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# Field_SWAT: A tool for mapping SWAT output to field boundaries

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ABSTRACT

The Soil and Water Assessment Tool (SWAT) hydrological/water quality model divides a watershed into hydrological response units (HRUs) based on unique land cover, soil type, and slope. HRUs are a set of discontinuous land masses that are spatially located in the watershed but their responses are not tied to any particular field. Field_SWAT, a simple graphical user interface (GUI)-driven tool, was developed to map SWAT simulations from the HRU layer to a user-defined field boundaries layer. This stand-alone tool ingests spatial and nonspatial SWAT outputs and helps in visualizing them at the field scale using four different aggregation methods. The tool was applied for mapping the SWAT model's annual runoff and sediment outputs from 218 HRUs to 89 individual field boundaries in an agriculturally dominated watershed in Northeast Arkansas. The area-weighted spatial aggregation method resulted in a most suitable mapping between HRU and field outputs. This research demonstrates that Field_SWAT could potentially be a useful tool for field-scale targeting of conservation practices and communicating model outputs to watershed managers and interested stakeholders.



## 1. Introduction

The variable nature of surface runoff in response to management practices and the heterogeneous nature of physiographic characteristics such as topography, geology, and soils represent the challenges that hydrological modelers continuously face while modeling a watershed. Efforts to fully account for and represent management practices along with heterogeneous physiographic characteristics have resulted in the transformation of models from those that consider the entire catchment as a lumped unit to the contemporary, distributed models. The public availability of digital data such as digital elevation models (DEM), soils, land use/land cover (LULC), and precipitation along with advances in computing resources have all contributed toward the push for adoption of distributed models (Johnson, 2009). Distributed models divide a watershed into smaller units to represent spatial variability across the whole area. Models such as the erosion impact calculator (EPIC; Williams et al., 1984), precipitation-runoff modeling system (PRMS; Leavesley et al., 1983), hydrological simulation program–FORTRAN (HSPF; Bicknell et al., 1997), soil and water assessment tool (SWAT; Arnold et al., 1998), MIKE-SHE (Bathurst, 1986), and Modelo de Erosão Físico e DIStribuido (MEFIDIS; Nunes et al., 2005) can be categorized as semi- or fully-distributed based on the delineation of smallest land unit for calculating model responses. While SWAT uses the term hydrological response units (HRUs) for denoting smallest modeling unit, several other terms have also been used in the literature such as grouped response units (Kouwen et al., 1993), hydrologically similar units (Karvonen et al., 1999), and representative elementary areas (Wood et al., 1988).

Delineation criteria for HRUs have evolved with watershed models. Topographic-based HRUs were first delineated by Leavesley et al. (1983) for storm hydrograph simulation in the PRMS model. In this approach, a watershed is conceptualized as a series of interconnected rectangular flow planes and channel segments. Channel segments are delineated based on the flow direction from the digital elevation model and flow is routed over the flow planes and channel segments. Flügel (1995) introduced the concept of homogeneity of HRUs by lumping land areas having similar physiographic characteristics represented by LULC, soils, and topography. An underlying justification for such delineation is that the dynamics of hydrological processes within an HRU have small variation compared to that among different HRUs. Bongartz (2003) compared the topographical approach by Leavesley et al. (1983) and the homogeneous HRU-based approach by Flügel (1995) and reported that for smaller catchments ($<200\ \mathrm{km}^2$) homogeneous HRU provided better representation of the catchment. The SWAT model has adapted the homogenous HRU concept and requires users to specify threshold of land cover, soil, and slope, which is then used to create HRUs (Neitsch et al., 2005). Different thresholds produce different distributions of HRUs. Details of this delineation process are provided later in this paper.

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Gitau (2003) suggested that using thresholds resulted in loss of information and should be used only when the number of HRUs created (a function of drainage area and thresholds) results in acceptable computation costs. Gassman (2008) observed that the incorporation of HRUs in SWAT is being regarded as both strength and weakness of the model. Although, the method of HRU delineation has allowed the flexibility to adapt the model to sizes ranging from field plots to entire river basins, the nonspatial nature of HRUs is regarded as a key weakness of the model (Gassman et al., 2007).

Recently, there have been several applications of the SWAT model for identifying priority pollutant-contributing areas at the subwatershed scale (Tripathi et al., 2003; Saraswat et al., 2010) and the HRU scale (White et al., 2009; Ghebremichael et al., 2010). These applications recognize the disproportional nature of pollutant contribution in a watershed and seek to spatially identify those areas that are considered hotspots of pollution. The ultimate aim is to target conservation practices, instead of random implementation, in order to gain maximum pollutant reduction (Parajuli et al., 2008). However, in reality, agricultural conservation practices are applied at the field scale (whole or part of a field) and hence, field-level targeting is a key to watershed pollution management (Daggupati et al., 2011). Current SWAT HRU outputs do not provide the right spatial scale for transferring model results to actionable items for watershed pollution management.

Our overall goal in this study was to simplify SWAT model HRU outputs and provide a tool that allows watershed managers and conservation agencies to visualize results to user-defined boundaries, such as fields, so that they can target implementation of conservation practices. To realize this goal, our specific objectives were to (1) develop a spatial algorithm to aggregate HRU level outputs by mapping it to field boundaries within a watershed, and (2) incorporate the algorithm in a user-friendly and stand-alone geospatial software that allows visualization of SWAT HRU output to user-defined field boundaries.

## 2. Methodology

### 2.1. SWAT HRU delineation concept

In the SWAT model's graphical user interface, ArcSWAT, creation of HRU is a two-step process. In the first step, the SWAT model divides the drainage area of the watershed into smaller subwatersheds. These subwatersheds are delineated based on a user-defined threshold area approach or using a user-defined subwatershed boundary layer. In the second step, the subwatersheds are further divided into discontinuous land masses, which are delineated, based on (a) aggregation using a user-defined threshold for land cover, soil type, and slope range within each subwatershed, followed by (b) a geographical information system (GIS)-based spatial overlay scheme. This process of HRU creation, noted in the second step above, can be explained further using an example as illustrated in Fig. 1.

In this example, we assume a rectangular subwatershed of size 30 cells ($5 \times 6$) with four, three, and two different types of land cover, soil, and slope categories, respectively (Fig. 1a). It is further assumed that HRUs have been delineated using a threshold of 20% (6 cells), 30% (9 cells), and 20% (6 cells) for land cover, soil, and slope, respectively. This implies that any land cover, soil, and slope occupying less than or equal to six, nine, and six cells, respectively, in the subwatershed will be lumped with the adjacent dominant cells. Because of application of this thresholding for the HRU delineation, category four in land cover and category one in soil will be lumped with adjacent areas since they fall below the threshold (Fig. 1b). A spatial overlay is performed (Fig. 1c) such that all cells having the same combination of land cover, soil, and slope are given a unique HRU identification number (Fig. 1d and Table 1). Note that these thresholds were selected only to demonstrate the concept of HRU delineation in the SWAT model and should not be construed as a guideline for other studies.

Several observations can be made from this example. First, there is an evident loss of information since land cover category four and soil-type category one do not exist for model calculations. It may be argued that, in trying to achieve a balance between watershed representation and computational efficiency, some compromises need to be made. However, depending on the project goals, one must be aware of which land cover, soil, or slope categories are lost in the process of HRU delineation and

**Table 1**
Unique combination of land cover, soil, and slope of the HRUs delineated in Fig. 1.

| | HRU ID | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| **Land cover** | 1 | 1 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 3 | 3 |
| **Soil** | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Slope** | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |

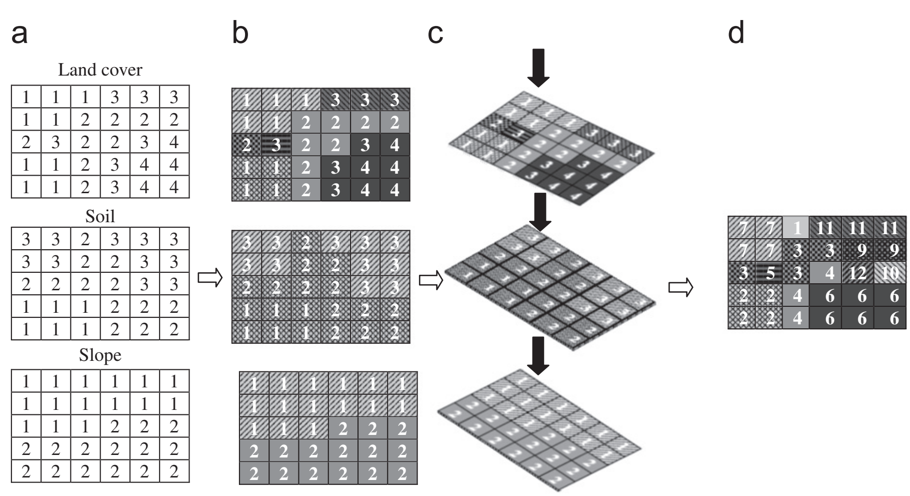


**Fig. 1.** Illustration of SWAT model HRU development algorithm. (a) Thematic maps of land cover , soil, and slope; (b) lumped categories within each map after applying a threshold of 20, 30, and 20% for land cover, soil, and slope, respectively. *Note*: lumped areas have similar cell background; (c) overlay of layers from (b); and (d) final HRU distribution.

decisions must be made accordingly. Second, it must be highlighted that not all HRUs are contiguous in nature (e.g., HRU number 3 in Fig. 1d). Although, it may appear that only one cell (category 5) separated three other cells belonging to category 3, this pattern of noncontiguity can be more pronounced on a subwatershed scale. The mapping algorithm development, described in the following section, suitably accounts for this fragmented nature of HRU outputs.

### 2.2. Mapping algorithm

The mathematical foundation for HRU to field-level visualization is important to understand at this time. Let the instantaneous state of a typical SWAT model response for a particular subwatershed be described by a vector $X(t)=(x_1, x_2,\ldots, x_i)$. For instance, the vector $X$ may represent runoff or sediment yield from HRU location $x_i$ and at time step t. The responses summed over a period of time can be described as

$$\int_{i=1}^{m} x_i\,dt = v. \tag{1}$$

where $v$ is the daily, monthly, or annual SWAT output from a subwatershed with $m$ HRUs.

Now consider a case where we wanted to visualize SWAT output from individual fields for the same subwatershed. In this case, let the instantaneous state of a typical SWAT model response for a particular subwatershed be described by a vector $Y(t) = (y_1, y_2,\ldots, y_j)$. Again, the vector Y may represent runoff or sediment yield from field locations $y_j$ for the same time step t such that

$$\int_{j=1}^{n} y_j\,dt = w, \tag{2}$$

where $w$ is the daily, monthly, or annual SWAT output from a subwatershed with $n$ fields subjected to the constraint that

$$v = w. \tag{3}$$

The main purpose of the algorithm is to calculate $y_j$ (i.e., output from field boundaries) using $x_j$ (i.e., HRU output). This requires an approach for consolidating runoff or sediment loading responses from different HRUs that are encompassed within individual field boundaries. To explain this further, let us consider a typical field scenario with the same land cover and soil type but with two different slope classes. As we have seen in the HRU delineation concept earlier, HRUs are land areas with unique land cover, soil, and slope; thus for this field scenario, it would mean the presence of two HRUs, designated as HRU-1 and HRU-2, within this field boundary. It becomes relevant to revisit the SWAT model approach for estimating surface runoff and sediment loading. The model estimates surface runoff using the SCS curve number equation (USDA SCS, 1972). Since every part of an HRU receives the same amount of rainfall and has the same soil physical properties, the water depth resulting from precipitation excess is spatially constant within an HRU (Flügel, 1997). Similarly, the SWAT model uses the modified universal soil loss equation (MUSLE; Williams, 1975) to calculate sediment yield. All factors governing the MUSLE equation are constant within an HRU. Note that there is no routing simulated between HRUs; daily output from all HRUs within a subwatershed are aggregated to calculate the total overland loading. These concepts indicate that field-level response could be estimated using some spatial data aggregation method from all the HRUs that are part of a field.

Spatial data aggregation is often preferred in environmental analyses because certain patterns are better revealed at specific scales (Bian and Butler, 1999). Methods of aggregation vary depending on the type and spatial scale of data. Some of the typical aggregation methods include mean, mode, geometric mean, and area-weighted average (Srinivasan and Arnold, 1994). A computer-based tool developed to implement the mapping algorithm is discussed in the next section and provides users with the option of aggregating HRU output using any of these four methods.

### 2.3. Field_SWAT for implementing mapping algorithm

The mapping concept was implemented as a user-friendly graphical user interface called Field_SWAT. Field_SWAT is developed using the MATLAB programming environment (MATLAB, 2010) and deployed as a stand-alone (does not require any proprietary software) tool to reach a wide community of users. The tool has been developed to interact specifically with the SWAT model developed using a ArcSWAT interface and the folder structure that it creates. Field_SWAT has three major components (or panels): Input Data, Display, and Status/Output (Fig. 2). The input data panel contains three user-driven and sequentially accessible set of tools, which can be used to feed the input interactively for visualizing outputs at field level. The input data panel requires the user to define the base folder (or the Field_SWAT folder) on the computer where subsequently all the data will be stored. Once this folder is identified, three subfolders are automatically created: Shape, Raster, and Output. These folder names are intuitive and indicate the type of data (vector or raster) that is stored in the respective folders. The functioning of Field_SWAT following this step is explained below and illustrated in Fig. 3.

Once the Field_SWAT folder is created, the user is required to identify the SWAT project folder using the browse button on the interface. The completion of this step results in the execution of two background tasks by Field_SWAT. During the first task, the *Watershed\Grid* folder within SWAT's project folder is identified and a copy of the HRU layer (hru1.aux) is copied from the *Grid* folder into the *Raster* folder of Field_SWAT. It is pertinent to note that HRU boundaries created by ArcSWAT are stored in both vector and raster formats. However, we have used the HRU raster format layer because the tool is built to process raster data. The HRU layer is a raster, geo-referenced, and categorical data layer that contains HRU ID for each cell in the watershed. The HRU layer is created using the ESRI (2010) proprietary grid format. Since, one of the objectives of this study was to develop the tool in a stand-alone

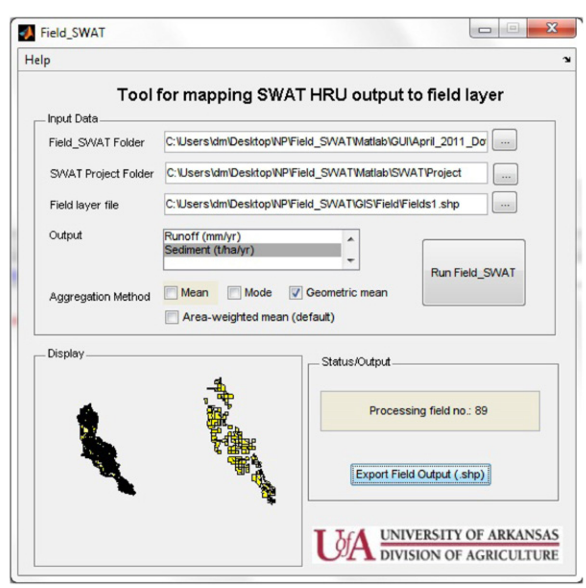


**Fig. 2.** Field_SWAT interface for implementation of mapping algorithm.

format (i.e., independent of other software) it was necessary to first convert the grid file to a generic raster storage format. To accomplish this, we incorporated the open-source geospatial data abstraction library (GDAL, 2010) within Field_SWAT, which allows it to instantaneously convert the proprietary grid file to a geo-referenced tag image file format (GeoTiff). This GeoTiff file, a copy of the HRU layer (hru1.aux), is stored in the *Raster* folder under the name hru1.tif. The GeoTiff format was selected because it is readable by a wide variety of commercial and open-source remote sensing and GIS software. Thereafter, metadata information of the HRU layer (corner coordinates and cell size) is read for creating a three-dimensional orthogonal grid (hereafter referred to as Field_SWAT grid) that encompasses the total watershed drainage area (Fig. 4). The number of rows, columns, and cell size is displayed in the status window, which should be helpful to the user in deciding appropriate field size for using the tool. The Field_SWAT grid has a three-dimensional structure with the $x$ and the $y$ axes representing the latitude and the longitude values while watershed level information is stored in layers ($z$ axis) as and when the data become available during Field_SWAT setup. As noted previously, the grid file (hru1.tif) created by GDAL has the HRU ID information embedded for each cell, which is read by Field_SWAT and stored in the first layer of the $z$ axis (Figs. 3 and 4).

The second task performed by the tool on selection of the SWAT project folder is to copy the HRU vector shapefile created by SWAT in its *Watershed\Shapes* folder to Field_SWAT's *Shape* folder. This file is later used to display the HRU level outputs from the SWAT model in the display panel for comparison with the field-level output.

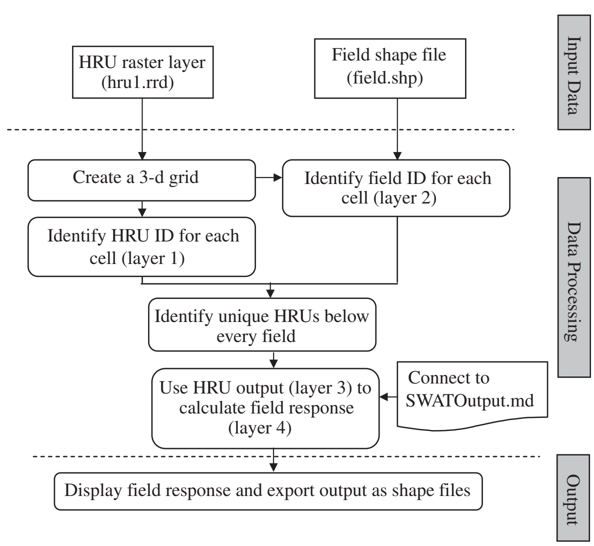


**Fig. 3.** Flowchart showing the functioning of the Field_SWAT tool.

The next input required by Field_SWAT is the field boundary layer, which is required as a polygon vector shapefile format (say, field.shp; Fig. 4). Typically, this may be developed by the user either by manually tracing the boundaries in GIS software using an aerial image as basemap or by collecting corner coordinates of the field using a global positioning system. This layer may represent one or more fields in the watershed with a unique ID for each field. The extent of each field must be equal to or greater than the cell resolution of the HRU layer, otherwise a default of zero loading is assigned. Field_SWAT reads this polygon layer to identify individual field boundaries. To convert this vector-based information into Field_SWAT's grid-based information, every element in the grid is uniquely associated with an overlying field ID using an algorithm developed by Hormann and Agathos (2001) that is incorporated in the INPOLYGON function in MATLAB. These field IDs are stored in Field_SWAT grids' second layer (Figs. 3 and 4). This completes the input data requirement for Field_SWAT.

Subsequently, the user is required to select one of the two outputs (annual runoff or sediment) for which this tool is designed and click on the Run Field_SWAT button. The algorithm then connects to SWAT's output database (SWATOutput.mdb)

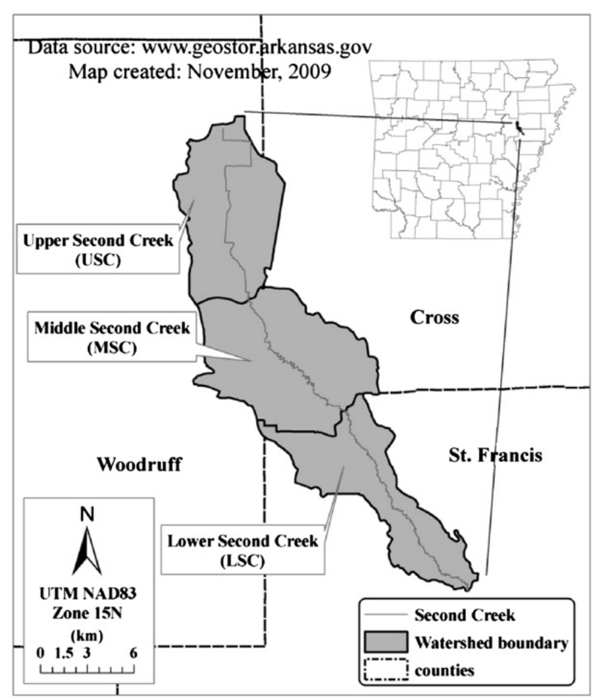


**Fig. 5.** Second Creek watershed boundary showing the major creek and location of the watershed within Arkansas.

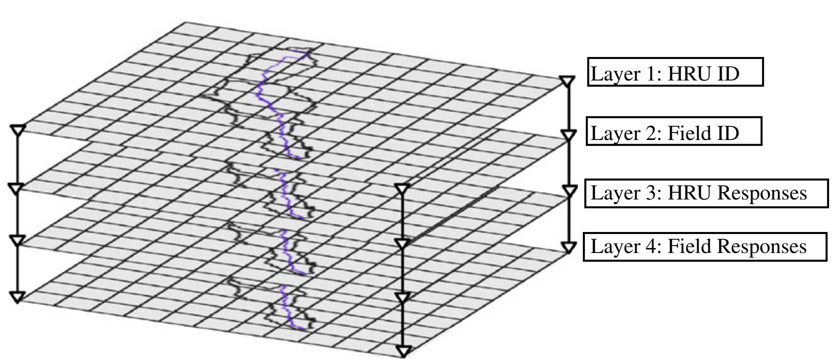


**Fig. 4.** Illustration of the Field_SWAT grid used to store various watershed level information.

stored in *Scenarios\Default\TablesOut* folder and extracts the annual runoff or sediment yield (based on user's choice) for each HRU and stores it in the third layer of the Field_SWAT grid (Figs. 3 and 4). The mapping between HRU (first layer) and field (second layer) is used to identify all HRUs that fall under a particular field. All HRUs used to calculate field output and their minimum and maximum loading informations are stored in the Output folder for any postprocessing.

To calculate the pollutant loading from each field, a aggregation method is required to map the HRU output to field output. The tool provides users with four options including mean, mode, geometric mean, and area-weighted mean to perform the spatial aggregation. The results, based on the chosen method of data aggregation, are displayed in the display panel of Field_SWAT. The tool also lets the user export the results in the form of a shapefile, stored in its *Output* folder, for developing custom maps in a GIS environment or for further analysis.

**Table 2**
Statistical summary of HRU and field-scale annual runoff and sediment outputs.

| Output scale | Aggregation method | Runoff (mm) | | Sediment (t/ha) | |
|---|---|---|---|---|---|
| | | Average | SD | Average | SD |
| HRU | None | 262 | 122 | 5.0 | 5.6 |
| Field | Mean | 271 | 52 | 5.4 | 1.9 |
| | Mode | 313 | 78 | 6.1 | 2.7 |
| | Geometric mean | 293 | 66 | 5.9 | 2.3 |
| | Area-weighted mean | 296 | 66 | 5.2 | 2.6 |

## 2.4. Test run

To demonstrate the working of the above algorithm, the SWAT model (ArcSWAT 2.1.4 interface and SWAT 2005 algorithm) was set up for the agriculturally dominated Second Creek watershed (189 $km^2$) in Arkansas (Fig. 5). This is a subwatershed of the 8-digit hydrological unit code (HUC) L'Anguille River Watershed (HUC 08020205). The Second Creek flows in the northwest–southeast direction through the Woodruff and Cross Counties before it drains into the L'Anguille River near Palestine in the St. Francis County. The 12-digit HUC subwatersheds starting from north are Upper Second Creek (USC), Middle Second Creek (MSC), and Lower Second Creek (LSC). The watershed terrain is flat with about 95% of the drainage area in the 0–3% slope category. The overall land cover of the watershed is primarily row crop agriculture (66.9%) followed by forest (22.2%). However, USC and MSC have about 78.5 and 84.5% agricultural areas, respectively, making this watershed a suitable candidate to test this field-scale mapping algorithm.

Key inputs to the SWAT model were the digital elevation model (30 m resolution), NHD high resolution flowline stream layer (1:250,000 scale), LULC (Fall 2006; 28.5 m resolution), and soil survey geographic (SSURGO) soil map. The subwatershed boundary was delineated using the 12-digit HUC watershed boundary using the user-defined watershed delineation option in ArcSWAT. The HRUs were delineated without applying any thresholding for the LULC, soil, and slope categories. This resulted in 218 HRUs, which had a minimum, maximum, mean, and standard deviation of 0.0001, 24.9, 0.86, and 2.66 $km^2$, respectively. Historical daily precipitation and temperature information was incorporated in the model using a national weather service

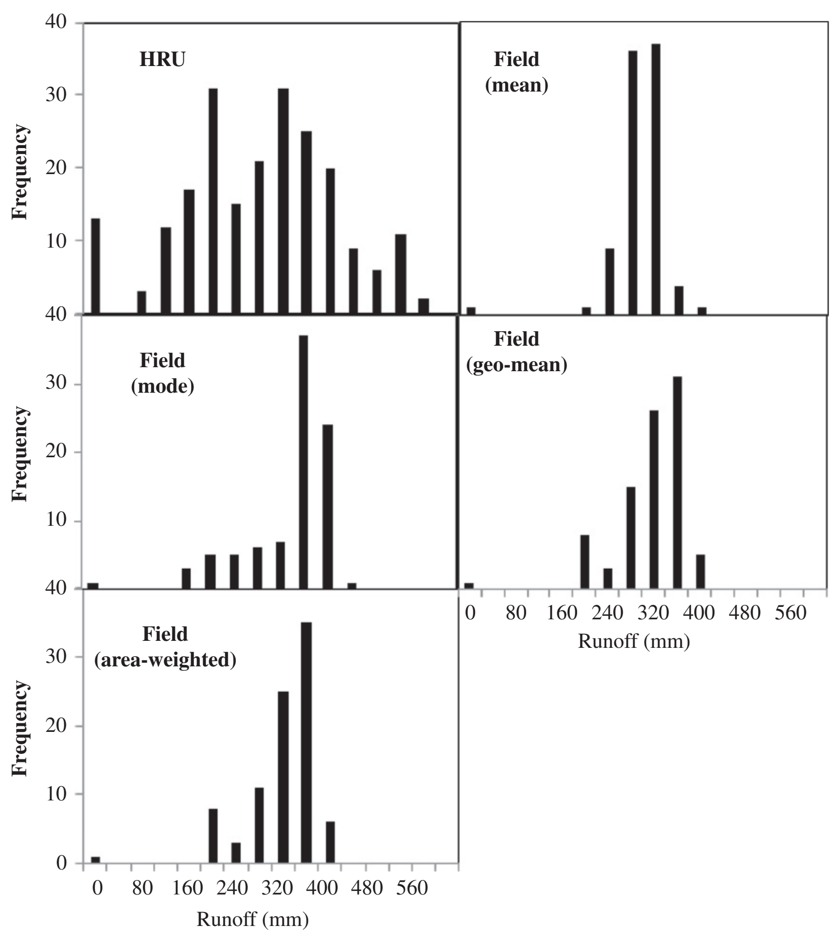


**Fig. 6.** Histogram of the SWAT HRU and Field_SWAT runoff output using various aggregation methods.

weather gage data at Beedeville (COOP ID, 030536; lat/lon, 35°28′N/91°03′W; elev, 73.2 m) and was assigned to each sub-watershed. Other weather parameters such as wind speed, solar radiation, and relative humidity were simulated by the model using its internal weather generator. The model was run on an annual scale from 1992 to 1999. No attempts were made to calibrate the model since the focus of this project was implementing and evaluating the functionality of the mapping algorithm. The Field_SWAT tool was run using a field layer GIS shapefile that had 89 polygons representing arbitrarily selected fields and other land parcels in the test watershed. Note that the field layer was manually delineated in a GIS environment using aerial imagery as basemap.

The performance of the tool and effect of spatial aggregation method were evaluated by statistically comparing the histograms of annual runoff and sediment yield for SWAT HRU and Field_SWAT results and visually observing the effects of spatial aggregation. Finally, the stand-alone nature of this tool was tested on computers that did not have a MATLAB environment installed on them.

## 3. Results and discussion

The Field_SWAT tool was used for mapping SWAT HRU results for the Second Creek watershed. The Field_SWAT grid for this watershed, similar to SWAT's HRU layer, consisted of 1023 rows and 655 columns resulting in 670,065 grid points with 30 m$^2$ cells. The 30 m$^2$ cells in the HRU layer resulted from the use of 30 m DEM that was used while developing the SWAT model. We also verified that areas of HRU calculated from Field_SWAT were comparable to the areas reported by HRU_FR variable in the HRU files (.hru) and with areas calculated from hru1.shp in ArcMap, both of which are developed while setting up the SWAT model.

### 3.1. Statistical comparison

The means and standard deviations of the annual runoff and sediment provided in Table 2 summarize the statistical changes through various aggregation methods. The statistics for HRU output were calculated using only those HRUs that contributed to the 89 fields in the field layer. In general, it was observed that spatial aggregation resulted in increasing the means and reducing the standard deviations. The mean runoff increased from 3.4 to 19.5% while sediment yield mean increased from 4.0 to 22.0% depending on the choice of aggregation method. On the contrary, the standard deviations decreased from 36.1 to 57.4% for runoff and 51.8 to 66.1% for sediment yield depending on the aggregation method. This was expected because any spatial aggregation method typically reduces the low frequency values at both ends of a histogram (Isaaks and Srivastava, 1989; Bian and Butler,

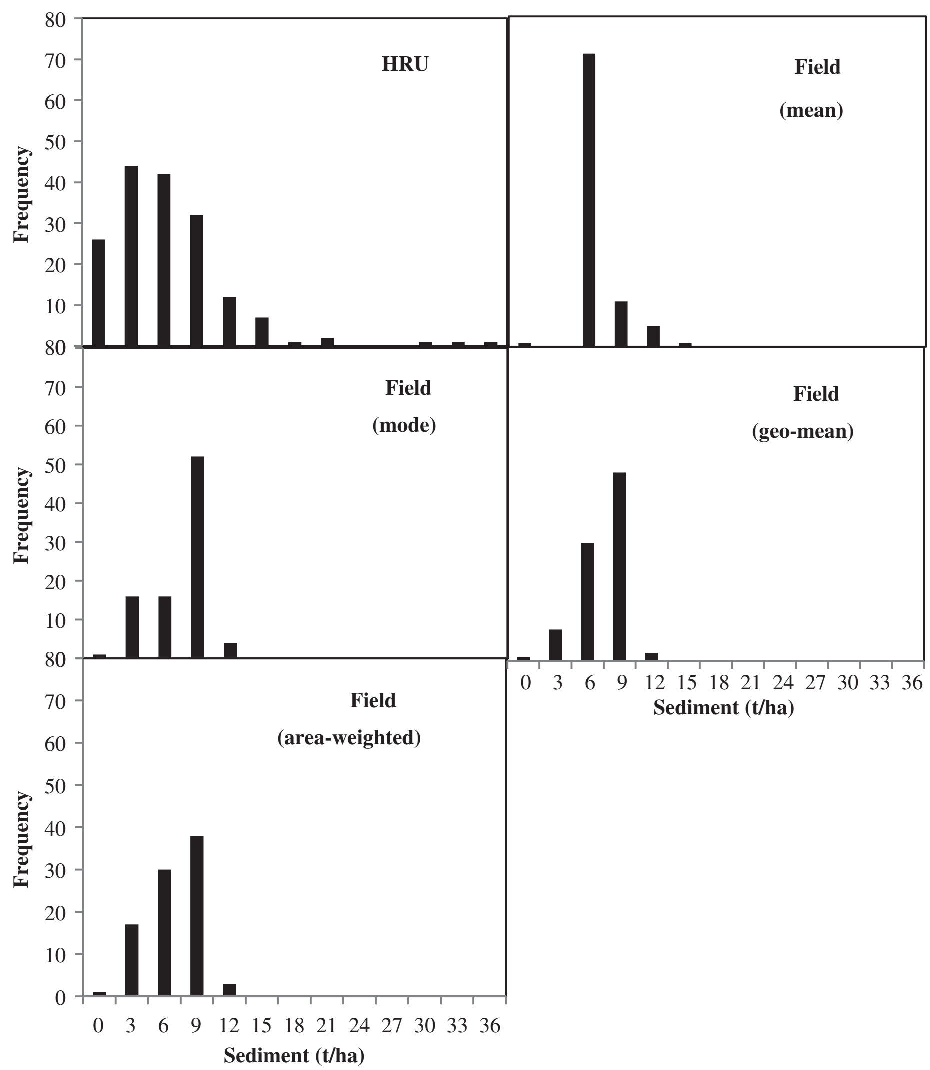


**Fig. 7.** Histogram of the SWAT HRU and Field_SWAT sediment output using various aggregation methods.

1999). Consequently, we expect the mean to shift slightly on the higher side. This effect can be clearly seen in Figs. 6 and 7. Application of aggregation methods resulted in taller and tighter distributions. Based on results in Table 2 and Figs. 8 and 9, it appears that either mean or area-weighted mean aggregation methods would be a suitable choice for visualizing field outputs for the Second Creek watershed because their means tend to be closer to those of the original dataset. However, since this tool is expected to assist watershed managers with spatial field-level targeting, it was important that the aggregation method also produce a visually consistent field output.

### 3.2. Visual comparison

Field_SWAT outputs were visually compared with the HRU level runoff and sediment yield output using color-coded maps (Figs. 8 and 9). In deciding the range of responses to be used for color-coding these maps, we arbitrarily selected four equal intervals. The Field_SWAT software was run four times to test the four aggregation methods. Each aggregation method produced slightly different results when compared with the original HRU output. The mean and geometric mean aggregation methods resulted in smoothing of the original data. This was particularly evident during sediment mapping (Fig. 9), where most fields in the northern and central portions of the watershed were mapped as green because of the presence of the gray (0.0–2.6 t/ha) and yellow (7.3–15.6 t/ha) sediment yield classes in the original map. On the contrary, the area-weighted mean produced a more spatially consistent map when the HRU and Field_SWAT outputs were visually compared. This was because the area-weighted method normalizes the contribution of each HRU based on its area within the field.

Based on statistical and visual observations, the area-weighted method was most suitable for mapping the HRU output to fields for the Second Creek watershed. For field-level targeting, the area-weighted map showed several fields in the middle second creek subwatershed having above average sediment loading (Fig. 9). These fields could be subjected to further on-site verification or targeting conservation practices. It is also interesting, however, to observe that mapping using the mode method preserved one of the highest runoff-yielding fields in the central part of the watershed while all other methods tended to smooth the output for this field (Fig. 8). Fields such as this may be of interest to someone who is targeting potentially higher runoff areas in the watershed for conservation practices. Availability of multiple aggregation methods provides Field_SWAT users with the flexibility of rapidly mapping HRU outputs using various methods.

To further evaluate the effect of area-weighted averaging, we visually compared the HRU and Field_SWAT sediment yields at a finer spatial scale in an area, which had a combination of rice and soybean fields along with some forested areas (Fig. 10). In general, it was observed that HRU sediment yield varied even within a field, which is not the case for Field_SWAT results. Field_SWAT results are concentrated in nature, align to the boundaries of the field, and hence, provide a clear visualization of model responses. Forested areas fell in the green (0.00–5.00 t/ha) category of sediment yield in the HRUs, which was transferred exactly in Field_SWAT mapping results. The effect of area-weighted averaging was prominent in some agricultural fields, and resulted in

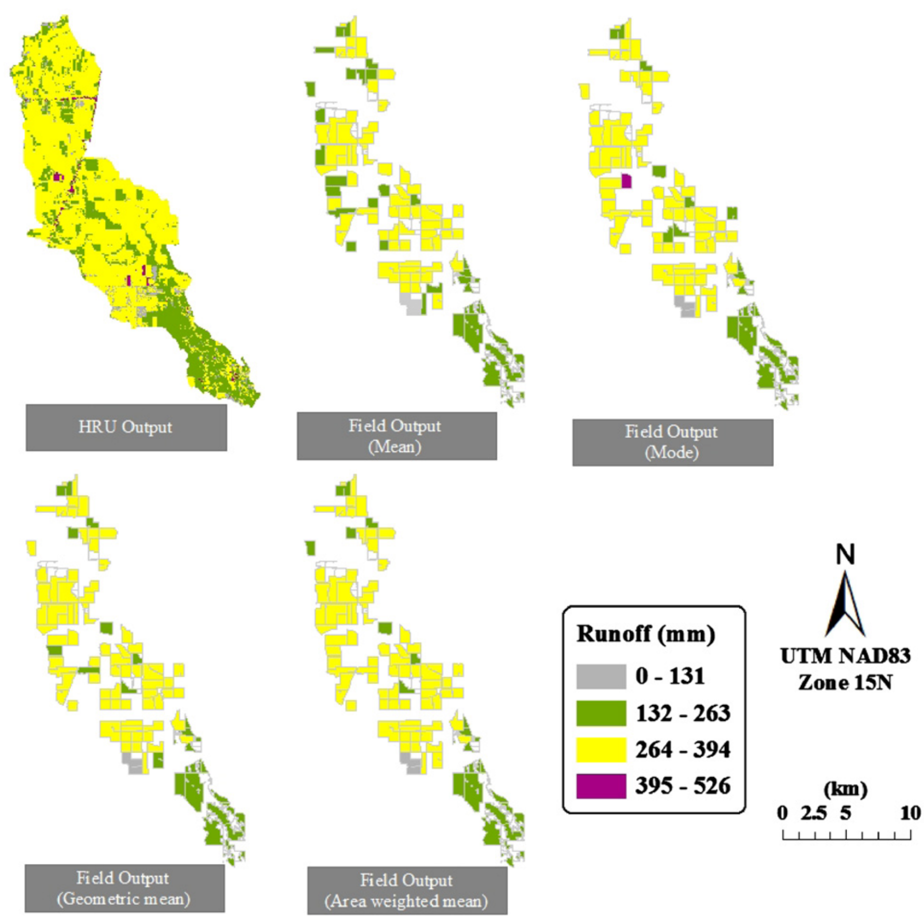


**Fig. 8.** Comparison of annual runoff from SWAT HRU and field-scale output using various spatial aggregation methods.

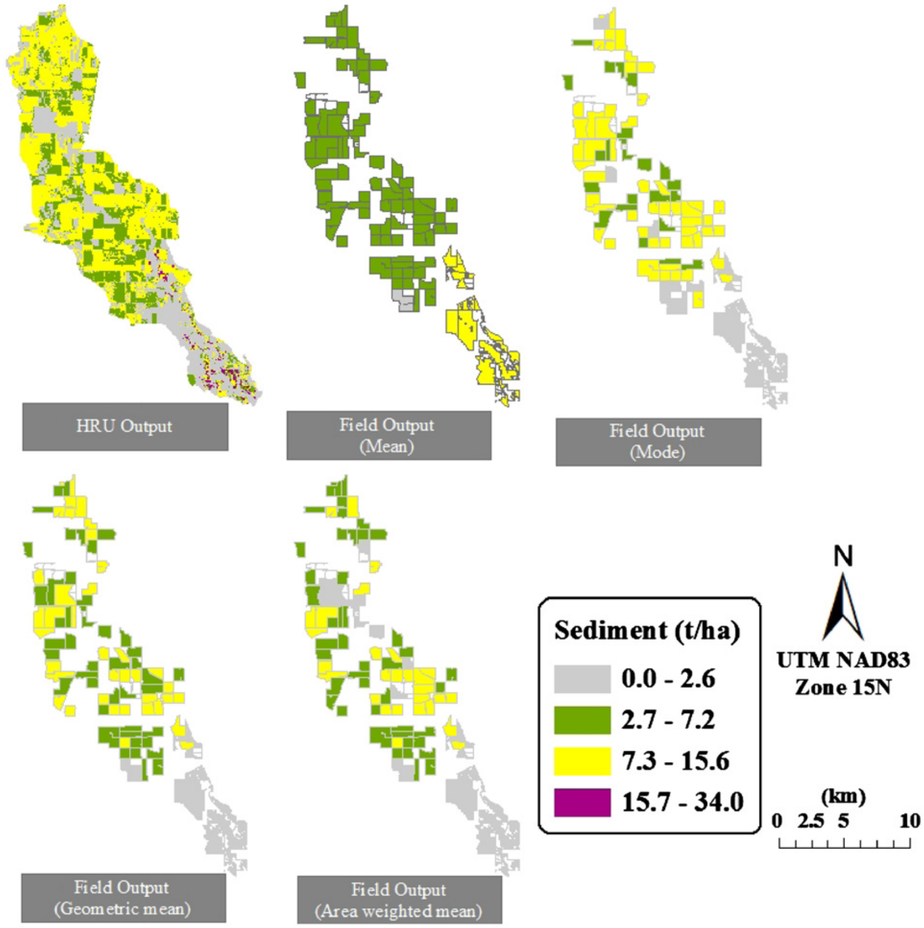


**Fig. 9.** Comparison of annual sediment yield from SWAT HRU and field-scale output using various spatial aggregation methods.

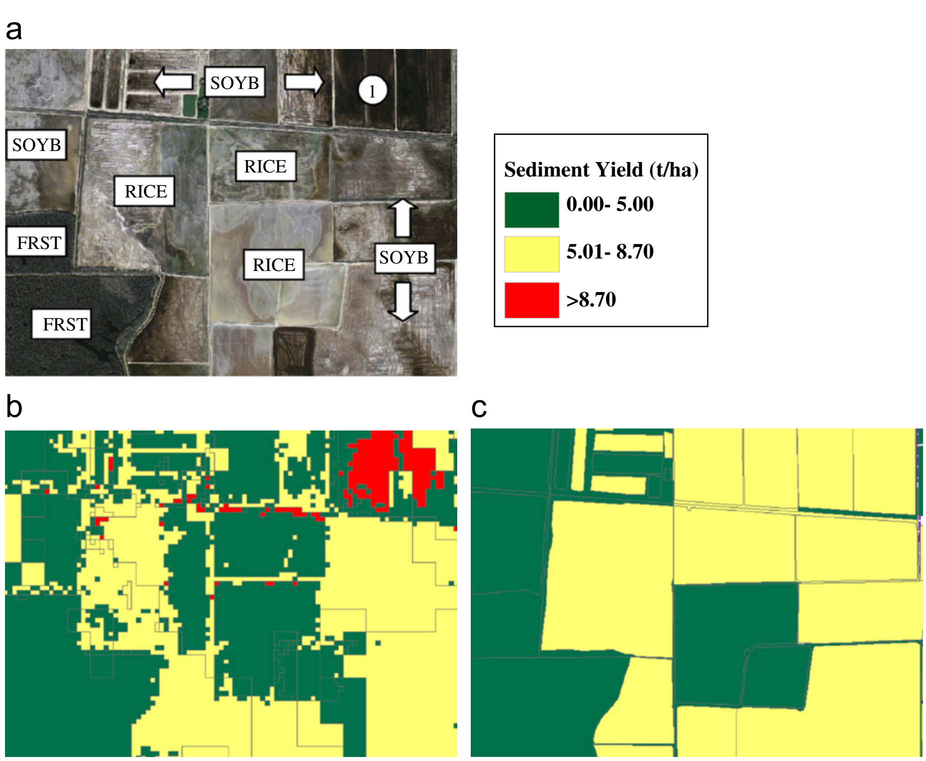


**Fig. 10.** Comparison of SWAT HRU and Field_SWAT sediment yield at finer spatial scale. (a) Aerial imagery of an area showing combination of forest (FRST), rice (RICE), and soybean (SOYB) land covers, (b) SWAT HRU output, and (c) Field_SWAT output.

the intermediate category of sediment yield of encompassed HRUs being applied to the field when three or more categories were present. For instance, the soybean field on the top right corner (labeled 1 in Fig. 10a) had a combination of green (0.0–5.00 t/ha), some yellow (5.01–8.7 t/ha), and red ( > 8.7 t/ha) sediment yield categories in SWAT's HRU results (Fig. 10b). This was mapped as the intermediate yellow category in Field_SWAT results (Fig. 10c). Similar effects can be seen for other agricultural fields in Fig. 10. Results like these can be used by watershed managers to identify a suite of conservation practices for fields that contribute greatly to watershed pollution.

Although the SWAT model was initially developed as a river basin scale model, it has been recently used for field-scale runoff (Anand et al., 2007), sediment, and nutrients (Gollamudi et al., 2007) assessment studies. In these studies, the model was set up for individual fields using the field edges as the watershed boundary while field-scale monitoring data were used for calibration and validation. Veith et al. (2005) set up the SWAT model for a 39.5 ha watershed consisting of about 22 fields and used the phosphorous (P) loadings from HRUs to validate the Pennsylvania P-index, a simple measure used to assess field vulnerability to P losses. They concluded that the SWAT model better represented natural processes at the field scale and its complexity made it a favorable choice for P-index calculations. Overall, it appears from recent literature that there is a concerted effort to use and improve the SWAT model results at the field scale. We envision that the development of a Field_SWAT mapping algorithm and its implementation as a stand-alone software program will facilitate the use and further investigation of SWAT's field-scale abilities. No attempt was made in this study to validate field responses, as the focus of the study was to develop a visualization tool. A thorough testing of this tool will require edge-of-the-field water quality data and that will be addressed in future efforts.

### 3.3. Software performance

The Field_SWAT software package (algorithm and supporting libraries) occupies about 233 MB of computer memory (hard disk space). To use any software that is developed in MATLAB, the end user should have a set of supporting libraries called the MATLAB compiler runtime (MCR) installed on the computer. This freely available library (230 MB) is packaged with the Field_SWAT software and must be installed before starting the Field_SWAT tool. Please note that this is a one-time install for any tool developed in MATLAB. We tested the software on a computer on which MATLAB was not present to verify its stand-alone capacity. On a desktop computer with Intel® Pentium® D CPU 3.40 GHz processor with 2 GB of random access memory (RAM), the install time for the MCR library was about 6 min. After the installation of the MCR library, the Field_SWAT tool took about 1 min to get started while the mapping of 89 fields of Second Creek watershed using any of the aggregation method took an additional minute.

## 4. Summary and conclusions

The concept of HRU development is one of the least discussed aspects in SWAT model literature. This paper provides details of the HRU delineation process in the SWAT model using an example. In general, it was understood that HRUs are fragmented areas of land, which can be spatially located in a watershed but are not synchronous to any physical boundaries. We developed a user-driven stand-alone graphical user interface, called Field_SWAT, to map the HRU level annual runoff and sediment output from the SWAT model to a user-defined field boundary layer. Once a SWAT model is developed and satisfactorily calibrated and validated, the only requirement of this tool is a user-defined boundary layer. Four different methods—mean, mode, geometric mean, and area-weighted mean—provide users with options for mapping HRU outputs using multiple spatial aggregation techniques. It must be stressed that this tool does not produce any new model simulation but simply transfers HRU output to user-defined field boundaries using one of the four spatial aggregation methods. The tool was tested on the agriculturally dominated Second Creek watershed SWAT model using a layer consisting of 89 fields. Based on statistical and visual results, it was observed that the abstract HRU outputs were best mapped to field outputs using the area-weighted aggregation method. Considering that the SWAT HRU results are now being used to identify critical nonpoint source pollution areas in the watershed (White et al., 2009), this tool can be used for field-level targeting and enhancing communication between SWAT modelers and watershed managers/stakeholders.

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