

## **The life-span of a small high mountain lake, the Vordere Blaue Gumpe in the Bavarian Alps**

**DAVID MORCHE<sup>1</sup>, CHRISTIAN KATTERFELD<sup>2</sup>,  
SEBASTIAN FUCHS<sup>1</sup> & KARL-HEINZ SCHMIDT<sup>1</sup>**

<sup>1</sup> *Department of Geography, Martin-Luther-University Halle-Wittenberg, D-06099 Halle, Germany  
david.morche@geo.uni-halle.de*

<sup>2</sup> *Department of Geography, University of Basel, Klingelbergstrasse 27, CH-4056 Basel,  
Switzerland*

**Abstract** The Reintal valley in the Wetterstein Mountains in Upper Bavaria has been dammed by large rockslide deposits in some localities. Behind one of the dams a small lake, the Vordere Blaue Gumpe, was still in existence until 23 August 2005. The lake was a natural sediment sink, decoupling an area of about 1.6 km<sup>2</sup> from fluvial sediment export out of the sediment cascade of the Reintal valley. The bergsturz event occurred about 200 years ago. It was dated by evaluating historical maps, paintings, photographs and sketches. Present research is focused on multi-temporal changes of the alluvial deposits of the delta by analysis of aerial photos and geodetic surveying. Volume loss of the lake is closely related to bed load input during extreme events and shows the geomorphic coupling of hillslope and channel systems. From regression analyses of the annual volumetric change of the lake volume, the life-expectancy of the lake was estimated to be about 15 years, before an extreme high magnitude event in August 2005 filled the lake completely with sediment. Now, after the filling of the lake, with the coupling of the catchment area of the Vordere Blaue Gumpe to downstream fluvial sediment export, higher solid load transport is expected in the lower reaches with possible negative effects on infrastructure.

**Key words** Bavarian Alps; bed load; fluvial sediment transport; geodetic surveying; geomorphic coupling; high magnitude event; lake sedimentation

### **INTRODUCTION**

Fluvial sediment transport and geomorphic coupling are the main research topics within the joint-project “Sediment cascades in Alpine Geosystems” (SEDAG). The project aims at quantifying, modelling and coupling different geomorphic processes in a cascading system (definition after Slaymaker, 1991). An attempt to model a sediment cascade with field data from the Reintal valley shows plausible results (Becht *et al.*, 2005). Since 2000 our subproject has concentrated on fluvial sediment export and analyses of the sediment sources and sinks and river channel changes (Morche, 2005; Morche & Schmidt, 2005; Schmidt & Morche, 2006).

### **STUDY AREA**

The lake “Vordere Blaue Gumpe” is situated in the Reintal valley in the Northern Limestone Alps about 80 km south of Munich, near Garmisch-Partenkirchen, southern Germany (Fig. 1). The Reintal is located in a syncline composed of homogenous Triassic

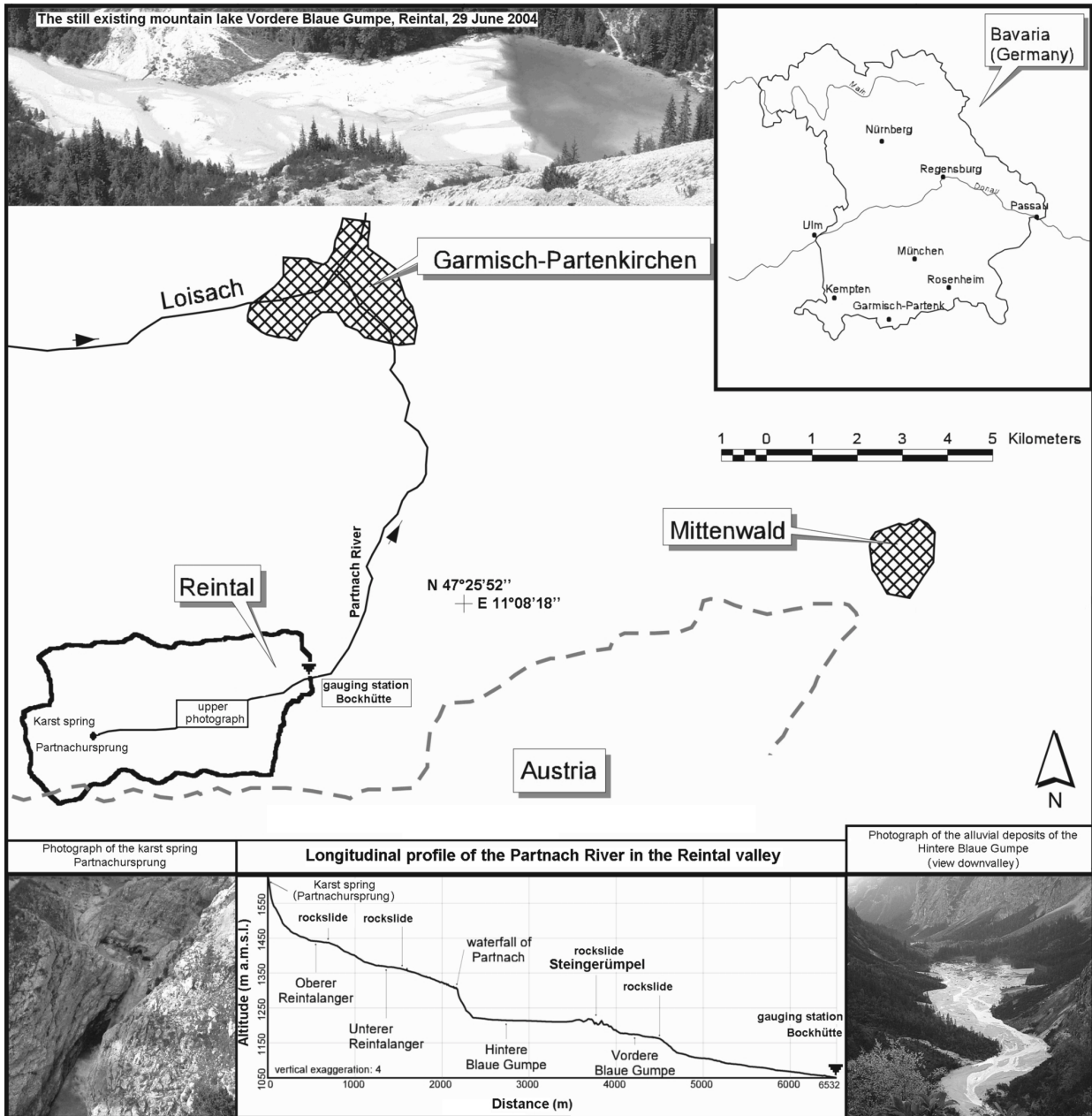


Fig. 1 Location of the study area.

limestone (Wettersteinkalk). Due to glacial erosion a U-shaped valley has developed. The predominant landscape forming processes are low frequency/high magnitude landslide events (bergsturz) and rockfalls (Katterfeld, 2002; Keller & Moser, 2002). These gravity processes form most of the sediment storage types on the valley floor and flanks as talus sheets, talus cones and bergsturz deposits. There is a high spatial and temporal variability of sediment transfer on these landforms (Schrott *et al.*, 2006). Sediment sinks were created by fluvial processes as terraces and alluvial fans (Schrott *et al.*, 2003). Behind the landslide deposits, temporal sediment sinks developed. The Reintal valley is drained by the Partnach River. The mean discharge of the karst spring “Partnach-Ursprung” is about  $1.5 \text{ m}^3 \text{ s}^{-1}$  (Morche, 2006). The hydrological regime of

the Partnach River in the Reintal valley is buffered by karst hydrological processes (Schmidt & Morche, 2006). Every year the Vordere Blaue Gumpe (lake) runs dry in late summer. Due to the valley bottom damming by bergsturz deposits the subcatchment of the Vordere Blaue Gumpe (1.6 km<sup>2</sup>) is decoupled from the bed load transport of the Partnach River (Schmidt & Morche, 2006).

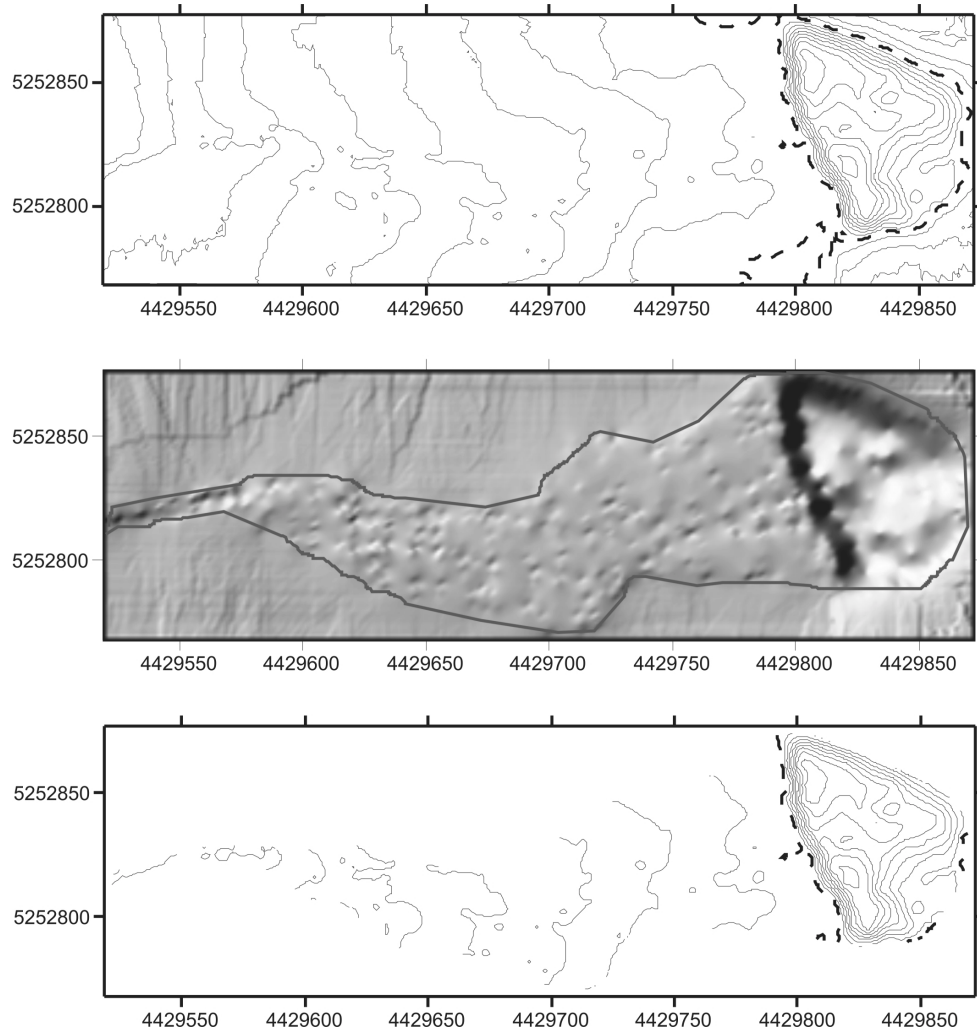
## METHODS

### Analyses of multi-temporal aerial photographs, historical sketches and maps

Historical sketches, maps, picture postcards and photographs as well as oral traditions were documented to analyse the historical development of the lake and the delta growth in the alluvial deposition zone. Most of the material was supplied by the “Marktarchiv” archive of the municipality Garmisch-Partenkirchen. For the last few decades aerial photos (panchromatic, orthorectified) have been used for multi-temporal analyses. Permission has been granted to publish only small parts of the data (Table 1).

**Table 1** List of data used.

Data	Date	Source	Publication permission
Historical sketch	early 18th century	Brandner (1993)	no
Oral tradition	1759	cited in Brandner (2002)	
Historical sketches	1774	Brandner (2002)	no
	1789	Brandner (1993)	no
Watercolour painting	1806	© Staatliche Graphische Sammlung München, inventory number: 15219 Z	yes
Oral tradition	1807	cited in Dopuscheg (1934)	
Landesuraufnahme (first official mapping and surveying of Bavaria)	1815	© Bayerisches Landesvermessungsamt (LVA)	no
Painting	1836	Brandner (1993)	no
Picture postcards	about 1900	Marktarchiv Garmisch-Partenkirchen	no
	about 1910	Marktarchiv Garmisch-Partenkirchen	no
Photographs	about 1925	Dopuscheg (1938)	no
	about 1935	Dopuscheg (1938)	no
Aerial photo	1945	© LVA	no
Aerial photos (panchromatic) scale 1:10000	1960	© LVA	no
	1973	© LVA	no
	1983	© LVA	no
Aerial photos (panchromatic) scale 1:15000	1993	© LVA	no
	1999	© LVA	yes
Aerial photo (digital orthophoto) scale 1:12400	2003	© LVA	yes
Photographs	August 2005	Own data	
	September 2005	Own data	
Geodetic measurements	2000–2005	Own data	



**Fig. 2** The 2004 geodetic survey as an example for data processing: (a) original grid; (b) horizontal projection of the 3D surface layout of the grid and the boundary (bold line); (c) blanked grid. The bold dashed line in (a) and (c) shows water level (1170 m a.m.s.l.). Diagram axes are labelled with Gauß-Krüger coordinates.

### Geodetic surveying

GPS measurements of two reference points on the banks of the lake were made in 2000. For the geodetic survey a Tachymeter (ELTA REC 300) was used. Geodetic surveying of the lake bottom surface was carried out during the autumn low water period in each field season from 2000 to 2005.

### Analyses of geodetic attained data

Digital elevation models were created using the SURFER software. The best fit interpolation was achieved by the kriging geostatistical method. For each geodetic measured surface, a grid was calculated (Fig. 2(a)). For analysis of the surface changes of the alluvial deposits, each grid was blanked by a boundary file (Fig. 2(b) and (c)).

To detect annual changes of the remaining volume of the lake, each blanked grid was subtracted from that of the previous observation period starting with 2001–2000, 2002–2001 and so on.

## RESULTS

There is only little information available on the Reintal valley before the 19th century. On three historical sketches, one from the early 18th century, the others from 1774 and from 1789, published in Brandner (1993, 2002), the lake Vordere Blaue Gumpe is not shown. The oral tradition of Sedlmayer from 2 October 1759 (cited in Brandner, 2002) only mentions the lake Hintere Blaue Gumpe and the bergsturz deposits called “Steingerümpel”, both upstream of the lake Vordere Blaue Gumpe (Fig. 1). The first reference to the lake is the watercolour painting “Blaue Gumpe im Reinthalle, 1806” by Max Joseph Wagenbauer, Germany’s first high mountain painter, who painted the lake by order of King Max I Joseph on an excursion in 1806 (Fig. 3). It shows the lake without any alluvial fills. Fresh debris flow activities on the talus cone on the left can be seen. There are very coarse angular bergsturz deposits without any vegetation cover in the foreground. This watercolour painting is displayed at the Staatliche Graphische Sammlung München (Governmental Collection of Graphics, Munich). The second reference is an oral tradition of Graf von Bray from 7 August 1807, who described the Vordere Blaue Gumpe as “einen von Kalkfelsen eingefassten kleinen See” (cited in



**Fig. 3** The “Blaue Gumpe im Rheinthal”; a watercolour painting by Max Josef Wagenbauer from 1806, © Staatliche Graphische Sammlung München, inventory number 15219 Z, permission to publish from 07 February 2006.

Doposcheg, 1934, p.28). The translation of the quotation means a small lake bordered by limestone rocks. On the first official map of Bavaria from 1815 (Landesuraufnahme) the lake and the landslide downstream of it are shown. According to this information the landslide event and the origin of the lake Vordere Blaue Gumpe can be bracketed in the short time period between the years 1789 and 1806.

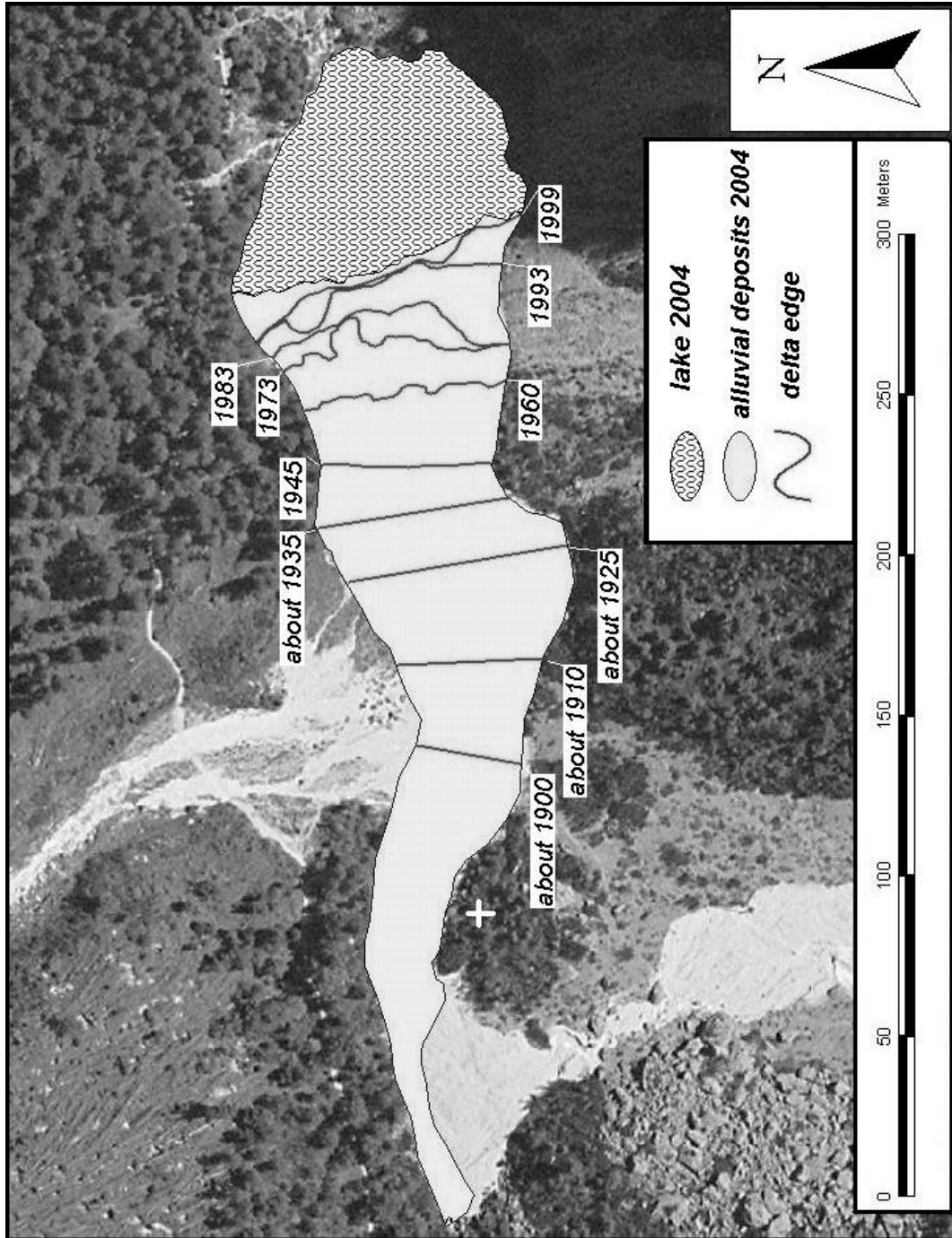
On the 1815 map the lake basin is completely filled with water, there are no sediment deposits at the mouth of the inflowing Partnach River and it covers an area of approximately 17 500 m<sup>2</sup>. A landslide (“Steingerümpel”) about 300–400 years earlier caused the damming of the lake Hintere Blaue Gumpe (Schrott *et al.*, 2003) in an upstream reach (see profile and photograph in Fig. 1). The Vordere Blaue Gumpe was thus decoupled from bed load transport input from upstream reaches of the Partnach River (Schmidt & Morche, 2006) and its total sediment input originates from slopes and slope channels. The most important sediment sources are a right tributary dominated by debris flows and aquatic slope processes (Fuchs, 2005) and a second tributary from the left (Fig. 4), which is dominantly fed by snow-avalanches (Heckmann *et al.*, 2002). Both sediment sources were mapped in 1815 and they have been active until today (Katterfeld, 2002). The left-side slope channel deposits are shown in a painting from the year 1836 (published in Brandner, 1993).

The evolution of the alluvial deposits and the delta front was reconstructed by using picture postcards and historical photographs (Table 1, Fig. 4). The dating of the picture postcards is easily achieved by the written date or postmarks but the date of the photographs shown cannot be determined exactly. Therefore the ages of the delta edge stages in first half of the 20th century may be subject to some error. In about 1900, alluvial deposits covered an area of about 3070 m<sup>2</sup>. About 10 years later the area had grown to about 4140 m<sup>2</sup>. In 1925 the delta covered 5870 m<sup>2</sup> and in 1935 about 7160 m<sup>2</sup>. In 1945 the area covered by alluvial deposits was enlarged to about 8160 m<sup>2</sup>. The delta front is mapped for this stage using an aerial photo showing the whole study area completely covered by snow. Only the shadow of the edge of the alluvial sediment body indicates the location of the delta front line. In 1960 the lake is completely filled by water, so the delta front could be clearly digitized from the panchromatic aerial photo. In 1960, 9458 m<sup>2</sup> are covered by sediment. In the following three decades the alluvial deposition area was enlarged to 10535 m<sup>2</sup> (1973), 10935 m<sup>2</sup> (1983) and 11807 m<sup>2</sup> (1993) (Fig. 4). By 1999 the alluvial deposition area had grown to 12076 m<sup>2</sup> (Fig. 4).

**Table 2** Annual peak flow, remaining lake volume, volume changes and bed load together with annual sediment yield and denudation rate of the Vordere Blaue Gumpe catchment.

Year	HQ (m <sup>3</sup> s <sup>-1</sup> )	RV (m <sup>3</sup> )	ACV (m <sup>3</sup> )	Bed load 1(t)	SY (t km <sup>-2</sup> year <sup>-1</sup> )	D (10 <sup>-4</sup> mm year <sup>-1</sup> )
2000	8.7	12312				
2001	5.6	12144	-169	252	157	1
2002	11.4	10999	-1145	1718	1074	7.2
2003	5.2	10454	-545	818	511	3.4
2004	8.6	9821	-633	950	593	4
2005	50 (estim.)	~0	-5296	7944	4963	33.1

HQ: annual peak discharge; RV: remaining lake volume; ACV: annual changes of lake volume; SY: annual sediment yield; D: annual denudation rate.



**Fig. 4** The delta edge development of the alluvial deposits of the Vorderer Blaue Gumpe between 1900 and 2004. Flow direction of the Partnach River is from left to right. Note, the white bold cross has the coordinates 47°24'36"N and 11°03'57"E; background data source: Orthophoto from 4 September 2003, © Bayerisches Landesvermessungsamt, permission to use and publication from 28 July 2004, reference number: VM3831B-oN/2600.

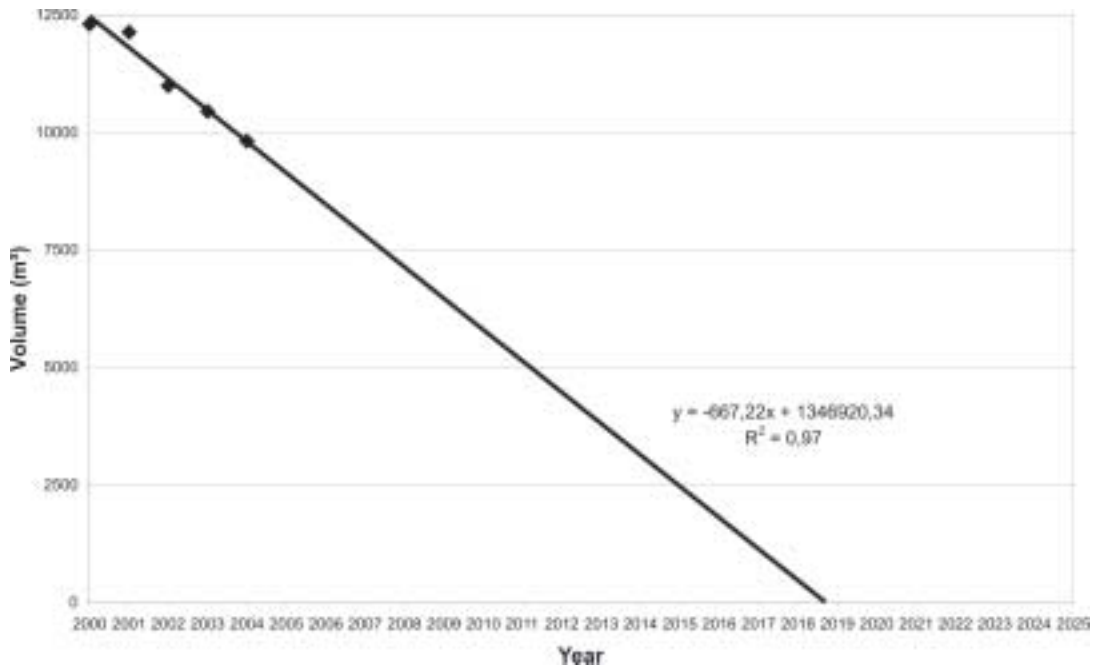
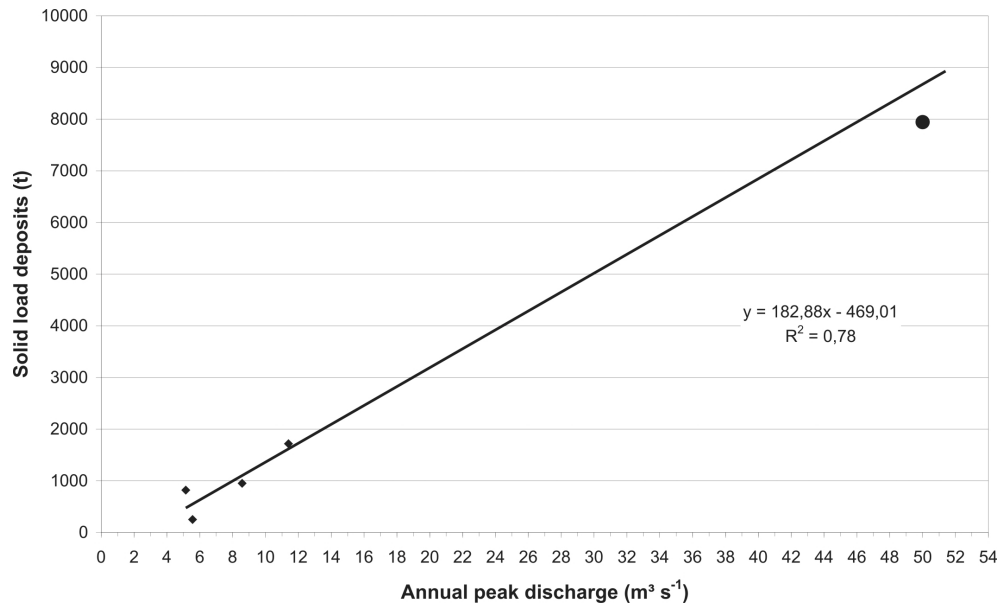


Fig. 5 Calculated life-expectancy of the lake Vordere Blaue Gumpe.

Volumetric data analyses have been possible since 2000 when the geodetic surveys started. Due to varying magnitudes of flood events in the different observation periods there are higher or smaller changes in the lake volume, bed load input, sediment yields and denudation rates (Table 2). Regression analyses of the geodetic measurements 2000–2004 show a life-expectancy for the lake of about 15 years (Fig. 5). Masses were calculated using a bulk density for the alluvial sediment of  $1.5 \text{ t m}^{-3}$  according to Becht (1995), who made similar measurements on alluvial deposits in the Höllental, a valley nearby. The mass fluxes express the bed load input by the Partnach River. Most of the annual bed load is transported during single flood events.

There is a strong relation (coefficient of determination  $\sim 0.8$ ) between the deposited annual bed load and the annual peak discharges measured at the gauging station “Bockhütte” (Fig. 6). This station is located about 2 km downstream of the Vordere Blaue Gumpe (Fig. 1). Discharge and sediment transport data at this station were used to determine the total sediment export from the Reintal catchment (Morche, 2005; Schmidt & Morche, 2006). The bed load transport in the Vordere Blaue Gumpe sub-catchment was very high in the observation periods from 2000 to 2004 compared with the three times larger bed load contributing area at the gauging station “Bockhütte”. Total masses deposited in the lake were higher by a factor of about 20 and the sediment yields by a factor of 60. Further studies are needed to find explanation for these large differences. One explanation may be that large parts of the Vordere Blaue Gumpe catchment are bare of vegetation and the sediment source availability is high. The flood event of 23rd August 2005 with an estimated peak discharge of about  $50 \text{ m}^3 \text{ s}^{-1}$  filled up the lake with sediments, so its existence ends at that time. It has to be pointed out that the natural dam breached and the present-day surface of the alluvial deposits in the former lake lies at about 1169 m; this is 1 m below the former water level. Only about  $5300 \text{ m}^3$  were deposited (Table 2).





**Fig. 6** Relation between annual peak discharge (gauging station Bockhütte, see Fig. 1) and solid load deposits. Note, the 2005 bold point is not included in the regression function.

However, the extrapolated established rating curve between annual peak discharge and deposited solid load fits very well with the 2005 data (bold point in Fig. 6). It has to be taken into account that, because of the shortness of the observation period (5 years), only four data sets were used for regression.

## CONCLUSION

The life-span of the mountain lake Vordere Blaue Gumpe was about 200 years. The termination of the lake was caused abruptly by a high-magnitude/low-frequency flood event. This event coupled the subcatchment of the Vordere Blaue Gumpe to the downstream solid load transport of the Partnach River with an additional bed load contributing area of 1.6 km<sup>2</sup>. This will have serious consequences in terms of higher bed load export out of the Reintal valley and steeper flood hydrographs of the Partnach River. Due to the higher runoff peaks and greater runoff variability that have to be expected because of the enlargement of the connected catchment area and the de-buffering of the system, downstream residents and riparian owners have to consider the new conditions when using and planning infrastructure. Bridges and forest roads which were destroyed during the flood are in the process of being reconstructed. There are also consequences for hydropower stations and a lumber mill operated by riparian owners, because of the greater suspended sediment concentration and increased bed load transport.

**Acknowledgements** The study is financially supported by the Deutsche Forschungsgemeinschaft (German Science Foundation) and the Strukturfonds of the Martin-

Luther-University Halle-Wittenberg. For the field campaigns, driving permission from the Forstamt Garmisch-Partenkirchen and cars from the Martin-Luther-University were made available. Franz Wörndle, archivist of the municipal archive Garmisch-Partenkirchen, provided historical data. The information on the 1806 watercolour painting of was given by Dr Oliver Sass (Department of Geography, University of Augsburg). Sabine Wölfel (Staatliche Graphische Sammlung München) provided a scanned copy and permitted the publication. Special thanks go to Karl Wörndle and his family as well as Charly Wehrle and his team at the alpine hut “Reintalangerhütte” for help and support in the field, and last but not least to our graduate and post-graduate students (Holger Redlich, Ingo Sahling, Maik Unbenannt, Markus Witzsche) for their active assistance during the field campaigns. The corrections and helpful comments of the reviewer are greatly appreciated.

## REFERENCES

- Becht, M. (1995) Untersuchungen zur aktuellen Reliefentwicklung in alpinen Einzugsgebieten. *Münchener Geographische Abhandlungen*, Bd. A 47, München, Germany.
- Becht, M., Haas, F., Heckmann, T. & Wichmann, V. (2005) Investigating sediment cascades using field measurements and spatial modelling. In: *Sediment Budgets 1* (ed. by D. E. Walling & A. J. Horowitz), 206–213. IAHS Publ. 291. IAHS Press, Wallingford, UK.
- Brandner, J. (1993) *Rund ums Landl*. Adam, Garmisch-Partenkirchen, Germany.
- Brandner, J. (2002) Zugspitzerstbesteigung schon im 18. Jahrhundert? In: *Das Reintal. Der alte Weg zur Zugspitze*. (ed. by C. Wehrle), 75–77. Panico Alpinverlag, Köngen, Germany.
- Doposcheg, J. (1934) *Zugspitze und Zugspitzbahn*. Geschichtlich-Naturkundlicher Führer. Garmisch-Partenkirchen, Germany.
- Doposcheg, J. (1938) *Berge und Pflanzen in der Landschaft Werdenfels*. Geschichtlich-Naturkundlicher Führer. Garmisch-Partenkirchen, Germany.
- Fuchs, S. (2005) Multitemporale Untersuchungen zur Reliefdynamik in einer alpinen Sedimentkaskade (Reintal, Wettersteingebirge). Diploma Thesis, Martin-Luther-University Halle-Wittenberg, Halle, Germany.
- Heckmann, T., Wichmann, V. & Becht, M. (2002) Quantifying sediment transport by avalanches in the Bavarian Alps—first results. *Z. Geomorph. NF Suppl.* **127**, 137–152.
- Katterfeld, C. (2002) Multitemporale Untersuchungen von durch gravitative Prozesse generierten Reliefformen in einem alpinen Einzugsgebiet. Diploma Thesis, Martin-Luther-University Halle-Wittenberg, Halle, Germany.
- Keller, D. & Moser, M. (2002) Assessments of field methods for rock fall and soil slip modelling. *Z. Geomorph. NF Suppl.* **127**, 127–135.
- Morche, D. (2005) Calculating the fluvial sediment output in high mountain catchments. *RMZ—Materials & Geoenvironment* **52**, 99–102.
- Morche, D. (2006) Aktuelle hydrologische Untersuchungen am Partnach-Ursprung (Wettersteingebirge). *Wasserwirtschaft* **96**, 53–58.
- Morche, D. & Schmidt, K.-H. (2005) Particle size and particle shape analyses of unconsolidated material from sediment sources and sinks in a small Alpine catchment (Reintal, Bavarian Alps, Germany). *Z. Geomorph. NF Suppl.* **138**, 67–79.
- Schmidt, K.-H. & Morche, D. (2006) Sediment output and effective discharge in two small high mountain catchments in the Bavarian Alps, Germany. *Geomorphology* (in press).
- Schrott, L., Hufschmidt, G., Hankammer, M., Hoffmann, T. & Dikau, R. (2003) Spatial distribution of sediment storage types and quantification of valley fill deposits in an Alpine basin, Reintal, Bavarian Alps, Germany. *Geomorphology* **55**, 45–63.
- Schrott, L., Götz, J., Geilhausen, M., & Morche, D. (2006) Spatial and temporal variability of sediment transfer and storage in an Alpine basin (Bavarian Alps, Germany). *Geographica Helvetica* (submitted).
- Slaymaker, O. (1991) Mountain geomorphology: a theoretical framework for measurement programmes. *Catena* **18**, 427–437.