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Please direct questions regarding the Graphical User Interface (EML and C++) to Prabhakar Reddy and questions regarding the underlying models (SML, GMD and CKB) to Dr. Montas.

Overview

This paper presents the development of a Graphical User Interface (GUI) to a Decision Support System (DSS) for NonPoint Source (NPS) pollution control on watershed scales. The GUI and all components of the DSS are entirely embedded in ERDAS IMAGINE and the system is launched from the main toolbar. The system uses IMAGINE’s GIS functions for data storage and pre–processing, SML for hydrologic simulation (finite differences) and the Knowledge Engineer for spatial decision–making processes. The GUI, written in EML, ties these components together and permits interactive selection of study watershed, pollutant of concern and model, interactive input of design meteorological parameters and integrated support for data pre– and post–processing commonly used in NPS pollution analyses. The integrated system is expected to be of tremendous instructional value for the graduate engineering course ENBE 633 "NonPoint Source Pollution Control” and also represents the next generation of tools needed by land managers and planners to evaluate the effects of past and future land uses on water quality. The demand for this type of tool is expected to significantly increase during upcoming years because of growing public concern over the environment.
1. Introduction

Non–Point Source (NPS) pollution, that which emanates intermittently from spatially distributed sources as a result of land use and meteorological events, is a major contributor to the degradation of surface water quality in the US and worldwide (Novotny and Olem, 1994). This type of pollution can be controlled by the adoption of improved land surface management methods (Best Management Practices, BMPs) which essentially prevent potential pollutants from leaving the land. The process of identifying appropriate BMPs typically involves 6 steps: 1) select an area of interest (typically a watershed); 2) gather all pertinent spatial data about this area; 3) identify pollutant(s) of concern in this zone; 4) identify critical sources (hot spots) of the pollutant(s) in the study area; 5) select appropriate BMPs for each hot spot and 6) evaluate the reduction in pollution resulting from application of the selected BMPs. Performing these steps has historically been rather difficult because of the wide land base over which NPS pollution is generated and the complex transport processes that it undergoes prior to reaching surface water bodies.

In recent years, researchers have started to combine Geographic Information Systems (GIS), distributed parameter hydrologic models and Expert Systems (ES, or other forms of Artificial Intelligence (AI)) to aid in the analysis of NPS pollution and the selection of appropriate BMPs (Montas and Madramootoo, 1992). The results are Decision Support Systems (DSS) that can store base data, simulate pollutant transport, identify hot spots and help human operators in identifying effective BMPs for arbitrary spatial locations. A decade ago these systems had to be developed by combining a variety of tools through non–standard external interfaces but recent advances in GIS software now permit them to be seamlessly integrated within a single package. The result is enhanced usability since the user no longer needs to know the intricacies of several individual software packages in order to analyze NPS pollutant transport.

The Model Analysis Laboratory in the Biological Resources Engineering Department of the University of Maryland at College Park has recently used ERDAS IMAGINE to develop a DSS for NPS pollution control planning at watershed scales (Montas et al., 1999a). The DSS is made up of loosely coupled components which are all integrated in IMAGINE. The base data is stored in .IMG files, hydrologic models are written directly in SML and with Model Maker and the Expert System is implemented using Knowledge Engineer. The DSS is mainly a research tool but it is also used in the graduate level course ENBE 633: "NonPoint Source Pollution Control". In this course, the students use the various components of the system to analyze NPS pollution control problems and develop BMP allocation plans for small watersheds in Maryland (Montas et al., 1999b, 2000). The loose coupling of the system, while flexible, has been a major issue for the students who often end up struggling with the multiplicity of data and model files and losing sight of the overall process of BMP allocation planning. Clearly, the practical application of the conceptual materials presented in the NPS class can benefit greatly from an integrated, top–level, Graphical User Interface (GUI) for the DSS.
2. Objective

The principal objective of this project is the development of a top–level GUI for the BMP allocation DSS. The target GUI has the following characteristics and functionalities:

- rational interface to the problem of BMP allocation for NPS pollution control
- interactive selection of study watershed, pollutant of concern and model
- interactive input of design meteorological parameters
- integrated support for data pre–processing
- accessible from IMAGINE main toolbar
- written in EML

Secondary objectives of the project include update of the hydrologic models used in the DSS so that they are compatible with the top–level EML (i.e. so that they take input arguments provided by the GUI) and development of a process by which knowledge bases can be updated dynamically (so that filenames corresponding to leaves in the decision tree can be updated on the fly by the GUI).

Background information on the hydrologic models, expert systems and data sources used by the DSS are briefly described in the next section. The approach used to develop the top–level GUI that integrates these components into a cohesive package for BMP allocation planning is then discussed in section 4.

3. Background on the NPS Pollution Control DSS

At its core, the Decision Support System consists of 3 types of components: 1) data management (GIS); 2) hydrologic models, and; 3) expert systems. The operation of the system essentially follows the 6 steps given in the introduction: 1,2,3) the watershed of interest is selected using the GIS, pertinent data are subset via GIS operations and a pollutant of concern is selected; 4) the hydrologic model is then run to identify hot spots; 5) the expert systems are used to determine appropriate BMPs for each of the hot spots, and, finally; 6) the reduction in NPS load with BMPs is evaluated using the hydrologic model. Steps 5 and 6 may be iterated to reach a desired load reduction.

3.1. Geographic Information System

IMAGINE is used to store all data required to run the hydrologic models and expert systems. The current dataset is for Dorchester county, Maryland. All data are stored in Maryland State Plane coordinates (NAD 83) with a 30 m raster cell size. Watershed boundaries and stream networks were obtained from NRCS digital data files. These watershed boundaries correspond to the 14–digit classification of the USGS. The topographic data were derived mostly from USGS 30 m Digital Elevation Models (DEM) but some quadrangles were missing for the area of interest and had to be digitized from 7.5 minute paper maps and then rasterized.
Soils data were obtained from the NRCS SSURGO digital coverage which has a map scale commensurate to the pixel size used in the DSS. Attribute tables containing surface and depth integrated properties were derived from the SSURGO data tables. The relevant data include soil permeability, porosity, depth to bedrock and high water table depth.

Land cover data were obtained by interpreting and digitizing, on–screen, a mosaic of Digital Ortho–photo Quarter Quads (DOQQs) obtained from the Maryland Department of Natural Resources (DNR). Two classes were formed: farmland and non–farmland and specific land uses (specific crops, pasture or other agricultural use) were then assigned at random to the farmland fields. Random allocation was used because the studies carried out using the DSS are of a conceptual nature and to respect the privacy of land users. The file produced by this process should not be interpreted as representative of actual cultural practices in any given part of the county. Attribute tables were developed for the land use coverage so that all relevant model parameters (e.g. Manning’s surface roughness coefficient, plant uptake of nutrients) would be available at the time of a simulation.

3.2. Transport Models

The DSS includes two major techniques, implemented in SML, for identifying NPS pollution hot spots: process modeling and indexing. Indices are easier to compute spatially but generally less accurate than process models. The two indices implemented in the DSS are the Virginia Water Quality Index (WQI) relating to sediment pollution and version Draft#56 of the Maryland Phosphorus Index relating to phosphorus transport. Both indices are calculated on a pixel by pixel basis using SML scripts and assume high values where the potential for NPS pollution from their respective pollutant is high (hot spot).

The Model Analysis Laboratory has developed two process models: Hydromod and Hydrosub for identifying NPS hot spots. Both models conceptualize an area of interest (watershed) as consisting of a contiguous set of control volumes into and out of which water and pollutants move due to transport processes. In the current implementation, the control volumes are chosen to coincide with the pixels of the raster GIS. Differential equations describing solute transport processes in and out of control volumes are discretized and their discrete, finite–difference, form is implemented in SML scripts.

Hydromod is a transient surface flow and transport model used to describe the movement of surface pollutants (e.g. sediments) in watersheds in response to a single storm event (Montas et al., 1999b). The SML script that implements this model includes a variable time–step size which preserves the quality of the solution. The outputs produced by Hydromod include depth of detainted water over time, pollutant concentration in detainted water over time and pollutant delivery to streams. The time–dependent spatial outputs are stored as stacks and can be displayed as "movies" using the movie sequence tool in IMAGINE. Hydromod also calculates the total amount of pollutant lost by each pixel and determines NPS hot spots from the upper tail of the corresponding histogram based on a variable threshold.
Hydrosub is a steady–state subsurface flow and transport model that describes the movement and fate of soluble pollutants transported by water below the soil surface (Montas et al., 2000). These solutes travel relatively slowly and may undergo phase changes (reactions) during this travel. A plant nutrient (nitrogen or phosphorus) may for example be taken up by a plant for nutrition and hence be removed from the transport system. Hydrosub includes such processes and may hence be used to evaluate the effects of surface vegetation on subsurface pollutant concentrations (e.g. in phytoremediation). The equations solved by Hydrosub are nonlinear and the SML script that implements the model solves them via an iterative process that simulates time–stepping. Hydrosub produces several outputs including steady–state water table elevations, subsurface flow velocities and spatial distribution of pollutant delivery to streams. Hydrosub also calculates steady–state pollutant concentrations in each pixel and uses the upper tail of the corresponding histogram and a variable threshold to determine NPS hot spots.

3.3. Expert Systems

The expert systems implemented in the DSS are inspired by medical practice and separate the BMP selection process into two steps: diagnosis and prescription (Montas et al., 1999a). The diagnosis expert system is aimed at determining the most likely probable cause for excessive pollutant export by a NPS hot spot. This diagnosis is performed based on data stored in the attribute tables of the soils, topography, land cover and streams data layers. The prescription expert system is focused on identifying all appropriate BMPs for reducing pollutant export. The prescription is performed based on the diagnosis of the most likely probable cause for excessive export and on the attribute data stored in the GIS.

The knowledge incorporated in the diagnosis and prescription expert systems was acquired from advanced textbooks on NPS pollution control (Novotny and Olem, 1994), government documents (EPA, 1993) and personal experience. This knowledge was formalized using the 3 step approach of Genesereth and Nilsson (1987): 1) definition of the universe of discourse; 2) definition of relations and functions, and; 3) development of predicate calculus sentences. The universe of discourse was chosen to coincide with objects stored in the GIS and produced by the hydrologic models. These include soil types, crops, slope categories and pixels (control volumes). Relations and functions between these objects were defined, as necessary, and a series of well–formed predicate calculus sentences representing NPS diagnosis and BMP selection knowledge were then developed.

The predicate calculus sentences were translated into decision trees and implemented in IMAGINE using the Knowledge Engineer . Relations and functions were translated into graphical models, using Model Maker, when necessary. The resulting system produces diagnosis and prescription on a pixel by pixel basis. A separate graphical model is then used to assign a single prescribed BMP to each farmland field classified as a hot spot (containing at least one hot spot pixel) by using a zonal MAJORITY operation where zones are defined by the land cover raster.
4. Development and Operation of the Top–level DSS GUI

The GUI is developed to provide the user of the DSS with an integrated perspective on the system’s components, to foster its rational use in the development of BMP allocation plans and to help with data processing tasks.

4.1. Access to the Top–Level GUI

Access to the GUI is gained either from the DSS icon (with a map of Maryland) on the IMAGINE main toolbar: 

Utilities → Decision Support System

or from the Sessions menu:

Session → Utilities → Decision Support System

Once the GUI has been properly installed the main toolbar will be changed from its original version to:
4.2. The Top–Level DSS GUI

The Top–level GUI is designed to provide access to the two main parts of the NPS pollution control planning process: 1) Data pre–processing (gathering) and 2) Data analysis. Data pre–processing consists of the preparation of a base set of data layers from which individual study areas (watersheds) can later be extracted to run the hydrological model and the expert systems. Data analysis on the other hand, consists of selecting a specific study area (watershed) and pollutant of concern, identifying the corresponding NPS hot spots and selecting appropriate BMPs for these hot spots. The separation of the NPS control process into these two tasks is quite convenient to the user since it permits the same analysis to be performed several times on different watersheds that are all part of a larger study region (for example a county) without having to re–specify base data input file names each time.

To reflect this major division of tasks, the Top–level GUI is made up of two major buttons: Preprocessor and Simulation/Diagnosis/Prescription:

```
<table>
<thead>
<tr>
<th>Decision Support System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preprocessing of Data Layers ...</td>
</tr>
<tr>
<td>Simulation/Diagnosis/Prescription ...</td>
</tr>
<tr>
<td>Close</td>
</tr>
</tbody>
</table>
```

Pressing either button opens the corresponding DSS module, each of which includes a button that leads the user to the alternate module for "sideways" transfer of control. The two modules are described in the following subsections.

4.3. Data Preprocessor

The pre–processing module enables the DSS user to define the input data to be used in the NPS analysis. This data may be either for a region in which several watersheds will be analyzed or possibly, for a single watershed. The entire base dataset for the DSS consists of 8 image files, some of which may be computed from other files. Once the base data has been specified, the user has the option of "saving" this base data for later use. The "save" operation actually only saves a list of input filenames in a separate text file and this list can be re–read into the system at a later time to continue the analysis of a given region.

The GUI of the Preprocessing module is shown below. The radio buttons on the left allow the user to specify that he/she is either creating a new base data set or simply loading and possibly modifying an existing dataset. In the later case, the file box at the top right of the window lets the user browse for the appropriate base data file name. The main part of the window allows the user to specify the names of files to be used in forming the base dataset.
Four data types: cropland, DEM, DOQQ and slope may be specified in these fields called Data Set I while flipping the Tab to Data Set II allows for the 4 remaining input data to be specified: land cover, soils, streams and watershed (see below).

Buttons have been incorporated under each file box to let the user view the image being selected in an IMAGINE Viewer or see its projection and cell size information to help in the data selection process. Slope data may furthermore be calculated directly from the DEM data by pushing the corresponding radio button right above the Percent Slope file box.
Buttons located at the right of the window enable the user to clear all entered data file names (Reset), save the name of all input data files under the base data set file name stipulated in the uppermost file box (Save All), proceed to the Simulation / Diagnosis / Prescription module (Continue...) or quit without saving the base data file names (Quit).
4.4. Simulation Diagnosis and Prescription Module

The simulation, diagnosis and prescription module provides the user with access to the working components of the DSS. The module’s main window is shown below:

The upper part of the interface lets the user select the base data formerly created using the Preprocessing module and also the specific study area on which the analysis is to be performed (top right). The study area is an AOI which can be created at this stage of the analysis using the "Create Study Area" button or chosen amongst existing AOI files using the "Choose Study Area" button. Once the study area has been properly identified, its name appears next to the "AOI:" label at the top right of the window and and the interface button become activated.

The next lower part of the GUI allow the user to select a pollutant of concern and model for the simulations. The available pollutants are agrichemicals because of their important contribution to NPS pollution. The available models are Hydrosub, Hydromod and the Maryland Phosphorus Index discussed in section 3. Selecting a specific pollutant has an effect on the allowable models. For example, the phosphorus index cannot be used if the pollutant of concern is nitrogen or a pesticide. Accordingly, the GUI disables the MPI option in this case.

Below the pollutant and model input section is the modeling parameter component of the
GUI. This section lets the user specify the time step, simulation duration, annual rainfall and Evapotranspiration rate to be used in Hydrosub simulations. Buttons are also available to run the model which produces an image file that identifies the NPS pollution hot spots in the study area. These hot spots, identified on a pixel by pixel basis, may be viewed by pressing the "View Results" button. The hot spot threshold may then be modified if the user judges that either too much or too little of the land has been classified has hot spot. This part of the GUI is disabled if another model has been selected for hot spot identification.

The next level of the GUI lets the user perform diagnosis and prescription activities at the touch of a button (literally). Pressing the corresponding buttons launches the Expert Classifier’s Inference Engine with knowledge bases (CKB files) developed for the specific pollutant selected above. Results of both hot spot diagnosis and BMP prescription can be viewed at this stage by pressing the "View Results..." button which launches a Viewer containing the corresponding Image file output by the expert system.

The final level of the GUI lets the user take a virtual tour of the study area and view prescribed BMPs overlaid on the DEM in 3–D. This feature and the "Create Maps" feature associated with the bottom–right–most button of the GUI will be implemented in a future version of the DSS GUI.

A final level of user support is provided by the documentation which accompanies the GUI and includes a README file and a Help document which describe additional features and known bugs of the system.

5. Summary and Conclusions

A top–level GUI providing a rational interface to a BMP allocation DSS for NPS pollution control has been developed. The GUI permits interactive selection of study watershed, pollutant of concern and model, interactive input of design meteorological parameters and integrated support for data pre–processing.

The GUI and all components of the DSS are completely embedded in ERDAS IMAGINE. The GUI is written in EML and accessible from the IMAGINE main toolbar. The GIS used by the DSS is IMAGINE. The hydrologic models (solved via finite differences) are written in SML and the expert systems are implemented using Knowledge Engineer decision trees. The one exception was the need to implement an external parser (in C++) to modify the names of input data files used by the decision trees so that they match the output files produced by the hydrologic models. The development also required minor modifications of the original SML models of the DSS to take input arguments supplied by the GUI.

The GUI driven DSS is expected to be a tremendous didactic tool for the teaching of the course ENBE 633 in coming years. It also represents the type of next generation tool needed by land managers and planners to effectively evaluate the potential effects of past and future land uses on water quality. The BMP allocation plans that it helps to produce may be used, for example, to develop incentive programs aimed at encouraging hot spot
land owners to adopt surface management practices that prevent NPS pollution. In view of the growing public concern over the environment one may envision that the demand for and application of this type of tool will only increase in both near and distant future.

6. Acknowledgments

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7. References


