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# MODELING SOIL EROSION USING EPIC SUPPORTED BY GIS, BOHEMIA, CZECH REPUBLIC

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*The Environmental Productivity Impact Calculator (EPIC), a complex semi-empirical environmental model with distributed parameters, was used to estimate water erosion on 18 fields of a small (1.42 km$^2$) agricultural catchment called Cernici in a foothills region of Central Bohemia, Czech Republic. Some input data for EPIC (areas, elevations, lengths and slopes) and the field-to-field sediment delivery ratios were prepared using a Geographic Information System. Average erosion rates predicted by EPIC were highest in May to September if the Uniform Soil Loss Equations (USLE) was used. The MUSLE (modified USLE) and AOF (Onstead-Foster method) also showed high erosion rates in December-January. The largest simulated soil erosion rates were found on a few ploughed fields on which crop rotation prone to erosion combined unfavorably with high field slopes and highly erosive weather. A change of crop rotation helped reduce the erosion.*

## INTRODUCTION

The degradation of water resources is an important issue world wide, and most often relates to the capturing and transport of pollutants by water. From a practical point of view there are two distinct types of water pollution in a catchment: (i) point source pollution which is associated with industries, municipalities and large farmyards, from which the pollutants are discharged to natural waters at a point like a pipe or a ditch, and (ii) non-point source pollution which occurs over a wide area and is usually associated with land use activities such as agricultural cultivation, grazing, and forest management practices. Agriculture is often considered the largest contributor to non-point source pollution of both surface and subsurface water systems.

The factors influencing non-point source surface water pollution include soil erosion and sedimentation and erosion of stream banks, washing out of nutrients and organic material from livestock wastes and agricultural land, and storm runoff from urban areas and atmospheric deposition. Adsorption to the surface of sediment particles provides a mechanism for transport of many contaminants derived from agricultural fertilizers, pesticides and industrial waste. Deposition of sediments carrying such load in the channel or on the flood plain can have detrimental consequences for ecology and agriculture. The sediment released into the river system can promote channel instability and cause bed degradation. The deposition of sediments reduces reservoir capacity, promotes upstream flooding and leads to abrasion of turbines (Bathurst et al., 1991).

The Geographic Information System (GIS), a technology designed to store, manipulate, and display spatial and non spatial data, has become an important tool in the spatial analysis of factors such as topography, soil, and land use/land cover. GIS provides a digital representation of the catchment, which can be used in hydrologic modelling. It is used to estimate the parameters that enter the hydrological models by analysis of terrain, land cover or other features. The land surface slope, land use and soil characteristics can be extracted using this technique. Except for a few cases, GIS has usually been employed separately in its own environment, uncoupled from soil erosion models requiring the modeler to exchange data between them manually. This approach has been applied in this study.

The Environmental Productivity Impact Calculator (EPIC) model and GIS software (ARC/INFO and IDRISI) were applied in this study to a small experimental agricultural catchment, called Cernici, located in Bohemia in the Czech Republic. Soil erosion and erosion control became important issues in the Czech Republic during the last few decades when unsustainable management practices became widespread such as creating and cultivating large fields, irrespective of limitations imposed by the terrain, and growing crops prone to erosion (such as maize for silage) on a large scale in foothill regions. These trends have not yet been fully corrected, even though agricultural production has dropped, the fields have become on average smaller, and public awareness of the of erosion control problems has increased.

## THE STUDY AREA

The catchment is located in Central Bohemia, Benesov district, within a foothill zone of the Bohemo-Moravian Highland. It belongs to a geomorphologic unit called “Vlasim hilly country”. The catchment recipient is drained by a small unnamed stream about 1800 m long. The name “Cernici” was given to the catchment according by a small village located downstream. The total area of the catchment is 1.42 $km^2$ and its altitude varies between 465 and 520 m a.s.l. Its shape is oblong, elongated in the north-south direction.

## MODEL INPUT PREPARATION

Large amounts of different types of data are required to run the EPIC model. Some of the data, were obtained in tabular form from the Research Institute of Soil and Water Conservation, Prague-Zbraslav, Czech Republic. Some other data, representing various characteristics of the catchment like land use, soils and elevation, were obtained from the same source as maps or digitized geographical data files. These data were handled in GIS. The first level of integration of the model and GIS was implemented, which means that some, but by far not all of the input data required for the model were prepared using GIS, and supplied to the model by external means.

## MODEL INPUT PREPARATION USING GIS

The GIS systems used in this study were ARC/INFO and IDRISI. All basic maps were digitized in ARC/INFO. As however PC ARC/INFO is vector-based and can not handle raster data, the geographical information had to be reprocessed in IDRISI in order to obtain the required input data for EPIC. The coverages created in ARC/INFO were transferred to IDRISI using the Import and Export modules of both systems. The whole catchment was divided into 18 fields as they actually exist, and the area of each field was computed. A map showing the fields is shown in Figure 1(a). The contour map, after transferring the information from ARC/INFO, was also prepared in IDRISI format. The interpolation of contour lines was carried out and a mean filter (low pass) was applied, to remove some artifact angularity. Then the interpolated contour map was confined to the catchment interior and reclassified. The resulting DEM map is shown in Figure 1(b). The slope map in percent was created using the SURFACE module, to which the DEM map was an input. The computed mean

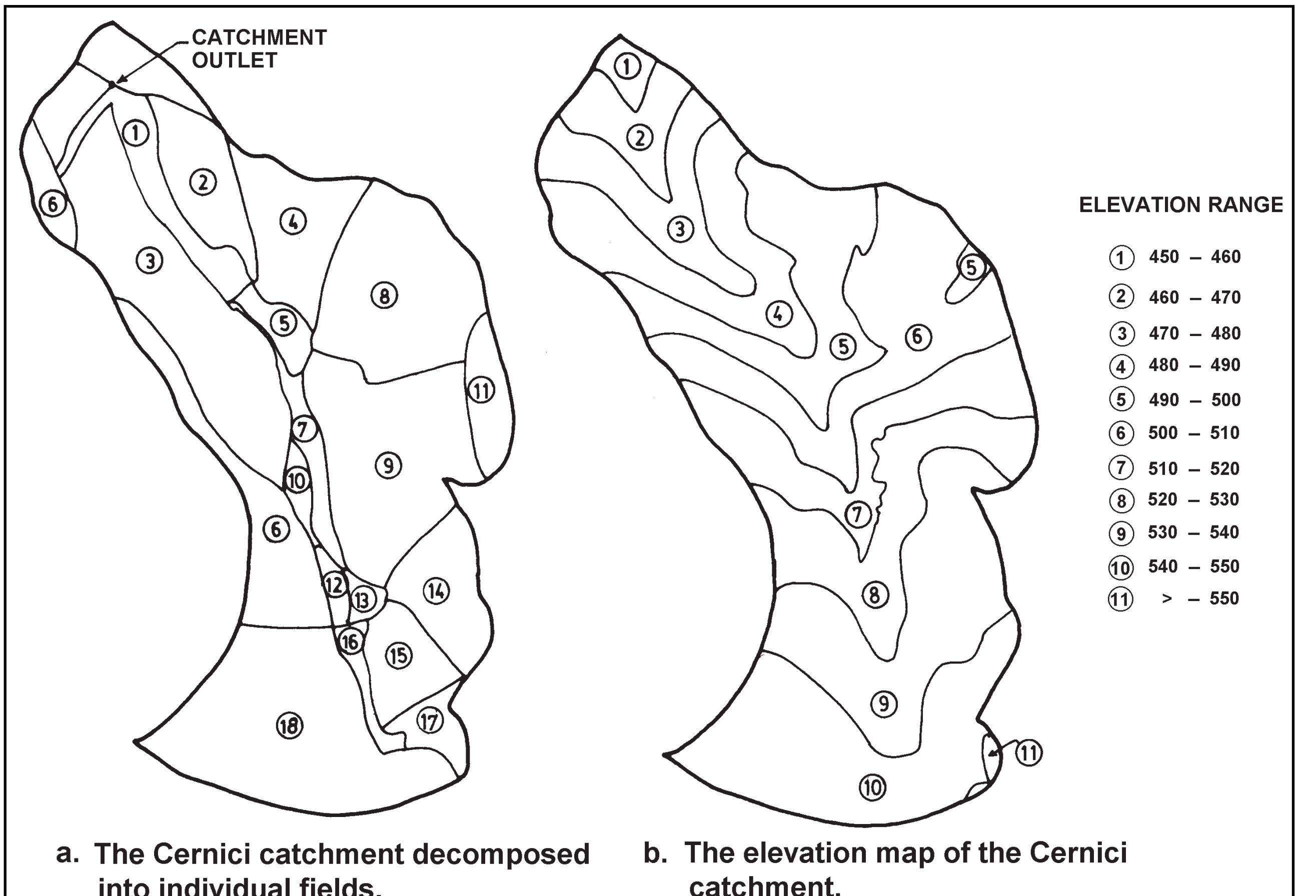


Figure 1. The Cernici catchment.

value of slope for the entire catchment was 8.9 percent. It compares well with the value computed by ARC/INFO, 9.69 percent, and this map was used to calculate average slope in individual fields. The average elevations and slopes of individual fields were calculated after overlaying the map of fields with the elevation map and slope map, respectively. The range of elevations for each field was also calculated as well as the channel length and the field slope length. The channel course was estimated manually for each field as either coinciding with the stream reach adjacent to the field (where it existed) or the most probable path of concentrated runoff from the field. The channel slope for each field was calculated using the terrain elevation difference and the channel length. All parameters of individual fields generated in this way are listed in Table 1.

Table 1. Characteristics of Individual Fields within the Cernici Catchment

| Field No. | Area (ha) | Average elevation (m) | Field elevation range (m) | Average fields slope (m/m) | Channel lenght (m) | Average fields slope lenght (m) | Channel elevation difference (m) | Average channel slope (m/m) |
|---|---|---|---|---|---|---|---|---|
| 1 | 5.3 | 472 | 460-480 | 0.10 | 562 | 187 | 20 | 0.036 |
| 2 | 6.5 | 483 | 470-485 | 0.11 | 524 | 262 | 15 | 0.29 |
| 3 | 20.2 | 493 | 465-515 | 0.10 | 1011 | 300 | 50 | 0.049 |
| 4 | 9.4 | 485 | 485-490 | 0.10 | 262 | 300 | 5 | 0.019 |
| 5 | 2.1 | 488 | 480-495 | 0.08 | 284 | 112 | 15 | 0.053 |
| 6 | 12.3 | 516 | 515-535 | 0.06 | 299 | 337 | 20 | 0.033 |
| 7 | 2.5 | 508 | 480-505 | 0.11 | 852 | 150 | 25 | 0.043 |
| 8 | 17.4 | 507 | 490-510 | 0.09 | 450 | 450 | 20 | 0.044 |
| 9 | 18.9 | 522 | 505-525 | 0.11 | 450 | 450 | 20 | 0.033 |
| 10 | 1.0 | 515 | 510-525 | 0.09 | 225 | 150 | 15 | 0.066 |
| 11 | 3.8 | 517 | 500-520 | 0.07 | 300 | 187 | 20 | 0.066 |
| 12 | 1.0 | 526 | 525-530 | 0.10 | 225 | 112 | 5 | 0.022 |
| 13 | .98 | 526 | 520-525 | 0.08 | 112 | 112 | 5 | 0.044 |
| 14 | 6.6 | 538 | 530-545 | 0.05 | 300 | 300 | 15 | 0.050 |
| 15 | 4.9 | 538 | 510-540 | 0.08 | 225 | 225 | 10 | 0.044 |
| 16 | 1.6 | 534 | 525-540 | 0.07 | 375 | 75 | 15 | 0.040 |
| 17 | 2.5 | 546 | 540-550 | 0.11 | 225 | 187 | 10 | 0.022 |
| 18 | 25.0 | 544 | 530-545 | 0.08 | 562 | 450 | 15 | 0.027 |

Note: field 19, which is downstream of the measured catchment outlet, is not considered.

## OTHER INPUT DATA FOR THE MODEL

Some of the model input parameters were estimated using GIS. The rest of them were estimated by other techniques, using the available data records from the Cernici site and its surroundings. Where no data were available, the required information was retrieved from the EPIC data base. The EPIC input files were mostly edited using the UTIL software which is supplied together with EPIC.

The basic EPIC user-supplied input file consists of a title, the program control codes, general data, water erosion data, weather data (monthly statistics), wind erosion data, soil data, operation variables, operation schedule and references to the daily weather data files. Among those, the weather and soil data play an exceptional role because they provide a fundamental characteristic of the site and, at the same time, can usually be taken from national general-purpose data bases. Therefore, the first step was to prepare the weather and soil data sets.

Weather data can be input into EPIC either as daily values for each day of simulation or as weather parameters (monthly statistics) based on long-term observed data series. In our case, there were five years (1992-1996) of observed daily data available from the nearby Cetchice weather station which included rainfall, maximum and minimum temperature, and relative humidity.

The weather parameters required by EPIC in the form of monthly statistics for each month of the year were prepared. The EPIC simulation requires the soil profile to be divided into several layers. The data required for each layer include: depth from the soil surface to the bottom of the soil layer, dry bulk density of the moist soil ($t/m^3$), wilting point (m/m), field capacity (m/m) and content (%), silt content (%), organic nitrogen content (g/t), soil pH in water suspension, sum of bases (cmol/kg), organic carbon content (%), calcium carbonate content (%), cation exchange capacity (cmol/kg), coarse fragment content (% vol), nitrate content (g/t), labile phosphorus content (g/t), crop residue (t/ha), bulk density in the oven dry state ($t/m^3$), phosphorus sorption ratio, saturated hydraulic conductivity (mm/h), and organic phosphorus content (g/t). For the purpose of EPIC simulations, the soils in the entire catchment were regarded as homogeneous and describable by a single data set.

### Management Information Data

EPIC also requires data on agriculture management, such as the crops grown, planting and harvesting times of each crop, type of tillage, crop rotation, type of irrigation, and fertilizer application rates. The field crops actually grown in the catchment are barley, rye, wheat, oats, triticale, rape, flax, poppy, potato, clover, maize for silage and legume-cereal fodder mixtures. Some parts of the catchment are covered with low quality permanent meadow grass or by forest. EPIC allows for simulations of many crops commonly grown in different parts of the world, but the some crops and cultures have to be approximated by substitute crops, bearing in mind the main purpose of simulation, which in our case is estimation of erosion.

The actual dates of sowing, planting, harvesting and the accompanying tillage operations of individual crops in individual years were not fully available. Therefore, these dates were modeled as fixed for a given crop in a given crop rotation context, without any regard to instantaneous weather conditions. The fixed dates of sowing, planting and harvesting were set forth, based on the information obtained from local managers, as approximate averages of usual actual dates of these operation while the extent of the accompanying tillage operations was minimized, only to make the hydrological and erosional conditions in the model similar to reality.

## RESULTS AND ANALYSIS OF SIMULATION

The main objective of the present study was to compute the soil erosion, but before the model simulation for carrying out soil erosion studies, the water balance was satisfied. The water balance components estimated by EPIC for individual fields as well as for the catchment as a whole comprise precipitation, actual evapotranspiration, surface runoff, percolation below the soil profile (further on referred to as 'percolation'), subsurface runoff and drainage runoff.

After satisfying the water balance equation (after calibration of the model) soil erosion studies were carried out. EPIC uses six alternative methods for estimation of soil erosion:

- Universal soil loss equation (USLE)
- Modified Universal Soil Loss Equation (MUSLE)
- Onstead-Foster modification of USLE (AOF)
- Small watershed version of MUSLE (MUSS)
- MUSLE with individual coefficients (MUSI)
- Theoretically derived version of MUSLE (MUST)

USLE depends strictly upon rainfall as an indicator of erosive energy while MUSLE, MUSS, MUST and MUSI consider only surface runoff as a cause of erosion (more accurately, of the sediment yield). AOF contains a combination of the rainfall and surface runoff energy factors.

Of these USLE, MUSLE and AOF were considered for estimation of soil erosion in this study. The simulated daily amounts of erosion from individual fields as predicted by USLE, MUSLE and AOF were first summed to obtain the gross erosion in the whole catchment. In the case of USLE, the algorithms for modeling surface runoff and erosion are independent, which makes it possible to predict erosion on days when there is no runoff and runoff on those days when there is no erosion. To a lesser extent, this is also true for AOF, while there are explicit parallels between surface runoff and the erosion predicted by MUSLE. The predicted magnitude of erosion is highest with USLE, medium with AOF, and lowest with MUSLE. The seasonal distribution of erosion estimated by USLE suggests that the highest risk of erosion occurs from May to August, when the rainfall erosivity is highest and the fields are not adequately protected by vegetation. The erosion estimates used on MUSLE and AOF suggest that considerable erosion occurs in winter months also, due to snowmelt. As expected, erosion on permanent meadows and in forests is very low.

One has to realize, however, that the figures obtained in this way are the on-site erosion, while some deposition of the eroded material certainly occurs during its travel downstream. This is particularly true for the USLE estimates of erosion, while the MUSLE type erosion equations actually provide estimates of sediment yield from a small catchment. The sediment delivery aspect has also been considered in this study and the results are presented in a later section.

## Erosion Control

The USLE suggests that there are at least two controllable factors of soil erosion, namely, the erosion control practice and the crop management. So, even though the limited extent of this study did not make it possible to simulate and evaluate in detail various erosion control scenarios for the catchment studied, the effect of change of the above mentioned two factors is briefly considered.

Erosion can be controlled by applying different erosion control practices. The erosion control practice factor, PEC, is the ratio of soil loss with a support conservational practice like contouring, strip cropping or terracing, to that with straight row farming up and down. While one cannot expect that either contouring or terracing would become widespread in the region studied, the strip cropping, even it does not exactly follow the contour lines, may be and is being applied. In order to estimate the effect of strip cropping practices on soil erosion, a lower level of erosion control practice factor was tested namely PEC=0.6, which is a very conservative estimate of PEC for strip cropping (Sharpley et al., 1990).

One of the most effective methods to reduce the soil erosion losses is to keep the soil surface covered with vegetation or mulch for as large a part of the year as possible. The role of the vegetation or mulch cover is accounted for by the crop management factor C. EPIC simulates the variation of C in time according to the crop development and tillage operations applied. In the present study the simulated crop rotations for different fields were kept as close as possible to real field conditions in individual years of the period 1992-1996. It is evident from the results that the average annual soil erosion rate (USLE) was highest (over 20 t/ha/year) on the fields 2, 3, 8, 9 and 17, i.e. on arable fields managed by the Agricultural Cooperative Cechtice. This is due to the fact that these fields are arable lands, their average slope is high, and the coming of high intensity rainfall coincided with the times when the soil surface was not adequately protected by vegetation. The validity of the latter statement can be tested by changing the simulated rotation on these fields. If the operation modules of the EPIC input files for fields 2, 8, 9 and 17 are replaced by the corresponding module for field 4, the resulting average annual erosion rate decreases considerably.

## Sediment Delivery

The gross soil erosion evaluated and discussed in the previous section is the on-site erosion, especially if USLE is used for its estimation, and it has to be further routed to the catchment outlet for estimation of the sediment yield of the catchment. The sediment delivery ratio expresses the percentage of the on-site eroded material that reaches a designated downstream location. For routing the soil erosion through individual fields of the Cernici catchment, a most probable routing network was suggested on the basis of connectivity, elevation and slope of each field and if it was adjacent to the main stream. This network is shown in Figure 2.

The magnitude of the sediment delivery ratio for a particular field which is to be applied to the gross erosion produced by that field, as well as to the sediment inflow from the upstream fields, is

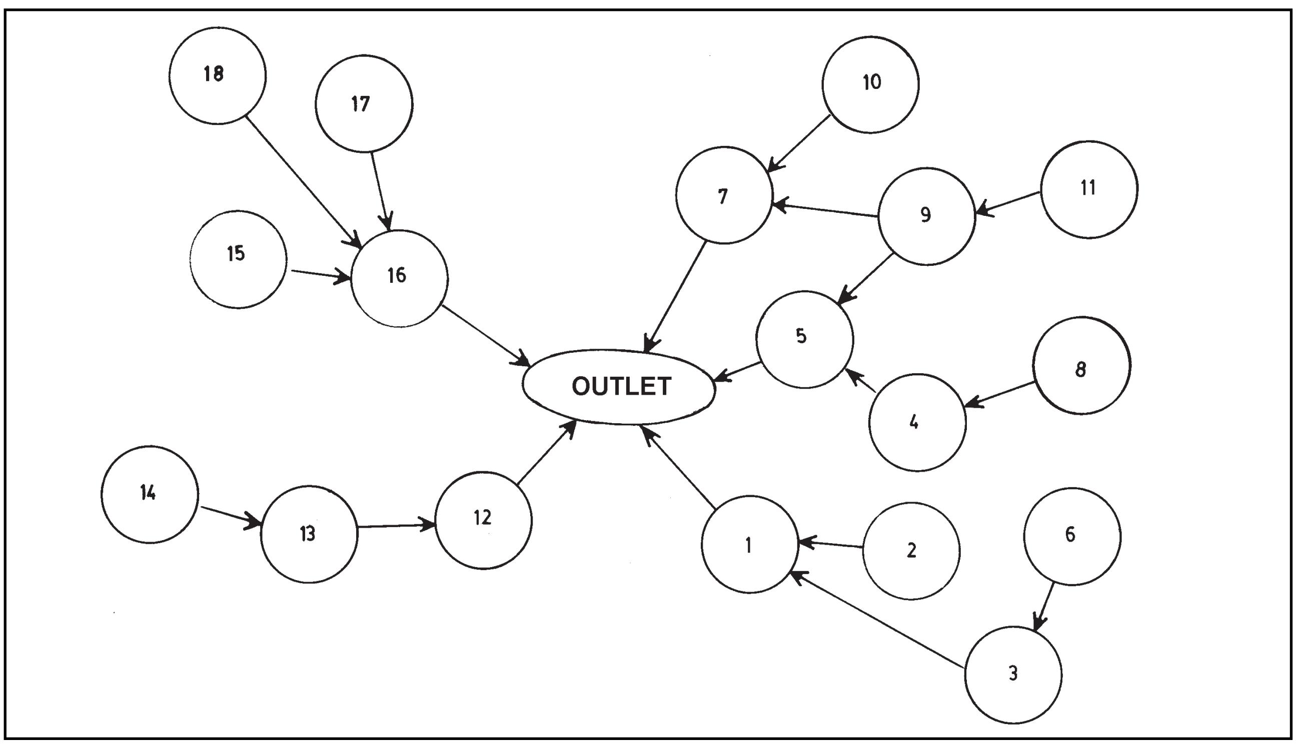


Figure 2. A probable network for sediment routing through individual fields.

influenced by a wide range of geomorphological and environmental factors including the nature, extent and location of the sediment sources, relief and slope characteristics, drainage pattern and channel conditions, vegetation cover, land use, and soil texture. In this study, three factors have been considered the most important, namely, the field area, land use and topography. This can be expressed symbolically as:

$$SDR = C1*C2*C3 \tag{1}$$

where

*SDR* is the sediment delivery ratio,

*C1* is the factor of field area

*C2* is the factor of land use

*C3* is the factor of topography

All terms and factors in this equation are dimensionless.

The probability of entrapment of eroded particles increases with the size of the drainage area. The sediment delivery ratio *SDR* then decreases with increasing drainage area *A*. A typical relationship is (Maidment, 1993):

$$SDR = 0.41\ A^{-03} \tag{2}$$

where

*A* is the catchment (field) area in km$^{2.}$

The right-hand side of this equation can be regarded as a first estimate of the field area factor *C1*. It however becomes higher than 1.0 for small areas, which is not acceptable. Therefore the formula was modified so that the maximum value of *C1* does not exceed 1.0:

$$C1 = Exp(-a *A) \tag{3}$$

where the coefficient *a* was estimated as 0.02 ha-1.

This formula does not produce *C1* above unity (as long as the area *A* is positive) and, for the fields of the size encountered in Cernici, gives similar values as in equation (3). A similar study carried out by Walling (1983) reveals that the relationship between drainage area and sediment delivery ratio also shows exponential decay.

The land use factor *C2* can be approximated on the basis of the crop management C-factor of USLE. EPIC uses different crop management factors for different crops and different stages of their development. These values, as produced by EPIC for each day of simulated period, might be taken as the *C2* factor for routing of a particular erosion event on the same day. However, as a first approximation, constant values of *C2* were used in this study, one value for arable fields (1.0), one value for meadows (0.2), and one value for forest areas (0.2).

The topography factor *C3* can be based on the difference of average elevations between the field in question and an upstream field. This, however, implies that *C3* is not a unique property of a particular field but an attribute of a pair of neighboring fields. In our case, the average elevations of all fields were estimated and the elevation of each field was divided by the elevation of the upstream connecting field as per the probable network shown in Figure 2. In this way, the *C3* factor for each field was calculated and tabulated in Table 2.

All three factors (*Cl*, *C2* and *C3*) were multiplied together to get the value of the sediment delivery ratio. The resulting values of SDR for each field, along with the values of *Cl*, *C2* and *C3*, are given in Table 2.

Table 2. Sediment Delivery Ratios and Their Contributing Factors for Individual Fields

| Field No. | Area (ha) | Vegetation Factor (C2) | Elevation Factor (C3) | Area Factor (C1) (Rev) | SDR (Rev) |
|---|---|---|---|---|---|
| 1 | 5.3 | 0.2 | | 0.90 | |
| 2 | 6.5 | 1.0 | 0.75 | 0.88 | 0.20 |
| 3 | 20.2 | 1.0 | 0.50 | 0.83 | 0.33 |
| 4 | 9.4 | 1.0 | 0.50 | 0.96 | 0.42 |
| 5 | 2.1 | 0.2 | 0.75 | 0.78 | 0.19 |
| 6 | 12.3 | 1.0 | 0.50 | 0.95 | 0.38 |
| 7 | 2.5 | 0.2 | 0.75 | 0.78 | 0.18 |
| 8 | 17.4 | 1.0 | 0.75 | 0.95 | 0.52 |
| 9 | 18.9 | 0.2 | 0.75 | 0.71 | 0.10 |
| 10 | 1.0 | 0.2 | 0.75 | 0.68 | 0.24 |
| 11 | 3.8 | 0.2 | 0.75 | 0.98 | 0.16 |
| 12 | 0.8 | 1.0 | 0.50 | 0.93 | 0.87 |
| 13 | 1.0 | 0.2 | 0.75 | 0.98 | 0.33 |
| 14 | 6.6 | 0.2 | 0.75 | 0.98 | 0.14 |
| 15 | 4.9 | 1.0 | 0.75 | 0.88 | 0.76 |
| 16 | 1.6 | 1.0 | 0.50 | 0.91 | 0.71 |
| 17 | 2.5 | 1.0 | 0.75 | 0.97 | 0.93 |
| 18 | 25.0 | 0.2 | 0.50 | 0.95 | 0.11 |

These sediment delivery ratios were applied to the gross erosion of each field estimated by USLE and to the sediment inflow from the upstream field. The result was routed to the downstream field and so on down to the catchment outlet, following the network as shown in Figure 2.First, the erosion estimated by USLE for each ‘most upstream’ field in t/ha was converted into tons by multiplying it by the area of the field. Then, SDR of that field was applied to this value to get the value of sediment yield from that field. This value was then added to the erosion value of the downstream field where the procedure was repeated. In cases of bifurcation, the yield was equally distributed to the two downstream fields. In this way, the sediment yield at the outlet was obtained. The procedure can be applied to the erosion amounts over any time period, because the routing does not imply a time delay.

The average simulated annual sediment yield at the catchment outlet during 1992-1996 was 346 t, while the gross erosion (USLE) was 2848 t. Hence only 12 percent of the total soil erosion became sediment yield at the outlet of the entire catchment. The sediment delivery ratio for the catchment as a whole was calculated using the same procedure. It was 11.0 percent, which is very similar to the value found by routing. A verification of the model could only be done for the two erosion events for which observed data were available and such that the observed erosion event coincided with the simulated erosion event (this was not always the case). A comparison of observed and simulated values for these two events is given in Table 3.

Table 3. Comparison of Measured and Simulated Individual Erosion Events (Entire Catchment)

| **Date** | **Measured Values** | | **Simulated Values** | | | |
|---|---|---|---|---|---|---|
| | Sample (1) | Concentration (g/l) (2) | Erosion t/day (3) | Direct runoff ($m^3$/day) (4) | Concentration ? | Concentration after routing (g/l) |
| 30/05/95 | V2 | 84.810 | | | | |
| | V3 | 4.349 | | | | |
| | V4 | 157.700 | | | | |
| | V5 | 31.120 | | | | |
| | V6 | 81.980 | | | | |
| | V7 | 89.670 | | | | |
| | Average | 74.44 | 340.22 | 3738.75 | 90.99 | 11.05 |
| 22/07/95 | | | | | | |
| | V1 | 2.024 | | | | |
| | V2 | 2.522 | | | | |
| | V3 | 17.79 | | | | |
| | V4 | 17.66 | | | | |
| | Average | 9.85 | 1749.91 | 17003.48 | 102.91 | 12.51 |

The measured and simulated sediment concentrations were almost the same for the second event (22/07/95), while the measured values were considerable higher for the first event. This indicates that (a) the erosion sediment yield simulated by EPIC with the added-on SDR sub-model are realistic, and (b) the available measurements from the Cernici catchment are not sufficient for a quantitative calibration of the model.

## CONCLUSIONS

The EPIC input files prepared for 18 different fields of the small Cernici catchment were subject to a sort of calibration, in the course of which the EPIC outputs were compared with measured data. The simulated average sediment concentration in stream water at the outlet during a flood can be made to agree with the average of measured concentrations of the simulated gross erosion amounts on individual fields. Concentrations are not simply summed over the entire catchment but, instead, are routed from one field to another along a probable sediment flow network, using the appropriate sediment delivery ratios. If the EPIC-type modeling were to be carried out on a larger scale, one would need a more intimate coupling of GIS and the model under a common user-interface shell.

The largest soil erosion was estimated by simulation on the ploughed fields 2, 3, 8, 9 and 17. The causes of this effect have not been analyzed thoroughly because of a shortage of time. The main factor was probably the high average slope of the fields, but it was also shown that if the simulated crop rotations on these fields were changed, the erosion estimates become smaller. Therefore, crop rotaton itself was concluded to be a crucial erosion control factor.

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