ALPINE AREAS AS SOURCES OF NUTRIENT EMISSIONS INTO RIVERS

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1 INTRODUCTION

A comprehensive quantification of nitrogen (N) and phosphorus (P) emissions to Austrian surface waters on national level was performed in 2005 (Windhofer *et al*., 2005) using the MONERIS model (Behrendt *et al.*, 1999). The model was initially developed for the quantification of nutrient emissions of large and meso-scale lowland river basins in Germany. In general, the application of the model to Austrian conditions worked quite well in regard to the calculation of N and P emissions and river loads and the identification of the main sources and pathways of emissions to the surface waters. However, it was found that some catchments with high proportion of alpine areas show inadequate model performance, which indicates that particular background emissions from alpine areas should be subjects of detailed model revisions. ..

A follow-up activity for improvement of the modeling of N and P emissions into Austrian surface waters (Zessner *et al*., 2011) is the basis of this paper. The specific focus of the present paper is on quantification of mainly sediment-bounded phosphorus inputs from alpine catchments into the Austrian river systems. Such inputs are of specific interest in the frame of phosphorus balances at catchment scale as they might have significant magnitude (Zessner *et al*., 2005a) and can be considered as background emissions which cannot be reduced by implementation of mitigation measures in the catchment.

2 MATERIAL AND METHODS

2.1 Alpine test catchments

To acquire more details on emissions in alpine catchments and to revise some of the MONERIS model´s approaches, 29 test-catchments in the Austrian Alps have been selected. Monitoring data at 29 stations for dissolved inorganic N (DIN) load calculations and 26 stations for total P (TP) load calculations were available. The main selection criteria for the test catchments were:

- complete data set for a MONERIS-application (*e.g.* land cover, hydrogeology, soil properties, N-deposition rates, morphology (70 x 70 m grid size), population, types and quantities of waste water disposal, agricultural practice, *etc.*);
- catchment size from 70 to 400 km^2;
- uniform distribution of the test-catchments over the alpine landscapes of Austria;
- long-term time series on river flow with high resolution (15 minutes) at the catchment outlet;
- availability of water quality data (*e.g.* temperature (T), nutrients (DIN and TP) and suspended solids (SS)) at the outlet at least over five years with least monthly frequency;
- location of gauging stations for river flow close to the location of water quality monitoring stations (less than 10% deviation between the their catchment sizes);
- only extensive agricultural production (summer pastures) and share of arable land in the catchment less than 2% of the catchment area;
- low population density: less than 30 inhabitants per km^2;
- no significant impacts of hydro-power production, hydrologic impoundments or water abstraction.

2.2 Natural soil erosion from open areas

In the 2.14-version of MONERIS (Vehnor *et. al*, 2011), natural sediment yield from open areas is calculated with a fixed value of 4 t SS per hectare per year. From SS load measurements in alpine rivers it is demonstrated that this assumption in many cases leads to erroneous results. Particularly from open areas covered with glaciers, much higher area-specific SS loads were measured (Meschik, 2010), whereas other catchments without glaciers showed much lower area-specific SS export. This expressed the necessity to use different area-specific SS inputs from open areas with and without glaciers. An inverse approach for calculation of area-specific inputs from open areas with and without glaciers has been applied in order to get the best fit between measured and modelled SS loads for the considered test-catchments. Sediment yield from naturally covered areas (woodland, shrubland) has not been changed in the 2.14-version of MONERIS.

2.3 P concentrations in SS from open areas

Concentrations of P in eroded soils from open and naturally covered areas in the 2.14-version of MONERIS are calculated with a constant value of 150 mg P per kg SS. This is a value derived from natural soils of forested areas. Data from test catchments show that these values do not reflect the particulate P concentrations of the SS from open areas in the Austrian Alps. Concentrations of P in SS from solid rock weathering are significantly higher in most of the cases. Values have been adapted according to results from the test-catchments. A differentiation between the concentrations of P in SS from catchments dominated by limestone and igneous rocks (mainly schist and gneiss) was supported by the monitoring results from test-catchments.

2.4 Implementation and validation

To supplement the data of the 29 monitoring stations at the outlet of the test-catchments, additional monitoring stations for catchments strongly influenced by alpine areas have been chosen for validation of the revised approaches. Sixteen monitoring stations were found for model validations which had a TP sampling frequency of at least 12 times a year over 5 years. Modelled nutrient and SS loads have been compared to loads calculated from daily discharge and measured nutrient as well as SS concentration data. Finally, the revised approaches have been applied to all Austrian catchments for an extended comparison of nutrient loads derived from measurements and from model calculations.

3 RESULTS

3.1 Characterization of nutrient transport in alpine catchments

Monthly variations of runoff (Q) as well as of DIN, SS and TP loads are shown in Fig. 1 to give an impression about the transport of nutrients in different Austrian mountain creeks. The figure shows monthly values of a typical year from the investigated period. Q values are monthly averages calculated from daily values. Monthly SS, TP and DIN loads have been calculated based on average runoff and average concentrations (two measurements per month) for each month. Two different types of rivers with about 100 km^2 catchments size have been chosen to present typical transport variations in Fig. 1. The first one (headwater of Mürz) is located in the most eastern part of the northern Alps (Fig. 1 (A)). The mountain´s peaks in this region reach maximum elevations of about 2000 m a.s.l.. The average elevation of the chosen catchment is 1270 m a.s.l.. The catchment is mainly covered with forests and to some extent with alpine pastures. Open mountainous areas cover only small parts of the catchment. The highest Q is usually in April and May during snowmelt. This is also the time with the transport of the highest DIN loads, which – because of only little fluctuations in the concentrations during the year – are strongly correlated to the discharge. Peak loads of SS and TP are mainly transported during single storm events. They usually occur between April and October.

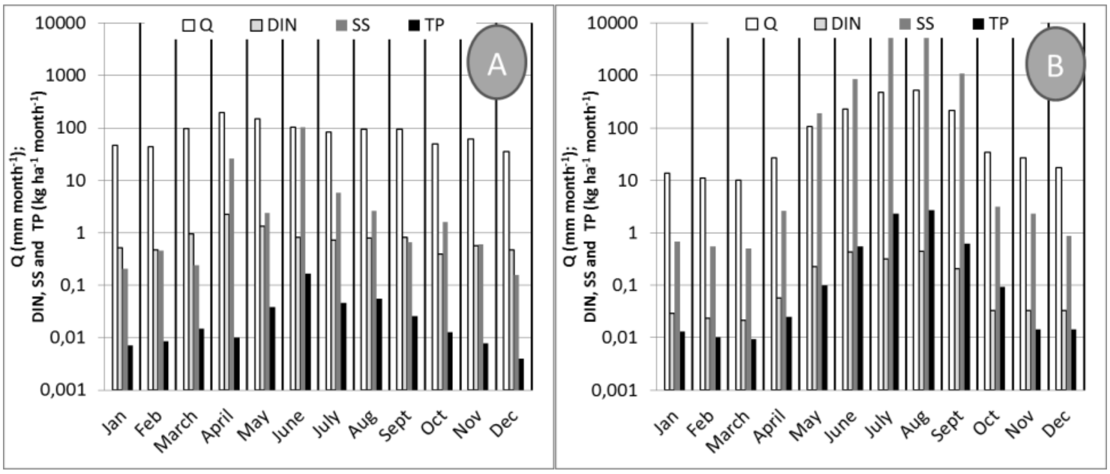

Figure 1 Typical annual variations of Q as well as of DIN, SS and TP loads of two Austrian mountain creeks. (A): Mürz river, eastern part of northern Alps, average elevation of the catchment 1270 m a,s,l., (B): Rofner Ache, central Alps, average elevation of the catchment 2915 m a.s.l., 30 % covered with glacier.

The second case is a creak in the central Alps (Rofner Ache, Fig. 1 (B)). Peaks in this region reach up to 3700 m a.s.l. (Ötzthaler Alpen). The average elevation of this second catchment is 2912 m a.s.l.. 30 % of the catchment is covered with glaciers. River discharge during July and August is about 50 times higher than in winter. A substantial part of the nutrient fluxes is transported from June to September. SS loads increase to 5 t per ha and month during this time, TP loads to almost 3 kg per ha and month. TP loads become higher than DIN loads during this season. As compared to the situation in the Mürz the area-specific Q is lower in winter but higher in summer. Area-specific DIN loads are generally much lower in the Rofner Ache as in the Mürz, while area-specific SS and TP loads are similar low in both rivers in winter but much higher in the Rofner Ache during the whole summer. All together the Rofner Ache represents a river in the highest parts of the Austrian Alps where nutrient exports are dominated by the transport of SS from rock weathering and abrasion from the movement of glaciers. The catchment of Rofner Ache releases extremely high P-loads (6 kg TP per ha and year). In contrast, Mürz is characterised by a relatively low P-output (0.2–0.3 kg TP per ha and month).

3.2 Natural soil erosion from open areas

Inputs of SS via natural erosion dominate the TP loads in alpine catchments (Meschik, 2010). The comparison between observed and modelled SS loads, which are based on the original MONERIS 2.14 export coefficients, shows significant deviations (Fig. 2 (A)). In catchments without influences of glaciers, SS emissions were overestimated with the MONERIS model calculations. Thus, one coefficient has been introduced to the MONERIS model for open mountainous areas covered by glaciers (35 tons per hectare and year) and one for open mountainous areas not covered by glaciers (0.2 tons per hectare and year). The latter is close to values derived for woodlands (Behrendt *et al.*, 1999). The implementation of these SS-export coefficients lead to a significant model performance improvement in the alpine test regions (Fig. 2 (B) as compared to Fig. 2 (A)).

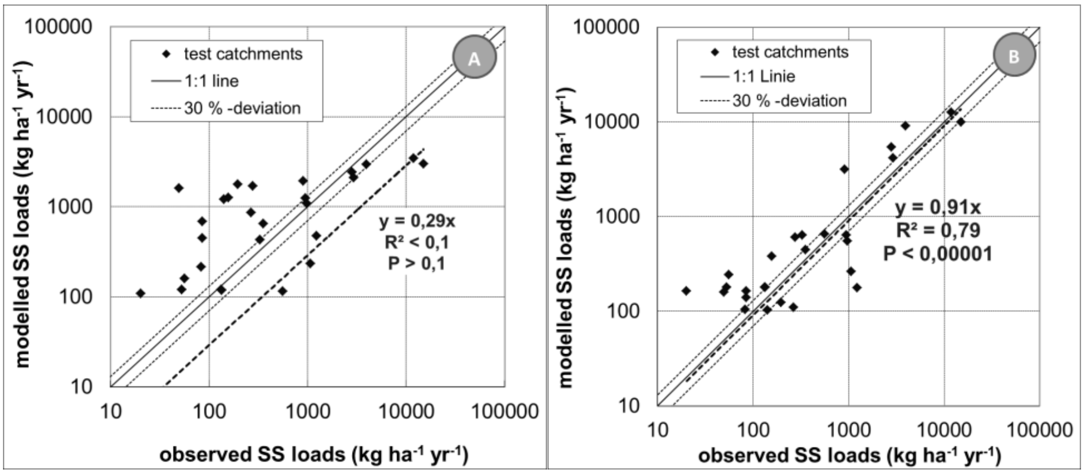

Figure 2 Observed versus calculated SS loads before (A) and after (B) implementation of modifications of MONERIS model.

3.3 P concentrations in SS from open areas

Fig. 3 shows the relationship between the SS load and the particulate P load in the rivers of the selected case study catchments. Based on this correlation, the average P concentration in SS for rivers in mountains with predominantly limestone was derived as about 590 mg P per kg SS (trend line of dark dots). For mountains with gneiss/schist formations, the average P concentration in SS was derived to be about 790 mg P per kg SS (trend line of grey dots). These values are supported by the mean concentration of TP in the earth's crust of about 700 to 900 mg P per kg SS (Brown and Musset, 1982; Audesirk and Audesirk, 1999).

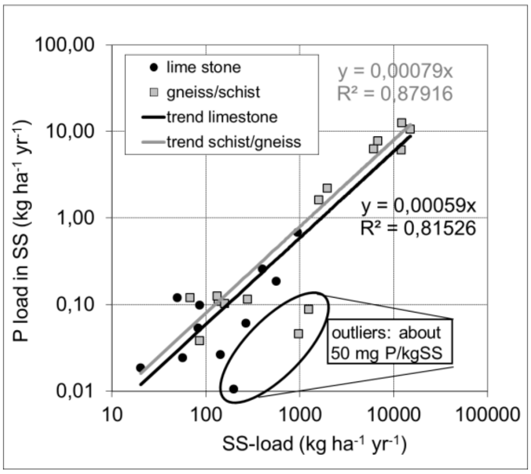

Figure 3 Correlation between SS and particulate P loads in alpine test catchments.

Results indicate that the average P concentrations in SS in these alpine catchments are far above the P concentrations of 150 mg P per kg SS of natural soils, which is currently used as "background concentration in SS" in the MONERIS 2.14 model. Significantly lower concentration of TP in natural soil as compared to solid rocks is a result of the long-lasting soil genesis with permanent losses of P in soluble forms. Therefore, this low specific P concentration seems to be appropriate for natural soils, but not for SS stemming from rock weathering of alpine regions. For three test catchments, strongly differing P concentrations in SS have been found (Fig. 3 outliers). It was not possible to relate these outliers to specific rock properties. Therefore it was not possible to use these outliers to derive model coefficients for rocks with low P content. Table 1 summarises the model coefficients finally used for calculation of natural soil erosion from open areas.

Table 2 Model coefficients for calculation of natural soil erosion from open and naturally covered areas.

Natural erosion rate from open mountainous areas (> 1000m); original version 2.14	t/(ha*a)	4
Natural erosion rate from open mountainous areas without glacier (> 1000 m); modified	t/(ha*a)	0.2
Natural erosion rate from mountainous areas with glacier; modified	t/(ha*a)	35
Soil P content of naturally covered and open areas; original version 2.14	mg/kg	150
Bare rock P content from open areas (lime stone, good porosity), modified	mg/kg	590
Bare rock P content from open areas (schist/gneiss, poor porosity), modified	mg/kg	790
Exceptional cases of bare rock with low P content; modified	mg/kg	50
Soil P content of naturally covered areas; no modifications	mg/kg	150

3.4 Validation and implementation

After implementation of the above mentioned modifications of MONERIS, a significant improvement of model performance was achieved for TP (Fig. 4). Nevertheless, still about 40% of calibration and 50% of validation catchments have a deviation of more than ±30% in comparison to the observed annual TP loads. Both the modelling and observation of TP loads are difficult and uncertain due to the uncertainties in the input data, model structure, model parameters and observation data. Even annual TP loads derived from monthly concentration measurements over a six year period are highly uncertain due to unsteady SS and TP transport (Zessner *et al.*, 2005b) and the difficulties and limitations of the proper detection of sediment carrying flood events..

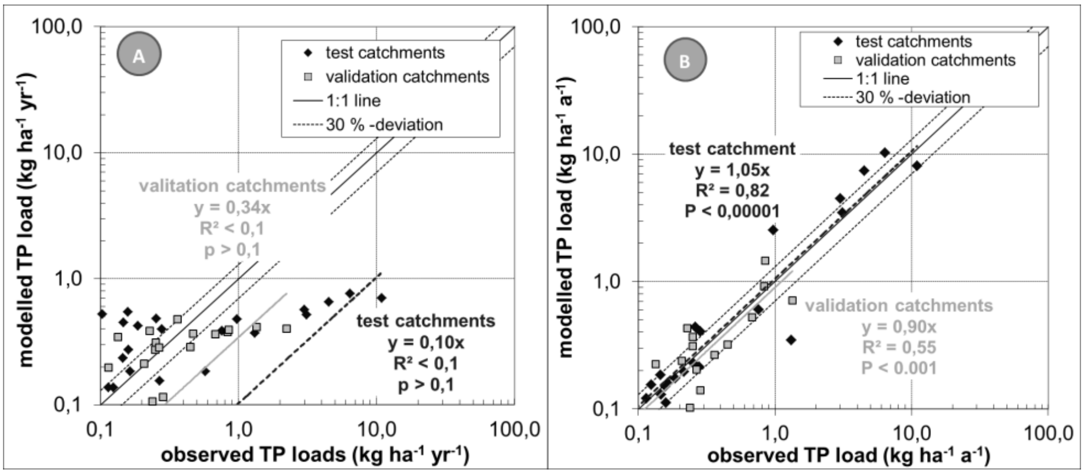

Figure 4 Observed versus modelled annual TP loads of mountainous test and validation catchments before (A) and after (B) implementation of modifications in the MONERIS model.

4 CONCLUSIONS

In respect to SS and TP emissions into river systems from alpine catchments the following conclusions can be drawn:

- Mountainous areas especially covered with glaciers are significant sources of SS loads of rivers. Area specific inputs from glaciers are in the order of magnitude of 35 t SS per ha and year.
- These inputs are dominated by the transport of SS from rock weathering and abrasion from the movement of glaciers.

- P concentrations of these rocks are in the same order of magnitude than well fertilized agricultural soils (up to 800 mg P per kg).
- Therefore P inputs in catchments with relevant share of high mountains are significantly impacted by erosion from bare rocks. Area specific inputs may reach values of more than 10 kg P per ha and year.
- This erosion needs to be considered for explanation of P-balances of such catchments and the resulting river loads.
- Nevertheless, impacts of these inputs on river water quality are questionable, as availability of P in SS from rock erosion is low.

A significant improvement in respect to modelling of P emissions from mountainous catchments with a size of 70 to 400 km^2 has been achieved by implementing the following aspects into the MONERIS model:

- A differentiation of area-specific SS inputs for mountainous open areas covered with or without glaciers has been introduced.
- New input parameters for P concentrations in SS from limestone and schist/gneiss rocks have been defined.

5 REFERENCES

Audesirk T.and G. Audesirk, 1999: Biology, Life on Earth, 5th Ed., Prentice-Hall, 1999.

Behrendt H., P. Huber, D. Opitz, O. Schmoll, G. Scholz and R. Uebe, 1999: Nutrient Emissions into River Basins of Germany, Texte 23/00, Umweltbundesamt Berlin, 261 pages.

Brown G.C. and A.E. Mussett, 1981: The Inaccessible Earth (2nd ed.). Taylor & Francis. p. 166. ISBN 0045500282.

Meschik P., 2010: Nährstoffflüsse im Einzugsgebiet der Ötztaler Ache - Einfluss der Erosion und der Geologie. Diploma thesis at the Institut für Wassergüte, Ressourcenmanagement und Abfallwirtschaft, 96 pages in german.

Venohr M, Hirt U, Hofmann J, Opitz D, Gericke A, Wetzig A, Natho S, Neumann F, Hürdler J, Matranga M, Mahnkopf J, Gadegast M, Behrendt H. Modelling of Nutrient Emissions in River Systems – MONERIS – Methods and Background. International Review of Hydrobiology 2011; 96 Issue 5: 435–483.

Windhofer G., B. Schwarzl, E. Schwaiger, A. Aschauer, M. Zessner, I. Zieritz, H. Behrendt, 2005: Frachtabschätzung des Eintrags in österreichische Oberflächengewässer aus diffusen und punktförmigen Quellen. Technical Report, Federal Environmental Argency Vienna, 2005: 93 pages, in german.

Zessner M., C. Schilling, O. Gabriel, U. Heinecke, 2005a: Nitrogen fluxes on catchment scale: the influence of hydrological aspects. Water Science and Technology, 52 (2005), 9; pages 163 - 173.

Zessner M., C. Postolache, A. Clement, A. Kovacs, P. Strauss, 2005b: Considerations on the influence of extreme events on the phosphorus transport from river catchments to the sea. Water Science and Technology, 51 (2005), 11; pages 193 - 204.

Zessner M, Kovacs A, Schilling C, Hochedlinger G, Gabriel O, Thaler S, Natho S, Windhofer G. (2011) Enhancement of the MONERIS model for application in alpine catchments in Austria, International Review of Hydrobiology, Volume 96, 2011, Number 5, pages 541-560.

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Alpine areas as source of nutrient emissions into river systems

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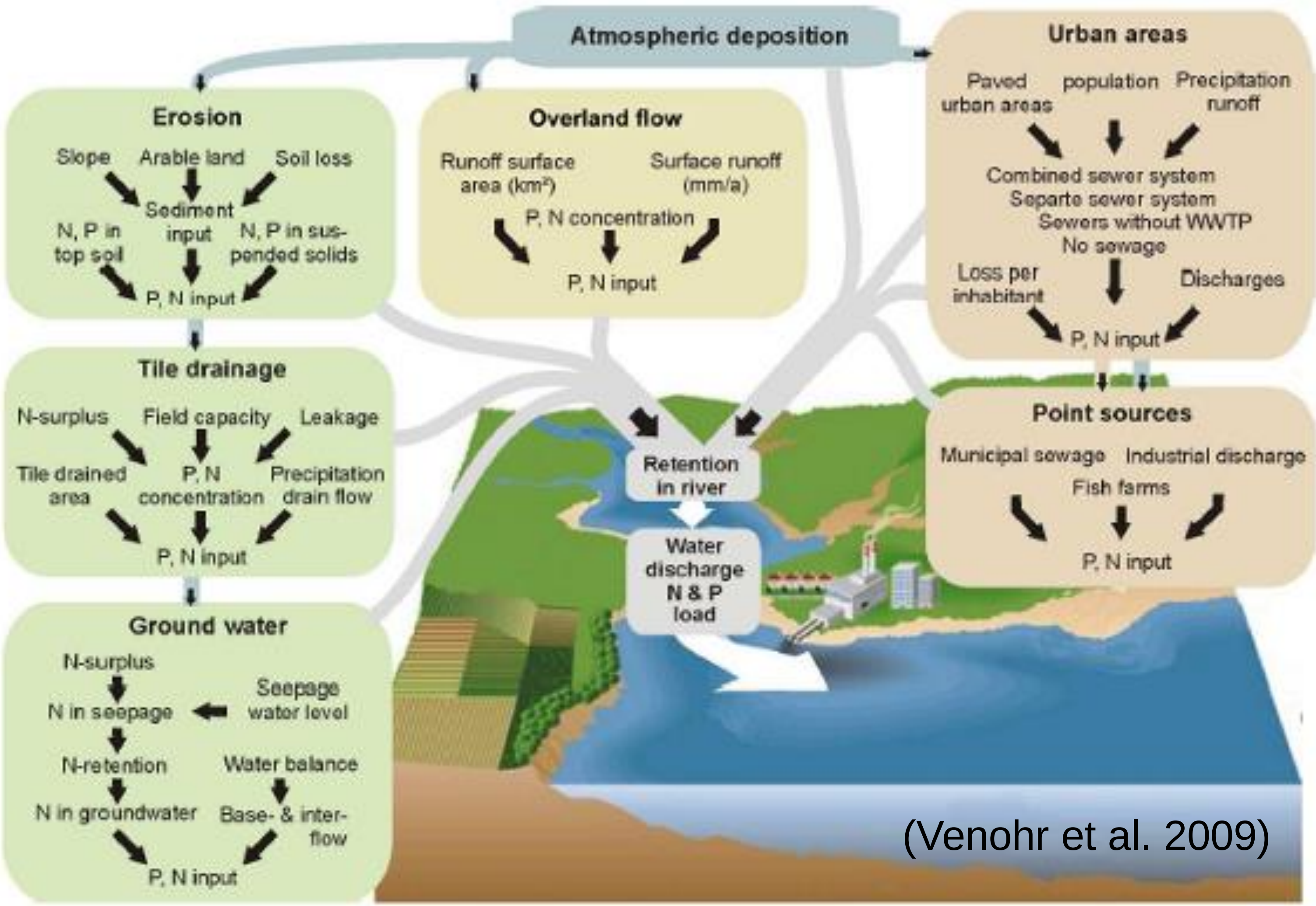
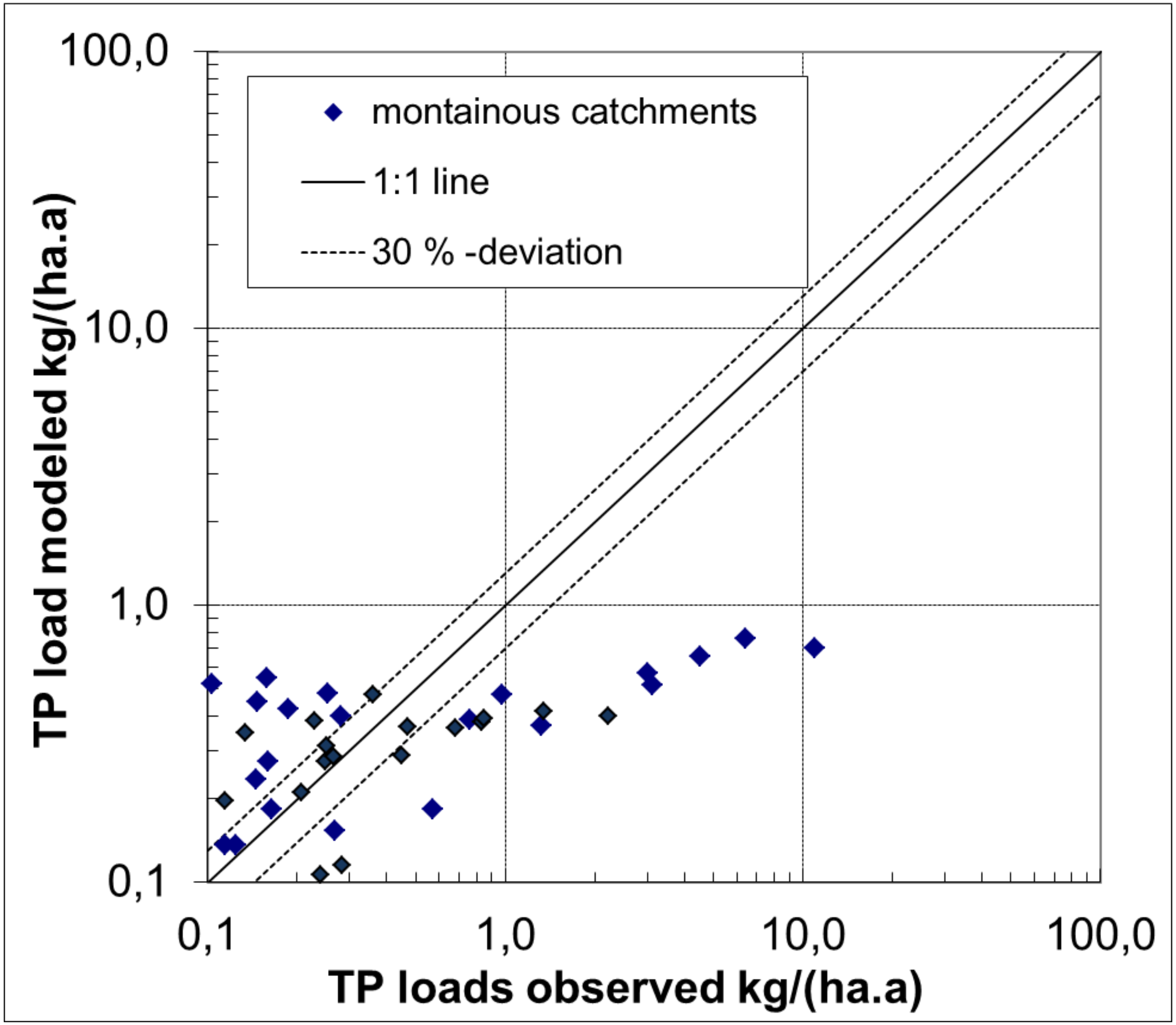
Background

- Nutrient balances of river systems show sources and pathways of nutrient emissions to river systems and set them in relation to in stream concentrations
- They are needed as basis for assessment of the effectiveness of measures for reduction of nutrient pollution
- Unmanageable background loads can have an significant impact in specific cases, this can be of high importance in an international context (e.g. Danube River Basin)
- Investigations with the emission model MONERIS showed strong deviations between modeled and observed nutrient loads (N and P) in some Austrian alpine rivers
- Especially very high TP loads in some rivers could not be explained

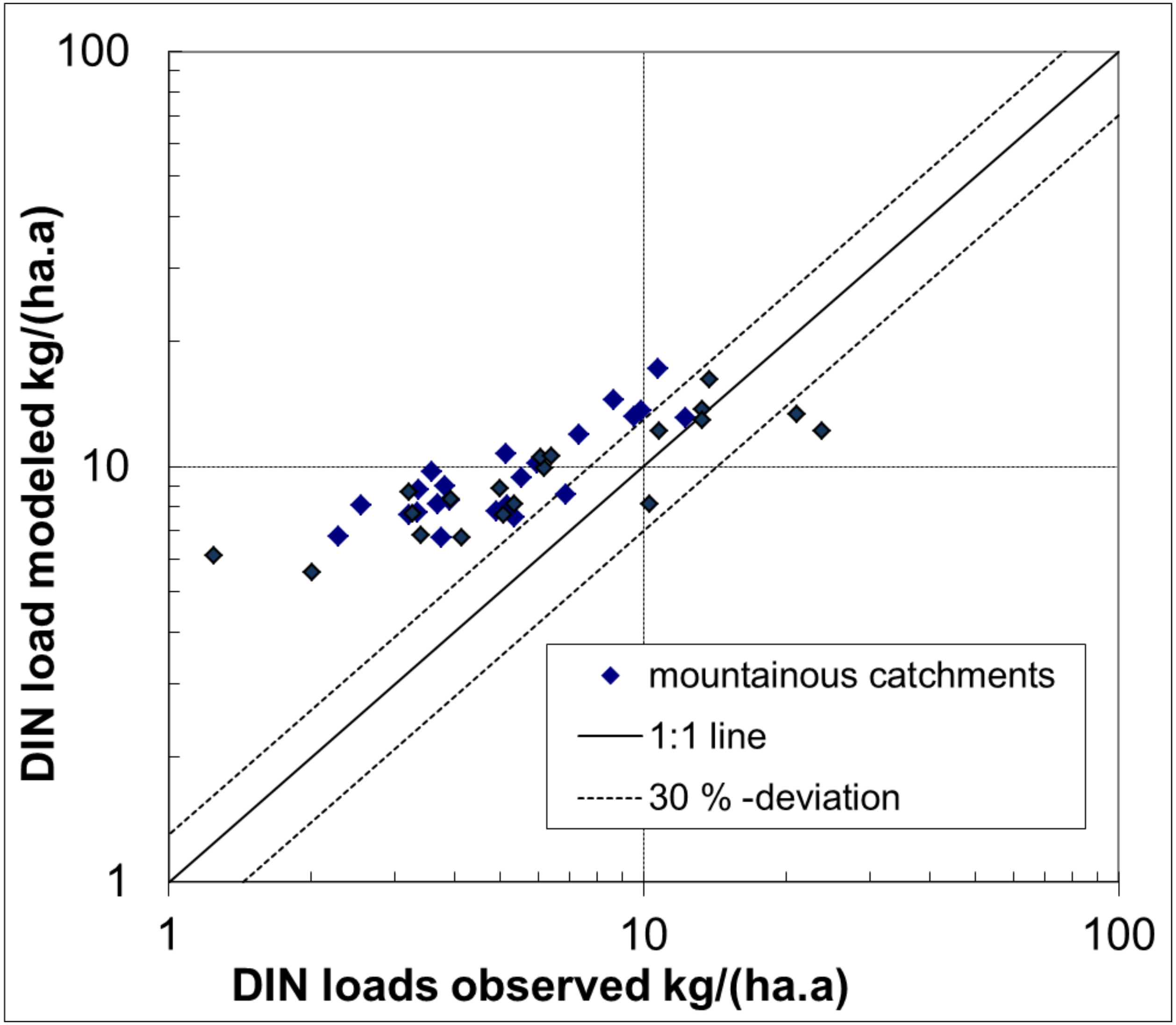
MONERIS


Atmospheric deposition
Erosion
Slope
Arable land
Soil loss
Sediment input
N, P in top soil
N, P in suspended solids
P, N input
Overland flow
Runoff surface area (km²)
Surface runoff (mm/a)
P, N concentration
P, N input
Urban areas
Paved urban areas
population
Precipitation runoff
Combined sewer system
Separte sewer system
Sewers without WWTP
No sewage
Loss per inhabitant
Discharges
P, N input
Tile drainage
N-surplus
Field capacity
Leakage
Tile drained area
P, N concentration
Precipitation drain flow
P, N input
Retention in river
Water discharge N & P load
Point sources
Municipal sewage
Industrial discharge
Fish farms
P, N input
Ground water
N-surplus
N in seepage
Seepage water level
N-retention
Water balance
N in groundwater
Base- & inter-flow
P, N input
(Venohr et al. 2009)

Problems with MONERIS in alpine catchments



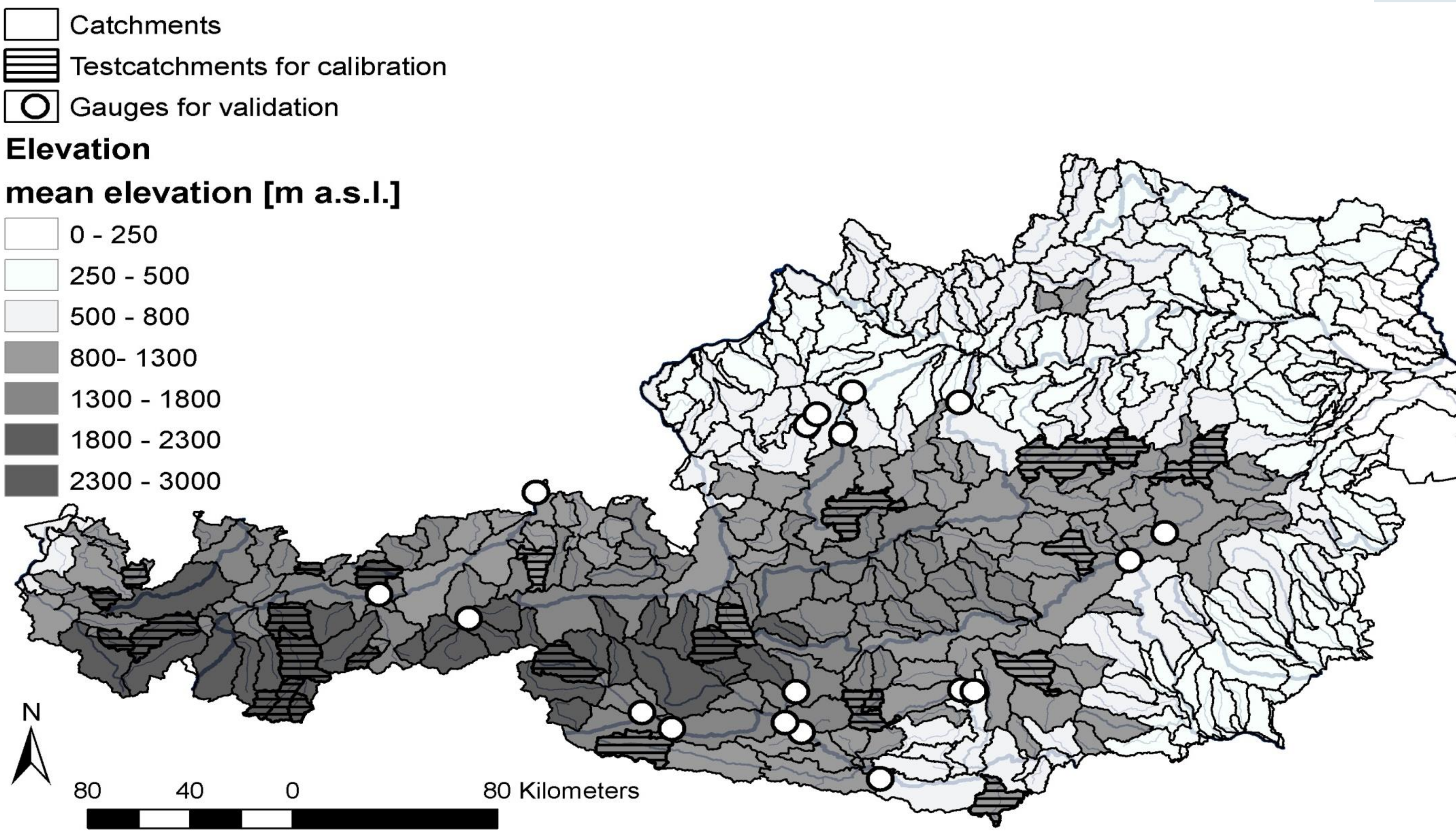
Problems with MONERIS in alpine catchments



Criteria for selection of test catchments

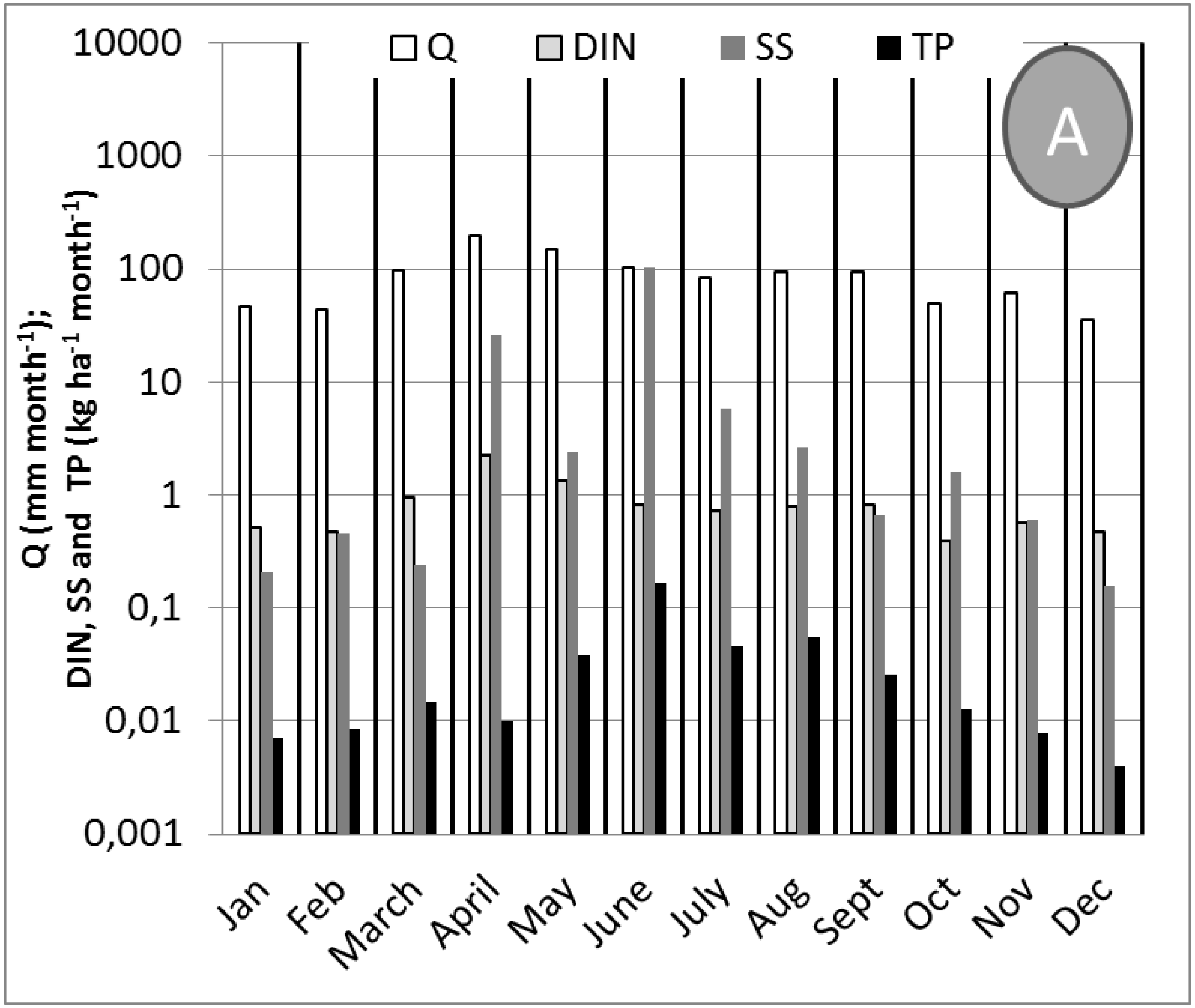
- Catchment size between 70 and 400 km^2
- Distribution over the alpine landscapes of Austria
- Long term data set for flow at the outlet
- Water quality data at least 12 measurements per year over 5 years
- Less than 2 % arable land in the catchment
- Low population density
- No significant impacts by hydro power production, hydrologic impoundments or water abstraction

Alpine test catchments



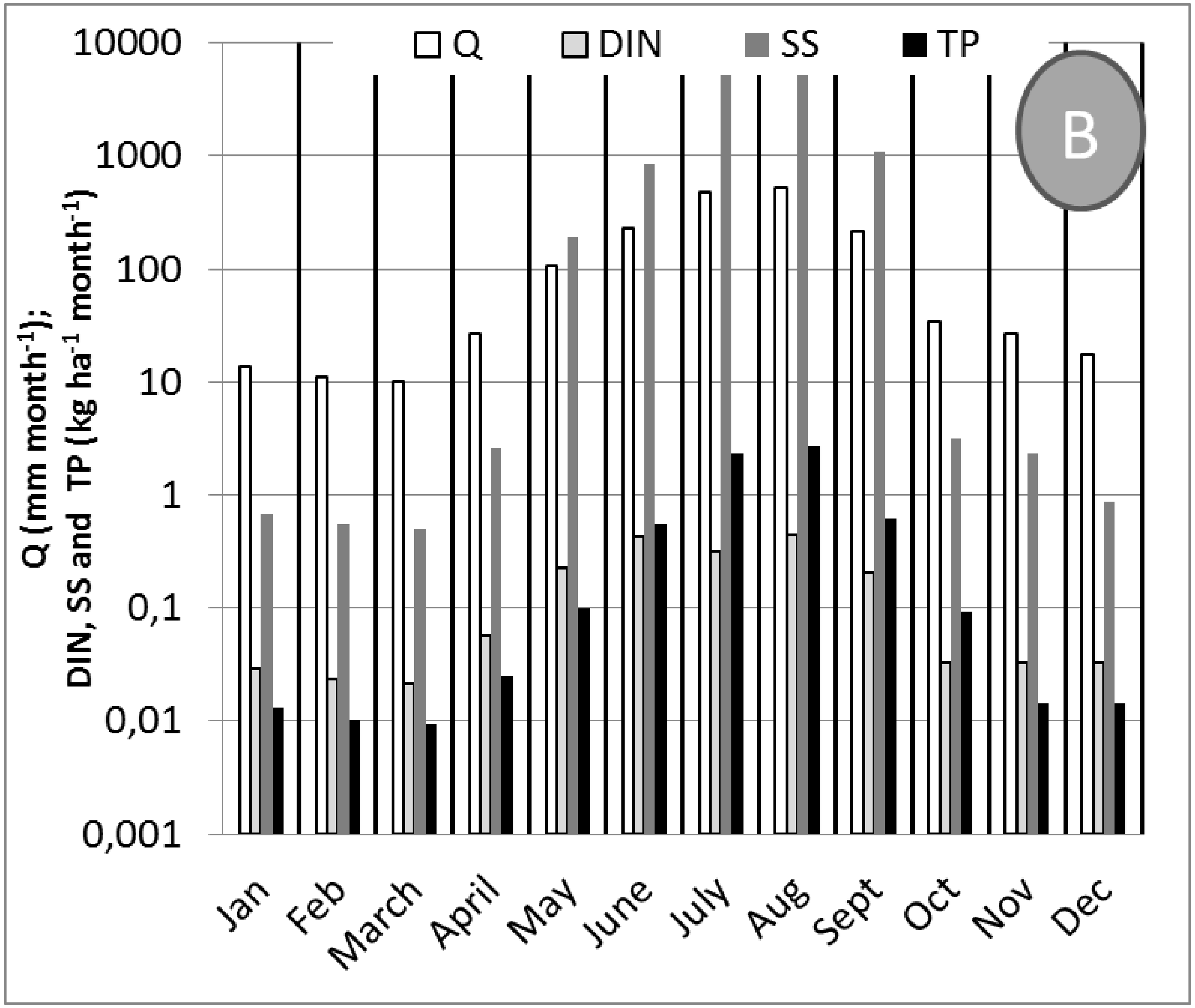
Differing transport characteristics for nutrients

Mürz:
eastern part
of northern alps
Average elevation
1270 m a.s.l.

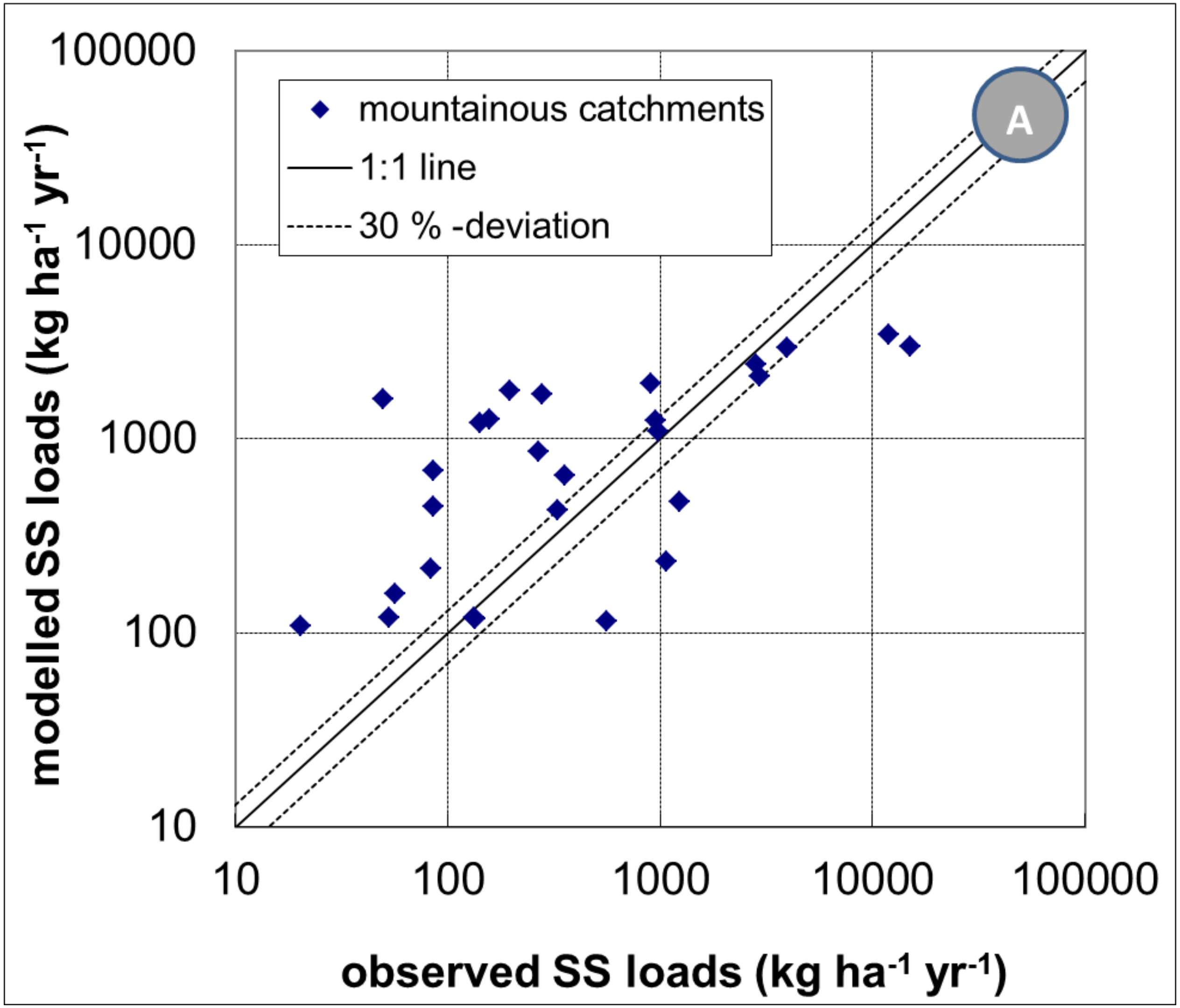


Differing transport characteristics for nutrients

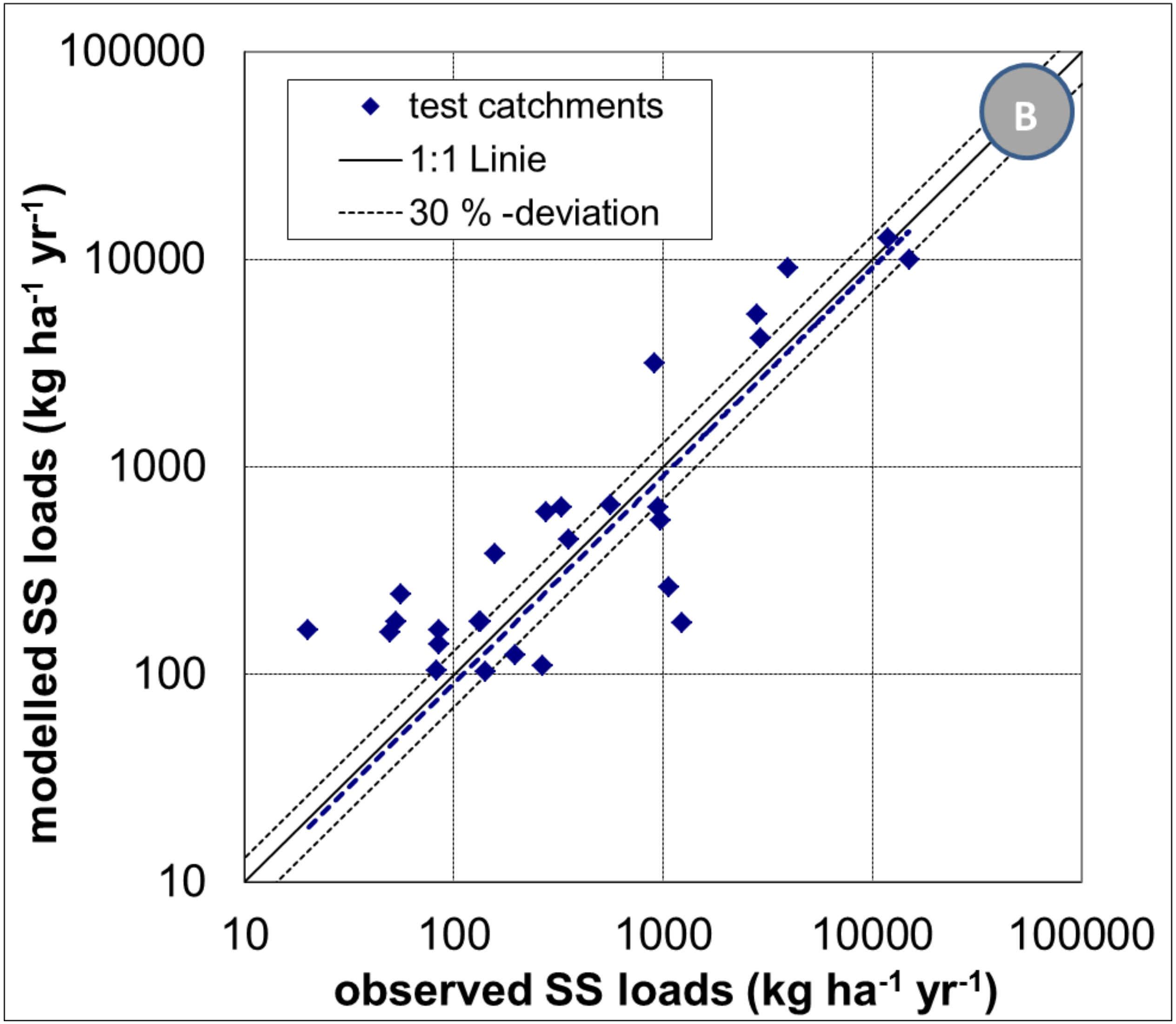
Rofener Ache:
central alps
Average elevation
2915 m a.s.l.
30 % covered with
glaciers



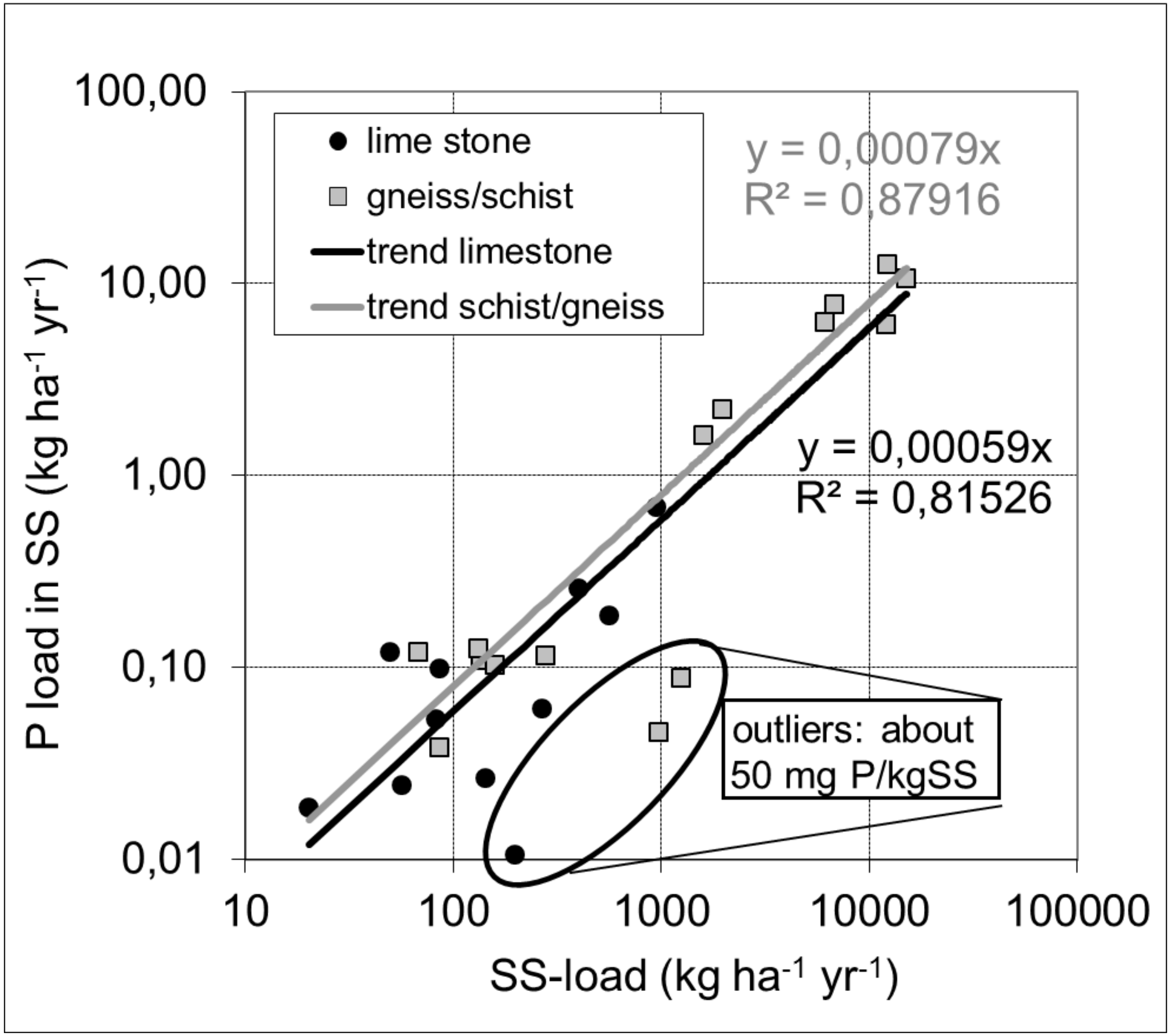
SS loads from open areas (basic version)



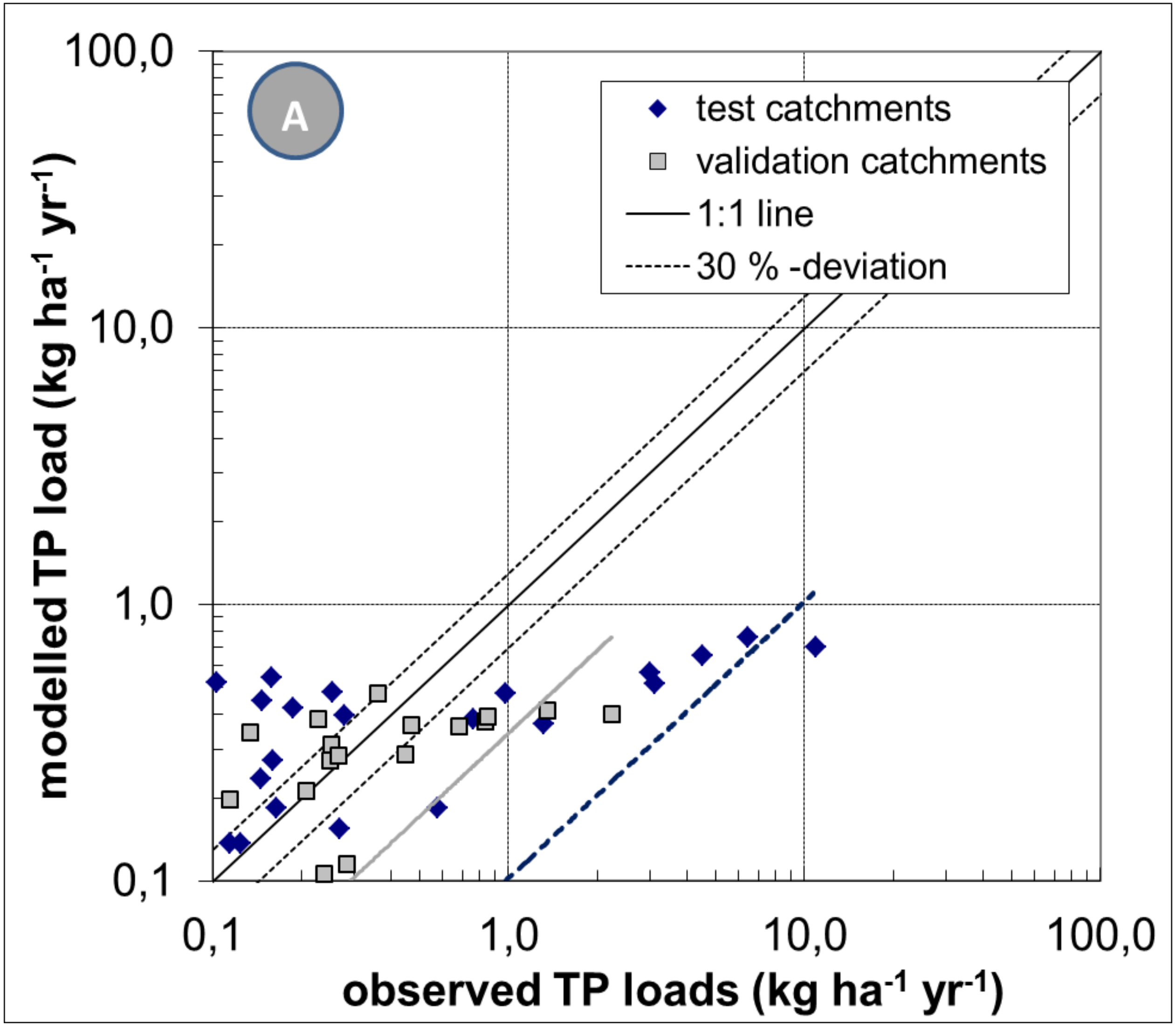
SS loads from open areas (improved version)



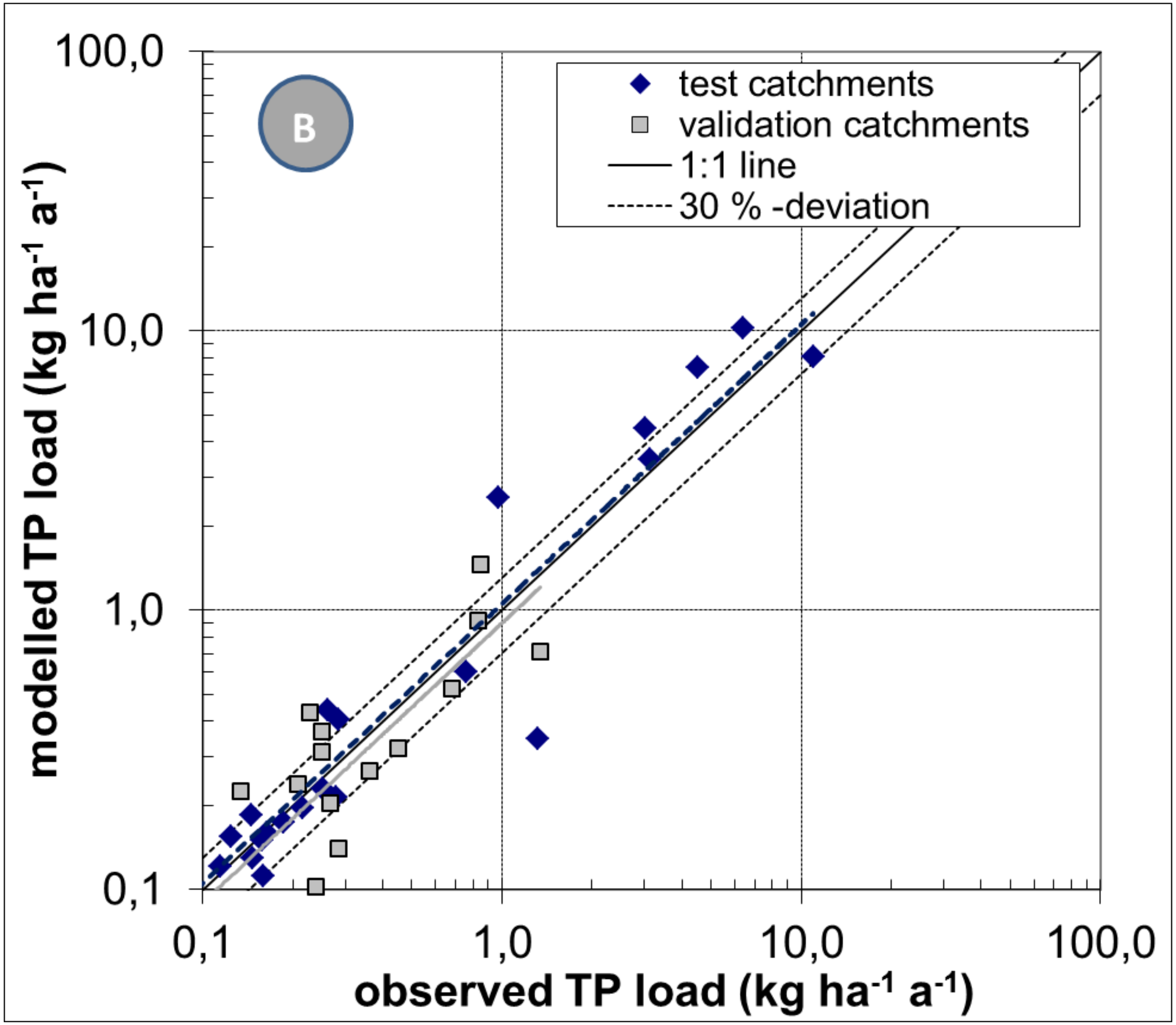
PP concentrations in SS from open areas



Modell performance (TP) – basic version



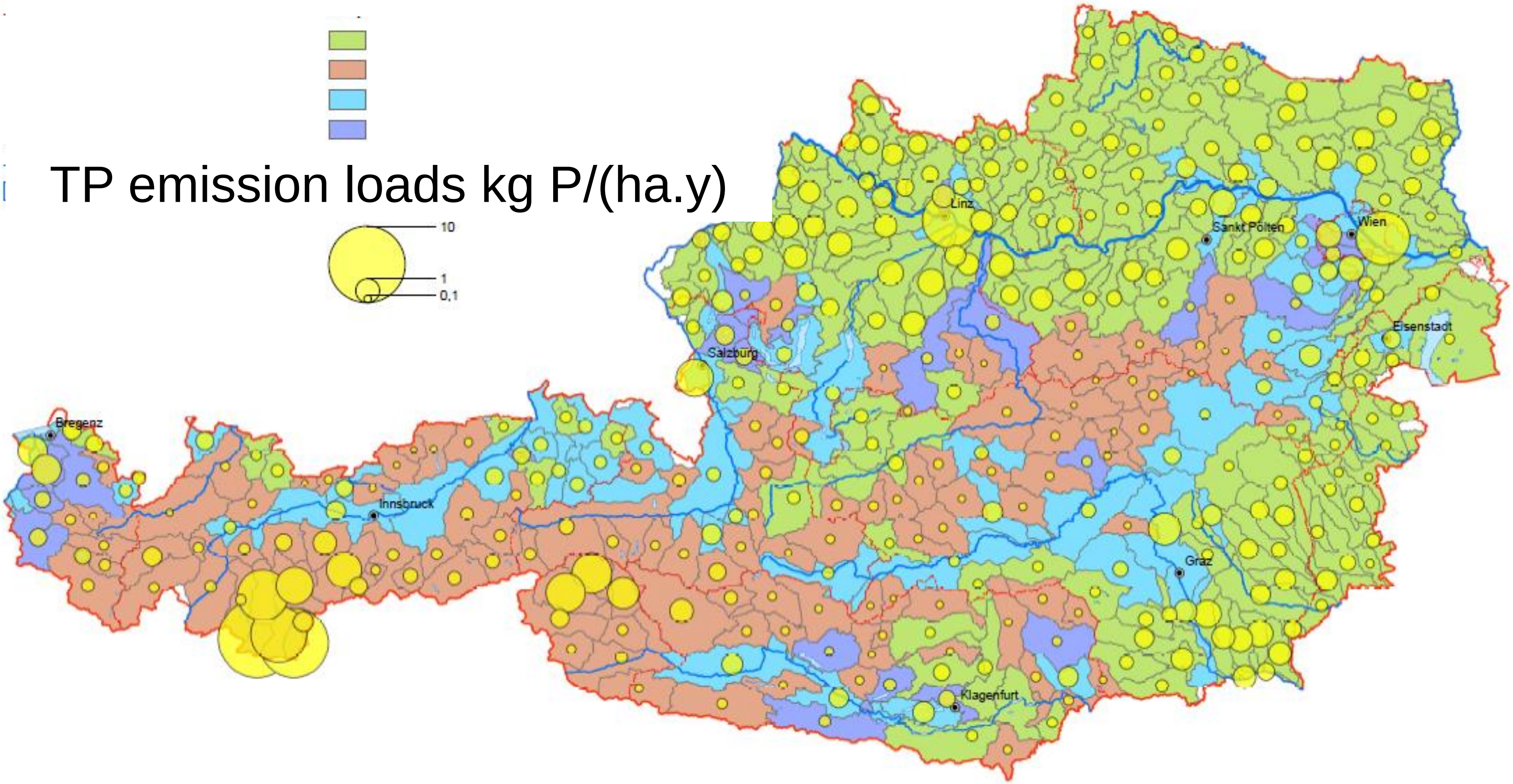
Modell performance (TP) – improved version



Country wide results: total phosphorus

- Main sources of TP emissions

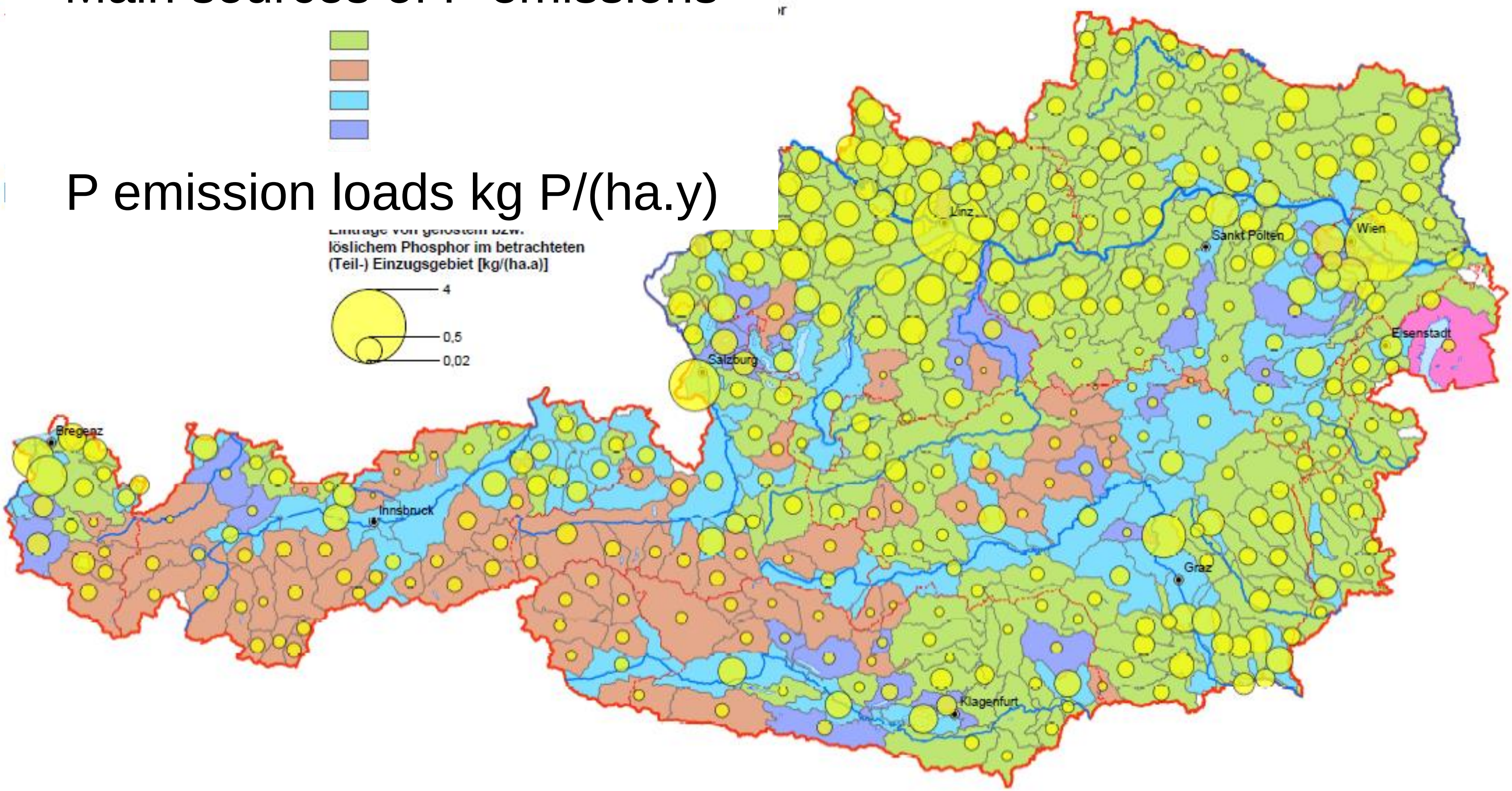
- TP emission loads kg P/(ha.y)



Country wide results: dissolved/soluble P

Main sources of P emissions

P emission loads kg P/(ha.y)



Conclusions

- High SS loads from alpine areas with glaciers (rock weathering)
- P concentrations in these SS are similar to fertilized agricultural soils
- High P background loads from high alpine areas
- Impact of these inputs on river ecology questionable (low P availability)
- Need to be considered for P-balances of these catchments
- A differentiation of P forms including considerations of availability and transformation processes is needed for emission modeling on catchment scale