An Interface between the Agricultural Non-Point Source (AGNPS) Pollution Model and the ERDAS Imagine Geographic Information System (GIS)

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Abstract

The U.S. Department of Agriculture developed the Agricultural Non-Point Source (AGNPS) pollution model. The AGNPS pollution model simulates the behavior of runoff, sediment, and nutrient transport from watersheds that have agriculture as their prime use. This model has been used extensively by scientists conducting hydrologic or water quality analyses using computer modeling in an attempt to further understand the complex problem of managing non-point sources of pollution in a watershed hydrology domain. A difficulty with AGNPS is creating and formatting all of the data necessary to execute the model to conduct landscape modeling and watershed analyses. A unique Windows-based program, the AGNPS Data Generator (*ADGen*), has been developed to simplify the task of preparing and creating the input for AGNPS through an interface with ERDAS Imagine (a Leica Geosystems product). Because of the complexity and quantity of the input required and the nature of the output text file produced by AGNPS, *ADGen* is a helpful tool for the researcher who is trying to analyze non-point source pollution.

Keywords

pollution model, non-point source, GIS, landscape, AGNPS, watershed, environmental modeling, software

I. INTRODUCTION

Often researchers use a geographic information system (GIS) to process existing data sources to develop inputs for watershed models. Scientists have been coupling GIS data handling and processing capability to water models for years (Olivieri *and others*, 1991; Grayson *and others*, 1992; Tim *and others*, 1992; Brown and others, 1993). One example of a watershed-scale model is the Agricultural Non-Point Source (AGNPS) pollution model, developed by the U.S. Department of Agriculture in response to the complex problem of managing non-point sources of pollution (Young *and others*, 1995). Today there are a number of interfaces that use GIS and the AGNPS model to simplify the process of watershed analysis, but only a few that have been created for the Microsoft Windows operating system (Tim, 1996; Liao and Tim, 1997; He *and others*, 2001; Mankin *and others*, 2002; Bhuyan *and others*, 2002). We created a unique windows-based GIS–AGNPS interface for the ERDAS Imagine software package (a Leica Geosystems product). This interface is better than existing interfaces because it further automates the creation of parametric values and reduces the off-line preliminary efforts required by the user of the AGNPS model.

The abundance of software available for Windows today and the relative ease of working in the PC environment provide an opportunity for designing and implementing interfaces for water-quality models for use with Windows-based GIS packages. The ERDAS Imagine software package is a collection of software tools designed specifically to process raster data and is one such GIS environment (ERDAS, 1999). Imagine allows users with some programming knowledge to implement new capabilities using its Developers' Toolkit and the C programming language. Imagine includes its own graphical user interface (GUI) scripting language known as the ERDAS Macro Language (EML).

The capabilities of EML are extensive for the needs of both users and programmers. Using these capabilities, we developed a GUI from EML to ease the burden of formatting data and entering switches on a command line. In addition, Imagine includes a modeling language, known as Spatial Modeler Language (SML), which uses a graphical editor for creating models. These SML created models can be used to place graphics representing input data, functions, criteria, and output data on a page to create a model by drawing its flow chart. A user can create and execute the operations specified in the graphical models with SML.

Using just a few arguments, a user can execute the AGNPS model from a simple command line. The AGNPS model requires 22 input parameters (covering hydrologic, soils, drainage, agricultural management, and other information–Young *et al.*, 1995). The difficulty lies in creating and formatting the required 22 parameters for each cell in a watershed. The parameters vary from simple cell numbers to complicated values based on elevation, land cover, or soil type (Young *and others*, 1994, 1995; Agricultural Research Service, 2005). By utilizing the

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Imagine Developer's Toolkit, geographers and programmers at the U. S. Geological Survey created the *AGNPS Data Generator* (*ADGen*) program to compute all of the parameters necessary for AGNPS to solve this problem of integrating geospatial datasets and generating the AGNPS model parameters (Finn *and others*, 2002, 2003; Usery *and others*, 2004).

Measurements of hydrometeorological processes depend, in a large part, on the terrain surface. Usually via a computerized extraction method, several topographic parameters can be calculated directly from a Digital Elevation Model (DEM), particularly a watershed drainage network that is of interest in this case (Band, 1986; Tarboton and others, 1991; Martz and Garbrecht, 1992; Garbrecht and others, 2003). Although the general concept of GIS aided AGNPS modeling is not new, the software development activity that resulted in ADGen is new. The focus of our developmental approach was to streamline the process of going from a few important data sources to a complete output of the model, including visualization of that output data spatially that previously didn't exist in a tool for use by researchers (Figure 1). All terms in figure 1 will be explained later in the paper; it is referred to here to illustrate the relationships inherent in the ADGen interface.

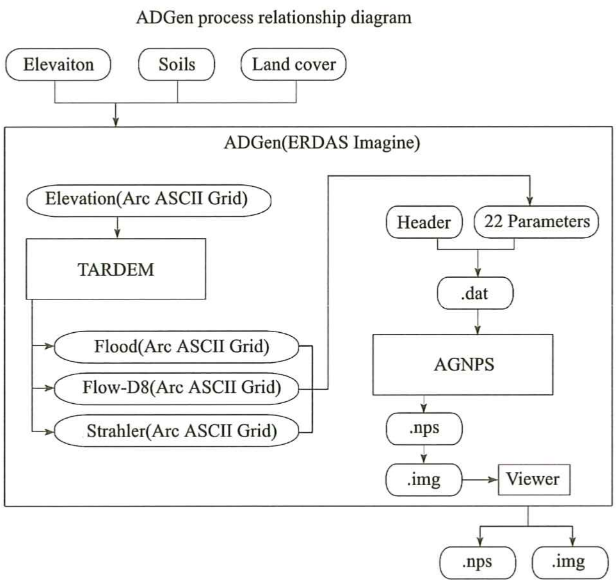


Figure 1. Relation diagram

The *ADGen* interface for Imagine 8.4 or higher was written to run on Windows NT, 2000, and XP operating systems to specifically automate the process of creating data for AGNPS version 5.0 by using only elevation, land cover, and soil data. The actual program implements EML for the GUI, SML for creating parameters, and a C program to format, convert, and process data. In addition to setting up the interface, EML also executes the models. Since the entire package is written using SML and the Developer's Toolkit, the only images that are used are in Imagine's "*.img" format; therefore, format conversions are not necessary. As a software wrapper (program) around the model, *ADGen* doesn't actually improve the model output but performs a valuable service by making the data more informative through visualization of the geospatial data in a way that is considerably easier to use and significantly more efficient computationally. It can help scientists solve problems more efficiently than the other existing Windows/ GIS interfaces.

Analysis of AGNPS results requires interpreting the output of an American Standard Code for Information Interchange (ASCII) file. Not only is this a large text file for watersheds covering significant aerial extent, the issue of human readability is exacerbated by a lack of formatting keywords. For this reason, *ADGen* provides the user with an image generated from the ASCII file. The Imagine viewer makes it easy to examine the image, point by point, to see the results the model produced. It also eases comparison of the output because one can link multiple viewers containing these images to display different data for a specific cell in the watershed.

II. DATA GENERATION

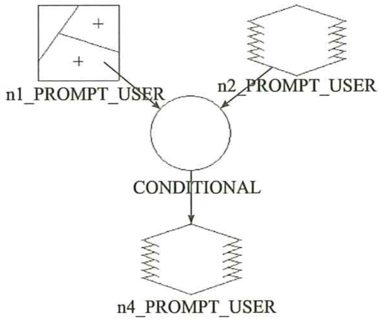
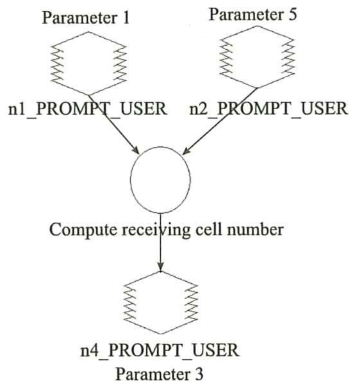
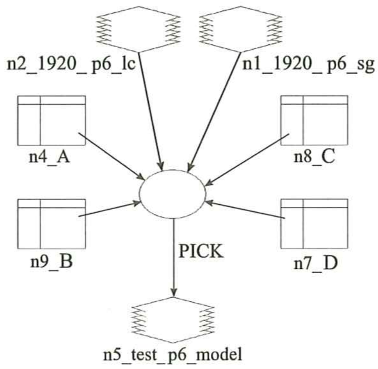
The user interface was written to execute at a screen resolution of 800×600 pixels or greater. Table 1 summarizes the generation of the requisite input parameters for AGNPS. The main window displays items are shown in Figure 2, including the requisite parameters to run *ADGen*, with buttons and filenames. Examining figure 2 reveals that some parameter buttons appear to be missing [for example, parameters 2 (cell division), 4 (receiving cell division), and 13 (practice factor)]. Because they are handled in unique ways (such as "hard-coded" values), there are no buttons for these parameters (Finn *and others*, 2002).

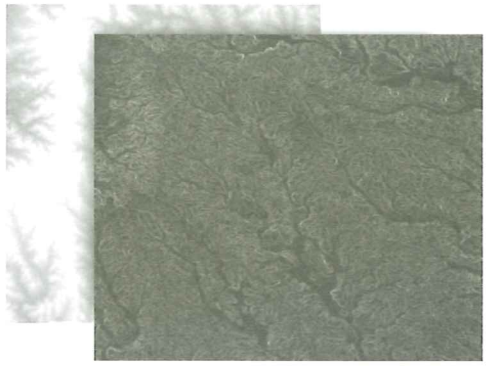
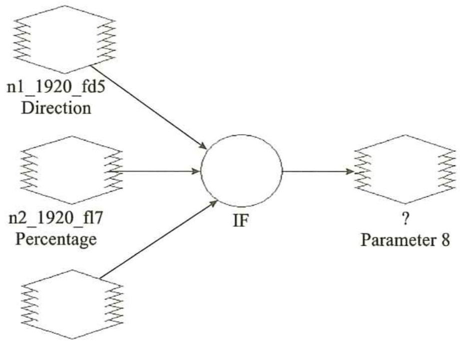
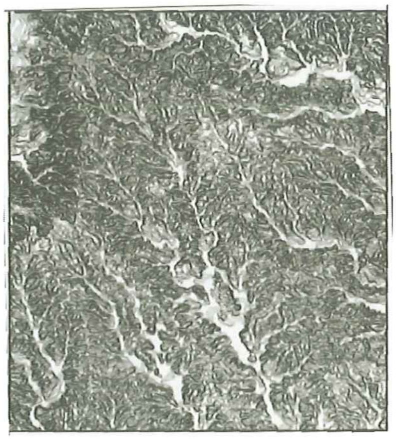
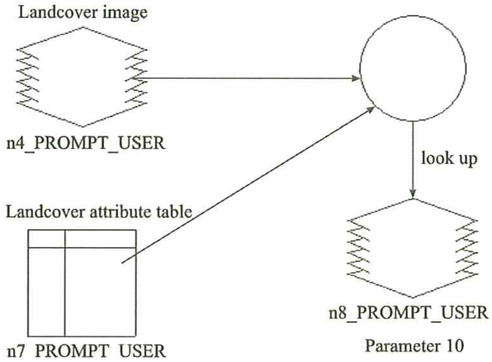
Since the intended use of AGNPS is to understand the complex problem of managing non-point sources of pollution, the model simulates the behavior of runoff, sediment, and nutrient transport from watersheds that have agriculture as their prime use. All model parameters are accounted for by *ADGen* (table 1). As seen in Figure 1, there are three data sources that an analyst will need to generate in model inputs. At the end of the parameter list is a space for an input filename for a "stacked image." A stacked image is a raster file created by overlaying different components (layers) of a GIS dataset containing all of the data for one theme in an image file. In this case the stacked image is the layers representing the input files. The buttons on the bottom row are discussed later.

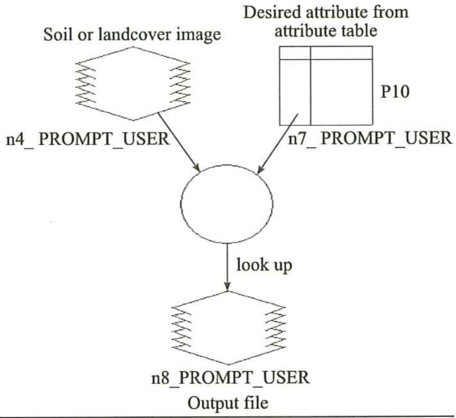
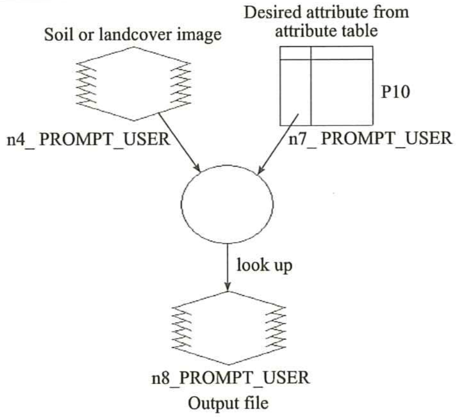
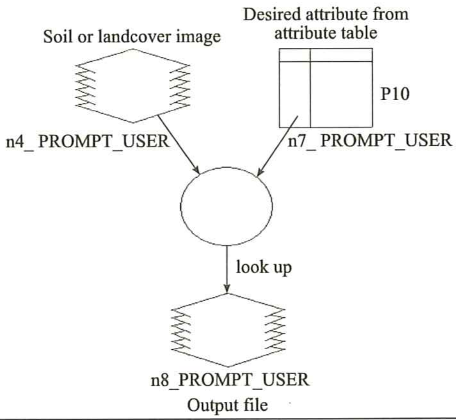
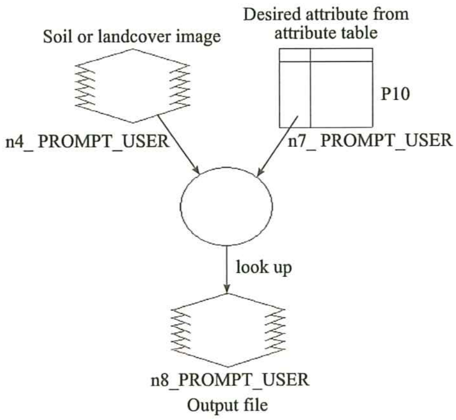
III. THE PARAMETER BUTTONS

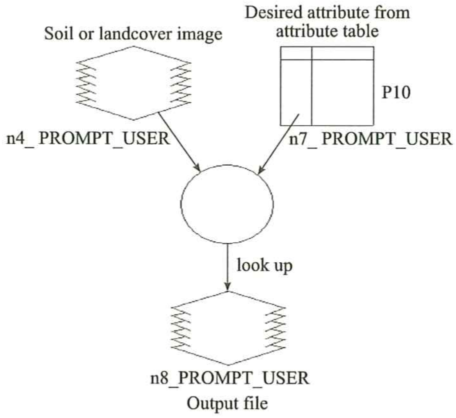
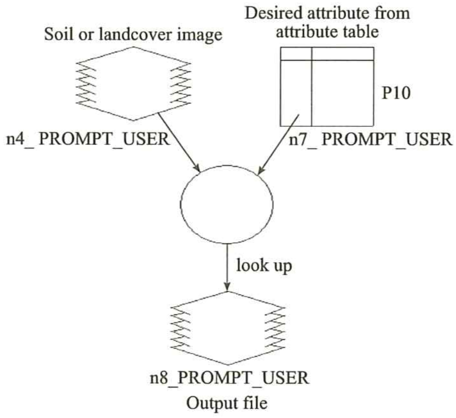
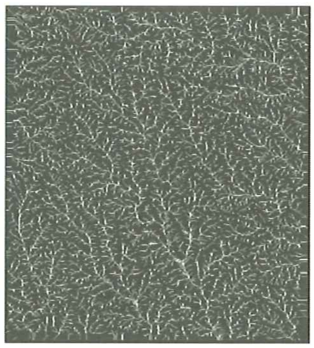
Parameters 1 through 17. Selecting any of the parameter buttons generates a window for creating the corresponding parameter. Table 1 shows a functional description of the transformation of the raw data into the required model inputs for each parameter. We coded each window using EML.

Table 1. Automatic generation of the required AGNPS input parameters

Number	Title and description of parameter generation	Diagram
1	**Cell Number** Uses as input a DEM and an Arc Coverage cutout of the watershed. It first creates a cutout image of the DEM. Next, it automatically numbers the cells in ascending order beginning with the uppermost left cell to provide each cell with an unique ID.	
2	**Cell Division** Set to zero. No cells were divided.	Not Calculated with ADGen
3	**Receiving Cell Number** Calculated by using cell number (parameters 1) and flow direction (parameter 5) within Imagine Spatial Modeler. Uses this information to label each cell with the cell number from which it receives runoff.	
4	**Receiving Cell Division** Set to zero. No cells were divided.	Not Calculated with ADGen
5	**Flow Direction** Created using the TARDEM program, with subsequent processing with Imagine Spatial Modeler to edit flow-direction values. Uses as input the DEM, converts it into an ASCII table, and with the aid of the program suite TARDEM, labels each cell with a value between 1 and 128, each value representing the flow direction of water within the watershed (See Figure 3).	 *(Image is faded from the original DEM, left, into Parameter 5's output, right)*
6	**SCS Curve Number** Determined by Imagine's Spatial Modeler, using the soil information and land cover as cross-referencing lookup tables. Uses an algorithm for Spatial Modeler that first checks the soil attribute table to determine the hydrologic soil group value for each cell; then cross-references this value with the land cover attribute table and classification to determine the runoff curve number for antecedent moisture condition II. (Natural Resources Conservation Service, 2001)	

Number	Title and description of parameter generation	Diagram
7	**Average Land Slope** Calculated by using Imagine Spatial Modeler's PERCENT SLOPE function on the DEM. to produce an output where the value of each cell represents the slope length of that cell.	 *(Image on left is the original DEM, background, with Parameter 7's output, foreground)*
8	**Slope Shape Factor** Calculated by using Cell Number (parameter 1), Flow Direction (parameter 5), and Land Slope (parameter 7) within Imagine Spatial Modeler. Uses an algorithm for Spatial Modeler that calculates the output using the values of the center cell and both the cells in front of and behind it (location based on flow direction) within a 3¡Á3 sub-matrix. (See Finn and others, 2002)	
9	**Slope Length** Calculated by executing a model that uses land slope (parameter 7) and a maximum slope length within Imagine Spatial Modeler. Uses 300 meters as a nominal maximum slope length, calculates Slope Length with the following equation: Slope_Length = 300-(Avg_Slope * 6.6666) Where 6.6666 is a coefficient that yields a length of 1m for a 45 degree slope, and 300m for a slope of 0 degrees.	
10	**Overland Manning's Coefficient** Created with Imagine Spatial Modeler by using land cover as a look up table. Creates an output from the Attribute Table of the image of Overland Manning's coefficients.	

Number	Title and description of parameter generation	Diagram
11	**Soil Erodibility Factor** Created with Imagine Spatial Modeler by using soils as a look up table.	
12	**Cropping Factor** Created with Imagine Spatial Modeler by using land cover as a lookup table.	
13	**Practice Factor** Set to one (1).	Not Calculated with ADGen
14	**Surface Condition Constant** Created with Imagine Spatial Modeler by using land cover as a lookup table.	
15	**COD (Chemical Oxygen Demand) Factor** Created with Imagine Spatial Modeler by using land cover as a lookup table.	

<table>
<tr><th>Number</th><th>Title and description of parameter generation</th><th>Diagram</th></tr>
<tr><td>16</td><td>Soil Type
Created with Imagine Spatial Modeler by using soils as a lookup table.</td><td>
</td></tr>
<tr><td>17</td><td>Fertilizer Level
Created with Imagine Spatial Modeler by using land cover as a lookup table.</td><td>
</td></tr>
<tr><td>18</td><td>Pesticide Type
Set to zero (0).</td><td>Not calculated with ADGen</td></tr>
<tr><td>19</td><td>Number of Point Sources
Set to zero (0).</td><td>Not calculated with ADGen</td></tr>
<tr><td>20</td><td>Additional Erosion Sources
Set to zero (0).</td><td>Not calculated with ADGen</td></tr>
<tr><td>21</td><td>Number of Impoundments
Set to zero (0).</td><td>Not calculated with ADGen</td></tr>
<tr><td>22</td><td>Type of Channel
Created by running DEM through stages of TARDEM program, and then through Imagine Spatial Modeler along with land cover. Converts DEM into an ASCII table of values (see Parameter 5) and then uses the executables d8.exe, flood.exe, and gridnet.exe from the TARDEM program suite to create an ASCII output table where each value contains the Strahler order associated with it. Then reconverts table to an image. With the aid of a land cover image and the value of the row containing water in the attribute table, it then uses a model to build an image where each value gives the channel type.</td><td>
(Parameter 22's output—see the description in the following section.)</td></tr>
</table>

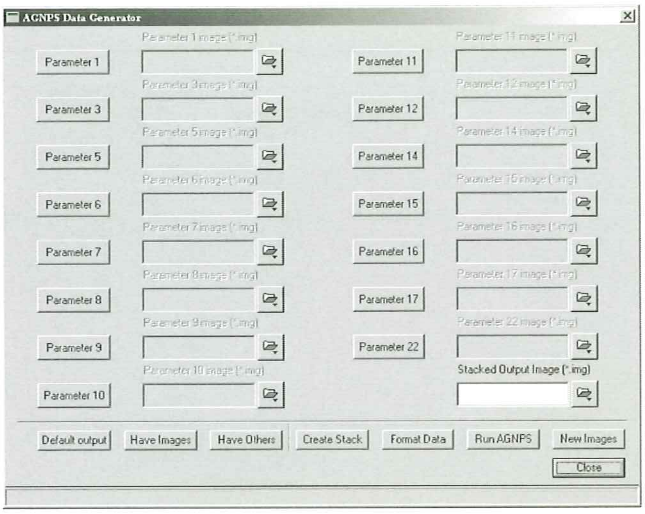


Figure 2. Main interface of AGNPS data generator

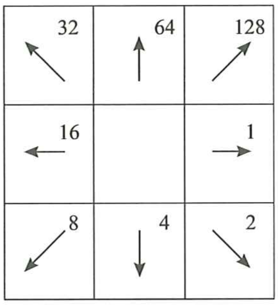


Figure 3. Flow direction values (using a 2^n notation-from Finn and others, 2002)

Displaying each of these new windows launches the models for creating the corresponding parameters. Originally written in SML, we thoroughly tested the models and then converted them into Imagine scripts (*.mdl). This allowed the EML code to call each script as a job. The algorithm then sends the information entered to one of the parameter windows as input to the script, which runs and creates a new image.

The new window then disappears showing only the main window. At this point, the name of the new image is located in the filename corresponding to the model that the user executed. A user can click the folder icon for any filename when the "Have Images" button has been clicked and select the filename to use. Otherwise, the option to do so will be disabled and the folder icon will remain grayed-out. We have created some of the windows as modal windows, meaning that only the window for the current parameter will function until that window has been closed.

Type of channel (parameter 22) code. Since most GIS packages don't normally have a function to create Strahler stream order values, analysts generally use program extensions (or add-ons) to create these values. We did not have Strahler stream order value files (images) with high enough order values to meet our needs in interfacing with the AGNPS model. AGNPS uses values ranging from one to eight, representing types of channels; this value is used to determine sediment deposition by particle size (Young *and others*, 1994). The GIS packages we investigated for this purpose generally calculated a stream order of five or less. In the AGNPS model, a value of five represents an ephemeral stream and a value of four represents a grass waterway (Table 2). A value of six and seven represent intermittent and perennial streams respectively (Table 2). Intermittent and perennial streams were the minimal target specification for the watersheds tested (Usery *and others*, 2004). For *ADGen*, we used a suite of programs called TARDEM (Tarboton, 2000) to generate the Strahler stream order. This collection of programs works with elevation data to create a stream order that we could map to the input channel type for AGNPS. Separately from an *ADGen*-spawned process, TARDEM is executed to pass the executable name along with the required arguments. Using the return value, *ADGen* ensures that TARDEM completed successfully.

Table 2. AGNPS channel type (after Young *and others*, 1994)

Value	Channel type
1	No definitive channel
2	Drainage ditch
3	Road ditch
4	Grass waterway
5	Ephemeral stream
6	Intermittent stream
7	Perennial stream
8	Other channel type

The ASCII output from TARDEM serves as input to a spatial model, which then reassigns the stream orders with a value of five or less to re-code them as intermittent streams. In order to use TARDEM, an ASCIIGRID file (a specific interchange format developed for Arc/Info raster files) is required. Therefore, we wrote code to convert an image to an Arc/Info ASCIIGRID and back to an image.

The ASCII file is simple to create by writing the header followed by data in rows, where white space separates each value and the value for number of columns from the header controls the rows. The image creation from the final ASCII file is simple because the Strahler stream order is 8-bit integer data; thus, no extra binary conversion is needed. The Type of Channel (Parameter 22) code also executes programs very similar to the method used in the main window to execute AGNPS. Each program is executed as a separate process.

IV. ADDITIONAL FUNCTIONALITY

The buttons along the bottom row of the GUI (Figure 2) provide additional functionality to the *ADGen* program. If the parameter image input files (*.img) already exist, the "Have Images" button commands the EML to enable or disable all of the filenames so that a user can enter them. The "Have Others" button displays a new window for entering other parameters not listed in the main window, such as "Cell Division" (parameter 2) or "Receiving Cell Division" (parameter 4). There are no models for these parameters because, as designed, they are hard coded in the program.

The "Create Stack" button uses all of the parameter filenames and the output stack filename as input to an Imagine "layermerge" model that stacks multiple layers into one image. Most of the information for the model is hard coded, except for the count (or placement in the stack) and the filenames. A user can accomplish the same process within Imagine by clicking the "Interpreter" button from the toolbar, then "Utilities," then "Layer Stack."

Formatting data. Once a user creates an image stack of the parameters, the data must be formatted correctly for entry into AGNPS. However, an extra argument, the cell number of the main outlet cell for the watershed, is required. This can be determined by following the "Flow Direction" (parameter 5) image to where it flows from the "Cell Number" (parameter 1) image. Unfortunately, at this time, this is something that is not automated and must be done manually by the user. The outlet cell is required in order to set up the data file for AGNPS.

At this point the "Format Data" button is selected and the C program is invoked. After the user enters the data file name and outlet cell into the "Format Data for AGNPS v5.0" window (Figure 4), the "Run" button will pass the execution to a function. The function name in the EML and the C code are different, but are related to each other in "ErdSetup.c" in a table of type "Eeml_TranslationTable". This table relates the EML function name to the corresponding C function in "Generator.c". The declarations for each function in the C code are in "ErdSetup.h".

We have extensively documented the C code to explain the logic, but a brief overview follows. A buffer is established to hold one row of data for the layers from the stacked image. These data are written to an output buffer one row at a time.

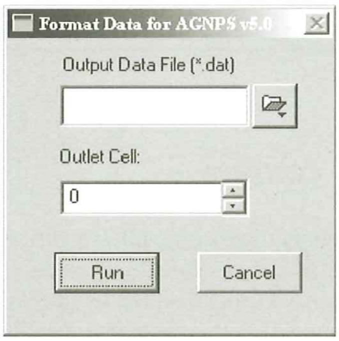


Figure 4. Format data window

Since these data are in floating point form, the Imagine software package divides each floating point value into four 8-bit sections and stores them within the buffer as binary data. Binary data for each cell are collected and converted into numeric form.

The algorithm then scans the row of data to look for any cell that is in the watershed by checking to see if the "Cell Number" (parameter 1) is greater than zero. If it is, all data for that cell are written to the output data file for AGNPS in the correct format (spacing, order, and data type). The program also checks values (soil, fertilizer, etc.) that make it necessary to include "optional" information.

The "Run AGNPS" button displays a new window for the input arguments of AGNPS v5.0. Like some executables for creating "Type of Channel," *ADGen* spawns a new process for AGNPS, passes these arguments to the C program (which then executes AGNPS), and uses the return value for control.

Creating new output images. After executing the AGNPS program, the output file (*.nps) can be used in conjunction with Cell Number to create images that display the results. The "New Images" button executes another block of the C program to display filenames for those two files as well as others. Once the user enters the two filenames along with the nine new image names to be created, the results can be analyzed.

This function does nearly the opposite of the function to format the data for AGNPS. The space for the data must be initialized by creating the buffers and image files. Nine buffers are initialized to hold all the data that the code places into nine images (Table 3) during each pass of the "Cell Number."

If a "Cell Number" is zero, then that is the value in the new images. If the value is greater than zero, the program reads data from the ".nps" file and places them in the corresponding cell as the current "Cell Number" value, using the ".nps" values for the different layers and images instead. The ".nps" values are converted to binary and placed in the correct positions for each cell.

The data are written one row at a time. However, since AGNPS splits the data within the ".nps" file, *ADGen* has to iterate through all the rows of "Cell Number" twice. The first time through the rows, the program creates the first seven images. The next grouping of information (nutrient data) begins in the "nps", and the rows of "Cell Number" are cycled through again. At the end, the program writes all of the map information and projection information for each new image to the Imagine file. Examples of *ADGen* created images of AGNPS output are shown in figures 5 through 7.

The default output button is used to establish a common output file prefix for the user. This allows *ADGen* to attach the

Table 3. *ADGen* output images of AGNPS version 5.00 (from Finn and others, 2002)

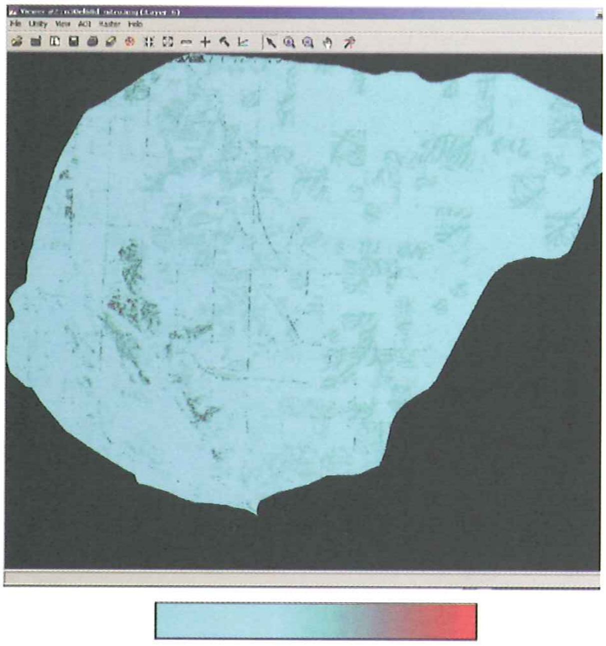
Filename	Band	Definition	Units
xxxhydro	++		
	1	Drainage Area	acres
	2	Equivalent runoff for the cell (Overland Runoff)	inches
	3	Accumulated runoff volume into cell (Upstream Runoff)	inches
	4	Upstream Concentrated Flow (Peak Flow Upstream)	cfs
	5	Accumulated runoff volume out of cell (Downstream Runoff)	inches
	6	Downstream Concentrated Flow (Peak Flow Downstream)	cfs
	7	Runoff generated above cell	%
xxxclay	++		
	1	Eroded sediment (Cell Erosion)	tons/acre
	2	Upstream sediment yield	tons
	3	Sediment generated within cell	tons
	4	Sediment yield	tons
	5	Deposition in the cell	%
xxxsilt	++	Repeat for same variables as xxxclay	
xxxSAGG	++	Repeat for same variables as xxxclay	
xxxLAGG	++	Repeat for same variables as xxxclay	
xxxsand	++	Repeat for same variables as xxxclay	
xxxtotal	++	Repeat for same variables as xxxclay	
xxxnitro	++		
	1	Drainage area	acres
	2	Cell sediment nitrogen	lbs/acre
	3	Sediment attached nitrogen	lbs/acre
	4	Soluble nitrogen in cell runoff	lbs/acre
	5	Total soluble nitrogen	lbs/acre
	6	Soluble nitrogen concentration	ppm
xxxphospho	++		
	1	Cell sediment phosphorus	lbs/acre
	2	Sediment attached phosphorus	lbs/acre
	3	Soluble phosphorus in cell runoff	lbs/acre
	4	Total soluble phosphorus	lbs/acre
	5	Soluble phosphorus conc.	ppm
	6	Cell COD yield	lbs/acre
	7	Total soluble COD	lbs/acre
	8	Soluble COD concentration	ppm

user-specified prefix to all output file names when using the program. This option must be set at the start of generating the parameter outputs for this to work throughout the process.

This generation of new output images is probably the primary aspect of *ADGen* to demonstrate that the ADNPS pollution model can be made significantly more friendly for a user, and more effective and efficient through the use of a GIS interface as was developed here.

V. QUALITY CONTROL

To meet research requirements, *ADGen* was developed as an experimental software package. It was tested internally using a cross-programmer testing method. In addition, the software was independently tested (Fuller, 2003). This provided us with valuable feedback. Additional tests are encouraged. The *ADGen*

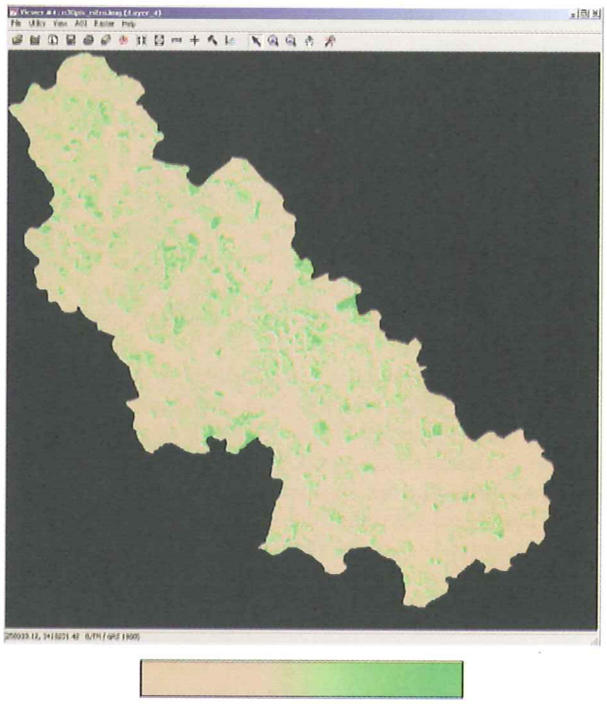


0.1305 19.8134
Soluble nitrogen concentration (ppm)

Figure 5. ADGen image of nitrogen output for the EL68D wasteway, washington. single band: band 6, drainage area

0.0000 8.5046
Total soluble phosphorous (lbs/acre)

Figure 6. ADGen image of phosphorous output for the little river, georgia. single band: band 4, total soluble phosphorous



0.0000 26.1521
Soluble nitrogen in cell runoff (lbs/acre)

Figure 7. ADGen image of nitrogen output for the piscola creek, georgia. single band: band 4, total soluble nitrogen

executable for Imagine, source code, test datasets, and User's Guide are available at: http://carto-research.er.usgs.gov/.

VI. CONCLUSIONS

While AGNPS provides a great deal of information on non-point source pollution, it is important that researchers have an efficient method for dealing with the difficulty of generating the data that AGNPS requires. An efficient method for analyzing the data it produces also is required. With available GIS packages such as ERDAS Imagine, a Windows-based program to simplify the task of creating the input for AGNPS has been designed and developed.

In addition, output from AGNPS was used to create multiple images that visually display the data geospatially for easier analysis. Because of the complexity and quantity of the input required and the nature of the output text file produced by AGNPS, *ADGen* is a helpful tool for the researcher who is trying to analyze non-point source pollution. It provides users with a powerful interface as well as more efficient methods for creating data.

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