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IMPACT OF HYDRAULIC SCHEMES ON OLT RIVER AND ON ITS FLOODPLAIN ENVIRONMENT IN CIUC DEPRESSION, HARGHITA COUNTY, ROMANIA

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Abstract

This paper presents the effects of regularization and embankment of the Olt River and drainage of its floodplain on the groundwater table from meadows and on the erosion base levels of tributaries within Ciuc Depression. The hydraulic works reduced the wetlands and had important impact on the aquatic flora and fauna of the river and its floodplain. Measurements and observations (before 1985 and after implementation of hydraulic works in 2008) undertaken upon the river, upon the drainage systems from the flooding area and their functionality underline the negative effects of these works on the environment and remedies were proposed. Upstream section of the regularized river (between Miercurea Ciuc and Sancraieni) presents erosions, dropping of the groundwater level, and inutility of drainage. On downstream section (Sancraieni-Tusnad) the silting processes of the river worsen discharge conditions of the drained water. The river section erosion, the lowering of water level in channel, overlaid with excessive drainage led to declining of groundwater table, which dries up peat layers, lead to an increasing frequency of the smoldering self-ignition in large peat areas. Due to peat burning the environment is affected by air pollution and total sterilization of soil by living organisms. Proposed remedies refer to the river bed bottom stabilization at the designed levels using thresholds, water level controllers within drainage systems and a new operating regulation.

Key words: drainage of the meadow, ground water table dropping, peat smoldering combustion, river regulation, riverbed erosion

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1. Introduction

Radical regularization of rivers involving new watershed, with reduced length (by righting the route, cutting the bends), increase of the general slope and decrease of the bed roughness due to shore protection, gabion walls and bottom leveling (ensuring gradually changes) essentially modifies the flow dynamic characteristics. These interventions increase the flow velocity and, through hydrodynamic processes, involve morphological changes of the riverbed (Băloiu, 1980). Stability of a riverbed is estimated based on the specific potential power of the current, according to Eq. (1) (Boariu et al., 2013; Brookes, 1988; Diaconu, 1999).

$$Ps = \gamma . Q . I / B \qquad (1)$$

where: Ps is the specific potential power (W m^{-2}), γ specific weight of water (N m^{-3}), Q - river discharge (m^3 s^{-1}), i hydraulic gradient, and B the top width (m).

The river flow considered in the calculations by Eq. (1) is that which fills the riverbed. The modified riverbed is stable for Ps <35 W/m^2 (without any consolidation works), tending to morphologically change above these values. For Ps>35 W/m^2 the

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riverbed remains stable only through consolidation works. For *Ps*> 100 W/m^2 the tendency of the water stream, without consolidation, is to return the modified riverbed to its original one.

In order to reduce the flooded surfaces within the floodplain, the river is embanked. Flood defense in the built up areas are for social and industrial facilities, railways and roads protection while in other areas are for land conversion to intensive agricultural exploitation and crop protection (Giurma, 2003).

Dammed water course stability is also assessed through the specific potential power of the fluid current (Eq. 1) with full minor riverbed. Instability of the minor riverbed imperil dikes. In this situation the riverbed has to be stabilized with consolidation works. For computation of these defense works, the maximum flow, with the calculation probability, together with the width B between dykes are considered. Protection against floods by damming interrupts the lateral connectivity of water bodies in the riverbed and floodplain.

Surface leakage from the floodplain and higher neighboring land are collected and discharged into the river (natural collector) by interception channels formed parallel with the dikes. They also operate for water infiltration interception through and under the dikes during high levels in the river (Giurma, 2003).

In order to achieve a favorable ratio of air / water in soils for crops, in the protected territories of the floodplain, drainage facilities, such as open, closed or mixed drains, shall be set. They carry out the assumed drainage time for crops. Thus, the artificial drainage and collection networks supplement the natural one which consists of the river and its tributaries (Blidaru et al., 2006).

Natural floodplain includes higher areas at the river bank and near the terrace, lower zones, such as old dead arms, backwater areas, wetlands and lands with high soil moisture, and those which allow the formation of certain types of soils (usually alluvial or clayish alluvial soils) depending on climatic and local conditions (Stătescu and Pavel, 2011).

In many cases, peat lands are frequently found in floodplains, which are important ecosystems for biodiversity, carbon storage and hydrological integrity (Joosten and Clark, 2002). Peat lands cover over 4 million km^2 (3%) of land surface and store one third of the existing carbon in the soil and 10% of freshwater resources.

Excessive removal of water in peat lands leads to their ignition, which is reported in tropical, temperate and boreal areas, e.g. in Southeast Asia (Page et al., 2002), North America (Frandsen, 1997), Finland (Pitkänen et al., 1999), UK (Bragg and Tallis, 2001; Maltby et al., 1990) etc. Smoldering of peat takes place at 250 – 500 ^{0}C and the advancement speed is 1-50 mm/h. It can be initiated by weak heat sources resulting from the transformation of anaerobic biochemical processes in aerobic ones, releasing volatile organic compounds, carbon monoxide and poly-aromatic hydrocarbons (Bertschi et al., 2003). Drained peat smoldering is a heat source; its spreading further within the soil reduces peat moisture and enables fire maintenance. For smoldering combustion there are three characteristic zones: the preheat – the drying of the peat by evaporation; the combustion, when pyrolysis and oxidation reactions occur with heat release; and the charcoal and ashes zone, when burnt materials cool (Rein et al., 2008). Combustion duration varies from days to months, years or even centuries (Varner, 2005).

Emissions from smoldering combustion of peat contain CO_2, CO, CH_4, C_2H_4, C_3H_6, aldehydes, acetic and formic acids, alcohol, nitrogen and sulfur compounds respectively (de Sousa Costa and Sandberg, 2004). The main mass of emissions is made of CO_2 and CO. The forest and peat smoldering in Indonesia in 1997, burned 790,000 ha of forest (730,000 ha peat) and released 0.19 to 0.23 Gt carbon in the atmosphere, that is 250 t/ha as average. Smoldering peat in Indonesia in 1997 was equivalent to 13-40% of the global emissions amounts of carbon from burning fossil fuel (Page et al., 2002).

The effects of uncontrolled peat burning have negative environmental impacts by: sterilization of soil, destruction of roots, seeds, plants, microorganisms and even some wildlife. Gas emissions are deteriorating air quality, and creating public health problems (Usup et al., 2004).

The objectives of the study refer to:

- study of natural conditions of the territory, of the designed hydraulic works and their characteristics at the moment when they were put into operation;
- behavior of hydraulic works (river regulation, embankment and drainage) during 23 years of operation;
- proposals for remedy: riverbed stabilization using thresholds, equipping of the drainage systems with level controllers, and interventions in regulations for design and operation of these land reclamation and river regulation works.

Methods used for the research:

- survey on the evolution of regularized river channel, its influence on the hydrogeological conditions of the floodplain (monitoring of groundwater level in wells, and observations upon the drainage systems functionality)
- mathematic simulation of hydraulic works impact on the groundwater table, calibrated using field observations (water level in wells, bordering river hydrographs, rainfalls);
- observations upon the drying peat layers, on their self-ignition, and monitoring the smoldering and air pollution;

2. Hydraulic schemes in the Olt River and its floodplain in Ciuc Depression

The Olt River regulation and embankment between Mădăraş and Tuşnad localities and floodplain drainage within Ciuc Depression came into operation in 1985 (Fig. 1).

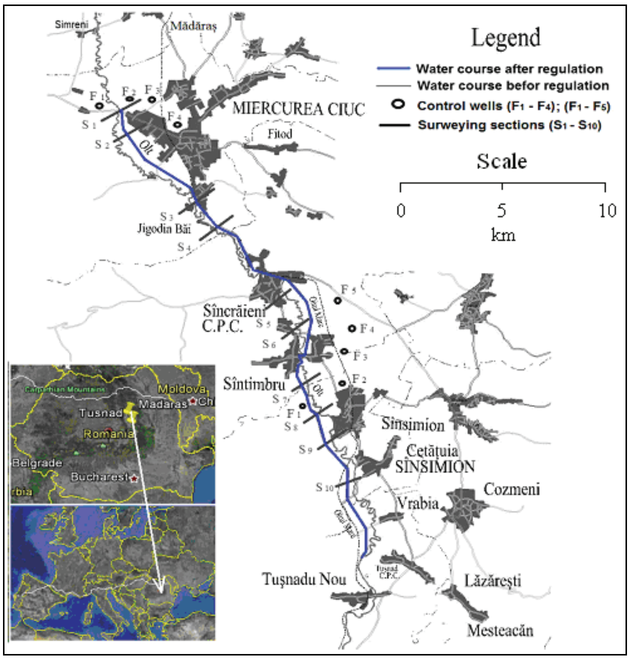


Fig. 1. The Olt River course before and after regulation, between Mădăraş and Tuşnad

2.1. Natural characteristics of the studied area

The studied area is located in Ciuc Depression, at altitudes between 637 and 780 m and is bordered by mountains over 1550 m high (Harghita, Hăşmaş and Ciuc Mountains).

The **landscape** is varied, set in steps, descending towards the Olt River Valley, comprising: mountains, pre-alpine hills, terraces and floodplains. The floodplain encompasses the meandered river, the shore bank, intermediate marshy areas with low elevation, then terraces. These landforms are fragmented by the river tributaries.

The **climate** is of mountain-type, sheltered one, typical for enclosed depressions, featuring annual average temperatures between 6 and 8°C, with variations on a range of 72°C (from -35°C to +37°C). The average annual rainfall is 602 mm, and the potential evapotranspiration 584 mm. The resulting yearly water balance is in an excess of 38 mm on average.

Soils formed in depression bioclimatic conditions are clayish alluvial soils and alluvial soils with groundwater table at small depth; the soil layer is thin (from 0 up to 60cm). They are formed on peat layers that sometimes are at the ground surface.

Geologically the floodplain consists of sandy clay, mud, sand, gravel and peat. The peat layer thickness is from 1.55 to 1.75 m; it is based on more or less permeable layers and it is covered by the soil.

From a **hydrogeological** point of view, the area is characterized by unconfined groundwater (sometimes at the ground surface) over one or more confined aquifer layers.

The river **hydrology** is characterized by the density of the flow net of 2.2 km/km^2 and flows with different characteristic probabilities given in Table 1.

Table 1. The Olt River characteristic flow rates (m^3/s)

Gauge station	***Frequency (%)***							
	0.1	0.5	1	2	3	5	10	50
Mădăraş	280	205	170	147	120	105	85	2.45
Sâncrăieni	290	210	180	150	125	115	90	4.76
Tuşnadu Nou	605	440	360	305	255	205	160	6.79

Daily average flow hydrograph at Miercurea Ciuc and Sâncrăieni gauge station for 2008 is presented in Fig. 2.

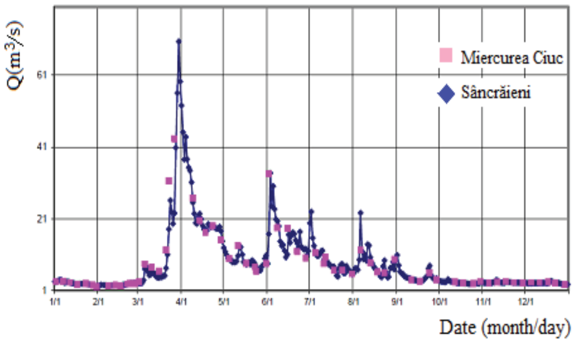


Fig. 2. Daily average flow rate on the Olt River

2.2. Hydraulic schemes in the Olt River and its Floodplain in Ciuc Depression

Regulation of the Olt River within Ciuc Depression consists of: a new riverbed between Miercurea Ciuc and Tuşnad, rectification of the cross section in the upstream sector, longitudinal slope correction and bank protection at the intersection with communications infrastructure. The new riverbed between Miercurea Ciuc and Tuşnad Ciuc shortened the river length by 34%, from 32.5 km to 21.5 km (Fig. 1). The slope of the river is decreasing towards downstream from 0.125 % to 0.06 %, and the Manning roughness coefficient is about 0.03.

The adjusted riverbed has a trapezoidal shape, with bottom width *b* varying between 10 and 20 m (Fig. 3a). In many areas the bed is consolidated (Fig. 3b): within built up areas, along intersections of roads, railways, and intake works. Elsewhere the riverbed was only calibrated. Riverbed conveys average monthly flow for 30 cm safety guard.

The total damming length within the river basin is up to 78 km; between the analyzed sections S1-S10 (Fig. 1) this length is 21.5 km. The dikes are at variable distance from the shore b_1 between 5 and 55 m, and are built for 5% exceeding probabilities in built up areas and 10% outside (Fig. 3). The longitudinal profile of the river channel bed between Miercurea Ciuc and Sânsimion (sections S2-S10) is shown in Fig. 4.

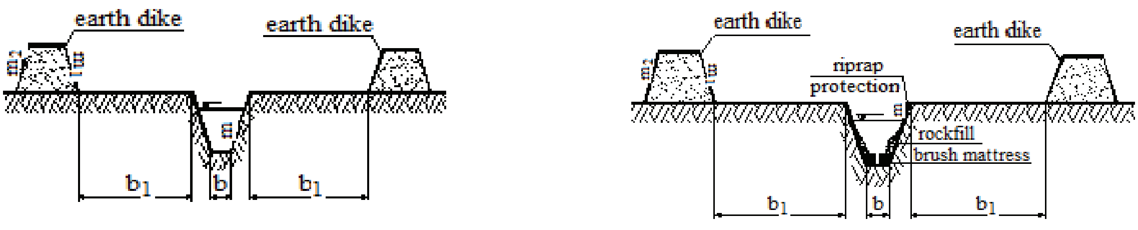


Fig. 3. The Olt River typical cross-section: a) regulated, b) consolidated

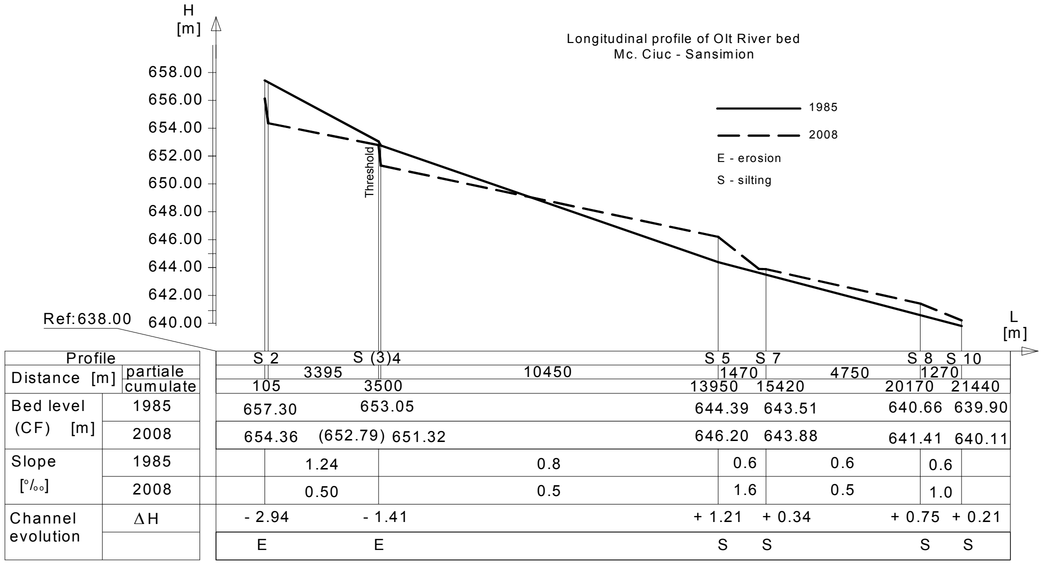


Fig. 4. The Olt Riverbed longitudinal profiles between Miercurea Ciuc and Sânsimion (S1-S10)

The drainage of the embanked floodplain is made of 13 systems, with open channels and closed drains (partly). Drainage channels have check valves only at their outlet. Single direction check valves are designed to protect the embanked floodplain from river floods.

2.3. Behavior of hydraulic works

The evolution of the arrangements characteristics from the entry into service (1985) and after 23 years of operation (2008) refers to: the regularized river bed, embankments and land drainage.

2.3.1. Regulated riverbed

Morphological stability analysis of settled bed between sections S2 and S3 indicates that the specific potential power is almost double than the value corresponding to equilibrium (Table 2).

The new unconsolidated riverbed (minor and major) is exposed to morphological changes shown in Figs. 3, 4, 5 and 6. In the analyzed sector of 21,440 m (Miercurea Ciuc - Sântimbru) there are bank and bottom erosions upstream, in a length of about 9300 m (Figs. 4 and 5), followed by bottom clogging and bank erosion (Figs. 4 and 6).

The erosion of the riverbed bottom has considerable values in the upstream section, between 0.0 and 3.0 m. In water intake sections (S1 and S3), due to erosion, the stabilization of the riverbed was necessary to ensure water level for capture rates. Stabilizing and strengthening the cross section after a few years of operation required the implementation of a concrete traverse (threshold). On a portion of the bed and shore, protection was made with stone pitching.

Table 2. Specific potential power of the regulated and embanked riverbed

Olt River (S2-S3)	*h (m)*	*B (m)*	*I ($^o/_{oo}$)*	*Q (m^3/s)*	*P (W/m^2)*
Full riverbed	3.1	25.45	1.25	132.5	63.9
At dikes level	4.0	40.34	1.25	206.0	62.6

This stabilization has been achieved in 1987 (Fig. 7). Due to excessive erosion of the banks, reinforcement with stone pitching (Fig. 8a) or gabions (Fig. 8b) was required.

2.3.2. Embankments

The embankments worked within the designed parameters, standing out against annual floods (Fig. 9a). They require ongoing maintenance works. Bridges are designed for limit conditions (Fig. 9b).

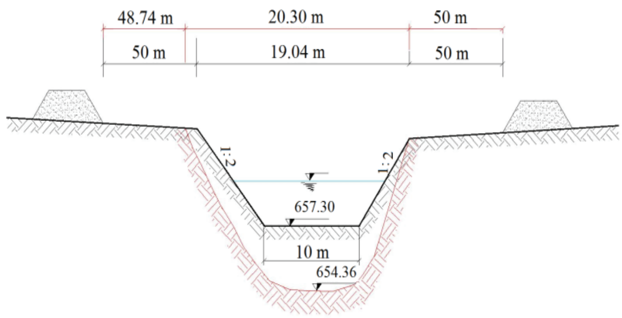


Fig. 5. Erosion of the riverbed in section S2

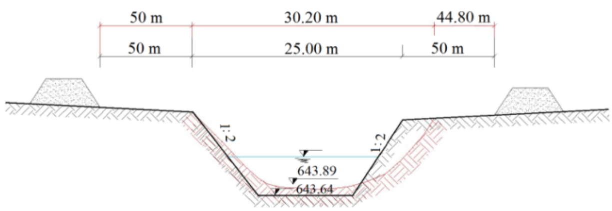


Fig.6. Deformation of riverbed in section S6

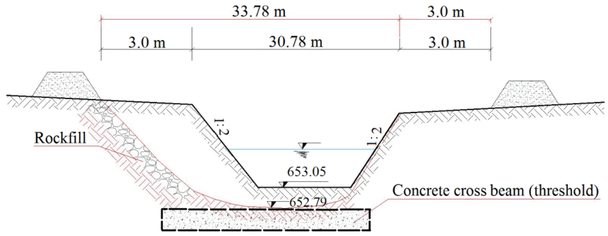


Fig. 7. Deformation and consolidation of the bed in section S3-S4

2.3.3. Land drainage

Drainage facilities were built simultaneously with the regularization and embankment of the river and functioned normally in the early years. After the riverbed erosion, groundwater level dropped and the floodplain drainage channels have lost their role; they collect excess water from surface runoff only (Fig. 10). These observations were demonstrated by simulating the dynamics of groundwater surface with the software package FEFLOW 5.1 for 1985 and 2008, for the period March 1 to October 31 (outside the frost season), along 243 days. An important result of the simulation is the groundwater level resulted in 6 sections of different lengths.

Fig. 8. Consolidation of bank a) with dry stone pitching; b) with gabions

Fig. 9. Flood on the Olt River in 2005 a) the behavior of dikes b) the limit size of the bridge

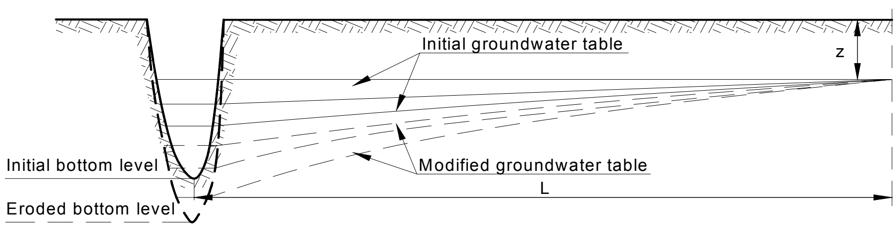


Fig. 10. Effect of the river hydrograph and bed erosion on the floodplain groundwater table

On Fig. 11 there are represented characteristic elevations of: the ground, the waterproof bed of the phreatic, the depth of channels (drains) and the groundwater level at the beginning, middle and at the end of simulation period. It is noted that in 1985 the drainage systems collected surface runoff and contributed to lowering of the groundwater table (their drainage role). Channel depth was below the water table (Fig. 11a). In 2008, in consequence of riverbed erosion and excessive drainage, groundwater level dropped below the bottom of the drainage channels with 50 ... 80 cm approximately (Fig. 11b).

Overall, in 23 years of operation due to the riverbed erosion (upstream Sâncrăieni), groundwater levels dropped on average between 0 and 70 cm. In river sectors with clogging (downstream Sâncrăieni) worsened the drained water discharge conditions.

3. Environmental effects of hydraulic arrangements

Hydraulic works in the Olt River in Ciuc depression have many effects on the natural environment and different socio-economical aspects, some positive and some negative.

3.1. Positive effects

By regulation and damming of the Olt River the risk of flooding decreases throughout the floodplain. Drainage facilities within the dammed area create conditions for conversion of land use (from meadows, pastures, marshes, wetlands to arable). All this leads to an improved quality of life.

3.2. Negative effects

Regulating the river without building elements for forced stabilization of the new water course leads to dynamic instability of the bed, possible changes in morphology (tendency to return to the initial slope conditions, route etc). The bed erosion is occurring upstream, and clogging downstream.

Erosion in depth of the riverbed jeopardizes intakes, lowers the floodplain groundwater table, increases erosion on tributaries (by lowering the base level of erosion), damages the banks and, sometimes, endangers the dykes. Clogging downstream involves silting on tributaries and increases the flood risk. The discharging of the drainage systems is partially compromised.

Radical regularization of the riverbed changes the wildlife habitat (feeding, resting, shelter and breeding). Some of the ichthyofauna species disappear or become rare, others proliferate.

Damming breaks water bodies' connectivity from the riverbed and floodplain, eliminating breeding habitat of some fish species. Embankment and drainage reduce the wetlands surface and have important impact on the aquatic flora and fauna of the floodplain. Only a few protected wetlands (marshes) are maintained in contact to the river (Table 3) (Darvas, 2011; Ghinea 2012).

The area of the meadow occupied by trees, consisting of *Quercus robur, Ulmus laevis, Plopulus nigra, Salix fragilis white, Viburum opulus, Eunonymus Europeans, Cartaegus nigra* was drastically reduced.

Hydrophilic herbaceous vegetation consisting of *Scirpus, Typha, Phragmites, Carex hirta, Iuneus spinosa, Juncus effuses, Agrostis canina, Agrostis alba stolonifera, Cala magrostis villosa, Alopecurus pratensis, Descharusia caespitosa, Molinia caerulea* was replaced with wheat, rye, barley, oats, flax, hemp, potatoes, sugar and fodder beet, but leaving large areas covered by grasses and perennials.

In the protected ecosystems (from Table 3) vegetate 16 glacial relicts such as: *Saxifraga hirculus, Drosera angelica,* 4 species protected by the Berne Convention and 19 species on the Red List, as: *Drosera rotundifolia, Marsh epipactis, Orchis laxiflora* and rare species *Fritillaria meleagris* and *Trollius europeus*.

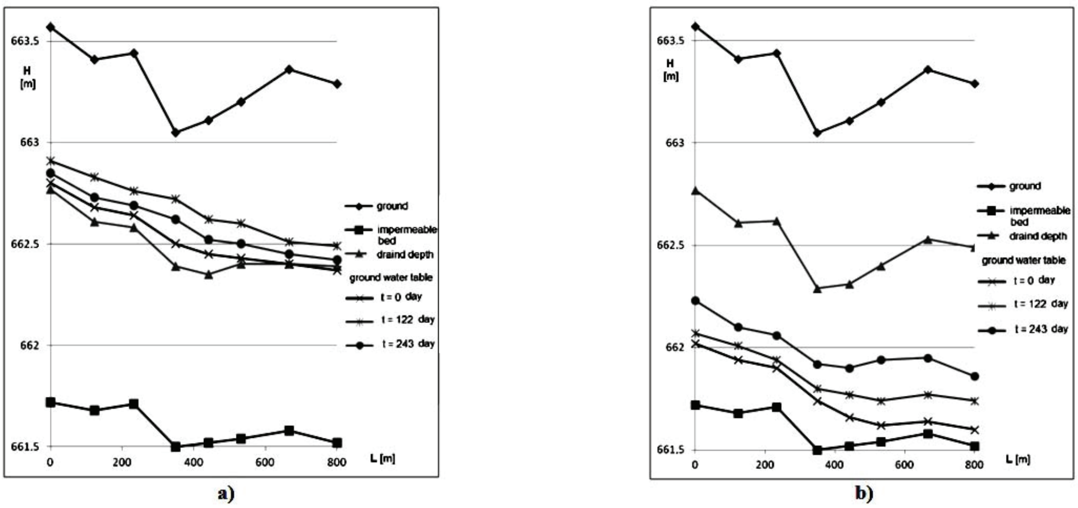


Fig. 11. Characteristic levels and phreatic head along section 3-3, a) 1985, b) in 2008

In ichtyologic terms the river is characterized by *Cottus globioPhoximus phoximus, Barbatula barbatula, Barbus petenyi, Globio globio, Albumoiles bipunctatus, Carassius Carassius, Aspius aspius*. Species as *Squalius cephalus* and *Perca fluviatilis* are expanding, but *Carassius auratus gibelio* and *Salmo trutta fario* are decreasing.

Rare birds in the area are: *Crex crex, Cioconia cioconia, Cioconia nigra* and *Aquila pomarina*. Bird migration routes on the studied area (Central-European-Bulgarian or Russian-Adriatic Sea routes) are crossed by: *Anser sp., Anas sp., Tringa sp., Calidnis sp., Charadrius sp., Vanellus Vanellus*.

Amphibians are represented by *Bombina variegate, Hila arborea* and *Rana temporaria*.

Quoted salamanders and reptiles are: *Triturus cristatus, Lacerta agilis, Natrix natrix* and *Natrix tesselata.*

Riverbed invertebrates are *Vertigo moullinsiana* and *Vertigo angustior*.

Insects are the *Antisoptera.*

Water Mammals are *Lutra lutra* and *Castor fiber* (recently restored).

Table 3. Groundwater in contact to surface water on Olt River in Ciuc Depression (ROOT01)

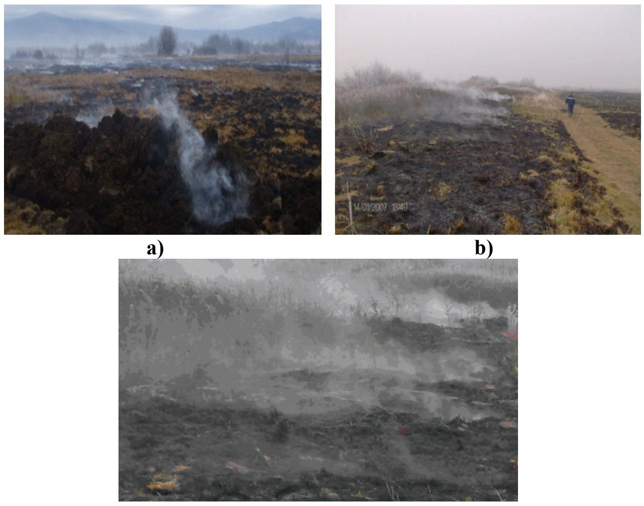
Terestrial ecosistem	***Area (ha)***
Marsh Csemo-Vrabia	5
Marsh Nyirkert	4
Marsh Borsaros - Sâncrăieni	1
Marsh a Benes	4

Drainage channels, poorly equipped with means for adjusting the water level, quicken water collection and discharge into the emissary. The overlapping influence of the new riverbed erosion with that of drainage on water table descent rates, dries peat lands, turns the biochemical processes of these layers from anaerobic to aerobic, and finally, increases the risk of smoldering the peat. Peat burning was reported from Ciceu, Remetea, Sicureni, Joseni and other locations on several hectares almost every year (Figs. 12 and 13).

Before 1987 peat burning was not present in the area; it began when the groundwater level decreased, which happened after a few years of operation of the hydraulic works. The increasing content of CO, benzene and NH_3 pollutants in the atmosphere at Miercurea Ciuc in October-November 2011 are shown in Figs. 14, 15 and 16.

a) b)

Fig. 12. Burning peat at Ciceu (a-2007 b-2011)



a) b)

c)

Fig. 13. Burning peat: a) Ciceu (2007), b) Joseni (2011) and c) Sicureni (1995)

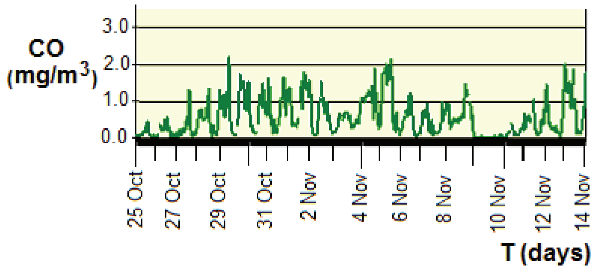


Fig.14. The concentration of CO

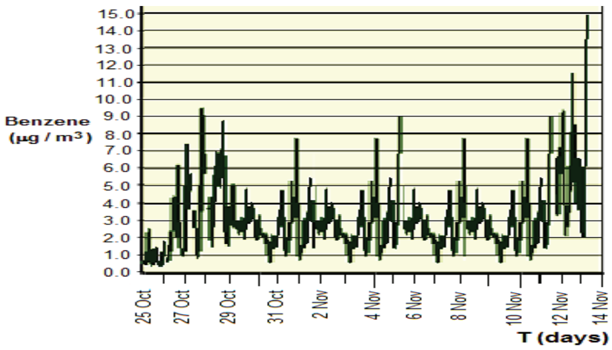


Fig.15. The concentrations of benzene

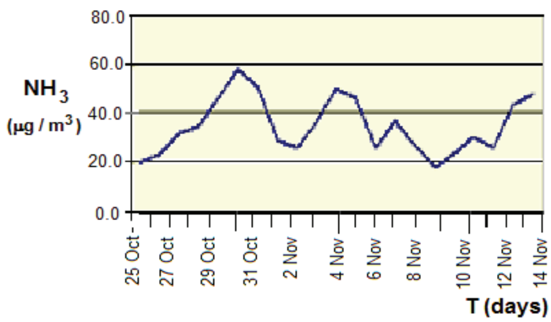


Fig. 16. The concentrations of NH3

Although the air pollutants did not exceed the admissible limits at Miercurea Ciuc, their increase was felt since 17.10.2011, when the last peat burning from Ciceu began. Peat smoldering at Joseni and Ciceu in 2011 lasted for one month.

Air quality monitoring data in 2011 has been registered by the Office of Environment Protection and Water Management System of Harghita County.

4. Conclusions

The hydraulic arrangements within Ciuc Depression, i.e. the radical regulation of the main river course, the embankment and the drainage facilities, had considerable effects on the environment in the area, both positive and negative. The possibility of flooding diminished, the wetlands and areas with excessive soil moisture turned into lands with higher efficiency use. The radically regulated riverbed presents high instability, with considerable morphological changes of the channel (erosion, clogging).

The river sections with erosion, the lowering of water level in the channel, overlaid with excessive drainage (systems poorly endowed with level control equipment) led to the groundwater table lowering, drying of peat layer and increased smoldering frequency.

Radical regulation of the riverbed essentially modified fauna and flora habitats having important effects on the species. Embanking and draining within floodplains considerably reduced wetlands, with multiple effects on the environment. Restoring is difficult, expensive, and it would only solve the above mentioned problems partially. It consists of:

- stabilization of the longitudinal profile of the Olt River at designed values by achieving transversal beams (thresholds), chutes, combined with bottom and shore protections;
- providing the drainage systems with equipment to regulate the groundwater level;
- the development of operating rules for hydraulic works in order to maintain the groundwater at required levels.

Acknowledgements
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