Prediction, valuation and ecological effects of future stream water quality based on socio-economic scenarios and climate change predictions for 2050.

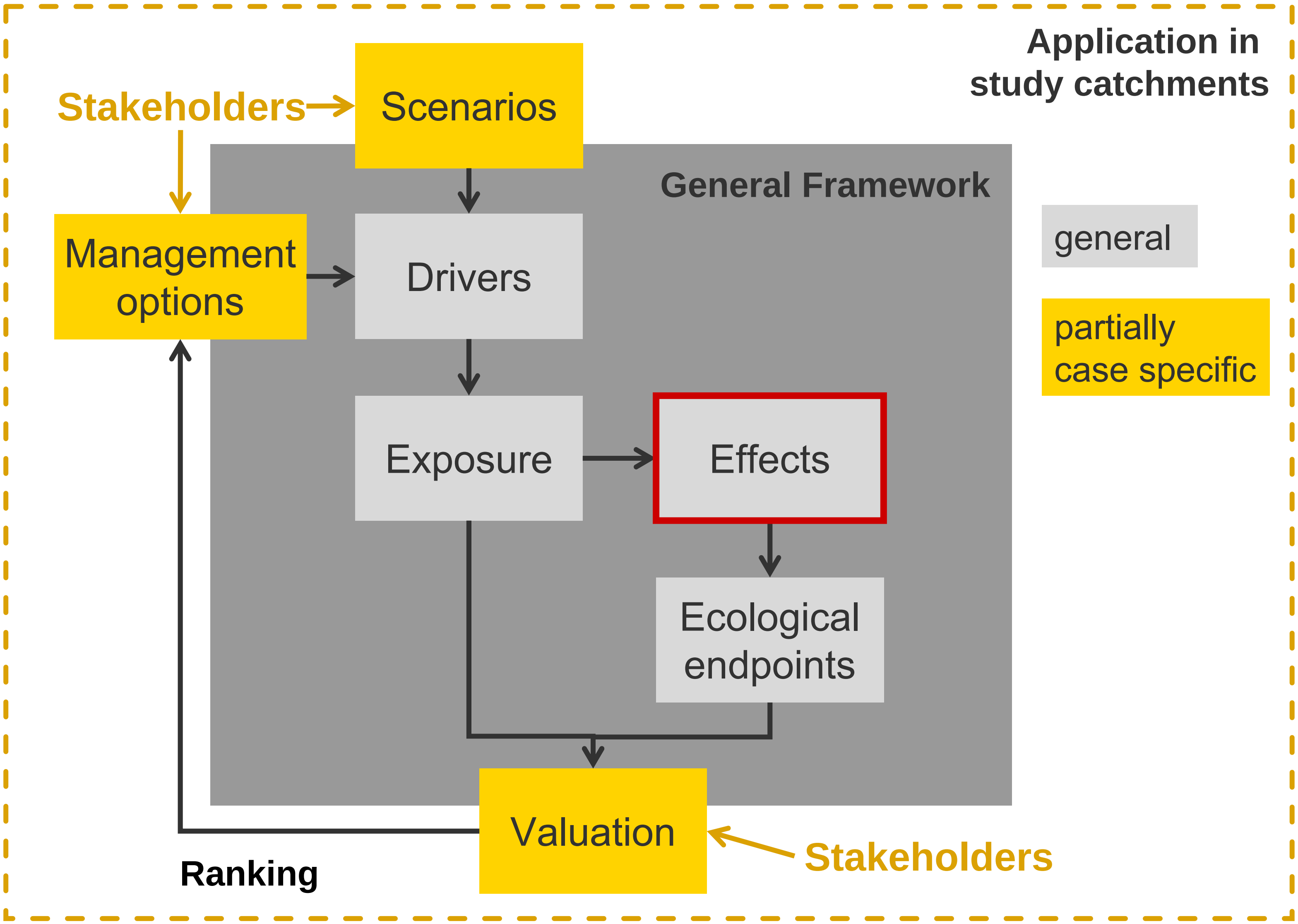
Nele Schuwirth, Mark Honti, Anne Dietzel, Peter Reichert, Christian Stamm

Project "iWaQa":
Integrated management of river water quality
within the National Research Program 61
on Sustainable Water Management

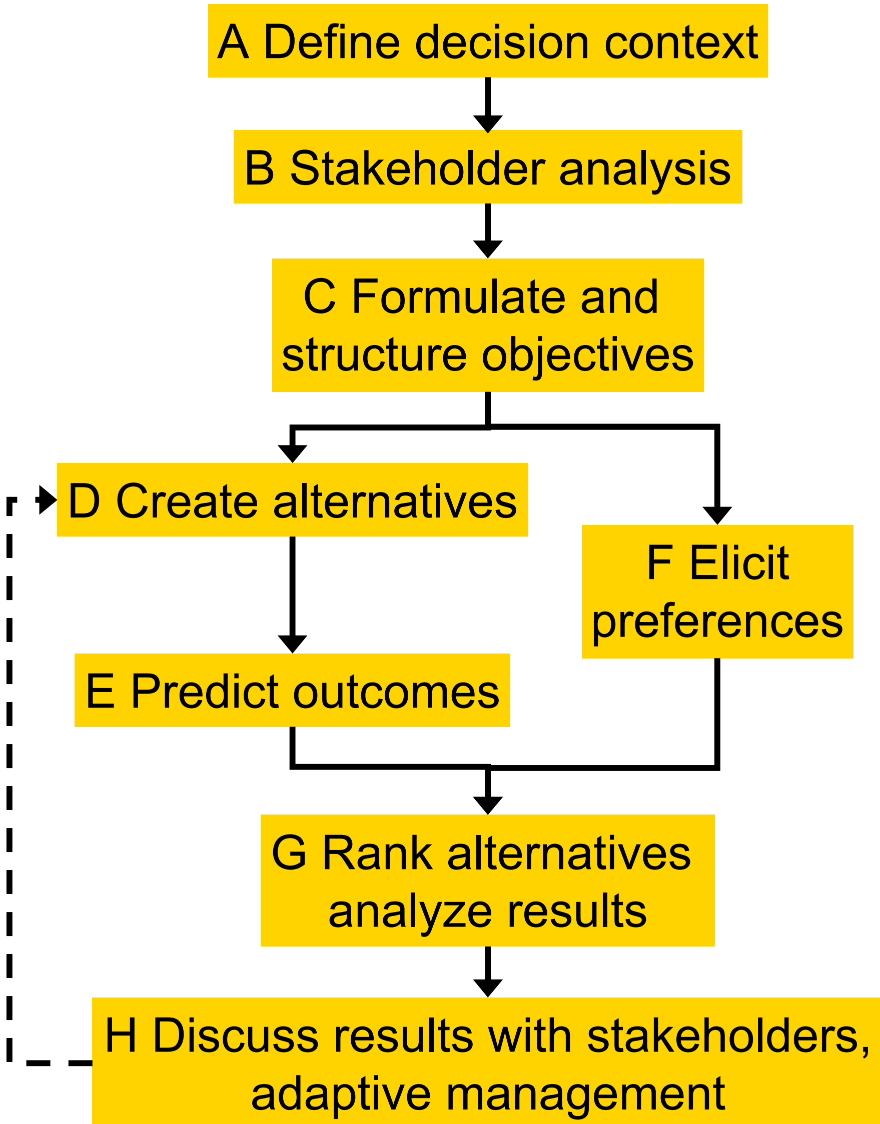
Eawag: Swiss Federal Institute of Aquatic Science and Technology

Conceptual framework - project iWaQa

"Integrated management of river water quality"



Decision Analytic Framework



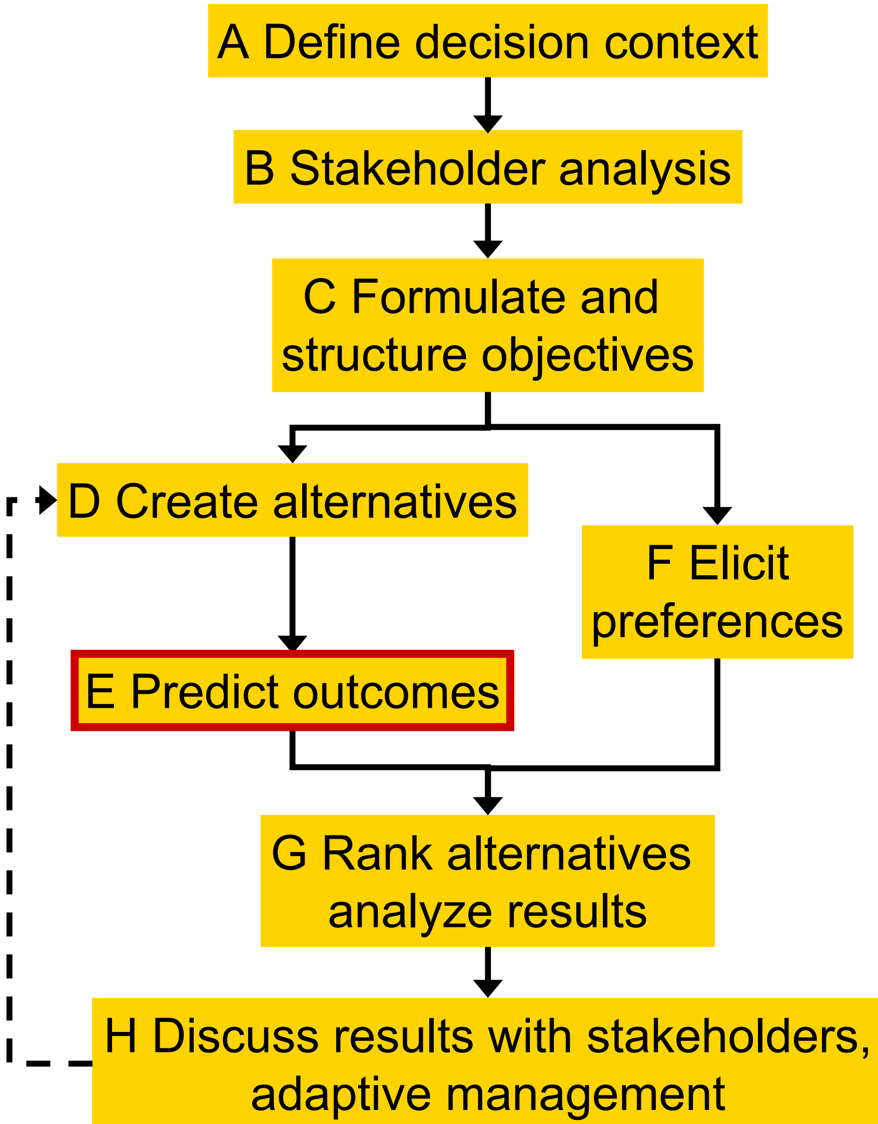
Aims:

- Learning about management alternatives
- Learning about stakeholder opinions
- Learning about influence of uncertain future
- Identification of potential consensus-solutions

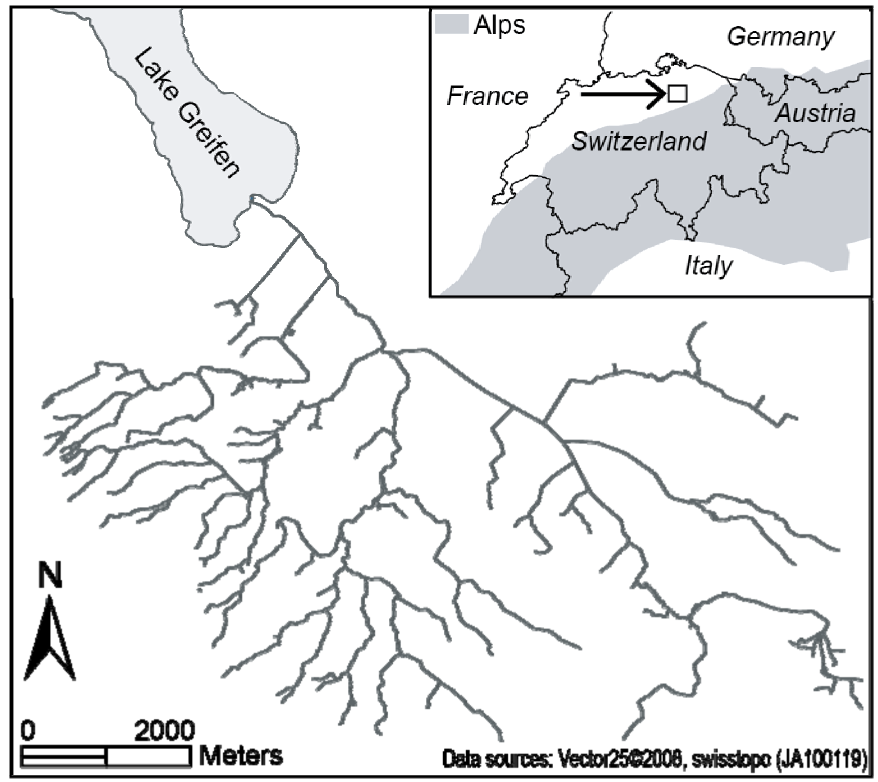
→ separating prediction of outcomes (experts) from evaluation (subjective opinion)

Schuwirth et al. 2012 EJOR: Methodological aspects of multi-criteria decision analysis for policy support: A case study on pharmaceutical removal from hospital wastewater

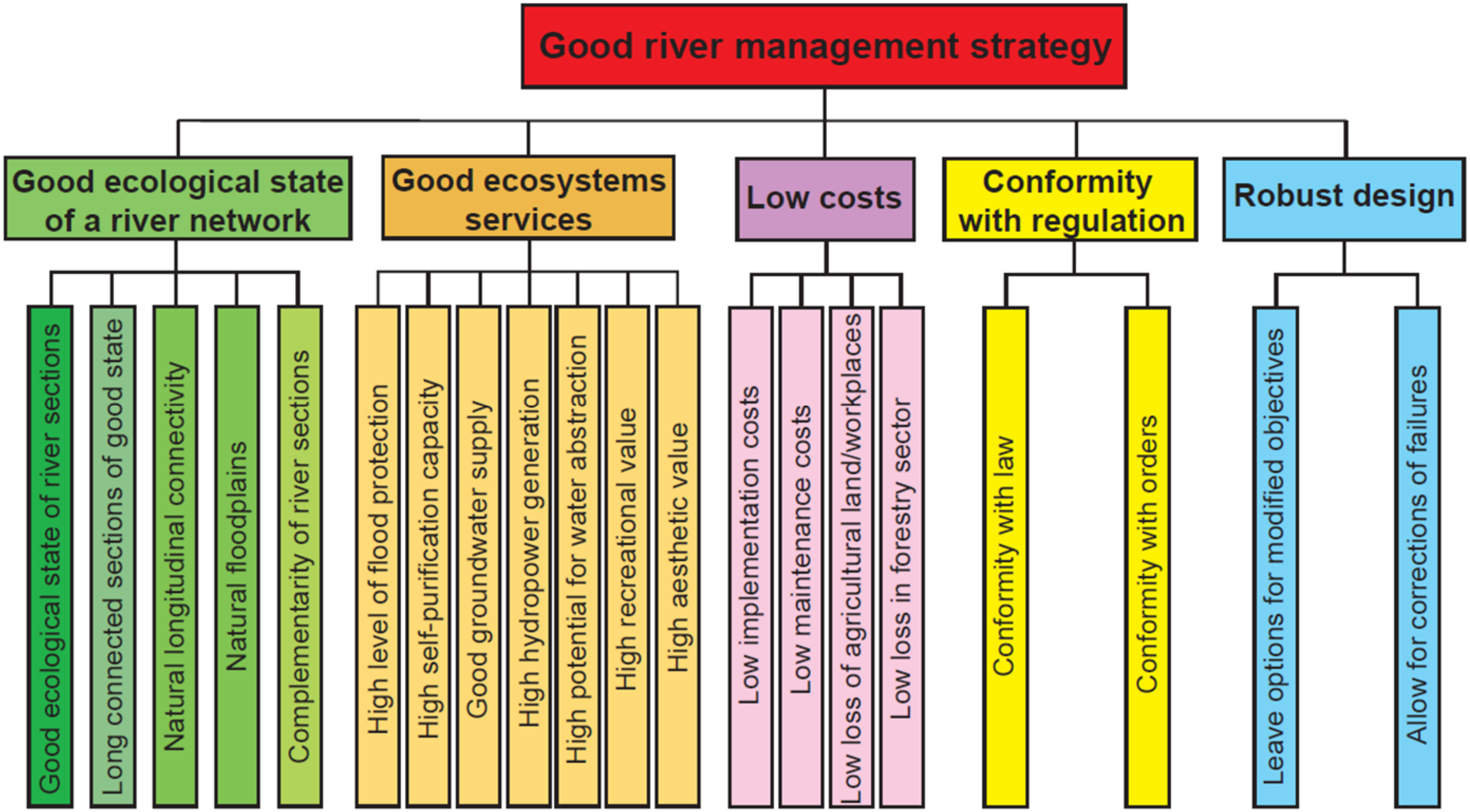
Decision Analytic Framework



How to improve river water quality in a catchment of the Swiss Plateau?

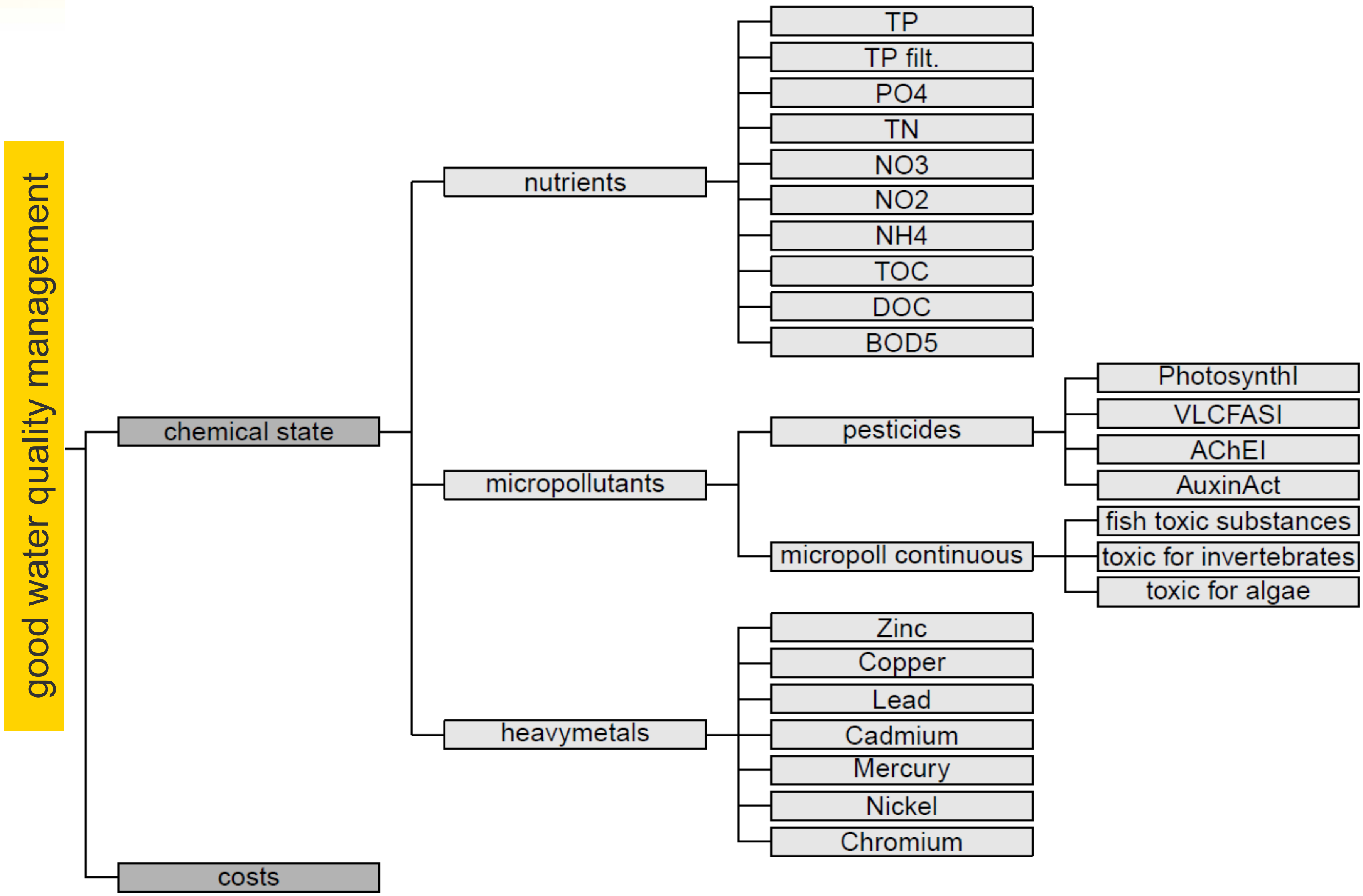


C Objectives River Management



Reichert et al. 2011 WEL; Reichert et al. (submitted):The Conceptual Foundation of Environmental Decision Support

C Objectives Water quality management



D Create alternatives

Sources of impairment

urban
material protection

agri-culture
surface runoff

urban
gardening

river water quality: sources of pollution

agri-culture
tile drainage

urban
drainage
sewer overflows

Waste-water-treatment-plants

D Create alternatives

Management alternatives to improve water quality

- none: current management practice
- A: combination of all measures

urban material protection

- fac: banning the use of biocides in facades

urban drainag e sewer overflows

- cso: increase CSO buffer volume
- pav: decrease area of impermeable pavements
- inf: increase rain water infiltration from roofs

WWTP

- wwtp: upgrade WWTP to remove micropoll.

agri- cultur e

- bio: change to organic farming
- nat: change to ext. agriculture - nature park
- buf: install buffer strips to reduce spray drift

E Socio-economic scenarios horizon 2050

Boundary conditions that cannot be influenced by WQ management alternatives

	mean income	population	urban area
Status quo	+0.4 %/year	as today	as today
Boom	+4	+730 %	+300 %
Doom	-1.5	-20 %	-
Quality of life	+2	+20 %	+5 %

Boom

Doom

Quality of life

Developed in a stakeholder workshop, Lienert et al. (submitted)

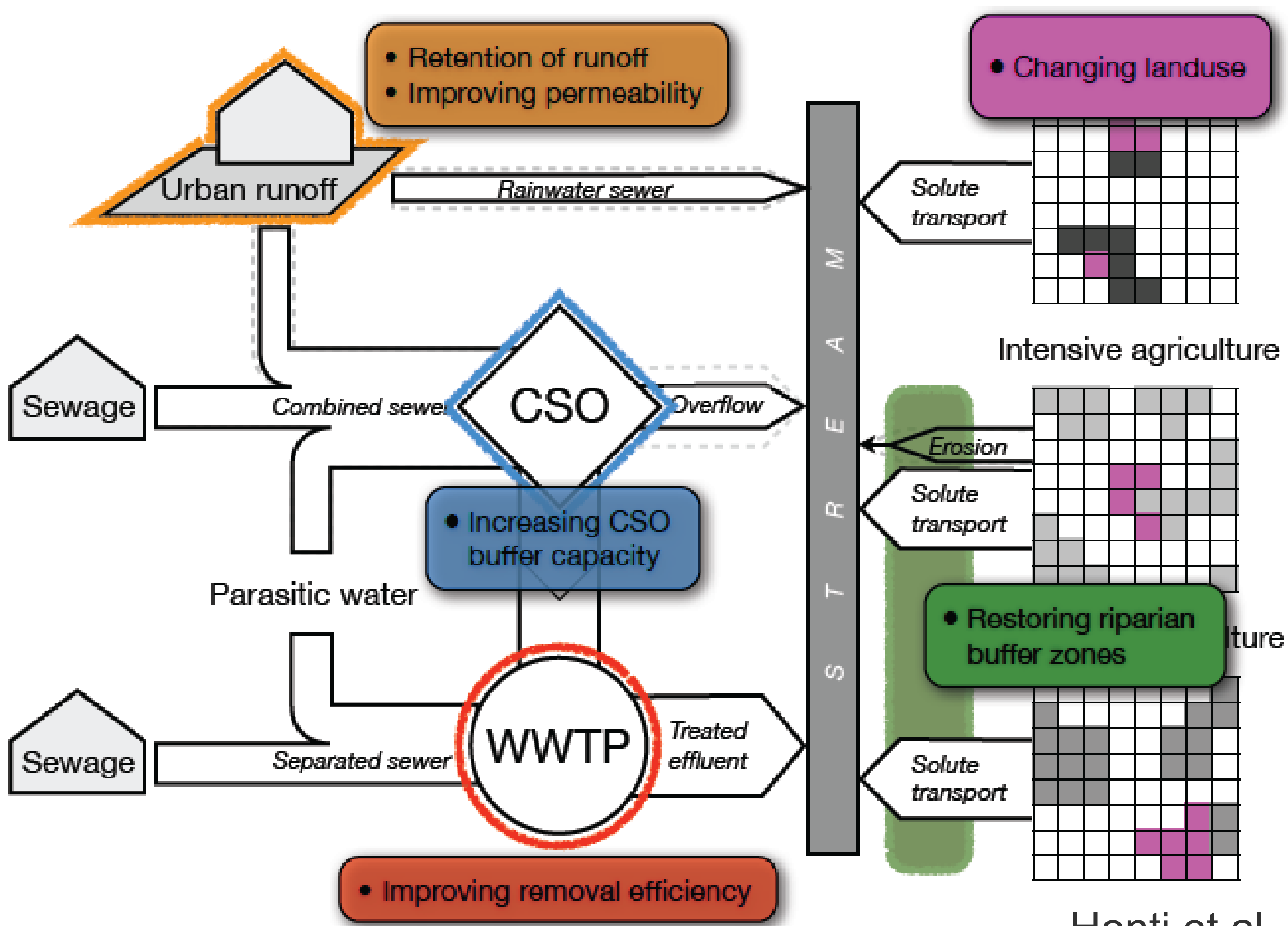
E Climate change - horizon 2050

- IPCC A1B emission scenario (scenarios hardly differ until 2050)
- 10 ENSEMBLES GCM-RCM model chains, daily data for precipitation & air temperature
- Neyman-Scott Rectangular Pulses (NSRP) model to generate hourly precipitation
- UKCP09 weather generator (which is based on the NSRP model) for daily values of other weather parameters

Honti, M., Scheidegger, A., Stamm, C. (2014): Importance of hydrological uncertainty assessment methods in climate change impact studies. Hydrol. Earth Syst. Sci. Discuss., 11, 501-553

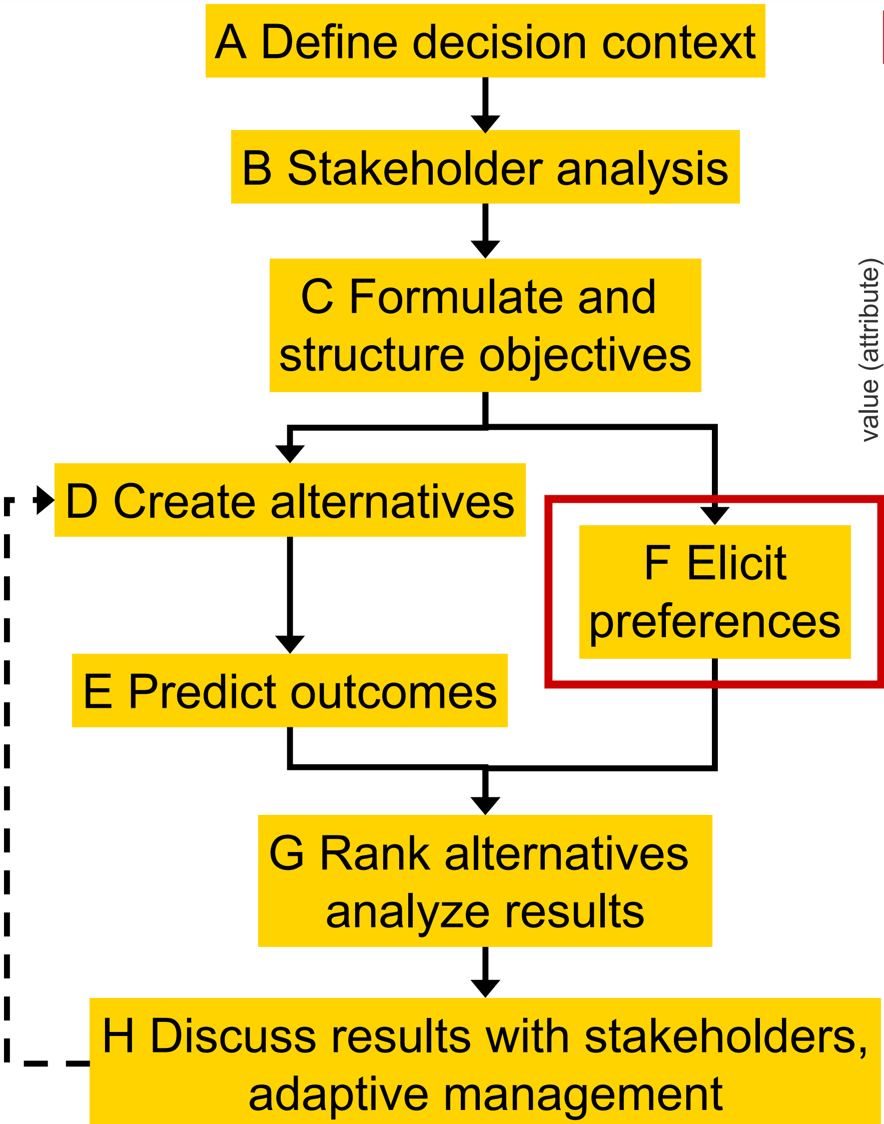
E Water quality model

Pollutant transport management



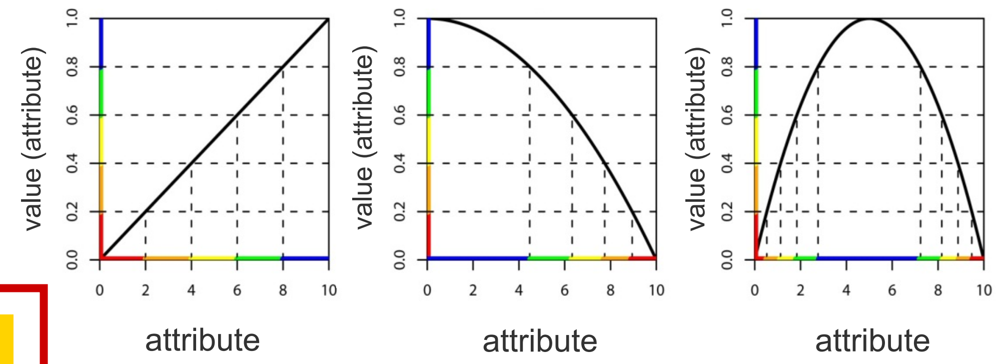
Honti et al. (in prep.)

F Preferences



Multi-attribute value theory

1. value functions for lowest level sub objectives

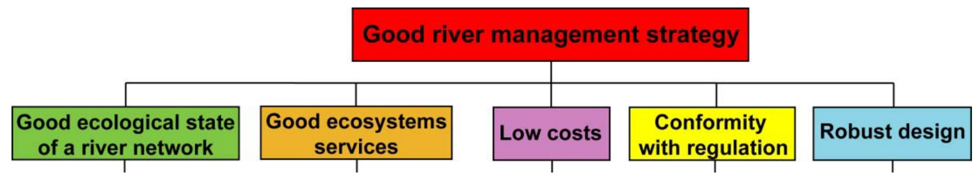


2. hierarchical aggregation:
trade-offs between objectives

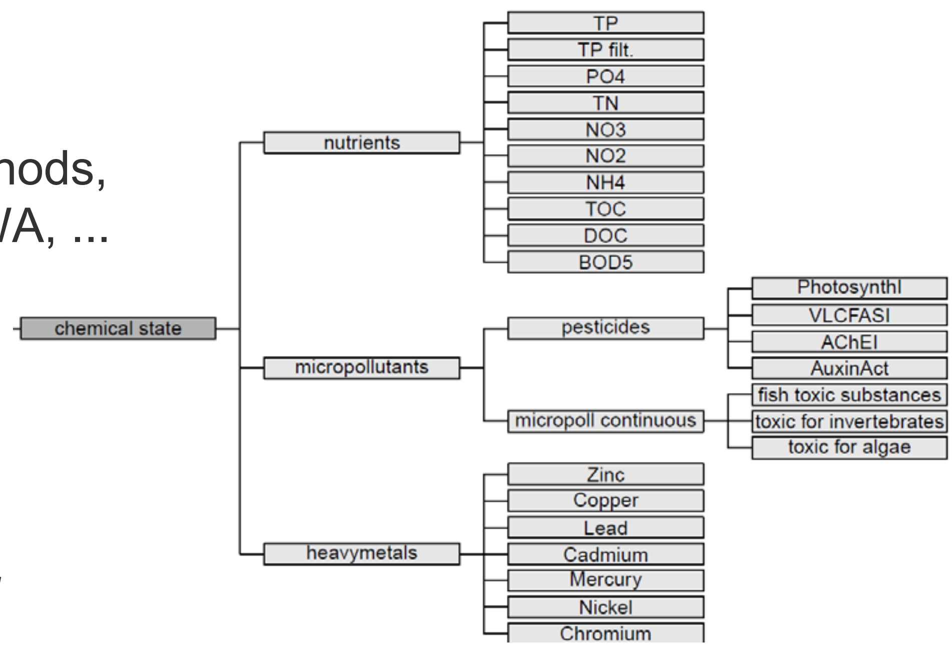
Schuwirth et al. 2012 EJOR: Methodological aspects of multi-criteria decision analysis for policy support: A case study on pharmaceutical removal from hospital wastewater

F Elicitation of Preferences

- Higher levels:
  societal values
  elicited from stakeholders
  case specific

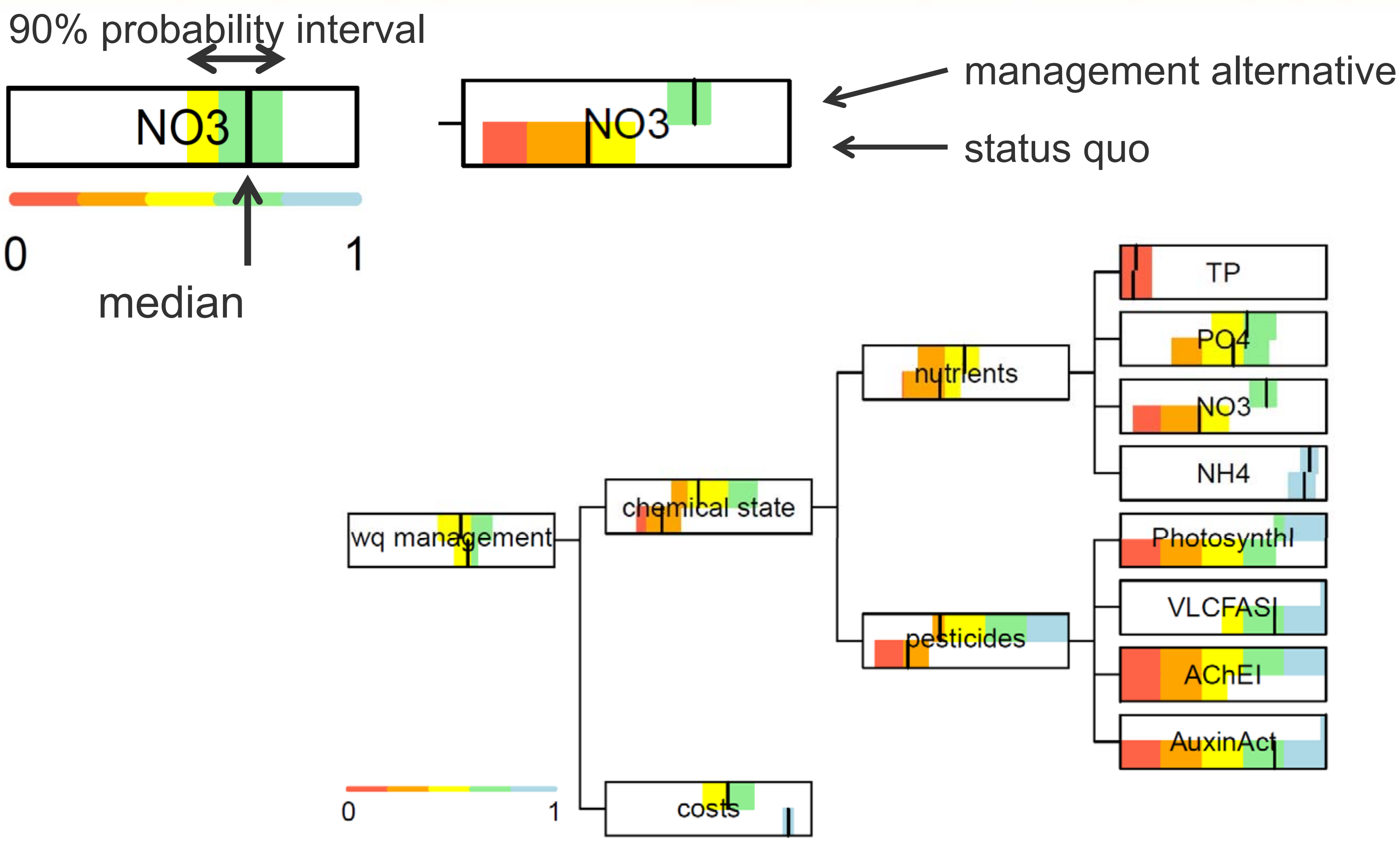


- Lower levels of some branches:
  require expert knowledge
  should be generic
  translation of existing assessment methods,
  e.g. www.modulstufenkonzept.ch, LAWA, ...



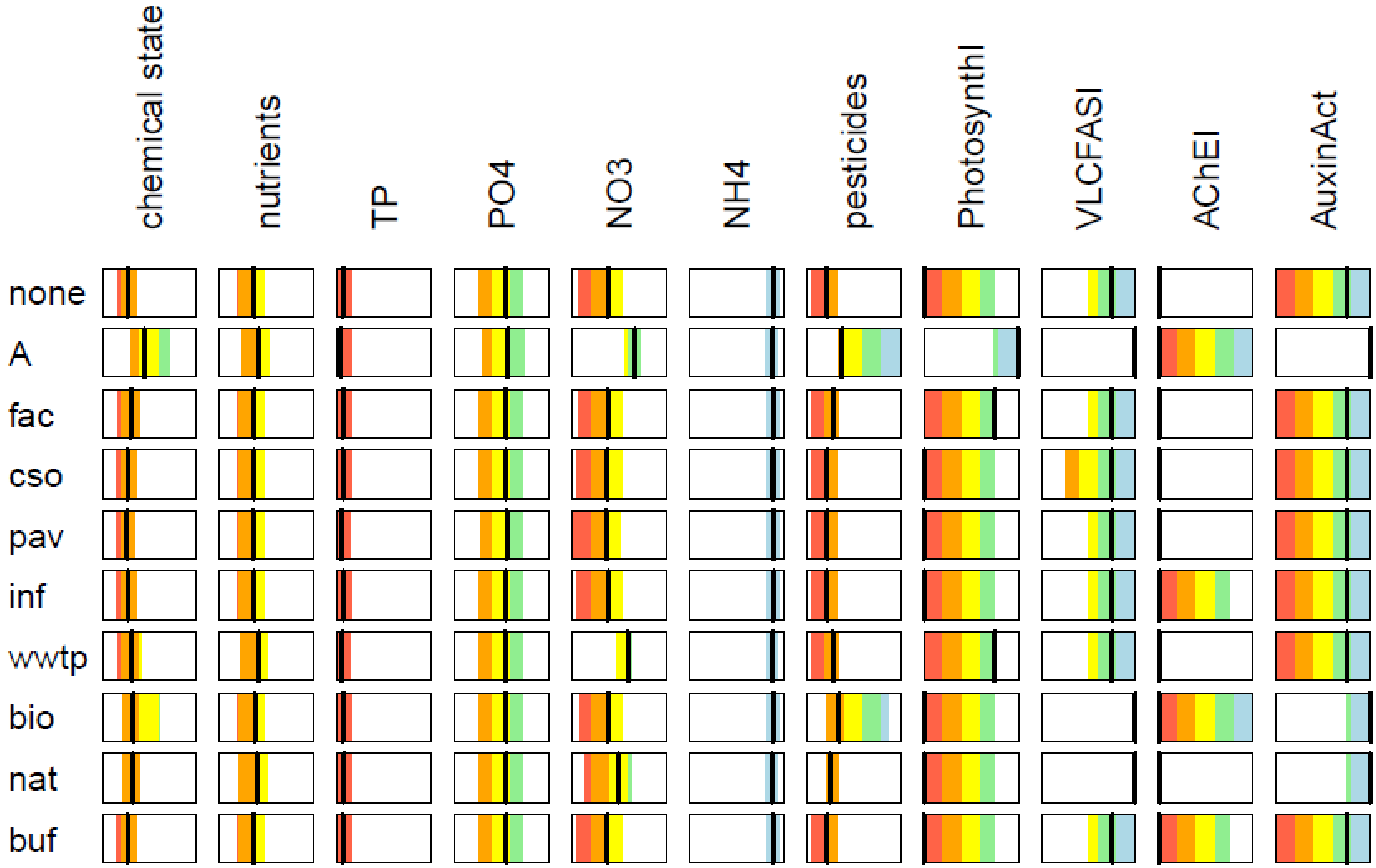
Langhans, Lienert, Schuwirth, Reichert (2013): How to make river assessments comparable: a demonstration for hydromorphology. *Ecological Indicators* 32, 264–275

G Visualization of results - hierarchy



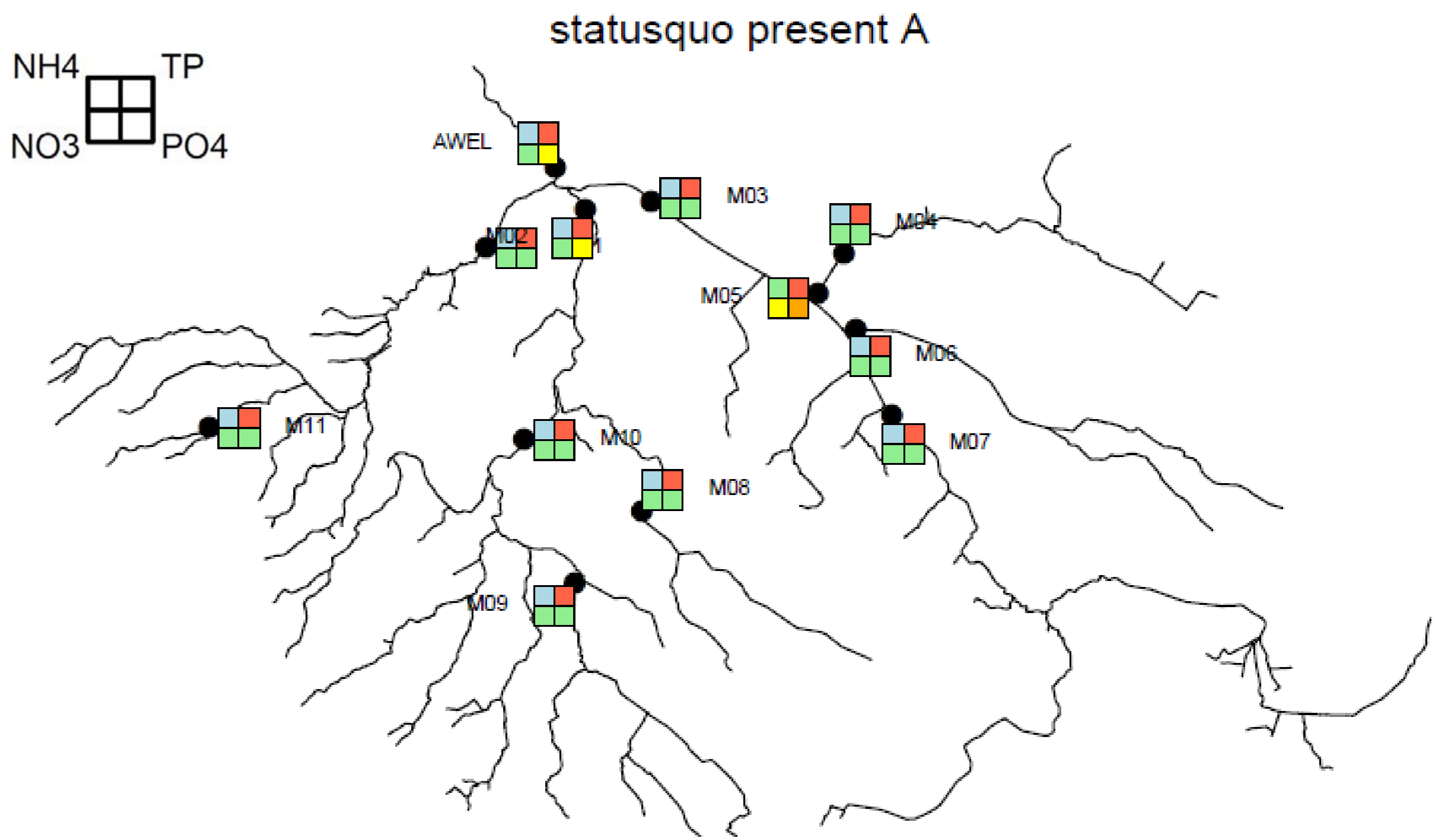
Reichert, Schuwirth, Langhans (2013): Constructing, evaluating and visualizing value and utility functions for decision support, *Environmental Modelling & Software* 46, 283-291. [see also R-package “utility”.]

G Visualization of results - table



Reichert, Schuwirth, Langhans (2013): Constructing, evaluating and visualizing value and utility functions for decision support, *Environmental Modelling & Software* 46, 283-291. [see also R-package “utility”.]

G Visualization of results - catchment



Reichert, Schuwirth, Langhans (2013): Constructing, evaluating and visualizing value and utility functions for decision support, *Environmental Modelling & Software* 46, 283-291. [see also R-package “utility”.]

Prediction of ecological effects: Streambugs

Motivation - predicting the community composition of macroinvertebrates in (wadeable) streams to:

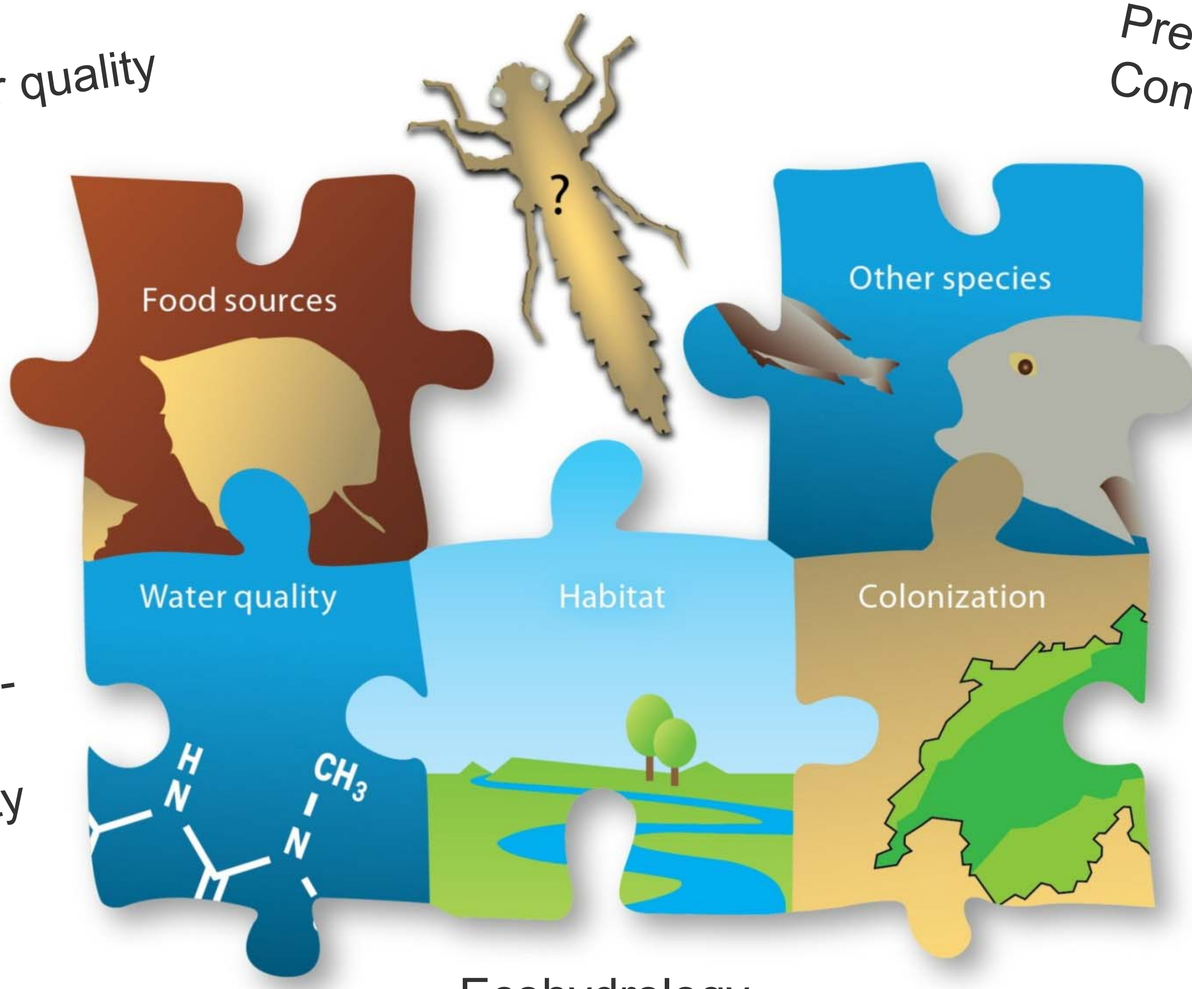
- test **understanding** of **ecosystem functioning**
- test hypotheses on **food-web stability**

- identify influential sources of **human disturbance**
- predict consequences of **management** options
(river restoration, upgrade of waste water treatment plants)
- assess impact of **future development** (climate change, land use)

Prediction of ecological effects: Streambugs

Leaf litter quality
Shading

Predator-Prey
Competition



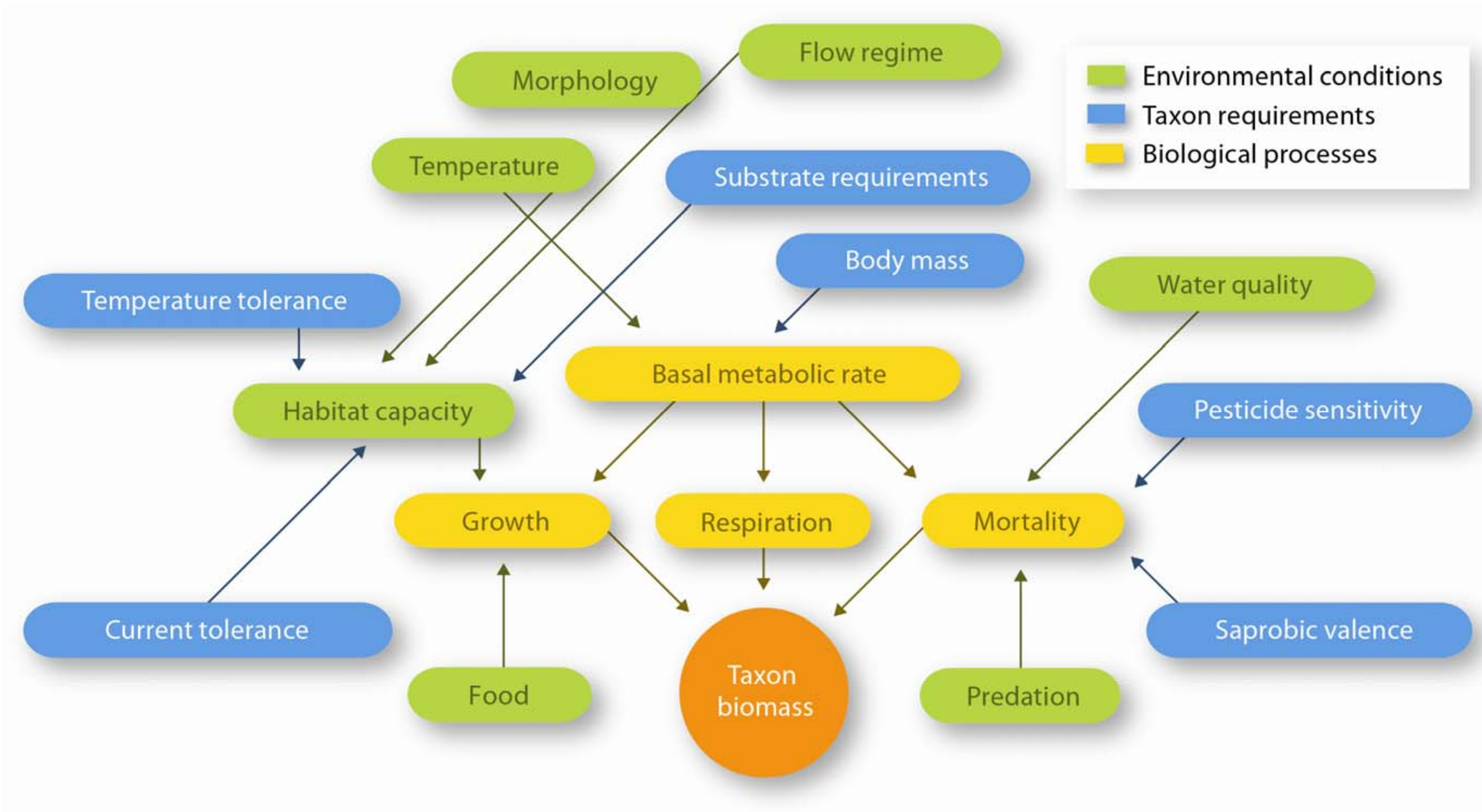
Pesticide-
stress
Saprobity

Dispersal,
Disturbance

Ecohydrology

Schuwirth & Reichert (2013): Bridging the gap between theoretical ecology and real ecosystems: modeling invertebrate community composition in streams. *Ecology* 94, 368–379.

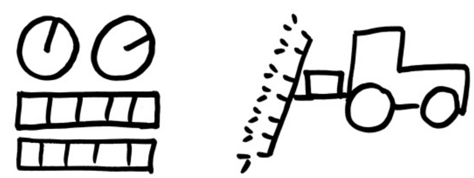
Streambugs 1.0



Schuwirth & Reichert (2013): Bridging the gap between theoretical ecology and real ecosystems: modeling invertebrate community composition in streams. *Ecology* 94, 368–379.

Ecological traits from databases

- feeding types
- body mass M
- energy content
- habitat tolerances (current, temperature, substrate, pH, salinity)
- sensitivity towards pollutants (pesticides, saprobic conditions)
- mobility, emergence, ...



e.g. www.freshwaterecology.info
SPEAR ("Species at risk", Liess et al 2008)
Tachet (Tachet et al. 2000)

Site specific model input

1. environmental conditions

•Temperature (mean water temperature, summer maximum)

•Flow conditions (no-slow-medium-high current class)

•Microhabitat/substrate

•Light conditions (shading, light intensity at the river bed)

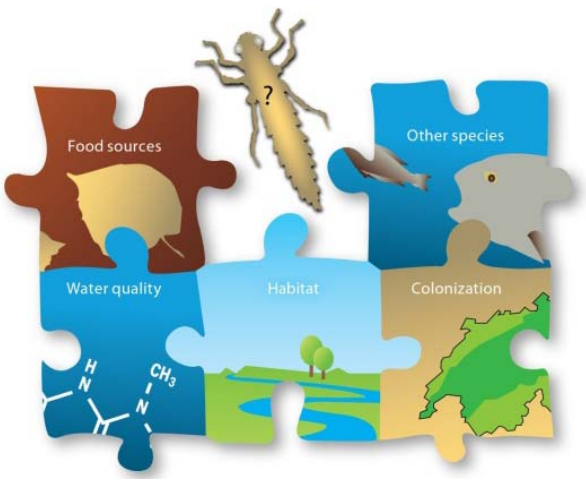
•Input of organic material (leaf litter input, suspended OM)

•Water quality (nutrients, organic matter, organic contaminants)

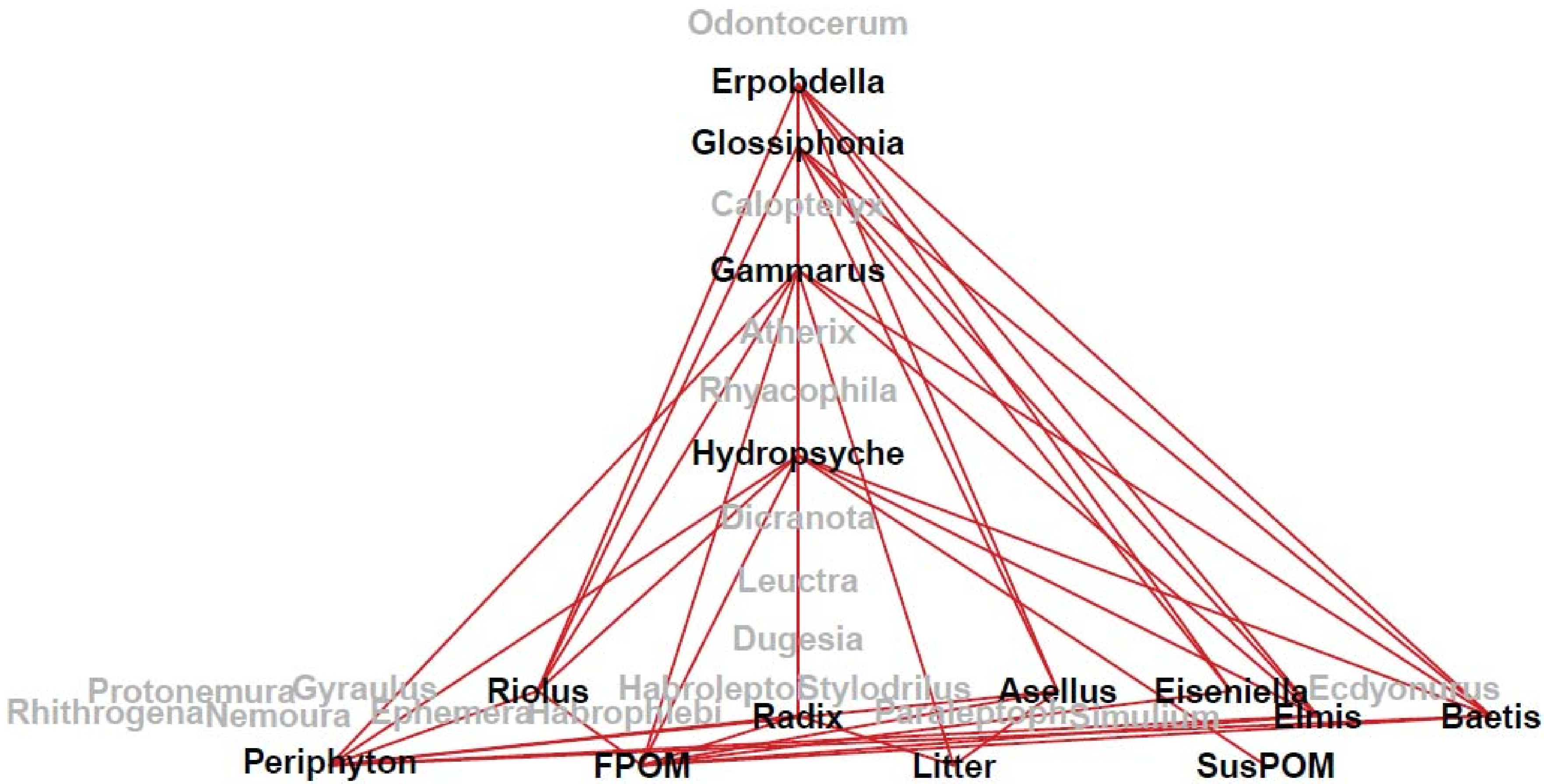
2. regional taxa pool (to exclude dispersal limitation)

Model output

- observation probability for each taxon at each site from equilibrium biomass density at constant environmental conditions

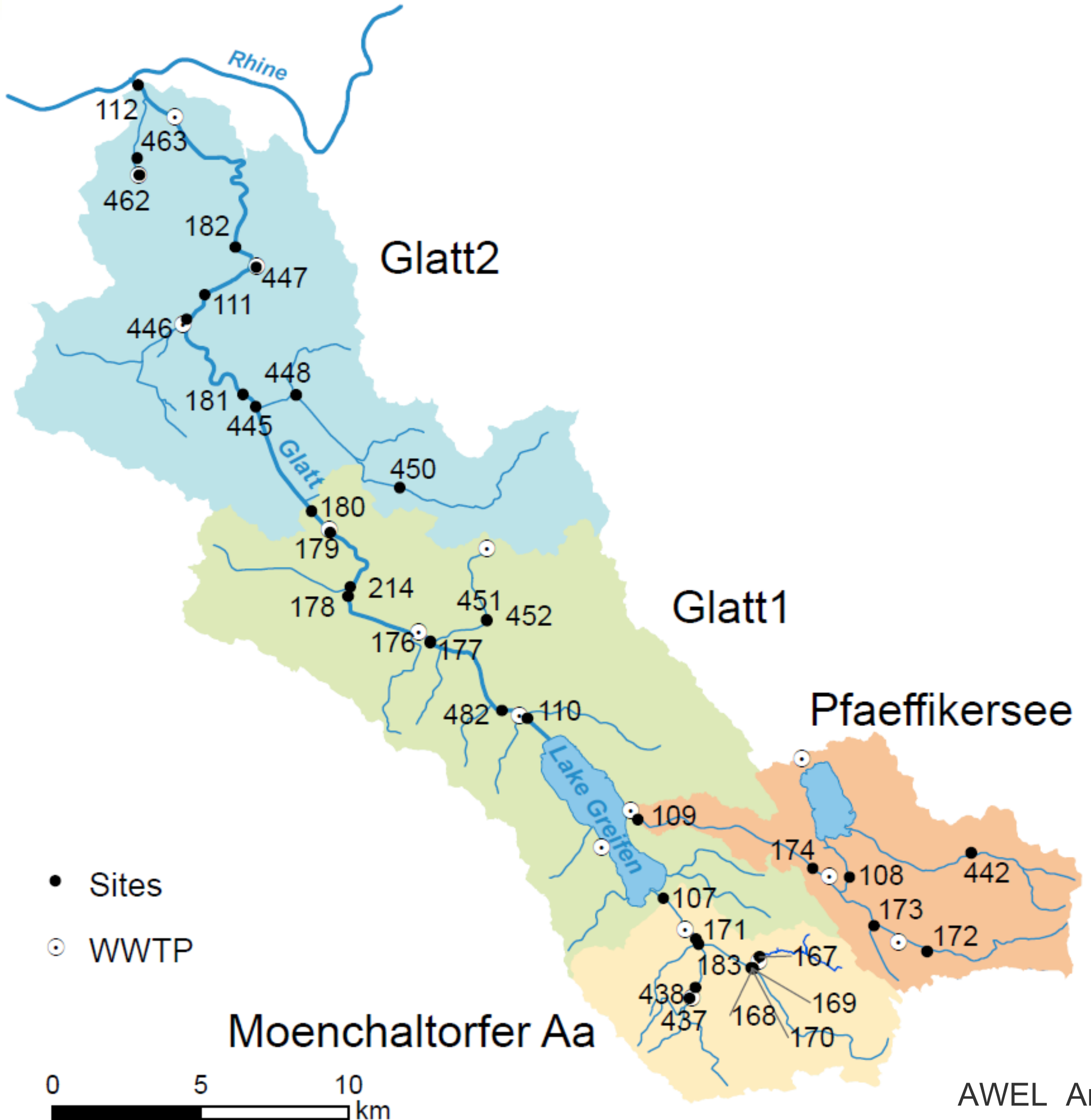


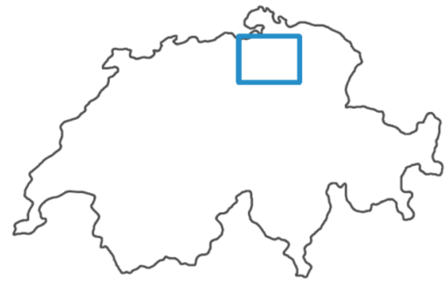
Model output - Food webs



taxa with p(obs)>0.5 taxa with p(obs) < 0.5

Catchment Glatt - Greifensee, Canton Zurich





Glatt-catchment: 36 sites

AWEL Amt für Abfall, Wasser, Energie und Luft:
Zürcher Gewässer 2012, Entwicklung – Zustand - Ausblicke

Results

Results with prior parameter distribution (without calibration)

sub-catchments	no of presence/ absence records* a	max no. of results in agreement with observations b	sum of taxa modelled correctly c	% correct c/b
Pfäffikersee	1155	957	731	0.76
Mönchalt. Aa	1600	1296	966	0.75
Glatt 1	2275	1839	1325	0.72
Glatt 2	2030	1689	1253	0.74
total	7060	5781	4275	**0.74**

*6-11 sites per subcatchment, 4-9 observations per site, ca. 32 taxa

Model calibration with Bayesian inference at each sub-catchment increases compliance with data (to about 90%)

Importance of environmental influence factors - traits

% correct results with mean prior parameter values

sub-catchments	incl. all	excl. **T**-pref.	excl. **sapro**.	excl. **current**	excl. **pest**.	excl. **feedt**.	excl. TSCP	excl. TSCPF
Pfäffikersee	**0.76**	0.77	0.74	0.71	**0.63**	0.73	0.54	0.44
Mönchalt. Aa	**0.74**	0.74	0.72	0.69	**0.60**	0.73	0.50	0.48
Glatt 1	**0.71**	0.70	0.71	0.64	0.63	**0.61**	0.53	0.40
Glatt 2	**0.72**	0.71	0.71	0.63	0.66	**0.60**	0.55	0.39
total	**0.73**	0.73	0.72	**0.66**	**0.63**	**0.65**	0.53	0.42

- excl. **temperature** preference and **saprobic** valence has minor influence
- **current** preference, sensitivity to **pesticides** and feedingtypes are important factors to predict community composition of macroinvertebrates

Conclusions

- mechanistic models are valuable tools to integrate and communicate knowledge about cause-effect relationships and to test hypotheses
- most critical aspect is **treating uncertainty** in an adequate way
- multi-criteria decision support provides a framework to combine **objective** scientific **predictions** about future development and consequences of management alternatives with **subjective valuation** of stakeholders
- facilitates synthesis of large interdisciplinary projects


Thanks for your attention!
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Acknowledgment

Thanks for your attention

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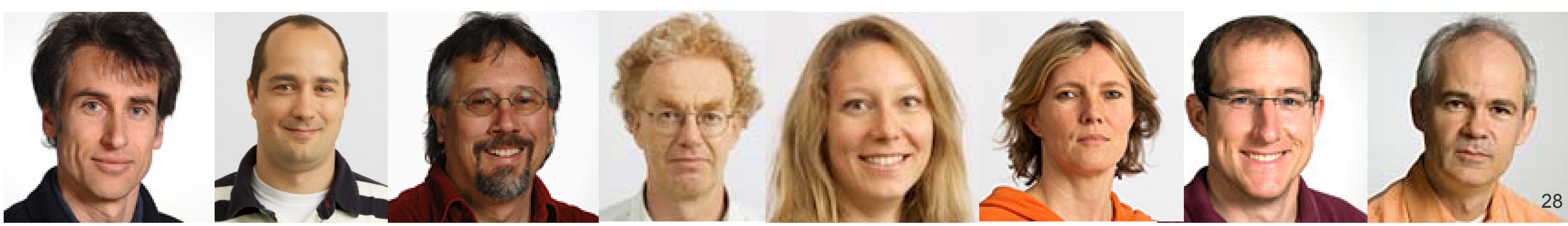
Project iWaQa: "Integrated River Water Quality Management"
SNF Swiss National Research Program 61 "Sustainable Water Management"

iWaQa Team:
Christian Stamm, Mark Honti, Chris Robinson, Peter Reichert, Anne Dietzel,
Rosi Siber, Nico Ghielmetti, Jörg Rieckerman, Mark Gessner

All people who gave access to databases and measured data!



References MCDA in environmental management

Langhans, Lienert, Schuwirth, Reichert (2013): How to make river assessments comparable: A demonstration for hydromorphology, *Ecological Indicators* 32, 264-275.

Reichert, Borsuk, Hostmann, Schweizer, Spörri, Tockner, Truffer (2007): Concepts of decision support for river rehabilitation, *Environmental Modelling & Software* 22, 188-201.

Reichert, Schuwirth, Langhans (2013): Constructing, evaluating and visualizing value and utility functions for decision support, *Environmental Modelling & Software* 46, 283-291. [see also R-package “utility”.]

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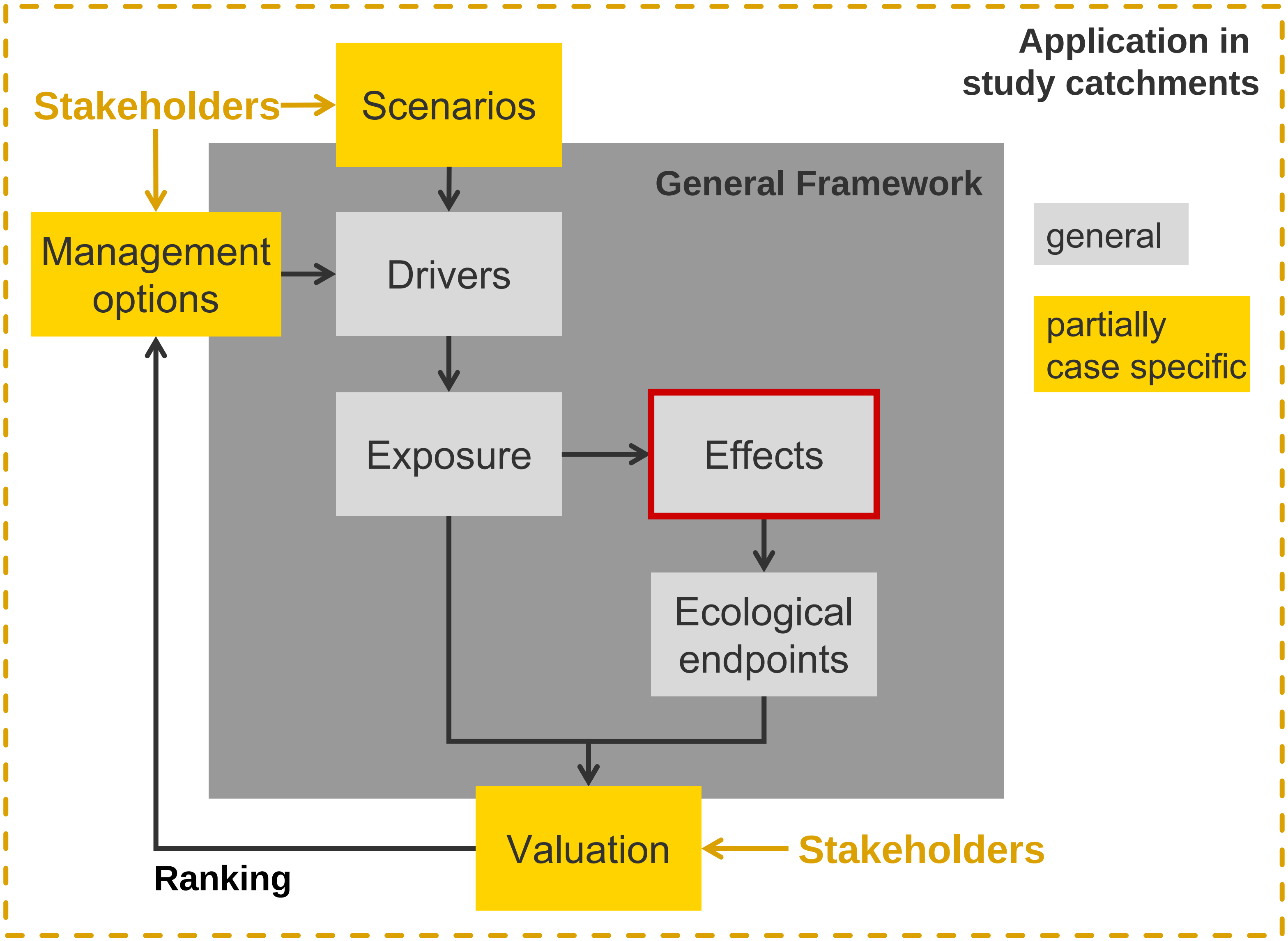
Scholten, Reichert, Schuwirth, Lienert (in prep): Tackling uncertainty in multi-criteria decision analysis - Applied to water supply infrastructure planning.

Schuwirth, Reichert, Lienert (2012): Methodological aspects of multi-criteria decision analysis for policy support: A case study on pharmaceutical removal from hospital wastewater. *European Journal of Operational Research* 220, 472-483.

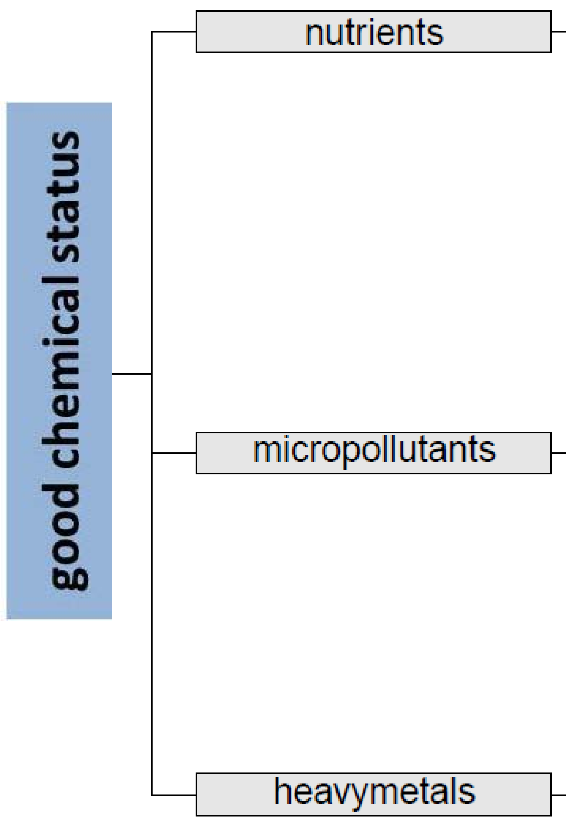
Schuwirth, Stamm, Reichert (2012): Incorporation of uncertainty in decision support to improve water quality. In: Seppelt, Voinov, Lange, Bankamp (Eds.): International Environmental Modelling and Software Society (iEMSs), 6th Biennial Meeting, Leipzig, Germany, 1005-1012.

Conceptual framework - project iWaQa

"Integrated management of river water quality"



F Value functions based on assessment programs



Translated from Modul-Stufen-Konzept

www.modulstufenkonzept.ch

Langhans und Reichert 2011 WEL
Langhans *et al.* 2013 Ecological Indicators

AWEL method based on Chèvre *et al.* 2006

Junghans et al. 2013,
based on Götz et al. 2010

AWEL method based on LAWA criteria

AWEL Amt für Abfall, Wasser, Energie und Luft, Kanton Zürich, Statusbericht 2006: Wasserqualität der Seen, Fliessgewässer und des Grundwasser im Kanton Zürich.
LAWA: Übersicht über Qualitätsanforderungen der EG, der internationalen Flussgebietsgemeinschaften und der LAWA; www.umweltbundesamt.de/wasser/themen/ow_s2_2.htm

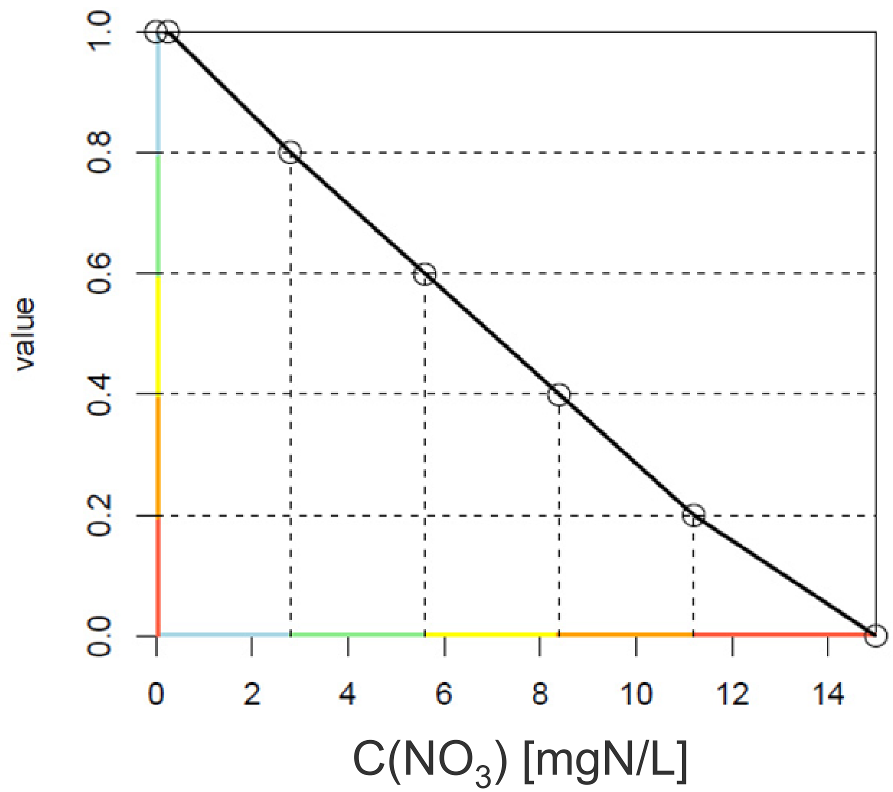
F Value function for lowest level sub-objectives

Translation of existing assessment procedure into measurable value functions

www.modulstufenkonzept.ch

Quality class	
very good	C < ½ Z
good	½ Z ≤ C < Z
moderate	Z ≤ C < 1.5 Z
poor	1.5 Z ≤ C < 2 Z
bad	C ≥ 2 Z

Z: legal quality standard, C: concentration

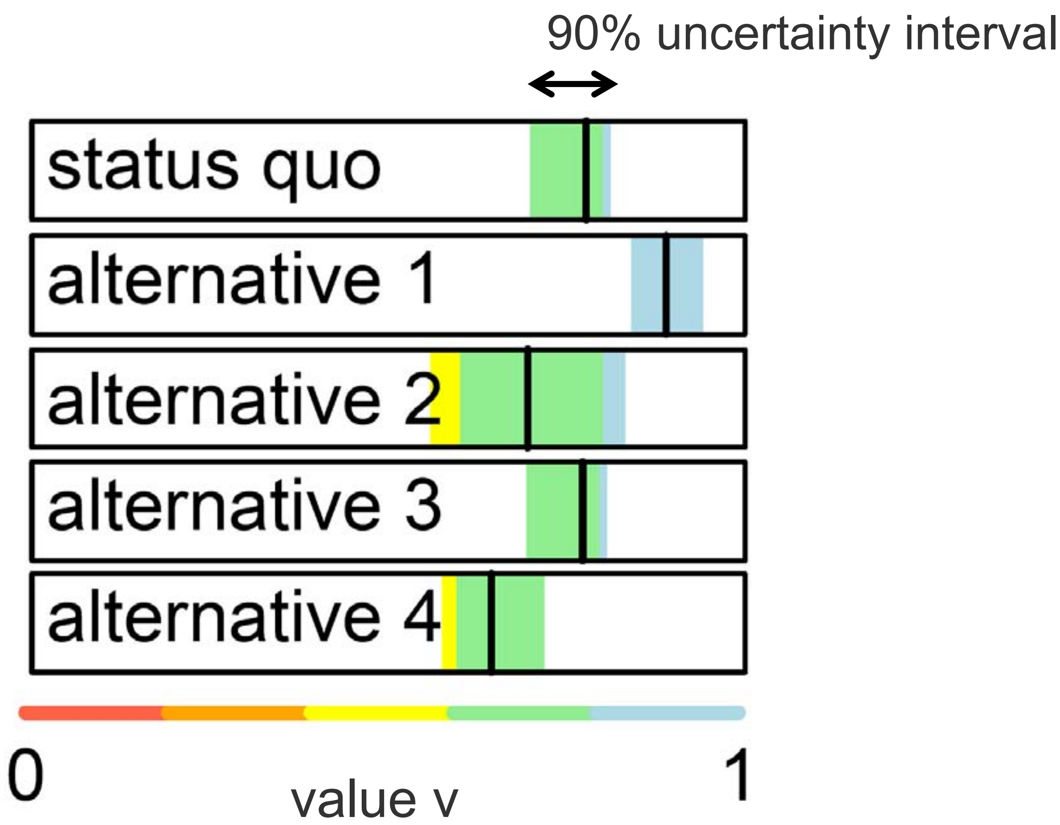


advantage: improvement within a class is visible, avoids rounding error
assumptions: all class transitions are equally valuable, piece-wise linear interpolation

Langhans et al. 2013 *Ecological Indicators,* Langhans & Reichert 2011 *Wasser Energie Luft*

G Visualization of results

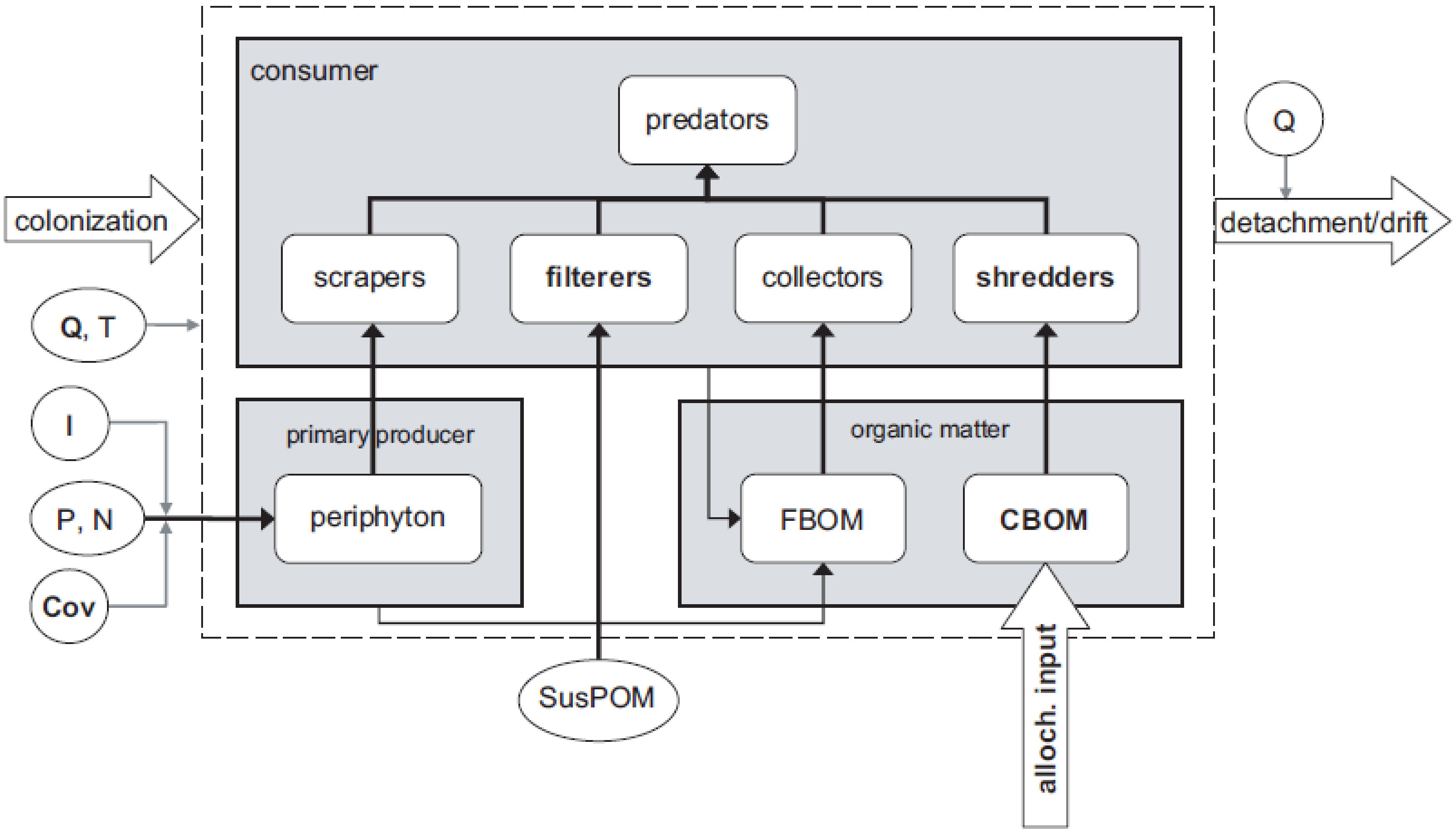
Propagating uncertainty to overall value



Compare alternatives, stakeholders, scenarios - identification of potential consensus solutions

ERIMO: Ecological River Model based on functional groups

N. Schuwirth et al. / Ecological Modelling 222 (2011) 91–104



Schuwirth, Kühni, Schweizer, Uehlinger, Reichert 2008 Freshwater Biology

Schuwirth, Acuña, Reichert, 2011 Ecological Modelling

ERIMO: Ecological River Model based on functional groups

- good representation of functional aspects
- short term dynamics: seasonal effects, disturbance, ecosystem resilience

- functional groups not (that) sensitive to water quality
- omnivory can not be implemented
- structural aspects hidden

→ taxonomic resolution needed

Model formulation

Differential equations for the biomasses of all taxa and of organic matter per river length $\boldsymbol{B} = (B_1, \ldots, B_n)$ [gDM/m]

stoichiometric coefficients $\boldsymbol{\nu} = \{\nu_{ij}\}$

process rates $\boldsymbol{r} = (r_1, \ldots, r_m)$ [gDM/m^2/a], which depend on parameters $\boldsymbol{\theta}$

$$\frac{d\boldsymbol{B}}{dt} = \boldsymbol{\nu} \; \boldsymbol{r}\left(\frac{\boldsymbol{B}}{w}, \boldsymbol{\theta}\right) \; w$$

R-package "stoichcalc"
Reichert & Schuwirth 2010, Environmental Modelling and Software

Metabolic Theory of Ecology

T-corrected maximal rates of whole organism biomass production

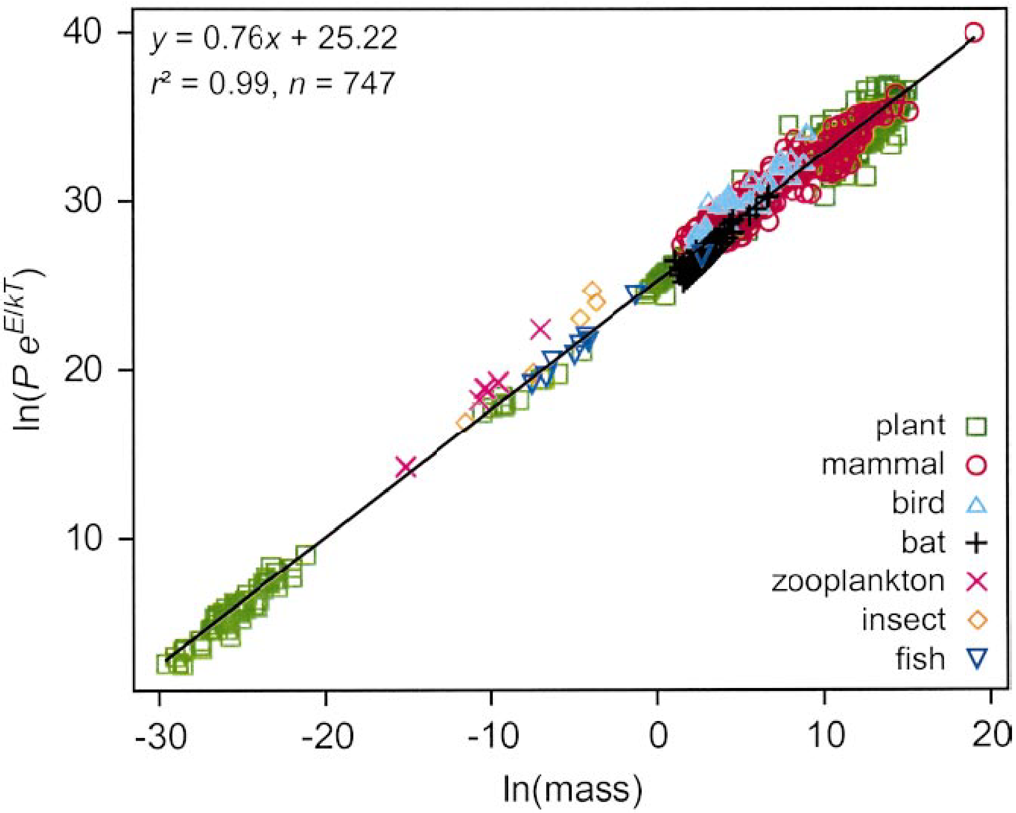


FIG. 2. Mass dependence (mass measured in grams) of temperature-corrected maximal rates of whole-organism biomass production ($Pe^{E/kT}$, measured in grams per individual per year) for a wide variety of organisms, from unicellular eukaryotes to plants and mammals (from Ernest et al. 2003). Data, which span >20 orders of magnitude in body size, have been temperature corrected using Eq. 6. The allometric exponent, indicated by the slope, is close to the predicted value of ¾ (95% CI, 0.75–0.76).

from Brown et al 2004: *Ecology,* 85(7), 2004, pp. 1771–1789

Growth, respiration and death rates

$$r_{\text{gro on } j} = f_{\text{gro}} \cdot f_{\text{gro } i} \cdot f_{\text{lim food}} \cdot f_{\text{pref } j} \cdot f_{\text{self inh}} \cdot f_{\text{basal } i} \cdot r_{\text{basal metab}}$$

$$r_{\text{resp } i} = f_{\text{resp}} \cdot f_{\text{basal } i} \cdot r_{\text{basal metab}}$$

$$r_{\text{mort } i} = f_{\text{mort}} \cdot f_{\text{basal } i} \cdot r_{\text{basal metab}} \cdot f_{\text{org contam}} \cdot f_{\text{saproby}}$$

$f_{org\ contam}$ factor dependent on pesticide pollution and sensitivity of the taxon

$f_{saproby}$ factor dependent on organic matter pollution and classification of the taxon in the saprobic system

$f_{self\ inh}$ factor depending on temperature regime, current regime, substrate

Growth rate of consumers

$$r_{\text{gro on } j}^{\text{cons}} = \underbrace{f_{\text{gro}}}_{\text{fit from large datasets}} \; f_{\text{gro } i} \; f_{\text{lim food}} \; f_{\text{pref } j} \; f_{\text{self inh}} \; f_{\text{basal } i} \; \underbrace{r_{\text{basal metab}}}_{\text{basal metabolic rate}}$$

Growth rate of consumers

$$r_{\text{gro on } j}^{\text{cons}} = f_{\text{gro}} \underbrace{f_{\text{gro}\,i}} f_{\text{lim food}} f_{\text{pref } j} f_{\text{self inh}} \underbrace{f_{\text{basal}\,i}} r_{\text{basal metab}}$$

taxon specific parameters, prior mean = 1

account for variation of individual taxa around MTE predictions

Growth rate of consumers

$$r_{\text{gro on } j}^{\text{cons}} = f_{\text{gro}} \; f_{\text{gro } i} \; \underbrace{f_{\text{lim food}}}_{\text{food limitation}} \; f_{\text{pref } j} \; f_{\text{self inh}} \; f_{\text{basal } i} \; r_{\text{basal metab}}$$

$$f_{\text{lim food}} = \frac{{D_{\text{food}}}^{q}}{{K_{\text{food}}}^{q} + {D_{\text{food}}}^{q}}$$

One process for each food source *j*

D_{food} biomass density of the sum of all food sources

K_{food} halfsaturation density, at which growth rate is reduced to 50% of the max

Growth rate of consumers

$$r_{\text{gro on } j}^{\text{cons}} = f_{\text{gro}} \; f_{\text{gro } i} \; f_{\text{lim food}} \; \underbrace{f_{\text{pref } j}}_{\text{food preference factor}} \; f_{\text{self inh}} \; f_{\text{basal } i} \; r_{\text{basal metab}}$$

$$f_{\text{pref } j} = \frac{D_j \; p_j}{\sum_f D_f \; p_f}$$

One process for each food source j

D_j biomass density of food source j

p_j preference factor for food source j

Growth rate of consumers

$$r^{\text{cons}}_{\text{gro on } j} = f_{\text{gro}} \quad f_{\text{gro } i} \quad f_{\text{lim food}} \quad f_{\text{pref } j} \quad \underbrace{f_{\text{self inh}}}_{\text{self inhibition}} \quad f_{\text{basal } i} \quad r_{\text{basal metab}}$$

Two alternative formulations (Monod and Blackman)

$$f_{\text{self inh Monod}} = \frac{K_{dens}}{K_{dens} + D}$$

$$f_{\text{self inh Blackman}} = \begin{cases} 1 - \dfrac{D}{2K_{dens}} & \text{for } D < 2K_{dens} \\ 0 & \text{for } D \geq 2K_{dens} \end{cases}$$

D biomass density of the taxon

K_{dens} half-inhibition density where growth rate is reduced to 50% of the max

$$K_{\text{dens}} = h_{\text{dens}} \cdot f_{\text{current}} \cdot f_{\text{temp}} \cdot f_{\text{substrate}}$$

depends on habitat conditions and specific preferences of the taxon

Catchment Glatt - Greifensee, Canton Zurich

Glatt-Greifensee: 36 sites

AWEL Amt für Abfall, Wasser, Energie und Luft:
Zürcher Gewässer 2012, Entwicklung – Zustand - Ausblicke