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EFFECTS OF CELL SIZE ON AGNPS INPUTS AND PREDICTIONS

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Distributed-parameter watershed models require division of a watershed into homogeneous areal units. The size of these units influences both model inputs and model accuracy. This study evaluated the response of the Agricultural Non-Point Source (AGNPS 5.0) model to different cell sizes. Red Rock Creek watershed, covering 135 km² of south-central Kansas, was modeled at four cell-size resolutions (260, 65, 16, and 4 ha), and 24-hr storm events with return periods of 0.05, 0.5, 2, 20, and 200 years were applied. Remotely sensed Landsat-5 TM images were used to obtain land-cover data, and soil and topographic data were extracted from GIS layers using an AGNPS-ARC/INFO interface. Runoff depth decreased with increasing cell size. However, sediment and nutrient yields decreased with increasing cell size from 4 ha to 16 ha and then increased with further increases in cell size. This was a result of two primary factors: flow-path length and slope estimates. Slopes were systematically underestimated for larger cell sizes by the AGNPS-GIS interface, resulting in decreases in overland erosion as cell size increased. Flow-path lengths were calculated internally by AGNPS and generally decreased with increasing cell size, causing decreases in channel erosion but increases in delivery ratios. The net effect was a local minimum at 16 ha for sediment yield. However, comparisons with measured stream flow and sediment yield indicated that cell size selection induced only a small model response compared to natural variability. We recommend cell size between (slope-length)² and the cell size that produces maximum modeled slope (in this study, 0.5 to 4 ha). However, the large variability in measured runoff and sediment yields might make cell-size selection less important than other model factors, such as antecedent moisture condition.

INTRODUCTION

Watershed models have long been used as prediction tools for surface water quality. Most of these models require the watershed to be divided into homogeneous units (either grid cells or subwatersheds) to represent the different model parameters for soil, land cover, topography, and stream morphology. In all cases, selection of cell sizes or the size of homogeneous units is an important issue that impacts model results. However, guidelines for selecting the size of these units are not well defined. This paper will focus on cell-size selection for the widely used Agricultural Nonpoint Source (AGNPS) model (Young et al., 1987). It should be noted that this study evaluated a version of AGNPS (v. 5.0) that is no longer supported. The newer version (AnnAGNPS; Bingner et al., 2001; Cronshey and Theurer, 1998) allows homogeneous units to be defined as either square grid cells or along subwatershed boundaries. In either case, it still uses many of the same algorithms that serve as the focus of this study.

Young et al. (1989) reported that cell size of 16 ha is recommended for watersheds exceeding 800 ha using AGNPS. Smaller cell sizes were recommended for smaller watersheds. They reported that accuracy of results can be increased by reducing the cell size, but acknowledged this also increased the time and labor required to run the model. Conversely, larger cell sizes (64 ha or one-quarter section) have been used successfully to generate model input parameters (Mankin et al., 2002) and to model stream flows and constituent concentrations (Mankin et al., 1999) and lake loadings (Mankin et al., 2003). For a 2,784-ha watershed in Illinois, Feezor et al. (1989) analyzed cell sizes of 1.6, 6.5, 26, and 103 ha, and found soil erosion, sediment N, and sediment P decreased and water-soluble N increased as cell sizes increased. They concluded that the smallest practical cell size should be used, but provided little rationale for this recommendation. Vieux and Needham (1993) used cell sizes of 1, 2, 4, 8, 12, and 16 ha for a single 25-year, 24-hour storm (11.2 cm) and compared runoff and sediment yield response within a small watershed (282 ha) in Minnesota. Whereas upland erosion was a maximum at 4-ha cell size, channel erosion ceased for cell sizes greater than 4 ha, and sediment yield had a local minimum at that cell size. The larger cell sizes resulted in shorter flow-path lengths, which reduced deposition and thus increased sediment transport efficiency. Independent stream-channel length estimation from a 1:12,000 scale aerial photo most closely agreed with the AGNPS flow-path length at 4-ha cell size. This provided some confirmation of 4 ha as the most accurate in this watershed and led to their recommendation that cell size be selected to best approximate channel length. Bingner et al. (1997) found a similar measure, drainage density (ratio of channel length to watershed area), provided a reasonable aid in selecting subwatershed size for the SWAT watershed model. Missing from each of these studies, however, were comparisons with actual runoff or stream-flow data that allow realistic assessment of the impact of cell-size selection on watershed-scale flow and pollutant loads.

Cell-size selection impacts the calculation of AGNPS outputs both directly, by changing cell areas and lengths, and indirectly, by the impact of cell size on the procedures used by the interface model to determine weighted average parameters for each cell. AGNPS outputs, such as sediment yield, are suggested to be most sensitive to slope, Universal Soil Loss Equation (USLE) soil erodibility (K) factor, CN, and hydrologic soil group (Young et al., 1987) and flow-path length (Vieux and Needham, 1993). For the AGNPS-GIS interface studied, Mankin et al. (2002) found 64-ha cell sizes produced poor estimation of slope but fair estimation of land-use parameters and very good estimation of soil parameters. The poor prediction of topographic factors demonstrates a poor match between the cell size, scale of topographic relief, and algorithms used to estimate slope, and suggests that cell-size selection should account for both watershed and model characteristics.

This study analyzed sensitivity of cell-size selection on interface model generation of input parameters, internal AGNPS flow-path length calculation, and AGNPS output predictions over a range of rainfall depths. In addition, measured flow and sediment yield were used to indicate importance of cell size, relative to other known sources of variability, in providing accurate model results.

MATERIALS AND METHODS

Study Area

The Red Rock Creek watershed (Figure 1), a subwatershed of Cheney Reservoir watershed (CRWQP, 1994), is located in south-central Kansas in Reno County and covers an area of 135 km^2. The watershed covers six 7.5-minute USGS quadrangle maps: Arlington, Yaggy, Partridge, Elmer, Castleton, and Pretty Prairie. Red Rock Creek runs for 24 km before its confluence with the North Fork of the Ninnescah River; 10 km of the creek are intermittent and 14 km are perennial. The average elevation of the watershed is 479 m. Watershed soils are mostly silty loams. About 32% of the watershed is rangeland, primarily tall-grass prairie with some woodland. Cropland covers 66% of the watershed, and 0.6% is residential area. The average rainfall in the watershed is 696 mm/year.

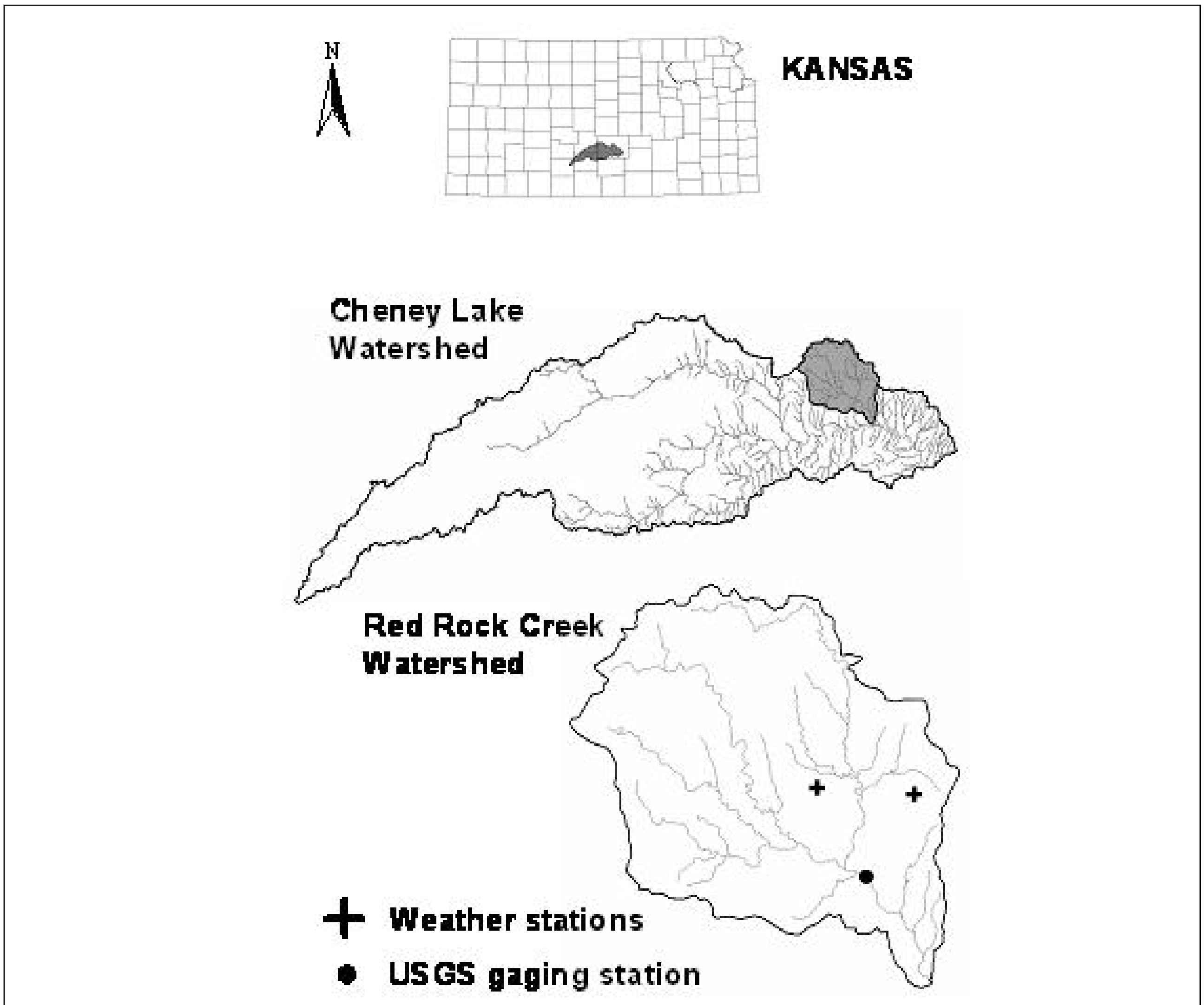

Figure 1. Study watershed.

The AGNPS model

The AGNPS 5.0 model is a single event, distributed parameter model (Young et al., 1987, 1989, 1994) used to estimate surface runoff, sediment yield, and nutrient loading from agricultural watersheds. A distinct feature of this model is the discretization of the watershed into square cells. Each cell is characterized by 22 input parameters, including NRCS curve number (CN), topographic parameters, channel parameters, USLE data, fertilization level, and soil texture. Sediment yield is calculated by a modified form of USLE (Wischmeier and Smith, 1978). Runoff depth is calculated by the CN method (USDA, 1972). The chemical transport section of the model estimates transport of N and P throughout the watershed using relationships taken from CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems, Smith and Williams, 1980) that account for variations in soil texture and a feedlot evaluation model (Young et al., 1982).

AGNPS input data generation

The AGNPS-ARC/INFO user interface developed by Liao and Tim (1997) was used to generate all AGNPS input data. Complete data were generated for each cell in the watershed at square grid sizes of 4, 16, 65, and 260 ha. The necessary GIS layers/coverages used as input data for the interface were obtained from the Cheney Reservoir Water Quality Project office, South Hutchinson, Kansas, and from the Kansas Data Access Support Center (DASC; http://gisdasc.kgs.ukans.edu/). The coverages included a boundary of the watershed, 1:24,000-scale soils, streams, areas known to have implemented conservation measures, and 7.5-minute DEMs. All the coverages were projected to the UTM coordinate system with datum NAD27, zone 14, with units in meters, and clipped with the boundary coverage of the watershed.

The 7.5-min DEMs (30-m resolution) were converted to TINs, which were used by the interface to extract slope, length of slope, and flow direction for streams and overland flow for each cell (Liao, 1997). The stream coverages, digitized from 1:24,000 scale maps by DASC, also were converted to grids with square cell sizes of 4, 16, 65, and 260 ha. A land-use coverage for the year 1998 was prepared from a Landsat TM image (30-m resolution) using unsupervised/supervised classification with Imagine software of ERDAS (Marzen et al., 2000). The land-use classes included high, medium, and low residue cover for wheat stubble; high, medium, and low vegetative cover for rangeland; other warm-season cropland (primarily corn and sorghum); woodland; water; and residential. For each land-use class, a value was assigned for USLE cover and management (C) factor, surface condition constant, overland Manning's coefficient, and fertilizer level as AGNPS input parameters (Young et al., 1994) (Table 1). In order to assign USLE conservation practice (P) factor, the coverage showing the areas having conservation practices was unioned with the land-use coverage. Expert opinion from USDA-NRCS Office, Reno County, Kansas, helped in the assignment of USLE P-factors to the resultant polygons. A soil coverage for each county of the watershed was obtained from DASC. A database of soil parameters, including USLE K factor, hydrologic soil group, soil-test data, and texture, were added as attributes to the polygon attribute table of the soil coverage for each map unit identification symbol. A CN coverage was made by unioning the land-use and soil coverages. Based on the location of the watershed, an average antecedent moisture condition (AMC) of 1.95 was selected (Koelliker, 1987).

A set of input data for each cell size was run with return-period storms of 200, 20, 2, 0.5, and 0.05 years. The method developed by Koelliker and Humbert (1989) and applied by Mankin et al. (1999) was used to determine energy-intensity (EI) values for different storms. This method assigns EI values to rainfall events of a given probability and adjusts the EI values for smaller storms until the

Table 1. Landcover Classes and Associated Parameters for Red Rock Creek Watershed

Landcover classes	Area (km^2)	Area (%)	CN[1]	C	n	SC
Water	0.85	0.6	100	0.00	0.99	0.00
Other crop	34.71	25.9	77	0.08	0.08	0.05
Woodland	1.69	1.1	59	0.002	0.40	0.29
Built-up area	0.75	0.6	74	0.003	0.15	0.01
Rangeland						
Low cover	5.33	4.0	78	0.15	0.10	0.01
Medium cover	31.96	23.8	68	0.042	0.15	0.15
High cover	5.62	4.2	60	0.003	0.20	0.22
Wheat						
Low cover	31.68	23.6	71	0.23	0.06	0.05
Medium cover	18.33	13.5	69	0.17	0.15	0.05
High cover	3.75	2.8	67	0.08	0.25	0.05
Total	135.00	100.0				

[1]NRCS curve number (CN), USLE cropping factor (C), Manning's overland surface roughness (n), and surface condition constant (SC) were used as inputs parameters to AGNPS.

sum of all storms agrees with an accepted EI value for the location (Wischmeier and Smith, 1978). This method assumes the EI value has the same probability as the rainfall event (Table 2). Hydrologic calculations used the NRCS TR55 method using a default K value of 484 to define the triangular hydrograph (Young et al., 1994). Geomorphic option of AGNPS, described in more detail below, was used for calculation of channel flow characteristics. The model outputs of runoff depth, sediment yield, total N and total P were recorded at the outlet of the watershed. Model outputs of upland and channel erosion contributions, delivery ratio (expressed as the percentage of upland erosion delivered to the outlet), and mean sediment concentration and yield at the outlet were also evaluated.

Table 2. Energy Intensity (EI) Values for Different Storms Selected for AGNPS Runs

Return period (yr)	Rainfall (mm)	EI (MJ-mm/ha-hr)
200	207.5	39.5
20	145.0	25.0
2	82.8	10.7
0.5	44.5	3.1
0.05	8.9	0.1

Flow-path length estimation

The total flow length in a particular cell is comprised of overland, shallow-concentrated, and concentrated flow components, each of which is estimated differently for primary and non-primary cells. A cell is primary when the flow originates from that cell. Non-primary cells receive flow from upstream cells. The following section presents the equations used in the geomorphic option of AGNPS to determine each of these lengths in English units, where 1 ha = 2.46 ac and 1 m = 3.28 ft.

The overland flow length is the travel path of a raindrop before it becomes shallow-concentrated flow. This is assumed to be the same as USLE slope length and is a user input. Overland flow length was fixed as 69 m for each cell in this study, regardless of the discretization. Thus, the slope length used in the USLE calculation of field erosion was constant.

The shallow-concentrated flow length is estimated internally by AGNPS.

$$L_{scf} = 0.375\ L_{cell} - L_{ov} \quad (\textit{primary cells}) \tag{1}$$

$$L_{scf} = 0.884\ L_{cell} - L_{ov} \quad (\textit{non-primary cells}) \tag{2}$$

where L_{scf} is shallow-concentrated flow length (ft), L_{ov} is the overland flow length (ft), and L_{cell} is the length of each cell (ft) calculated as $(43{,}560\ A_{cell})^{0.5}$, where A_{cell} is the area of each cell (ac).

Total flow length is estimated from the following relationships.

$$L_{total} = 153\ A_{cell}^{0.6} \quad (\textit{primary cells}) \tag{3}$$

$$L_{total} = L_{to\text{-}bottom} - L_{cells\text{-}in} = 153\ (A_{cell} + A_{da})^{0.6} - L_{cells\text{-}in} \quad (\textit{non-primary cells}) \tag{4}$$

where L_{total} is the total flow length (ft), $L_{to\text{-}bottom}$ is the total flow length to the outlet of a given cell (ft), $L_{cells\text{-}in}$ is the maximum $L_{to\text{-}bottom}$ of the cells draining into a given cell (ft), and A_{da} is the sum of drainage areas of all cells flowing into a given cell (ac).

The concentrated flow length is calculated from the other values as

$$L_{cf} = L_{total} - L_{ov} - L_{scf} \quad (\textit{primary cells}) \tag{5}$$

$$L_{cf} = L_{total} \quad (\textit{non-primary cells}) \tag{6}$$

where L_{cf} is the concentrated flow length (ft).

We computed overland, shallow-concentrated, concentrated, and total flow lengths in five randomly selected 260-ha cells for each set of 4-ha, 16-ha, 65-ha, and 260-ha cells within the randomly selected 260-ha cell. There were 4 65-ha cells, 16 16-ha cells, and 64 4-ha cells within each 260-ha cell.

Comparison to calibrated model

Calibration and verification of the AGNPS model for Red Rock Creek watershed was presented by Bhuyan et al. (2002). Stream-flow hydrographs and daily total suspended solids (TSS) concentrations for 1997 to 1999 were measured at a USGS gaging station installed within this watershed (Fig. 1). Bhuyan et al. (2002) converted these values into daily surface runoff and daily TSS in surface runoff to allow direct comparison with AGNPS output. Further model calibration by Bhuyan et al. (2003) found the best single value of AMC was 1.5, although individual-event AMC calibration provided the most accurate runoff predictions. For this study, we used AMC 1.95 for the sensitivity analysis of cell and storm sizes, consistent with general AGNPS procedures (Young et al., 1994). Results from the AMC-1.5 calibration were used to demonstrate the impact of AMC calibration relative to the cell- and storm-size analysis from this study.

RESULTS AND DISCUSSION

Effects of cell and storm size

Runoff depth decreased with increasing cell size for all storm sizes; larger cells generated smaller runoff depths (Table 3). On a percentage basis, the difference in runoff depths between the smallest (4 ha) and largest (260 ha) cell sizes studied increased slightly as storm size decreased, ranging from 8% difference for the 200-yr storm to 9% for the 0.5-yr storm (the 0.05-yr storm had no runoff).

Conversely, total N and total P in runoff generally increased as cell size increased (Table 3). In all cases, total N and total P in runoff were small fractions of the corresponding sediment-attached amounts. Below 65 or 265-ha cell sizes, depending on storm size, total N and total P in runoff were negligible. Sediment yield, total sediment N, and total sediment P exhibited a different trend.

Table 3. AGNPS Outputs at the Watershed Outlet with Different Cell Sizes and Storms

Parameters	Cell size (ha) 4	16	65	260
200-yr storm				
Runoff depth (mm)	123.9	123.7	123.4	122.9
Total sediment yield (Mg)	7,182	6,842	7,210	8,840
Total-N in sediment (kg/ha)	1.12	1.09	1.18	1.36
Total-N in runoff (kg/ha)	0.00	0.00	0.02	0.09
Total-P in sediment (kg/ha)	0.45	0.44	0.47	0.55
Total-P in runoff (kg/ha)	0.00	0.00	0.01	0.06
20-yr storm				
Runoff depth (mm)	71.1	70.6	70.4	70.1
Total sediment yield (Mg)	3,226	3,123	3,298	4,039
Total-N in sediment (kg/ha)	0.58	0.57	0.63	0.72
Total-N in runoff (kg/ha)	0.00	0.00	0.01	0.07
Total-P in sediment (kg/ha)	0.24	0.24	0.25	0.29
Total-P in runoff (kg/ha)	0.00	0.00	0.00	0.06
2-yr storm				
Runoff depth (mm)	25.4	25.2	24.9	24.7
Total sediment yield (Mg)	906	897	939	1,054
Total-N in sediment (kg/ha)	0.22	0.22	0.24	0.25
Total-N in runoff (kg/ha)	0.00	0.00	0.01	0.04
Total-P in sediment (kg/ha)	0.09	0.09	0.09	0.10
Total-P in runoff (kg/ha)	0.00	0.00	0.00	0.01
0.5-yr storm				
Runoff depth (mm)	5.6	5.3	5.1	5.1
Total sediment yield (Mg)	213	216	219	222
Total-N in sediment (kg/ha)	0.07	0.03	0.07	0.07
Total-N in runoff (kg/ha)	0.00	0.00	0.00	0.02
Total-P in sediment (kg/ha)	0.02	0.02	0.02	0.02
Total-P in runoff (kg/ha)	0.00	0.00	0.00	0.00

Watershed outputs of these parameters generally decreased as cell size increased from 4 ha to 16 ha and then increased with further increases in cell size from 16 ha to 260 ha (Table 3). As storm size decreased, the relative differences among outputs for different cell sizes became less pronounced.

More detailed erosion results (Table 4) show that both upland and channel erosion decreased slightly with increasing cell size. AGNPS predicted no channel erosion at cell sizes greater than 16 ha. The cell size of 16 ha seemed to be a threshold or critical cell size below which channel erosion contributed. Vieux and Needham (1993) found the threshold to be 4 ha for their smaller watershed.

Assessment of AGNPS inputs

Differences in average CN among cell sizes were small (Table 5), which generally corresponded to the small range in runoff depths with cell size (Table 3). The CN values decreased slightly with increasing cell size, though to a lesser extent than runoff depth. No variation in K factor was observed, and very little variation was found with C factor (Table 5). The small variability in C, K, and CN among the various cell sizes might be an indication that the interface's procedure of area-weighting land uses and soils data was effective, but might also be the result of either small variability in data-set values (i.e., the range of values for C, K, or CN is small for the types of land uses in the cell) or small variability of these parameters within the watershed (i.e., the variability of land uses that exist in the cell are small) (Mankin et al., 2002).

Regardless, small variability in C and K, as well as fixed overland flow length and EI values, indicated that differences in upland erosion for a given storm were caused by differences in cell slope.

Table 4. AGNPS Erosion Outputs for Different Size Cells and Storms

Parameters	Cell size (ha) 4	16	65	260
	200-yr storm			
Upland erosion (Mg/ha)	2.11	1.99	1.93	1.95
Channel erosion (Mg/ha)	0.11	0.04	0.00	0.00
Delivery ratio (%)	24	25	28	32
Mean sediment conc. (ppm)	431.2	412.6	440.3	514.4
Area-weighted yield (Mg/ha)	0.54	0.52	0.54	0.63
	20-yr storm			
Upland erosion (Mg/ha)	1.34	1.25	1.23	1.23
Channel erosion (Mg/ha)	0.11	0.04	0.00	0.00
Delivery ratio (%)	17	18	20	23
Mean sediment conc. (ppm)	337.9	329.4	352.8	412.8
Area-weighted yield (Mg/ha)	0.25	0.22	0.25	0.29
	2-yr storm			
Upland erosion (Mg/ha)	0.58	0.54	0.54	0.54
Channel erosion (Mg/ha)	0.09	0.02	0.00	0.00
Delivery ratio (%)	10	12	13	14
Mean sediment conc. (ppm)	265.1	265.8	284.2	306.9
Area-weighted yield (Mg/ha)	0.07	0.09	0.07	0.07

A large decrease in slope was found as cell size increased (Table 5). This is generally the case as larger cell sizes smooth the topography and do not account for slope changes at scales smaller than the cell size. However, this was exacerbated by the interface model due to the method used in generating the slope input files from DEM data (Mankin et al., 2002). Decreasing slope with cell size would decrease erosion. This indicates that selection of cell size must account for the scale of local topography. AnnAGNPS as well as other models (e.g., SWAT) recognize the importance of slope by using topography to determine subwatershed size. For square AGNPS grid cells, a reasonable representation of slope could be achieved by selecting cell sizes between L_{ov}^2 (minimum) and a cell size that would produce a maximum slope using the largest number of cells (maximum). In this study, the suggested range would be between 0.5 ha (69^2 m^2) and ≤ 4 ha.

Table 5. Mean ± Standard Deviations of NRCS Curve Number (CN), USLE C-Factor, USLE K-Factor, Slope, and Flow-Path Lengths Computed for Different Cell Sizes from Five Randomly Selected 260-ha Cells

Random Cell No.	Cell size (ha) 4	16	65	260
AGNPS parameters				
CN-factor	72.8 ±2.3	72.8 ±2.3	72.8 ±2.2	72.6 ±2.3
C-factor	0.122 ±0.021	0.121 ±0.018	0.122 ±0.021	0.122 0.021
K-factor	0.285 ±0.052	0.285 ±0.052	0.285 ±0.052	0.285 ±0.052
Slope (%)	0.810 ±0.407	0.567 ±0.239	0.429 ±0.169	0.237 ±0.081
Flow-path estimates[1]				
L_{total} (m)	10,579 ±1,828	6,471 ±1,936	3,232 ±2,419	3,470 ±2,492
L_{cf} (m)	8,844 ±2,032	5,626 ±2,030	3,111 ±2,398	3,470 ±2,492
L_{scf} (m)	4,615 ±432	3,447 ±183	2,407 ±224	1,354 ±0
DD (m/m^2)	0.00340	0.00216	0.00120	0.00133

Assessment of flow-path estimates

Flow length is calculated by AGNPS but not reported in output files. Thus, flow-path lengths were analyzed manually for all cell sizes within 5 randomly selected 260-ha cells within the watershed (Table 5). Overland flow length [L_{ov}] is fixed by user input and, thus, is constant for all cell sizes. However, shallow-concentrated flow length [L_{scf}, Eqs. (1) and (2)], concentrated flow length [L_{cf}, Eqs. (5) and (6)], and total flow length [L_{total}, Eqs. (3) and (4)] varied according to cell size. As cell size increased, L_{total}, L_{cf} and L_{scf} generally decreased, although L_{total} and L_{cf} demonstrated slight local-minimum lengths at the 65-ha cell size. For comparison, L_{cf} averaged 9,260 m for the 5 random cells from stream coverages digitized from 1:24,000 scale USGS ortho-quadrangle maps, which most closely agrees with the L_{cf} from smallest (4-ha) cell size (within 4.5%). Similarly, drainage density of 0.00340 m/m^2 at 4 ha was closest to the USGS-estimated 0.00356 m/m^2 (Table 5). Vieux and Needham (1993) also found flow paths of 4-ha cells gave the best agreement with digitized stream lengths.

Decreased L_{cf} has the effect of increasing channel slope for the same elevation difference. This led to decreased sediment deposition and increased delivery ratio as cell sizes increased (Table 4). The increase in delivery ratio together with the decrease in upland and channel erosion as cell size increased had offsetting effects on sediment concentration in the runoff flow (Table 4). For 200- and 20-year storms, sediment concentration decreased from 4- to 16-ha cell sizes (under the influence of a greater relative decrease in upland and channel erosion) and increased from 16- to 260-ha cell sizes (under the influence of a greater relative increase in delivery ratio). For the smaller 2-year storm, the balance of factors shifted slightly, causing sediment concentration to increase with cell size with a minimum at 4-ha cell size. The trend for sediment-bound nutrient data with changes in the cell sizes was similar to that of the sediment (data not shown).

Vieux and Needham (1993) also observed that some AGNPS output parameters demonstrated a local-minimum predicted output for a specific cell size, with increasing output values as cell sizes either increased or decreased from the local minimum. For their 282-ha watershed, a 4-ha cell size produced minimum sediment yield. The local minimum sediment yield for our 13,500-ha watershed occurred at 16-ha cell size. Taken together with the results of Vieux and Needham (1993), it is clear that total flow-path length decreases with increasing cell size, and that local minimums in model outputs occur at a cell size that is watershed specific.

Comparison to calibrated model

Although cell-size selection clearly impacted model inputs, calculations, and outputs, it was less important than AMC in providing reasonable estimates of runoff depth (Figure 2). The variability induced by cell size was considerably less than the variability in actual runoff (Figure 2a). Bhuyan et al. (2003) demonstrated that much of this variability could be addressed by accurate AMC prediction. This is demonstrated in Figure 2a by the runoff predictions that resulted by changing average watershed AMC from 1.95 to 1.5 (for 65-ha cell size); further improvements were possible by adjusting AMC for each event (Bhuyan et al., 2003). Similar to runoff, there was sufficient scatter in measured sediment yield that the differences in modeled yields among cell sizes ranging from 4 to 260 ha were relatively inconsequential (Figure 2b). Because of the fairly high linear correlation of runoff to sediment yield (R^2=0.86, Figure 2c), it is expected that more accurate estimation of runoff would also lead to improved accuracy of modeled sediment yield. Thus, from a practical perspective, the additional effort to collect higher resolution input data to allow reduced cell size might not be justified.

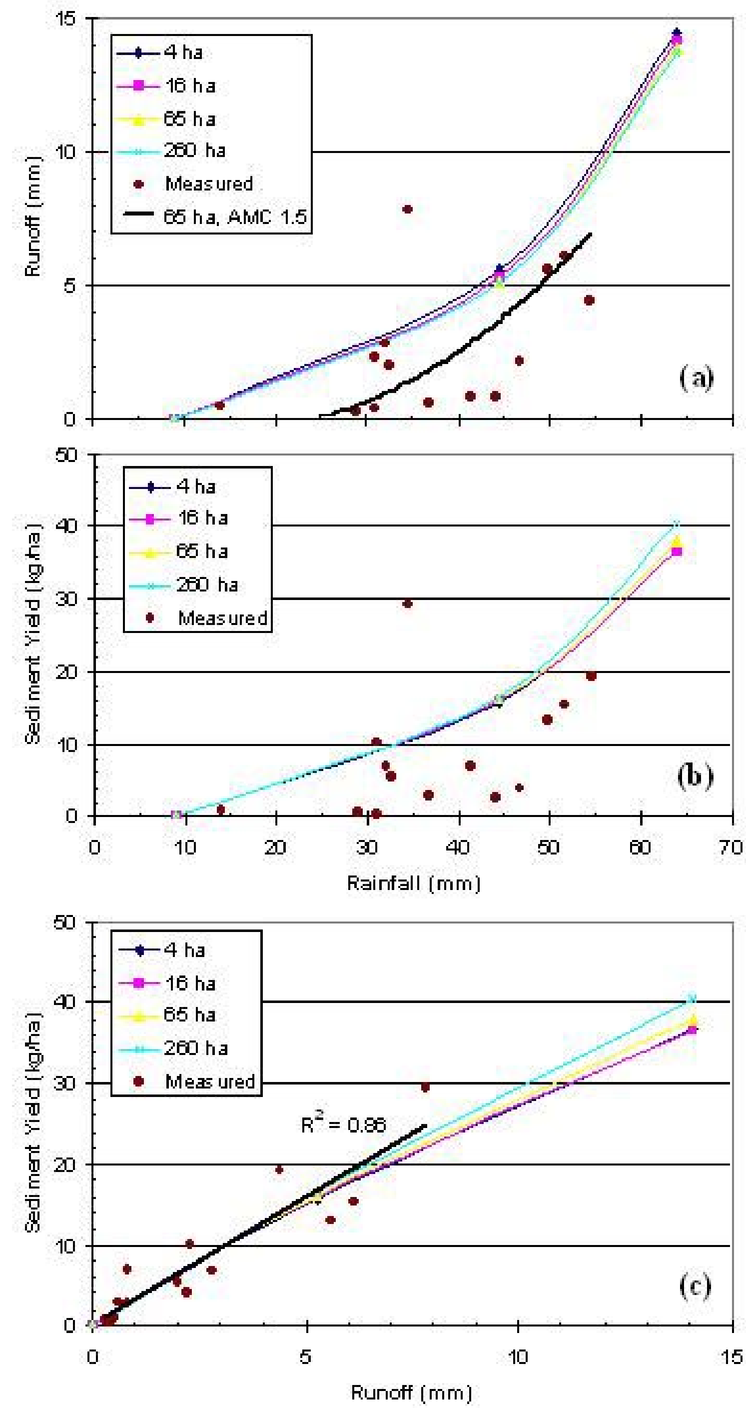

Figure 2. Effect of four cell sizes on modeled (a) runoff depth and (b) sediment yield vs. actual rainfall, and (c) modeled sediment yield vs. runoff depth (average watershed AMC 1.95). Also shown are (a, b, c) measured data for 14 events from 1997-98 (Bhyuan et al., 2003) and (a only) modeled runoff depth vs. rainfall for 65-ha cell size and average watershed AMC 1.5.

CONCLUSIONS

The AGNPS outputs of runoff depth, and sediment and nutrient yields varied with cell size. Runoff depth varied by up to 9%, sediment yield varied by up to 29%, and delivery ratio varied by up to 40% based on cell-size differences alone. These variations may be largely explained by differences in slopes and in flow-path lengths for overland, shallow-concentrated, and concentrated flows. Slopes were estimated from a DEM coverage using a GIS interface that systematically underestimated slopes for larger cell sizes. This resulted in decreases in overland erosion as cell size increased. Flow-path lengths were calculated internally by AGNPS based on cell size, user-selected overland-flow length, and program-default channel meander characteristics. Flow-path lengths generally decreased with increasing cell size, causing decreases in channel erosion but increases in delivery ratios. It is clear that cell size selection is a major determining factor in flow-length calculations and should be made with due consideration to local watershed conditions. We recommend cell size between L_{ov}^2 and a cell size that would produce maximum slope using the largest number of cells (in this study, 0.5 to 4 ha). However, it was also demonstrated that the large variability in measured runoff and sediment yields unaccounted in AGNPS renders the errors induced by cell-size selection relatively inconsequential.

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REFERENCES

Bhyuan, S.J., K.R. Mankin, and J.K. Koelliker. 2003. Watershed-scale AMC selection for hydrologic modeling. *Trans. ASAE* 46(2):303-310.

Bhuyan, S.J., L.J. Marzen, J.K. Koelliker, J.A. Harrington Jr., and P.L. Barnes. 2002. Assessment of runoff and sediment yield using remote sensing, GIS and AGNPS. *J. Soil and Water Conservation* 57(6):351-364.

Bingner, R.L., F.D. Theurer, R.G. Cronshey, and R.W. Darden. 2001. AGNPS 2001 website. Available at: www.sedlab.olemiss.edu/AGNPS.html.

Bingner, R.L., J. Garbrecht, J.G. Arnold, and R. Srinivasan. 1997. Effect of watershed subdividion on simulation runoff and fine sediment yield. *Trans. ASAE* 40(5):1329-1335.

Cheney Reservoir Water Quality Project Office. 1994. Watershed Pollution Management Plan. North Fork Ninnescah Watershed and Cheney Reservoir. South Hutchinson, KS.

Cronshey, R.G. and F.D. Theurer. 1998. AnnAGNPS – Non-point pollutant loading model. Proceedings of the First Federal Interagency Hydrologic Modeling Conference. April 19-23. Las Vegas, NV. pp. 1-9 to 1-16.

Feezor, D.R., M.C. Hirschi, and B.L. Lesikar. 1989. Effect of Cell size on AGNPS prediction. ASAE Paper No 89-2662. St. Joseph, Mich.: ASAE.

Koelliker, J.K. 1987. Hydrologic design criteria for dams with equal reliability. In: Irrigation Systems in the 21st Century, pp 100-107. American Society of Civil Engineers, New York, NY.

Koelliker, J.K. and C.E. Humbert. 1989. Applicability of AGNPS model for water quality planning. ASAE Paper No. 89-2042. St Joseph, Mich.: ASAE.

Liao, H.H. 1997. AGNPS-Arc/Info Interface User manual. Agricultural and Biosystems Engineering Department. Iowa State University, Ames, IA.

Liao, H.H. and U.S. Tim. 1997. An interactive modeling environment for non-point source pollution control. *J. American Water Resources Association* 33(3): 1-13.

Mankin, K.R., S.H. Wang, J.K. Koelliker, D.G. Huggins, and J.F. DeNoyelles. 2003. Watershed-lake water quality modeling: Verification and application. *J. Soil Water Conservation* 58(4): 188-197.

Mankin, K.R., R.D. DeAusen, and P.L. Barnes. 2002. Assessment of a GIS-AGNPS interface model. *Trans. ASAE* 45(5): 1375-1383.

Mankin, K.R., J.K. Koelliker, and P.K. Kalita. 1999. Watershed and lake water quality assessment: An integrated modeling approach. *J. American Water Resources Association* 35(5): 1069-1080.

Marzen, L.J., J.A. Harrington, Jr., S.J. Bhuyan, and J.K. Koelliker. 2000. Use of satellite imagery to determine landcover input variables in an AGNPS water quality model. ASAE Paper No. 002200. St. Joseph, Mich.: ASAE.

USDA, Soil Conservation Service. 1972. Section 4: Hydrology. In *National Engineering Handbook*. Washington, D.C.: USDA-SCS.

Smith, R.E. and J.R. Williams. 1980. Simulation of the surface hydrology. In Knisel, W. ed., CREAMS, A field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. USDA. ARS. Conservation Research Report 26, Vol. 1., Ch. 2, p. 15.

Vieux, B.E. and S. Needham. 1993. Nonpoint-pollution model sensitivity to grid-cell size. *J. Water Resources Planning and Management* 119(92): 141-157.

Wischmeier, W.H. and D.D. Smith. 1978. *Predicting rainfall erosion losses*. Agriculture Handbook No 537. Washington, D. C.: USDA-ARS.

Young, R. A., C. A. Onstad, D. D. Bosch, and W. P. Anderson. 1987. AGNPS, Agricultural Nonpoint Source Pollution Model: A large watershed analysis tool. Conservation Research Report No. 35. Washington, D.C.: USDA-ARS.

_____. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *J. Soil and Water Conservation* 44(2): 168-173.

_____. 1994. *AGNPS User's Guide*. Agricultural Nonpoint Source Pollution Model, Version 4.03. July, 1994. Oxford, Miss.: USDA-NRS-NSL.

Young, R.A., M.A. Otterby, and A. Ross. 1982. A technique for evaluating feedlot pollution potential. *J. Soil and Water Conservation* 37(1): 21-23.

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