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Turnover of Nitrogen and Acidification in the Small Headwater Catchment Markungsgraben

Klaus Moritz & Jochen Bittersohl

Bayerisches Landesamt für Wasserwirtschaft, Lazarettstrasse 67,
D–80636 München, Germany

Abstract

Since 1988 the Bavarian State Office for Water Management has investigated the small (1.1 km^2) high elevation catchment of the Markungsgraben in the Bayerischer Wald National Park. Despite decreasing sulphur deposition during the last decade no response in groundwater, springwater or runoff has been observed so far. In seepage water a decrease in sulphate concentrations could be found between 1989 and 1995. The annual sulphur budget at the catchment scale indicates a change from accumulation during the 1980's to release at the end of the 1990's. Even before the extensive spread of the bark beetle, the nitrogen saturated catchment had an NO_3-N output of 15 – 20 kg·ha^{-1}·a^{-1}. Until the present the biotic forest decline has caused severe impact on nitrate concentrations and nitrogen induced acidification of seepage and surface water but not on groundwater. The NO_3-N output has increased to more than 40 kg·ha^{-1}·a^{-1}.

Key words: acidification, element budget, sulphur, nitrogen

Introduction

In 1988 the Bavarian State Office for Water Management in cooperation with the Bavarian State Institute of Forestry started a project to study the impact of forest decline and acid rain on groundwater (Moritz & al. 1994). One of the selected investigation areas was the Markungsgraben catchment in the National Park Bayerischer Wald. After 1995 the investigations have been integrated into the Bavarian water resources management monitoring program (Moritz & Bittersohl 1999). The general aim is to get long-term information about water pollution in a typical landscape with respect to questions of water protection and water use.

The Markungsgraben is a part of the Große Ohe catchment. Here a cooperative network of hydrologic research has evaluated monitoring data for the last two decades (Nationalpark Bayerischer Wald 1999). Another important investigation of this network is the integrated monitoring program of the UN/ECE, which is carried out in the adjacent Forellenbach catchment (Beudert & Kantor 1999).

Site description

The catchment Markungsgraben with an area of 1.1 km^2 represents highland and upper slope regions (890–1355 m a.s.l.) of the mountain range at the Bavarian-Czech border. High relief energy is expressed by an average slope inclination of 27 %. The bedrock consists of coarse granite and gneiss with deeply weathered portions and periglacial and glacial overburden. Mineral soils (acid brown-earths) are acidified with pH_{CaCl} between 3.5 and 4.0 and base

Table 1. – Characteristics of used measuring points.

	Height above sea level	Tree species	Monitoring period
Seepage water, plot 1	970 m	Spruce	1989–1999
Seepage water, plot 2	975 m	Beech	1989–1995
Seepage water, plot 4	1290 m	Spruce	1989–1995
Seepage water, plot 5	980 m	Spruce	1992–1995, 1999
Springwater	1010 m		1987–1999
Groundwater 1	970 m		1987–1999
Streamwater (gauge station)	890 m		1987–1999

saturations below 10 % at 30 cm depth. The completely forested catchment is dominated by spruce stands in the highland region and mixed woodland in the lower zones of the slope regions. Starting in 1996 a bark beetle (*Ips typographus* L.) mass propagation resulted in the total destruction of the spruce stands, which covered 81 % of the catchment area (for details see ZIMMERMANN & al. 2000). Average water balance in an undisturbed period from 1989 to 1996 was 1684 mm precipitation and 1087 mm runoff.

Methods

The monitoring of the water and mass cycle included the observation of surface water, spring water, seepage water and atmospheric deposition (open field and canopy throughfall) with a frequency of two weeks. Groundwater was sampled in two wells six times a year. Runoff was observed continuously at a gauging station and sampled in two-week intervals. Three bulk-samplers (type funnel-bottle) were used for open field deposition, 15 for canopy throughfall respectively. Seepage water was sampled at 4 plots using 4 suction cups in the depths of 50 cm, 100 cm and 150 cm at each plot. The investigation started using a high spatial resolution (open field deposition at 3 plots, canopy throughfall in connection with seepage water at 4 plots, 2 spring and 3 surface water sampling points). In 1995 the monitoring activity was reduced to one measuring point of each water type, one spruce plot concerning atmospheric deposition and one open field plot (Table 1).

Water samples were analysed at the central laboratory of the Bavarian State Office for Water Management using standard methods. For details see MORITZ & al. (1994). Total deposition rates at the stand scale were calculated using the canopy model developed by ULRICH (1991). Sodium was used as a conservative tracer to estimate particulate and gaseous deposition. The element output was determined by applying fitted regressions to daily average runoff and fortnight chemical concentrations. Acid neutralisation capacity (ANC) was calculated as sum of base cations (BC) minus sum of strong acid anions according to the method of REUSS & JOHNSON (1986).

Results

Evaluating the data required differentiating between two periods of time for nearly all of the measuring points: (i) the undisturbed period until the end of the hydrologic year 1996 (ii) the following period with areal forest die-off by bark beetle infestation (compare with ZIMMERMANN & al. 2000).

During the last decade sulphur deposition in canopy throughfall at the spruce plot 1 de-

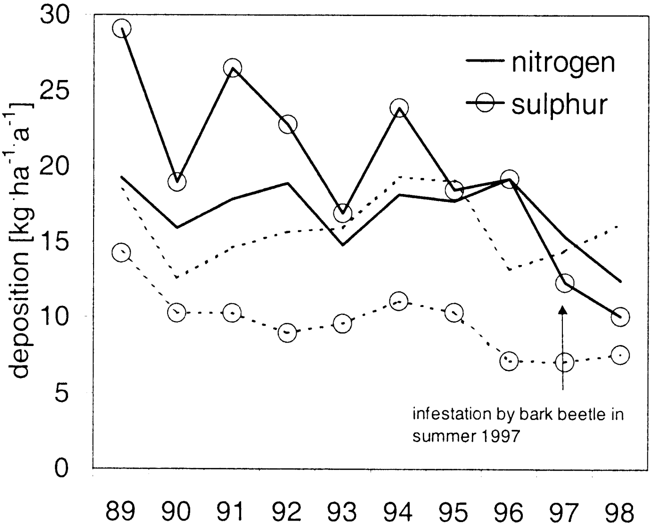

Fig. 1. – Deposition of sulphur and nitrogen at spruce plot 1 at 970 m a.s.l. (full lines-throughfall, dotted lines-open field), hydrological years 1989–1998.

creased from 30 kg ha^{-1} a^{-1} in 1989 to nearly 10 kg ha^{-1} a^{-1} in 1998 (Fig. 1). Data from the beginning of the 1980's showed regional sulphur deposition was even higher at that time (Beudert & al. 1997). Nitrogen deposition (NH_4-N and NO_3-N) for the spruce stand 1 oscillated between 15 kg ha^{-1} a^{-1} and 20 kg ha^{-1} a^{-1}. The average ratio between NH_4-N and NO_3-N was nearly 0.8. This stand was infested by bark beetle in summer 1997. The consequence was a loss of scavenging efficiency and reduced deposition rates of sulphur and nitrogen in 1998. This was representative of the entire catchment, as throughout the area, the bark beetle infestation was very wide-spread.

From the beginning of the study until 1995, a significant decrease of sulphate concentration was observed in the undisturbed seepage water of a highland spruce stand (plot 4, depth 100 cm, 0.27 mmol$_c$ l^{-1} to 0.14 mmol$_c$ l^{-1}) and a beech stand in the slope region (plot 2, depth 150 cm, 0.18 mmol$_c$ l^{-1} to 0.13 mmol$_c$ l^{-1}). This observation was in response to decreasing sulphur input. Sulphate concentration in stream water showed no long-term changes during base flow periods. Since 1996 a decrease of peak concentrations has coincided with the course of the areal bark beetle infestation (Fig. 2). Responsible processes included lower sulphur deposition, elevated water input into the soils and changing anion equilibriums (Kölling & Prietzel 1995) by increasing nitrate concentrations. A hydrologic characteristic of the slope region is the dominance of interflow, which causes lateral element transport and acidification flushes to stream water (Haag & al. 1999). The groundwater was classified as moderately acidified (Bittersohl & al. 1997). Sulphate concentration in groundwater (average groundwater table at 8 m) showed no response to decreasing deposition up to now.

Conservative chloride is an appropriate parameter to validate the accuracy of estimated water and element budgets. In the case of Markungsgraben a nearly balanced budget (average input 0.26 kmol$_c$ ha^{-1} a^{-1}, average output 0.24 kmol$_c$ ha^{-1} a^{-1}) indicates a sufficient quality of data. Despite decreasing sulphur deposition of 75 %, output with discharge did not change significantly (Fig. 3). Except of the hydrologic year 1995, an annual sulphur output

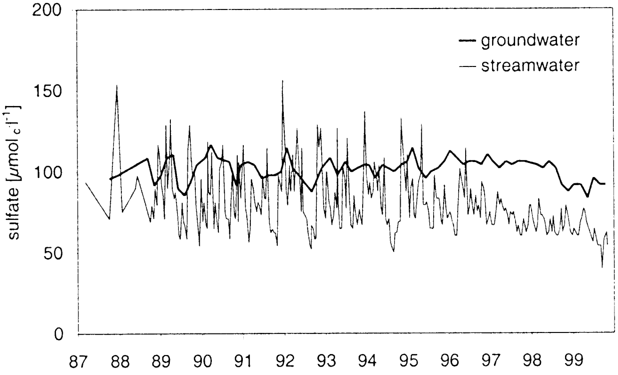

Fig. 2. – Time series of sulphate concentration in stream water at the gauge station and groundwater 1.

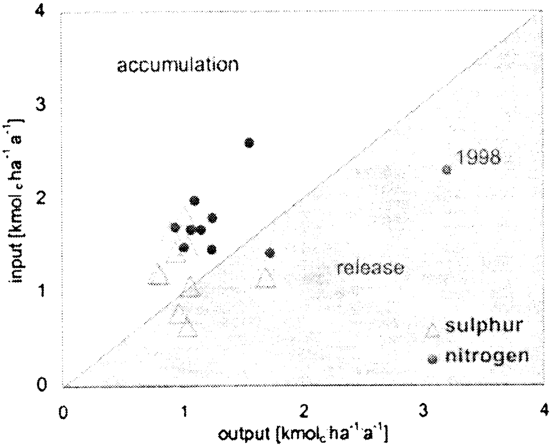

Fig. 3. – Annual input-output-balances of the hydrological years 1989–1998 (input: total deposition calculated by the method of ULRICH (1991) at spruce plot 1, output: calculating a daily output by using fitted regressions of daily average runoff and fortnight chemical concentrations at the gauge station).

of ~1 kmol$_c$ ha^{-1}·a^{-1} at the outlet of the catchment was calculated. During that year, a high discharge of 1649 mm caused an elevated element output. From this it becomes obvious that sulphur sources in soils and deeper zones cause a retardation of the improvement of both surface water and groundwater. Sulphur release has been observed at two plots in the adjacent catchment Forellenbach at stand scale (BEUDERT & KANTOR 1999).

Large losses of nitrogen up to 1.6 kmol$_c$ ha^{-1}·a^{-1} even before massive bark beetle infestation indicated the nitrogen-saturation of the catchment (Fig. 3). In 1997 and 1998, increasing excess nitrification in the soils of damaged areas resulted in nitrogen output of 1.7 kmol$_c$ ha^{-1}·a^{-1} and 3.2 kmol$_c$ ha^{-1}·a^{-1} respectively. In these two years nitrogen output of the catchment exceeded the atmospheric deposition (Fig. 3).

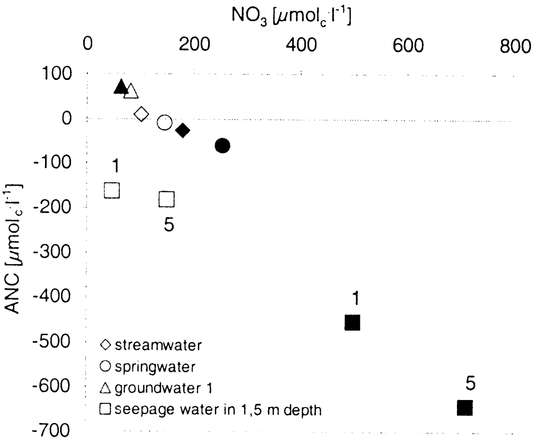

Fig. 4. – Average concentrations of nitrate and ANC before (open symbols) and after bark beetle mass propagation (full symbols) for different water types (seepage water at spruce plot 1 and at spruce plot 5).

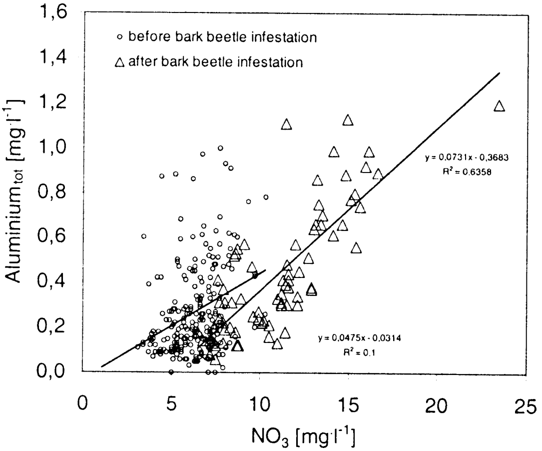

Fig. 5. – Relationship between aluminium and nitrate concentrations in stream water (at the outlet of the catchment) before and after bark beetle infestation.

Table 2. – Average water chemistry before and after bark beetle infestation (SP 1: seepage water plot 1, SP 5: seepage water plot 5, GW: groundwater 1, SW: springwater, R: stream water at the catchment outlet).

	before bark beetle infestation							after bark beetle infestation						
	pH	NO_3^-	SO_4^{2-}	ANC	BC	Al_{tot}	n	pH	NO_3^-	SO_4^{2-}	ANC	BC	Al_{tot}	n
		$\mu mol_c \cdot l^{-1}$				$mg \cdot l^{-1}$			$\mu mol_c \cdot l^{-1}$				$mg \cdot l^{-1}$	
SP 1	4,53	48	218	–162	120	1,58	88	4,44	497	144	–449	231	3,93	46
SP 5	4,63	155	176	–182	174	1,75	55	4,60	761	115	–668	216	5,82	5
GW	5,42	82	102	62	267	0,04	55	5,47	63	99	77	262	0,06	19
SW	4,88	150	115	–9	275	0,39	215	5,02	267	95	–63	314	0,75	79
R	4,85	105	85	9	217	0,27	229	4,89	189	68	–28	245	0,45	79

In general, total damage of spruce stands caused dramatic consequences to acidification of surface and near surface waters, but not to groundwater (Fig. 4). Peak nitrate concentrations in seepage water exceed 1600 $\mu mol_c l^{-1}$. Acid neutralization capacity decreased despite increasing base cations and decreasing sulphate (Table 2). High nitrate concentrations are accompanied by a strong release of aluminium in seepage water and considerable effects in spring and stream water. The variation of nitrate concentrations after bark beetle infestation in stream water can explain 64 % of total aluminium variation (Fig. 5). In contrast there was no correlation between these parameters during the undisturbed period until 1996, when aluminium was mainly controlled by sulphate.

Conclusions

Information about long-term development of catchments (acidification, water quality and drinking water resources) in response to decreasing atmospheric input of acid and sulphur is very important. Together with results from other catchments in Central Europe data from the Markungsgraben improves our knowledge about the recovery of acidified waters.

The improvement of seepage water we observed during a few years coincides to results from roof experiments (ALEWELL & al. 1997). In contrast to results from other regional and European investigations (SCHMEDTJE & BAUER 1999, LÜKEWILLE & al.1998) where most of the surface waters show decreasing sulphate concentrations none were found in the Markungsgraben until 1996. In springwater and groundwater no decrease of sulphate concentrations and acidification was found too. This is probably a result of specific conditions at the Markungsgraben catchment (high sulphur depositions, high sulphur storage in the soils). Similar observations are known from the Lehstenbach catchment in the granitic Fichtelgebirge mountains (LISCHEID & al. 2000). A relocation of stored sulfate in the deeper layers is assumed.

In relationship to biological communities, an ANC below a threshold of 0 $\mu mol_c l^{-1}$ can be proposed as critical. Average ANC of the Markungsgraben was 9 $\mu mol_c l^{-1}$ while during acidic pulses minima reach –100 $\mu mol_c l^{-1}$. Besides sulphate nitrate is an important driving force for the depletion of ANC especially after the forest damage.

If there was any recovery until 1999 the extensive influence of the areal forest die-off masked such a response of water chemistry both groundwater and surface water. On the other hand such a wide-spread „natural experiment“ of changing forest structures is an unique occasion to get data about the response of element and water cycles.

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