INTEGRATING GIS WITH ANNAGNPS WATERSHED MODEL FOR OPTIMAL PLACEMENT OF CONSERVATION PRACTICES IN AGRICULTURAL WATERSHEDS

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Abstract: The development of technology designed to maximize crop production while minimizing the impact to ecosystems services in agricultural watersheds is a complex undertaking. Integrated and multifaceted relationships exist between multiple systems controlling the transport of non-point source pollution from upstream croplands into downstream water bodies. Some of the known factors controlling non-point source production include: environmental conditions, type and location of sources, selection of farming practices, and implementation of efficient conservation measures. Existing watershed-scale modeling technology, such as the United States Department of Agriculture (USDA) Annualized Agricultural Non-Point Source pollutant loading model, AnnAGNPS, offers the necessary tools to describe existing conditions and even perform simulations of possible suggested scenarios. The challenge resides in the selection of conservation practices (or series of them), their key parameters, and their spatial allocation. This task is difficult due to the integrated nature between erosion sources and conservation systems. For example, implementation of a localized conservation practice upstream can have a positive effect locally; however, it could have a negative effect elsewhere in the watershed (clean water effect). To address this optimization task, a spatial decision support systems (SDSS) based on the AnnAGNPS model, GIS, and genetic algorithms, is being developed to support optimized spatial allocation of conservation practices in agricultural watersheds. In this study, we describe the developed foundational technology to link the optimization algorithm with the riparian filter strips component within the AGNPS system. The technology developed will be integrated with optimization algorithms and will support the long-term objective of determining an optimal alternative that would minimize soil erosion and maximize production area.

INTRODUCTION

In watershed systems, the transport of sediments from croplands to downstream water bodies is influenced by an integrated and multifaceted relationship between farming practices, sediment sources (sheet, rill, gully, and channel), and conservation measures. As the understanding of the impact of each of these factors upon sediment detachment and transport improves, new modeling technologies are being developed to support the decision making process of improving agricultural yield while reducing the ecosystem's pollution.

The Research Service (ARS) and the Natural Conservation Service (NRCS), both branches of the USDA, jointly developed the AnnAGNPS pollution modeling system (Bingner and Theurer, 2001). AnnAGNPS predicts the origin and movement of water, sediment, and chemicals at any

location within the watershed. The model was developed with multiple integrated components, to account for different sediment source areas and sinks, and considers the impacts of conservation practices upon the watershed. Pollutant and sediment tracking provides an important link to their sources enabling valuable insight into the effect and most effective placement of conservation practices. The model is capable of distinguishing between erosion processes (i.e., sheet and rill, tillage-induced ephemeral gullies, classical and edge-of-field gullies processes) and streambed and bank sources.

The challenge resides in the selection of conservation practices (or series of them), their key parameters, and their spatial allocation. Theoretically, there are infinite alternatives on how to implement conservation practices with varying cost and efficiency. However, there is a reduced number of alternatives that minimize sediment output through the implementation of conservation practices at the most critical locations within the watershed while maximizing crop yield through keeping production areas. This problem can be investigated using system-engineering concepts in the form of spatial decision support systems.

The utilization of SDSS can expedite the selection of the most appropriate solution. Our proposed technology integrates modeling (AnnAGNPS), database management, GIS, and optimization algorithms (genetic algorithms). The conservation practice selection and spatial allocation tool is still under development, however, the general linkage between the optimization algorithm, GIS, and the AnnAGNPS model is described in this text.

METHODS

The utilization of riparian vegetation in agricultural fields has been recognized as an effective conservation practice to reduce sediment/nutrients transport from croplands. A riparian buffer component (Momm et al., 2014) has been developed to estimate the influence of riparian vegetation on sediment loadings from sheet, rill, and ephemeral gully sources (Momm et al., 2012). Users can vary basic input parameters used to characterize riparian buffers through the development of a GIS raster grid layer describing the riparian zone spatial extent and vegetation type. This is usually a time consuming task which requires multiple iterations to select the appropriate riparian zone characteristics (width and vegetation type) as well as to spatially allocate riparian zones at the most efficient locations throughout the watershed.

The basic unit of the AnnAGNPS model is the sub-catchment (figure 1A). The entire watershed is sub-divided into sub-catchments and each of them is characterized based on a large number of parameters from multiple databases. To simplify the description of the proposed methods, only one sub-catchment is used (figure 1B). In the AnnAGNPS riparian buffer component (AGBUF), each sub-catchment is intersected with a user-provided riparian buffer layer (figure 1C) and key raster grid cells recorded (figure 1D). A candidate solution in AGBUF is represented as two raster grid layers: one defining the riparian zone extent (figure 1C) and another defining the riparian zone vegetation type.

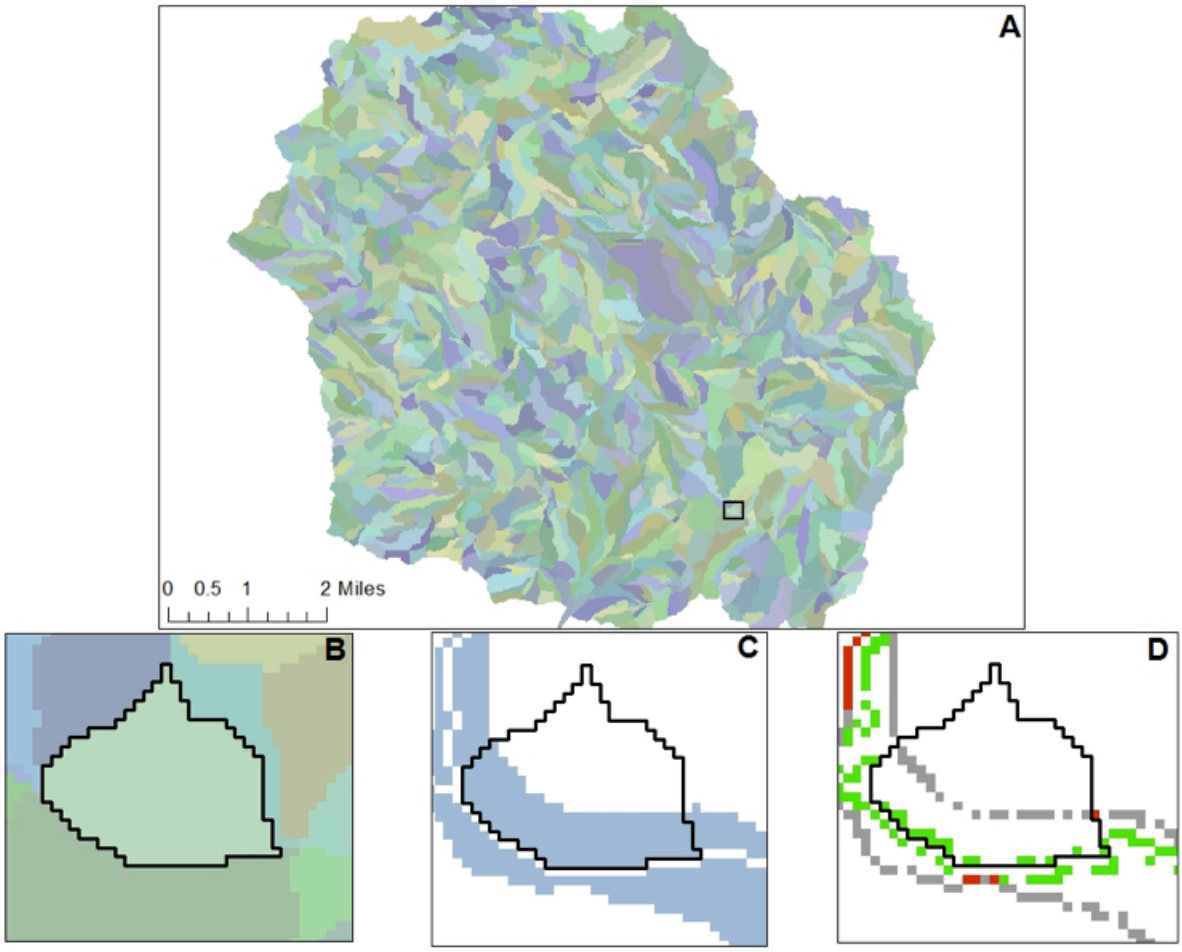

Figure 1 Watershed characterization into sub-catchments (A). Each individual sub-catchment (B) is spatially intersected with land cover layer containing riparian filter strip zone (blue layer in C). The raster grid cells receiving flow from outside the riparian zone (marked in gray in D) and having flow leaving the riparian zone (marked in green in D) are used as input information into the AnnAGNPS buffer GIS technology (AGBUF) described by Momm and others (2014).

The utilization of genetic algorithms (GA) as the optimization engine was sought to streamline the selection process. Genetic algorithms are computer programs inspired by the Darwinian theories of biological evolution, which states that individuals that best fit the environment that they live in will have a higher chance of survival and passing their genes to the next generation (survival of the fittest). During the evolutionary process, the program generates a set of candidate solutions randomly and sorts them based on user-defined fitness criteria. The top fit individuals are selected to form the new set of candidate solutions after crossover and mutation operations are performed. This iterative procedure is repeated until the stopping criteria are reached. For genetic algorithm, the set of candidate solutions is represented by a vector of bits (zeros and ones).

Our contribution was to develop an automated GIS procedure to translate candidate solutions from AGBUF representation (raster grid) into GA representation (vector of bits) and vice versa. The key component in this procedure is the generation of a list of rows and columns of the raster

grid cells marked as downstream edge locations (figure 2). These locations are marked within the grid with a value of 2 and describe raster grid cells located within the riparian zone and with flow exiting the riparian zone (green raster grid cells in figure 3A).

TYPE	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
ROW	1089	1090	1090	1091	1092	1092	1092	1093	1093	1093	1094	1094	1094	1095	1095	1095	1095	1095
COL	1050	1051	1052	1052	1053	1054	1055	1055	1056	1057	1057	1071	1074	1059	1060	1065	1066	1068

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 2 The list of raster grid cells marked as upstream riparian zone edge. These vectors are translated into a single vector of bits representing a candidate solution and are understood by the optimization algorithm.

<u>From AGBUF to GA:</u> The user provides a raster grid layer containing the maximum extent of the desired riparian buffer zone throughout the watershed. This is something that would not be practical to implement due to limited resources of conservation agencies and the significant reduction of farming area. However, this layer representing the maximum extent is used to develop a database of row and column information of the raster grid cells marked as riparian downstream edges (green raster grid cells in figure 3A and first three rows in figure 2). The maximum extent raster grid is represented as a vector of ones with the same size (length) as the vectors recording rows and columns of key raster grid cells (fourth row has the same size as the first three rows in figure 2).

<u>From GA to AGBUF:</u> In this part, the program uses the following as input: (i) flow vector layer, (ii) watershed sub-catchment layer, (iii) database of downstream edge raster cells, and (iv) binary vector (GA candidate solution). The algorithm starts by comparing the binary vector with the database of downstream edge raster cells. Only the rows and columns paired with the value of one in the binary vector are marked in the new riparian buffer zone raster grid (green raster grid cells in figure 3). The algorithm then iterates to determine and mark all the raster grid cells flowing into the already marked cells (blue raster grid cells in figure3). Examples of iteration over each buffer raster grid cell labeled 2 (in green) once (A), twice (B), and three times (C) are illustrated in figure 3. The output from the last iteration represents the raster grid layer containing the riparian buffer zone information (used as input into AGBUF).

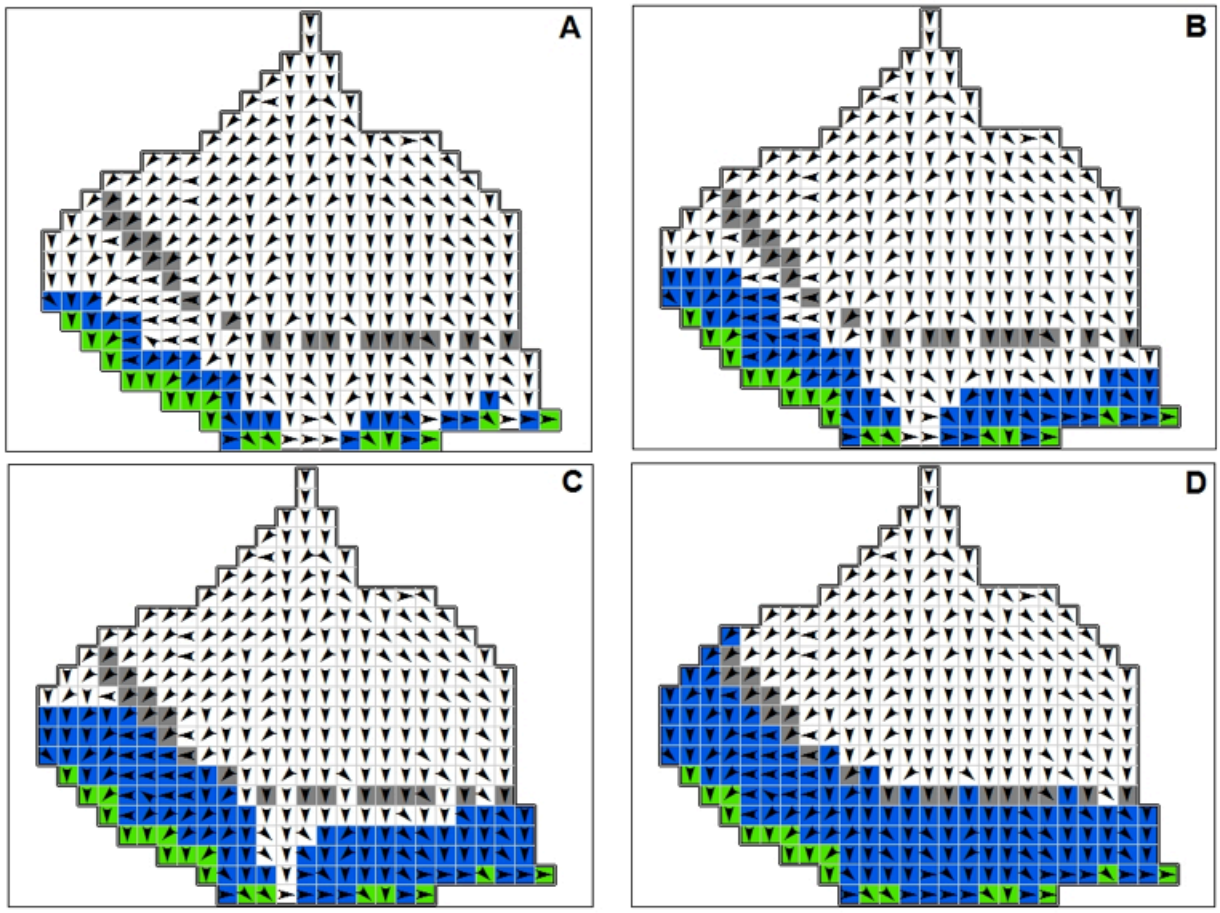

Figure 3 Iterative procedure to translate a candidate solution represented as a vector of bits into a raster grid file. Blue cells show the results of string to raster conversion after one (A), two (B), and three (C) cycles around each green raster grid cell. The final riparian buffer zone is obtained when the maximum width is reached (D).

Evolving Optimal Candidate Solutions: During the evolutionary process, GA generates and combines a large number of different candidate solutions. Different candidate solutions are generated by varying the zero and one values in each binary vector (figure 4). If a binary vector has only zeros, no riparian buffer is generated. A single value of one generates a riparian zone with the only one downstream edge raster grid cell; however its size varies depending upon the drainage pattern into the downstream edge raster grid cell (figure 4A). It is possible that a candidate solution would generate riparian filter strips off from the main concentrated flow paths (figure 4B and 4C), however they would receive poor scoring due to the estimated sediment trapping efficiency being low.

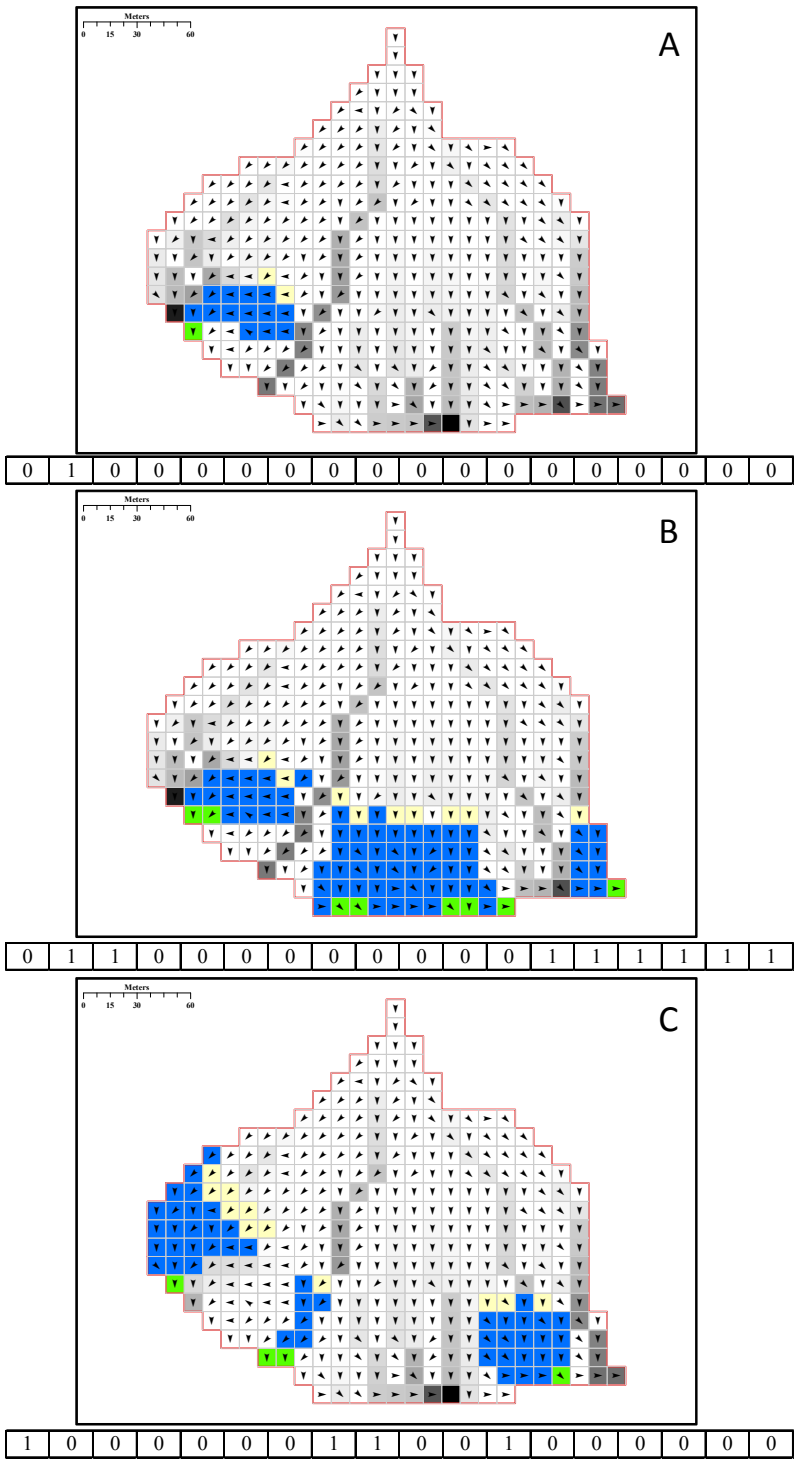

Figure 4 Examples of multiple scenarios in both representation formats: raster grid cell and vector of bits. Raster grid cells marked with gray scale symbology represent flow accumulation and indicate the presence of concentrated flow paths. Green represents downstream edge raster grid cells, yellow upstream raster grid cells, and blue riparian buffer zone raster grid cells. In the first scenario (A) only one of the downstream edge raster grid cells are activated. In the second (B) and third (C) scenarios (B) several downstream edge raster grid cells are activated, displaying the different configurations.

FINAL REMARKS

The described methods serve as the foundation to the development of a comprehensive SDSS integrating a well-established watershed modeling technology (AnnAGNPS), optimization algorithms (genetic algorithm), and GIS. Future developments will encompass the integration of these three components into a single system, with accompanying detailed documentation and easy-to-use graphical user interface.

Our long-term objective is to identify an optimal alternative that spatially locates conservation practices at the most critical locations throughout the watershed and determine their key design parameters. This optimal alternative should minimize nutrient-rich soil losses and, at the same time, maximize production area. Such technology represents an important step in understanding and accounting for the integrated effect of conservation practices and erosion sources by utilizing resources efficiently and promoting sustainable agricultural production.

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