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Sediment transport in large watersheds in the Czech Republic

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Sediment transport from agricultural land into rivers and reservoirs remains reasonable problem within the Czech Republic. During the collectivization period (around 1955) the landscape pattern was destroyed and intensive agricultural production was started in many regions. Erosion problems were largely escalated and in many reservoirs the water quality is highly affected from then by sediment transport and pollutants of agricultural production. Many silted reservoirs have problems with the storage capacity reduction and intensive euthrophysation during summer seasons.

For erosion assessment at larger scale, robust and simple modelling tools are needed. As a typical example USLE (Universal Soil Loss Equation by Wischmeier&Smith, 1978) is commonly used in the Czech Republic for many years at a plot-scale but modern GIS tools allow us using it (after a proper calibration) at larger scales. The calculation is then completed by SDR (sediment delivery ratio as proposed by Williams, 1977) of the watersheds and reservoir trapping efficiency (TE by Brune, 1953) implementation into the river (catchments) network scheme. SDR usage means lumped approach for catchments scale (of various sizes) but yet there was no better approach for large scale assessment available. There is Watem/SEDEM distributive model tested these days (VanRompaey et. al, 2001) as a possible more detailed approach. USLE&SDR method is generally validated for several catchments in the Czech Republic of up to 100 km^2 (Krasa, 2004). The map of soil erosion rates and sediment transport within the 4th order catchments (according to Czech standards) was also calculated in frame of previous research. Here, an application of described approach for about 1600 km^2 watershed size is presented, together with linkage of the stream network and sedimentation in all major reservoirs of the catchments calculation – the sediment is driven through the whole watershed and total amount of sediment trapped in the outlet reservoir (in its 64 years existence) of the watershed is estimated.

Brno, situated in South Moravia, is the second largest city of the Czech Republic. Above the city large reservoir was built on Svratka River in 1940 as a water source for Brno inhabitants and for several other purposes (e.g. recreation, flood protection etc.). The reservoir storage capacity is 18,400,000 m^3, its area is 259 ha and its watershed size is about 1584 km^2. There are many problems with the reservoir's water quality due to euthrophysation last years. There is another large Vir Reservoir (with storage capacity of 47,856,000 m^3) situated in upper part of the watershed. This reservoir was built in 1955 and according to Brune curves it cuts 95% of the sediment coming from northern part of the catchments (410 km^2). The whole Brno Watershed consists of 145 4^{th} order catchments and there is about 620 smaller reservoirs (in volumes from about 200 to 500,000 m^3) considered for the calculation. Moravian (catchment's) countryside is rather hilly (falling from Czech-Moravian Highland to south Moravia lowlands), highest altitude of the watershed is 832 m AMSL (northern part), average height of the watershed is 531 m AMSL and outlet is 220 m AMSL. Average precipitation is about 650 mm.$year^{-1}$ in the catchments. Northern hilly part of the watershed is mostly covered by forests and pastures, while there is much more arable land in middle and southern part. Total land use categories percentages (based on GIS land cover map) are: 38.83 % of forests, 24.07 % of grassland and fallows, 30.83 % of arable land, 5.55 % of built up areas and 0.72 % of reservoirs.

For the calculation following layers were prepared (fifteen meters grid size was used for sediment transport assessment as appropriate to the sources accuracy). DEM was prepared by Conic interpolation using PCI Geomatica routine, based on 1:25000 digital vector contour maps with contours' interval 5 m (Czech Military Institute of Cartography). Land Cover map was compiled from several available sources. All the layers were spatially registered according to commercial Landsat Land Cover Map of the Czech Republic available with 15 meters resolution. As a basic layer for identification of forests, agricultural land, main reservoirs and urban areas the original 190/25 Landsat ETM+ scene (bands 1, 2, 3, 4, 5 and 7) from September 2000 was used. The total database of streams and reservoirs was taken from official Czech Water Management Maps in 1:50000 scale. The vector database was basically edited to correspond with Landsat image. Then for definition of separate fields and cultures (e.g. pastures vs. croplands) vector database LPIS (Land Parcel Identification System from the Ministry of Agriculture) was used. Supervised classification and source layers combinations were applied to prepare final Land Cover map in 15 m resolution. Soil map was taken from official detailed Bohemian database in scale 1:5000 (Research Institute of Ameliorations and Soil Conservation in Prague). Forest areas (not covered by the detailed database) were taken from 1:200,000 generalized soil map.

As described above, the sediment transport assessment within a watershed is solved in three major steps. First – erosion rates are calculated using USLE and raster based GIS layers. Average annual soil loss ($t.ha^{-1}.year^{-1}$) by USLE is calculated as: A = R.K.L.S.C.P, where R is rainfall erosivity factor ($MJ.cm.ha^{-1}.h^{-1}.y^{-1}$), K is soil erodibility factor ($t.h.MJ^{-1}.cm^{-1}$), L is slope length factor (-), S is slope steepness factor (-), C is crop management factor (-), P rates erosion control practices (-). Most factors' values were accepted from official catalogues recommended for the Czech conditions by Research Institute of Ameliorations and Soil Conservation Prague (Janecek et al., 2002). R factor map was prepared based on revised R factor map of the Czech Republic published (Dostal et. al, 2004). There is a lot uncertainty about actual rain erosivity values in the Czech Republic. Values close to 20 $MJ.cm.ha^{-1}.h^{-1}.y^{-1}$ were recommended and used for many years in the Czech Republic (probably without deep calibration) but new research reveals much higher values. According the research in Brno watershed the values vary between 36∼68 $MJ.cm.ha^{-1}.h^{-1}.y^{-1}$. K factor was prepared by direct classification based on the soil map. It varies from 0.16 to 0.67 $t.h.MJ^{-1}.cm^{-1}$ on agricultural land. Morphologically oriented software USLE2D (Desmet&Govers, 1996) was used for evaluation of topographical factors LS, based on DEM and land-use map. Average annual C factor 0.005 was assumed on permanent grass-land. Average annual values of C factor on arable land were derived from average crop rotation obtained from catchment's farmers. 16 important agricultural producers from the catchments area were successfully contacted (they cultivate about 32% of total arable land of the catchments representatively). From their information, approximate maps of arable land C factor values for three significant periods of Brno reservoir history were prepared. Three major crop rotation schemes were presumed in following periods: 1940∼1954 (small family farms), 1955∼1990 (parcels aggregation, intensive animal production in large socialistic cooperative farms managed by state), 1991∼2004 (new profitable plants in trade competition). The average annual C factor values of the resulting maps varied between 0.114∼0.375 (for average crop rotations) on arable land. No special erosion control practices are known within the catchments so factor P was not included. The maps of average soil erosion rates (in 15 m resolution in $t.ha^{-1}.year^{-1}$) for the three mentioned periods were created by the layers multiplication. Information about total erosion rates within the 4^{th} order catchments was then obtained from these sources.

As the second step – SDR value of every watershed is based on its area (km^2), relief ratio ($m.km^{-1}$) and average runoff curve number value (CN, Williams, 1977). This is a lumped approach, but can be improved by division of the catchments to smaller watersheds and preparing the outflow scheme. Here 145 sub-catchments (4^{th} order catchments according to Czech standards) were processed to make a transport scheme so the SDR value was derived for them all. Sediment input into the streams within each sub-catchment (defined as sediment yield) is then obtained by multiplication of total erosion value and SDR.

For each sub-catchment total sediment input from upstream was counted up with the sediment input within the sub-catchment (sediment yield). In every sub-catchment the representative trapping efficiency (TE) of the reservoirs was calculated by Dendy's algorithm for Median Brune Curve (Brune, 1953; Dendy, 1978). The proper part of the sediment was then reduced by TE with respect to the sub-catchments connectivity and with consideration of the reservoir's position within the catchment and on the stream. For obtaining the TE values the average annual flow rates in every sub-catchment's stream and the reservoirs' capacities had to be estimated. These values were taken from available databases and interpolated for other positions at the streams.

The built up scheme then helped us to estimate the cumulative sediment flow through the catchments and average annual sediment input into Brno Reservoir for the three different periods. Total sediment input was then calculated by counting up all the periods' volumes. Except total sediment amount within Brno Reservoir estimation other aims were reached. The most endangered areas of the watershed (considering soil erosion) were localized, the most important sediment contributors (4^{th} order catchments) were defined and sediment volumes within all reservoirs of the catchments were estimated. According to the calculations, there is about 4,150,000 m^3 of the sediment trapped in Brno Reservoir, that means about 22% of the storage capacity reduction. This value is not verified by measurements yet, it is one of following steps of the research programme. Definitely sediment transport is important problem for the reservoir function and water quality as proved to be true in past years.

Presented approach was roughly verified on several measured outlet reservoirs in the Czech Republic (Krasa, 2004) for different watershed sizes (up to 100 km^2). The methodology was not used for such complicated catchments' scheme and for area of more than 1500 km^2 yet. So the result has to be taken as estimation where the relations between contributing areas and definition of endangered areas are definitely more relevant than absolute sediment volumes. Next step is to complete the verification by measurements of the sediment volumes in important reservoirs of the catchments and compare these with estimations. Also the definition of endangered areas gives us the possibility to realize scenarios of land cover changes in pre-selected areas and its efficiency for sediment transport reduction. From comparison of estimated sediment volumes in all retention ponds in the catchments and the main reservoirs becomes clear that importance of small ponds for total sediment transport reduction is minor comparing to efficiency of strategically placed reservoirs on main streams. Nevertheless definitely reasonable land management policy is necessary for Moravian areas with highly unstable loessial soils.

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