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Lake Mladotice in the Western Czech Republic – Sediments as a Geoarchive for Flood Events and Pre- to Postcommunist Change in Land Use since 1872

Achim Schulte[1], Bohumir Jansky[2] and Julius Česak[2]
[1]*Institute of Geographical Sciences, Department of Earth Sciences,*
Freie Universität Berlin, Berlin,
[2]*Department of Physical Geography and Geoecology,*
Charles University of Prague, Praha,
[1]*Germany*
[2]*Czech Republic*

1. Introduction

Landscape changes are distinguished into those generated by natural processes and those caused or triggered by human activity (Barsch et al. 1993; Jansky & Urbanova 1994; Favis-Mortlock et al. 1997; Bork et al. 1998; Voelkel 2005; Bičik & Kabrda 2007; Bičik & Jeleček 2009). The geoarchives do not reveal which of these factors ultimately caused greater soil erosion. Improved dating techniques are necessary to increase the temporal resolution of the sediment records which have clearly increased the level of knowledge in recent years (e.g. Geyh 2005, Kadlec et al. 2009).

When examining sediment archives from recent times, we may have the opportunity to identify the factors controlling sediment formation in much more detail (e.g. Junge et al. 2005). This was the case with the natural "experimental setup" at Lake Mladotice (western Czech Republic), where it was possible to analyse a sediment archive dating back to 1872. Since the onset of lake sedimentation, rainfall and runoff have been recorded (in some cases continuously) at monitoring stations located in the surrounding area of the catchment area of the lake (Schulte 2007, Schulte et al. 2007).

Air photos from several decades document pre- and post-communist land use changes in the lake's drainage basin. Furthermore, records exist of fertiliser programmes affecting sediments and hydrochemism. Because of the change in land use, increased soil erosion and a rise in the sedimentation rate were expected. Against this background, our investigations into the lake sediments and the drainage area of Lake Mladotice aim to address the following questions:

1. To what extent has land use changed in the drainage basin of Lake Mladotice since 1872?
2. Has the magnitude or frequency of the rainfall runoff events changed since 1872?
3. To what extent is the sediment record a product of the rainfall runoff events or the change in land use in the drainage basin?

2. Lake evolution and drainage basin

During the final days of May 1872, an extensive area of southwestern and western Bohemia was affected by a massive incident of torrential rain, which according to historical reports lasted from noontime on 25 May until the morning of the following day. The Pilsen rain gauge recorded two thunderstorms on 25 May 1872, from which a total of 40 mm of precipitation was measured (Skrejšovsky 1872). However, a far greater sum of precipitation fell north of Pilsen, where no rain gauge was in operation at that time. Nevertheless, Karel Kořistka, a prominent cartographer, provided a detailed description of the meteorological situation (Kořistka 1872): "Observed in Mladotice, a standing empty vessel that was 9 inches or 237 mm tall was filled to the brim within one hour's time to the point that additional rain overflowed the vessel…".

This report of 237 mm of precipitation in one hour was for a long time considered to be unrealistic. Only with the measurement of torrential rain in southern Slovakia – i.e. in a similar Central European climate zone, recorded on 12 June 1957, when 225.5 mm of precipitation fell during 65 minutes at Skalka by Šturovo (southern Slovakia) – was the feasibility of these earlier data confirmed (see Štekl et al. 2001).

The extreme precipitation in May 1872 caused an extraordinarily destructive flood which devastated the catchment areas of the Střela and Blšanka Rivers as well as most of the Berounka River basin below Pilsen. On May 26, at 2 pm, the discharge of the Vltava in Prague was measured at 3300 m^3/s, which represents the fifth largest flood observed since 1825 (Brazdil et al. 2005).

As a consequence of earthworks for a railway track at the footslope and the extreme rainfall event, large masses of rock slumped down from the western slope of the Potvorovsky Hill (546 m asl) into the Mladoticky valley during the night from 27 to 28 May, damming the creek with a massive dike (Fig. 1). Bedrock and mass accumulation mainly consist of

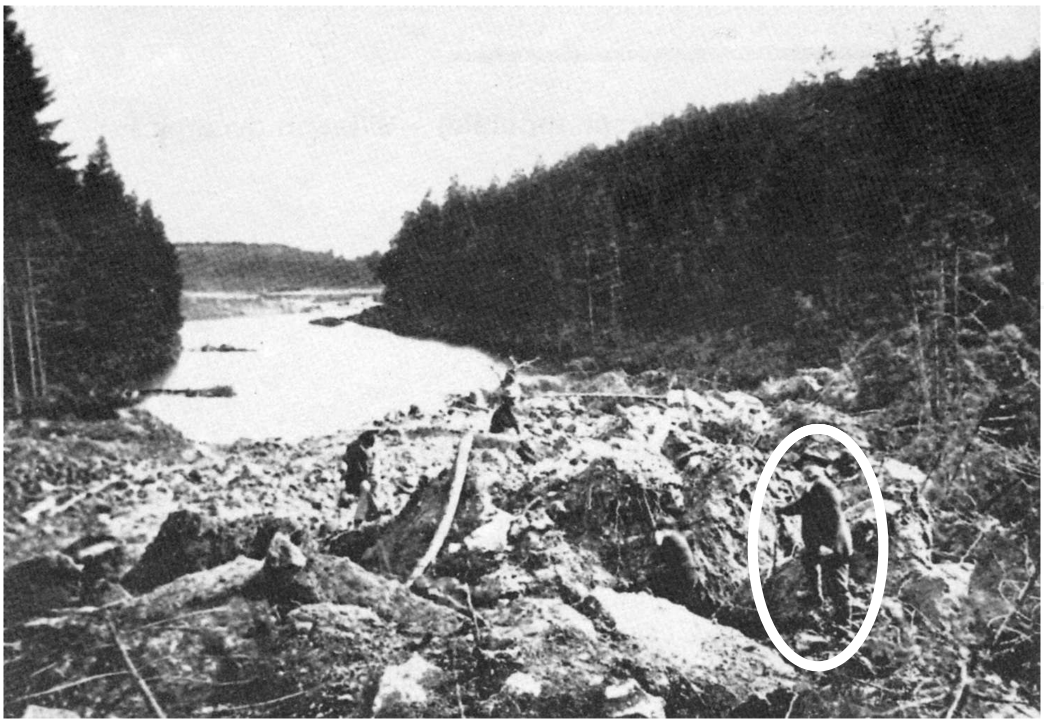
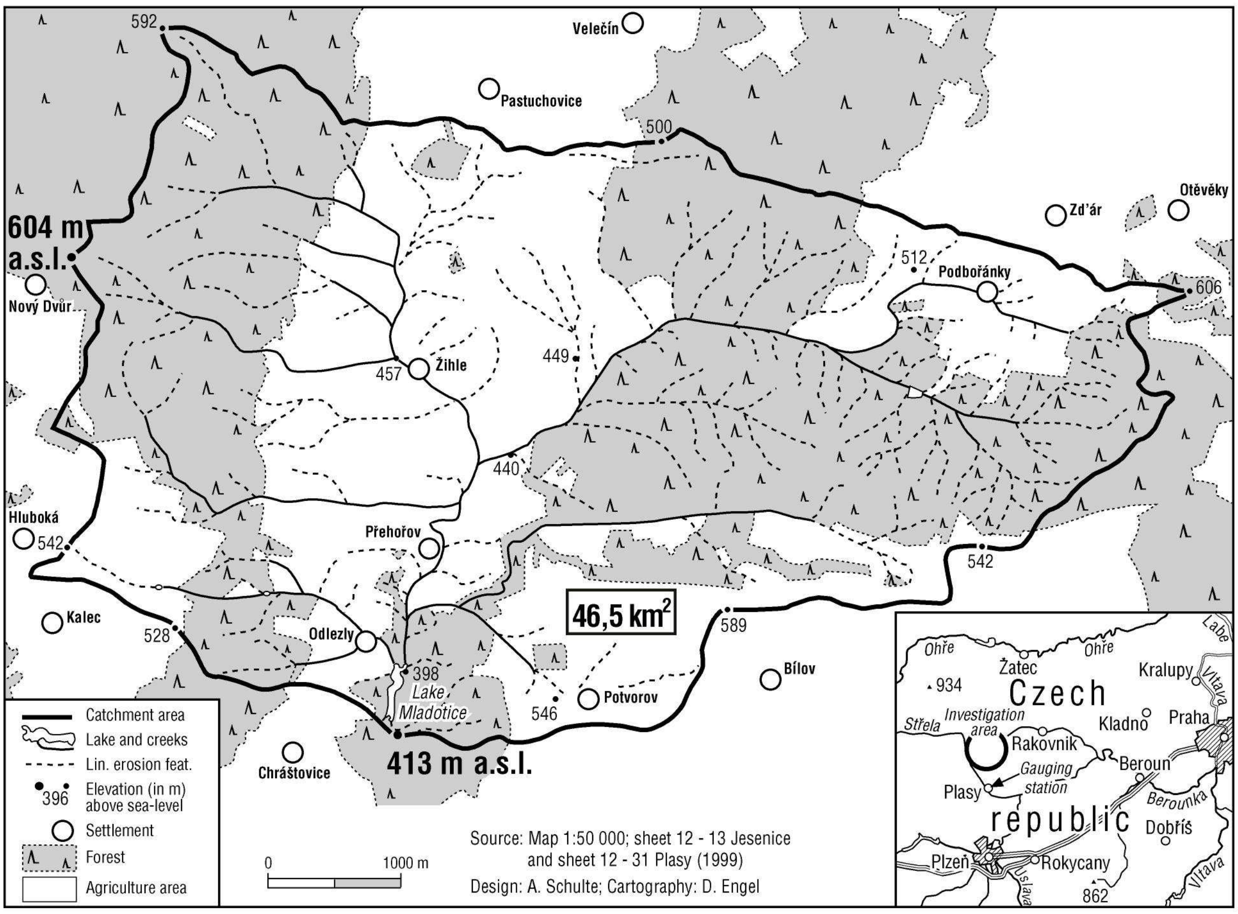


Fig. 1. Dammed valley immediately after the landslide in May 1872; the lake is emerging in the background. Print from Geografie (Sbornik ČSZ) 28, Praha 1912. Photo by C. Purkyně.

Palaeozoic shale, sandstone and conglomerate, with some Proterozoic phyllite and spilite and Palaeozoic granite (Česky geologicky ustav 1996). The created lake is, up to the present day, the only example of such a genetic type of lake in the Bohemian Massif.

The preconditions for a landslide to occur on the slopes of the Potvorovsky Hill originated long before the catastrophic landslide of 1872. It is evident that there were multiple causes, and these should be viewed in the light of their mutual connections and not as isolated factors, owing to the fact that each of them contributed to a certain degree to disrupting the stability of the slope, as is discussed in detail by Jansky (1976, 1977).

Lake Mladotice still exists in the western Czech Republic about 30 km north of Pilsen. The receiving streams of the lake outflow are the Střela and Berounka Rivers; the latter drains into the Vltava River south of Prague. The erosion level of the lake is 413 m a.s.l.; its surface extends over 4.74 ha. The lake's drainage area is approx. 46.5 km², about 50% of which is being intensively farmed (Fig. 2). The lake's drainage basin – including the type of land use – is typical for a larger region of western Bohemia.



Source: Map 1:50 000; sheet 12 - 13 Jesenice and sheet 12 - 31 Plasy (1999)
Design: A. Schulte; Cartography: D. Engel

Fig. 2. Drainage basin of Lake Mladotice and location of the study area in the western Czech Republic.

3. Methods

Geodetic and bathymetric measurements of Lake Mladotice were conducted in 1972, 1990 and 2003 (Jansky 1976, 1977; Jansky & Urbanova 1994; Česak & Šobr 2005). By comparing the results of these measurements, it is possible to analyse the dynamics of the lake's sedimentation in the past and to attempt to predict the further development of the lake basin: in other words, to determine a period after which the lake will be entirely filled with sediment.

To reconstruct land use shifts, the Military Topographical Institute in Debrovska (western Bohemia) supplied air photos taken in 1938, 1952, 1975, 1987 and 1998. Up to now only 2-D interpretation has been possible, because of the lack of overlap. The air photographs document a considerable land use change with the introduction of collectivisation (see below). We anticipate that stereoscopic 3-D interpretation of the air photos will show the removal of field terraces that accompanied field enlargement and also contributed to increased erosion (Janský 1976, 1977; Jansky & Urbanova 1994).

Rainfall data were analysed from six stations recording data since 1881 to assess the influence of natural factors on erosion, transport and sedimentation rates in Lake Mladotice. The rain gauges at Kralovice, Plasy, Mladotice, Manetin, Liblin and Valecin are not located in the drainage basin of Lake Mladotice, but they are the closest stations in the surrounding area. These records do not seem to be homogeneous for all events at all stations and need to be examined carefully to identify the rainfall events relevant to flooding. Rainfall runoff analysis should therefore focus on major events which covered the whole area of the rainfall stations, including the drainage basin of Lake Mladotice.

Runoff data serve to indicate the dimensions of past flood events. The nearest runoff gauge is located on the Strela River (Plasy Station, 775 km^2, Fig. 2 small map), which also drains the Mladoticky creek. Daily records at this gauge date back to 1941. It is assumed that large floods recorded at the Strela River were also experienced at the Mladoticky creek and that sediments were deposited in the lake during these events.

To classify current sedimentation conditions and sediment properties, we measured the oxygen content, conductivity, temperature, visible depth and stream flow of the lake water in the summers of 2003 and 2004 in a depth grid across the lake.

Sediment echo sounding was used to measure sediment distribution along profiles in the lake basin in order to find suitable sites for core drilling. Unfortunately the sediments were extremely poor in reflection owing to the great number of cavities in the lake sediments, and thus results were unsatisfactory. The analysis of the sediment cores confirms the great number of cavities.

In spite of this setback, we obtained information about the distribution of the sediments by extracting 13 short cores, each about 1 m in length. Five long cores were drilled down to the bottom of the sediments. The reference core ML 18/03 was extracted from the deepest part of the lake, and core ML 14/03 was investigated for diatom analyses (Fig. 3).

Reference core ML 18/03, with a total length of 4 m, underwent analyses of water content, density, grain size distribution, total sulphur, total carbon, total phosphorus, clay mineral composition, the isotope content of ^{137}Cs, ^{241}Am and ^{210}Pb as well as thin sections from the entire length of the core. Sediment samples were taken and analysed in 10 cm sections. The upper part of the sediment core ML 14/03 was investigated for diatoms (0–160 cm core depth). As agrochemicals can indicate system changes, we analysed their input into the lake. Fractionated organic analyses were conducted on four samples using GC-MS technology.

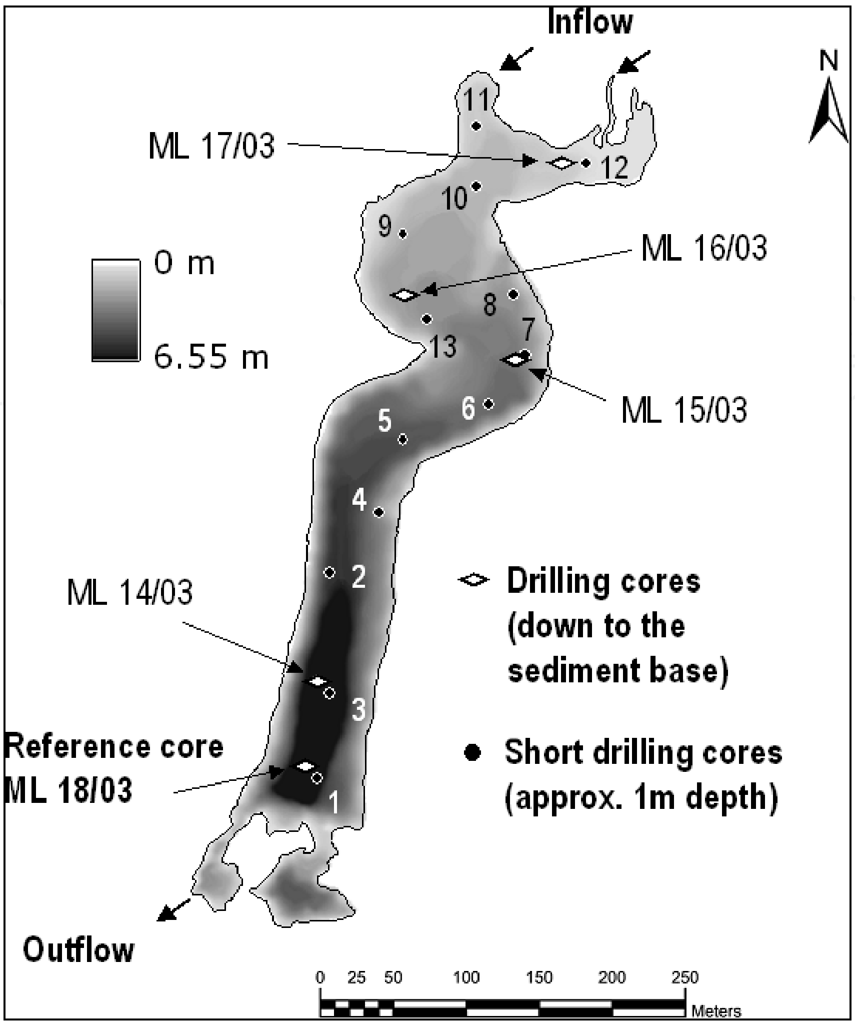


Fig. 3. Map of Lake Mladotice showing locations of short and long cores. Core ML 18/03 is located near the outflow with the maximum water depth.

4. Results

4.1 Sediment filling in the lake basin and fluctuations of lake water level

Comparative analysis of bathymetric measurements from 1972 and 2003 yielded the following results (Jansky 2003). The maximum depth of the lake decreased from 7.7 m to 6.7 m (Fig. 4). The 7 m depth level disappeared entirely, and the area of all other depth levels decreased - the 6 m depth level to 61% of its initial area from 1972, the 5 m level to 43%, the 4 m level to 60%. The decline in the area of shallow water levels was somewhat less dramatic – the 3 m level decreased to 72% of its 1972 area, while the 2 m and 1 m levels decreased to 69% and 76%, respectively.

A decrease in the water level's surface area was measured, i.e. from an initial 5.85 ha (1972) to 4.73 ha (2003). This means a decrease of 1.12 ha in the lake's surface area, i.e. 19% of its initial area in 1972. The maximum water level fluctuation between 1972 and 2009 was recorded at around 55 cm. Moreover, the automatic limnigraph has measured a fluctuation of 26 cm in the last 12 months. After the bathymetric curves were elicited, the water volume of the lake basin was calculated. From an initial volume of 141,380 m^3 in 1972, it decreased by 37,471 m^3 to 103,910 m^3; the water volume of the lake decreased by 26.5%.

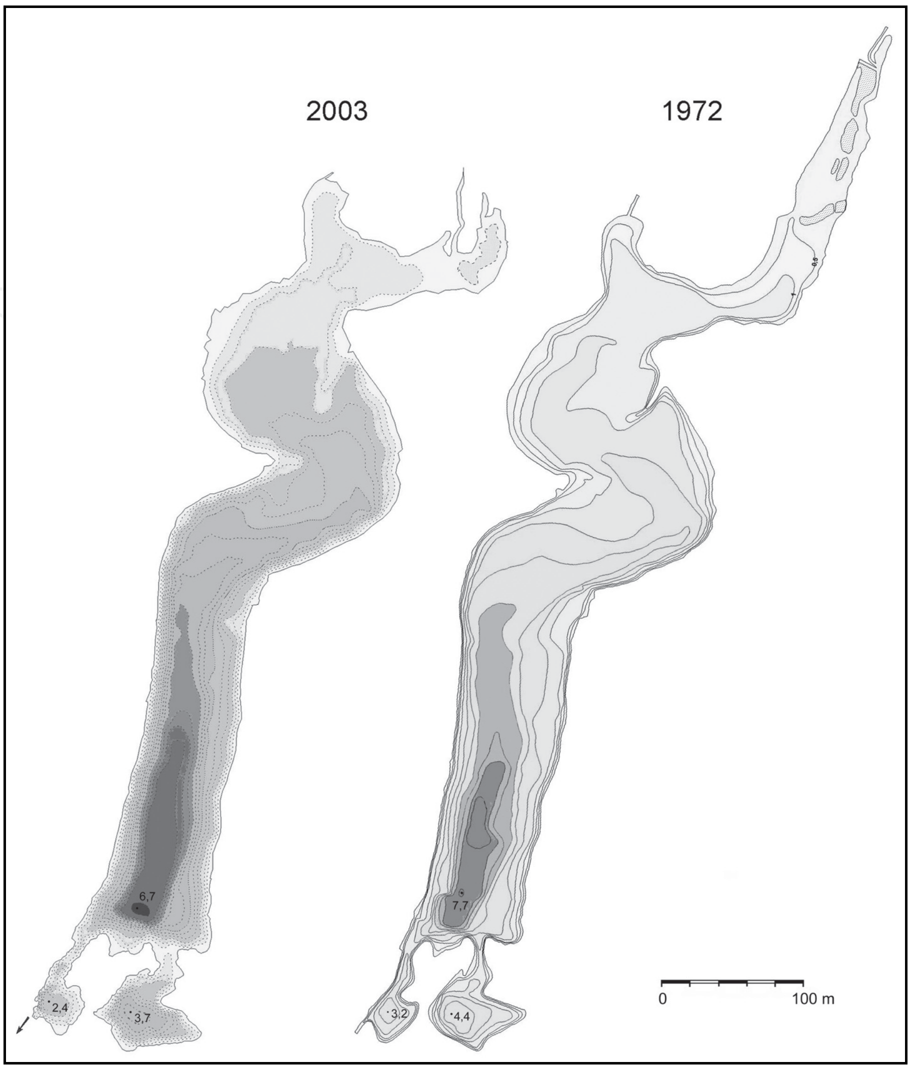
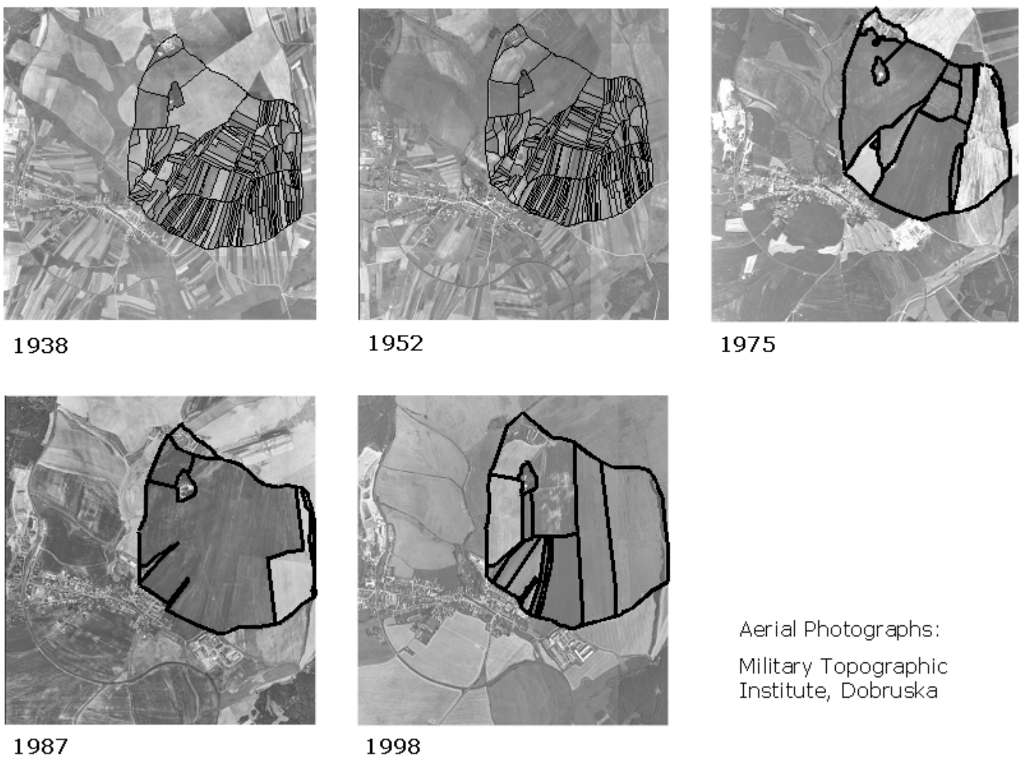


Fig. 4. The bathymetric maps of the Lake Mladotice from measurements in 1972 and 2003

4.2 Changes in land use and flood discharge

Landscape changes in the drainage basin of Lake Mladotice were reconstructed from air images. To visualise the land use changes, Fig. 5 displays as an example a field about 1 km^2 in size that is located northeast of Žihle (for orientation see Fig. 2). No changes are visible in the field patterns between 1938 and 1952. Collective farming had the greatest impact between 1952 and 1975, when fields were made much larger. A further increase in the size of some fields is visible in 1987. The photos taken in 1998 show that the size of the fields was reduced again after the political change in 1989. Bigger fields facilitate soil erosion due to longer slopes and increased surface runoff (see conclusions). Some quantitative data about land use changes were published in Schulte et al. (2006).

To clarify whether the system changes are due to natural or anthropogenic causes, we analysed the time series of discharge values at the Střela gauge at Plasy (775 km^2) from 1941 until 2002 (2003 is the year of sediment coring). Plausibility and homogeneity checks of the discharge data revealed discontinuities and varying trends in the years 1956 and 1978, so further studies were made in three separate periods (1941-1956, 1957-1977 and 1978-2002). In these three periods, the annual flood peaks show a falling tendency, i.e. a lower peak over the years (Fig. 6). The number of floods above a threshold of 5.5 m³/s increased slightly from 4.1 flood events per year (1941-1956) to 5.0 (1957-1977) and 5.1 flood events per year between 1978 and 2002.



Aerial Photographs:
Military Topographic Institute, Dobruska

Fig. 5. Air images of a field about 1 km² in size, northeast of the town of Zihle in the basin of Lake Mladotice (see Fig. 2). Collective farming had the greatest impact between 1952 and 1975.

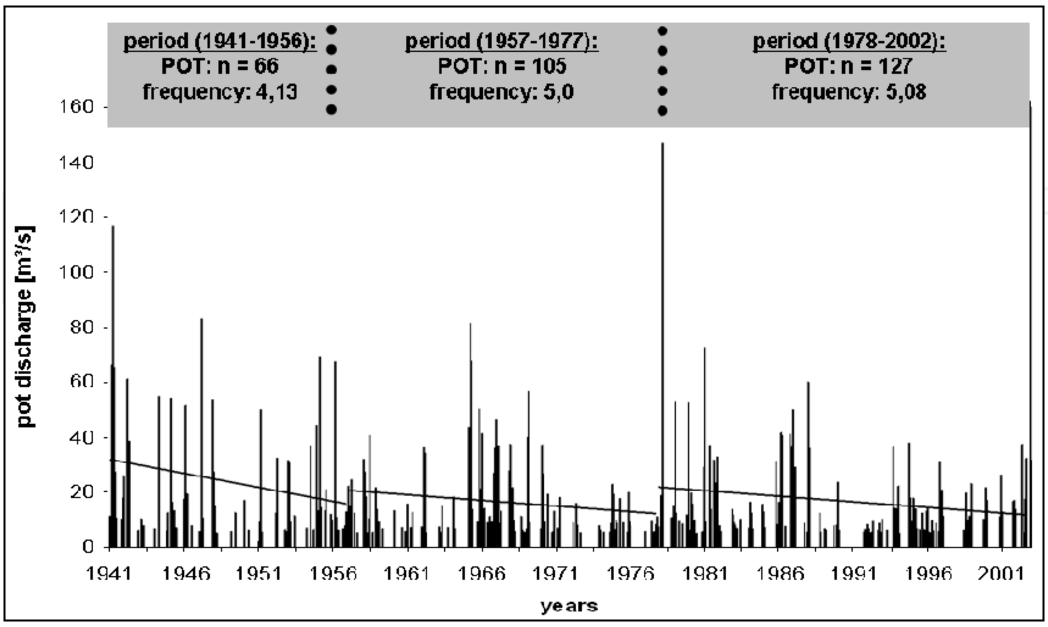


Fig. 6. Flood events at Plasy gauging station between 1941 and 2002, showing floods that exceed the threshold of 5.5 m³/s (pot = peaks over threshold).

Against the background of the contrary trends of magnitude and frequency of the time series of annual flood events, it does not seem possible to infer decreasing or increasing sedimentation in the lake. During the entire 1941-2002 period, only the 1978 flood is notable for having the highest peak discharge in the entire measuring period; accordingly, it has left a distinct event layer in the lake sediments (see below).

4.3 Stratigraphy and geochemistry of the lake sediments

The lake sediments of reference core ML 18/03 (location see Fig. 3) are largely muddy silts. The particle-size distribution indicates two noteworthy features: 1. Sand is found only in the lower sediment sequences. This is also the case in the other sediment cores and suggests that the sand was brought in by the Mladoticky creek. During the early decades there may have been some additional sediment input from the mass failure area, which was unvegetated during the first few years. 2. The particle-size median shows a distinct change in sedimentation at about 190 cm core depth. Below this depth, the sediment is coarser and the range fluctuates fairly widely; above it, the median remains constant at about 4 µm.

The sediment chemism of reference core ML 18/03 is shown in Fig. 7. Some of the contents of carbon (TC), phosphorus (TP) and sulphur (TS) double above a core depth of 190 cm. This system change is demonstrated even more clearly by the heavy metal levels. Pb, Cu, Ni and Zn rise sharply above 190 cm (Fig. 8). Other elements such as calcium (Ca) show an increase only in near-surface sediments above 60 cm, which correlates with the occurrence of calcite. Also TC, TP and TS show a marked increase near the surface. Owing to the phosphate content of the open water, the lake can nowadays be classified as eutrophic.

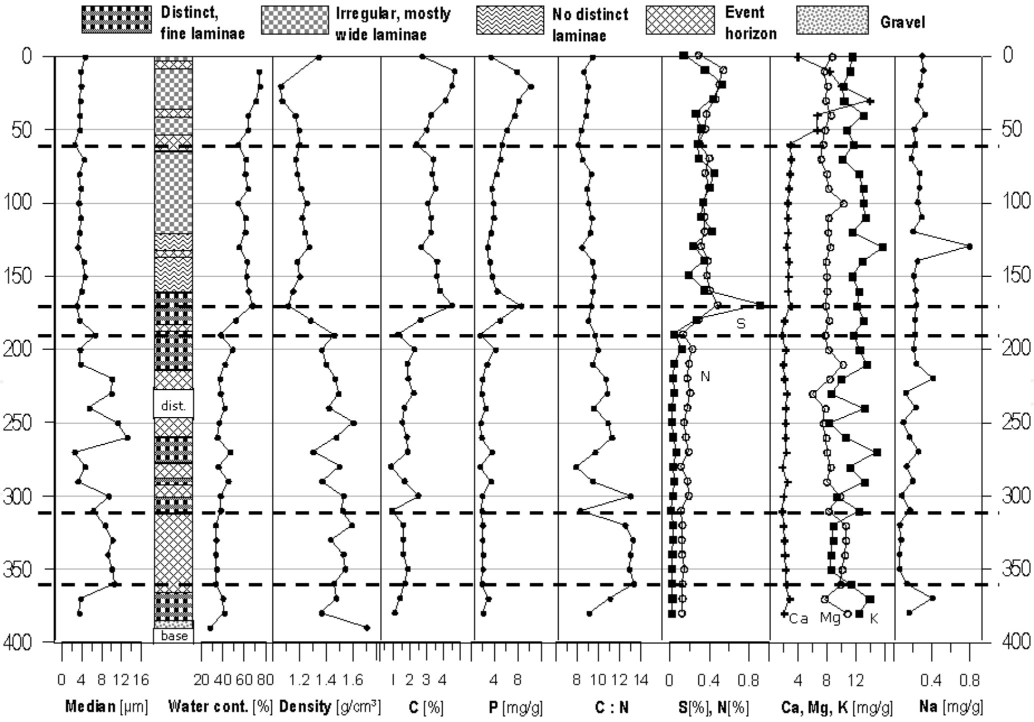


Fig. 7. Geochemistry of reference core ML 18/03 (median of grain size, C, S, N, C:N, Ca, Mg, K, Na, P). Changes in the element concentrations or the level are marked with dotted lines.

Sediment cores ML 14/03 and ML 16/03 (location see Fig. 3) show clear evidence of the system change. According to macroscopic and stratigraphic analyses of these cores, the system change occurred at different depths owing to the different thickness of the sediments. The sediment chemism of core ML 14/03 shows a distinct increase of TC and TS above a core depth of 200 cm (TS increases sixfold); core ML 16/03 shows the buildup of these elements at a core depth of 100 cm.

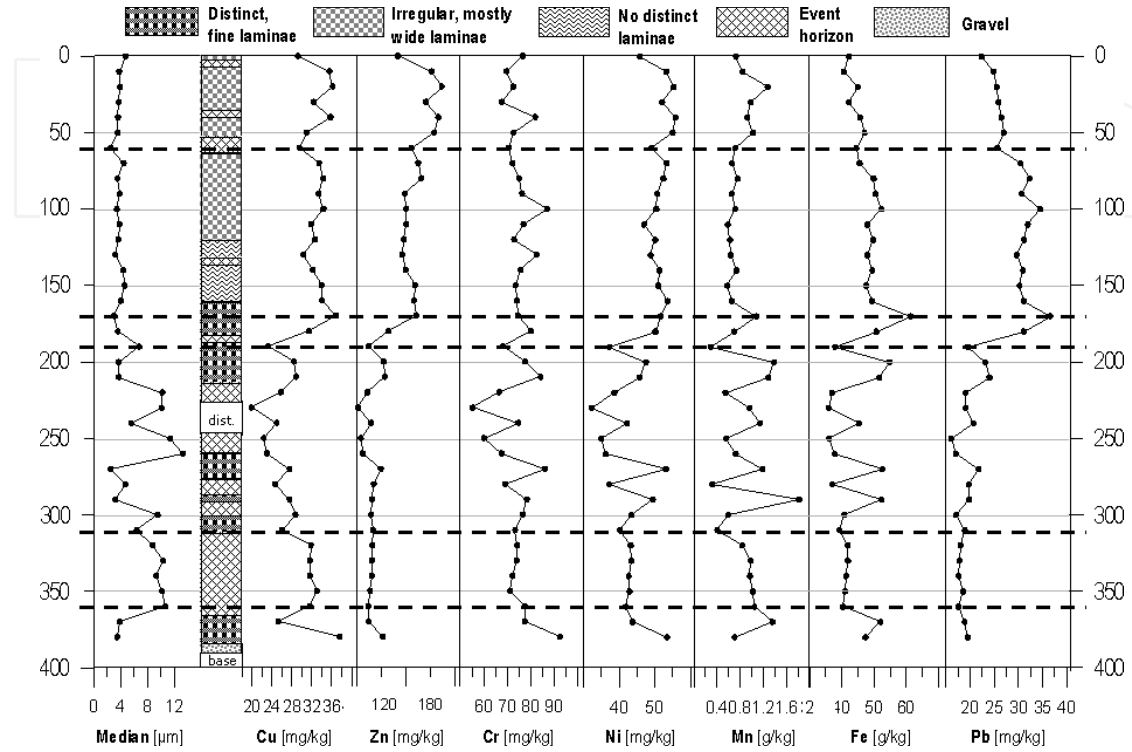


Fig. 8. Heavy metal contents in reference core ML 18/03 (median of grain size, Mn, Fe, Pb, Cu, Ni, Cr, Zn). Changes in the heavy metal concentrations or the level are marked with dotted lines.

4.4 Analyses of isotopes and diatoms

The absolute chronology of the sediments is also based on available isotope measurements of ^{137}Cs, ^{241}Am and ^{210}Pb (Fig. 9). The peak radiation of ^{137}Cs and ^{241}Am at a core depth of 100 cm is attributed to the 1963 maximum of bomb fallout which started in 1954. Americium clearly demonstrates bomb fallout because there was no emission of americium during the Chernobyl disaster. The peak at 40 cm core depth is assigned to the Chernobyl fallout in 1986.

Analyses of microfloral and faunal remains confirmed the system change between the upper and lower parts of the reference core (transition at 190 cm). However, a very high frequency of diatoms was found in the upper part of the core. Samples taken from core ML 14/03 from the sediment surface down to 166 cm core depth (location see Fig. 3), indicate that about 80-90 % of the individuals are planktonic and the remaining 10-20% are benthic diatoms. This uniform palaeolimnological stratification is interrupted by one distinct event at a depth of 66-76 cm, where the proportion of planktonic individuals drops to 15 % and the benthic forms increase to a peak of 85 %. This event indicates a high sediment inflow during a major flood. The analysis of the runoff data indicates that this big event relates to the extreme magnitude of the flood in 1978.

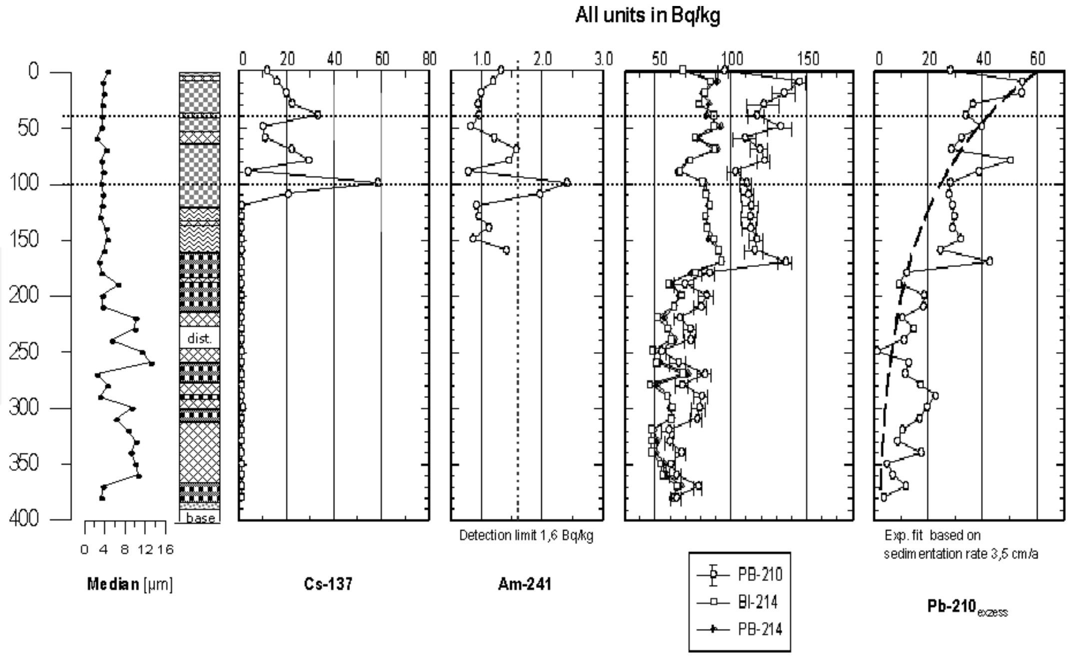


Fig. 9. Isotope contents in reference core ML 18/03 (^{137}CS, ^{241}Am, ^{210}Pb).

4.5 Agrochemical analyses

Agrochemical analyses of four samples in core ML 18/03 do not show the presence of pesticides such as DDT or any of its metabolites. Nor were any polychlorinated biphenyls (PCBs) found in the sediment samples. Fractionated qualitative and quantitative analyses reveal large quantities of polycyclic aromatic hydrocarbons (PAH). These compounds are evidently left over from incomplete combustion processes, and their presence in the sediment is due to atmogenic input into the sediments. The highest concentration is detected at a depth of 45 – 50 cm. The levels are comparable with concentrations in the sediments of other mountain lakes in central and southeastern Europe (Fernandez et al. 1999, Muri et al. 2003).

4.6 Thin sections, temporal resolution and sedimentation rates

Thin sections give an additional chronology, in some cases with an accuracy of one year. The new sediment data on geochemistry, isotopes, diatoms and thin sections especially of reference core ML 18/03 and partly of core ML 14/03 (diatoms) yield the following interpretation (see Fig. 10):

The 1872 landslide impounded the lake, and sedimentation began. Thin section analyses show that clastic sediments were deposited in annual layers above the base. In some cases the boundaries between the layers are blurred, resulting in erroneous ages for the lower part of the core. It was possible to count the layers up to 1883 with an error of ± 2 years. The average sedimentation rate was 1.8 cm/a.

This was followed by a 50 cm thick, homogeneous sequence of unbedded sediment. This sediment is interpreted as having been deposited during an event or a phase of events prior to 1890; the average sedimentation rate is about 9.1 cm per year. The material comes either from the still unvegetated mass failure area at the southern end of the lake (Fig. 3) or from flood input by the Mladoticky creek.

Up to 190 cm core depth, thick unbedded sequences alternate with annually bedded sediments. A layer count dated this depth to 1920. Partial blurring of the boundaries between the layers results in a possible error of ± 5 years. Owing to the alternation between event-dependent high sediment inputs and annual sediment layers, there are substantial variations in sedimentation rates between 6.7 and 1.8 cm/a.

Above 160 cm core depth, there is a clearly bedded diatom mud that can be dated relatively accurately by various sediment analyses. The start of bomb fallout in 1954 provides a time marker (120 cm core depth). The sedimentation rate between 1920 and 1954 was calculated at 2.1 cm/a. Maximum fallout at 100 cm core depth occurred in 1963 (sedimentation rate 2.2 cm/a). The next time marker is the flood of 1978, shown by a distinct event layer and a change in diatom composition. The sedimentation rate from 1963 to 1978 was calculated at 2.7 cm/a. Until the fallout from Chernobyl in 1986, the sedimentation rate fell only slightly to 2.5 cm/a. The rate is 2.4 cm/a between 1986 and the sediment surface (2003).

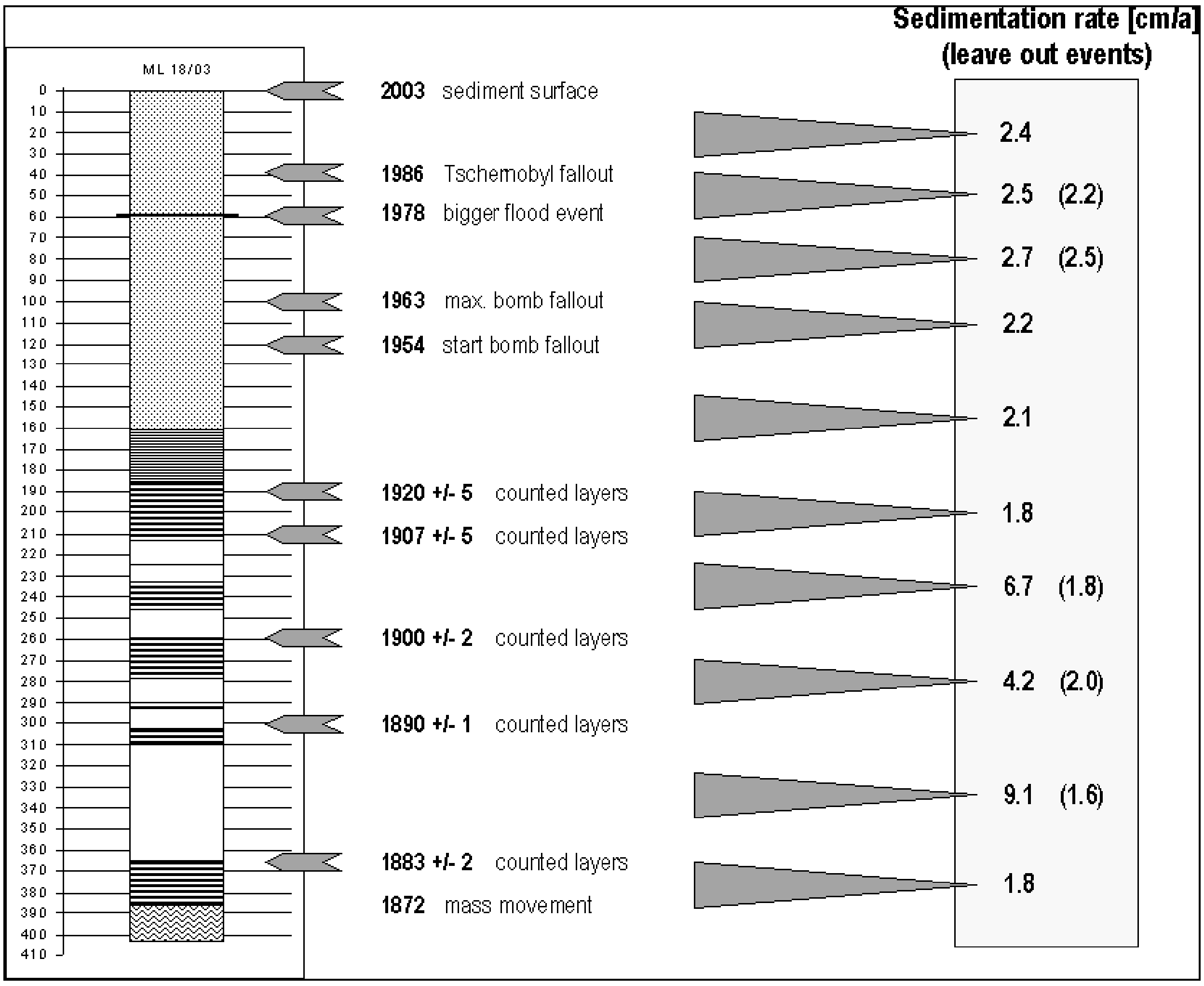


Fig. 10. Results of thin section analyses, temporal resolution and calculated sedimentation rates on the basis of the reference core ML 18/03.

5. Conclusions

Data obtained from various sediment analyses yield a high temporal resolution of the sediment stratigraphy. In 1920 the sedimentation rate was 2.1 cm/a; then came a slight rise, reaching 2.7 cm/a after 1963. Because this increase cannot be attributed to greater frequency or amplitude of big floods, we conclude that the switch to collective agriculture was responsible for the increase in sediment entering the lake. If we disregard the extraordinary event layers when calculating sedimentation rates, greater importance then attaches to the "change in land use" factor. The differences in sedimentation rates are smaller, but still remain (Fig. 10).

Collectivisation led to larger units of farmland. According to Janský (1976, 1977) and Janský & Urbanová (1994), the enlargement process was most active during the 1960s and 1970s and was accompanied by the removal of field terraces. In consequence, slopes became steeper and the fine colluvial material that had collected above the terraces over decades or centuries was easily remobilised. From then on, the bigger fields were worked by larger and heavier agricultural machinery, thus increasing soil compaction and erodibility. All three parameters (greater slope length, steeper slope angle, modified farming practices) intensify average soil erosion according to the Universal Soil Loss Equation (Wischmeier & Smith 1978). A substantial increase in sediment input and deposition might be expected, but did not occur to the anticipated extent.

These results may be interpreted in two ways. 1. The amount of soil erosion from the parts of the drainage basin used for agriculture corresponds to the sediment increase in the lake and the additional transport through the lake. 2. Soil erosion has increased much more than is indicated by the lake's sedimentation rates, because a (large) proportion of the sediments was deposited in colluvial, alluvial and lake inflow areas. If the latter is the case, such sinks are likely to provide relevant information.

In 31 years 37,471 m^3 of sediment accumulated in the lake basin. This represents a sedimentary deposit of 1,209 m^3 per year on average. If we consider the current volume of the lake basin of 103,910 m^3, this means that – under the existing dynamics of sedimentation - the lake would be entirely filled up within the next 86 years! In addition to the speed of sedimentation, the lake's drainage could also play a significant role in its future development. Over time, the outflowing creek will cut deeper and deeper into the lake's dam. During extreme floods, the drainage channel could be markedly deepened. This would mean the lowering of the water level and the quicker disappearance of the lake.

Processes of sedimentation in Lake Mladotice could be slowed by implementing thorough anti-erosion and soil protection measures throughout the entire catchment area draining to the lake along with changes in land use (with preference given to permanent grasslands and decreases in arable land).

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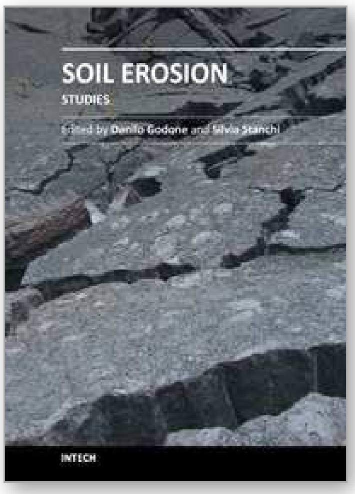

Soil Erosion Studies

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Soil erosion affects a large part of the Earth surface, and accelerated soil erosion is recognized as one of the main soil threats, compromising soil productive and protective functions. The land management in areas affected by soil erosion is a relevant issue for landscape and ecosystems preservation. In this book we collected a series of papers on erosion, not focusing on agronomic implications, but on a variety of other relevant aspects of the erosion phenomena. The book is divided into three sections: i) various implications of land management in arid and semiarid ecosystems, ii) erosion modeling and experimental studies; iii) other applications (e.g. geoscience, engineering). The book covers a wide range of erosion-related themes from a variety of points of view (assessment, modeling, mitigation, best practices etc.).

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University Campus STeP Ri
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Phone: +385 (51) 770 447
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InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821