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# Regionalization Methods for Watershed Management - Hydrology and Soil Erosion from Point to Regional Scales

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## ABSTRACT

**The increasing demand for watershed management tools at local and regional scales makes it necessary to develop regionalization techniques for applications of continuous process-based models. To be useful for decision-makers, models must be applicable to all parts of the world with minimum calibration and must consider spatial variability in modeling hydrological and soil erosion processes. We develop regionalization methods for the point model SIMULAT and the hillslope model of the Water Erosion Prediction Project (WEPP). These methods provide model simulations that include spatial variability in detail and are able to reduce time consuming simulation runs by using hydro-pedotopes or hillslope units to represent the hydrological or erosional behavior of a watershed or larger region. Each method is designed to use geo-referenced commonly available data in a Geographical Information System (GIS) by aggregation and disaggregation procedures with a minimum of quality lost in the spatial and temporal distribution of the original input data. The results show that these regionalization methods produce detailed spatially distributed results on a daily basis either for relative water balances components of hydro-pedotopes or soil detachment rates for cells along flow paths on hillslopes within a small watershed that match well with runoff and sediment measurements in both study areas. The evaluation of different quality of topographical model input on regionalization results demonstrates the importance of different data quality and scales on model assessment results and decision-making.**

## Introduction

There has been a long history of research aimed at developing models for water and pollutant transport from the pedon scale to watershed or regional scale (Renschler, 2000). Modern watershed models focus on the prediction of water fluxes for certain space and time scales. However, when the problem of interest is not at the scale of the model, there are difficulties in scaling both data and model results (also see Renschler et al., 1999). Often hydrologic processes are described depending on the model's scale, and decisions about the level of spatial aggregation in input data, analysis, and model output are influenced by the scale the model is designed to operate in.

The research presented here takes an alternative approach to model development that avoids many of these scaling problems. Regionalization of effective and representative model parameters - instead of scaling up by model concept simplification or data aggregation - allows the use of the same model concept on the small scale as well as the large scale. Representative model parameters avoid data limitations related to aggregation procedures. Hydrologic conditions and erosion processes are simulated at a small scale using process-based models, and then representative results are used in modeling at the watershed or regional scale (Renschler, 2000). The non-commercialized models SIMULAT (Diekkrüger and Arning, 1995) and the Water Erosion Prediction Project (WEPP) hillslope model (Flanagan and Nearing, 1995) were used in this study. The regionalization methods are designed to use standardized and commonly available data sources in a raster cell format prepared, analyzed, visualized, and stored by a Geographical Information System (GIS).

## Regionalization method for water balance assessment

A regionalization approach described by Bormann et al. (1999) allows detailed process-based hydrologic models to use far less data and computation time than traditionally required. The process-based point (one-dimensional) model SIMULAT (Diekkrüger and Arning, 1995) was used to simulate water balances for hydro-pedotopes. Hydro-pedotopes are defined as homogeneous areas of climate, topography, soil, and vegetation. Since the regionalization method is aimed to represent long-term hydrologic behavior on a weekly to monthly basis, the neighborhood and short-term changes in a hydro-pedotope environment were assumed to play minor roles. The method is based on the simulation of a limited number of representative hydro-pedotopes instead of simulating each hydro-pedotope of a region.

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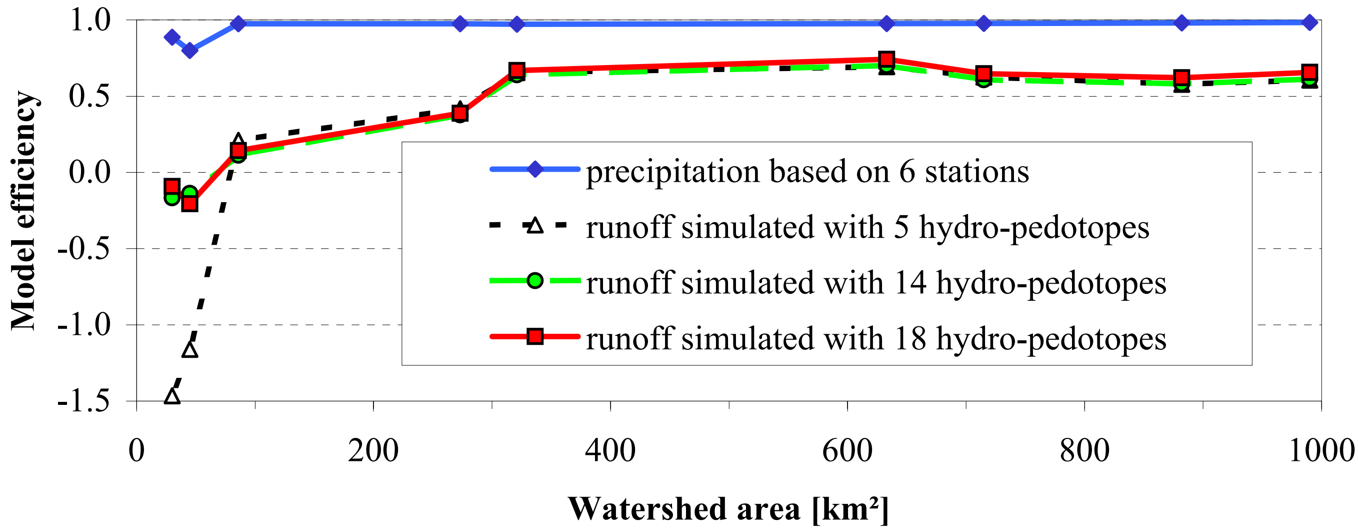


**Figure 1: Model efficiency of monthly precipitation of six representative instead of 31 stations and simulated runoff based on representative hydro-pedotopes for 9 observed watersheds within the Upper Leine watershed, Göttingen, Germany (1981-1989). The model efficiency (Nash and Sutcliffe, 1970) is smaller or equal to 1, where 1 indicates that observed and simulated values are exactly the same.**

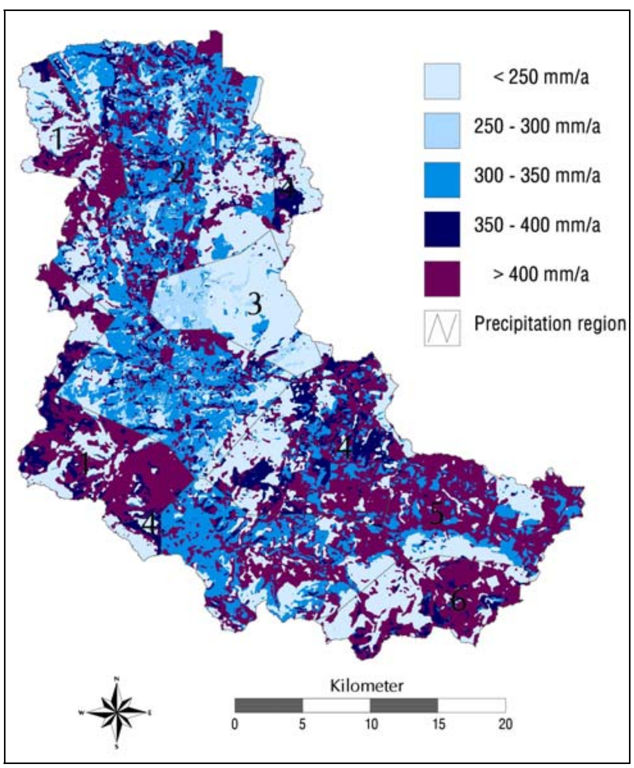


**Figure 2. Groundwater recharge for the 1000 km$^2$ watershed of the Upper Leine, Germany (1987). Note that model precipitation input is based on six homogeneous regions and local variations of water balances are a function of 18 representative hydro-pedotopes.**

Representative hydro-pedotopes were derived by clustering the water balance results for all theoretical combinations of soil, relief and land use characteristics for a particular region and choosing the centermost hydro-pedotope within a cluster. In a second step of the regionalization method integral soil values representing the soil hydrology, such as the water available for plants and the travel time, were used to combine theoretical hydro-pedotopes with real ones in a specific watershed or region. The approach is therefore only limited to a choice of hydro-pedotopes of a certain climatic region, but independent of any watershed characteristics within this region.

## Water balance assessment for the Upper Leine Watershed, Germany

The representative hydro-pedotope method was applied in several watersheds within the region of the Upper Leine, Germany, from 1981 to 1990 and compared to runoff measurements. Six representative rainfall measurement stations, derived from cluster analysis results of monthly precipitation characteristics, provide highly efficiently precipitation model input on a monthly basis in comparison to the Thiessen polygons of all 31 stations in the area (Figure 1). Routed surface runoff, interflow and groundwater recharge of 18 representative hydro-pedotopes produces acceptable model efficiencies for watersheds greater than 200 km$^2$ within the study region. Results have shown that accurate simulation can be produced with 18 representative hydro-pedotopes and enable the reduction of calculation time by up to 90% (Bormann et al., 1999).

The present concept allows highly detailed, continuous,

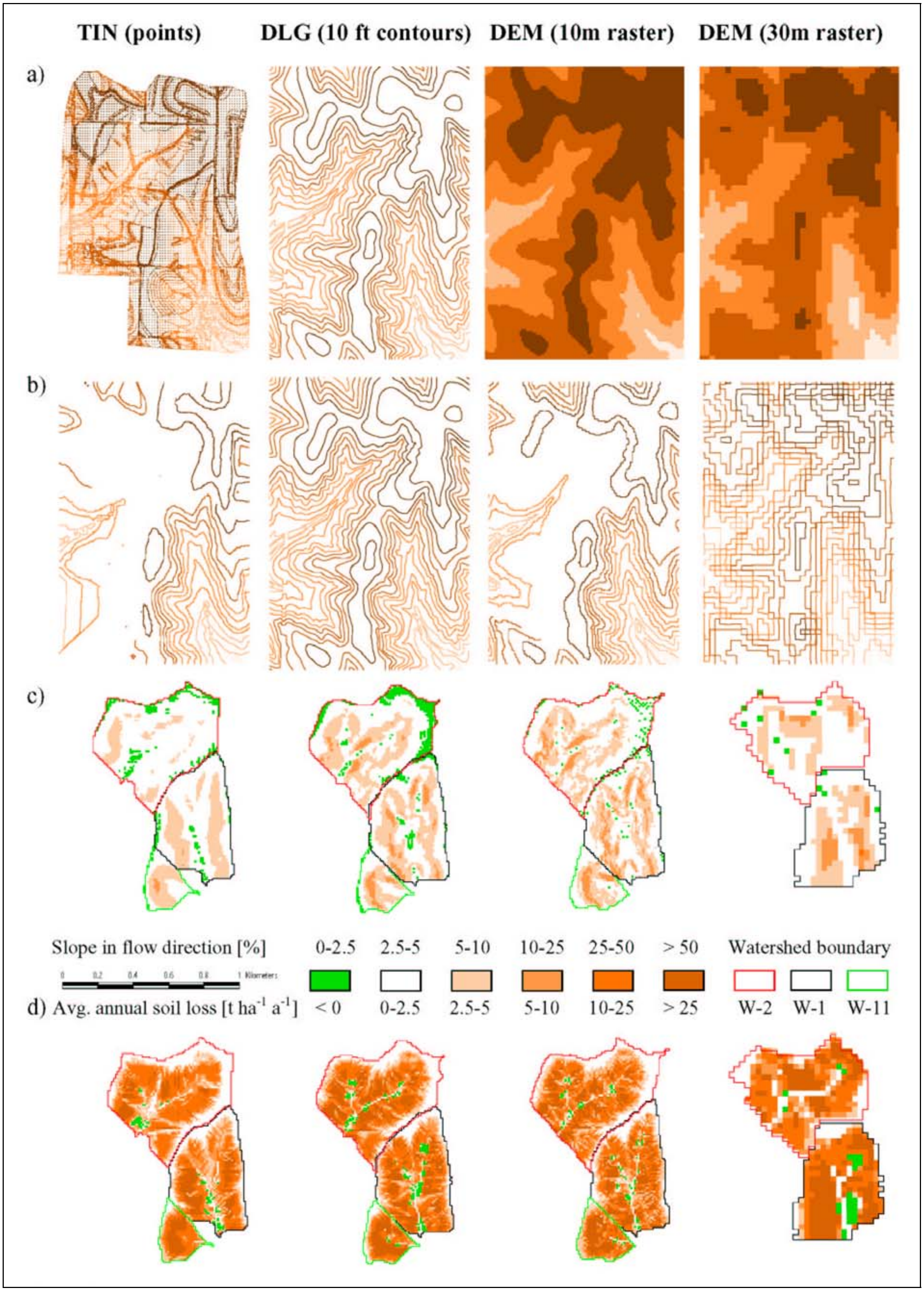


**Figure 3. Comparison of a) topographical input sources, b) derived 3m contour lines, c) slope discretization and d) soil erosion model results for three experimental watersheds at Treynor, Iowa, U.S.A. [TIN = Triangular Irregular Network (ARS), DLG = Digital Line Graph (USGS) and DEM = Digital Elevation Model (USGS)].**

process based hydrologic simulation in various time steps (in this study hourly time steps) without loosing spatially distributed information. This means that the spatially distributed water balance results are produced for the smallest geometry's given by a combination of data resolution of hydrological relevant characteristics of soil, land use, relief and climate. Instead of aggregating the how watershed discretization based on different elevation data sources effects soil erosion simulation results, the process-based, two-dimensional hillslope model of the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing, 1995) version 98.4 was used in this regionalization approach.

Model input was prepared for a specific watershed and then transferred and applied to neighboring watersheds without any calibration. Methods to derive representative hillslopes to reduce the number of simulations are in development and give good results for small watersheds (Cochrane and Flanagan, 1999). In contrast to the watershed independent method to derive representative hydro-pedotopes for water balances, the method used for soil erosion considers all flowpaths on a certain hillslope as a function of width and length and depend therefore on hillslope and watershed characteristics. To achieve detailed spatially distributed results on each hillslope the flowpath method described by Cochrane and Flanagan (1999b) was used. The flowpath method averages sediment and runoff of each flowpath cell discharging into a common channel raster cell. Channel routing is performed without any channel parameters and it is therefore assumed that there is no erosion or sedimentation within the channel. Just as with the water balance method, the flowpath method produces spatially distributed, regionalized results based on input data resolution by running time intensive simulations.

## Soil erosion assessment for the Treynor Watersheds, Iowa

The soil erosion assessment approach was tested for the 30ha experimental watershed W-2 at Treynor, Iowa. The exact same data input parameters (except for topographical characteristics) were used to simulate the neighboring watersheds W-1 (21ha) and W-11 (6ha). Precipitation and climate input for a six-year period (1985-1990) were taken from breakpoint measurements. Soil parameters for a silt loam soil series (Marshall-Monona-Ida-Napier) were taken from soil surveys and the WEPP soils database and no spatial distribution of soil characteristics within units was assumed. Management practice was taken from the crop calendar for six years corn with a conventional tillage system consisting of heavy disking in mid-April followed within two weeks by a shallow disking and harrowing.

To evaluate the effect of geo-referenced commonly available elevation data, sources of different resolution and quality were prepared and model results were compared with the commercially available Geographical Information System (GIS) Arc/Info. The following sources of the U.S. Geological Survey (USGS) with increasing accuracy (and decreasing availability) were compared with field measurements provided by the Agricultural Research Service (ARS):

- USGS 30m raster Digital Elevation Model (DEM) derived from high altitude photo-grammetry with a vertical resolution of 1m and an average vertical accuracy of 7m,
- USGS 10m raster DEM with a vertical resolution of 1ft (=0.304m) interpolated from
- USGS 10ft (=3.04m) contour lines from Digital Raster Graphs (DRG) with an average vertical accuracy of 15ft (=4.506m), and
- Highly detailed point measurement as Triangular Irregular Network (TIN) from ARS aerial photogrammetry.

A schematic overview of each data source (Fig. 3a) with derived discretization in 3m contour lines (Fig. 3b) demonstrate the decreasing accuracy of the topographical input from point and contour to raster data. The appearance of the 10ft contours and the contours derived from the 10m DEM is almost identical. The 30m raster data appear to be less accurate for representing the topography on this 1km$^2$ scale. After running the sinkhole removal and watershed discretization algorithms of TOPAZ, the slopes for each cell show the differences in the topography of each data source (Fig. 3c). On the 10m-raster level, the detailed TIN data has less steep areas than both USGS data. The interpolated contour lines provide a smoother surface through clear lines of classes than the 10m DEM interpolated from the same contour lines by the USGS that show more speckles in this classification of slopes. The USGS 30m-raster gives very basic topographic information on the watersheds and it failed to provide the information required to delineate the smallest watershed W-11. The DLG contours and the TIN data were then processed with the same interpolation algorithms in Arc/Info (TOPOGRID tool) to prepare raster maps in raster sizes of 30, 20, 15, 12, 10, 6, 5 and 4 meters. Analog raster sizes except of the original 30m DEM were produced by a simple approach based on weighted averaging of the 10m-raster DEM.

## Effect of topographical data quality on soil erosion assessment results

Results for the watershed area discretization provide good mapped watershed areas in the field for grid sizes of 20m and smaller (Fig. 4a). Using these data, storm event surface runoff is generally under predicted and has a tendency to increase with a decreasing raster cell size (Fig. 4b). Best results in comparison to observed long-term observations are simulated for cell sizes smaller than 10m. The routing taking not into account the channel cells itself, the total rainfall input and therefore runoff is less for larger raster sizes than smaller ones. The USGS data seems to produce better results in a long-term average of surface runoff than the detailed TIN data. But as the results show, the TIN data has to be considered as more accurate throughout the different raster cell sizes as the stable simulation results for average annual sediment yield indicate (Fig. 4c). Note that W-11 was assumed to have same sediment yield rate then observed for W-1 and that the

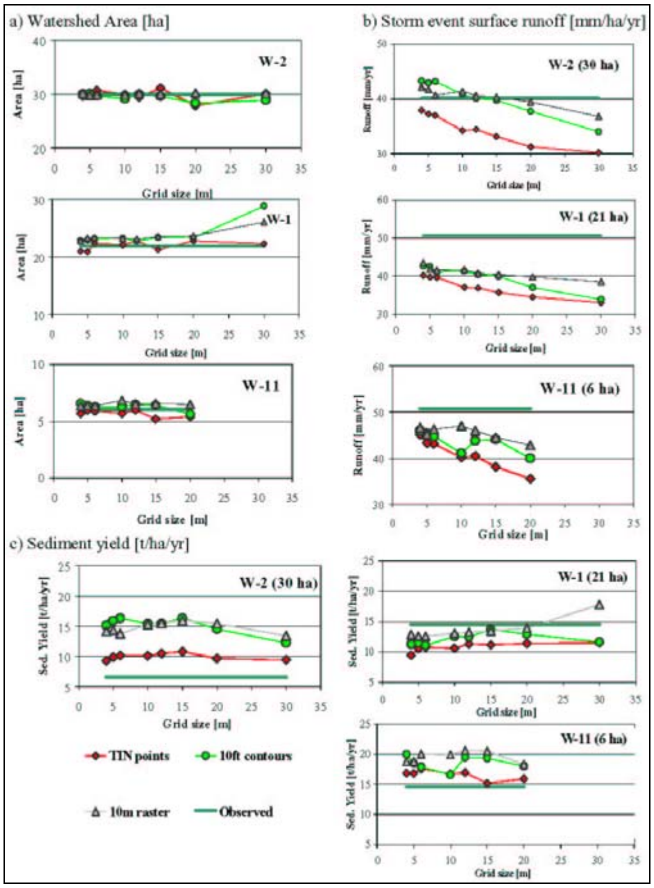

Figure 4. Average annual storm event surface runoff and sediment yield for watersheds W-2, W-1 and W-11 at Treynor, Iowa, U.S.A. (1985-1990). Note that regionalization method produces acceptable runoff and soil loss results without considering the effect of channel characteristics.

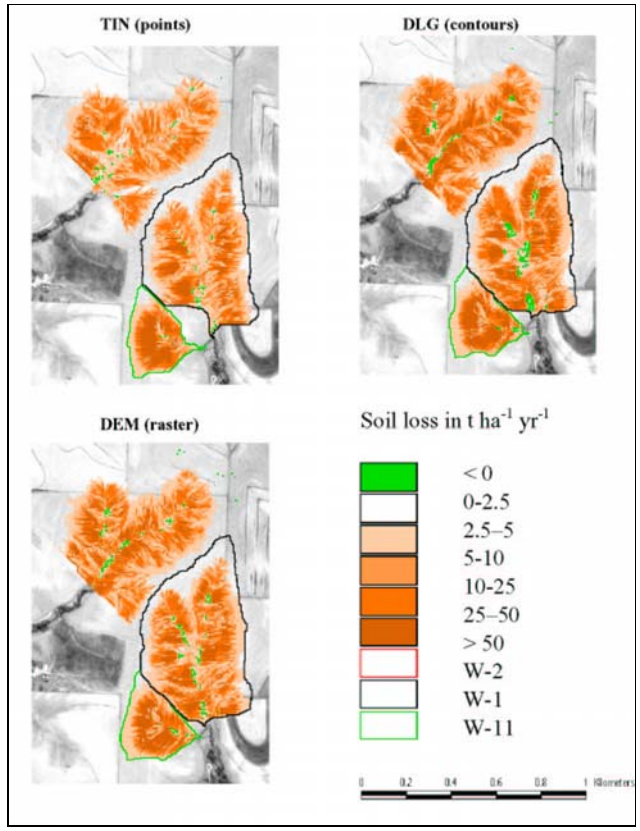

Figure 5. Detailed map of average annual soil loss for watersheds W-2, W-1 and W-11 at Treynor, Iowa, U.S.A. (1985-1990). Note that 4m interpolated topographic input of different data sources cause differences in erosion and flow path patterns on hillslopes within the watersheds.

regionalization method do not consider the effect of channel erosion and sedimentation in the watersheds. The larger the watershed the longer the channels, the greater a potential influence on model results due to channel characteristics.

The simulated spatial distribution of soil loss scan be shown as output (Figure 3d), but because there are no field observations or maps of erosion features the differences can be discussed only in a qualitative way. As the summary of all hillslopes in the watersheds, the spatially distributed results indicate less erosion for the detailed and more accurate TIN topography (Fig. 3d). The results can be processed at an even higher resolution than 10 meters (Fig. 5). The erosion patterns, based on the TIN data, give a more realistic pattern because the data allow the model to take into account small depressions and surface roughness. These features slow down and distribute surface runoff instead of channeling the runoff and increase soil erosion as on the smoothened surface interpolation based on contour lines. The USGS data causes more flowpaths entering the channels with a high sediment delivery from severely eroded hill slopes and therefore yields higher average annual soil loss for the whole watershed.

## CONCLUSION

Two different regionalization methods were presented for two process-based simulation models: a one-dimensional point model for water balances and a two-dimensional hillslope soil erosion model. The cluster analysis based regionalization method for regional and local water balances relies on representative hydro-pedotope independent of specific watershed characteristics and can be applied to other regions with similar climatic, soil and land use characteristics. Spatially distributed results of all the water balance components within the region give the possibility of assessing the hydrological behavior of the region. To achieve spatially distributed results for a regional soil erosion assessment each flowpath to a channel has to be simulated separately and weighted.

The quality and detail of spatially distributed topographical data may cause differences between simulation results that are also scale depending. Highly accurate and detailed topography produces the best erosion simulation results in comparison to commonly available data. The original USGS 10ft contour data is the most commonly available source of information in the US in contrast to the derived 10m raster data, the original contours appear to be the more reliable information for fulfilling the WEPP input requirements than interpolated 10m and 30m raster data. Nevertheless, the regionalization methods presented allow the application of each model approach for regional watershed management projects producing spatially distributed results local results needed by decision makers for real world problems.

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