Modelling soil erosion and sediment transport under different land management options in a southern Italy watershed

I. Abuiziah, T. Bisantino, F. Gentile & G. Trisorio Liuzzi
DISAAT Department, University of Bari "A. Moro", Bari, Italy

Abstract

The aim of the study is to investigate the influence of different land management options on the sediment load at the watershed scale. To reach this aim the Annualized AGricultural Non Point Source (AnnAGNPS) model was used in the Candelaro basin (2300 km^2). The watershed is located in a semi-arid area of southern Italy (Puglia region) and is affected by extensive erosion processes on the hillslopes. The sediment transport simulations have been compared with 15 years (1970–1984) data coming from measures taken in two sub-watersheds (Vulgano and Salsola). Afterwards the model has been applied for a period of 24 years (1985–2008) to evaluate the effects of different land management options on the sediment yield: traditional best management practices (BMPs), environmentally-targeted agricultural practices and water and soil conservation works. The results obtained in the first part of the work show that AnnAGNPS model performs well in simulating runoff and sediment yields at the watershed scale. Furthermore the analysis carried out shows that the model is an efficient tool to assess the influence of different management options in the long term and in different weather conditions.
Keywords: AnnAGNPS model, soil erosion, surface runoff, sediment yield, watershed, management options.

1 Introduction

Water quality and quantity is certainly the most challenging current and future natural issue, especially in arid and semi-arid regions. Water management is the most critical issue as it impacts the livelihood of people and the productivity of the land. Hydrological and erosive models form the basis for decisions regarding

www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/DEB120101

the development and management of water and land resources in a watershed. During the past four decades, a number of simulation models have been developed to aid in the understanding and management of surface runoff, sediment and nutrient transport processes. The widely used water quality models include ANSWERS (Beasley and Huggins [1]), AnnAGNPS (Bingner *et al.* [2]), EPIC (Sharpley and Williams [3]) and SWAT (Arnold *et al.* [4]).

The AnnAGNPS model was originally developed by the US Department of Agriculture, Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency (MPCA) and the Soil Conservation Service for the analysis of large agricultural watersheds ranging in size between 500 and 23,000 acres. The model was developed to analyze and provide estimates of runoff with primary emphasis upon sediment and nutrients transport from agricultural watersheds, and to compare the effects of various conservation alternatives. AnnAGNPS was calibrated, validated and applied for runoff and sediment yield in different geographic locations, conditions and management practices (Baginska *et al.* [5]; Sarangi *et al.* [6]; Yuan *et al.* [7]; Parajuli *et al.* [8]). The impact of the variation of the most meaningful parameters (R, K, C and P factors of USLE equation, CN curve number and MN Manning's roughness coefficient) on the model response was evaluated in several works (Yuan *et al.* [9]; Shresta *et al.* [10]). In semi-arid environments the model has been tested at different spatial and time scales (Licciardello *et al.* [11]). The model was calibrated and validated in northern Puglia (southern Italy) watersheds at event scale using twelve flood events, and in the long-term using ten years of runoff data (Gentile *et al.* [12]).

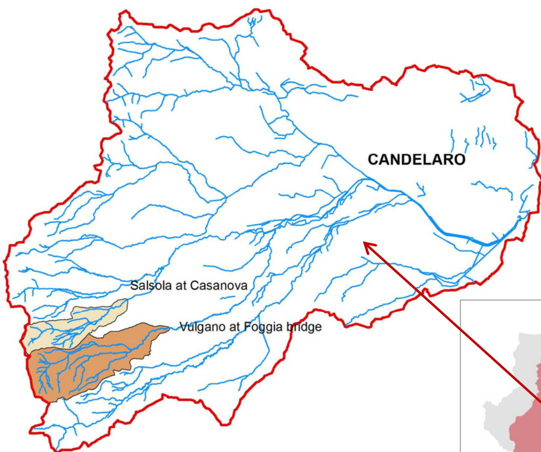
In this paper the model was used in the Candelaro watershed (northern Puglia – southern Italy) to simulate the runoff and sediment yield and to assess the impact of different land management practices. The study area is characterized by water availability insufficient to satisfy the irrigation demands and by an increasing groundwater exploitation that is used to compensate the supply deficit.

In order to determine the most suitable management practice, the effectiveness of the following conservation programs was assessed: the introduction of agricultural best management practices (BMPs) such as no-till plant; the employment of environmentally-targeted agricultural practices such as vegetated streams; the use of water and soil conservation works such as reservoirs. The effects of each factors individually and of their different combinations were evaluated. *Agricultural best management practices BMPs* aim at maintaining good soil structure that is a result of management systems that include: the regular use of soil-improving crops, the use of organic mulches during the critical stage of plant establishment, tillage practices that avoid unnecessary breakdown of soil structure. Significant improvements in water quality in agricultural watersheds could be achieved employing *environmentally-targeted practices* that consist of additional management practices such as riparian buffers, engineered wetlands, grassed waterways, filter strips and field borders. These practices improve water quality by reducing the amount of sediments reaching watercourses. *Water and soil conservation works* are hillslope works, reducing surface runoff and increasing local infiltration, and reservoirs collecting headwater flow and providing supplemental water for irrigation (Lacombe *et al.* [13]; Vachè *et al.* [14]).

2 Material and methods

2.1 The Candelaro watershed

The Candelaro torrent is one of the main water courses of the Puglia region (fig. 1). It is located in the northern part of the region on the typical geo-morphological environment of the Tavoliere plain (the largest alluvial plain in southern Italy and the second one in Italy). The surface area is 2330 km^2, the mean elevation is 300 m a.s.l. and the maximum elevation is 1150 m a.s.l.



Torrent		***Salsola***	***Vulgano***
basin area km^2		44.1	94.1
main channel lenght km		17.0	24.0
hydrographic network lenght km		126.1	195.4
altitude m a.s.l.	max	1025	1125
	mean	432	467
	min	189	179
main channel slope %		4.9	3.9
basin slope %		6.1	5.4

Figure 1: The Candelaro watershed and the two sub-watersheds: Salsola at Casanova and Vulgano at Foggia bridge.

The climate, generally defined as semi-arid Mediterranean, is warm and dry; but in large areas of the plain it is characterized by torrid summers and cold winter temperatures that often fall beneath zero. In the coastal belt the sea exercises a mitigating action and consequently the winters are less rigid and the summers less hot. The rainfall, concentrated in the October-April period, is scarce (approximately 500 mm per year). Flash floods are not rare. A particular

www.witpress.com, ISSN 1743-3533 (on-line)

climatic characteristic of the area is the high value of mean annual potential evapotranspiration, that ranges between 900 and 1100 mm. The study of the thermo-pluviometric data highlighted that the rainfall rate decreased about 30% during the last 40 years while temperature increased about 0.5°C. This produced an increase of the areas considered subject to the risk of desertification.

The pedology of the Candelaro watershed is almost heterogeneous, due to the different textures and soil compositions. In particular, most of the soils are characterized by the presence of clay and sandy clay. The former are located principally in the flat part of the plain, their origin is alluvial with low percentage of skeleton, high capacity of water retention and low hydraulic conductivity resulting in a low drainage velocity; the latter have higher percentage of sand and are settled in the high part of the plain (above 100 m a.s.l.) and along the Gargano border. These soils are characterized by high hydraulic conductivity, low water retention and a low capacity of retaining nitrogen compounds.

Daily streamflow and monthly sediment transport data for two sub-watersheds (fig. 1) (Salsola at Casanova and Vulgano at Foggia bridge) were available from the Italian Hydrological Service (IHS) gauging stations, referred to the period 1970–1984.

2.2 The AnnAGNPS model

The AnnAGNPS model is a continuous, distributed model which can be used to estimate surface runoff, sediment yield, and nutrient loading from an agricultural watershed (Bingner *et al.* [2]). A set of modules allows for the prediction of non-point source pollution loading within agricultural watersheds and can be used to assist in the creation of BMPs and other planning-related decisions.

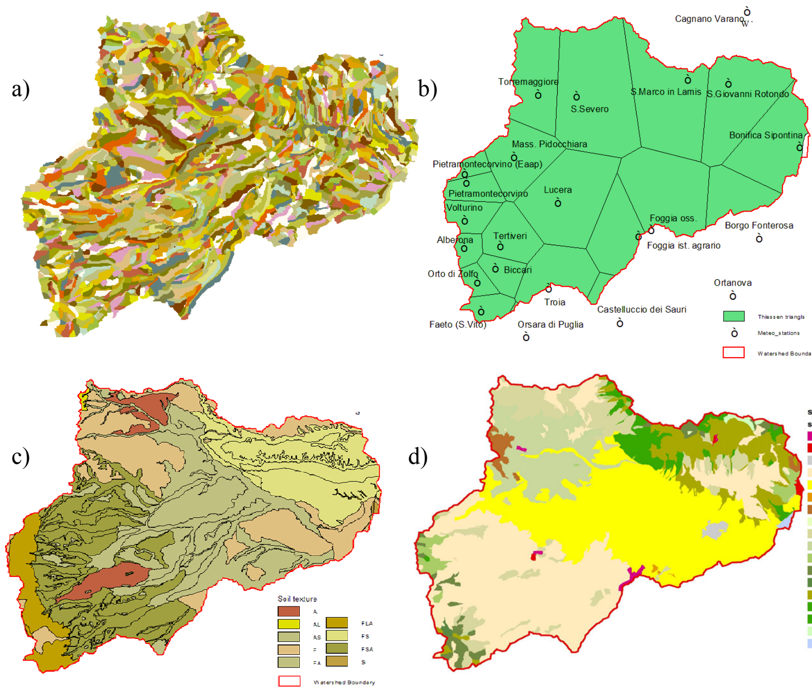
The hydrology is based on a simple water balance approach. Daily soil moisture accounts for runoff, evapotranspiration, and percolation, maintaining a water budget in the 2-layer soil system. The model computes runoff using the SCS Curve number method. Curve numbers are modified at the daily scale, based upon tillage operations, soil moisture and crop stage. Actual evapotranspiration is a function of potential evapotranspiration calculated using the Penman equation (Penman [15]) and soil moisture content. The peak discharge calculation is based upon the concept of unit peak flow of the modified SCS-NRCS TR55 method (Theurer and Cronshey [16]). Soil erosion is determined using the Revised Universal Soil Loss Equation (RUSLE). Sediment yield is computed with the HUSLE equation (Theurer and Clarke [17]), sediment transport is estimated using the Einstein equation and the Bagnold transport capacity.

The model requires several inputs such as landuse, surface condition, channel data, fertilization. Primary outputs include estimates of runoff volume, peak flow rate at the watershed outlet, area-weighted erosion for both upland and channel areas. Further outputs are the sediment delivery ratio, sediment enrichment ratio, mean sediment concentration and total sediment yield for each of the five sediment particle size classes. The watershed is subdivided into homogenous land areas with respect to the soil type, land use and management. These areas come from the original square grid cells and have appropriate hydrologic boundaries that are generated by the terrain-following Geographical Information System (GIS) software.

3 Results and discussion

3.1 Model calibration

AnnAGNPS input data used to describe the Candelaro watershed are the elevation map (NASA-DEM 90m), soil data (1:100000 ACLA project (Caliandro *et al.* [18])), land-use (1:100000 CORINE Land Cover), and climate data coming from 23 IHS meteorological stations for the period 1970–1984 (fig. 2).



A - Clay
Al - Silty clay
AS - Sandy clay
F - Loam
FA - Clay loam
FLA - Silty clay loam
FS - Sandy loam
FSA - Sandy Clay Loam
S - Sandy

1.1.1. - Continuous Urban Fabric
1.1.2. - Discontinuous Urban Fabric
1.2.4. - Airports
2.1.1. - Non-irrigated Arable Land
2.1.2. - Permanently Irrigated Land
2.2.1. - Vineyards
2.2.3. - Olive Trees
2.3.1. - Pastures
2.4.1. - Annual Crops Associated with Permanent Crops
2.4.2. - Complex Cultivation Patterns
2.4.3. - Principally Agriculture, with Natural vegetation
2.4.4. - Agro-forestry Areas
3.1.1. - Broad-leaved Forest
3.1.2. - Coniferous Forest
3.1.3. - Mixed Forest
3.2.1. - Natural Grasslands
3.2.3. - Sclerophyllus Vegetation
3.2.4. - Transitional Woodland Shrubs
3.3.3. - Sparsely Vegetated Areas
4.1.1. - Inland Marshes

Figure 2: Candelaro watershed input dataset: a) Sub-watersheds; b) Thiessen polygons; c) Soil texture; d) Land-use.

Specific databases were built to assign curve numbers values, hydraulic soil properties, erodibility factors K, rainfall erosivity factor R, crop parameters and in-field operation management practices. Land-uses were grouped in six classes: cropland, rangeland, forest, urban, fallow and pasture. For cropland individual databases were built for winter wheat, olive groves, vineyards and orchards.

The model was calibrated to current conditions in the Candelaro watershed using monthly runoff and yearly sediment loads for the period 1970-1984 in the Salsola and Vulgano sub-watersheds. Curve numbers and Manning's coefficients were adjusted to match simulated and observed values. Figure 3 represents the calibration results. The statistical indicators used for the evaluation of the model performance are the coefficient of determination (R^2) and the Nash-Sutcliffe model efficiency (NSE) (Nash and Sutcliffe [19]).

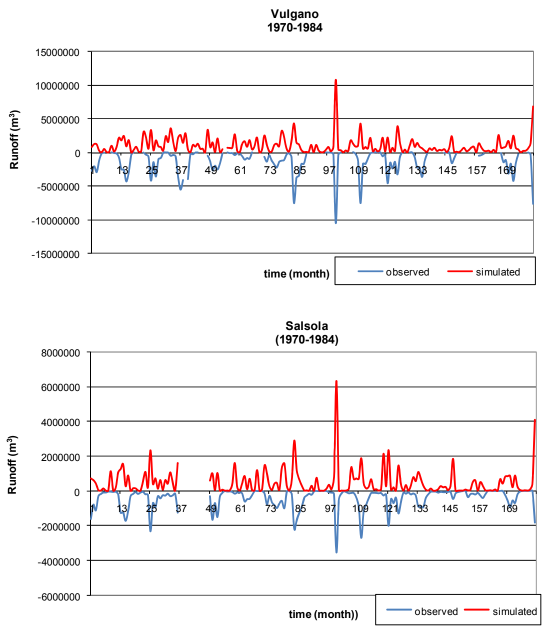


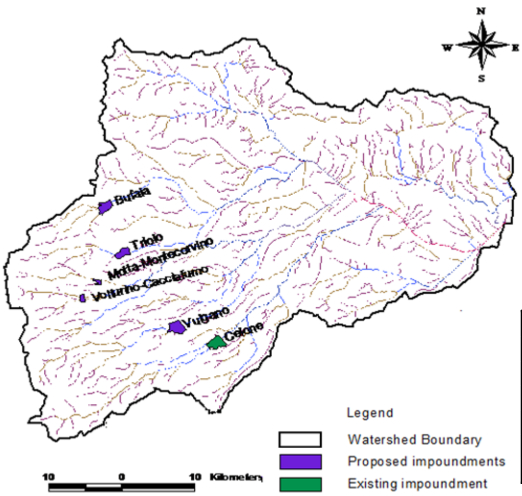
Figure 3: AnnAGNPS simulated vs. observed runoff (monthly scale) and sediment loads (yearly scale). Period 1970–1984.

3.2 Alternative management scenarios

The model has then been applied for a period of 24 years (1985–2008) using the parameters calibrated during the first phase of the work. The aim was to evaluate the effects of seven different land management options on the total sediment load at the watershed scale:

1. *CT* conventional tillage;
2. *VS_CT* vegetated streams in conventional tillage conditions;

3. *VS_Imp_CT* vegetated streams and impoundments (fig. 4) in conventional tillage conditions;
4. *NTP* no-till plant;
5. *VS_NTP* vegetated streams in no-till plant conditions;
6. *Imp_NTP* impoundments in no-till plant conditions;
7. *VS_Imp_NTP* vegetated streams and impoundments in no-till plant conditions.



Impoundment	Area (m^2)
Bufala	2312463
Motta-Montecorvino	484334
Triolo	1904625
Volturino-Cacciafumo	707397
Vulgano	3125709
Celone	2956899

Figure 4: Location of the proposed impoundments.

Figure 5 shows the cumulated and average yearly sediment loads for the period 1985–2008 for each of the seven land management options. The percent variation of the sediment load is calculated considering the conventional tillage condition as a reference value. The cumulative frequency distributions *cdf*$_s$ are reported in figure 6.

The conventional tillage provides the highest sediment load. Comparing no-till plant and conventional tillage a reduction of the sediment load of more than 20% is observed. The no-till plant *cdf* is shifted to the left respect to the conventional tillage for all sediment loads, but more for high values. This indicates that non conservative agricultural practices influence sediment load especially during the wet periods.

In conventional tillage conditions the use of vegetated streams determines a moderate reduction of the sediment load and this reduction is concentrated in dry periods, as highlighted from the *cdf* curves. The addition of impoundments gives an overall decrease of more than 20% distributed in all the periods.

In no-till plant conditions vegetated stream as well as impoundments determines a decrease of about 30% respect to the conventional tillage and their combinations gives an overall reduction of 36.7%. Their influence is significant in average weather periods.

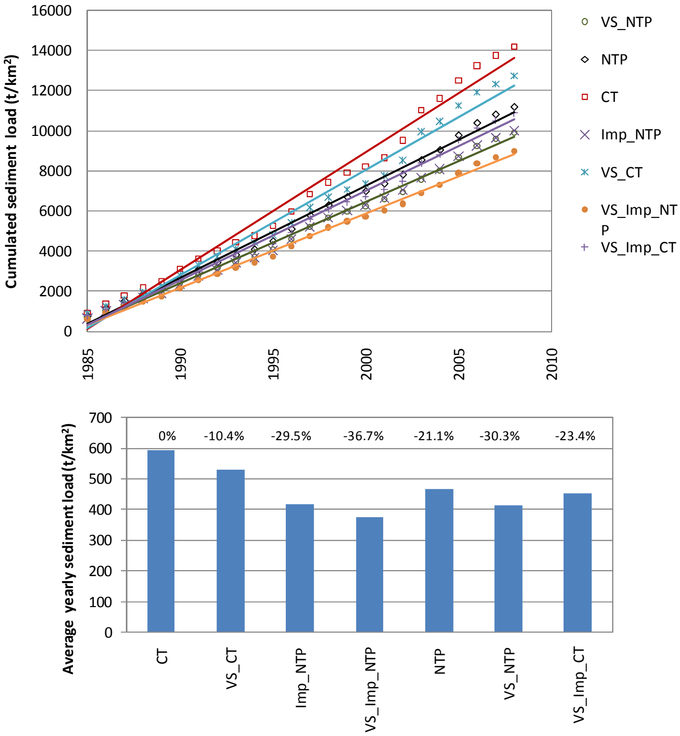


Figure 5: Cumulated and average yearly sediment loads.

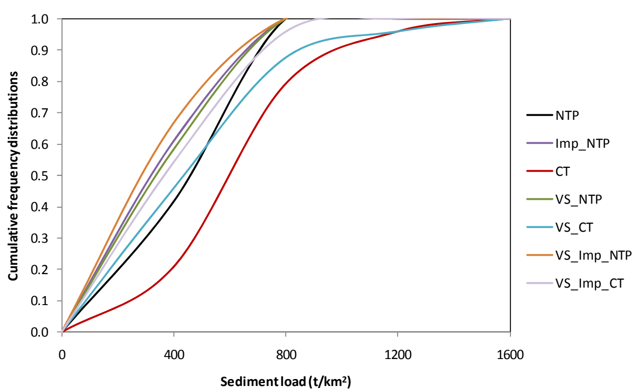


Figure 6: Cumulative frequency distributions.

www.witpress.com, ISSN 1743-3533 (on-line)

4 Conclusions

In this study the AnnAGNPS model was implemented to provide a basis for decision makers to plan alternative land management options and assess their impacts on runoff and sediment yield at the catchment scale. The sensitivity analysis helped in identifying the CN as the most important parameter in the calibration phase that was successful as evidenced by the reasonable match between the observed and simulated runoff and sediment yield values. The set of the optimized parameters along with the others representative of the system were then used to evaluate the effects of different land management scenarios. In particular the use of the AnnAGNPS model allowed us to quantify the relative effects on the sediment yield at the watershed outlet of the introduction of tillage in the agricultural areas, the use of hydraulic structures such as impoundments and the revegetation of the banks along the river network. It had also the capability of simulating the combined effects on the sediment yield deriving from the application of the three different scenarios. The results of the first phase showed that the AnnAGNPS model performed well in simulating runoff and sediment yield for both the Vulgano and Salsola sub-watersheds; the second phase showed that it is also a useful tool to make a sounded assessment of different land management options in the Candelaro basin. Agricultural practices have the major influence on sediment yield and the choice of conservative options gives important benefits especially during the wet periods. The addition of environmentally-targeted options and hydraulic works takes sediment loads at lower values also in average weather conditions.

Acknowledgement

Part of this work has been carried out during the Master's thesis in "Land and Water Resources Management: Irrigated Agriculture" at the CIHEAM–IAMB Mediterranean Agronomic Institute of Bari (Italy).

References

[1] Beasley, D.B. and Huggins, L.F., *ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation): User's Manual.* U.S. Environmental Protection Agency, Chicago, Illinois, 1982.
[2] Bingner, R. L., Theurer, F.D. and Yuan, Y., *AnnAGNPS technical processes documentation, Version 5.0. USDA-ARS.* National Sedimentation Laboratory: Oxford, MS, 2009.
[3] Sharpley, A.N. and Williams, J.R., *EPIC-Erosion/Productivity Impact Calculator*, USDA, Agricultural Research Service, Technical Bulletin No. 1768, Washington, D.C., pp. 235, 1990.
[4] Arnold, G., Srinavasan, R., Muttiah, R.S. and Williams, J.R., Large Area Hydrologic Modeling and Assessment. Part I. Model Development. *Journal of the American Water Resources Association*, **34**, pp. 73-89, 1998.

[5] Baginska, B., Milne-Home, W. and Cornish, P.S., Modelling nutrient transport in Currency Creek, NSW with AnnAGNPS and PEST. *Environmental Modelling and Software*, **18**, pp. 801-808, 2003.
[6] Sarangi, A., Cox C.A. and Madramootoo, C.A., Evaluation of the AnnAGNPS Model for prediction of runoff and sediment yields in St Lucia watersheds. *Biosystems Engineering*, **97**, pp. 241 – 256, 2007.
[7] Yuan, Y., Locke, M.A. and Bingner R.L. Annualized Agricultural Non-Point Source model application for Mississippi Delta Beasley Lake watershed conservation practices assessment. *Journal of Soil and Water Conservation*, **63(6)**, pp. 542-551, 2008.
[8] Parajuli, P.B., Nelson, N.O., Frees, L.D. and Mankin, K.R., Comparison of AnnAGNPS and SWAT model simulation results in USDA-CEAP agricultural watersheds in south-central Kansas. *Hydrological Processes*, **23(5),** pp. 748-763, 2009.
[9] Yuan, Y., Bingner, R.L. and Rebich, R.A., Evaluation of AnnAGNPS on Mississippi Delta MSEA watersheds. *Transactions of the ASAE* **44(5)**, pp. 1183-1190, 2001a.
[10] Shrestha, S., Babel Mukand, S., Das Gupta, A. and Kazama F., Evaluation of annualized agricultural nonpoint source model for a watershed in the Siwalik Hills of Nepal. *Environmental Modelling and Software*, **21(7)**, pp. 961-975, 2006.
[11] Licciardello, F., Zema, D.A., Zimbone, S.M. and Bingner, R. L., 2007. Runoff and soil erosion evaluation by the AnnAGNPS model in a small Mediterranean watershed. Transactions of the American Society of Agricultural and Biological Engineers (ASABE) 50(5): 1585-1593.
[12] Gentile, F., Bisantino, T. and Trisorio Liuzzi, G., Erosion and sediment transport modeling in Northern Puglia watersheds. *WIT Transaction on Engineering Sciences,* **67**, pp.199-212, 2010.
[13] Lacombe, G., Cappelaere, B. and Leduc, C., Hydrological impact of water and soil conservation works in the Merguellil catchment of central Tunisia *Journal of Hydrology* **359**, pp. 210– 224, 2008.
[14] Vachè, K.B., Eilers, J.M. and Santelmann, M.V., Water Quality Modeling of Alternative Agricultural Scenarios in the US Corn Belt. *Journal of the American Water Resources Association* **38 (3)**, pp. 773-787, 2002.
[15] Penman, H.L., Natural evaporation from open water, bare soil, and grass. *Proc. Royal Soc. (London),* Ser. A, 193, pp. 120-145, 1948.
[16] Theurer, F.D. and Cronshey, R.G., AnnAGNPS - Reach routing processes. *Proc. of the First Federal Interagency Hydrologic Modeling Conference.* Las Vegas, Nevada. April 19-23, pp. 1-25 to 1-32, 1998.
[17] Theurer, F.D. and Clarke, C.D., Wash load component for sediment yield modeling. *Proc. of the Fifth Federal Interagency Sedimentation Conference*, March 18-21, Las Vegas, NV: Subcommittee on Sedimentation of the Interagency Advisory Committee on Water Data, 1, pp. 7-1 to 7-8, 1991.

[18] Caliandro, A., Lamaddalena, N., Stellati, M. and Steduto, P., Caratterizzazione agroecologica della Regione Puglia. In Funzione della potenzialità produttiva: Progetto Acla 2. Puglia, Bari, 2005.
[19] Nash, J.E. and Sutcliffe, J.V., River flow forecasting through conceptual models part I - A discussion of principles. *J. Hydrol.*, 10, pp. 282-290, 1970.