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USE OF ANNAGNPS FOR WATERSHED MODELING IN SIWALIK HILLS OF NEPAL

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ABSTRACT

A study was conducted to evaluate the predictive capability of Annualized Agricultural Non Point Source (AnnAGNPS) model with respect to surface runoff, peak flow and sediment yield on a 130.8 ha watershed in Siwalik Hills of Nepal. Rainfall, stream discharge, surface runoff, sediment yield, topography, soil type, and land use were taken from database of MSEC project. The model was calibrated and validated by using the data of year 2001 and 2002 respectively. The model underestimated the runoff volume by 15% during calibration and 22% during validation .The average peak flows were overestimated by 2.5 to 4 times more than the observed values. Similarly, the model over predicted the average sediment yield by 120% and 153% of the measured values for the year 2001 and 2002 respectively. These results showed that the model performs well in simulating runoff volumes compared to the peak flows and sediment yield.

1 INTRODUCTION

Watersheds are environmental and land management natural units which determine the health of the nation. Several hydrological and water quality models have been developed over the past several years to assist in understanding hydrologic systems and pollutant loadings. These models range from simple screening and planning models, such as USLE (Wischmeir and Smith, 1978), to complex hydrological assessment model, such as CREAMS (Knisel, 1980), ANSWERS (Beasley, Huggins, and Monke, 1980), SPNM (Williams, 1980), EPIC (Williams et al., 1982), SWRB (Williams et al., 1985), GLEAMS (Leonard et al., 1987), WEPP (Nearing et al., 1989), AGNPS (Yong et al., 1989 and 1994), and PESTFADE (Clemente et al., 1993), HSPF (Donigian et al., 1995), SWAT (Arnold and Allen, 1996), EUROSEM (Morgan et al., 1998). These models can be used to predict erosion, sediment, nutrient and chemical transport from watershed. Modeling is considered as more cost effective and less time consuming as compared to the field studies. Simulations under various combinations of different factors of land and water management can provide comparative analysis of different options and then prove to be very useful guide as to what Best Management Practices (BMPs) can be adopted to minimize pollution from point and non-point sources.

The objectives of this study were: (1) to prepare the database for the simulation of Annualized Agricultural Non-Point Source (AnnAGNPS) model; and (2) to calibrate and validate the model for Siwalik hills of Nepal.

2 METHODOLOGY

2.1 Watershed Description

The study area, Masrang Khola watershed, falls in the Siwalik physiographic zones of central Nepal (Figure 1). The area of the watershed is about 130.8 ha which is of nearly square shaped. Nepal Agricultural Research Council (NARC) monitored the watershed with the collaboration of International Water Management Institute (IWMI) for Management of Soil Erosion Consortium (MSEC) from the year 2000 to 2002 (Shrestha, 2002).The climate in the area is subtropical to warm temperate. The average annual rainfall is about 2725 mm, of which more than 75% occurs in the monsoon season. The mean annual temperature is about 22^{0}C with a maximum of 35^{0}C in the month of May and a minimum of 9^{0}C in January. Majority of land has extreme slope whereas only 0.3% has gentle slope. Soils of the watershed are, in general, well to excessively drained, with gravels, sandy loam in texture, and acidic in reaction (Tiwari et al., 1989). The land use of the watershed was found to be mixed type. About 37% of land area is covered by natural forest, 42.5% for agriculture, 10.5% for rangeland and 10% for other uses.

The Siwalik, Chure commonly named, is a very fragile range of Hills in Nepal spreading from east to west between the Terai and the Inner-Terai. It is composed mainly of sand, gravel, pebbles, and a conglomerate of sand and limestone and covers 13% of the total land area of the country. Many small to big and transitory to perennial rivers of the Terai, which have individual identity or serve as tributary of the other rivers originate from the Siwalik. In reality, the Siwalik, at present, is under pressure and in the process of deterioration (Wagley, 1999).

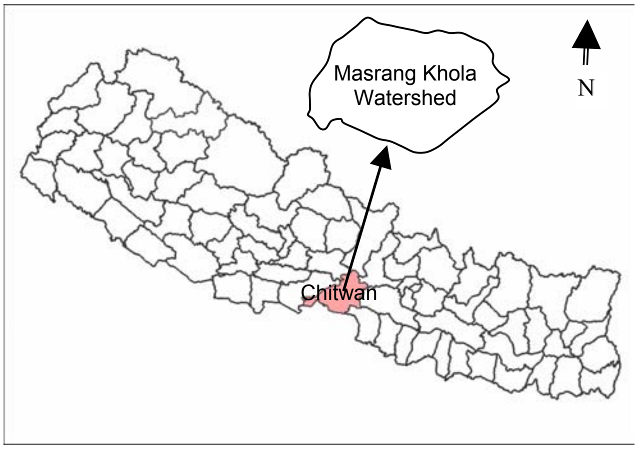

Figure 1: Location map of the study area

2.2 Model Description

AnnAGNPS is a distributed parameter, physically–based, continuous-simulation, watershed scale, non-point source pollutant model (Cronshey and Theurer, 1998). It is the result of a joint USDA Natural Resources Conservation Service and Agricultural Research Service effort to develop a system of models to predict non point source pollutant loading within agricultural watersheds. The single event Agricultural Non-Point Source (AGNPS) model was developed in the early 1980's by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency, and the Natural Resource Conservation Service (NRCS) (Young et al., 1989; Young et al., 1994).

The SCS curve number technique is used within AnnAGNPS to determine the surface runoff from a field. Soil moisture conditions are used to calculate an SCS curve number (CN), which forms the basis of the surface and subsurface runoff quantities for that day. AnnAGNPS does not actually use the CN for calculations, but instead the soil retention variable S to determine runoff (Qt).This value is adjusted for soil moisture conditions using curve fitting algorithms as used in SWRRB (Williams et al., 1985 and EPIC (Williams et al., 1982). The normal curve number (CN II) is calculated for soil moisture conditions between the wilting point and field capacity. When the soil is at wilting point, CN is corrected to antecedent moisture condition (AMC) I, for soil at a water content equal to field capacity the CN is corrected to AMC III and corrections are also made for intermediate values. AnnAGNPS also allows for the revision of cell runoff curve numbers based on any land management operations (i.e. harvest) that may occur in a day. The new curve number must be supplied by the user for these operations. If a field crop has been planted and is in the development stage, the existing CN will be adjusted to account for the transition period of crop growth.The algorithm used to calculate runoff is conceptually based on the SCS CN method, as used in SWRRB and EPIC, with the ability to apportion a larger percentage of water input to runoff without increasing soil water content or precipitation.

$$S = 254\left(\frac{100}{CN} - 1\right) \tag{1}$$

Where,
S= retention parameter (mm)
CN = curve number

With the value of S calculated for the current day, runoff is calculated by using the following equation:

$$Q = \frac{\left(WI - 0.2S\ \right)^2}{WI + 0.8S} \tag{2}$$

Where,
Q = runoff (mm)
WI = water input to soil (mm)

This is conditional on WI>0.2S, otherwise Q is equal to zero. From here, Q can be multiplied by the drainage area to give volume of runoff. S can later be converted to CN for use in other modules and to determine a composite CN for the cell.

Additional parameters are calculated associated with the runoff curve number for an individual field. The curve number parameters S1, S3, W1, and W2 are used to vary the curve number for a given day between the dry condition curve number (CN1) and the wet condition curve number (CN3) based on soil moisture storage. This module is run at the beginning of a simulation and any time the curve number for average conditions (CN2) changes (e.g., when a crop is harvested).To simplify data input, CN1 and CN3 are calculated as a function of CN2 based on curve fits. The equations, as given in the SWRRB and EPIC models, are:

$$CN1 = CN2 - \frac{20(100 - CN2)}{100 - CN2 + \exp[2.533 - 0.636(100 - CN2)]} \tag{3}$$

Or,

$$CN1 = 0.4 * CN2 \tag{4}$$

Whichever is greater and

$$CN3 = CN2 \exp[0.00673(100 - CN2)] \quad (5)$$

For the purpose of translating a runoff depth (Q, mm) into a cell-based hydrograph, determining peak discharge, and a pre-peak runoff fraction, the time of concentration in each cell can be inputted by the user or calculated by the AnnAGNPS model. Time of concentration is defined as the time required for water to flow from the hydraulically most distant point in the watershed (in this case, the cell) to the outlet, and is the sum of overland flow, shallow concentrated flow, and concentrated flow between those points in the cell. Calculations for each of these travel times are taken from the NRCS TR-55 (SCS, 1986) procedures with modifications by Theurer and Cronshey (1998) making this an "extended" TR-55 method. Once the hydraulically most distant point is determined, the model treats the first 50 m of flow as overland, the next 50 m as shallow concentrated, and the remainder of the length as concentrated flow. The peak discharge (Qp) is calculated by the following regression equation:

$$Q_p = 2.77777778 * 10^{-3} * P_{24} * D_a * \left[\frac{a + (c * T_c) + (e * T_c^2)}{1 + (b * T_c) + (d * T_c^2) + (f * T_c^3)} \right] \quad (6)$$

Where,
Q_p = peak discharge, m^3/s; D_a = total drainage area, hectares; P_{24} = 24-hr effective rainfall over the total drainage area, mm; T_c = time of concentration, hr, and a, b, c, d, e and f are the unit peak discharge regression coefficients for a given Ia/24 rainfall distribution type.

AnnAGNPS utilizes the Revised Universal Soil Loss Equation (RUSLE), Version 1.5 (Renard et al., 1997) for calculating daily sheet and rill erosion in individual cells.

$$A = R * K * LS * C * P \quad (7)$$

Where,
A = average annual soil loss (Mg/ha); R = rainfall-runoff erosivity factor; K = soil erodibility factor; LS = slope length and steepness factor; C = cover management factor and P = support practices factor

The RUSLE process in AnnAGNPS calculates the sediment delivery to a field edge when a runoff event occurs due to rainfall, irrigation, or snowmelt. Factors are either calculated or retrieved from previously calculated data. Because RUSLE itself does not account for deposition when estimating the amount of sheet and rill erosion from the field, the Hydro-geomorphic Universal Soil Loss Equation (Theurer and Clarke, 1991) is used to estimate the total sediment volume delivered from field to stream reach after deposition. For each of the five particle-size classes (clay, silt, sand, small aggregates, large aggregates) the delivery ratio is estimated by relative deposition based on density and fall velocity of the particles. For a given storm event and watershed outlet point, HUSLE requires upstream average RUSLE parameters, drainage area, volume of runoff, peak discharge, and RUSLE regression coefficients for the corresponding hydrogeomorphic area. The sheet and rill component from Theurer and Clarke (1991) is:

$$Sy = 0.22 * Q^{0.68} * q_p^{\ 0.95} * KLSCP \quad (8)$$

Where,
Sy = sediment yield (Mg/ha); Q = surface runoff volume (mm); q_p = peak rate of surface runoff (mm/s); and, L, S, C, P are RUSLE factors as per AHN 703.

Further details on the theoretical background of AnnAGNPS can be found in Bingner and Theurer (2003).

2.3 Input Requirements

2.3.1 Weather

The weather input file was created using recorded data from NARC in the watershed. Specific inputs required for the weather file are maximum and minimum daily temperatures, daily precipitation, average daily dew point, sky cover and wind speed.

2.3.2 Topography

Digital Elevation Model (DEM) was used to produce the input file necessary from TOPAGNPS program. Elevation data were used to divide the watershed into hydrologically defined subwatersheds or cells, to generate a flow network, and to create data for the AnnAGNPS input file, including cell area and cell slope. The size of the cell depends on the values of critical source area (CSA) and minimum source channel length (MSCL). The Critical Source Area is threshold (minimum) upstream drainage area below which a source channel is initiated and maintained and the Minimum Source Channel Length is the minimum acceptable length for source channel to exist. If the reach is a source channel, then a source area is defined at the top of the reach, as well as left-of-reach area and a right-of-reach area. If the reach is not a source channel, then only a left AnnAGNPS cell and a right AnnAGNPS cell contribute to the stream, as well as the upstream reach. For the Masrang Khola Watershed, a CSA of 4 ha and a MSCL of 50m were chosen to represent the existing stream network. Al together 41 cells and 17 reaches were defined (Figure 2).

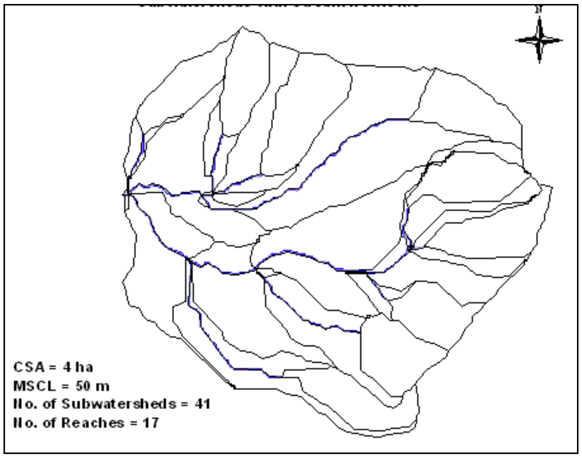

Figure 2: Subwatersheds and stream network generated for the study purpose

2.3.3 Soils

The dominant soil type was determined for each AnnAGNPS cell, and associated characteristics for that soil type ere assigned. Required inputs included particle size fraction, bulk density, albedo, saturated hydraulic conductivity, field capacity, and wilting point. The soils varied from sandy loams to loamy sands.

2.3.4 Crops and Cultivation Practices

Information on crops in the watershed was gathered from report prepared by MSCE/ NARC and field survey. The predominant crops were Maize, Millet, Rice, Bean, Black gram and Wheat.

2.3.5 Land Use

The landuse map was developed from IRSID Panchromatic Sub Scean B2 taken on 31 March 2001. The dominant landuse in each AnnAGNPS cell was assigned to the entire AnnAGNPS cell that represents the more than 30% of the total subwatershed area, and all associated properties (such as curve number) of that land use were assigned to the AnnAGNPS cell. Initial soil nutrient concentrations were based on the soil survey report prepared by MSEC/NARC.

2.4 Selection of Runoff Curve Numbers (CN)

Initial Runoff Curve Numbers were selected based on the land use, treatment practices and soil data for each AnnAGNPS cells (Table 1). The model itself updates the CNs values according to the changes in soil moisture and cover descriptions.

Table 1: Selection of CN values for each AnnAGNPS cell

Cover Descriptions	Initial Curve Numbers (CN)			
	Hydrologic Soil Groups			
	A	B	C	D
Bare soil	77	86	91	94
Seed broadcast	66	77	85	89
Row crops straight	67	78	85	89
Crop residue cover	74	83	88	90
Rangeland	49	69	79	84
Woodland	36	66	73	79

2.5 Estimation of RUSLE Parameters

2.5.1 Rainfall-Runoff Erosivity Factor (R)

Rainfall-runoff erosivity factor were estimated by using mean annual precipitation and modified Fournier index (F) (Renard et al.1994) methods. The equation which uses the mean annual precipitation is:

$$R-factor = 587.8 - 1.219 \cdot P + 0.00410 \cdot P^2, \text{ P> 850 mm} \quad (9)$$

Where,
R = Rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$)
P = Mean annual precipitation (mm)

The R-factors estimated from the Fournier index were very high. Therefore, R-factor from mean annual precipitation were used for the study. The estimated R-factor were 29576 MJ mm ha^{-1} h^{-1} $year^{-1}$ and 32258 MJ mm ha^{-1} h^{-1} $year^{-1}$ for the year 2001 and 2002 respectively.

2.5.2 Soil Erodibiltity Factor (K)

The K-factor was determined by the equation that uses the soil physical properties and organic matter content (Lal, 1994).

$$K = 2.8*10^{-7}*M^{1.14}*(12-a)+4.3*10^{-3}*(b-2)+3.3*10^{-3}*(c-3) \quad (10)$$

Where,
K = Soil erodibility factor ($t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$)
M = particle size parameter [(%silt +% VFS)*(100-%clay)]
a = organic matter (%)
b = soil structure code (very fine granular = 1; fine granular = 2; medium or coarse granular = 3; blocky, platy or massive = 4)
c = profile permeability class (rapid = 1; moderate to rapid = 2; moderate = 3; slow to moderate = 4; slow = 5 and very slow = 6)

The hydrometer method does not determine proportion of very fine sand (VFS) in the soil. Therefore, very fine sand content is estimated as the product of sand and silt divided by 100 (Mitchell et al., 1997). The permeability class was assigned as 2 for the sandy loam and 3 for the loam texture (USDA, 1983). The soil structure code was assumed to be medium or coarse granular and assigned the value as 3.

2.5.3 Topography Factor (LS)

The LS factors for each AnnAGNPS cell were determined using DEM rasters. The purpose of this procedure is to calculate the average RUSLE topographic factor (LS-factor) for each AnnAGNPS cell.

2.5.4 Cover Management Factor (C)

The C factor was computed by multiplying the soil loss ratio (SLR) and their corresponding percentage of annual EI. These values then summed and divided by the total percentage of annual EI value for the entire period.

2.5.5 Support Practice Factor (P)

The P factor was determined based on the conservation measures and the cover code assigned for specified land use (Table 2).

Table 2: Assigned Cover Code for Various Land uses

Land use	RUSLE predefined cover code
Cropland	5- light cover and/or moderately rough
Pasture	1 - established sod-forming grass
Rangeland	4 - moderate cover and/or rough
Forest	3 - heavy cover and/or very rough
Urban	2 - 1st year grass or cut for hay

The detailed procedure to calculate LS, C and P factors are described in AHN 703 (Renard et al. 1997).

2.6 Model Evaluation Criteria

The evaluation of the AnnAGNPS model included both calibration and validation processes. Performance of the model was based on qualitative (graphical displays) and quantitative (statistical measure) assessment. The qualitative procedures consisted of visually comparing the observed and simulated values. James et al. (1982) suggested a common method for evaluation of time series agreement by examination of the sum of the squared differences. Out of the equations they suggested for the error measurement, the "coefficient of performance for the error series A" (CP_A) is used in the studies related to hydrologic simulations. They have further suggested to subdivide the above term by the length of the series to obtain a measure of the error in individual values within the series known as coefficient of performance (CP'_A). The coefficient of performance approaches zero as observed and simulated values get closer. The equations to calculate CP_A and CP'_A are shown as below:

Coefficient of performance for the error series,

$$CP_A = \sum_{j=1}^{N} \left[S(i) - O(i)\right]^2 \tag{11}$$

Coefficient of performance,

$$CP'_A = \frac{CP_A}{\sum_{j=1}^{N} \left[O(i) - Oavg\right]^2} \tag{12}$$

Where,
O (i) = the ith observed parameter
Oavg = the mean of the observed parameter
S (i) = the ith simulated parameter
N = Total number of events

3 METHODOLOGY

3.1 Model Calibration

The measured daily runoff volume of the year 2001 at the watershed outlet was used to calibrate the model. The calibration steps continued by adjusting the SCS curve number (CN) values by trial and error with the graphical comparison (Figure 3) as well as the comparison of statistical parameters of measured and simulated runoff volume. The model was initially run without any change in the CN and calculated the Coefficient of Performance (CP'_A) (Table 3). The CN was then increased or decreased by certain percentage until the results of the statistical evaluation gives the best result.

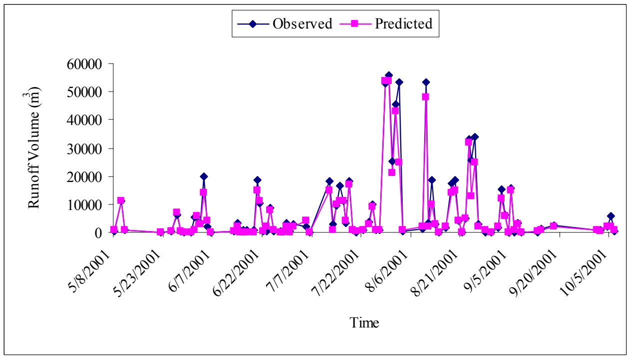

Figure 3: Observed and predicted runoff volume that gives the best fit during model calibration

Table 3: Change in Curve Number values and their corresponding CP’$_A$

Statistical Parameter	Initial CN	Change in CN			
		Reduction		Increase	
		2%	5%	5%	6%
CP'$_A$	0.125	0.068	0.356	0.064	0.063

As could be expected the model responded immediately to changes in CN by producing increased volume of water as CN is increased. However, the initially specified CN values were already high as they represented the real watershed conditions. This result shows that the model is giving a best simulation result with CP’A reaching to 0.063 when initial CN value is increased by 6%. The model underestimated the mean runoff volume by 15% as compared to the measured value with R^2 value of 0.93 (Figure 4). The underprediction of runoff volume is due to the under representation of cropland area and overrepresentation of rangeland area by the model. The model has underrepresntated the cropland by 5% and overrepresented the rangeland by 8%. The overestimation of rangeland and underestimation of cropland is the most likely source of runoff error.

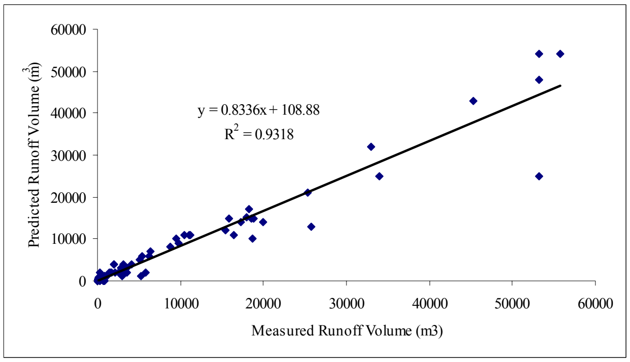

Figure 4: Measured and predicted runoff volume during model calibration

Yuan et al. (2001) also found that AnnAGNPS underestimated observed runoff volume on Mississippi Delta MSEA watersheds. Perrone and Madramootoo (1997, 1999), Binger et al. (1992) and Babel et al. (2004) also found that the older version of AGNPS model underestimated the runoff volume.

3.2 Model Validation

A new set of climatic and watershed management data of the year 2002 was taken for the validation of model. The model has slightly (22%) underestimated the runoff volume. The CP’$_A$ and R^2 values (Figure 5) are found to be 0.11and 0.91 respectively. These result shows that AnnAGNPS is suitable for predicting the runoff volumes with a best fit. The SCS curve number technique used in the runoff calculation in AnnAGNPS is thus can be used successfully in predicting the runoff volume in the local conditions.

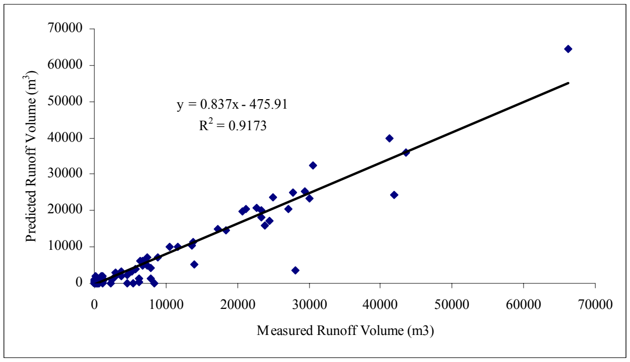

Figure 5: Measured and predicted runoff volume during model validation

3.3 Comparison between Observed and Simulated Parameters

3.3.1 Peak Flows

The model overestimated the average peak flows 2.5 to 4 times more than observed values. Haregeweyn and Yohannes (2003) also found that AnnAGNPS overestimated the peak flow with higher correlation coefficients. The model uses the Extended TR-55 (Theurer and Comer, 1992) method and curve fitting tables to generate regression coefficients in order to calculate the peak flow. Since there were no recording type rain gauges in the study area and it was not possible to calculate the energy intensity values, the most suitable standard SCS rainfall distribution Type I_a was selected as the storm type. This might be the source of error to estimate regression coefficient for the study area leading to over prediction of peak flows in the watershed.

3.3.2 Sediment Yield

The event wise measured sediment yield was taken for the comparison between observed and simulated values. The model overpredicted the average sediment yield by 120% with $R^2 = 0.48$ (Figure 6) and 153% with $R^2 = 0.62$ (Figure 7) of observed sediment yield for the year 2001 and 2002 respectively. The use of RUSLE and the parameters associated with determining soil loss are meant to be used as long-term estimates. For this reason, comparison of individual events may not agree as well as long-term annual values. The over prediction of sediment yield is also associated with the over prediction in peak flows by the model.

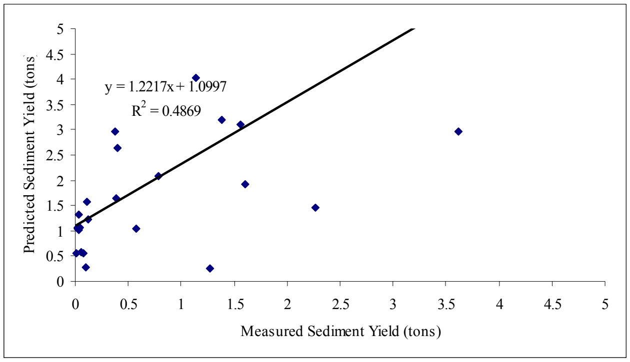

Figure 6: Measured and predicted sediment yield in 2001

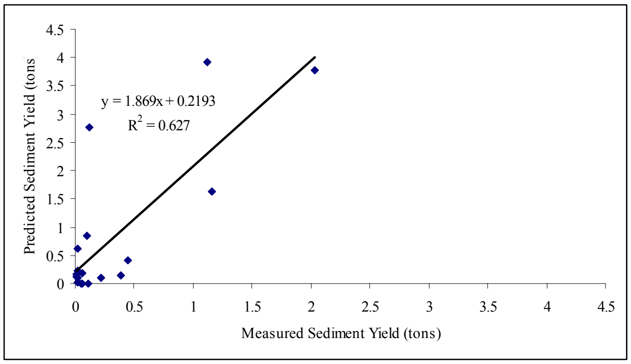

Figure 7: Measured and predicted sediment yield in 2002

4 CONCLUSION

The AnnAGNPS hydrologic/water quality model was used to predict surface runoff, sediment yield, and peak flow at the watershed outlet. The model has predicted the runoff volume within the range of acceptable accuracy which is reflected by small coefficient of performance. This indicates that the SCS curve number method used in the AnnAGNPS model is suitable for runoff volume prediction.

The model overpredicted the peak flow which shows that the extended TR-55 method is not well suitable for the calculation of peak flows in the study watersehed. Therefore it is necessary to modify or develop the equations which can reflect the local conditions to improve the model performance.

Sediment yield predictions are in the range of moderate accuracy. However, the performance of the model to predict the sediment yield can be increased by developing the suitable methodologies that can estimate the rainfall-runoff erosivity factor (R) more accurately from the daily rainfall data.

This study therefore revealed that, in general, the AnnAGNPS model can be used in simulating runoff volume, sediment yield in the watersheds of Siwalik Hills in Nepal with mixed types of land uses and steep slopes that can aid in formulation of different management strategies for the soil and water conservation.

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