Modelling soil erosion in a Mediterranean watershed: comparison between SWAT and AnnAGNPS models

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ABSTRACT

In this study, the simulations generated by two of the most widely used hydrological basin-scale models, the Annualized Agricultural Non-Point Source (AnnAGNPS) and the Soil and Water Assessment Tool (SWAT), were compared in a Mediterranean watershed, the Carapelle (Apulia, Southern Italy). Input data requirements, time and efforts needed for input preparation, strength and weakness points of each model, ease of use and limitations were evaluated in order to give information to users. Models were calibrated and validated at monthly time scale for hydrology and sediment load using a four year period of observations (streamflow and suspended sediment concentrations). In the driest year, the specific sediment load measured at the outlet was 0.89 t ha^{-1} yr^{-1}, while the simulated values were 0.83 t ha^{-1} yr^{-1} and 1.99 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively. In the wettest year, the specific measured sediment load was 7.45 t ha^{-1} yr^{-1}, and the simulated values were 8.27 t ha^{-1} yr^{-1} and 6.23 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively. Both models showed from fair to a very good correlation between observed and simulated streamflow and satisfactory for sediment load. Results showed that most of the basin is under moderate (1.4-10 t ha^{-1} yr^{-1}) and high-risk erosion (>10 t ha^{-1} yr^{-1}). The sediment yield predicted by the SWAT and AnnAGNPS models were compared with estimates of soil erosion simulated by models for Europe (PESERA and RUSLE2015). The average gross erosion estimated by the RUSLE2015 model (12.5 t ha^{-1} yr^{-1}) resulted comparable with the average specific sediment yield estimated by SWAT (8.8 t ha^{-1} yr^{-1}) and AnnAGNPS (5.6 t ha^{-1} yr^{-1}), while it was found that the average soil erosion estimated by PESERA is lower than the other estimates (1.2 t ha^{-1} yr^{-1}).

Key words: Soil erosion; Sediment load; SWAT; AnnAGNPS; PESERA; RUSLE2015

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1. Introduction

Watershed management plays an important role in the protection of soil and water (Nikolaidis et al., 2013; Abdelwahab et al., 2014; Bisantino et al., 2015). In areas under Mediterranean climate, a quantification of soil erosion and sediment transport is a challenge, depending on the great variability of the physical characteristics of the watersheds and on the peculiarity of the hydrological regime of streams that are generally intermittent (De Girolamo et al., 2015a, De Girolamo et al., 2018). Moreover, the European Commission focused its policies, on one hand, to maintain and restore the good ecological status of freshwater bodies and on the other to increase the awareness about soil erosion and to implement measures to reduce it. Therefore, within the Water Framework Directive (EC, 2000) and the Soil Thematic Strategy (EC, 2006), all the Member States are called to identify the areas having a high erosion risk and to adopt mitigation measures or Best Management Practices (BMPs) to improve water quality and decrease land degradation (Asres and Awulachew, 2010; Abdelwahab et al., 2016a; Vigiak et al., 2016).

Two methods are mainly used to assess the distribution of eroded areas: field monitoring and mathematical models. The first is laborious and expensive; hence, it can be carried out for small areas, while mathematical models need several input data and should be always applied by trained specialists. Models are fundamental tools for identifying critical source areas in large basins and, in addition, they allow to compare different scenarios such as climate change, land use change, and the impact of BMPs. For these reasons, a large number of mathematical models has been developed in recent decades able to simulate hydrological processes, as well as sediment and nutrient export at the basin scale. Merritt et al. (2003) analysed a number of empirical, conceptual and physically based models commonly used for modelling erosion and sediment transport. The Authors concluded that there is not “the best model” for all the applications, as the models differ significantly in complexity, data requirements, equations used to formalize processes and finally for the outputs they provide. The choice of a model should be done having in mind the general principle “a model right for the right reasons”. Hence, taking into account the final objective of the study and the scales at which the outputs are required, before selecting a model there is a need to examine carefully the extensity and quality of required data, the complexity of the model, the physical characteristics of the watershed (Singh, 1995; Surfleet et al., 2012). A large number of research articles have been published describing model applications at basin (Yuan et al., 2011; Abdelwahab et al., 2013 Chahor et al., 2014; Vigiak et al., 2015; Zhang et al., 2015; Boithias et al., 2017) or regional scale (Kirkby et al., 2003; Panagos et al., 2015a). Despite the ample debate on model applications provided in the literature, the choice of an appropriate model for a certain watershed remains a critical phase (Clark et al., 2008; Parajuli et al., 2009). Indeed, few studies compare the performances of erosion models based on different theoretical background and data requirements (Jattena et al., 1999; Chandramohan et al., 2015). Few studies, however, are based on a comparison between AnnAGNPS and SWAT in predicting runoff and sediment load (Sadeghi et al., 2007; Das et al. 2007; Heathman 2008; Parajuli et al. 2009), and no one of them has been conducted in Mediterranean watersheds. In these basins, due to the extreme spatial variability of both rainfall and physical characteristics, it is more difficult to simulate runoff and sediment transport than in other regions. Indeed, the dry season may constitute a critical point in the performances of the models especially in temporary streams, where the extreme low flow is generally overestimated (De Girolamo et al., 2017; Ricci et al., 2018).

The use of soil erosion modelling approaches at the large scale is fundamental (i.e. European scale) for decision-makers to address the Common Agricultural and Environmental Policies (Matthews A., 2013) and the Soil Thematic Strategy (EC, 2006). Models at European scale operating on standard datasets constitute a methodology that provides a basis for estimating the overall costs attributable to erosion and that objectively identifies areas where detailed studies and remedial measures are needed (Kirkby et al., 2008). However, erosion assessment at the local scale remains a key point in order to implement soil protection practices at the watershed scale (Panagos et al., 2015a).

The first objective of the present work was to analyse two of the most used models at basin scale for simulating streamflow and sediment load: Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) and Annualized Agricultural Non-Point Source (AnnAGNPS) (Theurer and Cronshey, 1998; Bingner et al, 2015) in terms of main outputs, input data and time requirements. The models were applied using the same dataset in the Carapelle (Apulia, Italy; 506 km^2), a typical Mediterranean watershed. The second objective was to analyse the effects of the different theoretical background and data resolution on soil erosion and sediment yield estimation. At this aim the results of the SWAT and AnnAGNPS models were compared with those provided by two important erosion models applied at European scale that have a different theoretical basis and use data with a different resolution in space and time: the Pan-European Soil Erosion Risk Assessment (PESERA) (Kirkby et al., 2008) and the Revised Universal Soil Loss Equation (RUSLE2015) (Panagos et al., 2015a).

The PESERA model (Kirkby et al., 2008) is a process-based model for soil erosion risk assessment at 1 km resolution across Europe. The RUSLE2015 (Panagos et al., 2015a) has been developed for soil loss estimation in the European Union at 100 m resolution using free and up to date database at the European scale. SWAT and AnnAGNPS models operate at basin scale. Both models have already been applied in the Mediterranean environment in recent years (Abouabdillah et al., 2014; De Girolamo et al., 2015b; Gamvroudis et al., 2015, Bisantino et al., 2015; Abdelwahab et al., 2016b).

Literature does not report studies comparing the performances of models applied at a specific area using data having a different resolution or comparing models at European scale with a model at the basin scale.

The analysis of such modelling applications is useful to help water resource managers in selecting a model on the basis of the physical characteristics of the watershed and availability of input data. In addition, the comparison of different model approaches gives a measure of the uncertainty due to the lack of knowledge about the right model to be applied for an estimate.

2. Materials and Methods

2.1 Study Area

The Carapelle watershed (Figure 1) is located in Southern Italy. The river headwaters are in the neighbouring Campanian region and most of the upper watercourse crosses the orographic system of the Daunia Hills, mainly consisting of flysch formations, in the Apulia region (Abdelwahab et al., 2013).

Mediterranean climate conditions prevail in the watershed with wet autumn/winter and dry spring/summer seasons (Trombetta et al., 2016). The rainiest months during the observation period were March (94.9 mm) and November (81.4 mm), while August (6.4 mm) was the driest. The hydrological regime, as peculiar of the Mediterranean intermittent streams, is characterised by high spatial and temporal variability with extremely low flow conditions or absence of flow in part of the river network during the summer months (June to September) and high flow conditions recorded in winter and early spring. Sheet and concentrated (rill) erosion are the main active processes in the area, even if bank erosion is also accounted for (Wasowski et al., 2007). The main economic activity is agriculture, with the production of winter wheat mainly in the flat areas, but also on hillslopes (Novelli et al., 2016). In the mountainous part of the watershed, forestlands and pasture are more frequent (Aquilino et al., 2014).

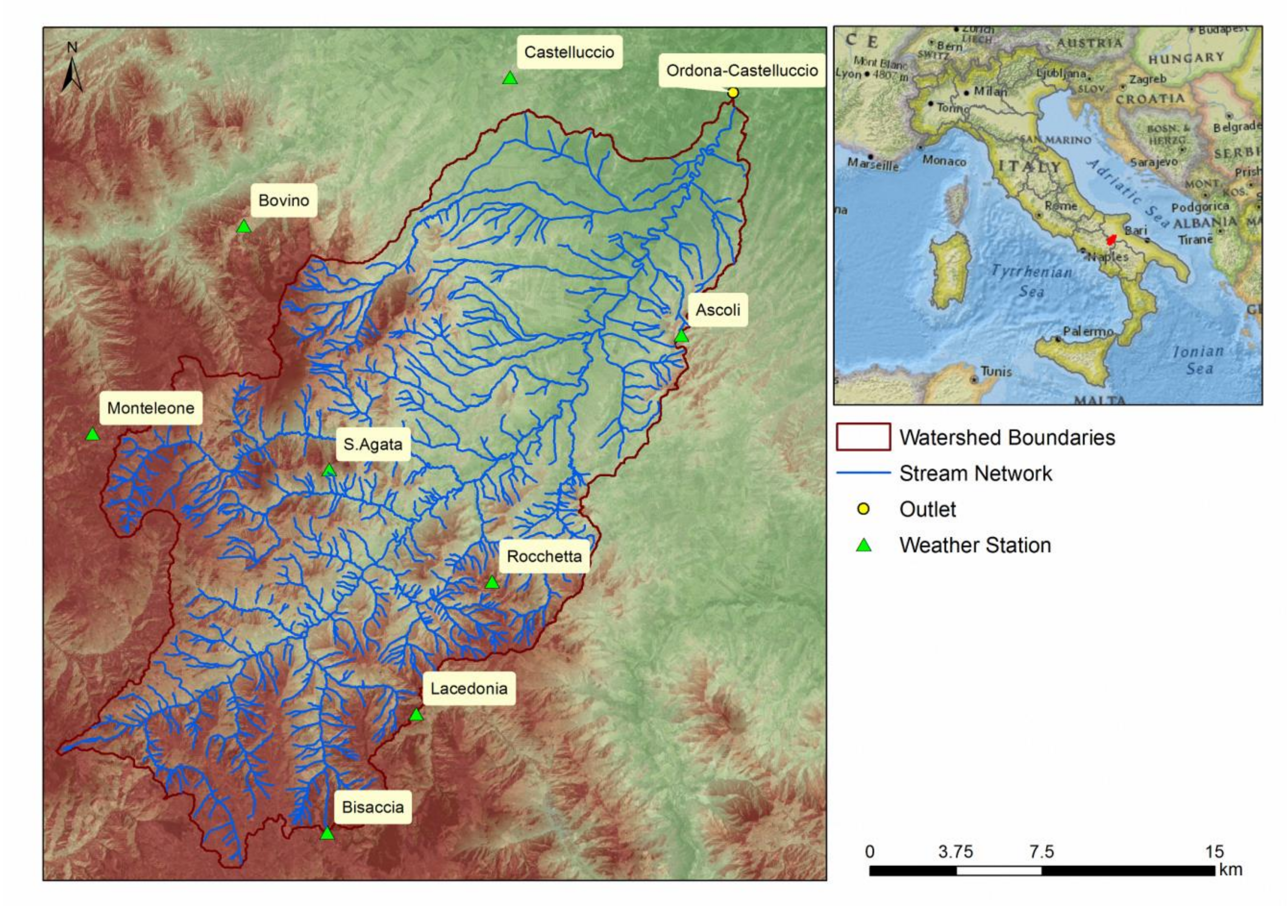

Figure 1

The outlet of this watershed corresponds to the point where a monitoring station is installed that is near the Ordona Village in Northern Apulia (41° 17' 50.347" N; 15° 36' 2.583" E). From the outlet, it derives a drainage area of 506 km^2, with an average elevation of 466 m a.s.l. and a mean slope of 8.2%. The main channel length is 52.16 km.

The monitoring station is equipped with two gauging systems, one for measuring suspended sediment concentration (SSC), and the other one for streamflow measurement and was operating from 2007 to 2011. For measuring streamflow, the Civil Protection Technical Service of Apulia Region runs an electromechanical and an ultrasound stage meters that register data every half an hour, while for the SSC measurement, an infrared optical probe that records measurements every five minutes, aggregated on 30 minutes, is used. The probe has two infrared sensors which are able to detect scattering at 90° and 140° and are inserted in a nearly thoroidal float, which in turn is inserted into a PVC tube. SSC data can be obtained through a built-in data logger. The instrument was calibrated and verified periodically as described in Gentile et al. (2010).

2.2 Model characteristics

SWAT2012 and AnnAGNPS V5.4.3 are watershed scale models developed to quantify the impacts of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Arnold et al., 1998; Theurer and Cronshey, 1998; Bingner et al., 2015).

SWAT and AnnAGNPS differ in several aspects that are both methodological (i.e. equations, watershed delineation) and formal (i.e. GIS interface). Figure 2 shows a scheme of the characteristics and outputs of each model.

SWAT has extensions for ArcGIS (ArcSWAT), QGIS (QSWAT) and MapWindowGIS (MWSWAT), while AnnAGNPS is a stand-alone application with an integrated MapWindowGIS.

Concerning the watershed delineation, SWAT first divides the area into sub-basins with a threshold area in hectares established by the user that defines the minimum drainage area required to form the origin of a stream, then further divides these sub-basins in Hydrologic Response Units (HRUs) that are the reference hydrological unit (or critical source areas) constituted by lumped land areas of unique land cover, soil and slope (Neithsch et al., 2009). AnnAGNPS model provides a cell-based spatial representation, with homogeneous land use, soil, and topographic conditions, using the TOPAGNPS and MAP Windows-based GIS interface within the model input editor (Bingner et al., 2015). The TOPAGNPS software (TOpographic PArameteriZation) is a digital landscape analysis tool that provides comprehensive processing and evaluation of raster DEMs to identify topographic features; measure topographic parameters; define surface drainage, flow direction and flow paths; subdivide watersheds along drainage divides into subcatchments; quantify the drainage network and calculate channel parameters; estimate representative subcatchment parameters (Martz and Garbrecht, 1992).

The SWAT model data preparation is characterised by three modules. The first is the SWAT Watershed Delineator, which allows the users to discretize the watershed, and the sub-watersheds by using the data derived from the DEM. The second is the SWAT HRU analysis tool, which combines data derived from land use, soil characteristics and slope maps in order to discretize the HRUs. The third is the SWAT Input Editor, which allows the user to create input database and modify all the model parameters.

The AnnAGNPS input files preparation consists of two main components. The first component is the TopAGNPS, an operational computer model which allows the user to extract data from a Digital Elevation Model (DEM), to subdivide the watershed and to assist in extracting the DEM-related stream reach (receiving reach, length, elevation and slope) and cell data (drainage area, elevation, aspect, land slope, time of concentration profile slope and length, LS-factor and receiving reach) by setting the Critical Source Area (CSA) and the Minimum Source Channel Length (MSCL) values. The CSA concept controls the watershed segmentation and all resulting spatial and topologic drainage network and subwatersheds characteristics. The CSA value defines a minimum drainage area below which a permanent channel is defined while MSCL is a parameter that is necessary to control the identification of very short channels that satisfy the critical source area criterion (Mark, 1984; Martz and Garbrecht, 1992). The second component is a MapWindow GIS-based interface within the AnnAGNPS Input Editor, which allows the user to import the extracted data from the GIS layers and visualize the results from TopAGNPS, while the input editor itself helps in the process of import/export and editing of input data (Justice and Bingner, 2015).

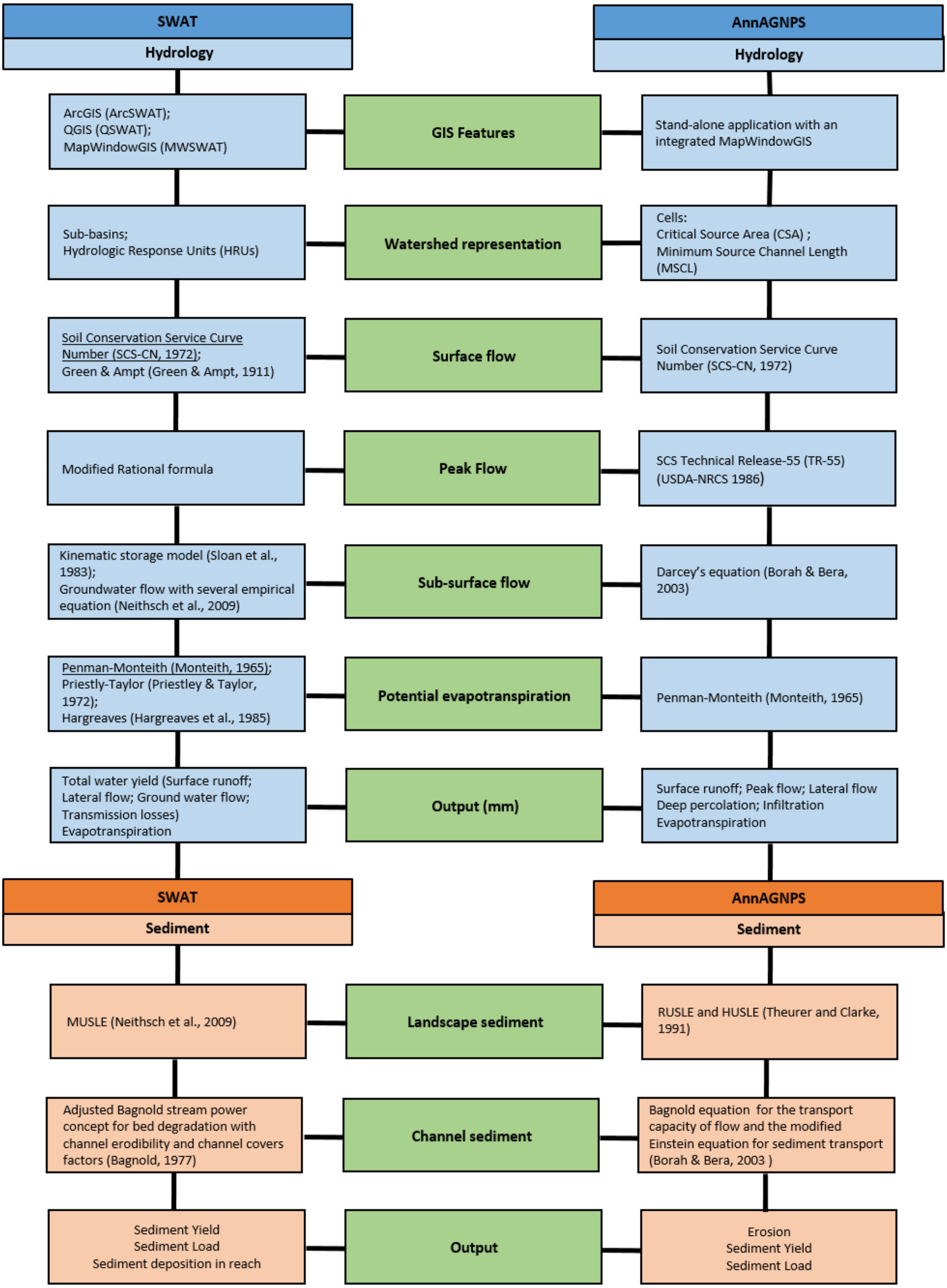
SWAT
Hydrology
AnnAGNPS
Hydrology
ArcGIS (ArcSWAT); QGIS (QSWAT); MapWindowGIS (MWSWAT)
GIS Features
Stand-alone application with an integrated MapWindowGIS
Sub-basins; Hydrologic Response Units (HRUs)
Watershed representation
Cells: Critical Source Area (CSA) ; Minimum Source Channel Length (MSCL)
Soil Conservation Service Curve Number (SCS-CN, 1972); Green & Ampt (Green & Ampt, 1911)
Surface flow
Soil Conservation Service Curve Number (SCS-CN, 1972)
Modified Rational formula
Peak Flow
SCS Technical Release-55 (TR-55) (USDA-NRCS 1986)
Kinematic storage model (Sloan et al., 1983); Groundwater flow with several empirical equation (Neithsch et al., 2009)
Sub-surface flow
Darcey's equation (Borah & Bera, 2003)
Penman-Monteith (Monteith, 1965); Priestly-Taylor (Priestley & Taylor, 1972); Hargreaves (Hargreaves et al., 1985)
Potential evapotranspiration
Penman-Monteith (Monteith, 1965)
Total water yield (Surface runoff; Lateral flow; Ground water flow; Transmission losses) Evapotranspiration
Output (mm)
Surface runoff; Peak flow; Lateral flow Deep percolation; Infiltration Evapotranspiration
SWAT
Sediment
AnnAGNPS
Sediment
MUSLE (Neithsch et al., 2009)
Landscape sediment
RUSLE and HUSLE (Theurer and Clarke, 1991)
Adjusted Bagnold stream power concept for bed degradation with channel erodibility and channel covers factors (Bagnold, 1977)
Channel sediment
Bagnold equation for the transport capacity of flow and the modified Einstein equation for sediment transport (Borah & Bera, 2003)
Sediment Yield Sediment Load Sediment deposition in reach
Output
Erosion Sediment Yield Sediment Load

Figure 2

The SWAT model operates on a daily time step and it provides a number of output files organized at different spatial scales: watershed, sub-basin, HRUs, and main channel reach. All the output files can be visualized at daily, monthly and yearly time scale (Arnold et al., 2012). The output files comprise the main components of hydrology (total water yield, surface runoff, groundwater flow, lateral flow, percolation, potential and actual evapotranspiration) and sediment (Figure 2). SWAT model provides the sediment yield at sub-basin and HRUs level calculated with the MUSLE equation, the sediment load and the deposition occurring in reach (Arnold et al., 2012).

The AnnAGNPS model allows users to view the results at watershed and sub-watersheds/cells scale. Model outputs comprise: surface runoff, peak flow, lateral flow, deep percolation, infiltration, actual and potential evapotranspiration, erosion, sediment load and sediment yield (Bingner et al, 2015). The term soil erosion for the AnnAGNPS model refers to the amount of soil detached from the landscape. For both models, the sediment yield (t) refers to the amount of sediment that moves through the landscape and reaches the channel. The sediment load (t) refers for both models to the amount of sediment that moves through the stream channels and reaches the sub-watershed or the watershed outlet (Arnold et al., 2012; Yuan et al. 2006).

2.2.1 Hydrology

In SWAT, the hydrological cycle is based on the classical water balance equation (Neithsch et al., 2009). For the simulation of surface runoff, both models use the Soil Conservation Service Curve Number method (SCS-CN, 1972) based on daily rainfall data. The SCS-CN is an empirical model that does not consider rainfall intensity and duration but only the rainfall volume. However, the SWAT model offers the alternative option to predict infiltration by using the Green & Ampt infiltration method (Green and Ampt, 1911). This method, which is physically based, simulates impacts of rainfall intensity and duration, in addition to the infiltration processes. It requires sub-daily rainfall data as it is a time-based model. The peak flow is estimated with the modified rational formula in SWAT and with the SCS Technical Release-55 (TR-55) method in AnnAGNPS (USDA-NRCS, 1986). Both models also consider the sub-surface flow: SWAT uses the kinematic storage model (Sloan et al., 1983) and AnnAGNPS uses Darcy’s equation (Borah and Bera, 2003). A substantial difference between SWAT and AnnAGNPS is that the latter does not simulate baseflow (Yuan et al., 2008; Zema et al., 2016), which is the contribution of groundwater into streamflow. SWAT allows the simulation of groundwater flow with empirical equations (Neithsch et al., 2009).

Three different options are provided by the SWAT model to estimate the potential evapotranspiration: Penman-Monteith (Monteith, 1965), Priestly-Taylor (Priestley and Taylor, 1972), and Hargreaves methods (Hargreaves et al., 1985; Allen, 1986; Allen et al., 1989). The amount of required input data varies among the methods. The AnnAGNPS model uses only the Penman-Monteith equation to estimate potential evapotranspiration. Both models are freely download open source code model and can be subjected to any developments of any of its components in a way that could facilitate any customized conditions.

The plant growth component is a simplified version of the corresponding module of the EPIC model. Phenological plant development is based on daily accumulated heath units, potential biomass is based on a method developed by Monteith, a harvest index is used to calculate yield, and plant growth can be inhibited by temperature, water, nitrogen or phosphorus stress. SWAT requires for each plant the heat units, while the AnnAGNPS needs yield units harvested per area.

2.2.2 Sediment

Landscape sediment is computed in SWAT with the Modified Universal Soil Loss Equation MUSLE (Williams, 1975) where the rainfall factor (R) is replaced with a runoff factor. Channel sediment is calculated using the Bagnold equation, where the maximum transport is based on the peak channel velocity. The Bagnold stream power can be adjusted to account for bed degradation with channel erodibility and channel cover factors (Bagnold, 1977; Neitsch et al., 2009). During the pre-processing phase, the SWAT model calculates the USLE topographic (LS) and USLE cover and management (C) factors. LS factor is calculated from the elevation map taking into account the slope within each HRUs. The C factor, instead, is calculated based on land cover and management basis and on the minimum C factor value defined for the plant/land cover in the SWAT Access database.

In AnnAGNPS, the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) is used to predict sheet and rill erosion but not field deposition, so the delivery ratio of the sediment yield to the stream is calculated by the Hydro-geomorphic Universal Soil Loss Equation (HUSLE). HUSLE (Theurer and Clarke, 1991) formula calculates the total sediment yield for a given storm event to any point in the watershed. Sediment reach routing is based on a modified Einstein deposition equation and the Bagnold suspended sediment formula is used to estimate the transport of sediment within the streams (Borah and Bera, 2003). During the data preparation pre-processing step, AnnAGNPS calculates the LS and C factors at a 15-day time step, to account for temporal variability based on crop and management practices applied in the field.

AnnAGNPS calculates the soil erosion, sediment yield, and sediment load as previously defined. SWAT model provides sediment yield at sub-basin and HRUs level, the sediment load and the deposition occurring in reaches (Arnold et al., 2012).

2.3 Model set up

The same data set was used to set up both models. Table I summarizes main data, their source and resolution. For AnnAGNPS, a threshold of 200 ha (less than 0.5% of the total watershed area) was fixed for CSA and a minimum source channel length (for MSCL) of 130 m was set to discretize the watershed and sub-watersheds stream network. These thresholds have resulted in dividing the watershed into 283 cells and 114 reaches.

For SWAT, a 2000 ha threshold critical source area was used, which divided the watershed into 17 sub-basins as in Ricci et al., (2018). In this work, in order to account for the spatial variability of parameters, a further threshold of 200 ha was then considered for delineating the 72 HRUs within sub-basins, instead of a percentage threshold (soil/land use/slope) set by Ricci et al., (2018). Although the number of AnnAGNPS cells is different from the number of HRU a check was carried out to make sure that both models respected the major classes of land use, soil type and slope (Parajuli et al., 2009).

The soil characteristics (texture, field capacity, wilting point, hydraulic conductivity) were derived from the Agro-ecological Characterization of the Apulia Region project named ACLA2 (250m). The dominant soil types are the silty clay loam, sand clay loam and loamy soils.

A description of land use in the watershed was determined from the merge between the Land Use Map (UDS) of Apulia and the Land Agricultural Use Map (CUAS) of Campania both with a resolution of 100 m (Table I). The winter wheat is the main crop in the watershed occupying more than 80% of the watershed area. Other land uses are olive groves, deciduous, coniferous and mixed forests, pasture and urban areas. Land uses derived from these maps were reclassified assigning a SWAT code as required by the model database.

AnnAGNPS input accepts five types of land use identifiers (cropland, pasture, forest, rangeland and urban), and only the predominant land use and management is used to represent each AnnAGNPS cell (Parajuli et al., 2009). The land uses were reclassified to fit the AnnAGNPS required land use input set.

The management operation data regarding winter wheat and olive, which are the main crops in the watershed, were collected from field surveys and farmer interviews. For winter wheat, a 4-year crop rotation was adopted with ploughing (25-40 cm depth) in August, harrowing in October and mineral fertilizers applications in December (fertilizer grade: 25-15-00) and February (urea). The crop was planted in November and harvested in July. For olive plants, on the other hand, three shallow tillage operations (ploughing and harrowing) were applied every two months starting in April, two fertilizations were applied in December (manure) and spring (fertilizer grade: 26-00-00), while the plants are harvested in November (Abdelwahab et al., 2016a). For each crop, these management operations were considered invariant within the watershed and included in both model simulations.

Daily weather data, from 2006 to 2011, (daily maximum and minimum temperatures, daily precipitation, solar radiation, wind speed, and dew point), acquired by eight weather stations located in the watershed and its perimeter, were used as climate input data for the simulations.

For the potential evapotranspiration, the Penman-Monteith method was selected, while for surface runoff the modified SCS-CN2 was used for both models.

The USLE support practice factor (P) used in the RUSLE and MUSLE equations was set to 1 since no conservation practices (terracing, contouring) were adopted in the Carapelle watershed to reduce soil erosion. The USLE soil erodibility factor (K) was calculated for each soil type using the equation developed by Lal and Elliot (1994). The R factor of RUSLE needed in AnnAGNPS was calculated as suggested by Ferro et al. (1999). A synthetic rainfall distribution type I outlined by the Natural Resource Conservation Service (NRCS) and described by USDA-SCS (1972) was considered. Bingner and Theurer (2015) stated that the storm type‘s rainfall distribution is used to determine the day’s rainfall maximum 30-minute intensity used to calculate the sheet and rills erosion, and also the peak discharge associated with the runoff at any location in the watershed.

Table I

Description	Data source	Data resolution
Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM) Data source: http://www.sinanet.isprambiente.it	20 × 20 m
Land use data	Land Use Map (UDS) of Apulia and Land Agricultural Use Map (CUAS) of Campania; http://sit.puglia.it; http://sit.regione.campania.it	100 × 100 m
Soil data	Agro-ecological Characterization of the Apulia Region ACLA2; Regione Puglia, 2001	250 × 250 m; 9 soil profiles
Weather data	Precipitation, solar radiation, wind speed, relative humidity, min. and max temperature, http://www.protezionecivile.puglia.it (2006-2011)	8 Gauging stations
Measured Data for calibration and validation	Four years of measured daily streamflow and sediment load (2007-2008; 2010-2011).	sub-daily (30-min) aggregated at daily time scale

2.4 Model calibration and validation

The models (SWAT and AnnAGNPS) were applied through the period 2007 - 2011. A four years period of sub-daily observed data aggregated at monthly time scale (streamflow and sediment load) was used to calibrate and validate the models. Data recorded in 2007 and 2008 were used for the calibration and data from 2010 to 2011 for the validation. Due to several lacks of recorded data in the 2009, this year was not included in the calibration and validation.

Prior to calibration, the most sensitive parameters, which are known to greatly affect runoff and sediment predictions, were selected for both models, as suggested by Malagò et al., (2017), Arnold et al., 2015, and Parajuli et al. (2009). The sensitivity analysis and the calibration of streamflow for the SWAT model was carried out with the automated tool SWAT-CUP by applying the Sequential Uncertainty Fitting version 2 (SUFI2) (Abbaspour, 2015), whereas AnnAGNPS was manually calibrated. A detailed description of the sensitivity analysis carried out for AnnAGNPS and SWAT model in the Carapelle watershed is reported in Bisantino et al. (2013) and Ricci et al. (2018), respectively. Moreover, for SWAT it was chosen to consider the Manning "n" roughness coefficient for the main channel (CH_N2) in the sediment load calibration as suggested by Sohrabi et al (2003) and Arabi et al. (2008). Table II shows the parameters subjected to calibration for both models and the final range of values used in this work. For both models, the calibration was carried out working on the most sensitive parameters starting from the hydrology which has been followed by the sediment, as suggested by several authors (Pagliero et al., 2014; Arnold et al., 2015; Malagò et al., 2015; Brouziyne et al 2017).

To calibrate AnnAGNPS, the baseflow component was separated from the streamflow hydrograph. The web-based Hydrograph Analysis Tool (WHAT, Lim et al., 2005) was used to separate base flow from streamflow both for simulated and measured hydrographs.

Since in temporary rivers most of the erosion processes are concentrated in the wet season (De Girolamo et al., 2015), it is of most importance to consider the model tendency to perfectly simulate during the wet season even with its satisfactory performance in the dry periods. Indeed, many authors have suggested separating wet and dry seasons (Lèvesque et al., 2008; White et al., 2009) in order to eliminate inconsistency during dry season and improve models performance. To investigate this issue, the data were split into two periods, wet (from November to April) and dry (from May to October), and the goodness of fit of predicted sediment by both models was reconsidered and compared with the results obtained considering the entire period (calibration and validation).

Models performance was evaluated at monthly scale using the coefficient of determination (R^2), Nash-Sutcliffe Efficiency index (NSE, Nash and Sutcliffe, 1970) and Percent Bias (PBIAS). Information about these statistical indicators can be found in Gupta et al., (1999); Krause et al., (2005); Legates and McCabe, (1999); Moriasi et al., (2007); and van Liew et al., (2003). For model evaluation, acceptable model performance values (NSE and $R^2 > 0.5$, PBIAS $\leq \pm 25\%$ for streamflow -surface runoff- and ± 55% for sediment load; if negative PBIAS indicates overestimations) are recommended by Moriasi et al. (2007) and by several studies conducted in areas under Mediterranean climate (Furl et al., 2015; Nerantzaki et al 2015; Briak et al 2016; Licciardello et al., 2017; Zettam et al., 2017).

Table II

Parameter definition	Acronym [a]	Fitted values SWAT	Fitted value AnnAGNPS
Hydrology			
Curve Number	CN2.mgt	65-94	60-92
Threshold depth of water in shallow aquifer	GWQMN.gw	0.3	
Groundwater delay time	GW_DELAY.gw	73	
Baseflow alpha factor	ALPHA_BF.gw	0.72	
Groundwater “revap” coefficient	GW_REVAP.gw	0.06	
Manning's "n" value for overland flow	OV_N.hru	0.09	
Soil available water storage capacity	SOL_AWC.sol	0.09-0.22	
Effective hyd. cond. in the main channel	CH_K2.rte	56.68	
Sediment			
Manning’s “n” roughness coefficient	CH_N2.rte	0.41	0.13-0.8
Maximum amount of sediment retrained during channel sediment routing	SPCON.bsn	0.003	
Sediment concentration in groundwater flow	LAT_SED.hru	250	
Peak rate adjustment factor for sediment routing in the sub-basin	ADJ_PKR.bsn	1.4	
Manning’s concentrated flow (Cell Data)			0.04
Root mass (crop data)			Wheat: 0-1200 kg/ha; Olive: 30000 kg/ha
Canopy cover (Crop Data)			0.5-0.8
% Rock Cover			10-15

2.5 Models at European scale

PESERA (Kirkby et al., 2008) is a process-based model designed to estimate long-term soil loss at a 1 km resolution that integrates the impact of topography, climate, land cover and soil into a single combined calculation of soil erosion. Precipitation is divided into components for surface runoff, evapotranspiration and changes in soil water content. The model first estimates storm surface runoff, and then uses the surface runoff for estimating sediment transport (proportional to the sum of surface runoff squared). The threshold for surface runoff formation (for infiltration excess) varies over the year. Total erosion depends on soil properties that replace the USLE erosivity and it is assessed at the base of slope (see the scheme in Kirkby et al., 2008). PESERA is a runoff-based erosion model, which predicts runoff with a daily time step, but it does not include the management operations (i.e. tillage). This may be an important limitation of the model, especially in Mediterranean mountainous basins where the up-and-down ploughing is quite common.

The climate input files are mean monthly data derived from Monitoring Agriculture with Remote Sensing (MARS) meteorological database of a 50 km grid cell that was successively interpolated at a 1 km grid cell (Jones et al. 2003) while land use data is based on CORINE 1990 resampled at a 1 km grid cell. The soil input data are based on the European Soil Database (ESDB) at 1:1,000,000 resolution (King et al. 1994; King and Jamagne 1995). The topographic input data are based on GTOPO30 which is a 30 m resolution global digital elevation model (DEM). The PESERA dataset and the detailed technical description of the model are freely available from ESDAC (Panagos et al. 2012).

The RUSLE is an empirically based model that relates management and environmental factors directly to soil loss and sediment yield. It is based on the USLE model but it has improved the effects of local weather on the prediction of soil loss and sediment delivery. The RUSLE2015 (Panagos et al., 2015a) was developed for soil loss estimation in the European Union at 100 m resolution using free and up to date database at the European scale. A large number of field sampling points (20,000), included in the Land Use/Cover Area frame (LUCAS) survey (Toth et al., 2013), were used to estimate the K-factor. The field sampling points were interpolated to produce a 500 m resolution K-factor map of Europe (Panagos et al., 2014a). The R-factor is calculated based on high-resolution temporal rainfall data collected across Europe (Panagos et al., 2015b). The C-factor is modelled either in the arable and non-arable lands. In arable lands, C-factor is based on crop composition and land management practices (Panagos et al., 2015c), while in the non-arable land a combination of land-use class and vegetation density is used. The LS-factor (Panagos et al., 2015d) is calculated using the recent Digital Elevation Model (DEM) at 25 m and applying Desmet and Govers (1996) equations. Lastly, the P-factor considers agro-environmental practices carried out for the protection against soil loss such as contour farming, stone walls and grass margins (Panagos et al., 2015e).

3 Results

3.1. Hydrology

At the end of the calibration and validation processes at monthly time scale, both models showed a satisfactory performance according to the criteria defined by Moriasi et al., (2007). Table III summarizes the SWAT and AnnAGNPS performances. As shown in the table, SWAT tended to underestimate mean monthly streamflow in the calibration period (PBIAS +6.12) and overestimated in the validation period (PBIAS -1.75). AnnAGNPS instead slightly overestimated surface runoff in calibration (PBIAS -1.75) and underestimated it during validation (PBIAS +22). Figure 3 shows measured and simulated total water yield (mm) through the calibration and validation periods for the

SWAT model (Figure 3 A, B) and measured and simulated surface runoff for the calibration and validation periods for the AnnAGNPS model (Figure 3 C, D).

Results show that mean monthly precipitation estimated by the SWAT model was always slightly higher than that estimated by the AnnAGNPS model, except in May and June. For the entire study period, the mean annual rainfall values were 686 mm and 637 mm, estimated by SWAT and AnnAGNPS, respectively. This discrepancy could be due to the different methods used by the models for counting precipitation. SWAT uses the centroid method (Swain and Patra, 2017), while AnnAGNPS uses the weighted average Thiessen polygon method (Zema et al., 2016). The largest difference in precipitation values between the two models was in December (8%), while the minimum difference was in June (0.1 %).

These differences also affect other factors, such as surface runoff, total water yield and sediment yield, as pointed out by Du et al. (2013). Both models underestimated surface runoff in very wet months. In summer and autumn, the results show no clear tendencies of the surface runoff simulations neither of overestimation nor of underestimation with respect to the observed surface runoff. The lower performances of the models resulted in validation period (2010/2011) are supposedly due to several extraordinary floods recorded at that time, which were underestimated by both models. For instance, in November 2010, the rainiest month in the simulation period (152 mm), a runoff record of 62.6 mm has been registered which was higher than the average value (54.7 mm) registered during the period 1987-2007 by the National Hydrographic Service.

Table III

		SWAT		AnnAGNPS	
		Streamflow ($m^3 s^{-1}$)	Sediment Load (t)	Surface Runoff (mm)	Sediment Load (t)
CALIBRATION	NSE	0.65	0.93	0.58	0.68
	PBIAS	6.12	-5.49	-1.75	-29.33
	R^2	0.76	0.94	0.68	0.72
VALIDATION	NSE	0.65	0.51	0.48	0.35
	PBIAS	-1.75	-19.58	22	15.49
	R^2	0.65	0.53	0.52	0.37

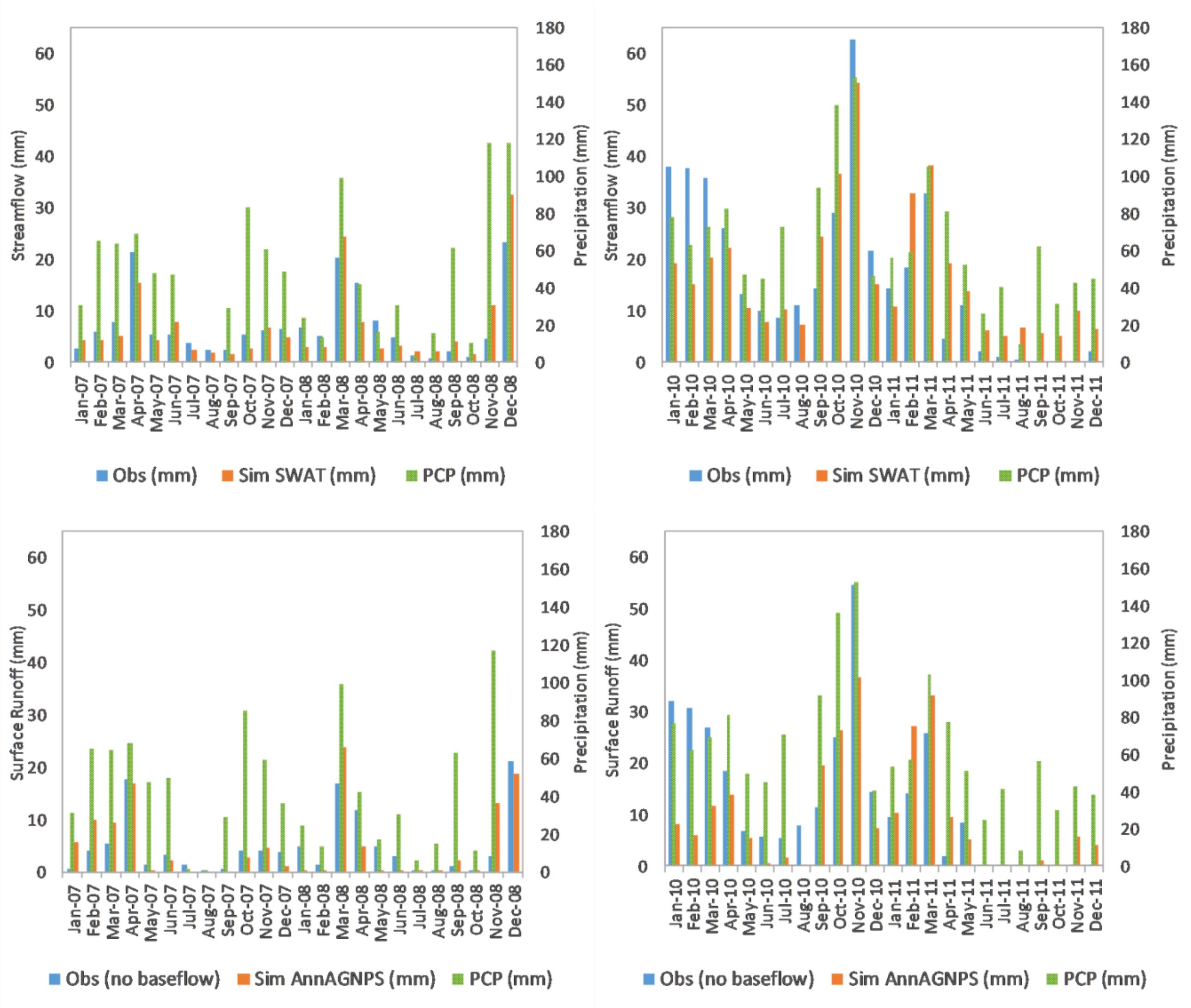

Figure 3.

3.2. Sediment

A very good correlation between observed and simulated sediment load was noticed for SWAT in calibration, as confirmed by the statistical indexes (Table III). Nonetheless, the SWAT performance was satisfactory during the validation period, showing a sediment overestimation bias.

AnnAGNPS instead, showed a good correlation between observed and simulated sediment through calibration as explained by the R^2 and NSE statistical indexes, while PBIAS showed an overestimation. During the validation period, an unsatisfactory performance (Table III) of the model in predicting sediment was noticed with a model tendency to underestimate sediment.

Figure 4 evidences that the trend of both models is similar. In the driest year (2007), the specific sediment load measured at the outlet was 0.89 t ha^{-1} yr^{-1}, while the simulated values were 0.83 t ha^{-1} yr^{-1} and 1.99 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively. A relevant difference was found among the years, in fact, in the wettest year (2010), the specific sediment load measured at the outlet was 7.45 t ha^{-1} yr^{-1}, while the simulated values were 8.27 t ha^{-1} yr^{-1} and 6.23 t ha^{-1} yr^{-1} for SWAT and AnnAGNPS, respectively.

A comparison between measured load and simulated values at the outlet was performed for the wet (November to April) and dry periods (May to October), as well as of the model performances. As Table IV shows, the reason of the unsatisfactory performance in sediment simulation, especially for AnnAGNPS, was its poor performance during the dry season, whilst in the wet season the statistical results were much improved. Both models overestimated sediment load in the dry seasons, especially in the validation period when the particularly rainy September and October 2010 resulted in high sediment loads simulated by the models (Figure 3B,C and Figure 4B,C). In the dry season, a high uncertainty can affect the spatialisation of the convective rainfalls, characterised by high intensity of short duration, as frequently these events are localised in small areas. This different model performances in wet and dry periods is typical of Mediterranean intermittent rivers (De Girolamo et al., 2015b; De Girolamo et al., 2017).

In November 2010, which was the rainiest month of the study period, both models tended to underestimated measured specific sediment load (5.29 t ha^{-1} yr^{-1}), as well as streamflow. SWAT underestimated the specific sediment load by 50% (2.4 t ha^{-1} yr^{-1}) while AnnAGNPS under predicted it by 66% (1.8 t ha^{-1} yr^{-1}).

Table IV

	Measured load	AnnAGNPS Sim load	SWAT Sim load	AnnAGNPS			SWAT		
	(t)	(t)	(t)	NSE	PBIAS	R^2	NSE	PBIAS	R^2
wet 2007/2008	101636	118981	102072	0.7	-17.1	0.8	0.9	-0.4	0.9
dry 2007/2008	6152	20426	11635	-167	-232.0	0.2	-14.7	-89.1	0.2
wet 2010/2011	514496	318858	513808	0.4	38.0	0.6	0.5	0.1	0.6
dry 2010/2011	71080	175984	186420	-5.5	-147.6	0.2	-4.3	-162.3	0.2

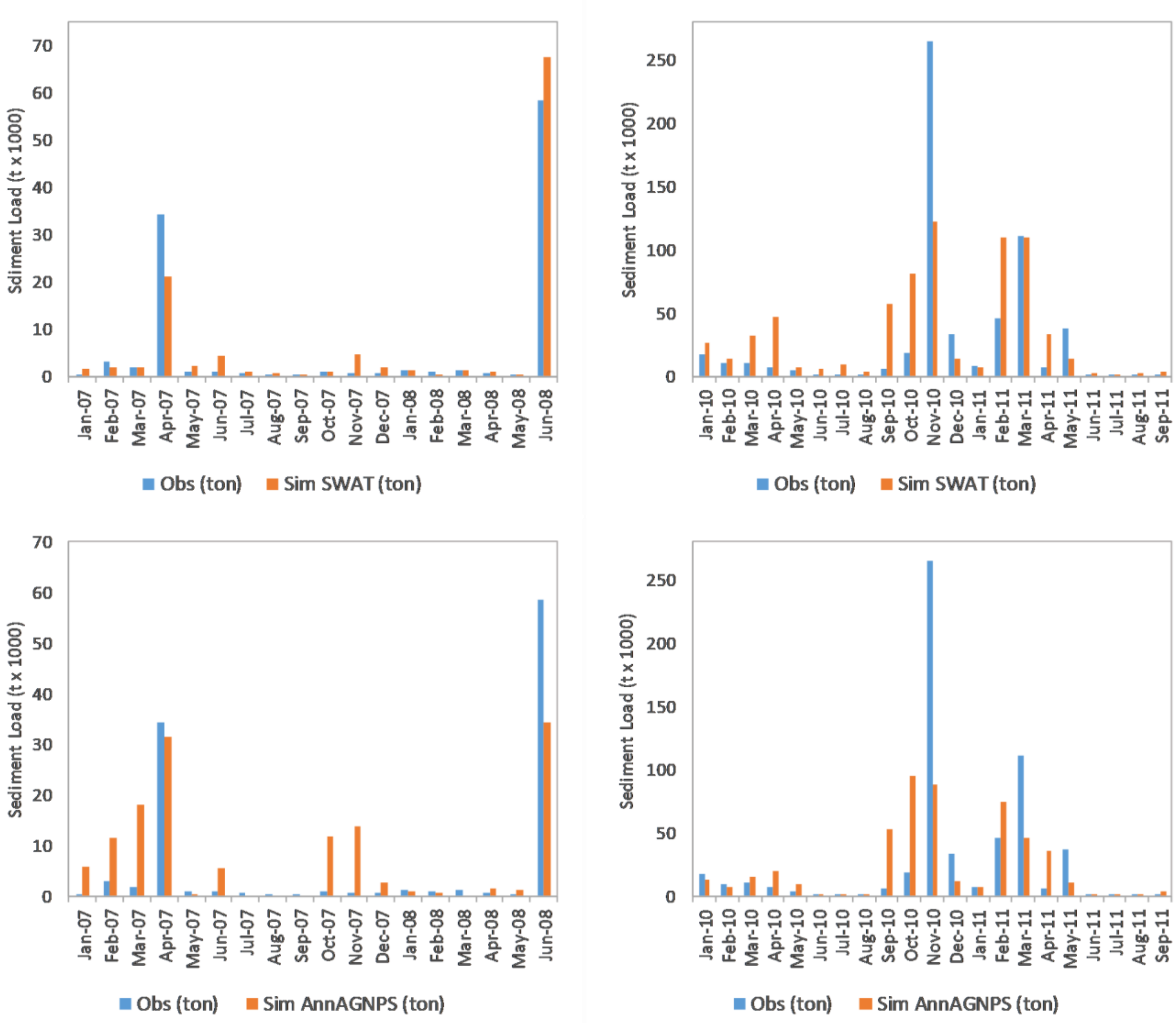

Figure 4.

3.3 Sediment source areas

One of the purposes for which erosion models are widely used is the identification of the sediment source areas (Xiaoyan et al., 2011; Pradhanang et al., 2013; Qi et al., 2017; Vigiak et al., 2017). In the Carapelle watershed, the specific sediment yield rate estimated by SWAT ranges between 0.3 and 31.3 t ha^{-1}yr^{-1} across sub-watersheds, while AnnAGNPS estimated a specific sediment yield across the cells between 0 and 37 t ha^{-1}yr^{-1}. Furthermore, the highest sediment yield contribution (cells/HRUs) was predicted for winter wheat fields, while forest and rangeland represented the land uses producing the lowest specific sediment yield. Table V shows the specific sediment yield estimated for winter wheat, which is the main crop in the basin, for three different slope classes. The highest values of specific sediment yield were predicted in steep slope areas and the differences within each slope class were due to soil type and rainfall amount.

Table V

	SWAT (HRUs)			AnnAGNPS (Cells)		
	Average slope steepness (m m^{-1})					
	>0.10	0.10-0.05	0.05-0	>0.10	0.10-0.05	0.05-0
	(t ha^{-1} yr^{-1})					
Max	54.7	21.5	5.5	37.5	22.9	6.6
Min	2.3	4.4	0.1	3.9	1	0.03
Avg	21.2	8.6	1.8	8	2.6	0.5

3.4 Comparing erosion models at Europe and basin scale

In order to compare our results with European modelling applications, a soil erosion map was obtained for the Carapelle watershed both from the European RUSLE 2015 and from the PESERA. Figure 5A, 5B, 5C, 5D show the spatial distribution of the specific sediment yield simulated by SWAT and AnnAGNPS and the soil erosion predicted by RUSLE 2015 and PESERA.

To better analyse the spatial distribution of the specific sediment yield and soil erosion rates and to make the visual comparison of the four maps easier, three different classes were identified: low soil erosion (0-1.4 t ha^{-1} yr^{-1}); medium soil erosion (1.4-10 t ha^{-1} yr^{-1}), and high soil erosion (>10 t ha^{-1} y^{-1}). The lower threshold is based on the rate of soil formation set by Verheijen et al. (2009) while the higher threshold is based on the value of severely erosion-prone areas by Kuhlman et al. 2010 and Panagos et al. 2015a. Here, the results provided by the SWAT and AnnAGNPS in terms of sediment yield, which is the amount of sediment that moves through the landscape and reach the channel, were analysed. The results of SWAT and AnnAGNPS models show that specific sediment yield decrease from upstream to downstream. Based on the above mentioned classification, the plain area show low specific sediment yield, while most of the Carapelle watershed is under a moderate and high specific sediment yield (Figure 5 A, B).

Hence, it is expected that results from European models are higher than those provided by the watershed scale models as RUSLE2015 and PESERA provide the soil erosion, which is a "gross erosion".

In the Carapelle watershed, RUSLE2015 estimates an average soil erosion rate of 12.52 t ha^{-1} yr^{-1} ranging between 0.03 and 53.5 t ha^{-1} yr^{-1} (99° percentile). These values are close to the specific sediment yield estimated by the SWAT model at HRU level that range from 0.0 to 54.7 t ha^{-1} yr^{-1} (99° percentile) with an average 8.8 t ha^{-1} yr^{-1}, whilst, AnnAGNPS show at cell level a mean value of 5.59 t ha^{-1} yr^{-1} ranging from 0 to 30.1 t ha^{-1} yr^{-1} (99° percentile). Indeed, the mean value across the watershed estimated by PESERA is 1.21 t ha^{-1} yr^{-1}, ranging from 0 to 5.7 t ha^{-1} yr^{-1} (Figure 5D). The boxplots in Figure 6 show the distribution of soil erosion predicted by RUSLE and PESERA and the specific sediment yield estimated by the SWAT and AnnAGNPS models within the Carapelle watershed. RUSLE2015 shows some extremely high values as well as the SWAT model, which are limited to very small areas, while the interquartile range for these models is very close.

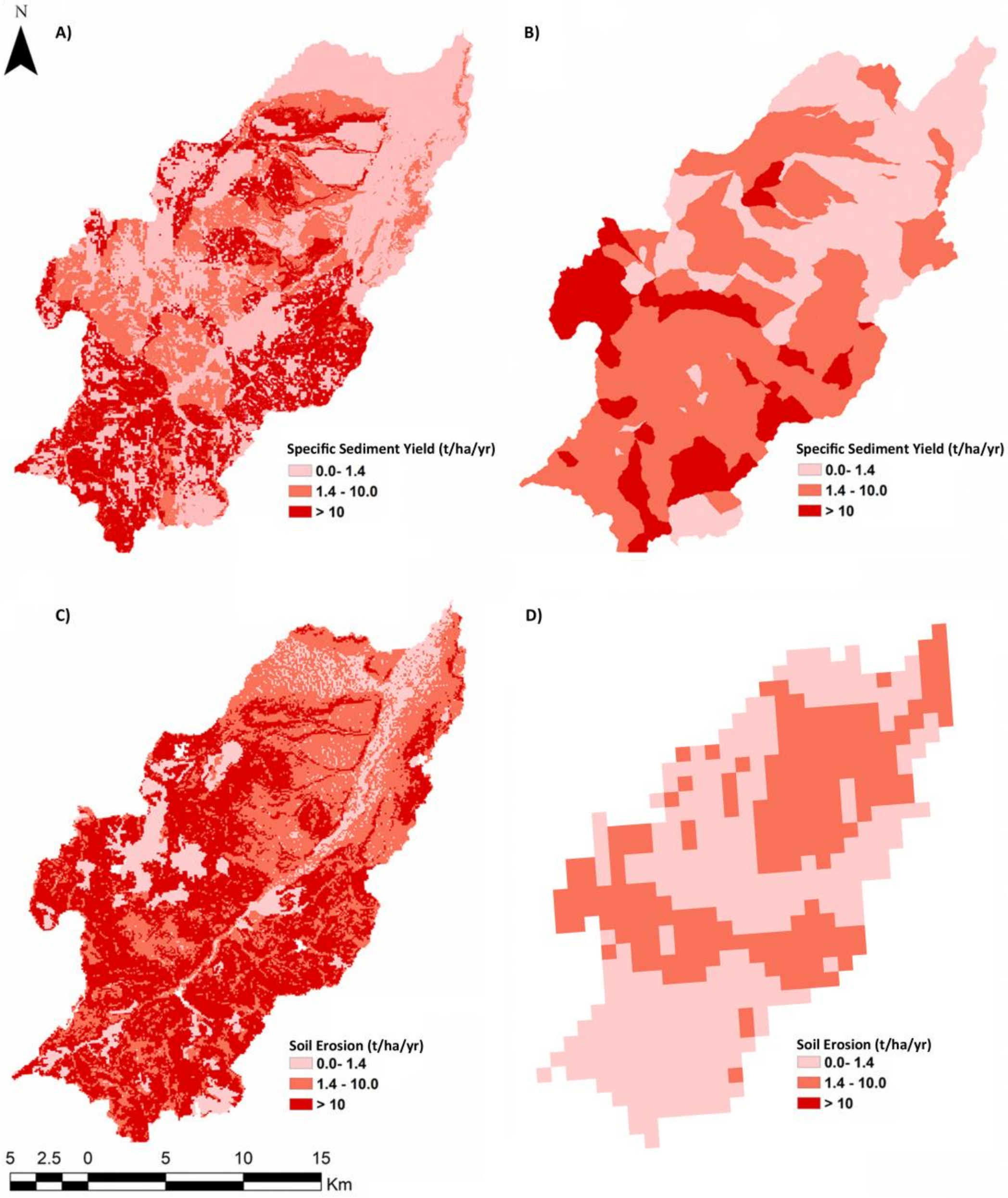
N
A)
B)
Specific Sediment Yield (t/ha/yr)
0.0- 1.4
1.4 - 10.0
> 10
Specific Sediment Yield (t/ha/yr)
0.0- 1.4
1.4 - 10.0
> 10
C)
D)
Soil Erosion (t/ha/yr)
0.0- 1.4
1.4 - 10.0
> 10
Soil Erosion (t/ha/yr)
0.0- 1.4
1.4 - 10.0
> 10
5 2.5 0 5 10 15
Km

Figure 5.

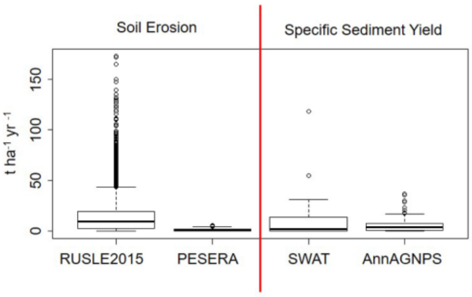

Figure 6.

4. Discussion

4.1 Modelling hydrology and sediment load

The results of the present study showed that both SWAT and AnnAGNPS are able to simulate hydrology and sediment load in basins under Mediterranean climate, although it is well known that hydrological modelling in the Mediterranean areas is a challenge due to the extreme variable condition of flow regime during seasons (De Girolamo et al., 2015b) and for the lack of available data (Oueslati et al., 2015).

The performance in simulating runoff was found satisfactory both for AnnAGNPS and SWAT models. The lower performances of the models resulted in validation period (2010/2011) are supposedly due to several extraordinary floods recorded at that time, which were underestimated (i.e. November 2010) or overestimated (i.e. July 2010 and March 2011) by the models.

For sediment load simulation, both models showed a tendency to underestimate sediment load in extremely wet months and to overestimate sediment load during the dry season. It seems that the difference between simulated and measured sediment load is higher for AnnAGNPS. Indeed, it seems that AnnAGNPS overestimates sediment load in dry years and underestimates in wet years. An explanation of the AnnAGNPS satisfactory results, instead of good, could be due to the manual calibration, as trying to find the best fit parameters manually using trial and error method is less efficient than doing this with an automated tool like SWAT CUP, regarding time consuming and computational reasons.

Results obtained in this work are in good agreement with the studies carried out by other authors using AnnAGNPS and SWAT. Parajuli et al. (2009) in their work found that both models generally provided fair to very good efficiency of simulating surface runoff and sediment load. Heathman et al. (2008) found a better performance achieved by SWAT over AnnAGNPS in streamflow prediction. Sadeghi et al. (2007), instead, found that AnnAGNPS was able to successfully predict monthly water discharge, while the SWAT model performances were very low.

The lower performance obtained in the validation period compared to the calibration and the underestimation of sediment load could be the result of several factors, for example, the effect of the bank collapse that is very common in semi-arid zones during flood events in the wet season (De Girolamo et al., 2015b). As known, hydrological models using the MUSLE or RUSLE equations cannot quantify properly these processes (Duvert et al., 2012).

The number of rainfall gauges and their position in the watershed, as well as the method used to assign the precipitation gauge for each sub-basin, strongly influence the modelling results. In the Carapelle watershed, the eight climatic stations were not uniformly distributed in the watershed. As a consequence, it may result in an overestimation of rainfall values assigned in some sub-basins, while other locations of the watershed could be severely underestimated (Bouraoui et al., 2005, Heathman et al., 2008). In addition, the centroid method used by the SWAT model to assign a precipitation gauge to a sub-basin could be less accurate than the Thiessen method used by AnnAGNPS (Masih et al., 2011; Galván et al., 2013; Ruan et al., 2016), especially in areas characterized by a complex topography (Tuo et al., 2016, Zeiger and Hubbart, 2017). The latter aspect contributes to simulate runoff differently in SWAT and AnnAGNPS and as a consequence also the simulated sediment load may result different, especially in rainy months.

It seems that the extreme high and low flow conditions are more difficult to simulate accurately than normal flow. An improvement in sediment load simulations for both models could be obtained splitting the analysed period in a wet and a dry period and operating a seasonal calibration scheme as suggested by Lèvesque et al., 2008, White et al., 2009, Zhangh et al., 2015, Guse et al., 2013, and Ricci et al., 2018.

4.2 Model applicability

Concerning the applicability of the SWAT and AnnAGNPS models in the Mediterranean region, we can conclude that either models can be potentially used by water resources managers in order to estimate sediment load, and to identify the critical sediment source areas where the different management options are needed to be implemented for sustainable land management. The SWAT model, however, requires time for its set up due to the large number of data necessary to fulfil all sections (e.g.: management practices) (De Girolamo et al., 2015b). On the other hand, compared to AnnAGNPS, SWAT offers the possibility to choose between several methods for the computation of the surface runoff and potential evapotranspiration. This latter aspect could be fundamental in areas where climatic data, such as daily data of wind speed, relative humidity and solar radiation, are not available. An advantage of SWAT is the ability of performing model sensitivity analysis, calibration, and validation with the help of automatic tools (SWAT-CUP) (Abbaspour et al., 2015). This allow users to identify the most sensitive parameters and calibrate the model, saving time and effort with respect to the usual manual calibration which strongly depends on user skills and knowledge. However, from the authors point of view, AnnAGNPS input preparation is user-friendly. The project setup and input preparation process takes less time than SWAT thanks to the MAP-Win GIS tool embedded in the AnnAGNPS input editor interface. The fact that all input files can be inserted, modified and exported in CSV format facilitates very much input data elaboration especially in large-size watersheds with large number of cells (sub-watersheds) and reaches (streams).

The major limitation in modelling water erosion and sediment transport with SWAT, as well as with complex conceptual models, is the over-parameterisation (Beven, 1996). The large number of parameters included in the equations that formalize hydrological processes is often calibrated using only the recorded data at the outlet, due to the absence of additional gauging stations within the basin. This can lead to problems of non-uniqueness of parameters and difficulty in verifying the results of sediment sources, paths, and sediment delivery in the upstream sub-basins that, hence, can be affected by a large uncertainty.

The major limitation in simulating streamflow with AnnAGNPS is the fact that it does not simulate the baseflow. At monthly time scale simulation, this aspect may have a limited influence, whilst it may be relevant when simulation of streamflow is required on a daily time scale. For days far from storm events, in fact, simulated daily streamflow results underestimated. Consequently, AnnAGNPS should be used with caution in eco-hydrological studies that require daily streamflow (De Girolamo et al., 2017), especially in Mediterranean streams.

4.3 Models at Europe and basin scale: the importance of a comparison

Our times are characterised by rapid changes in land use and agricultural practices as a response to climate change and international markets. These changes heavily impact on water resources and soils. Erosion by running water has been identified by the European Commission as the most severe hazard for soil that leads to a reduction of soil productivity and contributes to the desertification process in vulnerable areas. For this reason, it is important to assess the state of soil at European level (Kirkby et al., 2008). Maps of soil erosion at European scale constitute the first level of analysis for objectively identifying areas where detailed study are needed and where remedial actions should be implemented. It is well known that models operating with a different theoretical basis or using different input data (time period, spatial and temporal resolution) provide results that can differ in several aspects. Thus, a comparison among different modelling applications can be useful both to point out critical points and for giving a measure of uncertainty that affect the results. Furthermore, the comparison among models can also constitute an indirect method for calibrating or validating models as suggested by Vigiak et al. (2017; 2015). Thus, the two models applied at watershed scale, which were calibrated comparing observed and simulated sediment load at the outlet, could be used to validate models at European scale.

In the present work, although dataset and time period were different for each model application, the results provided by the RUSLE2015 model developed by Panagos are in good agreement with those provided by the SWAT and AnnAGNPS model, while soil loss predicted by PESERA for the Carapelle watershed is considerably lower than the other estimates (Figure 5 C, D). In part, this was expected since SWAT, AnnAGNPS and RUSLE2015 use the MUSLE and RUSLE equations which are based on similar concepts, while PESERA, which is a physically based model, estimates erosion in a different way.

In addition, it seems that the spatial distribution of the soil loss estimated by PESERA differs from the other models' predictions.

Differences were found both in the mountainous part of the basin, where PESERA estimates very low values and in the plain area, where it predicts higher values than SWAT and AnnAGNPS. Similar results were reported by Panagos et al., (2014b), who pointed out that the sediment loss module in PESERA predicts low erosion rates under complete vegetation cover. Coarse resolution and quality of the available input data may have contributed in estimating low values in the upper part of the basin. Indeed, climatic data from the MARS Project used by PESERA show a large difference from measured data in the Carapelle watershed, especially in the hilly area. This discrepancy was already highlighted by the authors of the PESERA model who pointed out that an advanced climate database, especially for rainfall, could improve the soil erosion predictions (Kirkby et al., 2008).

5. Conclusion

In this study, the application of two widely used models at basin scale (SWAT and AnnAGNPS) was evaluated as an assessment tool in studying hydrology and sediment load in the Carapelle, a Mediterranean watershed.

Models were calibrated and validated at monthly time scale using a four year period of observations and both showed from fair to a very good correlation between observed and simulated streamflow and satisfactory for sediment load data. SWAT and AnnAGNPS were also successfully implemented to identify critical sediment source areas and results showed that most of the basin is under moderate (1.4-10 t ha^{-1} yr^{-1}) or high- erosion risk (>10 t ha^{-1} yr^{-1}). SWAT requires time for the setting up and needs a large dataset, in addition, the large number of parameters included in the equations requires a specific knowledge for the calibration. On the other hand, it offers different options for calculating surface runoff and evapotranspiration and some specific tools for the auto-calibration and uncertainty analysis. From the authors' point of view, the AnnAGNPS input preparation is user-friendly, hence, if streamflow and sediment load are required to be simulated at monthly time scale, this model could be a good choice. Indeed, the AnnAGNPS does not simulate the baseflow and it could underestimate daily streamflow when no precipitation occurred for a while.

Moreover, the SWAT and AnnAGNPS models results in determining the entity and spatial distribution of sediment yield in the watershed were compared with soil erosion estimated by two well-known models implemented at European scale, the RUSLE2015 and PESERA. The model comparison presented here shows that there are differences among the model results that are due to the different theoretical basis of the models, to their spatial resolution as well as to differences in the input data.

This study shows that models have a great interest for their potential use by water resources managers in quantifying sediment yield and in identifying the critical areas within the basin where measures are needed to reduce erosion.

Finally, this study shows that the monitoring of sediment load in rivers, even if much cost and time consuming, is necessary to validate the sediment load estimations given by models at a local watershed scale.

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References

Abbaspour, K.C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., Kløve, B., 2015. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. J. Hydrol. 524, 733–752. Doi:10.1016/j.jhydrol.2015.03.027

Abdelwahab, O.M.M., Bingner, R.L., Milillo, F., Gentile, F., 2016a. Evaluation of Alternative Management Practices with the AnnAGNPS Model in the Carapelle Watershed. Soil Sci. 181, 293–305. Doi:10.1097/ss.0000000000000162

Abdelwahab, O.M.M., Bisantino, T., Milillo, F., Gentile, F., 2013. Runoff and sediment yield modeling in a medium-size Mediterranean watershed. J. Agric. Eng. 44. 31-40. Doi: 10.4081/jae.2013. (s1):e7

Abdelwahab, O.M.M., Milillo, F., Gentile, F., 2016b. Modeling soil erosion and sediment load at different time scales in a medium-sized watershed. In American Society of Agricultural and Biological Engineers Annual International Meeting, ASABE 2016. Paper N. 162461032, 1-13. doi:10.13031/aim.20162461032

Abdelwahab, O.M.M., Bingner, R.L., Milillo, F., Gentile, F., 2014. Effectiveness of alternative management scenarios on the sediment load in a Mediterranean agricultural watershed. J. Agric. Eng. 45 (3), 125-136. doi:10.4081/jae.2014.430

Abouabdillah, A., White, M., Arnold, J.G., De Girolamo, A.M., Oueslati, O., Maataoui, A., Lo Porto, A., 2014. Evaluation of soil and water conservation measures in a semi-arid river basin in Tunisia using SWAT. Soil Use Manag. 30, 539–549. doi:10.1111/sum.12146

Allen, R.G., 1986. A Penman for all seasons. J. Irrig. Drain. Eng. 112, 348–368.

Allen, R.G., Jensen, M.E., Wright, J.L., Burman, R.D., 1989. Operational estimates of reference evapotranspiration. Agron. J. 81, 650–662.

Aquilino, M., Novelli, A., Tarantino, E., Iacobellis, V., Gentile, F., 2014. Evaluating the potential of GeoEye data in retrieving LAI at watershed scale. Proceedings of SPIE - The International Society for Optical Engineering, 9239, art. no. 92392B. doi: 10.1117/12.2067185

Arabi, M., Frankenberger, J.R., Engel, B.A., Arnold J.G., 2008. Representation of agricultural conservation practices with SWAT. Hydrol. Process. 22, 3042–3055. DOI: 10.1002/hyp.6890.

Arnold, J.G., Youssef, M.A., Yen, H., White, M.J., Sheshukov, A.Y., Sadeghi, A.M., Moriasi, D.N., Steiner, J.L., Amatya, D.M., Skaggs, R.W., Haney, E.B., Jeong, J., Arabi, M., & Gowda, P.H. 2015. Hydrological processes and model representation: Impact of soft data on calibration. Trans. ASABE 58 (6), 1637-1660. http://dx.doi.org/10.13031/trans.58.10726

Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Santhi, C., Harmel, R.D., van Griensven, A., Van Liew, M.W., Kannan, N., Jha, M.K., 2012. SWAT: Model Use, Calibration, and Validation. Trans. ASABE 55, 1491–1508.

Arnold, J.G., Srinivasan, R., Muttiah, R.S., Williams, J.R., 1998. Large area hydrologic modeling and assessment - Part 1: Model development. J. Am. Water Resour. Assoc. 34, 73–89. doi:10.1111/j.1752-1688.1998.tb05961.x

Asres, M.T., Awulachew, S.B., 2010. SWAT based runoff and sediment yield modelling: a case study of the Gumera watershed in the Blue Nile basin. Ecohydrol. Hydrobiol. 10, 191–199. doi:https://doi.org/10.2478/v10104-011-0020-9

Bagnold, R.A., 1977. Bed load transport by natural rivers. Water Resour. Res. 13, 303–312. Doi: 10.1029/WR013i002p00303

Beven, K.J., 1996. A discussion of distributed hydrological modelling. In: Distributed Hydrological Modelling (ed. By M. B. Abbott & J. Ch. Refsgaard). Kluwer Academic Publ., Dordrecht, The Netherlands.

Bingner, R.L., Yuan, Y., Theurer, F.D., 2015. AnnAGNPS technical processes documentation, version 5.4. USDA-ARS, National Sedimentation Laboratory POB 1157, 598 McElroy Drive, Oxford, MS 38655

Bisantino, T., Bingner, R., Chouaib, W., Gentile, F., Trisorio Liuzzi, G., 2015. Estimation of runoff, peak discharge and sediment load at the event scale in a medium-size Mediterranean watershed using the AnnAGNPS model. L. Degrad. Dev. 26, 340–355. doi:10.1002/ldr.2213

Boithias, L., Sauvage, S., Lenica, A., Roux, H., Abbaspour, K., Larnier, K., Dartus, D., Sánchez-Pérez, J., 2017. Simulating Flash Floods at Hourly Time-Step Using the SWAT Model. Water 9, 929. doi:10.3390/w9120929

Borah, D.K., Bera, M., 2003. Watershed-scale hydrologic and nonpoint-source pollution models: Review of applications. Trans. ASAE 47, 789–803.

Bouraoui, F., Benabdallah, S., Jrad, A., Bidoglio, G., 2005. Application of the SWAT model on the Medjerda river basin (Tunisia). Phys. Chem. Earth 30, 497–507. doi:10.1016/j.pce.2005.07.004

Briak, H., Moussadek, R., Aboumaria, K., Mrabet, R., 2016. Assessing sediment yield in Kalaya gauged 16 watershed (Northern Morocco) using GIS and SWAT model. International Soil and Water 17 Conservation Research 4, 177-185. DOI; https://doi.org/10.1016/j.iswcr.2016.08.002

Brouziyne, Y., Abouabdillah, A., Bouabid, R., Benaabidate, L., Oueslati, O., 2017. SWAT manual calibration and parameters sensitivity analysis in a semi-arid watershed in North-western Morocco. Journal of Arabian Geoscience 10, 427. DOI 10.1007/s12517-017-3220-9

Chandramohan, T., Venkatesh, B., Balchand, A.N., 2015. Evaluation of Three Soil Erosion Models for Small Watersheds. Aquat. Procedia 4, 1227–1234. doi:https://doi.org/10.1016/j.aqpro.2015.02.156

Chahor, Y., Casali, J., Gimenez, R., Bingner, R.L., Campo, M.A., Goni, M., 2014. Evaluation of the AnnAGNPS model for predicting runoff and sediment yield in a small Mediterranean agricultural watershed in Navarre (Spain). Agric. Water Manag. 134, 24–37. doi:10.1016/j.agwat.2013.11.014

Clark, M.P., Slater, A.G., Rupp, D.E., Woods, R.A., Vrugt, J.A., Gupta, H.V, Wagener, T., Hay, L.E., 2008. Framework for Understanding Structural Errors (FUSE): A modular framework to diagnose differences between hydrological models. Water Resour. Res. 44, 1-14. Doi: 10.1029/2007WR006735

Das, S., Rudra, R.P., Gharabaghi, B., Goel, P., Singh, Ahmed, S., 2007. Comparing the Performance of SWAT and AnnAGNPS Model in a Watershed in Ontario, in: Watershed Management to Meet Water Quality Standards and TMDLS (Total Maximum Daily Load) Proceedings of the 10-14 March 2007, San Antonio, Texas. ASABE, St. Joseph, MI, p. 485. doi:https://doi.org/10.13031/2013.22481

De Girolamo, A.M., Pappagallo, G., Lo Porto, A., 2015a. Temporal variability of suspended sediment transport and rating curves in a Mediterranean river basin: the Celone (SE Italy). Catena 128, 135-143. http://dx.doi.org/10.1016/j.catena.2014.09.020

De Girolamo, A.M., Lo Porto, A., Pappagallo, G., Tzoraki, O., Gallart, F., 2015b. The Hydrological Status Concept: Application at a Temporary River (Candelaro, Italy). River Res. Appl. 31, 892–903. doi:10.1002/rra.2786

De Girolamo, A.M., Barca, E., Pappagallo, E., Lo Porto, A., 2017. Simulating ecologically relevant hydrological indicators in a temporary river system. Agricultural Water Management 180, 194–204 doi: DOI10.1016/j.agwat.2016.05.034

De Girolamo, A.M., Di Pillo, R., Lo Porto A., Todisco, M.T., Barca E., 2018. Identifying a reliable method for estimating suspended sediment load in a temporary river system. Catena 165, 442-453.

Desmet, P., Govers, G., 1996. A GIS procedure for automatically calculating the ULSE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation 51 (5), 427–433.

Du J., Shi C., Zhang C., 2013. Modeling and analysis of effects of precipitation and vegetation coverage on runoff and sediment yield in Jinsha River Basin. Water Science and Engineering. 6 (1), 44-58. DOI: https://doi.org/10.3882/j.issn.1674-2370.2013.01.004

Duvert, C., Nord, G., Gratiot, N., Navratil, O., Nadal-Romero, E., Mathys, N., et al., 2012. Towards prediction of suspended sediment yield from peak discharge in small erodible mountainous catchments (0.45-22 km2) of France, Mexico and Spain. J. Hydrol. 454, 42–55.

Ferro, V., Porto, P., Yu, B.. 1999. A comparative study of rainfall erosivity estimation for southern Italy and southeastern Australia. Hydrolog. Sci. J. 44, 3–23.

Furl, C., Sharif, H., Jeong, J., 2015. Analysis and simulation of large erosion events at central Texas unit source watersheds. J. Hydrol. 527, 494-504. DOI: http://dx.doi.org/10.1016/j.jhydrol.2015.05.014

Galván, L., Olías, M., Izquierdo, T., Cerón, J.C., de Villarán, R.F., 2013. Rainfall estimation in SWAT: An alternative method to simulate orographic precipitation. J. Hydrol. 509, 257–265. doi:https://doi.org/10.1016/j.jhydrol.2013.11.044

Gamvroudis, C., Nikolaidis, N.P., Tzoraki, O., Papadoulakis, V., Karalemas, N., 2015. Water and sediment transport modeling of a large temporary river basin in Greece. Sci. Total Environ. 508, 354–365. doi:http://dx.doi.org/10.1016/j.scitotenv.2014.12.005

Gentile, F., Bisantino, T., Trisorio Liuzzi, G., 2010. Erosion And Sediment Transport Modelling In Northern Puglia Watersheds. WIT Trans. Eng. Sci. 67, 14.

Green, W.H., Ampt, G., 1911. Studies on soil physics, 1. The flow of air and water through soils. J. Agric. Sci. 4, 11–24.

Gupta, H., Sorooshian, S., Yapo, P., 1999. Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. J. Hydrol. Eng. 4, 135–143. Doi:doi:10.1061/(ASCE) 1084-0699(1999)4:2(135)

Guse, B., Reusser, D.E., Fohrer, N., 2013. How to improve the representation of hydrological processes in SWAT for a lowland catchment - temporal analysis of parameter sensitivity and model performance. Hydrol. Process. 28, 2651–2670. doi:10.1002/hyp.9777

Hargreaves, H.G.A., Samani, Z., 1985. Reference Crop Evapotranspiration from Temperature. Appl. Eng. Agric. 1, 96. doi:https://doi.org/10.13031/2013.26773

Heathman, G.C., Flanagan, D.C., Larose, M., Zuercher, B.W., 2008. Application of the Soil and Water Assessment Tool and Annualized Agricultural Non-Point Source models in the St. Joseph River watershed. J. Soil Water Conserv. 63, 552–568. doi:10.2489/jswc.63.6.552

Jattena, V., De Roob, A., Favis-Mortlockc, D., 1999. Evaluation of field-scale and catchment-scale soil erosion models. Catena 37 (3-4), 521-541.

Jones, R.J.A., Grimm, M., Montanarella, L., 2003. Use of Meteorological data sets at European level for input to the PESERA Grid Model. PESERA (Contract QLKS-CT-1999-01323) final report.

Justice, V., Bingner, R.L., 2015. AGNPS Input Data Preparation Model User's Guide. Version 5.43. USDA-ARS, National Sedimentation Laboratory POB 1157, 598 McElroy Drive, Oxford, MS 38655

King, D., Daroussin, J., Tavernier, R., 1994. Development of a soil geographical database from the soil map of the European Communities. Catena 21, 37–26.

King, D., Jamagne, M., 1995. General theory about a model of the spatial organization and functioning of the soil in analyzing the soil. Eurasian Soil. Sci. 27 (4), 6–11.

Kirkby, M.J., Irvine, B.J., Jones, R.J.A., et al., 2008. The PESERA coarse scale erosion model for Europe-model rationale and implementation. European Journal of Soil Science 59 (6), 1293–1306.

Krause, P., Boyle, D.P., Bäse, F., 2005. Comparison of different efficiency criteria for hydrological model assessment. Adv. Geosci. 5, 89–97. doi:10.5194/adgeo-5-89-2005

Kuhlman, T., Reinhard, S., Gaaff, A., 2010. Estimating the costs and benefits of soil conservation in Europe. Land Use Policy 27 (1), 22–32.

Lal, R., Elliot, W., 1994. Erodibility and erosivity, in: Lal, R. (Ed.), Soil Erosion Research Methods. Soil and Water Conservation Society and St. Lucie Press, Ankeny, IA, Delray Beach, FL, pp. 181–208.

Legates, D.R., McCabe, G.J., 1999. Evaluating the use of “goodness-of-fit” Measures in hydrologic and hydroclimatic model validation. Water Resour. Res. 35, 233–241. doi:10.1029/1998wr900018

Levesque, E., Anctil, F., van Griensven, A., Beauchamp, N., 2008. Evaluation of streamflow simulation by SWAT model for two small watersheds under snowmelt and rainfall. Hydrol. Sci. Journal-Journal Des Sci. Hydrol. 53, 961–976. doi:10.1623/hysj.53.5.961

Licciardello, F., Toscano, A., Cirelli, G.L, Consoli, S., Barbagallo, S., 2017. Evaluation of sediment deposition in a Mediterranean reservoir: comparison of long term bathymetric measurements and SWAT estimations. Land Degradation & Development 28, 566–578. DOI: 10.1002/ldr.2557

Lim, K.J., Engel, B.A., Tang, Z.X., Choi, J., Kim, K.S., Muthukrishnan, S., Tripathy, D., 2005. Automated Web Gis based hydrograph analysis tool, what. J. Am. Water Resour. Assoc. 41, 1407–1416. doi:10.1111/j.1752-1688.2005.tb03808.x

Malagó, A., Pagliero, L., Bouraoui, F., Franchini, M., 2015. Comparing calibrated parameter sets of the SWAT model for the Scandinavian and Iberian peninsulas. Special issue: Evaluation of Water Resources with SWAT. Hydrological Sciences Journal 60 (5), 949-967. doi: 10.1080/02626667.2014.978332.

Malagó, A., Bouraoui, F., Vigiak, O., Grizzetti, B., Pastori, M., 2017. Modelling water and nutrient fluxes in the Danube River Basin with SWAT. Sci. Total Environ. 603–604, 196–218. doi:https://doi.org/10.1016/j.scitotenv.2017.05.242

Mark, D.M., 1984. Automatic Detection of Drainage Networks from Digital Elevation Models. Cartographica 21(2/3),168-178.

Martz, L.W., Garbrecht. J., 1992. Numerical Definition of Drainage Network and Subcatchment Areas from Digital Elevation Models. Computers and Geosciences 18 (6), 747-761.

Masih, I., Maskey, S., Uhlenbrook, S., Smakhtin, V., 2011. Assessing the impact of areal precipitation input on streamflow simulations using the SWAT model, J. Am. Water Resour. Assoc. 47, , 179-195.

Matthews, A., Greening agricultural payments in the EU's Common Agricultural Policy. Bio-based and Applied Economics, [S.l.], v. 2, n. 1, p. 1-27, mar. 2013. ISSN 2280-6172. Available at: <http://fupress.net/index.php/bae/article/view/12179>. Date accessed: 19 Apr. 2018. doi:10.13128/BAE-12179.

Merritt, W.S., Letcher, R.A., Jakeman, A.J., 2003. A review of erosion and sediment transport models. Environmental Modelling and Software 18, 761-799.

Monteith, J., 1965. Evapotranspiration and the environment. The state and movement of water in living organisma. XIXth symposium. Society for Experimental Biology, Swansea, Cambridge University Press.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith, T.L., 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans. ASABE 50, 885–900.

Nash, J.E., Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I — A discussion of principles. J. Hydrol. 10, 282–290. doi:https://doi.org/10.1016/0022-1694(70)90255-6

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2009. Soil and Water Assessment Tool: theoretical documentation V. 2009. Texas Water Resources Institute Technical Report No. 406 Texas A&M University System College Station, Texas 77843-2118

Nerantzaki, S.D., Giannakis, G.V., Efstathiou, D., Nikolaidis, N.P., Sibetheros, I.A., Karatzas, G.P., Zacharias, I., 2015. Modeling suspended sediment transport and assessing the impacts of climate change in a 21 karstic Mediterranean watershed. Science of Total Environment 538. 288-297.

Nikolaidis, N.P., Bouraoui, F., Bidoglio, G., 2013. Hydrologic and geochemical modeling of a karstic Mediterranean watershed. J. Hydrol. 477, 129–138. doi:10.1016/j.jhydrol.2012.11.018

Novelli, A., Tarantino, E., Fratino, U., Iacobellis, V., Romano, G., Gentile, F., 2016. A data fusion algorithm based on the Kalman filter to estimate leaf area index evolution in durum wheat by using field measurements and MODIS surface reflectance data. Remote Sensing Letters, 7 (5), 476-484. doi: 10.1080/2150704X.2016.1154219

Oueslati, O., De Girolamo, A.M., Abouabdillah, A., Lo Porto, A., 2015. Classifying the flow regimes of Mediterranean streams using multi-variate analysis: Classifying the Flow Regimes in Mediterranean Streams. Hydrological Processes 29 (22), 4666-4682. DOI10.1002/hyp.10530

Pagliero, L., Bouraoui, F., Willems, P., Diels, J. 2014. Large-Scale Hydrological Simulations Using the Soil Water Assessment Tool, Protocol Development, and Application in the Danube Basin. Journal of Environmental Quality 43, 145–154.

Panagos, P., Van Liedekerke, M., Jones, A., Montanarella, L., 2012. European soil data centre: response to European policy support and public data requirements. Land Use Policy 29 (2), 329–338.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C. 2014a. Soil erodibility in Europe: A high-resolution dataset based on LUCAS. Science of the Total Environment 479-480 (1), 189-200.

Panagos, P., Meusburger, K., Van Liedekerke, M., Alewell, C., Hiederer, R., Montanarella, L., 2014b. Assessing soil erosion in Europe based on data collected through a European Network. Soil Science and Plant Nutrition 60 (1), 15–29.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., Alewell, C., 2015a. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438–447. doi:10.1016/j.envsci.2015.08.012

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., et al., 2015b. Rainfall erosivity in Europe. Science of Total Environment 511, 801–814.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E., Montanarella, L., 2015c. Estimating the soil erosion cover-management factor at European scale. Land Use Policy 48C, 38–50, http://dx.doi.org/10.1016/ j.landusepol.2015.05.021.

Panagos, P., Borrelli, P., Meusburger, K., 2015d. A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. Geosciences 5, 117–126.

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J., Alewell, C., 2015e. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European Scale. Environmental Science & Policy 51, 23–34.

Parajuli, P.B., Nelson, N.O., Frees, L.D., Mankin, K.R., 2009. Comparison of AnnAGNPS and SWAT model simulation results in USDA-CEAP agricultural watersheds in south-central Kansas. Hydrol. Process. 23, 748–763. doi:10.1002/hyp.7174

Pradhanang, S.M., Briggs, R.D., 2013. Effects of critical source area on sediment yield and streamflow. Water Environ. J. 28, 222–232. doi:10.1111/wej.12028

Priestley, C.H.B., Taylor, R.J., 1972. On the Assessment of Surface Heat Flux and Evaporation Using Large-Scale Parameters. Mon. Weather Rev. 100, 81–92. Doi: 10.1175/1520-0493(1972)100<0081: OTAOSH>2.3.CO; 2

Qi, Z., Kang, G., Chu, C., Qiu, Y., Xu, Z., Wang, Y., 2017. Comparison of SWAT and GWLF Model Simulation Performance in Humid South and Semi-Arid North of China. Water 9, 567. Doi: 10.3390/w9080567

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agric. Handbooks.

Ricci, G.F., De Girolamo, A.M., Abdelwahab, O.M., Gentile, F., 2018. Identifying sediment source areas in a Mediterranean watershed using the SWAT model. L. Degrad. Dev. 29. 1233-1248. doi:10.1002/ldr.2889

Ruan, H., Zou, S., Cong, Z., Wang, Y., Yin, Z., Lu, Z., Li, F., Xu, B., 2016. Runoff simulation by SWAT model using high-resolution gridded precipitation in the upper Heihe River Basin, Northeastern Tibetan Plateau. Hydrol. Earth Syst. Sci. Discuss. 594. 1–23. Doi: 10.5194/hess-2016-594

Sadeghi, A., Kwang, Y., Graff, C., McCarty, G., McConnell, L., Shirmohammadi, A., Hively, D., Sefton, K.A., 2007. Assessing the Performance of SWAT and AnnAGNPS Models in a Coastal Plain

Watershed, Choptank River, Maryland, U.S.A. ASABE Meeting, Paper No. 072 032. ASABE, St. Joseph, MI.

Singh, V.P., 1995. Computer Models of Watershed Hydrology. Water Resource Publications, Highlands Ranch, CO.

Sloan, P.G., Moore, I.D., 1984. Modeling subsurface stormflow on steeply sloping forested watersheds. Water Resour. Res. 20, 1815–1822. Doi: 10.1029/WR020i012p01815

Sohrabi, T.M., Shirmohammadi, A., Chu, T.W., Montas, H., Nejadhashemi, A.P., 2003. Uncertainty Analysis of Hydrologic and Water Quality Predictions for a Small Watershed Using SWAT2000, Environmental Forensics 4 (4), 229-238, DOI: 10.1080/714044368

Surfleet, C.G., Tullos, D., Chang, H., Jung, I.W., 2012. Selection of hydrologic modeling approaches for climate change assessment: A comparison of model scale and structures. J. Hydrol. 464, 233–248. doi:10.1016/j.jhydrol.2012.07.012

Swain, B.J., Patra, K.C., 2017. Streamflow estimation in ungauged catchments using regionalization techniques. J. Hydrol. 554: 420-433. DOI: https://doi.org/10.1016/j.jhydrol.2017.08.054

Theurer, F.D., Clarke, C.D., 1991. Wash load component for sediment yield modeling. Fifth Fed. Interag. Sediment. Conf. 18-21 March 1991, 7-1-7-8.

Theurer, F.D., Cronshey, R.G., 1998. AnnAGNPS - Reach routing processes. In Proceeding 1st Fed. Interag. Hydrol. Model. Conf., 19-23 April, Las Vegas, NV, 1998.

Toth, G., Jones, A., Montanarella, L., 2013. The LUCAS topsoil database and derived information on the regional variability of cropland topsoil properties in the European Union. Environmental Monitoring and Assessment 185 (9), 7409–7425.

Tuo, Y., Duan, Z., Disse, M., Chiogna, G., 2016. Evaluation of precipitation input for SWAT modeling in Alpine catchment: A case study in the Adige river basin (Italy). Sci. Total Environ. 573, 66–82. doi:https://doi.org/10.1016/j.scitotenv.2016.08.034

Trombetta, A., Iacobellis, V., Tarantino, E., Gentile, F., 2016. Calibration of the AquaCrop model for winter wheat using MODIS LAI images. Agricultural Water Management 164(2), 304-316. doi: 10.1016/j.agwat.2015.10.013

USDA-NRSC, 1986. Technical release 55: urban hydrology for small watersheds. Technical release 55, 2nd ed., NTIS PB87-101580. Springfield, VA: USDA.

USDA-SCS, 1972. National Engineering Handbook, Section 4, Hydrology. Washington, DC USDA Soil Conserv. Serv.

Van Liew, M.W., Arnold, J.G., Garbrecht, J.D., 2003. Hydrologic simulation on agricultural watersheds: Choosing between two models. Trans. ASAE 46, 1539–1551.

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J., Smith, C.J., 2009. Tolerable versus actual soil erosion 41 rates in Europe. Earth-Science Reviews 94 (1-4), 23-38. DOI: 10.1016/j.earscirev.2009.02.003

Vigiak, O., Malagó, A., Bouraoui, F., Vanmaercke, M., Obreja, F., Poesen, J., Habersack, H., Fehér, J., Grošelj, S., 2017. Modelling sediment fluxes in the Danube River Basin with SWAT. Sci. Total Environ. 599–600, 992–1012. doi:https://doi.org/10.1016/j.scitotenv.2017.04.236

Vigiak, O., Malagó, A., Bouraoui, F., Grizzetti, B., Weissteiner, C.J., Pastori, M., 2016. Impact of current riparian land on sediment retention in the Danube River Basin. Sustain. Water Qual. Ecol. 8, 30–49. doi:https://doi.org/10.1016/j.swaqe.2016.08.001

Vigiak, O., Malagó, A., Bouraoui, F., Vanmaercke, M., Poesen, J., 2015. Adapting SWAT hillslope erosion model to predict sediment concentrations and yields in large Basins. Sci. Total Environ. 538, 855–875. doi:http://dx.doi.org/10.1016/j.scitotenv.2015.08.095

Wasowski J., Casarano D., Lamanna C. (2007). Is the current landslide activity in the Daunia region (Italy) controlled by climate or land use change? Proc. International Conference on "Landslides and Climate Change – Challenges and Solutions", Ventnor, UK, 41–49

White, M.J., Storm, D.E., Smolen, M.D., Zhang, H.L., 2009. Development of a quantitative pasture phosphorus management tool using the SWAT model. J. Am. Water Resour. Assoc. 45, 397–406. doi:10.1111/j.1752-1688.2008.00295.x

Williams, J.R., 1975b. Sediment-yield prediction with universal equation using runoff energy factor. p. 244-252. In, Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment yield workshop, USDA Sedimentation Lab., Oxford, MS, November 28-30, 1972. ARS-S-40

Wischmeier, W. H., Smith, D.D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook 282. United States Department of Agriculture (USDA), Agricultural Research Service (ARS). US Gov Printing Office: Washington, DC.

Wischmeier, W.H.. Smith, D.D., 1965. Predicting rainfall erosion losses from cropland east of the Rocky Mountains, Guide for selection of practices for soil and water conservation. Agriculture Handbook No.282. Agricultural Research Service, U. S. Dept. of Agric. Washington DC. 47 pp.

Xiaoyan, W., Qinhui, L., 2011. Impact of critical source area on AnnAGNPS simulation. Water Sci. Technol. 64, 1767 LP-1773.

Yuan, Y., Bingner, R.L., Boydstun, J., 2006. Development of TMDL watershed implementation plan using Annualized AGNPS. L. Use Water Resouces Res. 6, 2.1-2.8.

Yuan, Y., Locke, M.A., Bingner, R.L., 2008. Annualized Agricultural Non-Point Source model application for Mississippi Delta Beasley Lake watershed conservation practices assessment. J. Soil Water Conserv. 63, 542–551. doi:10.2489/jswc.63.6.542

Yuan, Y., Bingner, R.L., Locke, M.A., Theurer, F.D., Stafford, J., 2011. Assessment of subsurface drainage management practices to reduce nitrogen loadings using AnnAGNPS. Appl. Eng. Agric. 27, 335–344.

Zeiger, S.J., Hubbart, J.A., 2017. An Assessment of Mean Areal Precipitation Methods on Simulated Stream Flow: A SWAT Model Performance Assessment, *Water 9*, 459; doi:10.3390/w9070459

Zema, D.A., Labate, A., Martino, D., Zimbone, S.M., 2016. Comparing Different Infiltration Methods of the HEC-HMS Model: The Case Study of the Mésima Torrent (Southern Italy). Land Degradation and Development 28, 294-308. DOI: 10.1002/ldr.2591

Zettam, A., Taleb, A., Sauvage, S., Boithias, L., Belaidi, N., Sanchez-Perez, J.M., 2017. Modelling Hydrology and Sediment Transport in a Semi-Arid and Anthropized Catchment Using the SWAT

Model: The Case of the Tafna River (Northwest Algeria). Water 9 (3), 216. https://doi.org/10.3390/w9030216

Zhangh, D., Chen, X., Yao, H., Lin, B., 2015. Improved calibration scheme of SWAT by separating wet and dry seasons. Ecol. Modell. 301, 54–61. doi:https://doi.org/10.1016/j.ecolmodel.2015.01.018