Texas A & M University and U.S. Bureau of Reclamation

Hydrologic Modeling Inventory
Model Description Form
July 18, 2007

Name of Model:

MEFIDIS – Modelo de Erosão FÍsico e DIStribuído (Physically-based distributed erosion model.

Model Type:

Physically-based, spatially distributed, dynamic hydrological and erosion model for extreme weather events.

Model Objective(s):

1. Simulate runoff generation and routing, coupled with soil detachment, transport and deposition patterns for an extreme weather event within a single watershed.
2. Simulate the most important hydrological and erosion processes in medium- to large-sized Mediterranean watersheds using locally available data.

Agency and Office:

Center for Ecological Modeling, IMAR – Institute for MArine Research (hosted by the New University of Lisbon).

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Model Structure or Mathematical Basis:

Spatial distribution approach: grid-based.

Temporal distribution approach: time-step, solving equations with a finite difference approximation based on an explicit scheme.

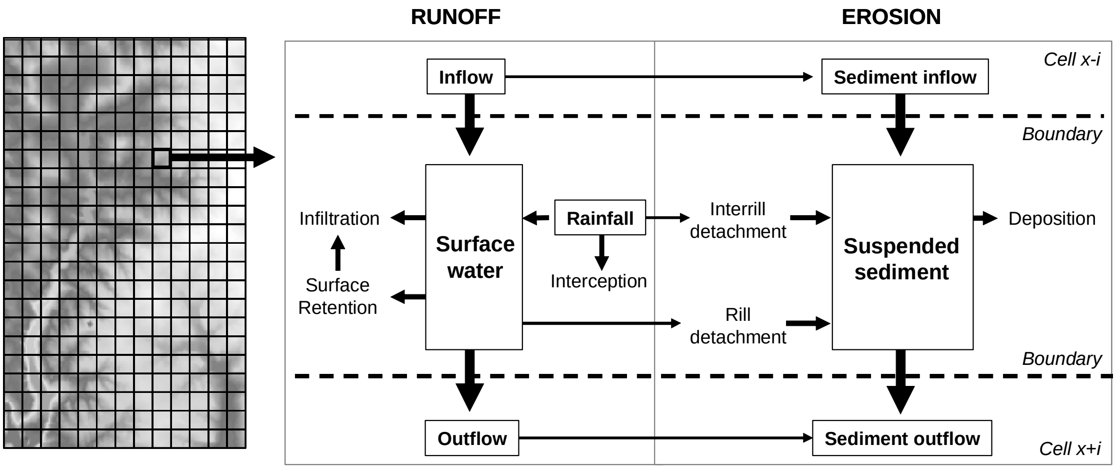
Runoff generation and routing processes:

1. interception – exponential storage decay function.
2. infiltration – one-layer Green-Ampt method.
3. surface retention – exponential storage decay function.
4. runoff generation – infiltration excess or saturation excess. The spatial distribution of saturated areas and soil moisture deficits can be calculated using the topographic wetness index and a TOPMODEL approach.
5. surface runoff routing – kinematic wave approach.

Sediment detachment, transport and deposition processes:

1. interill detachment – splash detachment based on a kinetic rainfall energy approach, using a soil detachability threshold and modified by ponded water.

2. surface runoff detachment, transport and deposition – sediment transport capacity approach, based on stream power.



Model Parameters:

The model is forced by rainfall, which can be parameterized using three alternatives:

1. rainfall duration and intensity (within-storm distribution simulated using hourly to subhourly coefficients);

2. rainfall data (breakpoint data, or rainfall measurements with 15 min resolution or better) for one or more stations;

3. moving storm radius, intensity, travel speed, and points of origin and destination.

Spatially-distributed parameters:

1. altimetry map (resolution of 100x100 m or better).

2. soil units map, with parameters per soil unit:
- median particle diameter;
- mass fraction of clay;
- soil shear strength;
- saturated hydraulic conductivity;
- porosity;
- matric potential;
- maximum depth.

3. land cover map, with parameters per land use type:
- depression storage capacity;
- interception capacity;
- Manning's roughness coefficient;
- pavement cover;
- vegetation canopy cover.

4. channel map (optional) with channel properties per section:
- Manning's roughness coefficient;
- channel width.

5. wetness index map (optional) with TOPMODEL parameters for the watershed:
- transmissivity decay rate with soil profile (m);
- soil water deficit at the start of the storm.

If the wetness index map is not used, the alternative parameter is average soil moisture at the start of the storm.

Spatial Scale Employed in the Model:

Resolution: tested from 5x5 m to 90x90 m cells.

Extent: tested between 0.013 Km^2 and 290 Km^2.

The wetness index-based soil moisture parameterization does not appear reliable for watersheds under 5 Km^2.

Temporal Scale Employed in the Model:

Resolution:
- tested from 1s to 9s timesteps;
- suggested linked to spatial resolution: use the Courant condition for a maximum runoff speed of 5 to 10 m/s.

Extent:
- tested from to 22 min to 100 hrs.
- suggested above the watersheds concentration time and below 48 hrs.

Input Data Requirements:

Maps in inovaGIS raster format (similar to the IDRISI binary raster format):
1. altimetry;
2. flow direction;
3. soil map;
4. land cover map;
5. channels (optional);
6. wetness index (optional).

Parameters in MEFIDIS ASCII (text file) format:
1. rainfall data (if breakpoint data is used);
2. soil parameters;
3. land cover parameters;
4. channel parameters (optional).

The remaining parameters are entered directly in the model interface. An auxiliary program is available to convert ASCII raster data (ArcInfo format) into inovaGIS raster data.

Computer Requirements:

MEFIDIS runs inside the Windows^{tm} operating system. No minimum computer requirements were detected so far, but the speed of model runs varies greatly with computer memory and processor speed. MEFIDIS also requires the installation of the InovaGIS mapping tool (supplied with the MEFIDIS package).

Model Output:

Output in map format, providing spatially-distributed results for the entire watershed at the end of simulation:

1. net runoff generation;
2. net soil loss.

Time-series for watershed averages and for user-selected points within-watershed:

1. instant surface runoff height;
2. accumulated interception;
3. accumulated infiltration;
4. accumulated runoff outflow from the watershed / point;
5. instant suspended sediment;
6. accumulated interill erosion;
7. accumulated rill erosion;
8. accumulated sedimentation;
9. accumulated sediment outflow from the watershed /point.

For user-selected points within-watershed, the model provides additional time-series:

10. instant flow velocity;
12. instant solid flow.

Parameter Estimation / Model Calibration:

Altimetry and rainfall data should be derived from measured data; the remaining parameters can be either measured or estimated. All soil parameters except soil depth can be estimated from texture data using PTFs; texture data can be obtained from soil samples or is available in national and international databases, such as those published by the ISRIC.

Furthermore, all landcover parameters can be estimated from landcover class using tabulated values commonly available in the literature. Tables to estimate channel n from surface type are also commonly available in the literature; channel width can usually be related with drained area using a power function.

Finally, if the wetness index method is used for soil moisture parameterization, watershed-scale soil moisture parameters can be calculated from pre-storm baseflow and baseflow recession curves. If a simple soil moisture estimate is required, MEFIDIS has provided good results with a Boolean estimation (the soil is either saturated or at field capacity) based on the elapsed time before the previous storm.

The most successful calibration strategy tested with the MEFIDIS model so far is to first calibrate the parameters for a single model cell; this has been done by adjusting model results to in-situ rainfall simulation tests. Afterwards, watershed-scale parameters are calibrated by comparing model results with outlet measurements, without changing cell-scale parameters. This insures that the model provides appropriate results at both scales. For this purpose, MEFIDIS has an automatic calibration module for single cells, allowing a Monte-Carlo test of all model input parameters including rainfall and slope; this module has been tested with up to 500 000 runs.

Model Testing and Verification:

The MEFIDIS model code has been extensively tested to assess equation results and verify mass balance losses. Furthermore, the rationality of the model's response to a number of important factors has been assessed:

1. changes to dominant erosion processes at the cell scale with rainfall intensity and slope;

2. correct identification of ephemeral gully formation thresholds in Mediterranean watersheds.

Model Sensitivity:

An extensive model sensitivity analysis at the cell-scale has been performed using a monte-Carlo method. Model results for runoff show that it is mostly sensitive to rainfall characteristics and parameters used to estimate soil water holding capacity: soil moisture, porosity and depth. Soil depth is only important for shallow soils; for example, storms with 100 mm/h lasting for 1 h are only sensitive to soil depths below 0.8 m. Furthermore, while runoff response is not very sensitive to saturated hydraulic conductivity and surface depression storage capacity, these parameters impose lower and upper limits (respectively) on the amount of generated runoff.

Soil erosion is mostly sensitive to rainfall intensity, slope, and the model results for surface runoff (and by inference to the parameters governing runoff generation). However, for greater rainfall and runoff rates the model also becomes sensitive to other parameters. With low slope grade (< 0.1 m/m) erosion response is also sensitive to soil median particle diameter and the Manning's roughness coefficient; for steeper slopes, the model becomes less sensitive to this parameters, but the sensitivity to surface depression storage and land cover by vegetation and pavement increases significantly. Finally, while erosion response is not very sensitive to soil shear strength, this parameter imposes an upper limit on the sediment detachment rate.

Model Reliability:

Model reliability in terms of robustness – its capacity to operate with a single parameter set under a number of different climatic conditions – was assessed for am agricultural humid catchment in Belgium (Ganspoel) and a rangeland semi-arid catchment in the southwestern US (Lucky Hills). In the agricultural catchment, the model was able to correctly simulate runoff and erosion from a number of storms with different magnitude with simple soil moisture parameterization (at saturation or field capacity, depending on the elapsed time before the previous storm). However, the model require different estimates of land cover parameters according to the storm date, to take into account crop growth stage; and the parameterization of soil crusting for the most intense storms was shown to greatly improve model results. Finally, the spatial patterns of soil erosion were shown not to be reliable at the model resolution (5x5 m in this exercise) but only at a coarser scale (about 50 x 50 m).

For the rangeland catchment, the model was shown to be robust using a single parameter set and a simple soil moisture parameterization (as described above). Model performance improved significantly with storm magnitude. This has been linked with the spatial and temporal homogeneity of landcover in the region.

The full results of these tests were published in:

Nunes JP, Vieira G, Seixas J, Gonçalves P, Carvalhais N, 2005. Evaluating the MEFIDIS model for runoff and soil erosion prediction during rainfall events. Catena 61 (2-3): 210-228.

Nunes JP, Vieira GN, Seixas J, 2006. MEFIDIS - A Physically-based, Spatially-Distributed Runoff and Erosion Model for Extreme Rainfall Events. In: Singh VP, Frevert DK (Eds.), Watershed Models. CRC press, Boca Raton: 291-314.

Model Application / Case Studies:

The following examples show case studies of different applications for the MEFIDIS model:

1. Estimating the sensitivity of runoff and soil erosion to climate change in small watersheds. This exercise, coordinated by the GCTE Soil Erosion Network, used a number of different hydrological and erosion models to test the impacts of changes to storm patterns and vegetation cover on runoff generation, peak runoff rates and sediment yield. The study area included one rural watershed in a humid climate (Ganspoel, Belgium) and a rangeland watershed in an arid region (Lucky Hills, southwestern US).

The results were published in:

Nearing MA, Jetten V, Baffaut C, Cerdan O, Couturier A, Hernandez M, Le Bissonnais Y, Nichols MH, Nunes JP, Renschler CS, Souchère V, van Oost K, 2005a. Modeling response of soil erosion and runoff to changes in precipitation and cover. CATENA 61 (2-3): 131-154.

2. Estimating the sensitivity of runoff and soil erosion patterns to climate change in Mediterranean watersheds. This exercise is a follow-up of the previous exercise, adding an analysis of the impact of changes to soil moisture patterns on runoff and erosion. Another difference is that the exercise uses a nested application of the SWAT model (for the seasonal scale) and the MEFIDIS model (for the extreme event scale). The model was applied to two large scale watersheds, one with a humid Mediterranean climate (Alenquer, Portugal) and the other with a semi-arid Mediterranean climate (Odeleite, Portugal). While full results of this exercise are yet unpublished, preliminary results can be found in:

Nunes JP, Vieira GN, Seixas J, 2006. MEFIDIS - A Physically-based, Spatially-Distributed Runoff and Erosion Model for Extreme Rainfall Events. In: Singh VP, Frevert DK (Eds.), Watershed Models. CRC press, Boca Raton: 291-314.

3. Estimating the importance of storm movement for runoff and erosion patterns at the watershed scale. This exercise tried to upscale results obtained at the laboratory scale using a moving rainfall simulation apparatus. The MEFIDIS model was modified to simulate moving storms with different intensities, radius and speeds over a Mediterranean watershed (Alenquer, Portugal). The impacts of storm movement over the basin's axis in two directions – upstream and downstream – were compared and analyzed. The results can be found in:

Nunes JP, de Lima JLMP, Singh VP, de Lima MIP, Vieira GN, 2006. Numerical modelling of surface runoff and erosion due to moving rainstorms at the drainage basin scale. J. Hydrol. 330 (3-4): 709-720.

4. Studying the impacts of forest fires on runoff generation and soil erosion rates. This exercise was a follow-up to an intensive data collection and rainfall simulation campaign in two recently burnt forest areas, Jafafe and Açores (Portugal). The model was calibrated using plot- and hillslope-scale data to help understand the most important processes driving changes to runoff and erosion response, and to assess the needs for model structure reformulation in order to apply it in recently-burnt catchments. This exercise will now proceed by applying MEFIDIS to a burnt catchment instrumented at both the field and watershed scales. Results are still unpublished at the moment.

Documentation:

A full description of the mathematical formulation and model structure of MEFIDIS, as well as examples of application, can be found here:

Nunes JP, Vieira G, Seixas J, Gonçalves P, Carvalhais N, 2005. Evaluating the MEFIDIS model for runoff and soil erosion prediction during rainfall events. Catena 61 (2-3): 210-

228.
Nunes JP, Vieira GN, Seixas J, 2006. MEFIDIS - A Physically-based, Spatially-Distributed Runoff and Erosion Model for Extreme Rainfall Events. In: Singh VP, Frevert DK (Eds.), Watershed Models. CRC press, Boca Raton: 291-314.

Other Comments: