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Evaluation of the AnnAGNPS Model for prediction of runoff and sediment yields in St Lucia watersheds

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The Annualised Agricultural Non-Point Source Pollution Model (AnnAGNPS) was used to predict runoff and sediment losses from a forested and an agricultural watershed of St. Lucia Island in the Caribbean. Digital elevation models (DEM) of the agricultural and forested watersheds were generated from digitised topographic data. Based on the critical source area (CSA) and minimum source channel length (MSCL) specifications, the agricultural watershed was discretised into eight cells and three channel reaches, and the forest watershed into 12 cells and five channel reaches. The weighted curve numbers (CNs) were used for the cells with multiple land uses. The CN was observed to be the most sensitive parameter in the prediction of runoff and was adjusted during calibrations. The calibration runs of the AnnAGNPS resulted in errors between observed and simulated values of 0–33% for the agricultural watershed and 3.3–46.2% for the forested watershed for runoff prediction. The sediment yield prediction error percentage during the calibration run varied from 18.2% to 40.5% for the agricultural watershed and 9.1% to 50% for the forest watershed. However, validation of the calibrated model for different rainfall events resulted in errors of 6.7–36% and a value for the coefficient of prediction ($C_{P'A}$) of 0.028 (agricultural watershed) and 3.4% to 36% with a value for the $C_{P'A}$ of 0.23 (forested watersheds) for runoff prediction. Validation of sediment loss for both the watersheds resulted in higher errors (23% to 55%) and $C_{P'A}$ value of 0.341 for both the watersheds. Also, the model prediction of average annual runoff and sediment loss revealed that the agricultural watershed sediment loss (73.3 t ha^{-1} year^{-1}) was significantly higher than for the forest watershed (7.2 t ha^{-1} year^{-1}). Further, the validated model was used to simulate the runoff and sediment losses under a recommended land management regime for the agricultural watershed, which resulted in an 18.5% reduction in runoff and a 63% reduction in sediment loss as compared to the current management practice. This study revealed that the AnnAGNPS can be successfully applied for assessment of runoff and sediment losses and subsequent land use planning to conserve the natural resources in the watersheds of St. Lucia.

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1. Introduction

The watersheds of St. Lucia and other Caribbean Island regions are subjected to flooding, erosion and sedimentation hazards leading to environmental, social and economical problems (Cox & Madramootoo, 1998). Thus, the proper quantification of soil erosion and runoff in the watersheds of St Lucia are essential for efficient land use planning and enhancing agricultural production and productivity (Rojas *et al.*, 1988). This can be achieved by detailed understanding and evaluation of the natural hydrological processes in these regions and through land use changes and best management practices (BMPs). The quantification of these complex watershed processes have been attempted by scientists and engineers leading to development of various empirical and process-based models to simulate the processes and validate on watersheds (Kizil *et al.*, 2006; Borah & Bera, 2004). Computer modelling is considered to be a cost-effective tool for assessing the impact of agricultural management practices on water quality at a watershed scale (Mankin *et al.*, 2002). Several non-point source (NPS) models have been developed to evaluate the concentration of agricultural chemicals, nutrients and sediment at both the field and watershed scale. Binger *et al.* (1992) compared the performance of Agricultural Non-Point Source Pollution Model (AGNPS) with Simulator for Water Resources in Rural Basins (SWRRB) in prediction of runoff and erosion from storms of varying sizes over upland, flat and terraced watersheds in Mississippi. They found that SWRRB and AGNPS performed best for the flat watershed, with estimates within 20% of observed data. The AGNPS model has been tested and validated for several locations in the United States. Young *et al.* (1989) tested AGNPS using data from 20 watersheds in the north-central United States and noted that the model tended to under-predict peak flows, although sediment yields compared favourably to observed data from three watersheds. The model runoff and sediment yields compared favorably with other water quality models. Mitchell *et al.* (1993) tested the model using an interface with Geographic Resources Analysis Support System–Geographic Information System (GRASS–GIS) on small watersheds (<30 ha) in Illinois over 4 years. No significant differences were found between simulated and observed peak runoff rates and sediment yields. Estimated runoff was significantly different at a probability α of 0.05. Srinivasan *et al.* (1994) applied AGNPS on a 124 ha watershed in Texas using the programming scripts within the GIS software to generate slope parameters for the model. The model performed adequately without prior calibration, with simulated sediment delivery within 5% of observed data. Data on runoff predictions were not presented. Choi and Blood (1999) used AGNPS to estimate peak flows and nitrogen concentration from an urbanised watershed in South Carolina and found that the model predictions of peak flows were within 14% of observed values, and that the model provided better estimates of nitrogen loads than widely used regression methods.

In a review of the AGNPS model applied to locations outside USA, Lo (1995) used AGNPS to assess erosion over two large reservoir basins (475 and 495 km^2) in Taiwan. Annual erosion rates were estimated at 259 and 903 $t\,ha^{-1}$, and annual sediment yields estimated at 1.3 and 2.7 million tones, respectively. Simulated erosion rates at some cell locations within the watershed exceeded 3000 $t\,ha^{-1}\,year^{-1}$. This prediction was reasonable based on observed sediment accumulation in the reservoirs. Perrone and Madramootoo (1997) tested AGNPS on a 26 km^2 watershed in Quebec, Canada and reported that runoff and sediment yield prediction were improved by curve number (CN) calibration using an antecedent precipitation index. However, peak flows were generally overestimated and the model was less reliable for complex storms and storms occurring during relatively cold climatic conditions. Lenzi and Di Luzio (1997) applied the model on a 77 km^2 watershed in northern Italy. The AGNPS model was found to under predict peak flows for small storm events and over predict peak flows for large events. Runoff was accurately predicted. Sediment yield and nutrient load estimates followed similar patterns as peak flows but were more accurately simulated. Grunwald and Norton (2000) tested AGNPS on two small watersheds in Bavaria, Germany using variants of sediment yield computations. They substituted the length and slope (LS) factor with a stream power algorithm and linked channel erosion by individual categories of particle size to runoff velocity and used three different methods to simulate runoff (uncalibrated CN, calibrated CN and the Lutz method). The calibrated CNs and the Lutz method coupled with the use of nested brackets created confusion. The modified sediment routines yielded improved estimates. Al-Sheriadeh *et al.* (2000) reported that the model was successfully applied to estimate sediment loads into an agricultural reservoir in Jordan. Leon *et al.* (2004) applied the model to watersheds of southern Ontario. The model provided realistic estimates of nutrient loads in runoff water for a wide range of storm events. For tested grid sizes, both the peak flows and observed runoff values were well reproduced by the AGNPS model. The model performed well for peak flows, runoff volumes, nitrogen and phosphorus predictions when compared with the observed watershed responses in southern Ontario. Kizil *et al.* (2006) applied AGNPS to estimate the runoff quantity and quality from the paved bison feedlot at North Dakota using the recorded data of 2 years period. The validation of AGNPS model resulted in higher correlation coefficients indicating its better performance than that of the empirical models.

The AnnAGNPS (Annualised AGNPS) is a continuous-simulation evolution of the single-event AGNPS model and is available as part of a suite of water quality models known as AGNPS 2001 which include channel degradation, stream water temperature and salmonid models. As with the single-event version, it was designed to assist in the evaluation of potential impacts of agricultural NPS pollution on water quality and the environment (Binger & Theurer, 2001). AnnAGNPS has been tested on a 21 km^2 watershed in Mississippi over a 10-year period (Binger & Theurer, 2001). Land use changes over time were incorporated into the simulations. Runoff estimates were generally 10% lower than observed, while simulated fine sediment yield was 33% of measured values. Binger and Theurer (2001) noted that the model performed well using uncalibrated CNs, suggesting a potential application in ungauged basins. In addition, the model was applied in quantifying input parameters (Binger &

Theurer, 2001). Baginska *et al.* (2003) evaluated the performance of AnnAGNPS model for a 255 ha watershed in Hawkesbury–Nepean drainage basin of the Sydney region. The model performed well for event-based runoff, but failed to predict the event-based nitrogen and phosphorous exports. However, for continuous simulation for monthly predictions, the model performed well for the pollutant loads. Suttles *et al.* (2003) applied the AnnAGNPS model to Little River Research Watershed (333 km^2) in south central Georgia to predict nitrogen, phosphorus, sediment, and runoff over a seven year period. Results from the simulation were compared to 7 years of monitoring data at the outlet of five nested sub-watersheds and at the outlet of the Little River Research Watershed (LRRW). The average annual predicted runoff in the upper part of the watershed was one-third to half of observed runoff. In contrast, predicted runoff in the lower part of the watershed was close to the observed data at the outlet of the watershed and resulted in an accuracy of 100%. Runoff under prediction was attributed to the method of land cover discretisation. The extent of forest land in the upper watershed (55–63%) and the fragmented landscape that has relatively small fields surrounded by riparian forests and tracts of forest resulted in overestimation of forested area in the watershed. In addition to runoff, sediment and nutrient loads were also under predicted in the upper part of the watershed. It was suggested that the prediction results can be improved through better input into the model, as well as modification of the processes within the model to account for forest and riparian conditions.

It was revealed from the review that the AnnAGNPS has not been evaluated in the watersheds similar to those found in St. Lucia. The objectives of this study were to evaluate the performance of AnnAGNPS model using the observed hydrological data from two contrasting watersheds (an agricultural and a forest watershed) of St. Lucia.

2. Study area and data acquisition

The agricultural watershed was located at Forestiere along the eastern divide of the Cul-de-Sac basin of St. Lucia within British West Indies (BWI) grid 1545353, 1545712 and 512175, 512399. The forested watershed was located near the southern divide of the Marquis basin within BWI grid 1545086, 1545601 and 516181, 516628 (Fig. 1). The agricultural watershed was 4.0 ha and the forest watershed 7.8 ha (Fig. 2), both drained by single main channels with inflow from small seasonal gullies. Slopes over the agricultural watershed ranged between 10° and 50°, and between 10° and 28° over the forested basin. The channel at the agricultural site was incised by 1–2 m with gravel bed. The channel at the forest site was dominated by large boulders, as was a large

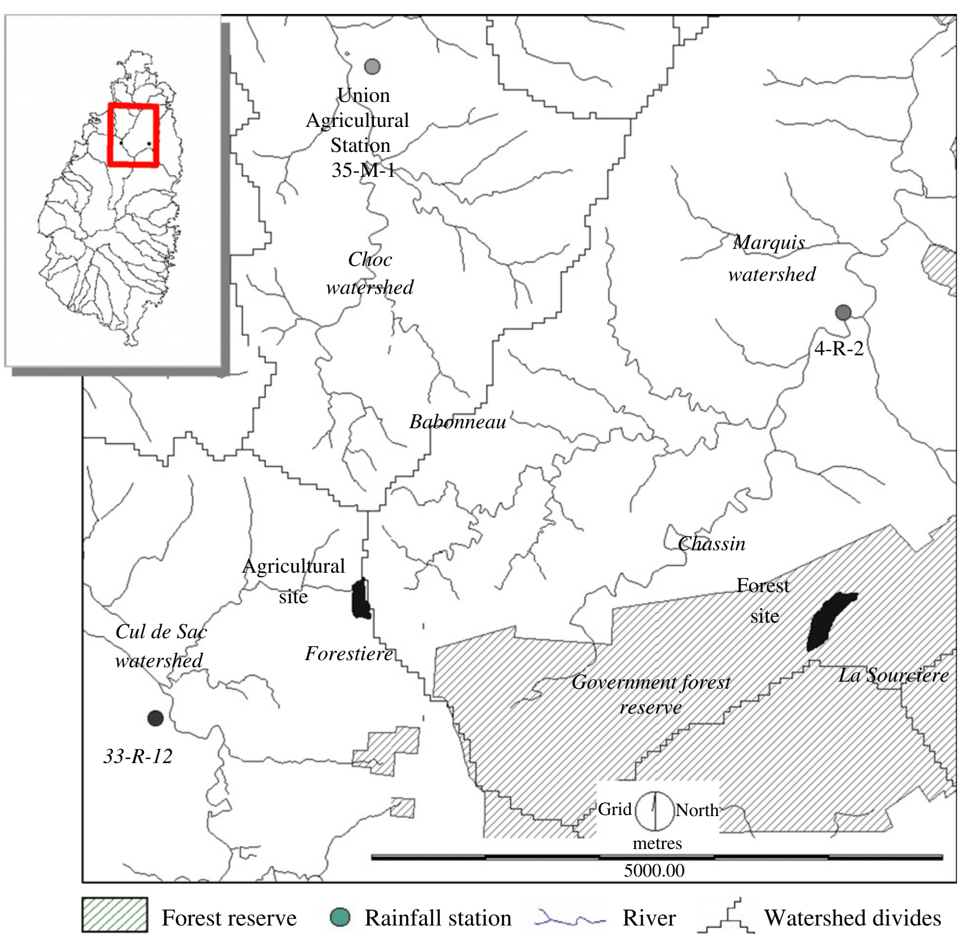

Fig. 1 – Location of study watersheds.

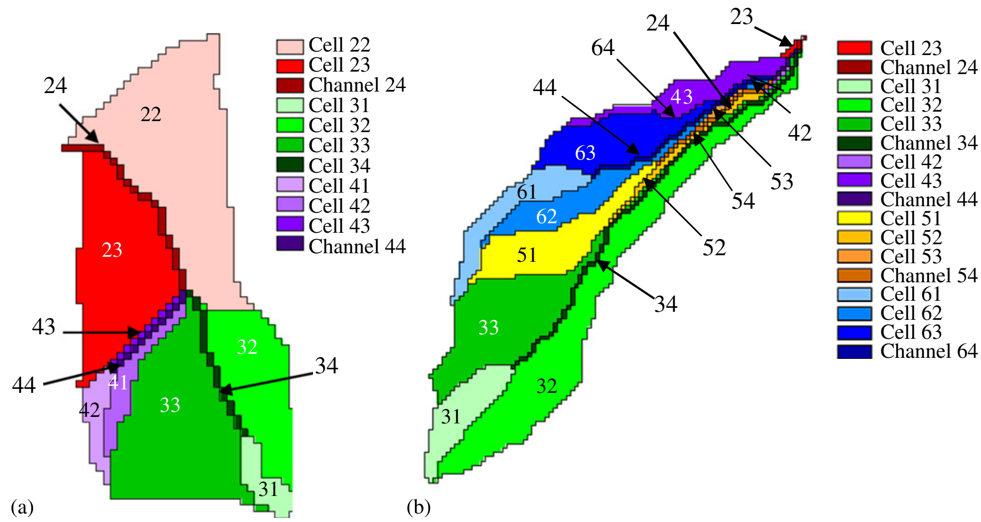

Fig. 2 – The study watersheds with discretised cells and channel reach (Italicized numericals) numbers for prediction of the runoff and sediment loss using the Annualised AGricultural Non-point Source Pollution (AnnAGNPS) Model: (a) Agricultural watershed; (b) Forest watershed.

proportion of the watershed, where rocky outcrops were common. Soils at both sites were derived from a mix of volcanic parent materials and the agricultural site was observed to contain a higher percentage of clay and the forested site contained higher percentage of coarse fragments and boulders (Stark *et al.*, 1966).

Approximately 60% of the agricultural watershed was under intensive banana cultivation with the remaining area under mixed cultivation that included tree crops (mango (*Mangifera indica*), citrus (*Citrus* spp.) and breadfruit (*Artocarpus altillis*)), and residual patches of forest. The watershed was severely degraded with no soil and water conservation measures. The impacts of farming have led to loss of topsoil, the eroded material settling within the lower reaches of river channels, or transported and deposited in the near-shore marine environment. The rainfall regime at both sites was similar. The estimated average annual rainfall depths at agricultural and forested watersheds were 2650, and 2350 mm, respectively. The higher rainfall at the agricultural site was attributable to the orographic effect of the mountainous region. The data used in analyses were acquired between July 1999 and February 2000. The recorded data of rainfall, runoff and sediment load from the hydrologic monitoring stations of both the watersheds for a period of 2 years having events of varying magnitudes (Cox *et al.*, 2006) were used for calibration and validation of the AnnAGNPS model.

3. AnnAGNPS model description

AnnAGNPS is a suite of models developed as a planning tool for agricultural watersheds (Binger & Theurer, 2005). It was developed jointly by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) and the USDA Natural Resources Conservation Service (NRCS). The AnnAGNPS v2.2 model simulates runoff, sediment, nutrient, and pesticide contributions from land to streams as a result of storm flow and irrigation. Runoff is calculated in the model using a variation of the TR–55 method (NRCS, 2001). Unlike the AGNPS model, where processes were simulated within square grid elements over the watershed, AnnAGNPS uses amorphous cells, each cell being a grouping of individual square grid elements, which collectively represent homogenous hydrological response units. The number of amorphous cells or hydrologic response units representing a watershed is a function of the size and spatial variability within the watershed. The sediment reach routing is based on a modified Einstein deposition equation using the Bagnold suspended sediment formula for the transport capacity by particle size class.

Support modules of AnnAGNPS facilitate data preparation for input into the model. The Topographic AGNPS (TopAGNPS) is a subset of the Topographic Parameterization (TOPAZ) program (Garbrecht & Martz, 1994) that discretises the watershed into amorphous cells and channel reaches. Another module, Agricultural watershed FLOWnet generation program (AGFLOW) (Binger *et al.*, 1997, 2001) extracts and formats the terrain parameters for the model (Binger & Theurer, 2005). A Visual Basic user interface performs the data transfer generated by AGFLOW and the assembly of the input files.

4. Data preparation for AnnAGNPS

The model required topographic, land use, soils and climatic data parameters. The following section will discuss how these parameters were derived including assumptions made, and how the model used them in generating outputs.

4.1. *Terrain parameterisation*

Cell landscape parameters were derived using TopAGNPS, a landscape analysis tool of AGNPS 2001 for topographic evaluation, drainage identification, watershed segmentation and sub-catchment parameterisation (Binger *et al.*, 1998). TopAGNPS consists of two modules, viz. the Digital Elevation Drainage Network Model (DEDNM) and the Raster Formatting (RASFOR) module. The DEDNM performed the terrain parameterisation and defined the drainage network, generated raster and tabular data that were used by other TopAGNPS modules. The RASFOR module was a stand-alone item that reformatted the DEDNM output to desired ASCII and GIS data formats. The DEDNM module required data specifying digital elevation model (DEM) parameters, processing options and user output options (contained in an ASCII file), the DEM for the watershed to be analysed, and critical source area (CSA) and minimum source channel length (MSCL) parameter values. The CSA is the threshold upstream drainage area beyond which a source channel is initiated and maintained (Garbrecht & Martz, 1994). The minimum source channel length is the minimum length for defined channels. The DEMs for the watersheds were generated from digitised topographic data. The agricultural basin DEM was created from a 1:2500 scale topographic map, while the forest basin DEM was generated from a 1:10 000 scale topographic map. A 5 m grid resolution was used for both watersheds. The CSA for the agricultural watershed was set to 0.1 ha and the MSCL to 50 m. The CSA for the forest watershed was set to 0.5 ha and MSCL to 100 m. Based on the CSA and MSCL specifications, the agricultural watershed was discretised into eight cells and three channel reaches, and the forest watershed into 12 cells and five channel reaches (Fig. 2). Following DEDNM processing, the RASFOR module was executed to reformat the DEDNM outputs to IDRISI format raster files. The DEDNM module also generated ASCII report and tabular files used by the AGFLOW module to derive cell and channel topographic-related parameters required by AnnAGNPS, specifically the cell and channel slopes, cell length slope (*LS*) factors, cell and reach elevations (Binger & Theurer, 2005).

4.2. *Land use and management parameterisation*

Based on the existing land use, cells within the agricultural watershed were classified into three broad field management regimes, viz. intensive banana cultivation (*Ag1*), mixed cropping with tree crops/bananas/abandoned cultivation (*Ag2*) and rangeland (RANG) corresponding to non-cropland, dominated by abandoned agricultural land and scattered woodland (Table 1). The actual spatial distribution of land covers were overlapped with the cell boundaries, however the model required that single field management regimes be

Table 1 – Initial land use and crop input parameters used for determination of cover management factor C in the AnnAGNPS model for four management regimes

(A) Management regime: *Ag1*—Predominantly intensive bananas.
Cells: 22, 23
Total area: 2.05 ha
Operations data: planting initialised in 1st year month 5, harvest in month 4 of 2nd year; crop residues added to soil following harvest
Planting density: typically 1850 stems ha^{-1}
Yield : assumed at 10 $t\,ha^{-1}\,yr^{-1}$

Parameter	*Values*	*Remarks*
1. Residue weight ratio	2.0	Estimated weight ratio of banana trash to crop weight
2. Crop residue, $kg\,ha^{-1}$		
30% surface cover	4200	Estimated amount of crop residue required to meet these levels of surface cover. Assumed that each stem contributed 25 kg residue at harvest (75% of 1850 stems harvested)
60% surface cover	8400	
90% surface cover	16 800	
3. Growth stage		
Initial	0.2	Approximate ratio of time in each growth stage. (e.g. maturity is assumed to span 50% of the crop life-span)
Development	0.3	
Mature	0.5	
Senescence	1.0	
4. Root mass, $kg\,ha^{-1}$		
1st 15 day period	5000	Estimated rooting density within upper 100 mm of soil over crop development span. Rooting density assumed to remain constant beyond the 4th 15 day period
2nd 15 day period	10 000	
3rd 15 day period	20 000	
4th to 24th 15 day periods	24 000	
5. Canopy cover (%)		
1st 15 day period	30	Estimated aerial coverage of the crop canopy over development span. Assumed to remain constant beyond the 4th 15 day period.
2nd 15 day period	70	
3rd 15 day period	80	

Table 1 (*continued*)

(A) Management regime: *Ag1*—Predominantly intensive bananas.

4th to 24th 15 day periods	90	
6. Rainfall height (m)		
1st 15 day period	1.0	Estimated distance of fall of raindrops to the soil following impact with crop canopy over crop development span. Assumed to remain constant beyond the 4th 15 day period
2nd 15 day period	1.5	
3rd 15 day period	1.8	
4th to 24th 15 day periods	2.0	

(B) Management regime: *Ag2*—Mixed cultivation dominated by tree crops (mango and coconuts); pockets of abandoned cultivation and bananas
Cells: 31,32,33,41,42
Total area: 1.89 ha
Operations data: Planting initialized in 1st year month 1, harvest in month 1 of 2nd year; Crop residues added to soil following harvest.
Planting density: Assumed 50% of optimal stocking level; 65 trees ha^{-1}
Yield: assumed a generic yield of 5 t ha^{-1} yr^{-1}

Parameter	*Values*	*Remarks*
1. Residue weight ratio	2.0	Estimated weight ratio of leaf litter, coconuts to crop weight.
2. Crop residue (kg ha^{-1})		
30% surface cover	2000	Estimated amount of crop residue required to meet these levels of surface cover
60% surface cover	5000	
90% surface cover	10 000	
3. Growth stage		
Initial	0.2	Approximate ratio of time in each growth stage
Development	0.3	
Mature	0.4	
Senescence	1.0	
4. Root mass (kg ha^{-1})		
1st to 24th 15 day periods	50 000	Estimated rooting density over crop development span. Rooting density assumed to remain constant beyond the 1st 15 day period
5. Canopy cover (%)		
1st to 24th 15 day periods	90	Estimated aerial coverage of the crop canopy over development span. Assumed to remain constant beyond the 1st 15 day period
6. Rain fall height (m)		
1st to 24th 15 day periods	10.0	Estimated distance of fall of raindrops to the soil following impact with crop canopy over crop development span. Assumed to remain constant beyond the 1st 15 day period

(C) Management regime: Rangelands (*RANG*) Cell: 43

Parameter	*Value*	*Remarks*
1. Root mass (kg ha^{-1})	30 000	
2. Canopy cover (%)	90	
3. Annual rainfall height (m)	10	
4. Surface residue cover (%)	90	

(D) Management regime: Non-cropland cells (*FOREST*); All cells of the forested watershed

Parameter	*Values*	*Remarks*
1. Root mass (kg ha^{-1})	50 000	
2. Canopy cover (%)	100	
3. Annual rainfall height (m)	20	
4. Surface residue cover (%)	100	

Table 2 – Soil composite parameters for the study watersheds used in model simulations

Cell ID	Dominant soil series at sampling locations (Stark et al., 1966)	Mean particle size classes[a]			Bulk density ($g\,cm^{-3}$)[b]	Very fine sand ratio[c]	Saturated hydraulic conductivity. ($mm\,h^{-1}$)[b]	Field capacity[b]	Wilting point[b]	Unstable aggregate ratio[c]	Organic matter ratio[a]	Structure code	Hydrologic soil group[d]
		clay ratio	silt ratio	sand ratio				cm^3 water cm^{-3} soil					
Agricultural site													
22	Bocage stony clay, Canelles clay	0.19	0.18	0.63	1.5	0.20	7.6	0.2258	0.1272	0.20	0.06	4	B
23	Anse clay	0.18	0.18	0.64	1.5	0.20	8.6	0.2208	0.1232	0.20	0.09	4	B
31	Canelles clay, Anse clay	0.30	0.16	0.54	1.4	0.20	2.7	0.2753	0.1731	0.20	0.13	4	C
32	Canelles clay, Moreau clay, Anse clay	0.24	0.22	0.54	1.4	0.20	4.8	0.2528	0.1459	0.20	0.09	4	B
33	Anse clay	0.26	0.17	0.56	1.4	0.20	3.8	0.2566	0.1552	0.20	0.09	4	C
41													
42													
43													
Forest site													
All cells	Garrand clay loam, Canelles clay, Anse clay	0.17	0.17	0.67	1.5	0.20	10.7	0.2120	0.1159	0.20	0.11	4	B

[a] Experimentally derived parameters.
[b] Derived from Saxton et al. (1986) based on mean clay and sand ratios.
[c] Assumed values.
[d] Based on SCS (1986) definitions using estimated saturated hydraulic conductivity. Cells 22, 23 at the agricultural site and those at the forest site were revised to hydrologic soil group B.

assigned to individual cells. The assignment was achieved by generalising the land cover based on relative dominance within the cell. As a result, cell numbers 22, 23, 41 and 42 were assigned an '*Ag1*' field management regime while cells 31, 32 and 33 were assigned an '*Ag2*' field management regime. Cell 43 was assigned a '*RANG*' management regime. The forested watershed was classified under only one management regime and all cells in the forest watershed were assigned non-cropland, i.e. '*FOREST*' land management regimes.

4.3. Soil parameterisation

In the AnnAGNPS model, out of a total 28 soil-based parameters, 12 parameters were required for runoff and erosion simulation. For agricultural watershed, measured particle size and organic matter ratios for each sample point were used to estimate mean particle size (clay, silt and sand) and organic matter ratios for each cell (Table 2). The soils at the forest site were assumed to be relatively homogenous over the watershed and data from the sample points were amalgamated into single mean clay, silt, sand and organic matter ratios. Using the published information of St. Lucia soils (Saxton *et al.*, 1986), the soil hydraulic parameters from amalgamated soil textural data, bulk density, saturated hydraulic conductivity, field capacity and wilting point ratios were derived for each cell (Table 2). The fine sand and unstable aggregate ratios were assumed to be 0.2 and the rock ratio was measured to be zero within all cells in the agricultural watershed, and 0.1 within the forest watershed (Madramootoo & Norville, 1990).

4.4. Climate input

The model required daily climatic data for the simulation period stored in a separate climate file. For model initialisation purposes data was included for a time span prior to the actual simulation period. Eight parameters were required for each day: (1) date; (2) daily maximum temperature; (3) daily minimum temperature; (4) precipitation; (5) dew point temperature; (6) percent sky cover; (7) wind speed; and (8) wind direction. Header data in the file included location latitude for estimation of solar radiation and daily precipitation over a period of 2 years. A value of 150 mm was assumed for the daily precipitation for a period 2 years of both watersheds.

Daily maximum and minimum temperatures were derived from the mean daily temperature surfaces for each month. The dew point temperatures were assumed equal to the mean minimum temperature for each day (Jensen *et al.*, 1990). Daily precipitation data was from on-site recorded rainfall and the daily average wind speed was derived from the mean daily wind speed surfaces for each month at the study watershed locations.

The model used an erosivity index E_I distribution number in the RUSLE sub-routine to estimate change in relative erosivity of rainfall over the year. An E_I number of 120, corresponding to the E_I distribution in Florida was assumed applicable to St. Lucia.

4.5. Simulation processing

Prior to simulation processing, the input files were checked for errors to ensure that the values entered were within acceptable ranges. The watershed flow routing network was built from the TopAGNPS data, and the reach processing order established. The upstream areas contributing to flow in each reach and downstream flow accumulation were defined based on routing order. The entire daily record in the climate file was read and checked. The simulation period was set from 1 July 1999 to 21 February 2000, however, the entire record input in the file spanned between 1 January 1998 and 29 February 2000. The model checked the cell time of concentration (T_c) in minutes for overland flow for each cell, for construction of the runoff hydrograph. The model used cell profile data derived from the AGFLOW module to compute T_c was the sum of travel times for overland flow, shallow concentrated flow and concentrated flow within the cell. In the model, overland flow was assumed to travel 50 m from the point of origin. The next 50 m was assumed to be shallow concentrated flow. Any cell flow length exceeding 100 m was treated as concentrated flow. Calculations were based on the SCS TR-55 method [soil conservation service (SCS), 1986]. Reach geometry parameters, specifically, reach length, reach top width, reach flow depth and valley width were computed by the model. The CNs were estimated for different land uses of the watersheds for both the watersheds (Table 3) and the weighted CNs for different cells of the agricultural watersheds were calculated (Table 4).

For erosion estimation, variables were set to initial values as specified in the crop and field operations data sections for each cell (Table 1). The values of RUSLE parameters, specifically soil erodibility K, slope length and steepness (LS), cover management C, single-storm erosivity E_I and support practice P factors were established for each non-water cell at the start of the simulation period. The value of the K factor was computed by the model based on a relationship for volcanic soils (Ruangpanit, 1985; Saxton *et al.*, 1986; Renard *et al.*, 1997; Cox *et al.*, 2006). The value of LS factor was generated from the AGFLOW module. The value of C factors were estimated for the cropland cells '*Ag1*' '*Ag2*' within the agricultural watershed based on soil loss ratios (SLRs) for 15 day intervals over the simulation period (Renard *et al.*, 1997). For the forest site, the model computed a single average annual value for C

Table 3 – Estimated curve numbers for land use/hydrologic soil associations for the study watersheds

Land use	Curve number			
	Hydrologic soil group			
	A	B	C	D
Intensive agriculture	78	85	85	97
Forest	45	50	55	60
Mixed tree crops	70	75	86	90
Settlement	79	86	91	98

Table 4 – Cell curve numbers (CN) based on weighted areal land cover used in initial simulation runs for the agricultural watershed

Cell ID	AnnAGNPS field ID	Hydrologic soil group[a]	Land use (ha)				Total area (ha)	Weighted area CN
			Intensive agriculture	Forest	Mixed cropping	Settlement		
22	Ag1	B	1.078	0.000	0.065	0.060	1.203	85
23	Ag1	B	0.555	0.223	0.000	0.000	0.788	75
31	Ag2	C	0.005	0.000	0.113	0.000	0.118	86
32	Ag2	B	0.003	0.000	0.533	0.015	0.550	75
33	Ag2	C	0.398	0.130	0.380	0.000	0.908	83
41	Ag2	C	0.085	0.020	0.000	0.000	0.105	83
42	Ag2	C	0.095	0.033	0.000	0.000	0.128	81
43	RANG	C	0.008	0.018	0.000	0.000	0.025	66

[a] Based on estimated saturated hydraulic conductivity (Table 2).

factor for all cells based on parameters specified in the land use data section of the model input file (Table 1). The management regime in cell 43 in the agricultural watershed was designated rangeland. The parameters used to derive the value of C factor for cell 43 of the agricultural site and all cells within the forest site are contained in Table 1. No parameters were required for estimation of P factor since there were no soil conservation measures within the watersheds. Each cell and reach was processed on a daily time step. For daily cell processes, soil moisture was tracked as a function of precipitation, evapotranspiration, percolation and runoff, defined in the water balance relationship (Binger & Theurer, 2005). The potential evapotranspiration (PET) was computed using the Penman equation. Percolation was estimated using the Brooks–Corey equation based on the soil hydraulic conductivity corresponding to the soil moisture content. The field operations schedule was looked up for each day to effect any operations scheduled for a given simulation day. Operations within the cell determined the runoff CN and specified the magnitude of parameters required in RUSLE sediment computations (Binger & Theurer, 2005). Deposition of various particle-size classes, clay, silt, sand, small aggregates and large aggregates, was calculated based on mass fall velocities. Aggregates were assumed to break down into constituent clay, silt and sand particles once deposited within a channel (Binger & Theurer, 2005). For each simulation, event files containing values of flow and sediment loads at the outlet were generated for each day (NRCS, 2001). These led to generation of source accounting output files with detailed water and sediment contributions from individual channel reaches and cells.

5. Model calibration and validation

The AnnAGNPS model was calibrated for both study watersheds using a subset of rainfall-runoff events recorded between July 1, 1999 and February 21, 2000. Another subset from the same data pool was used for model validation. Daily rainfall totals were first ranked in descending order, and alternating storm days, starting with the day with the highest rainfall, were selected for model calibration. The remaining days were used for validation. A total of 11 and eight storm days were used for model calibration, while 10 and eight storm days were used in model validation for the agricultural and forest sites, respectively. The calibration dataset contained sediment load data for 4 days for both sites, while the validation dataset contained sediment load data for 3 days for both sites. Since sediment transport and delivery was estimated based on runoff, so parameter calibration for runoff estimation preceded sediment yield parameter calibration. It must be reiterated that only fine suspended sediment was sampled at the watershed outlets. Therefore, the sum of the clay and fine silt components delivered to the outlet (estimated by AnnAGNPS) was used to calibrate sediment yield parameters.

AnnAGNPS did not simulate base-flow hence to compare the model predicted runoff to observed runoff, base-flow was separated from the observed runoff using the straight-line method (Viessman *et al.*, 1989). In the runoff simulation from both watersheds, cell CNs were varied by 10%, 15% and 25% around original values (Table 5) to determine the sensitivity of runoff in response to changes in CN.

For sediment yield calibration, preliminary parameter values were used for various crops presented in the RUSLE manual (Renard *et al.*, 1997) and adjusted to reflect the agricultural and non-agricultural land management regimes in the study watersheds. In these pre-calibration runs, it was observed that the unstable aggregate ratio and very fine sand ratios, used in calculation of the K factor, were observed to influence sediment yield to a much greater degree than the other soil parameters. Pre-calibration revealed that the C subfactor parameters with greatest influence over sediment yield were crown canopy ratio, rooting density and crop residue coverage.

In sediment yield calibration for the forest watershed the only parameters required were rooting density and surface residue coverage in estimation of the C factor. Unlike cropland cells in the agricultural watershed, single-value rooting density and surface residue coverage values were specified in

Table 5 – Adjusted curve numbers (CN) tested in runoff sensitivity for the watersheds

Cell ID	Initial weighted cell CNs	Adjusted CNs for model calibration					
		−25%	−15%	−10%	+10%	+15%	+25%
Agricultural watershed							
22	85	63	72	76	93	97	100
23	75	56	64	67	82	86	94
31	86	65	73	78	95	99	100
32	75	57	64	68	83	87	94
33	83	62	71	75	92	96	100
41	83	63	71	75	92	96	100
42	81	61	69	73	89	93	100
43	66	49	56	59	72	75	82
Forest watershed							
All cells	50	63	75	80	85	90	100

Table 6 – Sensitivity in runoff estimates to changes in curve numbers (CN) for the agricultural site

Calibration event day	Observed runoff, mm	Predicted runoff, mm Percentage change in CN						
		Original CNs	−25%	−15%	−10%	+10%	+15%	+25%
1 August 1999	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12 September	16.6	10.1	5.0	7.6	7.6	12.6	17.6	25.1
1 October	8.8	10.1	7.6	10.1	10.1	10.1	12.6	15.1
19 October	8.8	10.1	5.0	7.6	7.6	12.6	15.1	20.1
20 October	13.5	25.1	20.1	22.6	22.6	25.1	27.7	32.7
21 October	14.7	10.1	7.6	7.6	7.6	10.1	10.1	12.6
11 November	42.9	42.7	40.2	40.2	42.7	45.2	47.8	50.3
17 November	7.6	7.6	5.0	5.0	5.0	10.1	10.1	17.6
7 December	7.7	15.1	12.6	15.1	15.1	17.6	17.6	22.6
16 February 2000	7.3	5.0	5.0	5.0	5.0	7.6	7.6	12.6
21 February	87.6	82.9	75.4	77.9	80.4	85.4	93.0	98.0
Coefficient of prediction $C_{P'A}$		0.045	0.069	0.062	0.054	0.049	0.069	0.180

the model. Pre-calibration runs also assisted in determining the approximate range of these parameters for the forest site.

Simulated runoff, peak flow and sediment yield were evaluated against observed data using a coefficient of prediction statistic, $C_{P'A}$ (James & Burgess, 1982) given as

$$C_{P'A} = \frac{\sum_{i=1}^{n} [S(i) - O(i)]^2}{\sum_{i=1}^{n} [O(i) - O_{av}]^2}, \tag{1}$$

where $C_{P'A}$ is the coefficient of prediction; $O(i)$ is the ith observed parameter; O_{av} is the mean of observed parameters; $S(i)$ is the ith simulated parameter; and n is the number of events. Selection of the final calibrated parameters to be tested in the validation phase was based on smallest values of $C_{P'A}$ for simulated results versus observed data. Absolute prediction error within 20% in the model estimate was deemed acceptable (Binger *et al.*, 1992).

6. Results and discussion

Operation of the AnnAGNPS model several times without calibration revealed that the CNs, very fine sand ratio (FSR) and unstable aggregate ratio (UAR) in K factor estimation, crown cover ratio (CCR), rooting density (DR) and crop residue (required for 30%, 60% and 90% coverage) in the estimation of C sub-factors were very sensitive to the prediction of runoff and sediment yields.

6.1. *Curve number calibration*

For the agricultural watershed no improvement in runoff simulation was obtained by varying the CNs from the original values. The original CNs resulted in the best overall runoff estimation with a value for $C_{P'A}$ of 0.045. CNs adjusted upwards by +10% produced the next best estimates with a value for $C_{P'A}$ of 0.049 (Table 6). The largest proportional changes in runoff with CN variation were for the rainfall

Table 7 – Sensitivity in runoff estimates to changes in the curve number for the forest site

Calibration event day	Observed runoff, mm	Predicted runoff, mm Percentage change in CN						
		Original CN	+25%	+50%	+60%	+70%	+80%	+100%
24 July 1999	27.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 August	3.8	0.0	0.0	0.0	0.0	0.0	0.0	9.0
27 September	26.6	0.0	0.0	2.6	5.1	10.2	15.4	48.6
19 October	1.3	0.0	0.0	0.0	0.0	0.1	2.6	20.5
21 October	10.1	0.0	0.0	2.6	2.6	3.8	3.8	12.8
10 November	1.3	0.0	0.0	0.0	0.0	1.3	3.8	28.2
11 November	56.9	24.3	41.0	57.6	62.7	69.1	75.5	97.3
21 February 2000	60.7	3.8	12.8	25.6	33.3	42.2	52.5	85.8
Coefficient of prediction $C_{P'A}$		1.442	1.014	0.649	0.510	0.386	0.334	1.133

events on 12 September, 17 November and 16 February. This was characteristic of days with low rainfall and runoff, where changes in CN resulted in relatively large proportional changes in runoff, compared to days with greater runoff volumes. On the other hand, the calibration of events on 11 November and 21 February showed small changes in runoff prediction in response to changes in CN. Furthermore, antecedent rainfalls for these days were relatively low, and the model would have adjusted the CNs to antecedent moisture condition-I (AMC-I) based on the SCS criteria, minimising the effect of varying the CNs. The model predicted relatively narrow changes in runoff for 20 October in response to changes in CN, but unlike 11 November and 21 February, antecedent rainfall was much higher. Since runoff for October 20 rainfall was relatively high, CN adjustment led to small proportional changes in runoff.

For the forest watershed, CNs were adjusted upwards from the original CN with best agreement at a CN of 80% or 70% above the original value (Table 7). The $C_{P'A}$ was 0.334 for that CN. The next best simulation was obtained with a curve number of 85 ($C_{P'A}$ of 0.386).

Overall, it was observed that the model required higher CN values for predicting runoff more accurately. This estimation was due to moisture budgeting module of the AnnAGNPS model which partitioned relatively high volumes of precipitation to evapotranspiration losses on account of high year-round temperatures of St. Lucia. Another possible factor may be due to the undulating topography and presence of volcanic soils in which the water infiltrating at one location appeared at other locations with minimal percolation resulting in higher surface runoff. Therefore, the high CNs corroborated these factors and resulted in better prediction of runoff.

6.2. *Sediment parameter calibration*

For sediment yield calibration, the long duration events of 21 February and 11 November were used as the primary reference points for the agricultural and forest sites, respectively. The soils within all cells at the agricultural site were assumed to have a fine sand ratio (FSR) and unstable aggregate ratio (UAR) of 0.2. The estimated *K* factors for the soil types of St. Lucia ranged form a minimum of 0.0321 t h MJ^{-1} mm^{-1} for silty clay loam to a maximum of 0.0893 t h MJ^{-1} mm^{-1} for gravelly sand (Cox & Madramootoo, 1998). In testing the influence of FSR and UAR on the *K* factor computation, these values were varied by −100%, −50%, 50% and 100% around the original value. Increases in the FSR resulted in increases in sediment yield and reduction of the ratio led to reduced sediment yields. A 50% increase in the FSR increased sediment yields by approximately 30%, and a 100% increase in the ratio increased sediment yields by 45–60%. Reductions of the FSR reduced sediment yield by the same orders of magnitude. Sediment yield was less sensitive to changes in the UAR, less so to decreases in the ratio compared to increases. A 50% change in the UAR increased sediment yield by 20%, and a 100% change increased sediment yields by 20–30%. Decreases in the ratio lead to small declines in sediment yield of less than 10%.

Moreover, changes in the crown canopy cover had relatively large effects on predicted sediment yield. A decrease in crown canopy cover by 25% increased sediment yields between 36% and 56%. A decrease to 75% increased sediment yields upwards of 80% from the original yield estimate. Also, sediment yields were highly sensitive to reductions in root mass density in the top 100 mm of the soil. An increase in rooting density resulted in reduction of sediment yields while a decrease in rooting density increased the sediment yields at higher rate, i.e. a 50% decrease in root mass density resulted in an increase in sediment yields by as much as 80%, while a 95% decrease in the parameter resulted in an increase in sediment yields ranging from 216% to just over 280%. The model was also sensitive to changes in crop surface residue coverage or the mass of crop residue required to achieve various levels (30%, 60% and 90%) of surface cover. Lower values suggest less residue mass is required to attain a given level of surface coverage, implying that the crop residue is efficient in providing surface cover. Increasing this parameter by 100% resulted in modest increases in sediment yields ranging from 17% to 50%. Changes in sediment yields resulting from increasing the parameter between 50% and 100% were relatively small. Decreasing the parameter by 50% produced modest reductions in sediment yield, but dramatically decreased to over 80% of the original simulation as the parameter was reduced to 95%.

Also, while calibrating the parameters for sediment yield at the forest site, it was assumed that the FSR and UAR approximated 0.2. Their influence on the computed K factor was tested by varying these parameters by −100%, −50% and 150%, and the results in terms of sediment yield, were found to be similar to the agricultural site. A decrease in the FSR to zero yielded sediment decrease between 50% and 67%. Increasing the ratio by 150%, i.e. to a value of 0.5 resulted in an increased sediment yields by 12% (i.e. from 33% to 45%). Sediment yields were similarly less sensitive to changes in the unstable aggregate ratio as found with the agricultural site. Change in the UAR by −100%, changed sediment estimates by −12% to −33%, and changing the ratio by 150%, resulted in an increase in sediment yields by 25%.

The C factors for the agricultural areas of the St. Lucia varied from 0.03 for intensive agricultural land to 0.12 for intensive hill and banana cultivation (Cox & Madramootoo, 1998). The annual cover ratio (the ratio of ground covered by the canopy, to the total ground area) was set at 0.9 and assumed constant over all simulations. The annual root mass was varied over −40%, −50%, −60%, −70% and −80% from the revised value of 5000 kg/ha. Changes in soil loss were highly sensitive to changes in this parameter, more so than that for the agricultural watershed. A 40% decrease resulted in an increase in sediment from 177% to 277%, while an 80% decrease resulted in an increase in sediment in excess of 130% over the original yield. The surface residue cover parameter was varied over −10%, −20%, −25% and −50% of the original value of 100%. Sediment yields were not as sensitive to proportional changes in this parameter compared to annual root mass. A −50% change in the parameter, increased the sediment yield by 380%. Finally, the best simulations for the watersheds were obtained for calibration days using the crop and land use parameters as shown in Table 8.

Table 8 – Calibrated crop and land use parameters in sediment yield prediction

Agricultural watershed crop parameters	
Rootmass, kg ha^{-1}; *Ag1* management system	
1st 15 day period	500
2nd 15 day period	800
3rd 15 day period	900
4th to 24th 15 day periods	1000
Crop residue, kg ha^{-1}; *Ag1* management system	
30% surface cover	4200
60% surface cover	8400
90% surface cover	16 800
Rootmass, kg ha^{-1}; *Ag2* management system	
1st 15 day period	5000
2nd 15 day period	5000
3rd 15 day period	5000
4th to 24th 15 day periods	5000
Crop residue, kg ha^{-1}; *Ag2* management system	
30% surface cover	500
60% surface cover	1000
90% surface cover	2000
Rangeland land use parameters	
Annual root mass, kg ha^{-1}	3000
Surface residue cover, %	80
Forest watershed land use parameters	
Annual root mass, kg ha^{-1}	2000
Surface residue cover, %	100

6.3. *Model simulation using calibrated parameters*

6.3.1. *Agricultural watershed simulation*

The original CNs were retained for runoff simulation and the model was operated for the rainfall events and the results are presented in Table 9. The relatively accurate runoff simulation for the three major rainfall days (11 November, 17 November and 21 February) was important to note in the context of the primary objective of modelling, which seeks to simulate system responses to large erosion generating events. The worst predictions were for 12 September, 21 October and 16 February 2000 in which runoff was under predicted by 33.1%, 31.3% and 31.5%, respectively, likely due to high soil moisture and CN adjustment in response to the relatively high antecedent moisture condition. The coefficient of prediction, $C_{P'A}$ was estimated to be 0.014, indicating better model performance for runoff volume prediction.

Peak flows were overestimated for all days except for 3 days due to the higher antecedent moisture conditions arising from 5 day consecutive rainfall amounts prevailed over the watershed (Table 9). Observed peak flows were related to the peak storm discharge and in many instances the precipitation that generated peak runoff was only a fraction of the total daily precipitation. Large daily accumulations, as occurred on 11 November and 21 February, resulted in the overestimation of peak flow. However, good agreement was obtained between simulated and observed peak flow for 20 and 21 October as compared to other calibration days. The $C_{P'A}$ was estimated to be 0.624, indicating poor model performance for peak flow prediction. Also, the prediction error was more than 20% for most of the simulated events (Table 9).

The model under estimated the sediment yields for all the available data of four event days. The prediction error for the event on 21 February 2000 was the highest (−40.5%). The AnnAGNPS model predicted the runoff more accurately for the event of 17 November but simulated peak flow was overestimated and erosion was underestimated substantially higher than observed, possibly due to the inability of the model to account for the fact that the storm occurred during a relatively wet period and the precipitation duration was not sufficiently long to produce sustained erosive overland flow. The $C_{P'A}$ at 0.23 and the prediction error more than 20% indicated that the model failed to predict the erosion with acceptable accuracy.

6.3.2. *Forest watershed simulation*

The CN that yielded the best overall runoff estimate was 90. This could have been due to high ET estimates associated with the forest cover specification in the model, or high partitioning to percolation on account of erroneous soil parameters. In addition, it was also revealed that the runoff

Table 9 – Results of calibration run for the agricultural site

Calibration event day	Observed				Predicted					
	Rainfall, mm	Runoff, mm	Peak flow, $m^3 s^{-1}$	Soil loss, t ha^{-1}	Runoff		Peak flow		Soil loss	
					mm	% error	m^3 s^{-1}	% error	t ha^{-1}	% error
	8.9	1.0	0.011	—	0.8	−20.0	0.019	72.7	—	—
12 September	39.5	16.6	0.078	—	11.1	−33.1	0.054	−30.8	—	—
1 October	18.4	8.8	0.025	—	10.1	14.8	0.018	−28.0	—	—
19 October	33.9	8.8	0.078	—	10.1	14.8	0.128	64.1	—	—
20 October	35.4	13.5	0.034	—	12.1	−10.4	0.039	14.7	—	—
21 October	16.1	14.7	0.080	0.11	10.1	−31.3	0.07	−12.5	0.09	−18.2
11 November	57.4	42.9	0.169	0.15	42.7	−0.5	0.23	36.1	0.1	−33.3
17 November	26.3	7.6	0.106	0.02	7.6	0.0	0.19	79.2	0.015	−25.0
7 December	26.7	7.7	0.075	—	9.2	19.5	0.12	60.0	—	—
16 February 2000	13.1	7.3	0.042	—	5	−31.5	0.056	33.3	—	—
21 Feb	99.2	87.6	0.351	3.78	82.9	−5.4	0.15	−57.3	2.25	−40.5
	_Hlk104049211 Coefficient of prediction ($C_{P'A}$)				0.014		0.624		0.23	

Table 10 – Results of calibration run for the forest site

Calibration event day	Observed				Predicted					
	Rainfall, mm	Runoff, mm	Peak flow, $m^3 s^{-1}$	Soil loss, t ha^{-1}	Runoff		Peak flow		Soil loss	
					mm	% error	$m^3 s^{-1}$	% error	t ha^{-1}	% error
24 July 1999	28.2	27.5	0.208	0.02	23.5	−14.5	0.15	−27.9	0.01	−50.0
1 August	8.5	3.8	0.012		2.78	−26.8	0.009	−25.0		
27 September	48.3	26.6	0.243	0.04	24.8	−6.8	0.16	−34.2	0.03	−25.0
19 October	20.3	1.3	0.008		1.5	15.4	0.01	25.0		
21 October	12.7	10.1	0.082	0.01	7.9	−21.8	0.1	22.0	0.008	−20.0
10 November	27.9	1.3	0.036		1.9	46.2	0.068	88.9		
11 November	96.7	56.9	0.639	0.19	62.3	9.5	0.75	17.4	0.16	−15.8
21 February 2000	85.9	60.7	0.492	0.11	58.7	−3.3	0.52	5.7	0.12	9.1
	Coefficient of prediction ($C_{P'A}$)				0.014		0.063		0.052	

from the forest watershed was not as highly correlated to rainfall as was the case at the agricultural watershed, which was attributed to variable influences such as canopy interception, evapotranspiration and basin storage. Agreement between observed and simulated runoff data was not better than that obtained for the agricultural site, however, the $C_{P'A}$ was the same (0.014). The model overestimated the runoff of 19 October, 10 and 11 November by 15.4%, 46.2% and 9.5%, respectively (Table 10). The best estimate was for the runoff on 21 February with a prediction error of −3.3%. As previously noted, accurate simulation of larger runoff events was of more importance, and the model was able to generate reasonable runoff estimates despite the overestimation of the rainfall event on 10 November.

Simulation of peak flows were overestimated for five events and underestimated for 3 events of the forest watershed (Table 10). Of the days analysed the 21 February peak flow had the closest agreement to observed peak flow, with error of 5.7%. The worst estimate was on 10 November where the estimate was 89% of the observed, however, the magnitude of runoff was small (1.3 mm) and as noted previously, relative accuracy of estimation deteriorates with smaller runoff producing events. The association between simulated peak flow, the observed hydrograph and storm rainfall distribution was not as apparent as it was for the agricultural basin. This was attributable to the combined effects of canopy interception and storage that tends to dampen peak flows in heavily forested basins.

Sediment yields were relatively well estimated given the calibrated model parameters. The overall $C_{P'A}$ was 0.052. The events of 21 October, 11 November 1999 and 21 February 2000 resulted in sediment yields within the 20% prediction threshold. The best estimate was for 21 February where the predicted sediment was 9.1% of the measured value. The 24 July 1999 sediment yield was the poorest estimate at −50% of the observed value and could be explained by the fact that runoff was also underestimated by −14.5%. It was also revealed from the events of 11 November and 21 February that the higher runoff volumes produced higher soil losses (Table 10).

6.4. Model validation

6.4.1. Agricultural watershed simulation

The model was validated for 10 rainfall events of the year 1999 (Table 11). It was revealed that the best simulations were obtained for the 24 July, 6 and 27 September and 27 November events with prediction errors below 15%. However, the model prediction error for rest of the days ranged from 20% to 36% with acceptable coefficient of prediction of 0.028, as compared to 0.014 achieved with the calibration events. Some of these days such as 24 July, 29 September, 30 October and 10 November were of little significance in terms of simulation, because the observed runoff was below 5 mm and not expected to have generated any sediment.

Peak flows were all overestimated except the event of 24 July, within the general magnitude of error ranging from 20% to 122% (Table 11). The overall $C_{P'A}$ was higher than that calculated for the calibration days (Table 11) due to the fact that the prediction error was higher for all the events. The better simulated peak flows were for 24 July followed by 6 September.

Sediment data were not sufficient to evaluate the predictive capability of the model (Table 11). There was wide variation between the three data points. The worst simulation was for the event of 30 September, where the predicted error was −50%. This may be explained by the fact that there was relatively little rainfall in the 2 days just prior to the storm (13.9 mm) and the soil moisture tracking routine of the model considered this to be dry soil conditions.

6.4.2. Forest watershed simulation

Runoff estimation for validation days was poor in comparison to the agricultural watersheds (Table 12). The larger event days, specifically 17 and 27 November overestimated in excess of 25%. The best prediction was for 20 October with error of 3.4%. However, despite the higher rainfall for 12 September, runoff was underestimated due to the low antecedent moisture conditions. This finding was in line with the observed data of the gauging station within the forest watershed, which reveal that there was precipitation of 130.5 mm for 5 consecutive days before 12 September. Similarly, precipitation on 17 and 27 November occurred following relatively dry periods and the model apportioned less runoff from rainfall, as compared to the large calibration event days that followed significant rainfall. The simulated runoff-rainfall ratios for 17 and 27 November were 0.69 and 0.55, respectively, compared to 0.78 and 0.61 for 11 November and 21 February, respectively. Hence, although the model accounted for decreased runoff under the low antecedent soil moisture conditions, the relatively high calibrated CN did not allow for appropriate adjustment to a sufficiently low AMC I CN.

Similarly, the peak flows were generally overestimated, the margin of error increasing for large rainfall days (Table 12). The error in estimation was due to the inadequacy of the SCS daily rainfall distribution in constructing the runoff hydrograph and derivation of simulated peak flows.

Sediment loads were also relatively poorly estimated ($C_{P'A}$ at 0.341) (Table 12) compared to calibration days, the $C_{P'A}$ at 0.052 (Table 12). The 20 October sediment yield was underestimated but the 17 and 27 November sediment loads were overestimated, as the model calculated sediment delivery as a function of runoff. The error percentage of 20 October sediment yield (−23%) was the lowest, which is influenced by the accurate estimation for runoff.

7. Conclusions

A continuous hydrologic water quality simulation model AnnAGNPS was used to model runoff and sediment loadings from two small watersheds in St. Lucia under two contrasting land management regimes. The purpose of the investigation was to assess the performance of the model under St. Lucian

Table 11 – Results of validation run for the agricultural site

Validation event day	Observed				Predicted					
	Rainfall, mm	Runoff, mm	Peak flow, m^3s^{-1}	Soil loss, t ha^{-1}	Runoff		Peak flow		Soil loss	
					mm	% error	m^3 s^{-1}	% error	t ha^{-1}	% error
24 July 1999	15.8	3.0	0.010		2.8	−6.7	0.008	−20.0		
6 September	36.2	6.1	0.093		6.9	13.1	0.116	24.7		
27 September	52.9	38.0	0.207	1.89	35.1	−7.6	0.29	40.1	1.45	−23.3
29 September	10.8	3.2	0.006		2.5	−21.9	0.01	66.7		
30 September	26.6	5.0	0.064	0.02	6.8	36.0	0.09	40.6	0.009	−55.0
30 October	29.3	3.8	0.026		4.9	28.9	0.04	53.8		
10 November	18.3	1.7	0.009		2.1	23.5	0.02	122.2		
27 November	69.7	43.0	0.278	0.26	37.1	−13.7	0.531	91.0	0.19	−26.9
2 December	34.7	14.3	0.114		17.5	22.4	0.25	119.3		
8 December	20.2	5.4	0.077		6.8	25.9	0.11	42.9		
Coefficient of prediction ($C_{P'A}$)					0.028		1.234		0.095	

Table 12 – Results of validation run for the forest site

Validation event day	Observed				Predicted					
	Rainfall, mm	Runoff, mm	Peak flow, m^3s^{-1}	Soil loss, t ha^{-1}	Runoff		Peak flow		Soil loss	
					mm	% error	$m^3 s^{-1}$	% error	t ha^{-1}	% error
6 September 999	23.5	8.2	0.077		6.2	−24.4	0.06	−22.1		
12 September	42.9	23.6	0.181		19.7	−16.5	0.119	−34.3		
1 October	15.2	1.2	0.008		1.05	−12.5	0.012	50.0		
20 October	27.9	11.9	0.134	0.013	11.5	−3.4	0.156	16.4	0.01	−23.1
17 November	91.4	30.3	0.610	0.063	41.2	36.0	0.78	27.9	0.085	34.9
27 November	58.4	13.9	0.216	0.018	17.5	25.9	0.49	126.9	0.023	27.8
8 December	12.7	4.9	0.016		3.6	−26.5	0.034	112.5		
16 February 2000	2.9	7.3	0.069		8.5	16.4	0.047	−31.9		
Coefficient of prediction ($C_{P'A}$)					0.23		0.412		0.341	

climatic, hydrologic, topographic and land use conditions, with a view of future applications as a tool in support of watershed management planning.

For the agricultural watershed, the model estimated runoff volume reasonably well ($-0.5<C_{P'A}<14.8$) for days with high precipitation depths. Runoff depths for these days were estimated within 20% accuracy of observed values suggesting satisfactory performance of AnnAGNPS. The model was less accurate in estimating runoff for days with lower precipitation amounts. It was also observed that model performance was poor in simulation of runoff for the forest watershed. Peak flows were generally overestimated for both watersheds, which can be attributed to the method used by the AnnAGNPS model to derive the unit hydrograph. Runoff was most sensitive to changes in the curve number while sediment yield estimation was highly sensitive to the fine sand and unstable aggregate ratios associated with the *K* factor, rooting density, surface residue and crown canopy cover associated with the *C* factor. Therefore, further research in quantifying the magnitudes of these parameters are required to improve the performance of the model in small steep tropical catchments of St. Lucia. The results of the simulations in this study were with limited number of observed data due to the difficulty in generation of primary data in St. Lucia watersheds. The finding of these preliminary investigation suggested that the model can be applied for estimation of runoff and sediment losses with acceptable accuracy ($0<C_{P'A}<0.25$) and can also be interfaced with a decision support framework to guide selection of best management practices for integrated watershed management planning in St. Lucia.

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