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ASSESSING THE USE OF SUNKEN LANES FOR WATER RETENTION IN A LANDSCAPE

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ABSTRACT

Newly-designed structures and landscaping elements are often used for flood protection. This article assesses the use of existing sunken lanes for retaining water in a landscape and the sedimentation of washed-off soil. The article also describes ways how to preserve or, at least minimally disrupt, existing biotopes and landscape segments. Geodetic data from one specific sunken lane in South Moravia in the Czech Republic were transferred to a digital terrain model; 9 models were subsequently generated, each with a different longitudinal sunken lane bed slope. Retention dams consisting of gabions were placed in them. The number of dams, the volume of structures made of steel gabions, and the retention area volume behind the dams were determined for each model specifically. It was determined that the number of dams, as well as their total volume, increased with the average longitudinal slope of the sunken lane bed. It was also discovered that the retention volume remained almost the same, as it only very slightly decreases with an increasing longitudinal slope.

KEY WORDS

- *Sunken lane,*
- *Flood control,*
- *Water retention,*
- *Retention dam.*

INTRODUCTION

In the past, there were many more paths in the landscape than there are today. Paths gradually evolved from the first trails, which developed in the Neolithic Age around the earliest human settlements (Květ, 2003) to networks of forest and field paths that provided landowners with access to their land, and which also visually demarcated property, or in some cases, municipal, cadastral, or estate boundaries. As they lost their importance over time, they were abandoned and disappeared. Sunken lanes are among the most noticeable remains of old paths. They consist of trenches and channels of various depths, the widths of which correspond to foot paths or trails, but not to forest or field paths. They also usually have a sharp longitudinal slope. One Czech forestry dictionary (Konšel et al., 1940) defines a sunken lane as a section of a normal field path that has been carved sharply into the surrounding terrain. They are formed by the movement of wheels over soft soil; when such paths have been in use for a long time, they gradually sink and lead to increased erosion. Old sunken lanes can reach a depth of 5 or more meters and have banks that are almost vertical.

Identifying sunken lanes in the field by just visually observing the land can be problematic. Sunken lanes, especially abandoned ones, are always overgrown with self-sown vegetation and are often hard to tell apart from balks, overgrown orchards or small groves. They are easier to identify in forests, especially if they are surrounded by high forest stands. The number of sunken lanes in a landscape can vary significantly and depend on many geological, geomorphological, climatic and historical factors. For example, over a 1.3 km section of the left bank of the Hruškovice water course (in South Moravia in the Czech Republic), there are 3 sunken lanes of a similar size, but each of which are utilized differently (including the one we assessed).

A sunken lane can be considered to be the result of fluvial erosion – a gully – that has developed due to anthropogenic activities (Riedl,

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Zachar et al., 1973; Holý, 1978; Janeček et al., 2002; etc.). In forests, sunken lanes are created and enlarged or deepened as a product of logging and hauling erosion (Šach, 1988; Macků, 2000; Herynek, 2003).

Restoring their original transportation function is usually not appropriate due to the requirements of logging equipment. Moreover, sunken lanes are landscape segments that are protected under Czech Act No. 114/1992 Coll. on the Nature and Landscape Protection Act; therefore, only in exceptional cases can permission be granted to intervene in these biotopes. However, it is possible to insert crosswise grade control structures made of permeable material into sunken lanes, and these lanes can therefore be used for the retention of runoff water from neighboring catchments.

The aim of this article is to present the case of one sunken lane and how it could be used to retain water in a landscape and help settle washed-off soil sediment outside the built-up areas, while preserving the biotopes and landscape segments.

MATERIALS AND METHODS

In order to test the possible uses of sunken lanes for water retention, project materials and experience gained from the proposed and implemented anti-flood measures, as well as the restoration of land access via field paths taken in the municipality of Vlkoš (in South Moravia, the Czech Republic), were used. These measures were taken as part of a comprehensive land consolidation project.

The sunken lane focused on in this study is an abandoned field path, originating at the northeast border of the built-up part of the municipality (17.1726150°E, 48.9953753°N – see Fig. 1) and continuing in this direction towards the cadastral border. The length of the sunken lane is approximately 230 m; its average width is approximately 2.2 m; its deepest utilizable depth is approximately 2.2 m; and its banks range from being very steep to vertical. The average grade of the longitudinal slope of the sunken lane is approximately 5% in the direction of the municipality. The sunken lane was created in the fluvial terrace of the Hruškovice. The bedrock consists of Sarmatian and Pliocene sediments – clays, sandy clays, sands and gravels, which in places appear on the surface and in others are covered by accumulations of loess and airborne sand. The accumulation of slope sediments is limited at the base of the slopes. Currently, the sunken lane is overgrown with bushes and several fruit trees.

Five permeable gabion grade control structures (dams) with a total volume of 405 m^3 were proposed as part of the project design (PD) (Zlatuška, 2002). The total retention volume after deepening several retention areas is 1,709 m^3. The control structure specs are based on the technical recommendation of the manufacturer

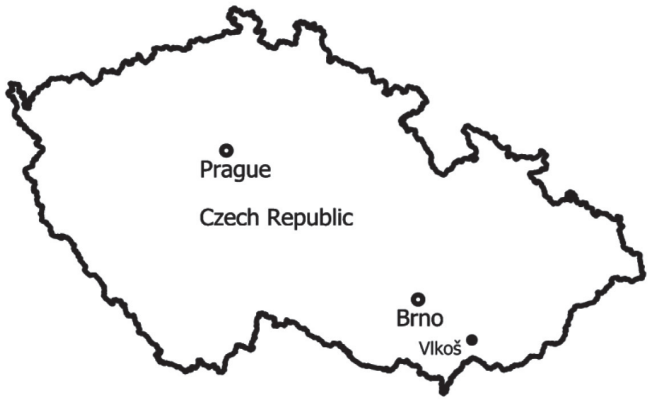


Fig. 1 *Locality of the KRADLOV sunken lane.*

(www.maccaferri.it) and on the author's experience in designing other similar structures.

Retention spaces having volumes almost identical to the volume of the runoff from the surrounding drainage basin were proposed in the PD. The control structure's seepage is significantly less than the flow rate through the open channel (the hydraulic conductivity for the clogged structures was estimated to be $k = 1 * 10^{-4}$ m * s^{-1}). The flow rate before the first control structure was calculated to be 0.0015 $m^3 * s^{-1}$.

The geodetic data acquired for creating the PD are used for modeling other models with an average longitudinal sunken lane bed slope ranging from 2% up to and including 10%. This scope has a practical basis: at a slope of less than 2%, the retention volume values would not be representative (the backwater length would be greater than the length of the sunken lane), whereas slopes of greater than 10% would require a greater number of control structures (and there would therefore be little space between them). The models were created in a digital terrain model (DTM) using AutoCAD Civil 3D 2012 (www.autodesk.com).

When the DTMs for the individual models were created, the same set of required geodetic connecting lines was used, while separate sets of the geodetic coordinates for each slope value in each model, or sets of coordinates with identical latitude and longitude values (X and Y), but with different altitude values (Z), were used. The Z value of each model was calculated using analytical geometry methods. The most basic step was to establish the AB line perpendicular to the sunken lane's axis, which intersects 2 geodetically surveyed points, or the projection of these two points on the XY plane (Z = 0.00m). The points on the sunken lane bed were selected from the survey marker coordinate set, and the Z value of their coordinates was calculated so that the average longitudinal bed slope corresponded with the given slope model – see formula (1). The Z coordinate

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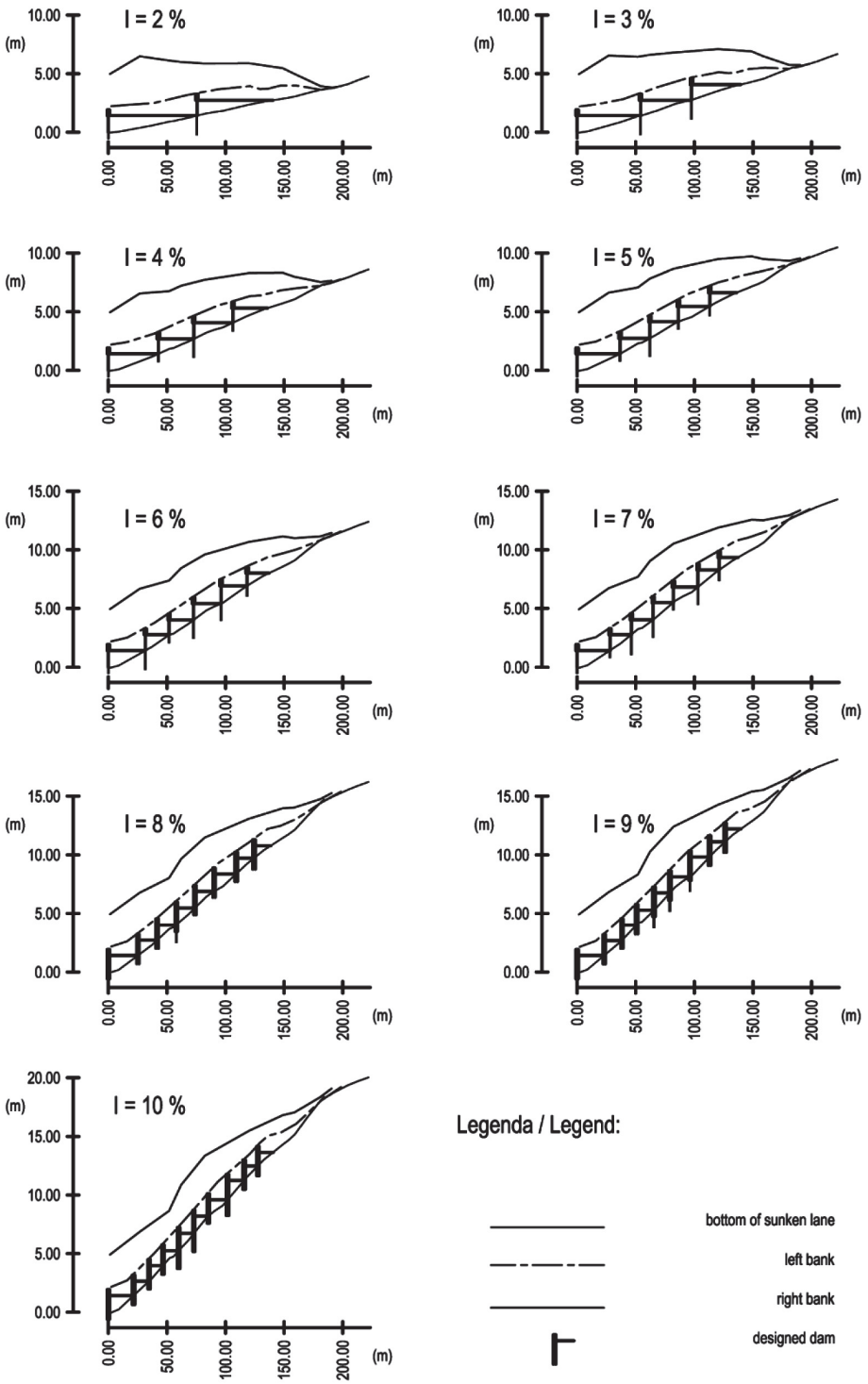


Fig. 2 *Longitudinal profiles.*

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value for the other points is dependent on the nearest point from the sunken lane bed and preserves the difference from the original survey in absolute altitude – see formula (2). The points were separated based on their position in order to preserve the original depth of the sunken lane so as to preserve a constant volume in the sunken lane in all the modeled cases.

$$Z_{Di;I} = 20 * i * (Z_i - Z_0) + Z_0 \quad (1)$$

$$Z_{Oi;I} = Z_{Di;I} + (Z_i - Z_D) \quad (2)$$

where:

- $Z_{Di;I}$ – the value of the Z coordinate of an i-th point on the sunken lane's bed in the model based on the I slope (m)
- $Z_{Oi;I}$ – the same for points lying outside the sunken lane's bed (m)
- 20 – a constant expression of the average longitudinal sunken lane's bed slope established by the DTM based on the original, surveyed coordinates (5 %); 20 = $1 * 0.05^{-1}$
- I – the average longitudinal slope of the sunken lane bed according to each model I (1)
- Z_i – the original, geodetically defined coordinates of the Z of the calculated point (m)
- Z_0 – coordinates of the Z of the midpoint of the AB line segment established by the DTM from the original, surveyed coordinates (m)
- L´ – the distance of the calculated point from the AB line segment or the length of the projection on the XY plane (m)
- Z_D – the original, surveyed coordinates of the Z of the nearest point on the sunken lane bed (m)

The longitudinal profiles for the proposed control structures are displayed in the original polygonal axis of the sunken lane – see Fig. 2.

The grade control structures are located in each model based on the following criteria:

- The location of the first (lowermost) structure must be identical to its location in the PD.
- The structure overflow levels must be 0.6 m below the level of the lowest bank; this figure is based on the design and implementation procedures, including the hydro-technical design of the structure.
- The centerline of the other control structures must be placed at the point of the intersection with the overflow level of the lower control structures and the terrain in the sunken lane bed along the design's centerline.
- The minimum height of the control structures, or the height of the weir edge above the sunken lane bed, must be 1.0 m; this is due to the size of the retention area behind the structure.
- In accordance with the PD, the width of the control structures was established to be 2.0 m.
- The bed and bank modifications in the retention areas behind the control structures were not planned.

RESULTS

A total of 9 models were generated. Each model had a specific number of control structures, gabion volumes, and retention area volumes behind them based on slope – I. The data are displayed in Tab. 1.

Tab. 1 *Gabion volumes and retention volumes behind the gabions, depending on the slope*

slope (%)	No. of gabion structures (1)	gabion volumes (m^3)	retention volumes (m^3)
2	2	115	432
3	3	153	409
4	4	195	385
5	5	243	380
6	6	285	382
7	7	332	378
8	8	375	368
9	9	428	372
10	10	479	381

It was determined that the number of control structures increased with the average longitudinal slope of the sunken lane's bed. This figure is numerically equal to the average sunken lane's bed slope in percentages. As assumed, it was confirmed that the total volume of the control structures grew with the increasing average longitudinal sunken lane's bed slope – see Fig. 3. The dependence expressed by equation (3) was determined by statistically testing (Drápela 2000) these two sets.

$$y = 45.5 * x + 16.44 \quad (3)$$

where: y – the total volume of the retention structures (m^3)
x – the average longitudinal sunken lane's bed slope (%)

Considering the fact that the coefficient of determination is $r^2 = 0.998$, based on equation (3), we can consider the intensity of the dependence to be very high – see Fig. 3.

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The relation between the average longitudinal sunken lane's bed slope and the total retention volume behind the control structures was also considered. It was determined that the retention volume remained almost the same – see Tab. 1; in practice, any differences in volume are negligible, considering the accuracy of the DTMs and subsequent construction. It can be stated that without taking into account the average sunken lane's bed slope, the retention volume hovers around an average value of 387 m^3.

The dependence expressed by equations (4) and (5) was determined by statistically testing these two sets:

$$y = 1.8193 * x^2 - 27.684 * x + 475.91 \quad (4)$$

$$y = - 5.85 * x + 422.54 \quad (5)$$

where: y – the total retention volume of the control structures (m^3)

x – the average longitudinal sunken lane's bed slope (%)

Considering the fact that the coefficient of determination is $r^2 = 0.9345$, based on parabolic equation (4), we can consider the intensity of the dependence to be very high – see Fig. 3. 3. For

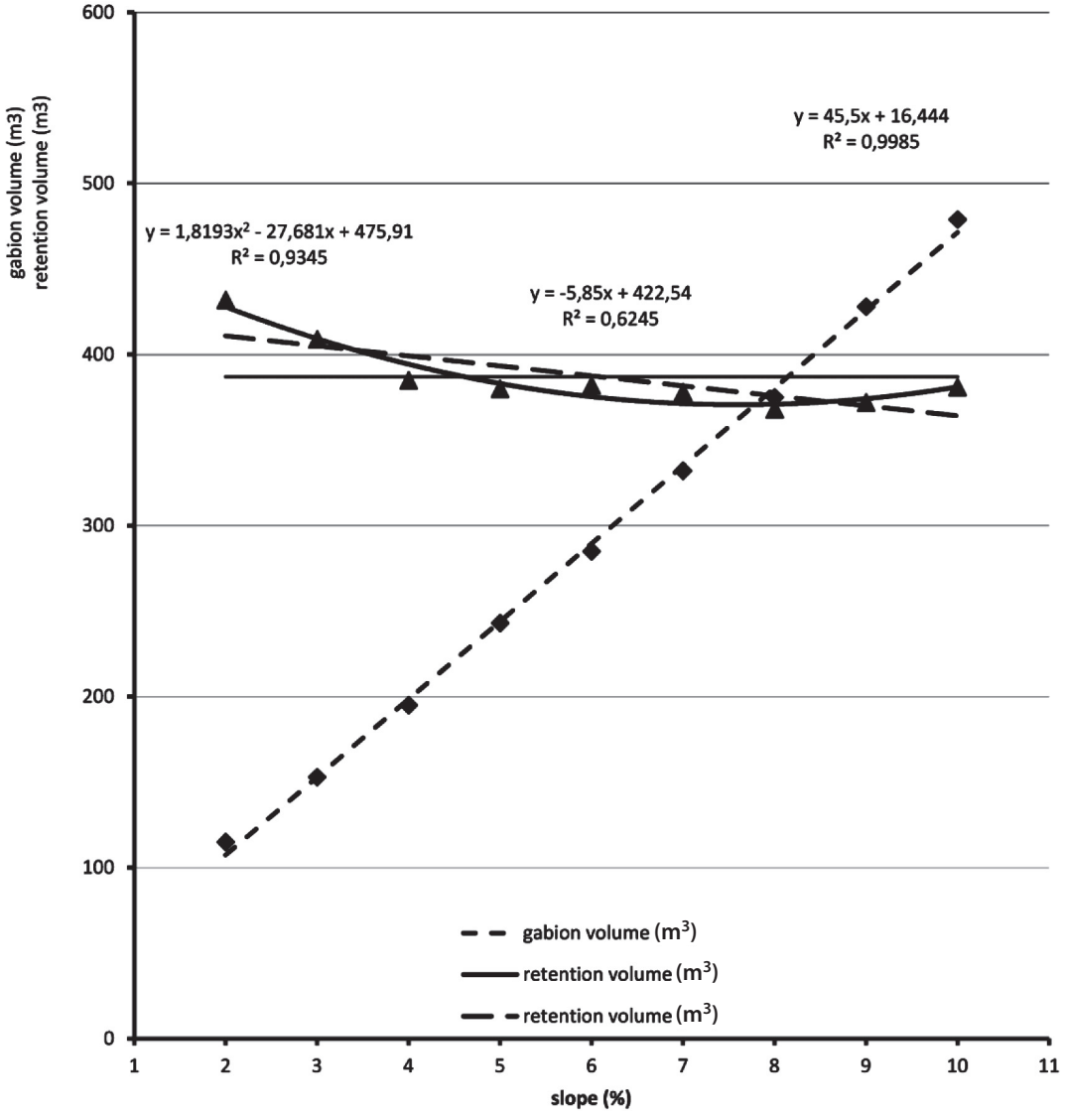


Fig. 3 *Graph of gabion volumes and retention volumes behind the gabions, depending on the slope*

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the more practically useful linear dependence of equation (5), the intensity of the dependence dropped to $r^2 = 0.6245$, thus indicating a great degree of dependence.

DISCUSSION

Methods and recommendations that can be used to achieve greater water retention in the landscape and reduce soil loss due to erosion are usually developed for and tested on larger areas; they are also usually connected to an assessment of the existing water retention characteristics of the soil and land cover or of the designed measures or equipment in the landscape – both on agricultural land and in forests (Janeček et al., 2002; Šach, 1988; Černohous et al., 2010; Dumbrovský et al., 1995; Podhrázská et al., 2009; Dabney et al., 2009; Rankka et al., 2006, Gill, 2006; etc.).

Published findings dealing with water and sediment retention in smaller catchment basins of only several hectares are not frequently found. Usually, the assessment is made for accelerated erosion in "live" developing gullies on large parcels of agricultural land, which result in lower crop yields and reduce the area of utilizable agricultural land, while at the same increasing costs for managing this land (Valentin et al., 2005). In this context the authors speak of the development of gullies as contributing to increased surface runoff (natural drainage ditches) and to speeding up the process of desiccation in semi-arid areas. They suggest a wide range of measures for the effective prevention of gully expansions, ranging from changing land cover to eliminating or limiting tillage, building stone structures, and stopping gully expansion by creating terraces and protective retention walls.

Sunken lanes in the landscape represent a specific type of gully that developed in the past and are currently relatively stable (stabilized, abandoned), and are considered to be an unchangeable fact with which current forest and agricultural landowners and renters have to deal with. This study combines a technical solution for lowering peak discharges using grade control structures and for reducing surface runoff from surrounding fields into the sunken lane. It sensitively combines the preservation of a landscape's character with water retention in the landscape, as well as anti-erosion and flood protection measures. In order to achieve these goals, methods for damming gullies were applied (Skatula, 1953; Riedl, Zachar et al., 1973; Hanák et al., 2008). Similar approaches to using grade control structures can be observed in other countries as well (Calinovici, 2008; Chiari et al., 2010; etc.).

The structures discussed above were built in 2003 and 2004 based on the PD. Since that time, torrential rain has tested the bed modifications and their functioning, which have resulted in runoff with a periodicity of N = 0.05, i.e., a flow rate of Q_{20}. The structure was not damaged; and in the retention area of some of the control structures, water remained until the following day. All the runoff was transferred to the receiving water body without any damage to the street and sewage system caused by the settling of the sediment (Zlatuška, 2004).

CONCLUSION

In conclusion, it can be stated that using sunken lanes for retaining water in a landscape is one way of intercepting runoff and sediments in close proximity to built- up areas and linear structures. The construction of control structures with retention spaces does not significantly affect a landscape's character and does not change the way the land is managed. It was determined that the volume of the studied sunken lane utilizable for water and sediment retention declines slightly with increasing the longitudinal slope. The volume of gabions in the grade control structures and their number are directly proportional to the longitudinal slope of the sunken lane bed. Considering the fact that there are many abandoned sunken lanes in landscapes, it would be suitable to include them in flood control measures. In order to understand the conditions and the limits of their use in more detail, other issues, which would likely have an impact on the effectiveness of a design, must be assessed. It can be assumed that the width of a sunken lane and the soil permeability in the sunken lane, or the filtration coefficient of the soil in the sunken lane bed, both on its sides and on neighboring agricultural land, would have an impact.

Acknowledgements

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