Universidade do Porto
FEUP Faculdade de Engenharia

MESTRADO INTEGRADO EM ENGENHARIA DO AMBIENTE

Stream Restoration and Meanders Position

Case Study of Černý potok, Ore Mountains, Czech Republic

Inês Alexandre Estrela Oliveira

Dissertação submetida para obtenção do grau de
MESTRE EM ENGENHARIA DO AMBIENTE – RAMO DE GESTÃO

Orientador UJEP (acordo Erasmus): Ing. Martin Neruda, Ph.D.
(Vice-Reitor para as Relacções Internacionais da Faculty of Environment of Jan Evangelista Purkyně University, Ústí nad Labem)

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MESTRADO INTEGRADO EM ENGENHARIA DO AMBIENTE 2010/2011

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MESTRADO INTEGRADO EM ENGENHARIA DO AMBIENTE

Erasmus Mobility Program

Faculdade de Engenharia da Universidade do Porto

Faculty of Environment of Jan Evangelista Purkyně University in Ústí nad Labem

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À minha avó…

"Aprender uma coisa significa entrar em contacto com um mundo do qual não se fazia a menor ideia. É preciso ser humilde para aprender."

Paulo Coelho

To my grandmother…

“"Learning something means coming into contact with a world of which you know nothing. In order to learn, you must be humble."

Paulo Coelho

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to my father, my sister and my mother, for all the energy and never letting me quit;

To you all, I repeat my words. “Thank you very much”.

Abstract

In a scenario of increasing population and increasing complexity of landscapes, rivers and streams around the world are obvious targets of "pressure" by Mankind and a major concern of the Environmental Management field of study. One common example of aggressive intervention in stream is the regulation and straightening of stream channels, with associated bed and banks pavement. On this case, the banks are drained, are induced inconvenient conditions for water retention and it is observed a decrease of the groundwater-level because of the higher flow rate caused by this intervention.

Černý potok, the Black Creek, is located in "Černá Louka Nature Reserve", near the border of North Czech Bohemia with Germany, in the Ore Mountains. In the 1980's, it was ameliorated and straightened. From 2001 to 2003 and from 2009 to 2010, *Černý potok* was revitalized to reestablish the stream channel natural conditions, to correct hydrological and hydrogeological parameters and restore the biodiversity of fauna and flora. UJEP, Jan Evangelista Purkyně University in Ústí nad Labem is responsible to conduct monitoring works. The monitoring works here presented regard the position of the new meanders.

In a selected longitudinal section, in 6/6/2011, was measured the flow velocity, the dimensions of the sediments and geodetic measurements were made as surveys of 10 cross sections, separated by approximately 10 meters. The GIS work with ArcGis 10 allowed representing the measurements in the map, the cross section profiles and the longitudinal profile, calculating the slope and sinuosity (and comparing with the situation in 1946, 1982 and 2010) and analyze the meanders position, as well as the width of the meanders belts.

The cross sections surveys can be a very simple method to evaluate the changes within the stream channel but, in this case, the surveys made didn't prove to be useful to the characterization of the meanders, although they are a potential good tool if conducted on the peaks and on the inflexion points of the meanders. The next measurements should, therefore, incorporate this approach and don't neglect the importance of the analysis of the bank and bed sediments and its transport in the stream.

Resumo

Num cenário de crescimento populacional e de crescente complexidade das paisagens, rios e cursos de água em todo o mundo são alvos óbvios de "pressão" pela Humanidade e o seu estudo tornou-se da maior relevância para a Gestão Ambiental. Um exemplo comum dessa "pressão" é a regulação e alisamento de cursos de água, em que as margens são drenadas, induzindo condições que impedem a retenção de água e um aumento de fluxo no canal.

O Černý potok, o Ribeiro Negro, está localizado na Reserva Natural "Černá Louka", no Norte da República Checa, nas Montanhas "Krusne Hory". Na década de 1980 foi regulado para fins ligados à agricultura. De 2001 a 2003 e de 2009 a 2010 foi revitalizado e foram restabelecidas as condições naturais do canal, corrigidos parâmetros hidrológicos e hidrogeológicos e restaurada a biodiversidade da fauna e flora. A UJEP, Jan Evangelista Purkyně University, em Ústí nad Labem, é responsável pela realização de trabalhos de monitorização. A área de monitorização apresentada é relativa à posição dos novos meandros.

Numa secção longitudinal seleccionada, em 06/06/2011, foi medida a velocidade da água, as dimensões dos sedimentos e foram realizados levantamentos geodésicos de 10 secções transversais do canal, equidistantes ao longo de cerca de 100 metros. O trabalho de SIG com o programa ArcGis 10 permitiu representar as medições no mapa, os perfis das secções transversais e o perfil longitudinal, o cálculo do declive e sinuosidade (e comparando com a situação em 1946, 1982 e 2010) e analisar a posição meandros, bem como a largura dos mesmos.

O levantamento geodésico de secções transversais apresenta-se como um procedimento simples para avaliar as mudanças no canal do rio. Contudo, neste caso, esse levantamento não se revelou útil para a caracterização dos meandros, embora seja uma ferramenta com bom potencial, se conduzida nos picos e nos pontos de inflexão dos meandros. As medições seguintes devem, portanto, incorporar essa abordagem e não negligenciar a importância da análise dos sedimentos dos bancos e do leito e seu transporte no ribeiro

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1. Introduction

The human intervention in nature can be observed on the most distinct phenomena and ecosystems, whether its effects are "silent", such as chemical alterations of the water properties, or quite "visible", like profound transformations in the landscape. Industrial or other development vectors have been leading to higher demands on surface water resources, whether we are speaking about drinking water, sewage treatment, surface drainage, or water for the actual industrial processes.

Therefore, in a scenario of increasing population and increasing complexity of landscapes, rivers and streams around the world are obvious targets of "pressure" by Mankind and a major concern of the Environmental Management field of study. What should be kept in mind is that besides having an unlikely endless room for human activities, streams support rich and important ecosystems, providing natural habitats for fish species and other aquatic animals, plants and all different kinds of wildlife.

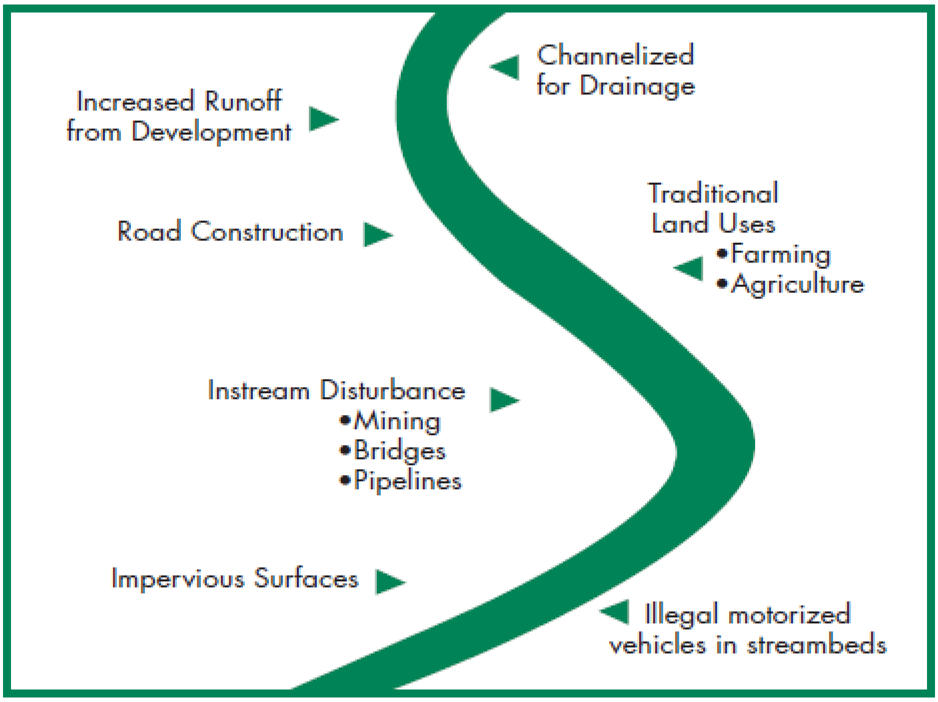


Fig.1: Physical stresses of the "modern era stream disturbance" (Whitehurst 2003)

Stream restoration became a complex field of study as it results of innumerous concepts and multidisciplinary research. For this reason, the bibliography although abundant can sometimes reveal itself confusing and it can be difficult to assess where one term ends and the next one starts.

In one hand, it is understandable, because the modern approaches to stream restoration don't have yet a long history. The boom happened during the last decades of 20th century, so, while many results and practices started to be published and spread without a correct and consensual validation, many concepts were mixed up and misused, in part because in hydrology there is the tendency to use different terms which have the same or similar meaning (Ward and Trimble,2004). In the other end, in the both planning stage and terrain work, some project decisions can be very subjective, due to various reasons from the specific goals of restoration to the unique characteristics of the restoration site. The reproduction of the restoration experience doesn't always contemplate good explanations for these decisions or even the decisions made. Adding to this fact, one central point of criticism of the generality of researchers regards the fact that many times the projects weren't and some still aren't minutely documented, which constitutes a barrier to the consolidation of restoration knowledge and concepts.

Thus, for someone not familiarized with restoration, one simple way of understanding and contextualizing its impact area can be analyze the most common discussion topics. In 1.1 it is presented a discussion synthesis of the existing bibliography towards chosen relevant points, intending to make a simple and clear coverage of the most important variations in viewpoints observed in stream restoration.

1.1. Discussing restoration: variety of approaches

Goals and restoration success

The particular case of human intervention in streams represents changes on the natural conditions of streams both “silent” and “visible”, from pollution to complete alteration of their geomorphology. More specifically, these changes can be, for instance, the loss of riparian flood storage, sedimentation and nutrient pollution, degraded fish habitat, and decreased aesthetic value (H. J. Corsair et al. 2009).

Along the increasing recognizing of this threats, river restoration has accelerated in recent years (e.g., James and Marcus 2006) and its efforts, by governments (both in legislation and action) and private organizations, have been aimed to the improvement of, for example, the water quality, fish passage or *instream* habitat, (Bernhardt et al. 2005). For example, in United States of America (which produced one of the largest and oldest compilations of bibliography concerning restoration projects), stream restoration has actually become a multi-billion dollar industry and a diversity of techniques have been developed and practiced, as well as different points of view about the term "restoration." Wohl et al. (2005) attribute this ambiguity to the wide range of stakeholder interests, scientific knowledge, scales of interest, and system constraints found in practice. In the other hand, Bernhardt et al. (2005) point out the common goals of restoration as the result of a review of over 38.000 projects identified as restoration projects in the United States. The conclusions reached show that the majority of projects had one or more of the following goals:

1. Enhance water quality;

2. Manage riparian zones;

3. Improve instream habitat;

4. Create fish passage;

5. Stabilize stream banks.

Although it is established why streams restoration is needed and several techniques are available to accomplish the restoration goals, what, in fact, represents a successful restoration is often defectively defined and difficult to determine, even after the restoration is complete. There are a lot of uncertainties regarding the impacts of restoration in what concerns to the benefits and the costs of changes in natural systems and there is also an absence of market data relevant to economic evaluation. (H. J. Corsair et al. 2009). In this context, the unclear definition of "restoration", which has also been named stream "rehabilitation", "renovation," or "reclamation," (Nunnally 1978; Ferguson 1991; Kern 1992), represents an extra obstacle to the definition of the project goals and evaluation.

"Restoration"

The approach to restoration made in the present work is based on the relatively new and quite consensual propose of river managers and scientists to use the term *"restoration"* for *projects which aim the support in the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system* (Wohl et al., 2005; Kauffman, 1997; Palmer, 2005; and Roni et al., 2002).

It should, however, be clarified that restoration projects don't always try to reestablish exactly the original natural conditions of the stream, as, in some cases, the changes occurred lead to irreversibility of the system and therefore it is impossible to recreate the structures and functions which previously existed in the ecosystem (Kauffman et al. 1997).

Recently, Palmer et al. (2005) proposed what they named the *standards for ecologically successful river restoration* and discussed their measuring and role in assessing the project success. An international group of river scientists supports these standards (Jansson et al., 2005), as well as practitioners (Gillilan et al., 2005).

Project tendencies

It is also particularly interesting to observe that these two slightly different approaches fit the types of restoration work which have been developed in North America and in Europe. In the article "A cross section of stream channel restoration" (1996), Kondolf reviewed a set of stream restoration project goals and activities in North America and Europe and although both sides use the techniques of bank erosion control, channel stabilization, channel relocation, the restoration of natural meanders and bed morphology, habitat enhancement, improved flood control and water quality improvement, North American projects seem to diverge from the European primarily on the use of simple methods to attain channel stabilization, while a substantial part of the European projects focus on habitat creation. Presenting the contrast between the goals and techniques, the article launches an appeal to the need of systematic studies to evaluate the success of stream restoration projects.

Postproject evaluation

By 1991, Holmes justified the need for improving approaches to postproject evaluation pointing out that the British National Rivers Authority found that, of around 100 enhancement projects completed on British rivers, only five had been the subject of postproject evaluation reports (Holmes 1991).

With Micheli, Kondolf (1995) presented the need of postproject evaluation arguing that, by then, river and stream restoration projects while increasingly numerous, rarely where submitted to systematic postproject evaluation and the wide dissemination of results without that evaluation wouldn't allow to learn lessons from successes and failures, and the field of river would not advance. The authors defended that postproiect evaluation must be included since the beginning in the design of each project and the evaluation technique choice should be based directly upon the specific project goals. Emphasis was given to the measurement of geomorphic characteristics, since they are the supporting physical framework to the riparian and aquatic ecosystems.

In the more ecological approach, it is pointed out that successful restoration shall stimulate measurable changes in physicochemical and biological components of the stream (Paler et al. 2005) and therefore the geomorphic variables would be insufficient for the postproject evaluation.

Restoration models and methodologies

With the maturation of theories in fluvial geomorphology and related disciplines, a scientific basis for its application in restoration projects has been provided (Graf 1996; Kondolf et al. 2003), and along the synthesis efforts more recently observed, the focus towards the advancement has been sharpened (e.g., Bernhardt et al. 2005; Palmer et al. 2007; Wohl et al. 2005). In this context, and referring to the importance of the postproject phase of evaluation, the growth and spreading of river restoration is justified by the experience gained by practitioners in translating academic research into applied designs (e.g., Haltiner and Beeman 2003). This knowledge translation led to the development of methodologies which provide a systematic approach regarding not only the actual design of the restoration, but also environmental management practices.

Related to the *design* issues, particularly the issue upon which depends a substantial share of the restoration success, the hydraulic design, extensive, theoretical and practical works have been developed. Several works concerning modeling, computational and mathematical, can be found in bibliography, from models of stream flow, floodplain, channel morphology, meandering or transport of sediments (as example, the works of Rantz, et al. 1982 and Liang 2007) to ecohydraulic and eco-hydrodynamic models to predict habitats (like the ones proposed by Bocklemann et al. 2004 and Tomsic et al. 2007). It is also possible to find works of combined models for geomorphology and habitat

In a more particular aspect of modeling, relevant for the present document, many authors emphasize the use of the modeling potentialities of computerized GIS, Geographic Informatic Systems, since the available analysis tools cover important needs of both practitioners and researchers and allow simple representations of the real situations, although the use of a GIS program should not alienate the time-cost relationship and the approximations made, as well as the errors possibly implied. The use of GIS in land cover analysis was an active discussion field, for instance, by Harris et al. (1997), but this resource turned out to be indispensible to restoration practitioners.

The very recent and most modern approach is the use of the Fluvial Information System (FIS), "a raster based GIS-type system designed to manage fluvial remote sensing data and automatically extract meaningful information", Graham and Cough (2011). The same authors defend that the knowledge of ecology and geomorphology is limited by the lack of methods applicable to catchment scale processes and this adaptation of GIS to fluvial systems (what they consider ”taking river restoration into the future”) is a major innovation for river science and management, providing visualisation methods of the stream morphology and flow that allow, for example, the identification of the obstacles to effective naturalised flow.

Addressing to the *environmental management* issues, efforts have been made to compile information and systematize the conception of a restoration project, in order to avoid mistakes which can possibly lead to unsuccessful restoration or unpredicted/undesired results. There are some variants but the main idea has a common ground. In Figure2 is presented the Teiga et al. approach to a methodology of river restoration. Focusing on the “continuous improvement” it is strongly reinforced the authors’ idea that assessment is an important step towards effective rehabilitation and should follow technical and scientific bases, providing comparable results, values which can also help evaluating the evolution of the measures implemented.

Fig.2: General scheme for the basic steps of stream rehabilitation (adapt. Teiga et al 2007)

Summarizing, the bibliography clearly shows the multidisciplinary character of stream restoration and the discussion around the presented topics provide a basis to understand the organics of restoration projects. For posterior discussion (in *chapter2.)* rest the issues of river related concepts in use and the streams classification available and their value.

1.2. Geographic contextualization of restoration projects: examples in Europe, Portugal and Czech Republic

Although not as documented as the restoration projects in North America, for instance, it is possible to find information about several restoration projects in Europe. The most well documented come from United Kingdom and Germany, but there is also information available about restoration in the other parts of the Continent.

United Kingdom

A very positive note to the restoration efforts in the United Kingdom was given in 2010, with the attribution of the International Thiess Riverprize, the world‟s largest environmental prize, which celebrates outstanding achievements in river management and restoration, to the tireless 50 years works towards the restoration of the famous River Thames, biologically dead in the 1950's due to pollution. The river has been transformed into a flourishing ecosystem crowded with fish, being observed the return of the sea trout as well as otter populations. Nevertheless, it is acknowledged that there is still a lot of improvement work to be done (Driver 2011).

In this context, among others, one interesting study case is the restoration of Cole River (140 thousand pounds was the cost of a 2km of restored river length), tributary of the Thames, from 1995 to 1996. The project involved several different techniques appropriated to different zones and the main achievement was the creation of 2 km of meandering river course which restored a higher frequency on the seasonal flooding of the adjacent land, farming land which became explored less intensively. During the first stages of postproject, high erosion and reshaping of the channel was observed and valuable lessons were originated from this case analysis (more information about this and other project in United Kingdom can be found on the archives of the RRC – River Restoration Center, a national information and advisory centre for river restoration and enhancement, and sustainable river management).

Germany

Some of the best examples, though, come from Central Europe. The program REURIS, born in 2007 in Brno, Czech Republic, and into force from 2008 to 2011, and it is a *Priority 3.1* of the European Union *Central Europe program*, concerning the development of a high quality environment by managing and protecting natural resources and heritage of central countries in Europe.

Perhaps, one of the most emblematic successful projects of restoration in Europe is the restoration of the Isar River, an urban river restoration project along 8 km, implemented in Munich, Germany. The "Isar Plan", with estimated costs rounding 30 million Euros, started to be conceptualized in the 80's, was launched in 1995 and the completion planned by 2011. The main channel was widened, the forelands where incorporated along the river and the floodplains and steep embankments secured with concrete and paving were replaced with flat and naturally developing banks. Also the artificially channelized river bed was transformed into a river bed of varying width with gravel banks and gravel stone islands in a system of dynamical evolution movements. It contemplates local flood protection, valorization of habitats for fauna and flora, the proving of a natural landscape within the city, creating the possibility of leisure and recreational use and, therefore, an overall investment in the future with a nature-oriented redesign of a river with an urban lifestyle of immeasurable value for the population (REURIS).

Fig.3 and 4: The Isar River before and after restoration (Arzet and Joven)

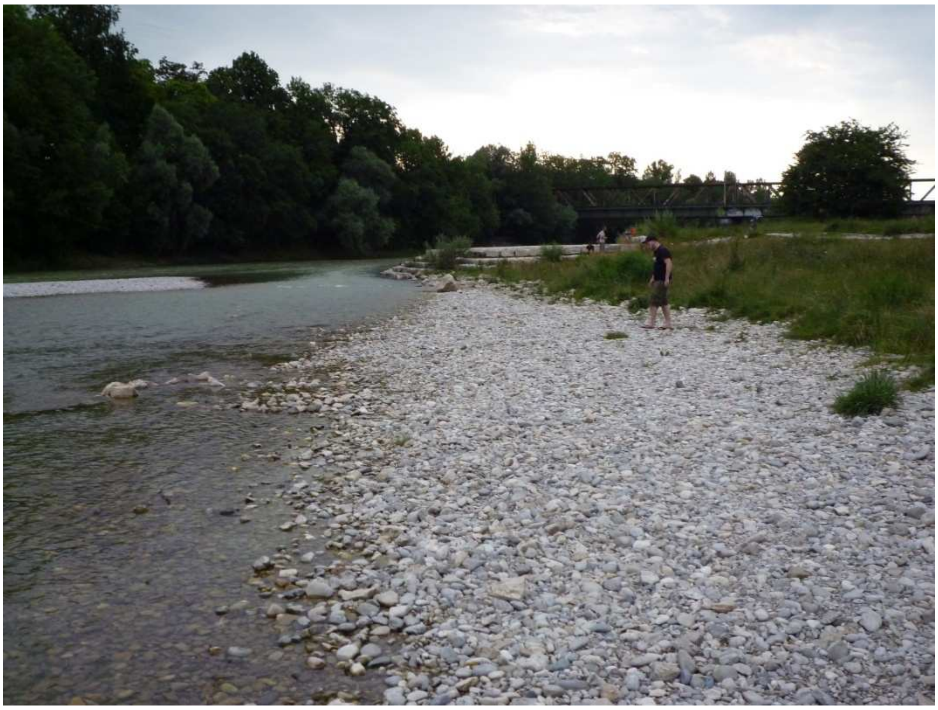


Fig5. Isar River in July 2011 (by Jan Říha)

Since the present work was developed within the European Exchange Program *Erasmus*, between the Faculty of Engineering of the University of Porto and the Faculty of Environment of Jan Evangelista Purkině University in Ústí nad Labem, some examples of restoration is this two countries are also listed.

Portugal

In Portugal, some projects documented are the rehabilitation of Uíma River, tributary of Douro River, with the goals of improvement of the quality of water, increase biodiversity, intervention at the level of cultural habits as well as at mobility, recreation areas, promotion of sports. Therefore, the construction of pedestrian and bicycle paths, improvement of accessibility, cultural valorization of the area and the installation of maintenance equipments to create a link between physical activity and touristic value, are some of the success parameter emphasized (Rodrigues 2008)

The same example of community involvement is observed on the revitalization project of Paiva River, also in the North of Portugal and considered the less polluted river in Europe in 2005. The costs were of approximately 600 thousand Euros, of private and public funding, and it included the rehabilitation pedestrian paths, bridges, small dams, ponds and mills, with the purpose of making Paiva visible and desirable to tourists and local communities. In this way, it was also possible to promote six surrounding small villages in a wide project of recovery of the religious heritage, tourism, cultural, environmental and historical marks of the region while fighting desertification and revitalizing the culture and traditional activities.

Fig. 6: Bank of Paiva River (by Ricardo Paiva)

In fact, the importance of creation of community infrastructures within the streams restoration project is common to practically all the projects included on the Metropolitan Area of Porto, the second biggest city in Portugal located in the North by the Atlantic Ocean. (*in* "Diagnóstico de Ambiente da Área Metropolitana do Porto", 2008, public release, portuguese version).

Some other examples in the center and south of Portugal are also available for consultation and most of them are included in the POLIS program, which main objective is to improve the quality of life in cities, through interventions in urban and environmental aspects, improving the attractiveness and competitiveness of urban centers that have an important role in structuring the national urban system.

Czech Republic

In Czeh Republic, integrated on the project REURIS, are interesting restoration projects directed to Old Ponávka River in Brno and in the Úslava river, Bozkov Island in Pilsen. In both projects, respecting the action line of REURIS, the main goals include the creation of green spaces and aims recreation activities. In the Brno project, the vision was to integrate green areas in the urban structures and transform Old Ponávka river in a blue-green axis, a project including a conceptual, implementation and dissemination phase. In Pilsen the goals was to enhance the Bozkov Island great potential for sport and recreation, since it is linked to the cycling paths along the Úslava. Studies proposed an architectural and landscaping solution that would extend and enhance the sport facilities, including a water playground but maintaining the natural and landscape value of the meadow-type landscape and a natural protecting system against flooding.

Between the finished projects there are also several examples. Some are highly criticized, like the Bílina river example. Although it was created a restoration plan, there were only placed stones for bank stabilization and no plantation of trees or real efforts towards revitalization. Also the project of the Agriculture Water Management Authority (extinct in 2001) for Modlá River in Lovosice, 1996, which is a typical example of a stream inserted in a farming land, although it relates good practices concerning the meandering techniques, there are persistant concrete panels and during the dryer months there isn’t enough water to keep a good constant flow.

The Borová stream restoration project is quite interesting. The stream flows through the western part of “Blanský les”, a Protected Landscape Area. The aerial photographs from 1947 show it was a stream freely flowing through a valley of pastures with natural meandering, but when the area was target of an extensive land drainage project, 1982-84, the channel was straightened in a trapezoidal shape channel and with semi-vegetated crete slabs, deepening the stream bed to an unnatural extent and over-enhancing its flow capacity. It was observed a damaging of the aqueous regime and degradation and decline of the native or nearly native species, decreasing biodiversity.

In 1994, Blanský les PLA Authority began to prepare the complex revitalization of Borová and during the two phases of implementation, 1999 and 2000, the stream went through a special type of revitalization resulting in a completely new watercourse was created, respecting a naturally occurring bed with a meandering course. The depth of the bed was considerably decreased and the length increased, a significant variation of slope of the watercourse was achieved, alternating slow flow sections with steeper sections forming small rapids, it was carried an extensive planting of trees along the banks of the stream and some original surrounding fields were renovated using local species of trees. The results of the project were the reduction in the speed of surface and underground water run-off, a rising of the water reserves in the landscape and the creation of habitats suitable for rare species of marshland life (CHKO Blanský Les 2006). The project cost was 6 890 000 CZK.

The Borová example is important to introduce the project of revitalization of Černý potok, the object of study of this work and which will be described further on this document.

1.3. Objectives

Integrated in the monitoring phase of the restoration project for the "Černý potok" stream, in Ore Mountains, Czech Republic, the present work aims to characterize the meanders position of a restored section of the stream and define a simple baseline of measurements and GIS analysis for the future scoping, in order to evaluate the stream system response to restoration.

1.4. Organization and structure of the thesis

This document is divided in six main chapters.

On the first, a presentation of stream restoration central discussing topic is made, as well as a presentation of several projects in Europe and, more specifically, in Portugal and Czech Republic. Goals of the developed work are established and information about organization and structure of this thesis is revealed.

On the second chapter is given an explanation about stream-related concepts, terms and characteristics, with emphasis on the meandering behavior. Problems within streams are identified along the associated restoration techniques.

On the third chapter is described the "Černý potok" restoration project regarding the problems which led to restoration, the restoration goals, works and future needs of monitoring. Some discussion about this point will be presented.

On the fourth chapter the methodology used to make the measurements in the stream is presented divided into four main topics: water flow velocity, sediments characterization, channel profiles and further GIS data treatment.

On the fifth chapter are included the results and respective discussion and on the sixth and last chapter are presented the study conclusions and recommendations for future work.

2. Stream Restoration

As already explained on the previous chapter, the study of stream systems is complex and time consuming. Therefore, although there is a lot to be said about the stream processes, physical, hydrological and ecological, and the restoration techniques, only what is relevant for the comprehension of this study will be focused.

2.1. Streams

The first step to understand river restoration is to clearly define the terms used to refer to streams. Ambiguity starts with the use of the terms stream, creek and river. Therefore, is here considered that **stream** is a flow of running water along the surface of earth in a channel with an open surface to the atmosphere. A **creek** is a small stream, generally a shallow or intermittent tributary to a river, and can be also called regional branch, brook, kill or run. A **river** is a large natural stream which can be fed by converging tributaries on the way to an ocean, lake or other body of water. To the area which contributes to discharge at a point of a stream (it can include surface runoff, interflow, groundwater flow, direct precipitation or any kind of discharge point like, for instance, industrial effluent) it is given the name of ***watershed***, *subwatershed*, *catchment*, *river basin* and/or *groundwater compartment* (Ward and Trimble 2004).

To the channel bottom of a stream is given the name **bed** and the lateral confines or channel margins (excluding flood stages) are called **banks**. The deepest part of the channel is called the **thalweg**. To the smoothly flowing segments of the stream it is given the name of **run**, a **pool** will be a segment where the water is deeper and moving slower and a **riffle** a segment where the flow is shallower and more turbulent. A **floodplain** is the land adjacent to a stream which experiences flooding during periods of high discharge (Goudie, 2004). The biological habitat in the immediate vicinity of a stream is called a **riparian zone**.

Stream geomorphology, or the formation of land by streams, is not easily described by scientific theories but the *geomorphologic work* is dependent of the balance between force and resistance. To understand this balance, it should be referred that, independently from the type of stream, there are basic characteristics that normally define streams (Whitehurst, 2003):

- **Slope** is the proportion of the vertical drop of a stream; ultimately, it's the vertical drop of a stream from its spring to its mouth; it is a very useful parameter because it allows calculating the proportion of fall to run, being presented the final result in **percentage**;
- **Discharge** is the volume of water carried by the stream, measured as a rate and given in **m^3/s** or also **l/s**;
- **Sediment load** and **particle size** describe the silt, sand, gravel, rocks, and other substances dragged and transported by flowing water.

Within the search for equilibrium between the presented variables, a stream can experiment stages of *stability* and *instability*. These two key concepts also cause frequently some confusion, especially because they aren't correctly used. There is a tendency to use them to describe the state of the banks or bed of the stream, which lead to the mistake of equate stability to fixed r rigid banks. The fact is that steams change naturally the shape and the position of their banks and therefore, a **stable stream system** should be addressed as one that is self-sustaining, keeps a general geometry over time periods of decades and has a balance between the import and the export of sediment (Ward and Trimble 2004).

Applying this notion to the relationship between the previously presented variables, it is possible to state that a channel will remain in equilibrium in order to maintain its stability if changes in sediment load and particle size are balanced by changes in water discharge and slope. Consequently, when the stability of the stream is challenged, the channel will respond by one of two processes: **degradation**, the picking up of sediment or system-wide bed-scour, or **aggradation**, the system-wide deposition of sediment (Whitehurst, 2003). Normally, both processes can be slowly or fasten observed in time and the changes can be measured.

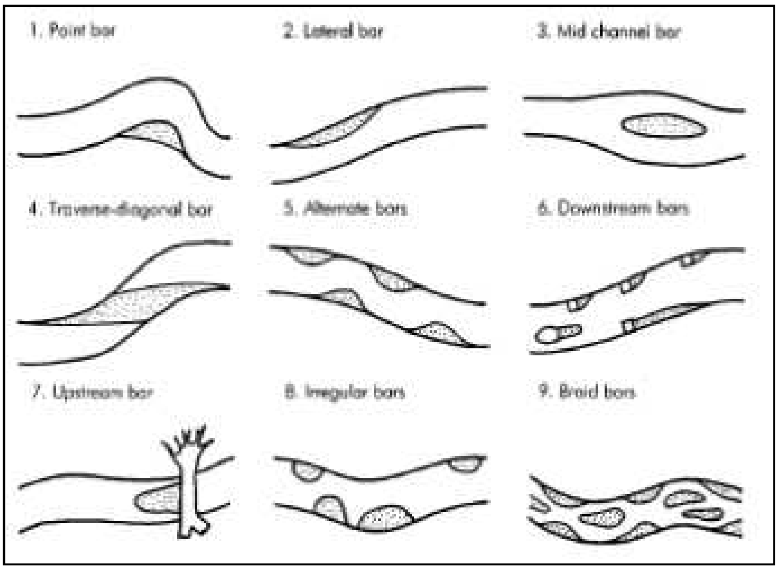
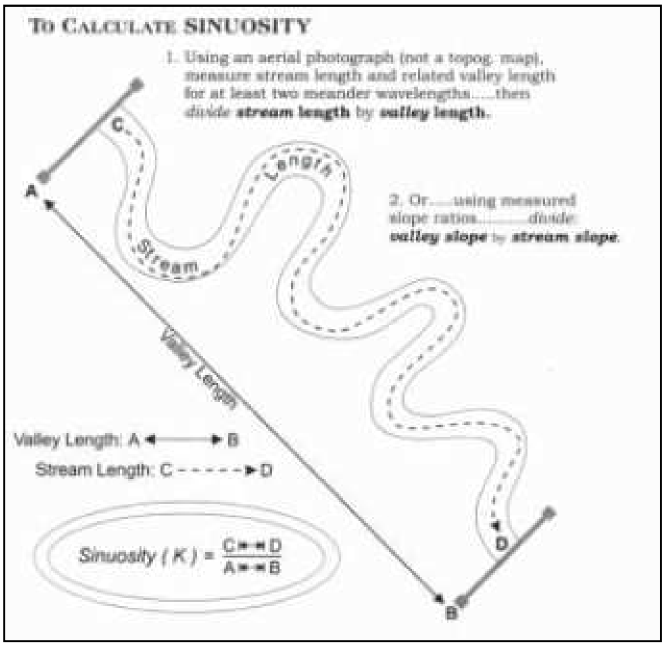


Fig. 7: Deposition of sediments in a stream

The processes of degradation and aggradation will create the channel profile. The **channel profile** is the slope in the direction of flow from a point of high elevation to a point of lower elevation. A **cross section** of a channel will be the slope from the top of one bank to the other. The **stream dimension** usually describes the geometry of a cross-sectional shape of a channel. The **bankfull discharge** is the channel-forming of effective discharge (Leopold, 1994) and transports the largest cumulative sediment load (Wolman and Miller, 1960).

Identifying the influence in stream morphology by geology, topography, size of the contributing watershed, flow velocity, discharge, sediment particle distribution, channel geometry and others, Leopold et al. (1964) observed the occurrence of three main channel patterns: **sinuous**, **meandering** and **braided**. These study points out the importance of the term **sinuosity (K)**, or the ratio between the stream length and the valley length.

If **K=1**, the channel is **straight** (it occurs rarely on natural streams, except in short distances) and if **K>1**, the channel is **sinuous**. According to Schumm (1977), if **K>1,5** the stream is said to meander and if the value exceeds **2,1**, the degree of meandering is **tortuous**.



TO CALCULATE SINUOSITY

1. Using an aerial photograph (not a topog. map), measure stream length and related valley length for at least two meander wavelengths.....then *divide* **stream length** by **valley length**.

2. Or.....using measured slope ratios..........*divide* **valley slope** by **stream slope**.

Valley Length: A ◄——► B

Stream Length: C - - - - - ► D

Sinuosity (K) = C↔D / A↔B

Fig. 8: Methodology to calculate sinuosity (N.C. Department of Environment and Natural Resources)

Fig. 9: Braided stream in the French Pyrenees (by Jan Říha)

2.2. Meanders

Studying meanders means studying the process of taking the eroded material from one river bank and making deposits of sediment on the opposite river bank (Neruda, 2010), according to the scheme of Fig. 10.

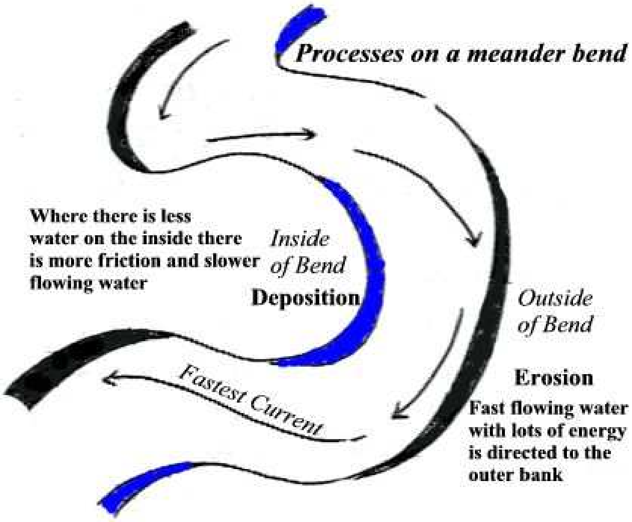


Fig.10 : Erosion and deposition on a meander (Dynamic Planet 2011/2012)

A lot of studies tend to analyze the accuracy of empirical relations of meander parameters for use in meander study (like Garnett P. Williams, 1986) and restoration procedures for the creation of meanders (like Rinaldi and Johnson, 1997). They lead to the definition of methodologies for construction of meanders in the context of restoration, as well as some classification systems for meanders.

In 1975, Brice classified the meanders into three types: equiwidth meanders, meanders with point bars and meanders with point bars and chute channels. ***Equiwidth meanders*** have only minor variability in channel width around meander bends and low width/depth ratios, erosion resistant banks, fine-grain bed material (sand or silt), low bed material load, velocities and stream power. Channel migration rates are also quite low due to the fact that the banks are naturally stable. The ***Meanders with point bars occur in channels*** that are significantly wider at bendways than crossings, with well-developed point bars but few chute channels and they present intermediate width/depth ratios, moderately erosion resistant banks, medium grained bed material (sand or gravel), bed material load, velocities and stream power. Unless banks are stabilized, channel migration rates are likely to be moderate. ***Meanders with point bars and chute channels*** occur in channels which are very much wider at bendways than crossings, with well-developed point bars and frequent chute channels, presenting moderate to high width/depth ratios, highly erodible banks, medium to coarse grained bed material (sand, gravel, and/or cobbles); heavy bed material load; moderate to high velocities and moderate to high stream power. Unless banks are stabilized, channel migration tends to be moderate to high.

In the search for a better river understanding and setting of restoration goals for meanders, Leopold and Wolman (1957, 1960) presented a match between the waveforms in bed topography and planform, pointing out their relationship with the mechanics of the flow, particularly with the turbulent flow structures responsible for shaping the forms and features of meandering channels. From the observation of the behavior of hundreds of streams, these authors, as well as others, aimed to deduct empirical relationships which should be followed in the restoration projects and, using the necessary adaptations, on meandering modeling and prediction.

These authors discovered that most rivers have a curvature radius to channel width ratio of 2-3 and are usually straight for less than 10 river widths. It should be the flow dynamics, particularly helical flow, and energy dissipation determining the meander shape. The curvature of a river decreases the sediment transport because of the dissipation of energy. They also observed that bank erosion occurs in a bend of a meander and an equal amount of deposition occurs on the opposite back so that the channel moves across its floodplain. If a channel does not move in its floodplain, then the material eroded from the curve will be transported until a point bar on the same side of the channel downstream. It should be understood that these are energetic processes but, although meanders cause energy loss, they are the configurations found in curved channels which offer the smallest energy loss. In this context, it is interesting to observe the phenomenon of **cutoff** or headcutting. When cutoff happens, the stream abandons one meander curve and opens a new shorter channel to the flow of water, as represented on the following picture.

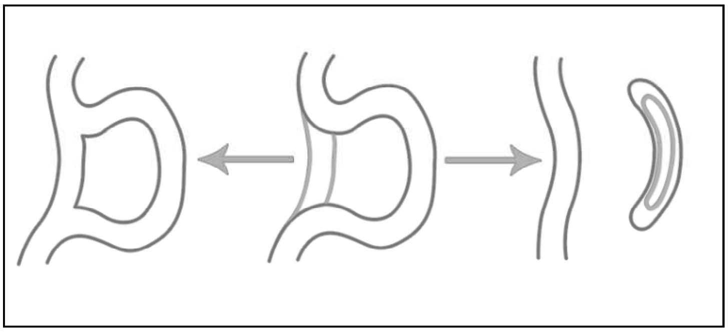


Fig.11 : Cutoff of a meander

In what concerns to the study of the landscape transformation within meanders configuration, a special attention should be given to the measurement of the **belt width of the meander**, the straight-line distance from the crest of the bend being evaluated to the crest of the next downstream bend and to the **overall belt width of the stream**, the straight-line distance from the two outermost bends of the channel (N.C. Department of Environment and Natural Resources). The reason is that these parameters allow a prevision of the floodplain as well as a better understanding of the sediments transport and bank stability.

The other important geographic characteristics of meanders are:

- **Meander wavelength (λ)** - distance between the axis of two consecutive meander bends located on the same side;
- **Radius of curvature (Rc)** - radius relative to the axis of the channel corresponding to a meander bend;
- **Amplitude**: distance between the axis of the curves of two consecutive meanders.

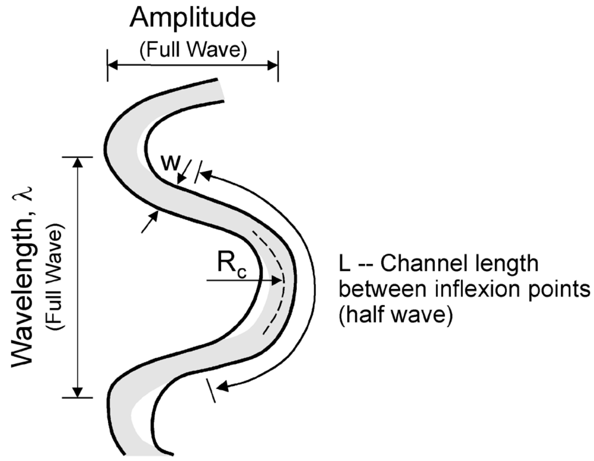


Fig.12 : Amplitude, wavelength and channel length of a meander (Doll et al.)

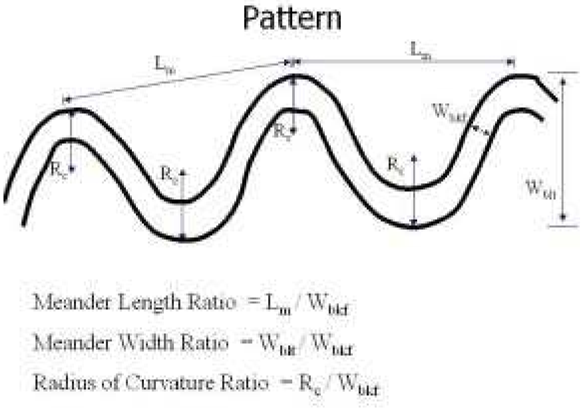


Fig. 13: Meander length, meander width and radius of curvature ratios (N.C. Department of Environment and Natural Resources)

One example of the application of the mentioned studies is the analytical approach to restoration assuming a sine-generated curve for the planform shape (Langbein, Leopold, 1966) and calculate x-y coordinates for the planform, but this theory of minimum variance is based on the hypothesis that the river will seek the most probable path between two points, with the minimum variance of bed shear stress and friction. Therefore, the study of the transformation in landscape occurred within restored meanders, whether this was the restoration approach or not, can provide important information about the accordance between reality and the deducted mathematical expressions and allow the assessment of the success of the restoration project.

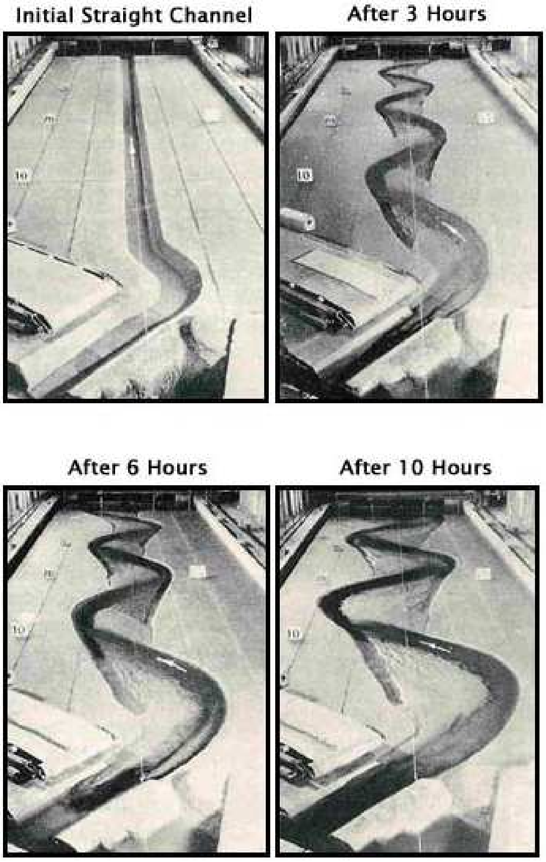


Fig. 14: Sand Flume Experiment Showing the Natural Tendency of Running Water to Develop Meander Patterns (Oxbow River and Stream Restoration, Inc.)

With more importance to the present work is the use of the mentioned data on the monitoring of the meanders evolution, a field that has been being perfected. Williams and Garnett based their studies on the Langbein and Leopold (1966) theory to examine the frequency of the ratio radius curvature to channel width and derive 40 empirical equations involving meander and channel size features. On their conclusions, the authors suggest that although channel width traditionally has served as a scale indicator, bankfull cross-sectional area and mean depth can be used for analyzing meander patterns. As it will be explained on the chapter dedicated to the used methodology, bankfull cross-sections survey was the approach made to evaluate the meanders position of *Černý potok.*

2.3. Classifying streams systems

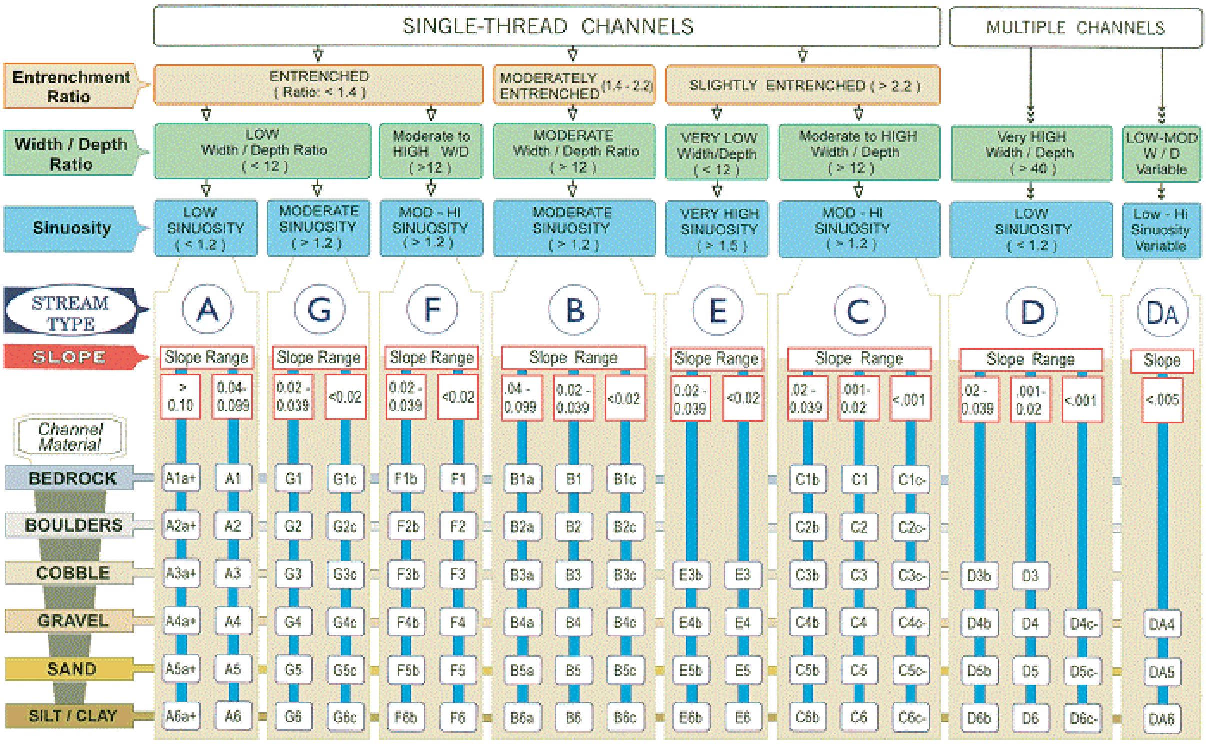
Another much discussed point is that although streams are governed by universal physical laws, every stream passes in a unique way through its landscape. What is established is that gravity and water are constants, so all streams tend toward a single ideal form. It will be the influence of the differences in location and physical conditions to originate the variety of forms we see. This happens because every stream balances erosion, transport, and deposition in the context of its climate and landscape. Nevertheless, natural stream systems have a propensity not to occur with random behaviors and their natural "efforts" to seek a probable balance of factors lead this phenomenon to the necessity of scientist to create a classification system for streams (USDA, 1994).

Classification systems are generally considered of the highest importance for the use in various stream studies, including restoration, since they aid in dividing stream networks into discrete working units, allowing a better understanding of the whole network. However, Kondolf (1995) warns against the application of classification systems in oversimplifying channel form and process and in confusing the stream classification exercise with understanding channel processes.

Along the decades, the efforts to classify streams resulted into simple and complex systems. One first simple approach is, usually, along with the water temperature, to determine the bed of the stream and if it is composed by sedimentary materials, the stream is called alluvial; if it is confined in a valley composed by cohesive rocky material, it will be a bedrock type of stream. More complex approaches address to the classification made by Leopold and Wolman (1957), Schumm (1977), Whiting and Bradley (1993) and others, including authors of local classification systems. The most popular classifications are, however, the Montgomery and Buffington's (1997) and the Rosgen's (1996). The firsts developed a classification system based on channel process that is most useful in high relief regions and Rosgen developed a classification system that includes mountain streams, but is most useful in its explanation of low gradient streams and techniques for restoration.

Because it isn't a goal of the present study to classify the restored river, it would be out of scope to explain these authors' classification methodologies, although they could be quite useful in what concerns to the sharing and comparison of scientific results in order to better understand a certain type of streams. In this context, Rosgen defined his list of classification goals being the following:

- Predict a river's behavior from its appearance;
- Develop specific hydraulic and sediment relationships for a given stream type and its state;
- Provide a mechanism to extrapolate site-specific data to stream reaches having similar characteristics;
- Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines.



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

Fig.15 : Rosgen's classification system for streams

2.4. Need of restoration and usual techniques

Because, as explained, they constitute dynamic systems, streams adjust to tectonic, climatic and environmental imposed changes (Dollar, 2000), in order to maintain a dynamic equilibrium between the energetic mechanisms of flow and sediment transport and the resisting forces of the stream bed, bank stability and resistance to flow (Soar et al., 2001). In another words, morphological changes in the channel can be observed as the stream adapts to an increase in the water flow or, searching a new state of equilibrium between the mentioned variables. Land use can lead to great changes in the stream system and, therefore, the need for restoration measures is usually reclaimed when the occurred changes are considered an irreversible degradation of the stream processes, geomorphic, hydraulic, or ecological.

One common example of this last idea is the regulation and straightening of stream channels, with associated bed and banks pavement. On this case, the banks are drained, are induced inconvenient conditions for water retention and it is observed a decrease of the groundwater-level because of the higher flow rate caused by this intervention. As well as in the cases of incised and eroding streambanks/channel and over wide channel, this situation calls for river restoration.

Regardless of the scale of the restoration objectives, projecting a restoration work requires a balance between the necessity and achievability of the restoration objectives based on a scientific evaluation, and economic and social constraints and must integrate a deep understanding of the processes that affect the river morphology, hydrology, and ecology and the cause of the disturbance to these processes.

Bellow are listed different kinds of needs for restoration which can occur and usual techniques applied (as explained by the Wild Fish Habitat Initiative):

- **Bank Instability –** stabilization techniques contemplating 1) riparian vegetation management and associated root stabilization of bank soils; 2) biotechnical slope protection; 3) armoring the stream channel with stone, cement, or other revetments; and 4) use of structures that extend into the stream channel to redirect the flow and reduce the erosive stream power on the banks.

- **Sedimentation** - addressing the source of sediment, the normal techniques applied are the reestablishment of vegetation on the eroding surfaces, slope regarding, removal of poorly constructed roads, and/or implementation of management practices that minimize erosion from road surfaces (Roni et al., 2002).
- **Over-widened channels -** restoration may require using excavated substrate material and importing gravel and cobble or blocks of riparian vegetation to narrow the stream channel; log jams and log complexes may also be used in decreasing the stream's width-to-depth ratio.
- **Channel incision -** examples of restoration actions for channel entrenchment are raising the elevation of the channel by: gully fill, check dams, beaver reintroduction, or complete valley re-grading.
- **Headcutting -** common headcut treatments are installing check dams, or sloping the bank face and laying in fabric and rock to control continued upstream migration of the nick point; other methods for headcut control are to elevate the channel by: gully fill or complete valley re-grading.
- **Channel avulsion -** channel avulsion is a sudden shift in channel location, so reactionary attempts should be made to stabilize stream banks to prevent further channel migration and excessive property loss.
- **Channel alteration -** restoration of an altered channel may require reconstructing the channel.

- **Berms, levees and dikes –** in some cases like in agricultural lands, complete removal of the levee or berm may not be desirable; in other cases, removal of the floodplain constriction may be needed to achieve desired reconnection of the stream and floodplain.
- **Flow alteration -** examples are dams and irrigation diversions, which can significantly decrease downstream flow; in highly-altered flow and sediment transport regimes (such as downstream of a dam) the current flow regime, sediment loads, and social and economic constraints on the system must be factored into the restoration approach.
- **Loss of fish habitat -** Common examples of habitat enhancement are the placement of materials, such as large pieces of wood or boulders into the stream channel, or manipulation of the channel itself to improve habitat for fish and/or other aquatic organisms.
- **Reduction in riparian vegetation or loss of riparian area -** restoration measures to address a reduction in riparian vegetation may simply require a passive restoration approach, such as a change in land use within the riparian area. Active restoration might include reseeding or replanting vegetation.
- **Fish passage barriers -** restoration of fish passage may include removal of the obstruction, replacing the culvert, or construction of a fishway, which provides a way through or around the obstruction; examples of culvert replacements include bridges, open-bottom culverts or embedded (for example, countersunk) pipe-arch culverts (Roni et al., 2002).

- **Irrigation canals and diversions –** restorations techniques are highly dependent on the local conditions and can be, for example, addressed to the elimination of fish passage barriers.
- **Predation or out-competition of native fish -** in such situations, the installation of a fish passage barrier is an important tool in conservation of native fishes.
- **Impacts from mining -** reclamation of mine sites and impacted areas downstream can be challenging and might involve several steps to restore the natural physical, biological, and chemical conditions of the stream channel.

3. The Project of Revitalization of Černý potok

3.1. The stream

Černý potok, the Black Creek, was probably named after the dark colors observed as a consequence of the concentration of humic acids which naturally occur in peat lands. It is a mountain stream and has a total length of about 5 km, including the part of the stream which flows in Germany. In Czech territory it has a length close to 2.5 km and flows through "Černá Louka (or *Black Meadow*) Nature Reserve", between the villages of Adolfov (Ústí nad Labem) and Habartice (Teplice), near the border of North Czech Bohemia with Germany and about 10km from Teplice, in the Krusné Hory (Ore Mountains).

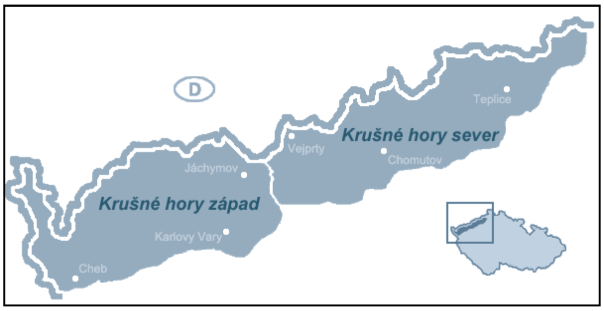


Fig.16 : Location of the "Ore Mountains"

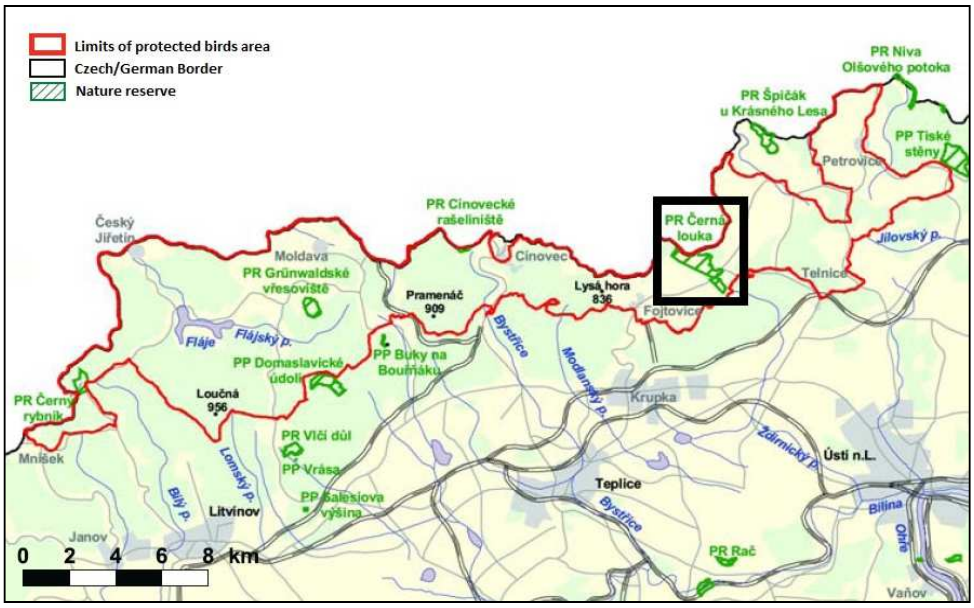


Fig.17 : Location of the "Black Meadow" (by ANCLP CR)

On its site, situated at 690 - 760 m above sea level, the annual precipitation rounds the 1000 mm and the land is covered with snow for approximately 100 - 120 days. 10 to 30 days are considered "summer days" and there are 50 -60 "frozen days".

Concerning the water quality parameters, in 2010, the measurements conducted by UJEP students to assess the water quality, classified *Černý potok* as having good and very good conditions according to Czech legislation. The review on their results presented an average pH between 6-8, high concentrations of dissolved oxygen and temperatures until the maximum of 9 °C. Due to old mining activities in the limits of "Černá Louka", special focus was given to the analysis of heavy metals, both in water and in the bottom sediments of the stream. The results of the analysis conducted in 2011 presented, however, slightly high concentrations of Zinc, Arsenic and Plumb. Already nearby, high concentrations of Cadmium and other heavy metals were measured in the bottom sediments, probably due to the referred old mining, but there aren't any recent news or reports about this matter. It is really interesting, although, that this values were found in this "clean" nature and they open a door for further investigation, concerning the pollution focus as well as the dynamics of the sediments transport.

Table 1 : Heavy metals concentration in the water and sediments, 06/06/2011

Substance	Conc. in water (mg/l)	Conc. in bottom sediments (mg/kg)
As	<0.2	86
Cd	<0.01	1,5
Cu	<0.02	9
Ni	<0.02	19
Pb	<0.1	48
V	<0.02	37
Zn	<0.005	81
Hg	<0.001	0,1

In the Czech database, *Černý potok* watershed has the number 1-15-02-030, for further details.

3.2. Context of the revitalization project

Due to the negative impacts of the widely spread practice of regulation techniques for stream channels, such as straightening, paving or bank drainage, in 1992, the Czech Ministry of Environment prepared a Program for revitalization of watercourses, approved and supported by the Czech Government. Also in this context of implementation of measures for nature and landscape protection, in 1998, "Černá Louka Nature Reserve", the area where *Černý potok* stream, spring, and two left and two right tributaries are located, was established as a protected area of the Natural Park "Východní Krušné Hory", created in 1995. With an area of 140 ha, the "Černá louka" is a part of an internationally significant wetland of peat, "Krušnohorská rašeliniště", which was registered on the Ramsar Convention on Wetlands list in May of 2008.

In fact, this Nature Reserve is also a site of the network Natura 2000, a network of protected areas designated according to common European Union (EU) principles in the territory of all member states. The aim of this network is to guarantee the protection of animal and plant species and habitats that are the most valuable, most threatened, rare or have limited distribution in some areas (endemic) at the European level. The two most important EU nature conservation directives to the Natura 2000 network address the conservation of the wild birds ("Bird Directive") and the conservation of natural habitats and wild fauna.

Being included on a protected area, attention was brought up to the problems associated to the stream in study and its influence on efforts of protecting the mentioned areas and their biodiversity and landscape.

The reason for restoration was the fact that *Černý potok* was in the 1980's ameliorated and straightened with stones and concrete weirs and the adjacent land was object of drainage for agricultural purposes. Small tributaries were also destroyed and the human intervention represented a very negative disturbance of the original hydrological system. The water was forced to flow at a much higher speed, being observed an increased runoff on the basin and a significant decrease of groundwater levels. Because of these transformations, the site experienced a lack of conditions to support the original biodiversity of the primary wetlands.

Therefore, the main goals for the revitalization project of Černý potok were:

- Reestablish the stream channel natural conditions;
- Correct hydrological and hydrogeological parameters regarding a better soil retention, lower channel discharge, higher groundwater level;
- Restore the biodiversity of fauna and flora.

These goals should reflect a good water management and an enhancement of the natural landscape characteristics of Černá louka.

Historically, the revitalization had two main phases:

- From **2001 to 2003** – within the program for revitalization of watercourses supported by the Czech government;
- From **2008 to 2010** – within the Operational Programme for the Environment (OPE) co-financed by the European Union (with the European Regional Development Fund and the Cohesion Fund) and implemented through the Agency for Nature Conservation and Landscape Protection of the Czech Republic (ANCLP CR).

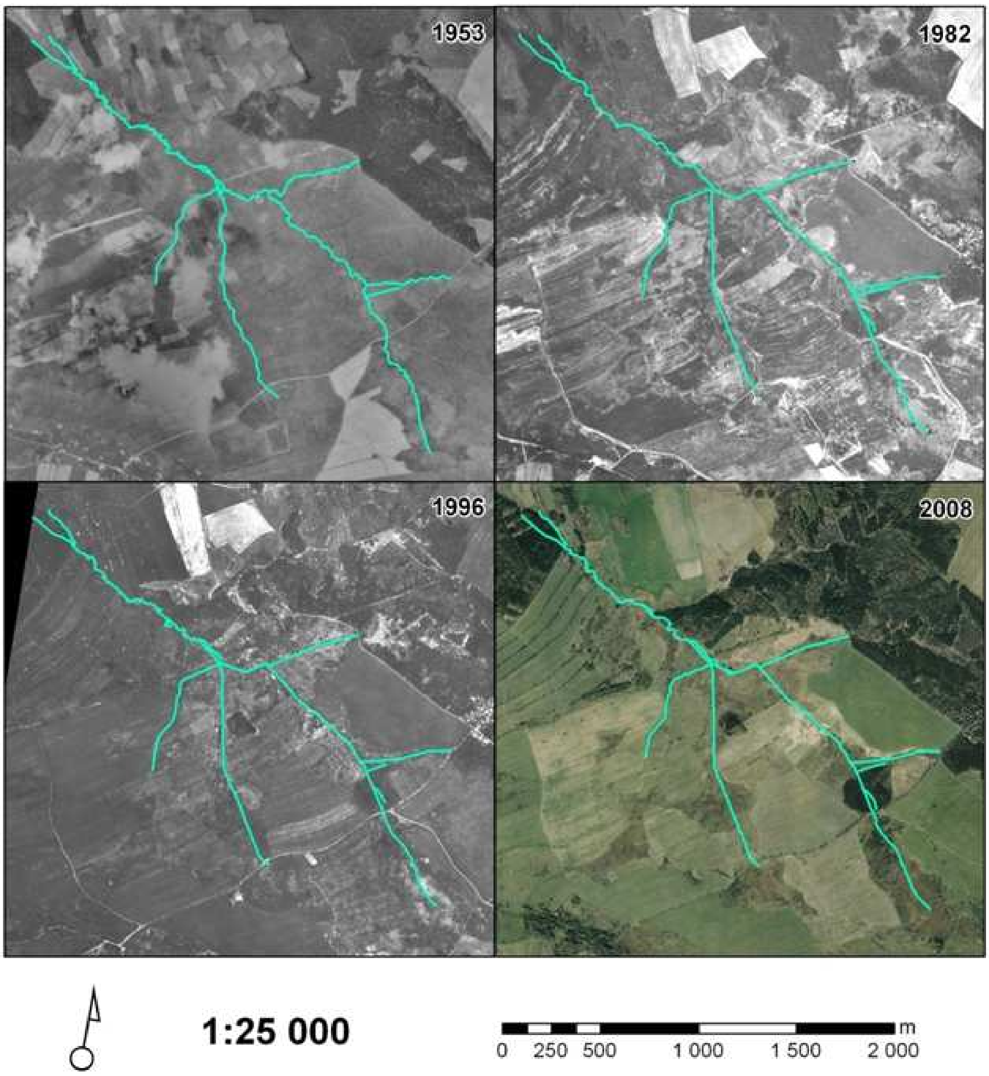


Fig 18: Evolution of the stream channel: before straightening (1953), after straightening (1982), before the 1st phase of revitalization (1996), before the 2nd phase of revitalization (2008) (by J. Zacharová)

The efforts of the second phase of the project are in accordance with the aim of the OPE (for the period of 2007 to 2013): to protect and improve the quality of the environment as a basic principle for sustainable development. The OPE is divided into eight priority axes and this revitalization project is under the priority axis number **6, "Improving the State of Nature and the Landscape"**, more specifically, under the "6.4 - Optimization of the landscape area of support". Its goals are:

- implementation of measures beneficial to the landscape and ecosystem diversity leading to an increase in the retention capacity of the landscape, protect and restore the natural flow regime and in reducing risk situations, in particular floods (support natural overflowing in flood plain areas, measures to improve the morphology of aquatic components of the landscape under the Directive 2000/60/EC, the Water Framework Directive, building restoration and retention areas that are not used for fish or serve just a fish that does not compromise the ecological functions of reservoirs, construction of polders, or system of polders with a total volume up to 50.000 m ^{3} , etc.);
- implementation of measures to protect against water and wind erosion to reduce negative effects of surface water runoff (the establishment or renewal of limits, infiltration strips and broad-base terraces, windbreaks, etc.).

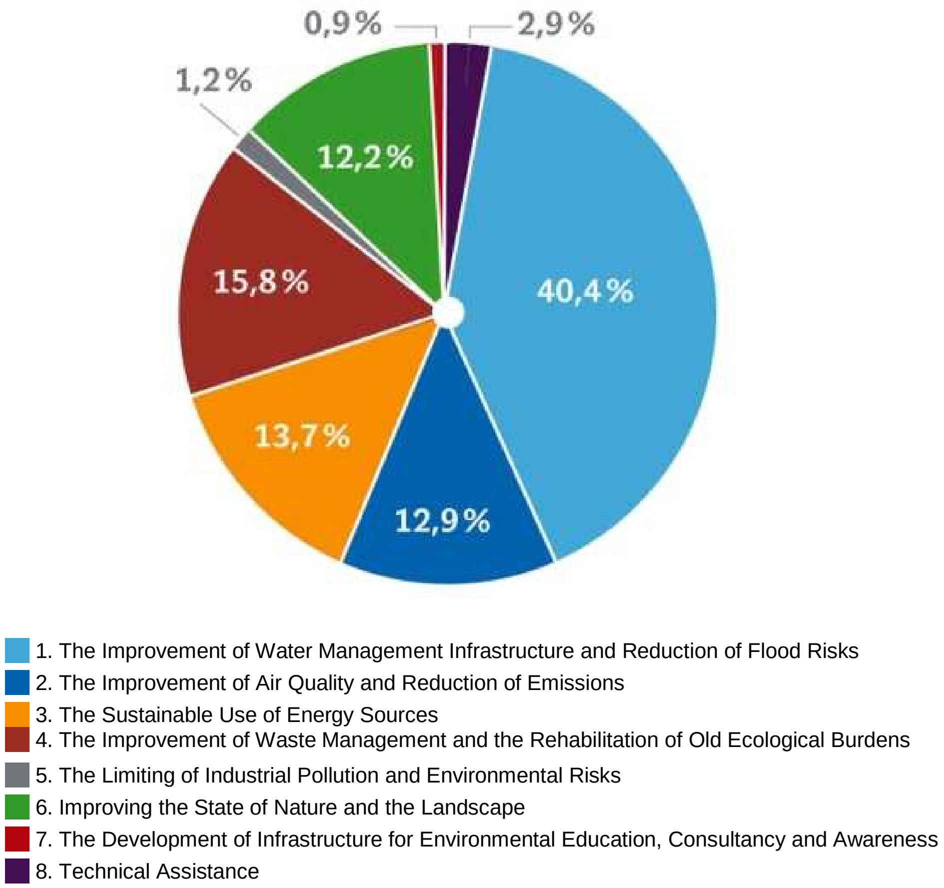


Fig.19 : Graphic of the distribution of funding by the several priority axes of the OPE

The total cost of the project was set at 7,7 million CZK (around 320.000 Euros) and the monitoring would be made by ANCLP CR in cooperation with the company responsible for the project and the Faculty of Environment of Jana Evangelisty Purkyně University in Ústí nad Labem (FŽP, UJEP). The study here presented was elaborated during the academic summer semester in this faculty and integrated in the Erasmus exchange program contract celebrated between the Faculty of Engineering of University of Porto and FŽP, UJEP.

3.3. Development of the project

The early stages of the revitalization (1999) only contemplated the planting of new trees and creation of pools. Then, as the project documentation was completed in 2000, the most important part of the works of the first phase of revitalization went on in 2001 and 2002, but they were suspended during the spring of 2003 and postponed indefinitely as a result of financial problems. In fact, the main difficulties concerned the ground works, which were reported to be very challenging.

By the year 2003:

- 21 pools were created;
- two sections of the stream were restored and approximated to the original stream channel;
- meanders were partially done;
- the channel was roughened by weirs;
- wetlands were reestablished.

The outplanting of trees was done independently of the ground works and a lot of the bushes planted died due to the lack of maintenance. Still, the scarce ecosystem was restored and special natural sites were created in order to support a higher biodiversity.

The second phase of the project was named "Revitalization of the Black Creek and its tributaries in the Black Meadow Nature Preserve - finish". Once again, the ground works were difficult and also limited by the climatic conditions of the site, as well as the established need to not interfere with the existing protected species. Therefore, the works would have to be conducted out of the nesting season of birds and metamorphosis of amphibians.

It was required to extend the transverse and longitudinal segments of the stream, to use natural materials, to integrate the possibility of lateral channel shaping by future floods, to potentiate the development of a natural riparian habitat, allowing the natural transport of the water to the floodplain by normal effects of driving hydrological forces when in the presence of a stream configuration which ensure a dynamic stability and avoid high concentrations of energy on the banks of the stream.

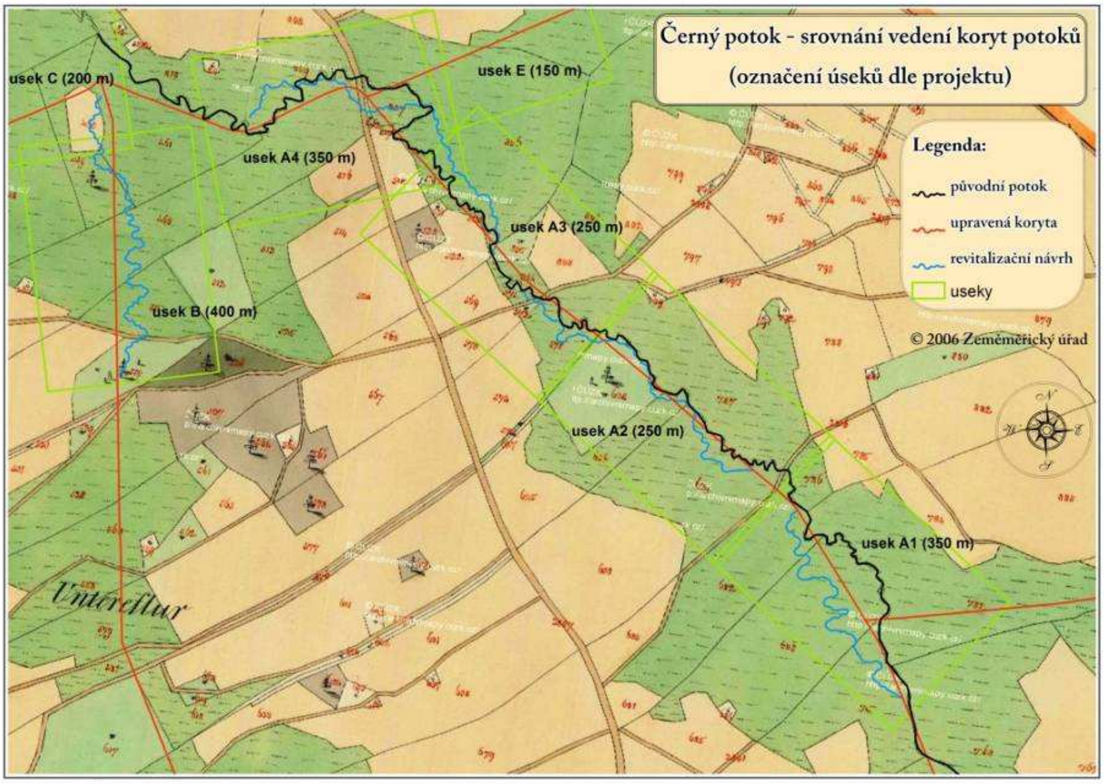


Fig. 20 : Project for revitalization by Ing. Vít Rous, Terén Design s.r.o. Teplice – in black, the natural chanel; in red, the straightened channel; in blue, the revitalized channel

To meet these requirements, the works in 2009 contemplated the following points:

- the new watercourse (forced to flow in a different direction then the old straight channel by a barrier) was designed for a lower runoff of 30 days (Q30d) without fortification of the banks;
- it was adopted the shape of a shallow plate, as rivers tend to naturally have;
- the required dynamic stabilization was made through the alteration of the channel to a more natural longitudinal profile with pools and riffles and the creation of meanders;
- the old channel was transformed into a network of big pools, to simulate the pools which naturally occur in wetlands;
- a few small dams (weirs) made from soil dredged from the new watercourse were built to create a pools cascade;
- due to geographical conditions, the new watercourse was projected to cross the old deep and straight channel in some points and to be close to the original channel of the stream when possible.

Fig. 21: Machinery opening meanders in the upper parto f the stream (by ANCLP CR)

The mentioned construction works took place on the period of August to November of 2009. In 2010 took place the major biological and landscape finishing arrangements, which started in the month of August. Different species of trees and bushes were planted in small groups along the new watercourse and old channels and pools. Trees were planted with the minimum distance of 2 meters and bushes 1 meter. The project was completed and entered on a phase of monitoring.

The main final parameters and conclusions were:

- Length of new flows – **1820 m** (target value - 1562 m);
- Area ponds with wetlands – **0.963 ha** (target value – 0,646 ha);
- Area for natural flood overflow (meandering belt) $Q_{100years}$ – **8 ha** (target value – 7.163 ha);
- Total area of newly created or restored wetlands with permanent or occasional small pools and running water – **4.3 ha**;
- The three main goals of the revitalization project were met – the interventions allowed an increase of the retention capacity of the landscape, a restoration of the natural flow regime and retention space and a substantial improvement of the habitat conditions for natural species of the wetlands (one particular aspect of meeting the biodiversity goals was the evidence of the permeability of the stream to the migration flow of trout, since this specie was observed in the upper part of the revitalized stream).

Fig 22: Pools created in the old channel and planted trees (by Jan Říha)

Fig.23 : New meanders (by Jan Říha)

Fig.24 : Step built with rocks (by Jan Říha)

3.4. Monitoring the revitalization project of *Černý potok*

The monitoring includes the evaluation of two main groups of indicators: one associated to **biodiversity** and the other to the development of the **new waterways**.

Related to the first group of indicators, already at the time of construction was possible to observe the positive consequences of the revitalization. On the banks of the new channel there were often viviparous lizard (*Zootoca vivipara*) and in the pools a large number of insects commonly called "jumpers". On the newly formed surfaces were frequently observed the bird species of lapwings (*Vanellus vanellus*) and the highly endangered common snipe (*Gallinago gallinago*). An ideal habitat for these grassland waders formed as a positive side effect of the revitalization, where the creation of dams was probably very important to those species because it allowed the water to rise to the surface as they need.

Fig. 25 : Life in Černý potok at the beginning of Spring (by Jan Říha)

However, the object of study of this work was the second group of indicators, settled that UJEP would evaluate the effectiveness and the benefits of the construction works on a selected segment of the stream with built meanders. The following chapter will describe how the monitoring works were conducted and which important information can be collected with the made measurements.

4. Methodology

The terrain measurements took place in the 6 of June of 2011 and contemplated water flow velocity and stream discharge, "pebble count" and sediments granulometry and surveys of cross-sections of the streams. The collected data were then analyzed and conclusions were reached.

4.1. Water flow velocity

To measure the water flow velocity, it was used a small current meter (OTT C2), specially used for measurement of flow velocity at low water levels with high precision, measuring flow velocities as of 0.025 m/s (the minimum depth of water to use the C2 is approx. 4 cm).

The current meter was assembled and the survey location was the starting point of the meanders study section. It was introduced in the water in the thalweg zone of the cross section and during 40 seconds the device measured the number of turns given by the propeller on the middle of the thalweg and close to the water surface. The number of turns given (N) was then divided by 40 seconds, resulting the number of turns per second (n), and according to the calculated value, a specific calibration equation associated to the current meter was chosen to convert the value *n* into flow velocity (in m/s) and calculate the discharge of the stream in that cross section, (in l/s).

Fig. 26: OC TT2 current meter

4.2. Sediment analysis

The first approach to the sediment analysis was with the “Wolman pebble count”, in order to describe quantitatively the bed material. It was done with two people, one to collect the pebbles and another to register the results. It was calculated the percentage of riffle/run and pool/glide along the surveyed longitudinal profile to determine the equivalent proportion of pebbles to collect from every feature). Then, the count was performed at each of the reaches along the stream channel, respecting the cross sections geometry, or, in another words, starting on the right bank and progressing to the left bank at every cross section and collecting the first pebble touched by the first finger without looking. 100 particles were collected to measure their intermediate axis but there wasn’t a special ruler available to measure these particles with accuracy and some errors occurred, especially in the definition of the intermediate axis of the particles.

Due to these inaccuracies in the application of the pebble count, a granulometry test was conducted in the laboratory to the collected samples of a sediments deposit, bank material and stream bead material from a pool. From every sample was collected 100g three times to conduct sieving tests. In the end, the particles diameter distribution was calculated.

Fig. 27: Column of sieves used

4.3. Geodetic measurements

It was selected a stream section of around 100 meters and geodetic data of cross-sections was collected approximately 10 meters apart along 100 meters of the stream length, resulting in the definition of 10 transversal profiles (or cross section profiles) created by 7 geodetic points. It was measured the position of the wood markers or poles which were fixed on both banks (a and b), around 1,50 m from the head of the terrain, the position on both heads of the bank terrains, the base of each bank and the central point of the terrain. The geographic information was obtained by the distances determined with the reading made by a teodolit of the Leica TPS800 Series, the TCR802, having as reference previously defined geographic stations.

Table 2: Scheme of the geodetic measured points in the cross sections

1	2	3	4	5	6	7
a	Right head of terrain **(Rht)**	right bank **(Rb)**	center **(C)**	left bank **(Lb)**	Left head of terrain **(Lht)**	b

Photographs accompanied the cross section surveys.

4.4. GIS data treatment

The programs ArcGis, version 10, was used to work on the geodetic data**.** ArcGis is a complete system for designing and managing solutions through the application of geographic knowledge. The works performed with the ArcGis tools were:

- representation of the surveyed cross sections (profiles) on the ortophoto of the site in 2010;
- determination of the **slope** of the total surveyed longitudinal section where were included the 10 profiles measured;
- comparison in the 2010 ortophoto of the stream channel in 1946, 1982 and 2010 and determination of the corresponding **sinuosity,** measuring the stream length and the valley length;

- representation of the **stream’s profiles**, transversal, with the points measured at the cross section surveys (numbered from 1 to 10), and longitudinal, through the representation of the stream central line in the ortophoto from 2010 and calculation of the stream length between the surveyed cross sections by the created digital terrain model (DTM) from the same ortophoto;
- measurement of the **meanders belt** in 2010 by drawing a central stream line along the channel on the ortophoto of that year, on thestudy section, and drawing complementary tangent lines to the meanders curves in order to calculate the desirable parameters.

The mathematical data as organized in Microsoft Office’s Excel and the photographs made on the terrain work were used to allow a more complete analysis.

5. Results and discussion

5.1. Water flow velocity and discharge

According to the calculated values of n and the specifications of the current meter, the chosen equation to determine the flow velocity (v) for a measurement period (T) of 40 seconds was:

$$1.77 - \frac{6.84}{v} = 0.1040.\mathrm{n} + 0.028 \quad (\mathrm{m/s}) \qquad (1)$$

Table 3: Velocity measurement data (6/6/2011)

Distance from right bank (cm)	Total water height (cm)	Height of measurement (cm)	N (turns)	n=N/T (turns/s)	v (m/s)
65	11	5	80	2	0.236
		10	102	2.55	0.293

The average flow velocity was 0.2646 m/s, at 65 cm from the right bank, on a section where the stream has a width of 1.50 m. This is a lower value compared to previous test measurements conducted in the upper part of the stream after the snow melting, in April, when velocities over 40 m/s were reached. This is a logical disparity of results, since the phenomenon of snow melting originates higher discharges in the channel and in June is expected a lower discharge.

The area of the section (S) was calculated multiplying the total stream width by the total height:

$$S = 1.50 \times 0.11 = 0.165\, m^2 \qquad (2)$$

The discharge was determined by multiplying the measured average velocity by S, obtaining

$$Q = v \times S = 0.2646 \left(\frac{m}{s}\right) \times 0.165\, (m^2) = 0.0436\, m^3/s = 43.6\, l/s \qquad (3)$$

5.2. Sediment analysis

As explained on the previous chapter, some inaccuracies were made when the "pebble count" was performed. Therefore a granulometry test with sieving was conducted to the samples presented in Fig.28.

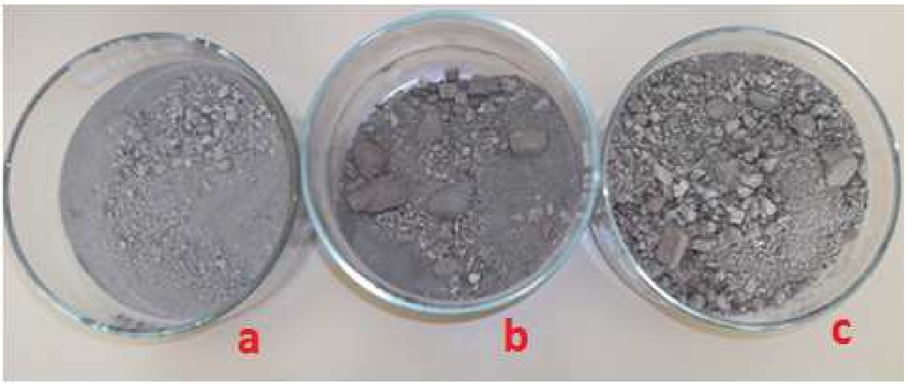


Fig. 28: Samples from the left bank (a), bed material of a pool (b) and from a deposit of sediments (c

The retained material in each sieve was weighted and this allowed knowing the percentage of particles retained by each sieve. The material not retained by a specific sieve is considered to have a smaller diameter then the correspondent to the sieve. The calculated cumulative percentages can be read on Table 4.

Table 4: Average cumulative percentages of material retained by the sieves

Sieve	Diameter (mm)	Deposit	Pool	Bank
1	10	3%	14%	19%
2	7.1	6%	26%	25%
3	4	13%	39%	35%
4	2	19%	44%	42%
5	1.6	21%	46%	44%
6	1.4	27%	48%	48%
7	1	52%	56%	62%
8	0.5	66%	64%	74%
9	0.315	76%	70%	81%
10	0.1	99%	98%	97%

According to its diameter (d), particles can be classified as (FEUP, MIEA, LCA 2009/10):

- Small stones – 2 mm < d < 60 mm;
- Sand – 0,06 mm < d < 2 mm;
- Silt – 0.002 mm < d < 0.06 mm
- Clay – d < 0.002 mm

Although the available equipment didn't allow distinguishing the particles with diameters under 0.1 mm, it is possible to observe that half of the particles had a diameter bigger than 1 mm. Therefore, 50% of the particles sampled were small stones and sands. When drying the samples in a proper oven, specially the bank samples and the pool samples were transformed into a unique block which had to be shattered for the sieving. This fact is the evidence that the channel, after restoration, is supported by silt and clay material on the banks and on the stream bed. Future measurements for the sediments analysis can, therefore, demonstrate the level of sedimentation and transport in the channel, by quantifying the occurrence of higher concentration of sands and small stones, for instance, the particles that don't seem to originally be the physical support of the stream channel.

The "Wolman's pebble count" can, in fact, have more advantages in the empirical understanding of the sedimentation phenomenon in the stream. The pebbles can be classified into a wider range of classes and there are already guidelines to calculate the tractive force and the critical tractive force inflicted by the water on the banks and on the stream bed, according to the percentage of particles having a specific diameter established for every different mathematical expression that was derived to provide this set of information.

The usefulness of the sediments analysis and the complementary calculation of the involved forces is the quantification of the occurred erosion and the possible prediction of future erosion, as well as, along time, the identification of abnormal values which can indicate the contribution of some extraordinary hydrological or geological phenomenon for the measured erosion.

5.3. Geodetic work and GIS data treatment

5.3.1. Terrain measurements representation

The first geodetics measurements to the revitalized stream took place in November of 2010. By then, the chosen section for surveying was located on the upper part of the stream on a meander which contained a small island in the middle. There were made measurements at every meter along the stream longitudinal section, which resulted on detailed geodetic information and allowed a very interesting GIS work and representation. Although this kind of detailed survey provides a high accuracy on the GIS analysis and makes possible a reliable 3D representation and several modeling tools, the fact is that it isn't so relevant to the evaluation of the meanders position and migration because, in one hand, with so much detail it was only viable to survey one meander and, in the other hand, the evaluation of one meander position is not representative of the overall transformations in the landscape occurred within these stream formations.

Another problem with the old measurements regards the chosen location. On the upper part of the channel, the stream's hydrodynamic characteristics are not fully developed and the meanders aren't so well identified. To choose an area downstream from the previous would contemplate a well developed stream and with better conditions to observe the changes of the meanders in time.

Therefore, the 2010 approach to the terrain measurements was abandoned and the new approach included geodetic data of cross-sections measured approximately 10 meters apart along 100 meters of the stream length on a downstream area were the stream is well developed and more sensible to changes.

To represent the measured profiles in ArcGis it was used an ortophoto of the study site, from 2010, and the DTM created to represent the ortophoto. The resolution of the ortophoto is of 0.2m. The DTM created was more detailed but with less accuracy (1m). Therefore, the ortophoto is more accurate than the DTM but the positioning of the features in reality can be until 0,2m apart from what is observed in the ortophoto.

To every measured point is associated a set of “x, y, z” coordinates. ArcGis is capable of reading those coordinates and associate them to the ortophoto data. The measured points can then be represent in the ortophoto to allow further measurements and calculations.

Fig. 29: Ortophoto (2010) of Černý potok and the chosen study site

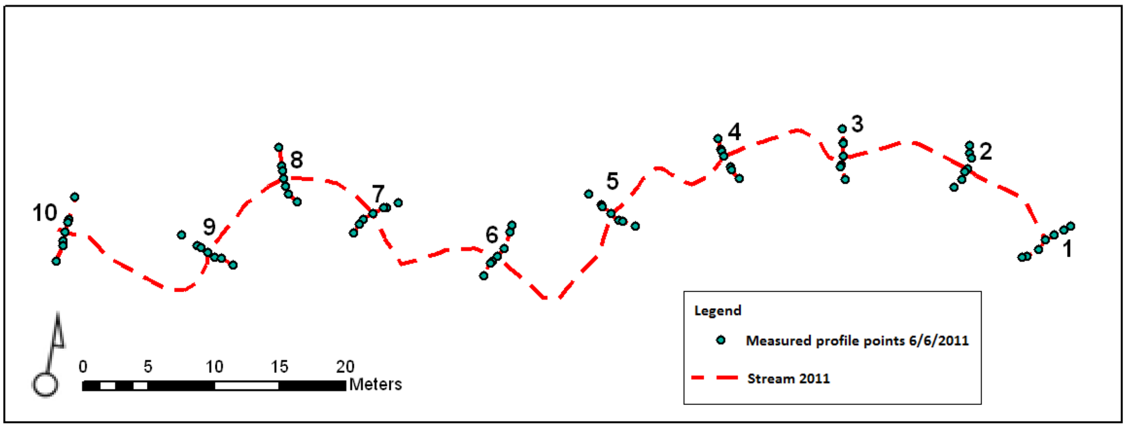
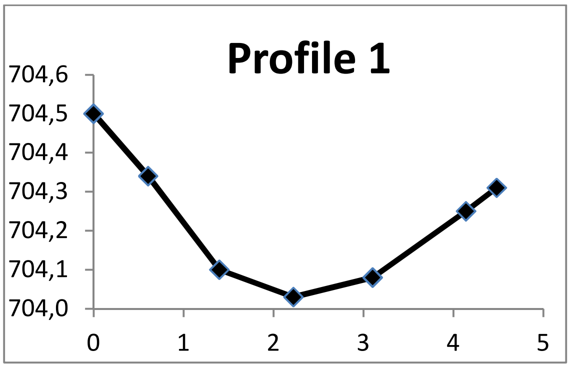
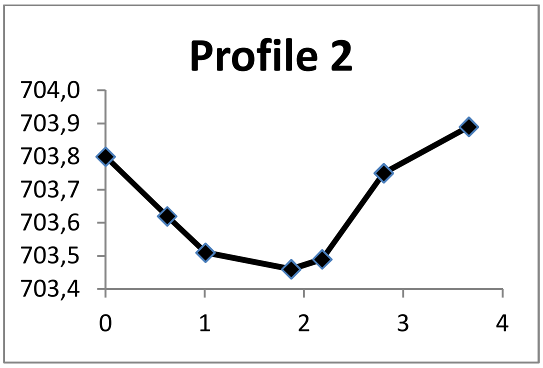
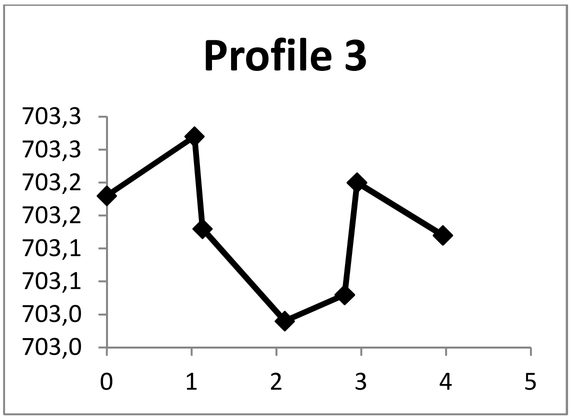


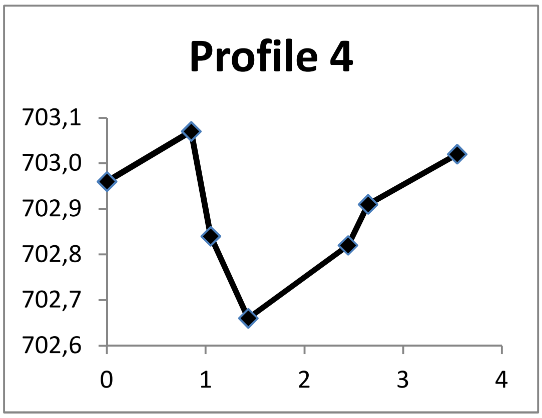
Fig. 30: Representation of the measured profiles

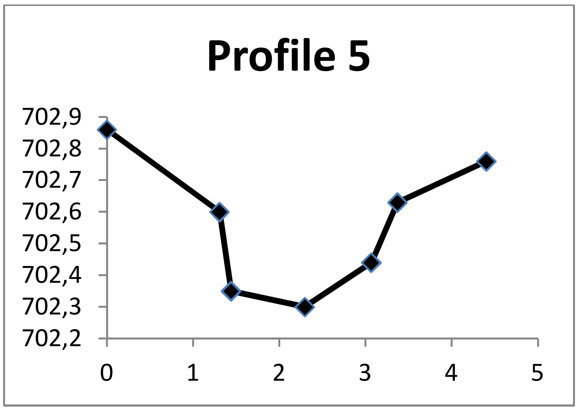
The first calculations were made to represent the 10 cross section profiles. In the ArcGis, the data of the 7 measured points of every profile were plotted as *XY* coordinates and in Excel the representative graphics of the profiles were created. While reading the graphics, the scheme of the geodetic measured points in the cross sections (Table 2, page 44) should be taken into consideration, as well as the fact that the terrain is highly irregular.

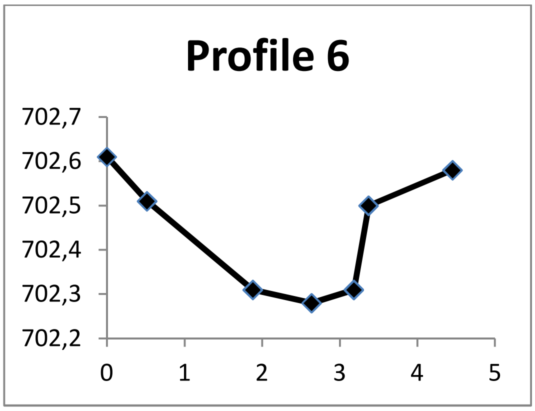












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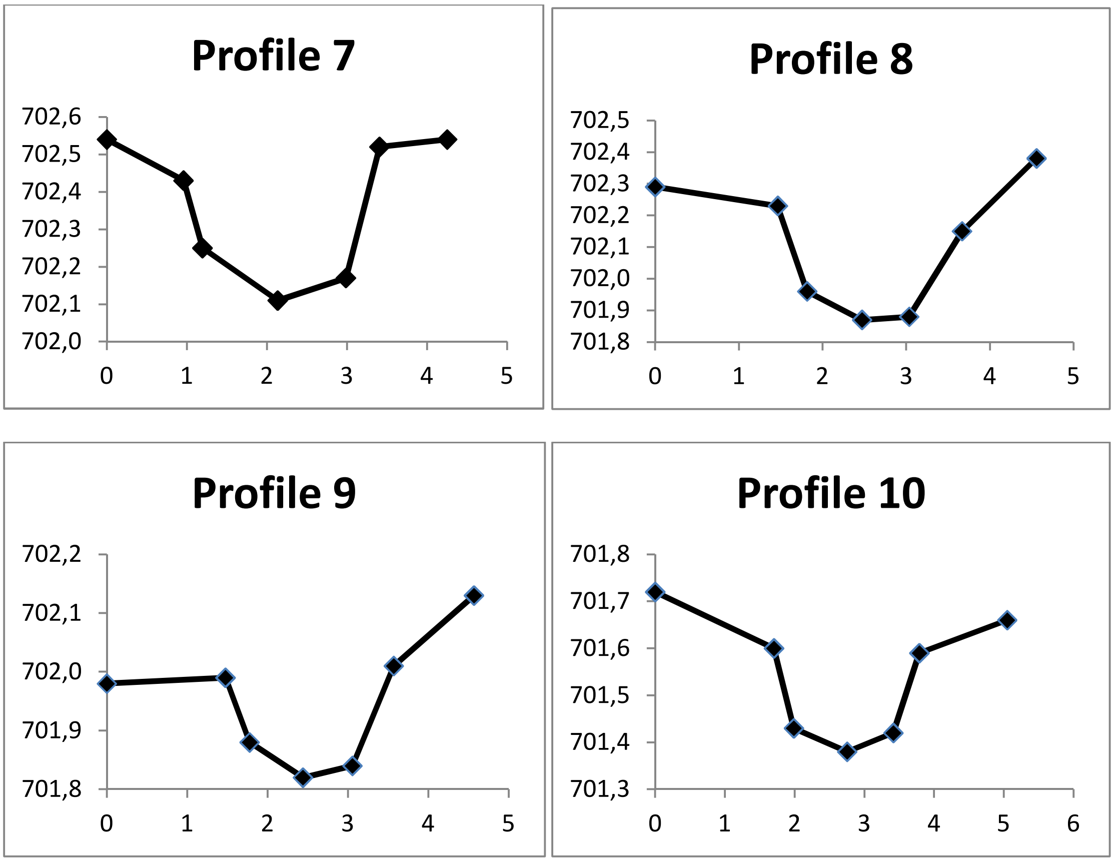

Fig. 31 (1 to 10): Graphic representation of the 10 cross section profile; in each graphic, from the left to the right, the represented points correspond to 7 measured points of the profiles (in meters)

Although the graphic representation doesn't give the real profile of the stream's cross section, it allows a simple analysis of the localization of the section marker on the right bank, the right head of the terrain, the right bank, the central point, the left bank, the left head of the terrain and the section marker on the left bank. To try to model the cross section with interpolations would have no advantages because the process would be based on the DTM and the ortophoto, which aren't detailed enough to assure a high quality representation of reality. For that, a survey with laser scanning (a very expensive geographic survey method) could be the more indicated.

The same applies to the longitudinal profile. ArcGis calculated the distances along the stream from the central point measured on Profile 1 to the central point measured on Profile 2, using the guidelines of the DTM. A graphic representation was made but the real importance of these calculations was to calculate the slope between the surveyed sections of the stream. The slope between profile 1 and profile 10 was calculated with the ArcGis tool of editing, merging and planarization function. The plotting of the data was done on the same assumptions explained previously and graphic representation was made.

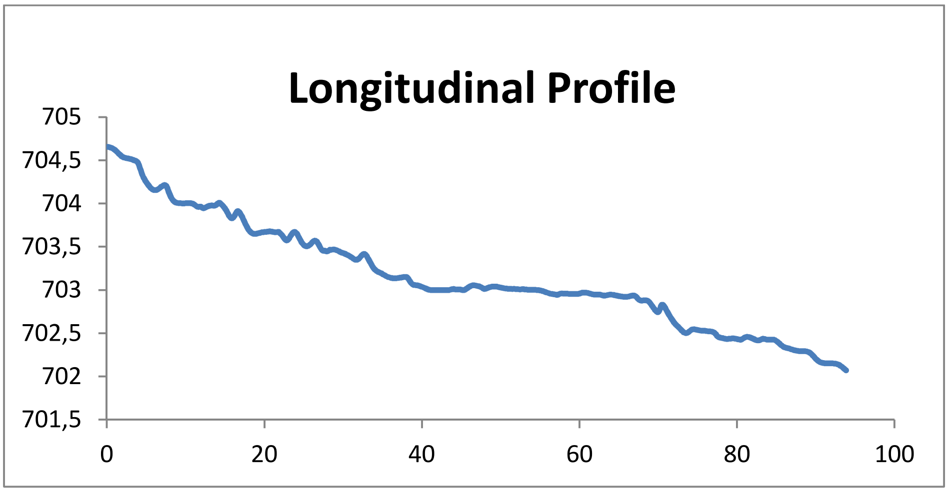

Fig. 32: Longitudinal profile of the stream from cross section 1 to 10 (the decrease of elevation on the flow direction, in meters)

The slope was calculated subtracting the height of the last point measured (Profile 10) to the height of the first point measured (Profile 1) and dividing the result by the total length between those two points:

$$\text{Slope} = \frac{704.66\text{-}702.07}{93.86} = 0.0276 = 2.76\% \tag{4}$$

The total length in (4) is given by 93.86 and not 100 meters, the proposed total survey section, because the 100 meters were measured along the right bank of the stream and the calculations were made for the total length calculated on the central line of the stream based on the DTM, and thus the observed differences.

To close this section, it is important to explain that the biggest strength of this type of representation is that it meets the monitoring needs established for the cross sections: to observe the changes on the profiles during time on the measured points. Because the points are symmetric, a lot of information can be gathered from the surveys, as, for instance, the differences on the elevation of the same point on each bank, the transformations on the channel width and the channel heights. This analysis would, therefore, be a simple indicator of the banks erosion. An example of a simple way to calculate the mentioned differences can be found on the following Table:

Table 5. (Divided in two): Example of calculation of the differences in height and width of the measured symmetric points

Point	1		2		3		4		5	
	width	**height**	**width**	**height**	**width**	**height**	**width**	**height**	**width**	**height**
a	0.00	704.50	0.00	703.80	0.00	703.23	0.00	702.96	0.00	702.86
Rht	0.61	704.34	0.62	703.62	1.03	703.32	0.85	703.07	1.31	702.60
Rb	1.40	704.10	1.01	703.51	1.13	703.18	1.05	702.84	1.44	702.35
C	2.22	704.03	1.87	703.46	2.10	703.04	1.43	702.66	2.30	702.30
Lb	3.10	704.08	2.18	703.49	2.80	703.08	2.44	702.82	3.07	702.44
Lht	4.14	704.25	2.80	703.75	2.95	703.25	2.64	702.91	3.37	702.63
b	4.48	704.31	3.66	703.89	3.96	703.17	3.55	703.02	4.40	702.76

	1		2		3		4		5	
	width	**height**	**width**	**height**	**width**	**height**	**width**	**height**	**width**	**height**
a-b	4.48	-0.19	3.66	0.09	3.96	-0.06	3.55	0.06	4.40	-0.10
rht-lht	3.53	-0.09	2.18	0.13	1.92	-0.07	1.79	-0.16	2.07	0.03
rb-lb	1.70	-0.02	1.18	-0.02	1.68	-0.10	1.39	-0.02	1.63	0.09

(Cont.)

Point	6		7		8		9		10	
	width	**height**	**width**	**height**	**width**	**height**	**width**	**height**	**width**	**height**
a	0.00	702.61	0.00	702.54	0.00	702.29	0.00	701.98	0.00	701.72
Rht	0.52	702.51	0.96	702.43	1.47	702.23	1.48	701.99	1.70	701.60
Rb	1.88	702.31	1.19	702.25	1.82	701.96	1.78	701.88	1.99	701.43
C	2.64	702.28	2.13	702.11	2.47	701.87	2.44	701.82	2.75	701.38
Lb	3.18	702.31	2.99	702.17	3.04	701.88	3.06	701.84	3.42	701.42
Lht	3.37	702.50	3.41	702.52	3.67	702.15	3.57	702.01	3.79	701.59
b	4.45	702.58	4.25	702.54	4.56	702.38	4.57	702.13	5.05	701.66

	6		7		8		9		10	
	width	**height**	**width**	**height**	**width**	**height**	**width**	**height**	**width**	**height**
a-b	4.45	-0.03	4.25	0.00	4.56	0.09	4.57	0.15	5.05	-0.06
rht-lht	2.85	-0.01	2.45	0.09	2.20	-0.08	2.09	0.02	2.09	-0.01
rb-lb	1.30	0.00	1.79	-0.08	1.22	-0.08	1.28	-0.04	1.43	-0.01

For instance, just observing the table and reading the values for “Rht-Lht”, is possible to conclude that the stream presents the biggest width on Profile 1 and the smallest width on Profile 4, from head bank to head bank. The same analysis can be made for any parameter as well, either height or width. As the future measurements can provide comparable data for the same analysis, it will be possible to observe were erosion or deposition occurred, since those will be the phenomena which will induce measurable changes in the values collected in this first survey.

5.3.2. Calculating the sinuosity and comparison between the stream in 1946, 1982, 2010 and 2011

With ArcGis, a representation of the stream channels in 1946, 1982, 2010 and 2011 was made. The representative lines of the flows were created based on the correspondent ortophotos. They were combined on a single map to allow a comparison between them.

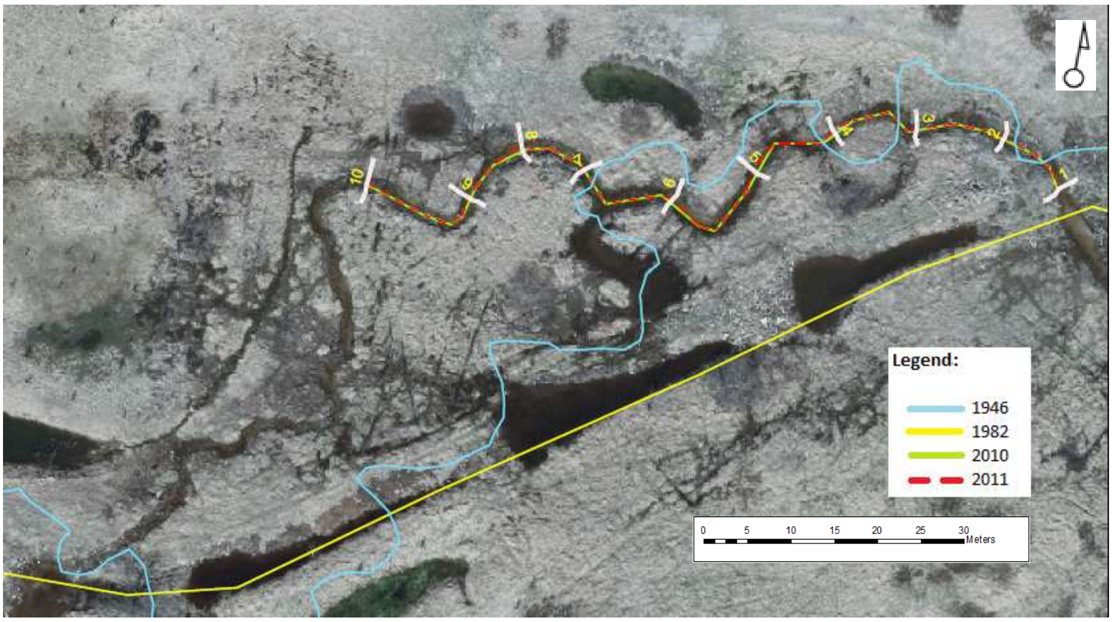

Fig. 33: Černý potok in 1946, 1982, 2010 and 2011

In Fig. 33, the phases through which the stream passed are well exemplified. The original stream, in blue, presents a high sinuosity, the straightened stream, in yellow, was located where now exists a cascade of pools (restored) and it is interesting to observe the differences between the restored channel and the original. From Profile 1 until the location of Profile 7, the restored stream is approximated to the original but from then on until the crossing of the old straightened channel, they follow quite different paths.

In this context, it was calculated the sinuosity of the different channels, with more detail for the 2011 channel. The sinuosity was calculated through the expression K=SL/VL, being SL the stream length and VL the valley length. Both parameters were calculated by ArcGis.

Table 6. Sinuosity in 1946, 1982 and 2010

Year	1946	1982	2010
SL (m)	150.23	83.2	97.04
VL (m)	75.65	75.65	75.65
K	1.99	1.10	1.28

Table 7. Calculation of the sinuosity for 2011

Profiles	1 to 10	3 to 10	4 to 10	5 to 10	1 to 6	1 to 5
SL (m)	96.14	77.59	67.14	55.83	54.13	40.30
VL (m)	74.93	59.27	50.17	41.59	41.70	33.02
K	1.28	1.31	1.34	1.34	1.30	1.22

In accordance to the map in Fig 33, in 1946 the stream presented a very high sinuosity, almost in the condition of tortuous meandering. In 1982, as expected, the sinuosity is close to 1 and in 2010 it increases again with the restoration for the value of 1,3, approximately, on the limit between a considered sinuous channel and meandering channel. As it is also possible to observe on the comparison map presented, the results in Table 7 show that the stream is more sinuous from on the second half of the surveyed section than on the first. The total sinuosity is the same calculated for 2010 because the bases for calculation must bethe same (ortophoto and DTM).

In fact, the small differences observed between the stream in 2010 and 2011 when both represented in the ortophoto could be measured, but the accuracy wouldn't be satisfactory, because while the only information of 2011 was provided by the cross section surveys, the information from 2010 is contained on the ortophoto and on the DTM, both integrated on the calculations associated to 2011. Therefore, the results for 2011 in what concerns to longitudinal profile, are a rough approximation to the 2010 data. This is the reason why, although calculated during the treatment of data, the distances between the central measured points of 6/6/2011 and the central point of the stream on the same section defined by the reading of the ortophoto, might not represent real differences and its inclusion on these document could originate the false idea of already having valid information about the migration of the channel.

5.3.3. Measuring the meanders

The goal of measuring the cross sections presented in 5.3.1 was to create a ground basis to assess the position and migration of the meanders. For that, it is necessary to determine the geometric parameters of the meanders. However, there are obstacles difficult to avoid with the established measurements.

The first obvious obstacle was that the cross sections surveys were conducted on the basis idea of collecting information every 10 meters of the study section, rather than on the peaks and the inflexion points of the meanders, the reference points to calculate the most of its characteristics. Therefore, the surveyed cross sections are not useful for this particular topic of the monitoring.

Another obstacle concerns the GIS potentialities, because with the ortophoto is sometimes hard to identify the meanders and to all the calculations with subjectively defined points can be associated a significant error, which can originate chain errors if the results aren't carefully used.

The second obstacle mentioned actually lead to the necessity of simplifying the first attempt to define the geometry of the meanders in study. It was tried to define the points which would represent the outer limits of the meander, in the adjacent bank, by reading the ortophoto, but the subjectivity and the uncertainty implied called for a different approach.

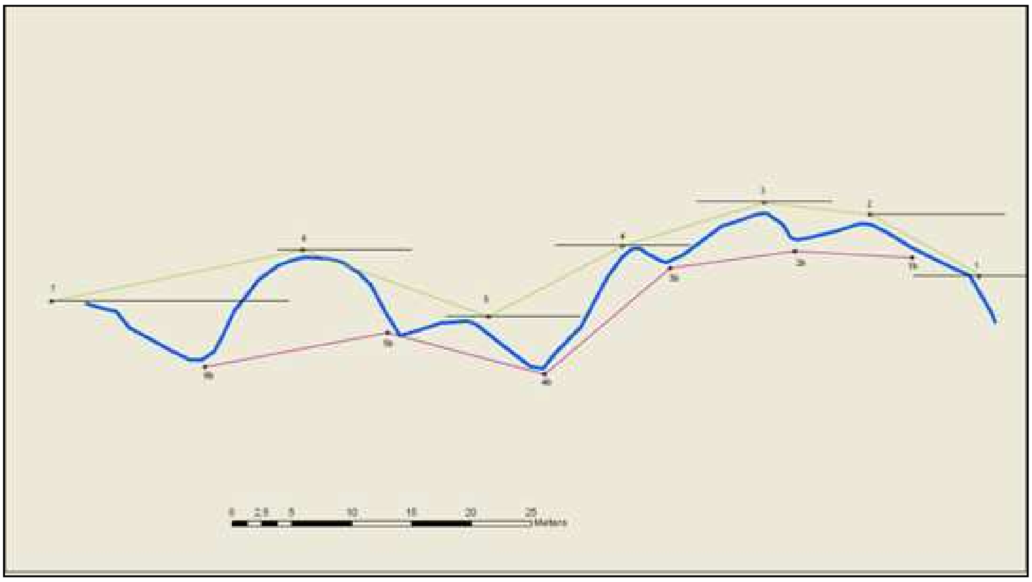

Fig. 34: Scheme of the first attempt to calculate the geometric characteristics of the meanders; the blue line corresponds to the central line of the stream created by drawing over the ortophoto of 2010; the yellow and purple limits were defined by joining the points which were marked on the ortophoto to represent the outer limits of the meander bend; those would be the references to calculate distances with the ArcGis measurement tools.

Because, in this case, only geodetic data can provide highly accurate results, it was decided to make only an academic measuring exercise, using the central line representative of the stream longitudinal profile to define the tangent lines to the meanders bends and to calculate the meanders belts. Due to the irregularity of the meanders and, in some sections, low sinuosity degree, it was only given focus to this parameter, being postponed for further works the measuring of the others geometric characteristics.

The section of study was extended downstream around 50 meters in order to incorporate one full restored section of stream beginning on the old straightened channel and finishing on the same channel, where possible phenomena of cutoff might occur. The section starts with small meanders, develops into bigger meanders and, finally, is again formed by smaller meanders until it reaches the old straightened channel. In Table 8 it is possible to observe this pattern, as the meander belt values, in meters, are smaller in the beginning, higher in the middle of the section and, again, smaller in the end.

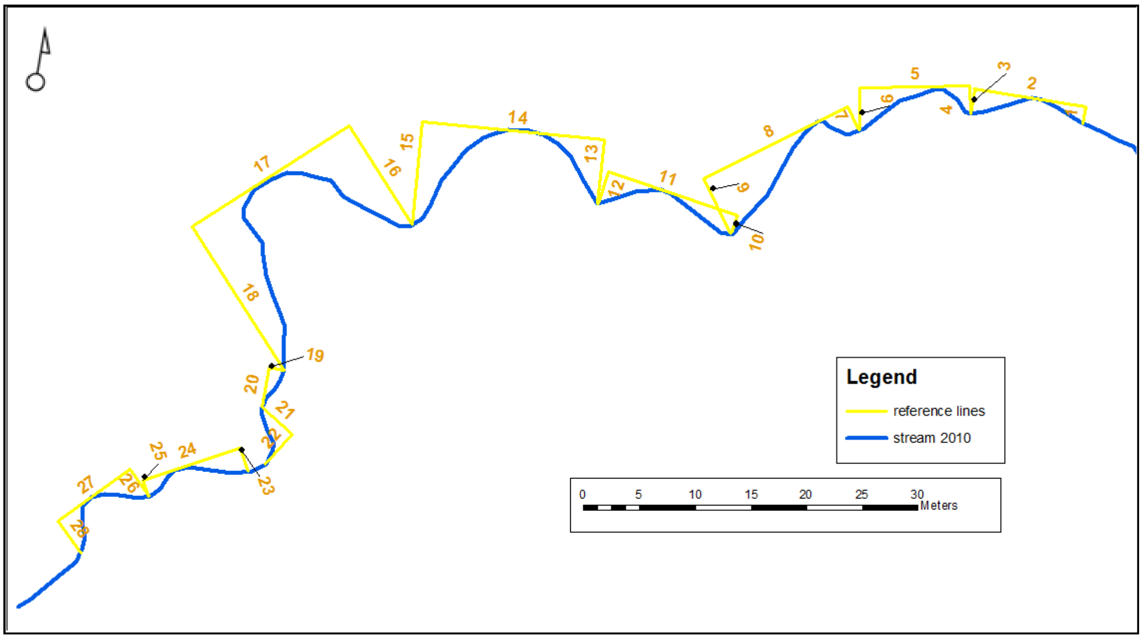

Fig. 35 : Representation of the reference lines for calculation of the meanders belts; the tangents to the meanders bends are guidelines and the other lines represent the actual meanders belts

Table 8: Values of the meanders belts

Meander (in the map, from left to right)	Reference number(map)	Meander Belt (m)
1	1	1.46
2	3	2.17
3	4	2.46
4	6	3.73
5	7	2.32
6	9	5.44
7	10	1.63
8	12	2.95
9	13	5.73
10	15	9.28
11	16	10.49
12	18	15.29
13	19	1.40
14	21	3.65
15	23	2.18
16	25	1.57
17	26	2.92
18	28	3.42

5.3.4. Discussing the meanders monitoring

An overview to the measurements conducted mainly point out the importance of a monitoring approach which can incorporate a flow velocity analysis, a sediments analysis and cross section geodetic surveys.

In what concerns to the practical work developed, the most unsuccessful topic was, probably, the sediment analysis, although the simple and clear presentation of results of the sieving might not show it at first. In fact, sieving is the procedure which can lead to the most unequivocal results in sediment analysis but its use must be well contextualized, because it is possible that the range of particles diameters covered by the sieves doesn't fully serve the goals of analysis, like in this case. On the other hand, the "pebble count" failed and the most known mathematical relations between flow forces, erosion rates and sediments size is based on the results of the that procedure. The biggest concern about the pebble count was that, although the results weren't accurate, they were plotted and analyzed as an exercise and they didn't seem to be exactly representative of the real stream material found on the features pool/riffle.

Thus, the discussion of these topics claims the need of a better understanding of the erosion and the deposition phenomena occurred in the analyzed meanders, which implies that the sediment analyses should be taken into higher consideration.

Addressing to the geodetic works and the GIS data treatment, these are two topics which in a combined application can potentiate maximum success for the monitoring goals. Although the cross sections surveyed were not completely adjusted to the meanders features which are important to be measured, as already explained, they can provide a simple direct observation of changes in a cross section and if a surveyed cross section is located on a key point of a meander, the phenomena of erosion and deposition can not only be graphically observed but quantified as well. Therefore, the suggested new localizations of the cross section surveys are on the peaks (the top key points) and inflexion points of the meanders.

One small detail could be added to the cross section survey: because this is a small stream and there is that possibility, also collect the data from the deepest point of the channel, in addition to the central point data or with its actual exclusion, to avoid having too much data. Nevertheless, the central point can also be an important comparison point when analyzing new measurements, so its exclusion should be well weighted.

For the data treatment in ArcGis, the possibility of having the accurate values of the outer limits of the meanders (and the correspondent complete cross section) offers the chance to calculate reliable results for the parameters which define the meanders geometry. Then, the values of these parameters can be compared with future measurements. Combining the calculated results, the cross section profiles and the map analysis, the meanders migration can be characterized and, in a period of years, probably also predicted. The proposed analysis also excludes the need to have constant recent ortophotos, because the representation of the new channel features would rely only on the accurate geodetic measures.

The next measurements are planned to be conducted 2 or 3 times per year, during the first years, and on the next measurement it is already expected to include the suggested corrections. Working with the new data shall provide an interesting comparison ground towards the first approach and the opportunity to test the efficacy of the proposed combination of methods.

6. Conclusions and Recommendations

River restoration is a complex field of study that requires the understanding of innumerous concepts from a variety of areas of Science, from Biology, to Hydrology or Physics, and a full commitment to every project and every restoration site addressed. To prove it is the fact that, although there is an abundant and extensive bibliography about river restoration, the personal experience on terrain ultimately dictates the specific needs of restoration and monitoring of the restoration project, as supported by several authors and by the experience with the Černý potok restoration project.

Concerning to the sediment analysis, it was settled the need of giving a better focus to this matter in order to better understand the processes of deposition and erosion which lead to meanders migration.

Referring to the cross sections surveys, they provide simple information which allows many comparisons and ratios calculation, but to monitor the meanders they should be performed at the meanders peaks and inflexion points, so that the phenomena of erosion and deposition can not only be graphically observed but also quantified.

The next monitoring should include a better sediment analysis, adjusted cross section surveys to the meanders peaks and inflexion points, should be linked to map observations and, as a complementary suggestion, the sections should be photographed in order to have a better visualization of the results (with a pedagogic purpose).

Apart from the developed work and as a closing note, it could add value to the project “Černý potok” a study with a Fluvial Information System (FIS) and a terrain survey with the already mentioned Laser Scanning.

Of significant interest for this area of research would be the efforts to assemble information to document the steps given on the searching for the best monitoring measurements, since the Černý potok example can be useful to the monitoring of other restoration projects.

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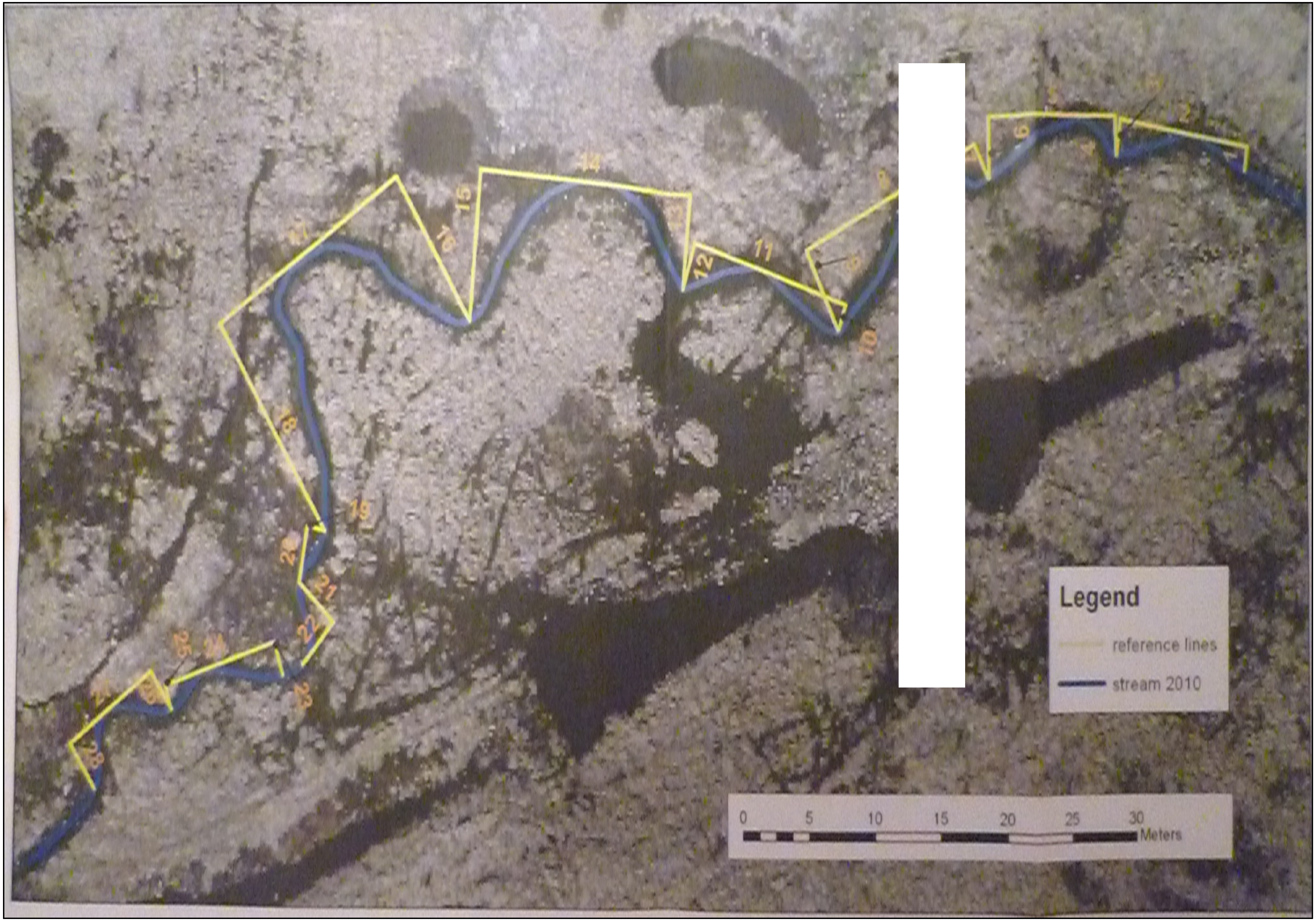
ANNEX 1 - Maps

a) **Reference lines to calculate the meanders belts**

b) **Černý potok in 1946, 1982, 2010 and 2011**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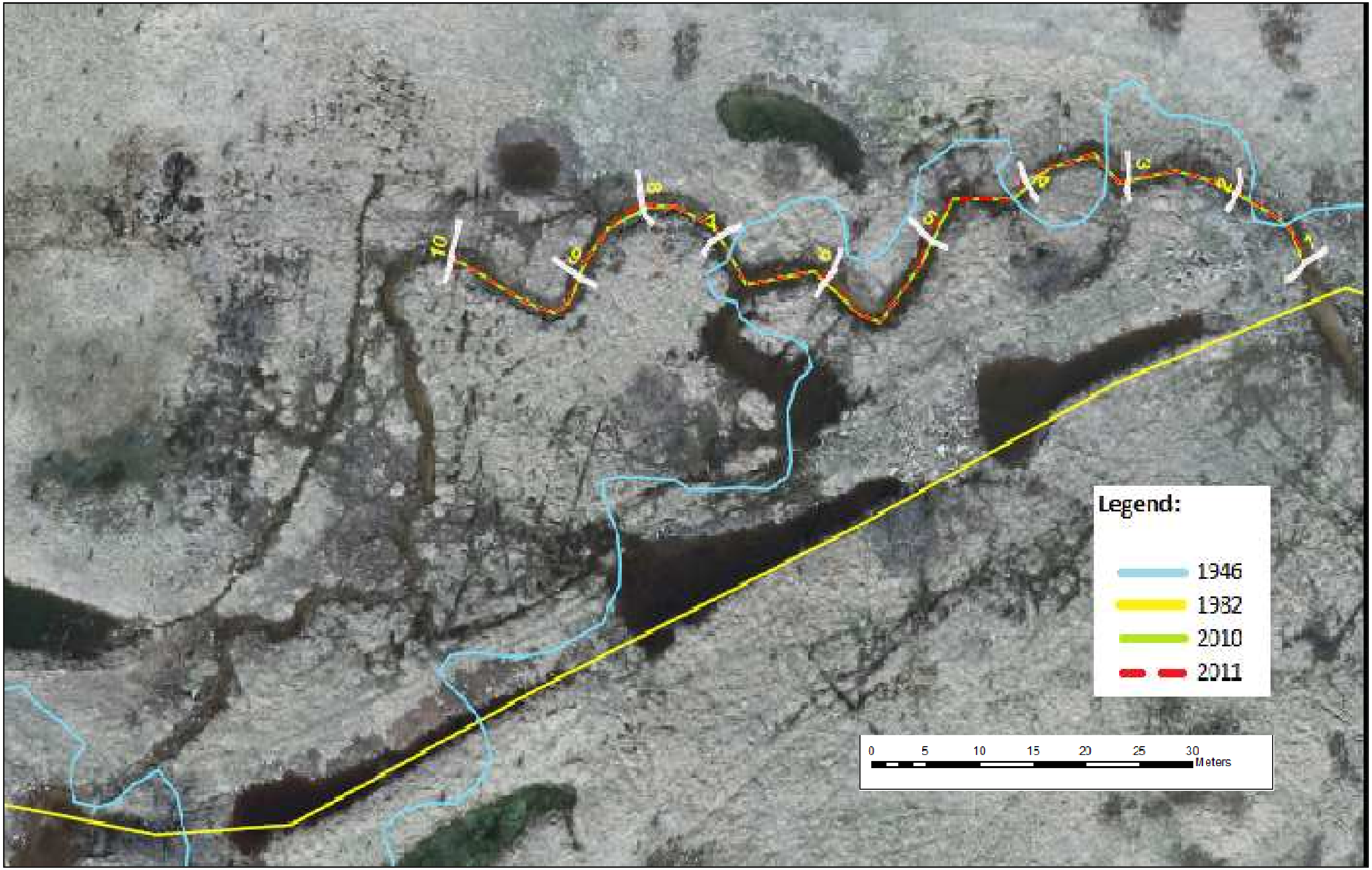
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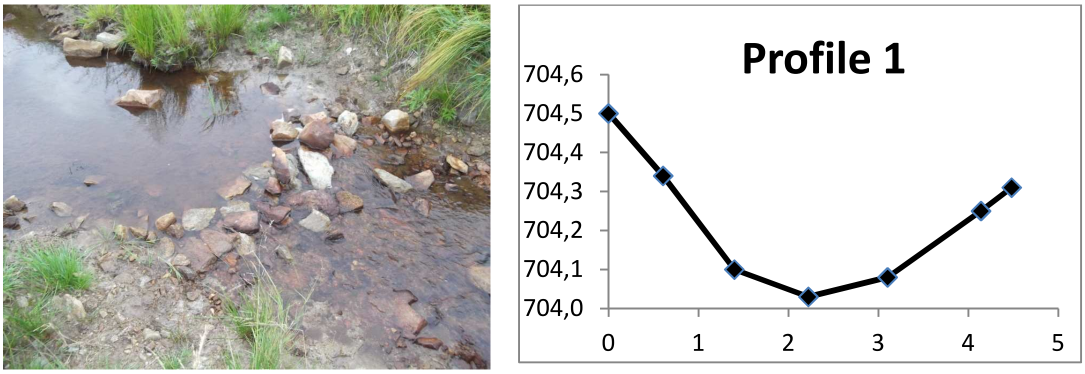
Legend:
1946
1982
2010
2011
0
5
10
15
20
25
30
Meters

ANNEX 2 - Sediment analysis

		Sand deposit			**Pool**			**Bank**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
	m (g)	100,0455	100,0237	100,0075	100,5571	100,3175	100,0474	100,0429	100,0036	100,0753
D (mm)	**10**	14,728	7,0169	22,3897	18,135	32,718	33,1360	18,198	19,4084	8,4759
	7,1	1,7673	3,45	10,3954	9,0916	1,8292	5,3769	9,4091	6,0579	7,0840
	4	27,2511	19,249	14,2032	10,992	6,3215	8,9780	11,1489	10,7107	14,2032
	2	32,4651	31,2505	24,4769	9,1982	6,0631	7,6365	11,0511	12,9983	16,6265
	1,6	7,0206	8,3358	5,8261	3,205	1,8512	2,2840	3,6337	3,6480	4,9014
	1,4	4,5995	4,3752	2,8184	1,4192	1,8519	1,7872	2,0455	2,7069	2,0963
	1	6,4156	8,4951	5,1989	5,1736	4,1043	4,2220	5,889	6,1643	8,2729
	0,5	7,6978	11,6174	7,3862	15,7945	12,4256	11,5353	11,7381	7,9430	9,2312
	0,315	2,5245	3,8151	3,0042	12,4796	15,2689	7,7059	6,0623	3,5065	8,5899
	0,1	2,0145	2,7974	2,9779	13,0147	13,9661	16,1889	17,5361	21,3872	19,0861
		106,484	100,4024	98,6769	98,5034	96,3998	98,8507	96,7118	94,5312	98,5674

ANNEX 3 - Cross section profiles



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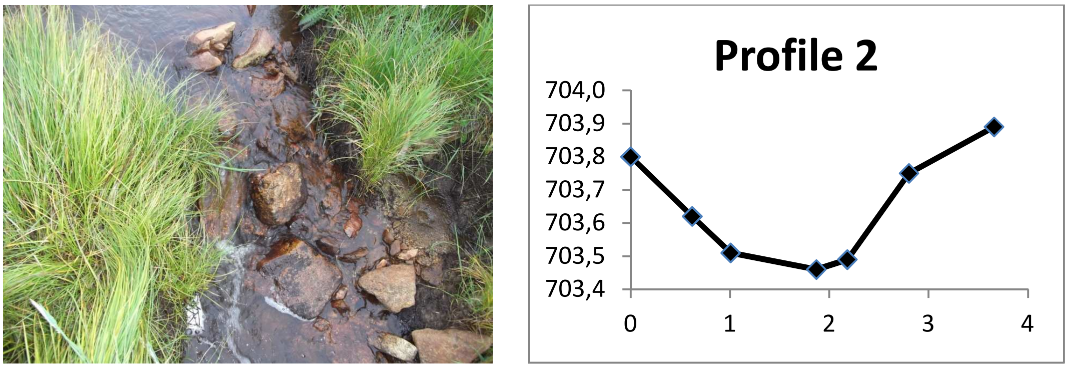

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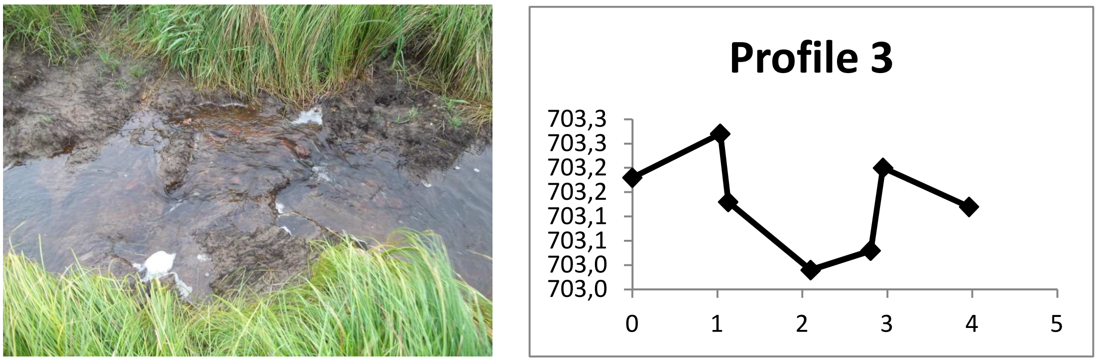

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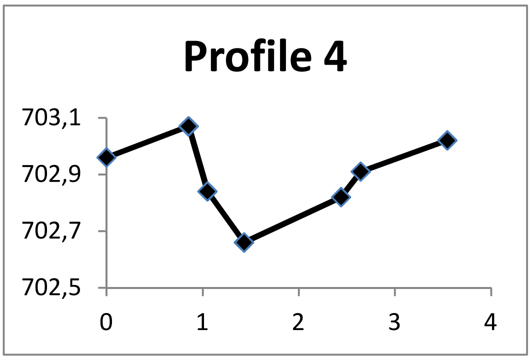

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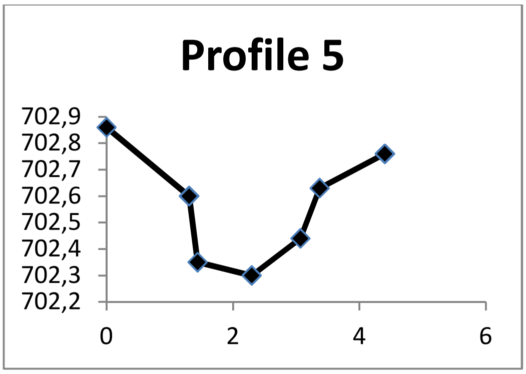

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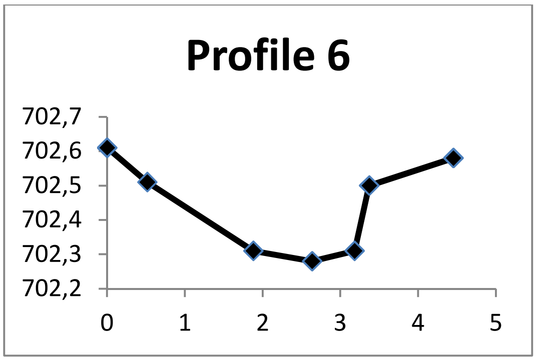

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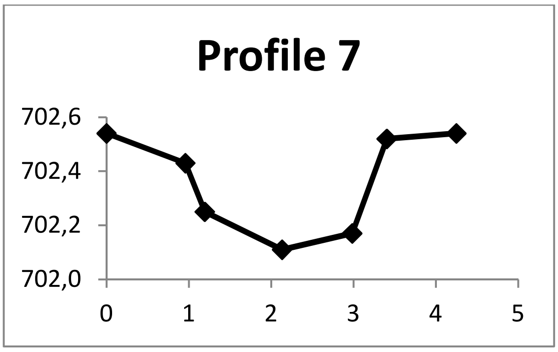

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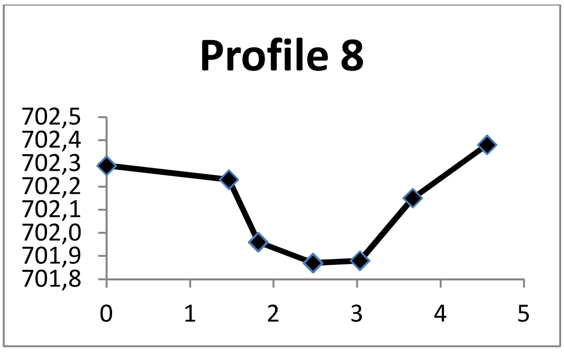
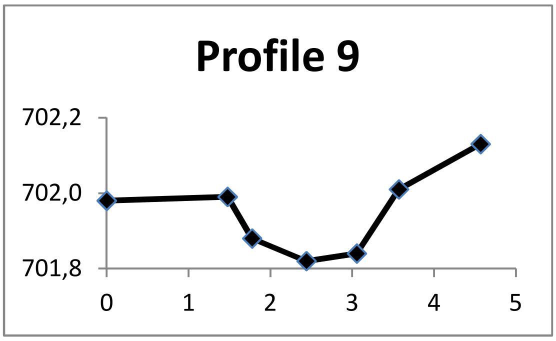
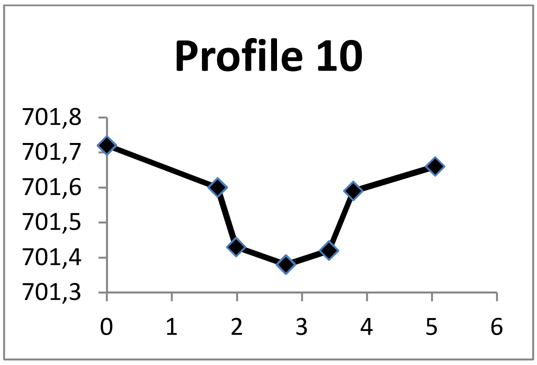


Profile 8



Profile9



Profile 10