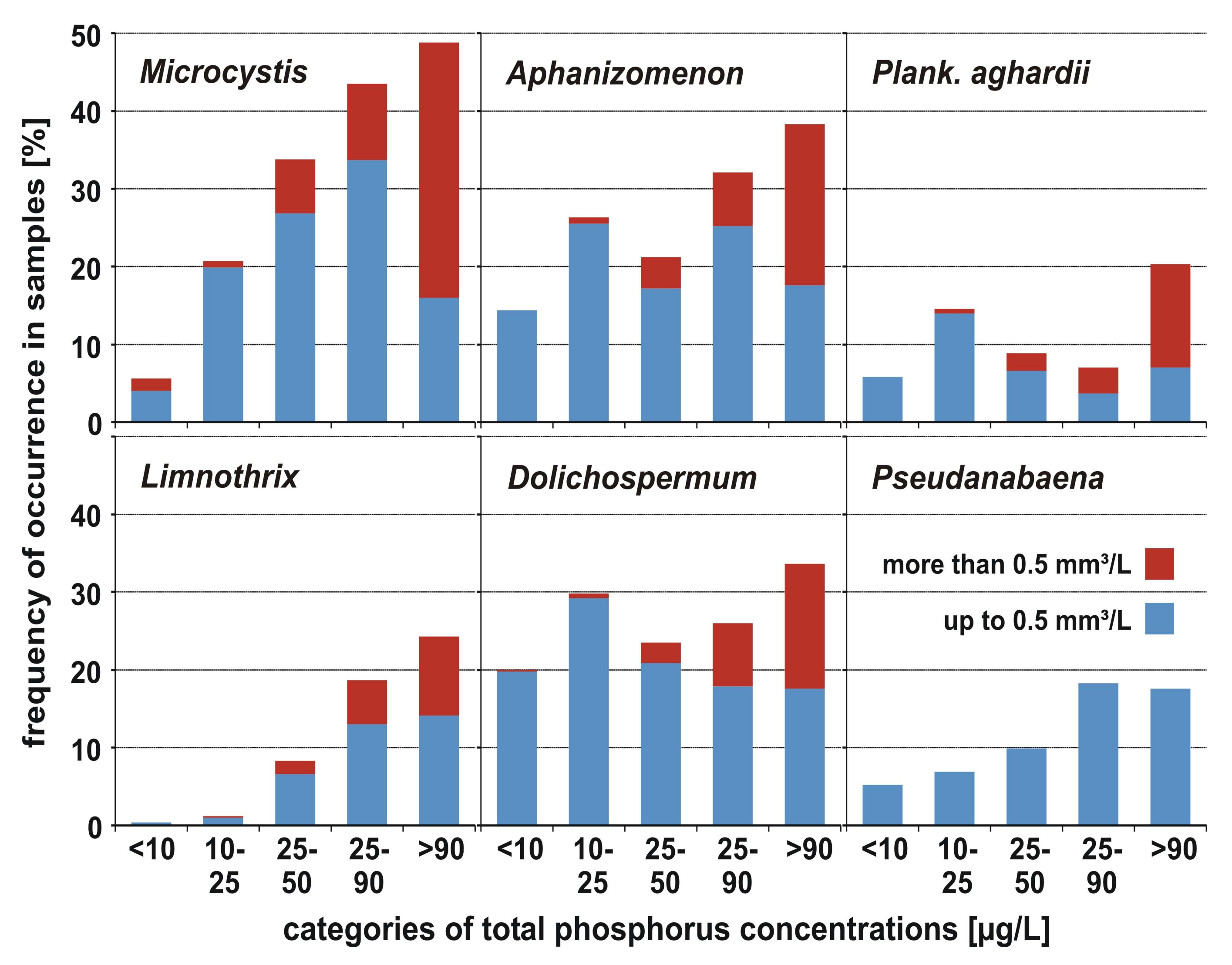
Waterbody conditions; phosphorus concentrations

Total phosphorus	Mixing conditions		Transparency	pH
>50 µg/L	Stagnant, >5-10 m, stable thermal gradients: Favours scum-forming taxa, i.e. *Microcystis, Dolichospermum, Aphanizomenon*	Stagnant, shallow and well mixed: Favours non-scum forming, i.e. *P. agardhii*; fine filamentous e.g. *Limnothrix*	Low; Secchi-depth often <1 m	pH >7 (often >8 or possibly >9 due to photosynthesis)
>20 - ≤50 µg/L	Stagnant, >10 m, stratified: potential for mass development of *Planktothrix rubescens* accumulating at the metalimnion		Moderate; Secchi-depth ~1- 3 m	pH ≥7
>10 - ≤20 µg/L	Fast flowing river	Lake or reservoir with residence <1 month	High; Secchi-depth ~3- 7 m	pH 6-7
≤10 µg/L	Mountain stream or brook		Very High - Clear water; Secchidepth often >7 m	pH<6
	exception: mats of cyanobacteria on surfaces			

Waterbody conditions; phosphorus concentrations

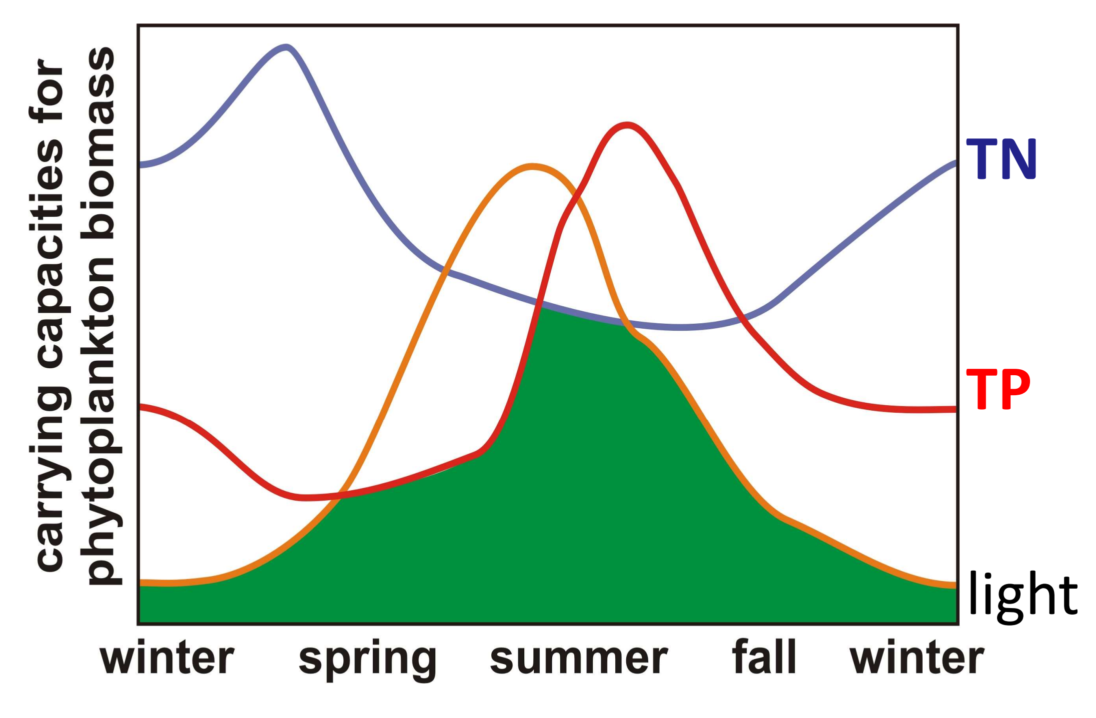
Frequency of occurrence in 1928 samples from 210 water-bodies

Number of samples per category from lowest to highest TP-concentrations: 501, 623, 302, 246, 256



Waterbody conditions; phosphorus concentrations

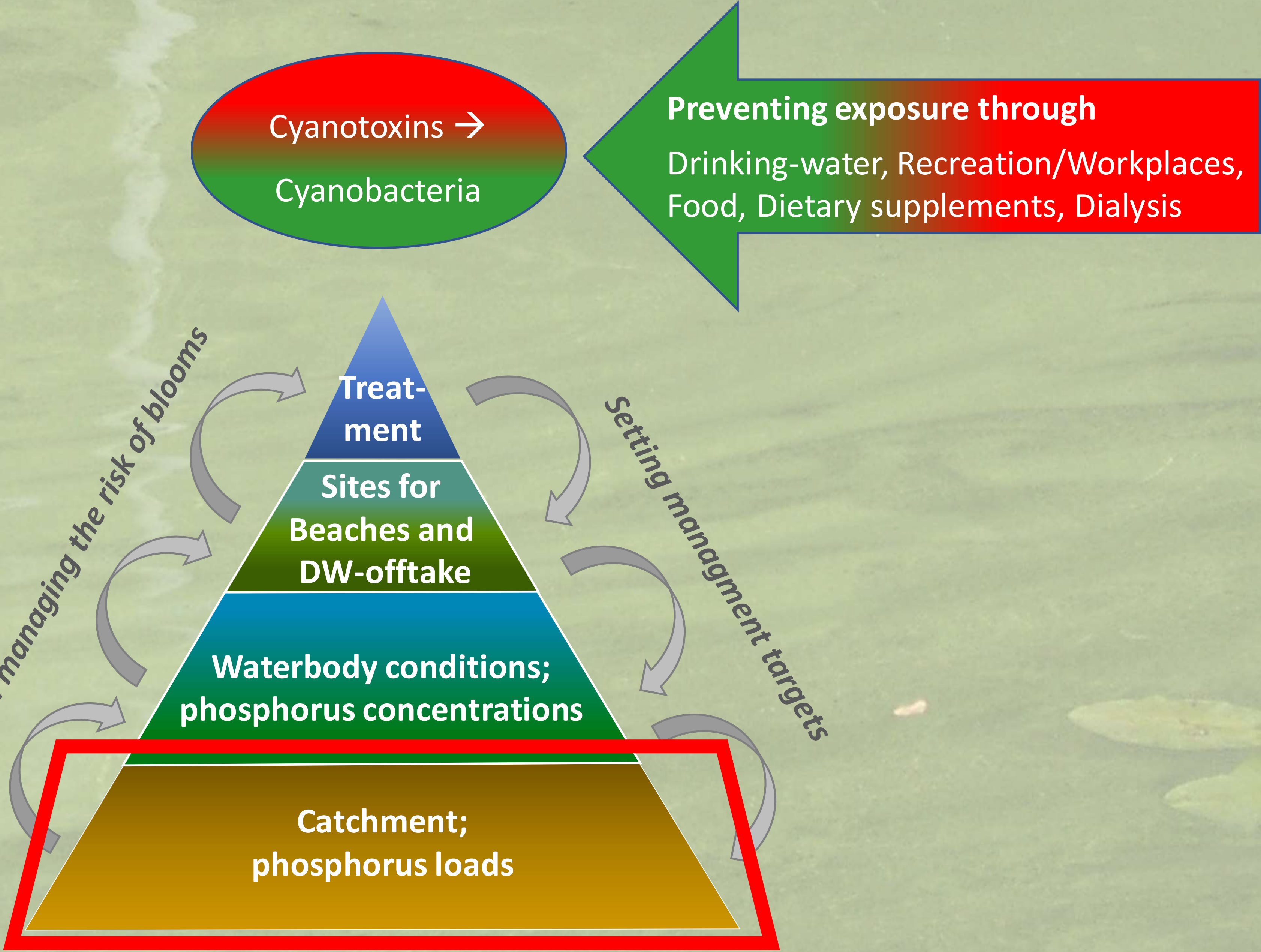
Why focus on total phosphorus (TP)?



- Law of limiting factor: limiting one does the job
- P is usually easier to control than N (cheaper in sewage treatment)
- Denitrification gets rid of excessive N (particularly in warm climates)

But:

- Where N is already limiting, enhancing that may be effective
- Excessive N damages macrophytes
- Estuaries ??

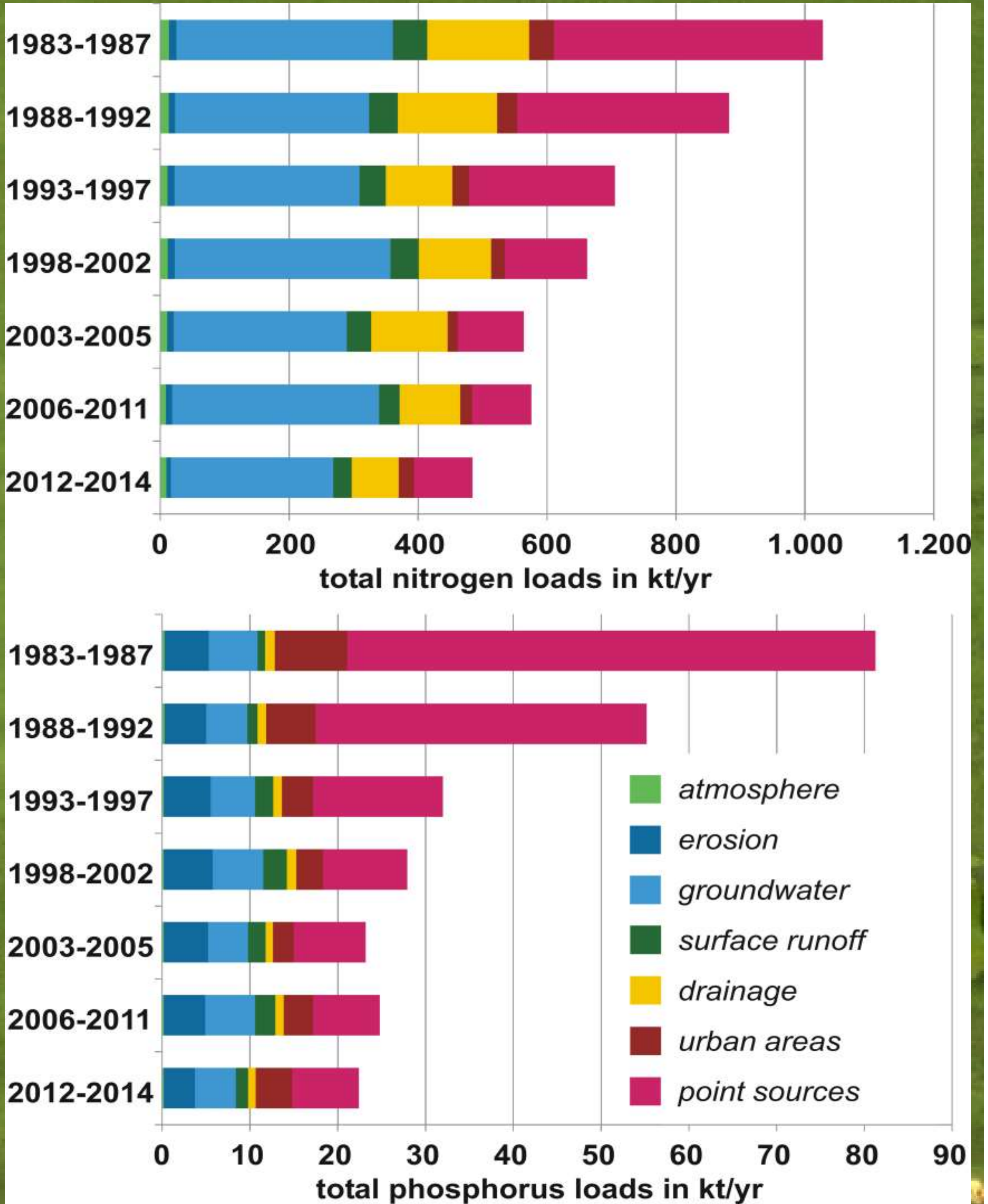

Cyanotoxins →
Cyanobacteria
Preventing exposure through
Drinking-water, Recreation/Workplaces, Food, Dietary supplements, Dialysis
Treat-ment
Sites for Beaches and DW-offtake
Waterbody conditions; phosphorus concentrations
Catchment; phosphorus loads
Assessing and managing the risk of blooms
Setting managment targets

Catchment; phosphorus loads

Loads of N and P to surface water-bodies in Germany

kilotons per year (kt/yr)

UBA (2017)

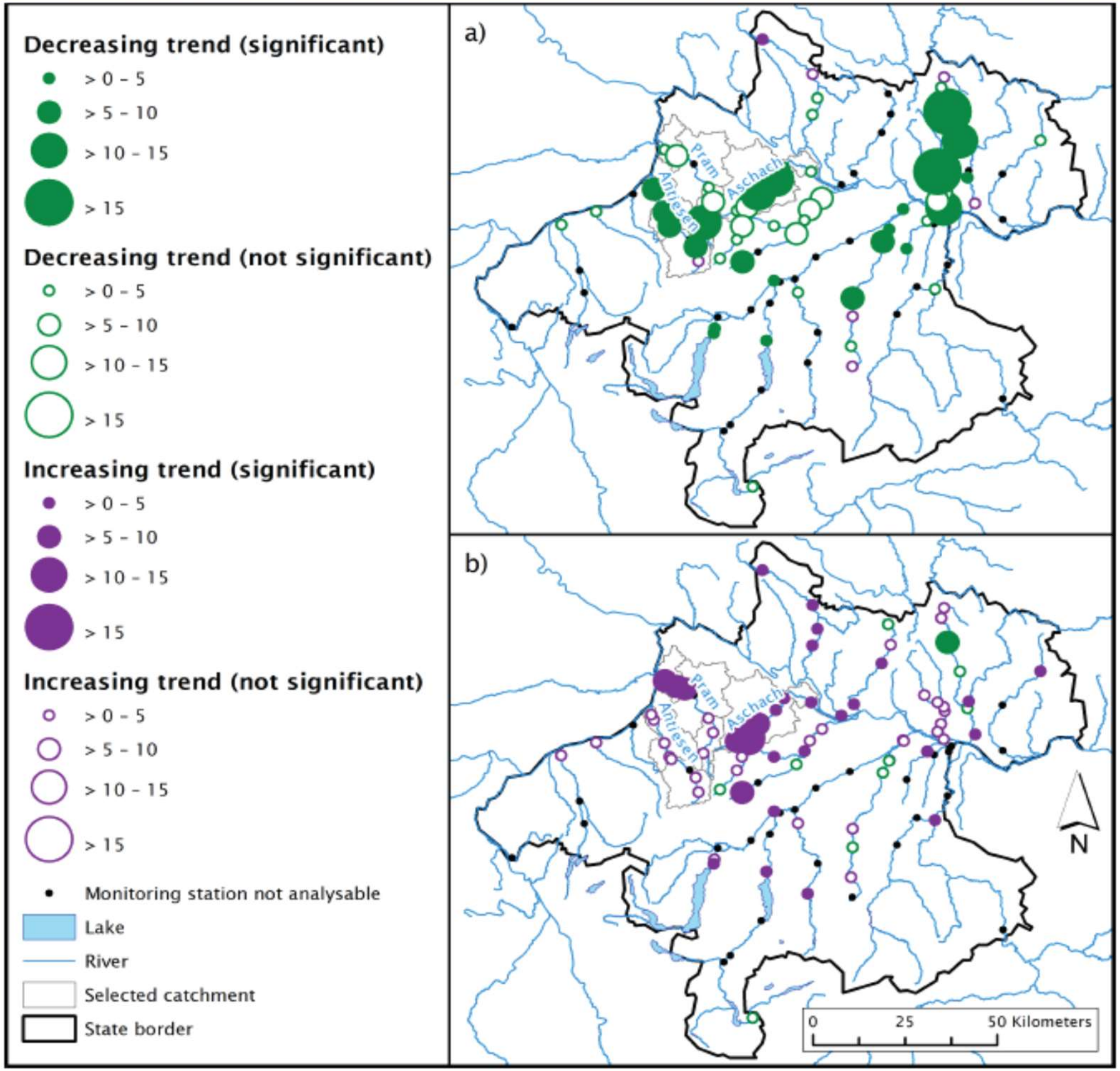


Catchment;
phosphorus loads

TCiW Figure 7.3 (Zessner):

Trends of TP, flow adjusted in surface waters in Upper Austria for:
(a) 1990-2000
(b) 2001-2004

[µg/L×year]

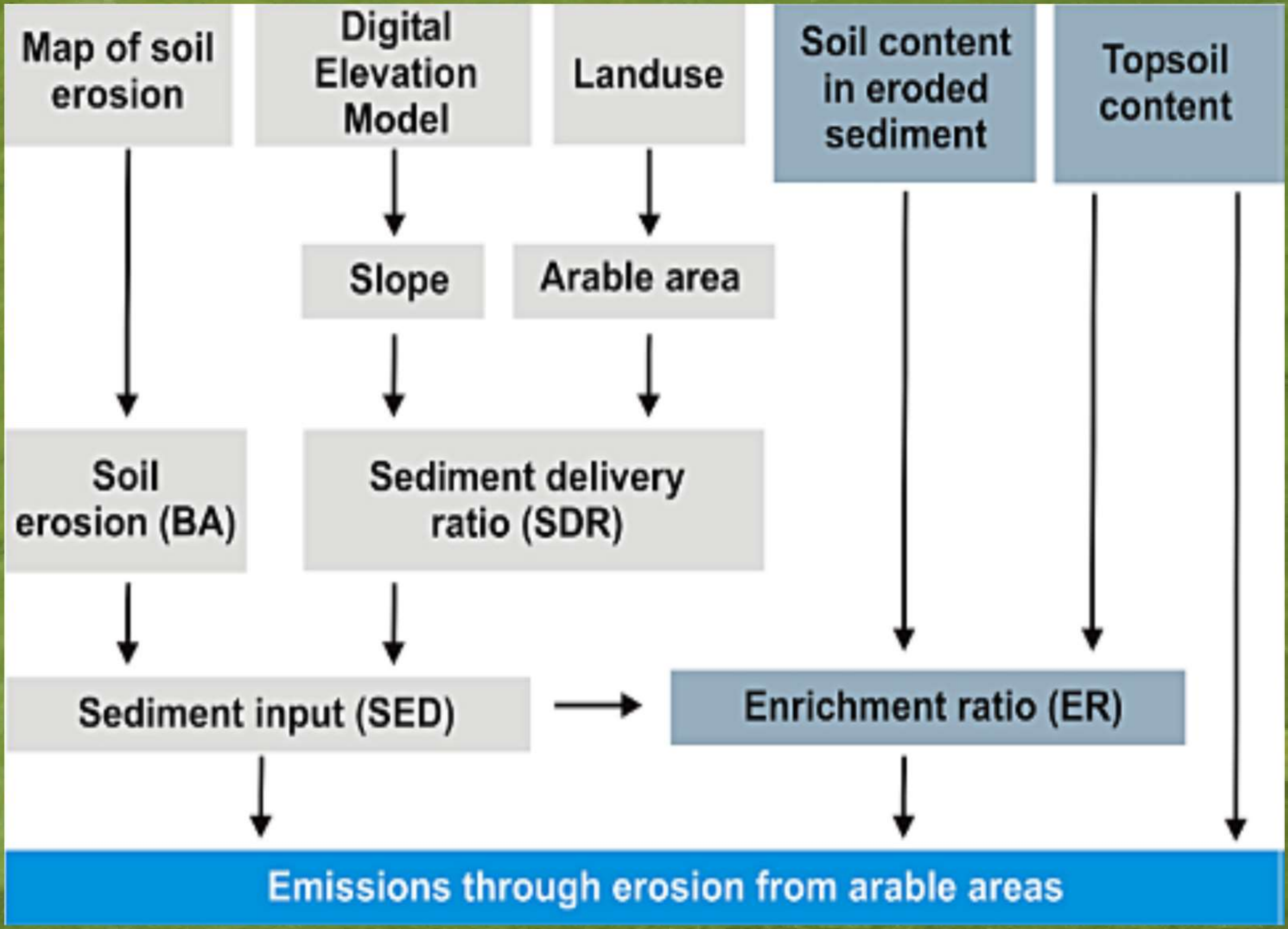


Catchment;
phosphorus loads

Setback distances / buffer strips around waterbodies - Itaipu

Catchment;
phosphorus loads

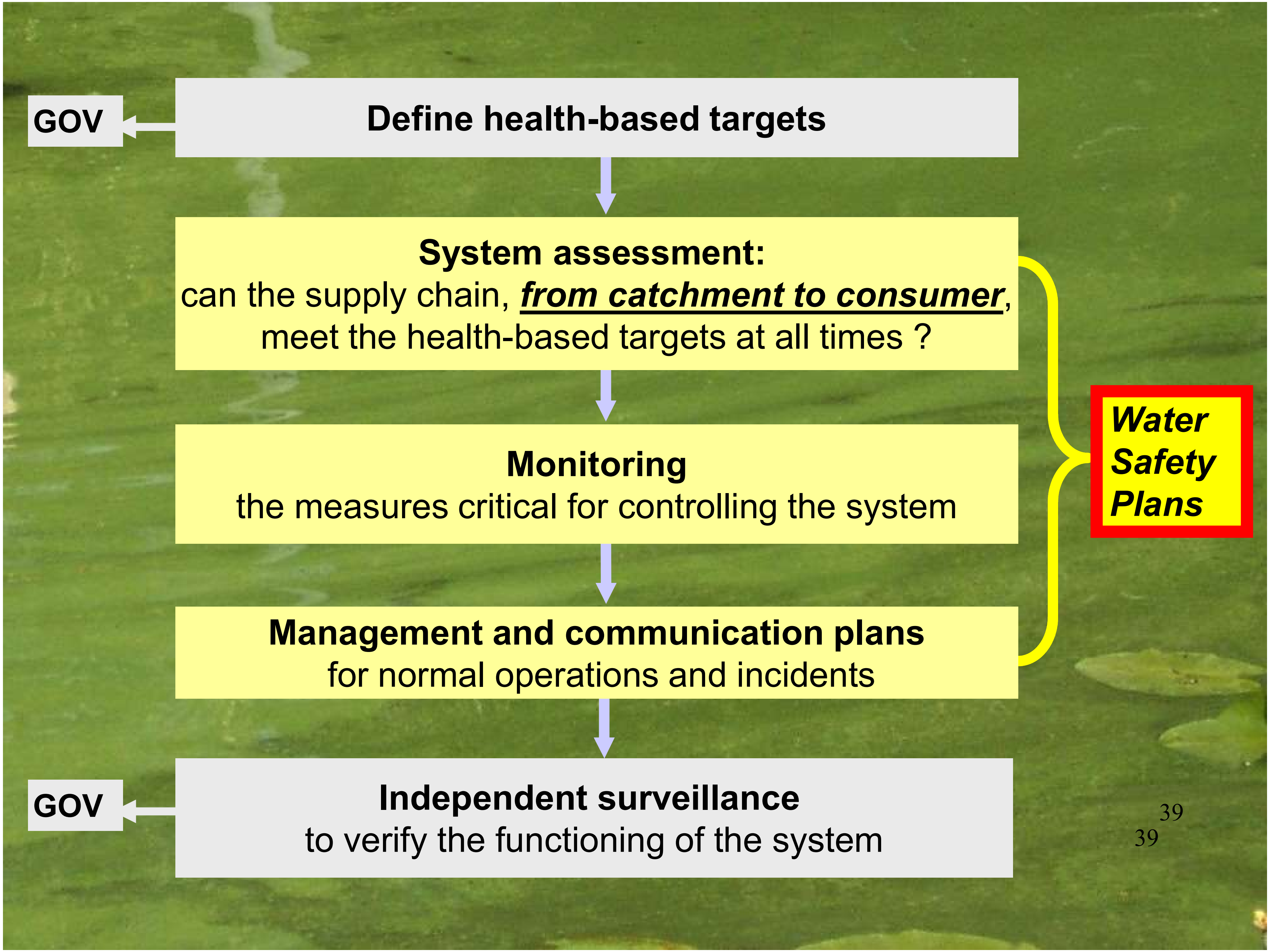
Modelling loads – information



Zessner in TCiW, Figure 7.4: **Input data** needed to quantify the emissions from erosion

Policy instruments to control diffuse loads from agriculture without farmers loosing income:

- Fertilising according to soil content (measured at the end of the growing season)
- Small-scale differentiation of areas fertilised by monitoring crop growth via drone or plane
- Balancing nutrients that enter the farm against those leaving it with the crop (records inspected by authority)
- Buying vulnerable areas in the catchment
- Subsidising farmers for extensifying their operations using limited amounts of agrochemicals
- Setback distances / buffer strips around waterbodies, possibly subsidised


GOV
Define health-based targets
System assessment:
can the supply chain, from catchment to consumer,
meet the health-based targets at all times ?
Monitoring
the measures critical for controlling the system
Management and communication plans
for normal operations and incidents
Water Safety Plans
GOV
Independent surveillance
to verify the functioning of the system

39

Water Safety Plans

<u>Steps</u>:

- **Assess the risks, including the efficacy of existing control measures**
- **From that, determine priority actions**
- **Define Control measures**
- **Validate that they are effective**
- **Document the system and the assessment**
- **Revise the WSP periodically**

For each Control Measure:

1. **Determine operational limit not to be exceeded**
2. **Determine <u>monitoring system</u> for that limit**
3. **Determine corrective action**

Water Safety Plans

Preliminary steps for developing a WSP

1. **Support of leading management**
   often underestimated !

2. **Form a Water Safety Plan team**
   excellent platform for intersectoral collaboration !

3. **Describe water supply (flow chart)**
   typically surprises pop up about aspects overlooked, not documented …

Take home messages:

1. **The catchment system is not hopeless – you ONLY have < 100 µg/L TP!** And there **<u>are</u>** effective catchment management approaches to reduce P loading:
   - Riparian buffer strips
   - Fertilising according to demand (soil P content/crop growth)
   - Regulations requiring farm gate budgets

   ➔ estimate TP loads from the catchment!

2. **Toxin cell quotas** are useful to understand „your bloom" – and do analyse toxins! **Please publish!** (Are regional analytical centers to provide that service an option?)

3. Consider using the WHO **Water Safety Planning** approach! (Umweltbundesamt provides training)

Comments, information on toxin/biomass ratios to:
ingrid.chorus@gmail.com


Thank you for your attention !

Developing a Water Safety Plan: the following slides show steps we did not have time to discuss.

For further guidance (in english) see also https://toxische-cyanobakterien.de/en/

Water Safety Plan: System and risk assessment

Direct indication		N	O	F	U	assessment	uncertainty
Humans / animals	Illness indicating cyanotoxins						
Cyanotoxins > 1 µg/L	Observed in water-body						
Cyanobacterial proliferation	Visible blooms, green turbidity						
Cyanobacterial biomass > 1 mm^3/L or 1 µg/l Chl.-*a*	Microscopy, Chl.-a analyses Pigment fluorescence						

N = no indication, O = occasional, F = frequent, U= uncertain information basis

Water Safety Plan: System and risk assessment

Water-body conditions		N	P	Y	U	Assessment ?	Uncertainty ?
General condition of water-body	e.g. eutrophic, deep with stable thermal stratification or shallow, mixed? retention time > 1 month ?						
Current condition s in water-body	e.g. elevated temperature; stratified? TP-conc. > 10-30 µg/L; low transparency ?						
... ? ...	... ? ...						

N = no indication, P= probable, Y = yes, U= uncertain information basis

Water Safety Plan: System and risk assessment

Nutrient loading	C	P	N	U	Assessment	Uncertainty
Assessment by catchment inspection						
Assessment through measuring and/or modelling nutrient loads						

C = control quite certain, P= probable, N = control not given,
U= uncertain information basis

Water Safety Plan: System and risk assessment

Bank Filtration **Slow Sand Filtration**	Y	P	N	U	Assessment	Uncertainty
Oxidising conditions						
Travel time > 4 weeks						
Fine-grained substrate						
Temperature > 10 °C						
Low accumulation of lysing cells on sediment						
… ? …						

Y = Yes, P = Partially, N = No, U = lack of information

Water Safety Plan: System and risk assessment

Reservoir offtake strategy	Y	P	N	U	Assessment	Uncertainty
Is offtake depth / site variable ?						
Is offtake continuously monitored for cells (e.g. fluorescence; particle counting; turbidity; daily sampling and microscopy)?						
Can adaption of offtake sites effectively avoid cell intake						
…. ? …						

Y = Yes, P = Partially, N = No, U = lack of information

Water Safety Plan: System and risk assessment

Drinking-water Treatment	Y	P	N	U	Assessment	Uncertainty
No pre-oxidation Step						
Flocculation and Filtration						
Flocculation and Flotation						
Post-oxidation						
Powdered activated carbon						
GAC (granular activated carbon filtration)						
… ? …						

Y = Yes, P = Partially, N = No, U = lack of information

Water Safety Plan: System and risk assessment - examples

hazardous event	hazard	risk; basis for assess-ment	uncertainty of assessment	control measures	residual risk; basis for assess-ment	uncertainty of assessment	measures
***Microcystis* bloom**	**MCYST in DW at several µg/L**	high; conc. in previous blooms	low; good understanding of WB from 10 years data				

Water Safety Plan: System and risk assessment - examples

hazardous event	hazard	risk; basis for assess-ment	uncertainty of assessment	control measures	residual risk; basis for assess-ment	uncertainty of assessment	measures
***Microcystis* bloom**	**MCYST in DW at several µg/L**	high; conc. in previous blooms	low; good understanding of WB from 10 years data	**1. DW treatment (ozone + GAC);**	medium; experience with MCYST, removal **but no 2. barrier!**	low; MCYST, was always effectively removed; literature confirms this	**1. mainten-ance ozone and GAC;**

Water Safety Plan: System and risk assessment - examples

hazardous event	hazard	risk; basis for assess-ment	uncertainty of assessment	control measures	residual risk; basis for assess-ment	uncertainty of assessment	measures
***Microcystis* bloom**	**MCYST in DW at several µg/L**	high; conc. in previous blooms	low; good understanding of WB from 10 years data	**2. farm ma-nagement**	medium; fertilisation management plans are just beginning to work	low; good loading model; confidence in prediction of load development	**2. Strengthen collabora-tion with farmers**

Water Safety Plan: System and risk asessment - examples

hazardous event	hazard	risk; basis for assess-ment	uncertainty of assessment	control measures	residual risk; basis for assess-ment	uncertainty of assessment	measures
***Microcystis* bloom**	**MCYST in DW at several µg/L**	high; conc. in previous blooms	low; good understanding of WB from 10 years data	**1. DW treatment (ozone + GAC);** **2. farm ma-nagement**	medium; experience with MCYST, removal; 2. barrier just beginning	low; MCYST, was always effectively removed; good load models	**1. mainten-ance ozone and GAC;** **2. catch-ment**
***Planktothrix agardhii* proliferation**	**Cyano-toxins; MCYST**	high; Secchi < 0.5 m; greenish	high; no phytopl. or cyanotoxin data	**Poor** DW treat-ment insuf.; intensive farming	high	high; no phytopl. or cyanotoxin data	**1. Phyto-plankton analyses** **2. Introduce bank filtrat.**

Water Safety Plan: System and risk assessment - examples

hazardous event	hazard	risk; basis for assess-ment	uncertainty of assessment	control measures	residual risk; basis for assess-ment	uncertainty of assessment	measures
***Microcystis* bloom**	**MCYST in DW at several µg/L**	high; conc. in previous blooms	low; good understanding of WB from 10 years data	**1. DW treatment (ozone + GAC);** **2. farm ma-nagement**	medium; experience with MCYST, removal; 2. barrier just beginning	low; MCYST, was always effectively removed; good load models	**1. mainten-ance ozone and GAC;** **2. catch-ment**
***Planktothrix agardhii* proliferation**	**Cyano-toxins; MCYST**	high; Secchi < 0.5 m; greenish	high; no phytopl. or cyanotoxin data	**Poor** DW treat-ment insuf.; intensive farming	high	high; no phytopl. or cyanotoxin data	**1. Phyto-plankton analyses** **2. Introduce bank filtrat.**
***Planktothrix rubescens* at offtake**	**high MCYST intake**	high; lit. = contain a lot	medium; cell data but no tox data	**Variable offtake**	medium; winter mix; Only PAC	medium; no own data	**1. tox data** **2. catchm.**