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IDEAS & INNOVATIONS

People in Ecosystems/Watershed Integration: A dynamic watershed tool for linking agroecosystem outputs to land use and land cover

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Land-use decisions in agriculturally-dominated regions such as the US Corn Belt largely attempt to maximize production of agricultural commodities. While this system is highly productive in terms of commodity crops, it also creates trade-offs in the form of negative environmental impacts (Robertson and Swinton 2005). Many unintended consequences of ecosystem impairment are subsequently passed on to society as "downstream" costs, which can span from local (e.g., fish kills in local streams) to global scales (e.g., greenhouse gas emissions) (Tegtmeier and Duffy 2004). Because of growing concern regarding these trade-offs, agricultural policy and grassroots social movements are moving toward the promotion of multifunctional landscapes to enhance commodity productivity, to produce a wider array of ecosystem goods and services for a broad suite of societal stakeholders, and to minimize (or eliminate) trade-offs (Ruhl et al. 2007; USDA 2008). For example, the Raccoon River watershed to the northwest of Des Moines, Iowa, provides important economic benefits for a multitude of private farm owners and operators, but it also provides drinking water and recreational opportunities for more than 400,000 people in the greater Des Moines area (DMWW 2010). A number of entities are working to maintain agricultural livelihoods while trying to increase the "awareness of watershed issues and help watershed residents develop environmental enhancements" (USEPA 2010). However, the complexity of the issues involved makes it challenging for all stakeholders to recognize the trade-offs resulting from changes in land use and management.

People in Ecosystems/Watershed Integration (PE/WI) is a simple spreadsheet tool designed to provide a scientific platform for teaching, discussing, and evaluating the trade-offs associated with agricultural land use and management. PE/WI encourages users to think through the complexity of social-ecological systems and their associated trade-offs and build comprehensive understanding of system outputs and outcomes at multiple scales. The use of PE/WI in many of natural resource management courses at Iowa State University also has the objective of facilitating the integration of a body of otherwise fragmented knowledge regarding land management and ecological processes by students into a unified whole. PE/WI can play a strong role in clarifying the complex linkage between land use/cover and ecosystem outputs within the context of realistic watershed boundaries.

PE/WI achieves these objectives by evaluating the ability of alternative land-cover configurations to produce marketable crops, improve water quality, sequester carbon, and enhance biodiversity. Users are allowed to adjust several variables; therefore, users design the virtual watershed to meet their perceptions and goals for an agricultural landscape. PE/WI instantly computes and outputs eight indices, including yield potential of several crops (i.e., corn, livestock, and timber), stream sediment load, average annual stream nitrate concentration, phosphorus delivery risk, habitat provision for biodiversity, and carbon storage. Users are then able to evaluate their landscape's overall performance and can attempt to optimize land-cover patterns according to multifunctional criteria.

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MODEL OVERVIEW

The PE/WI model is fully contained within a Microsoft Office Excel workbook and is composed of an interface worksheet; 2 predefined, fixed variable worksheets (topographic relief and soil permeability); 25 variable worksheets in which values change depending on user decisions; and 6 worksheets that compute output indices (habitat provision for biodiversity, sediment delivery, phosphorus delivery risk, agricultural yield, stream nitrate concentration, and carbon sequestration). Each pixel or cell of the watershed is predefined to be 30 by 30 m (98 by 98 ft). The user interface is divided into four components: user controls, maps of predefined physiographic characteristics, maps of output indices, and graphs of output indices (figure 1).

PE/WI's interface allows users to manipulate land use and land cover within the watershed. Land-use and land-cover

Figure 1

People in Ecosystems/Watershed Integration tool user interface.

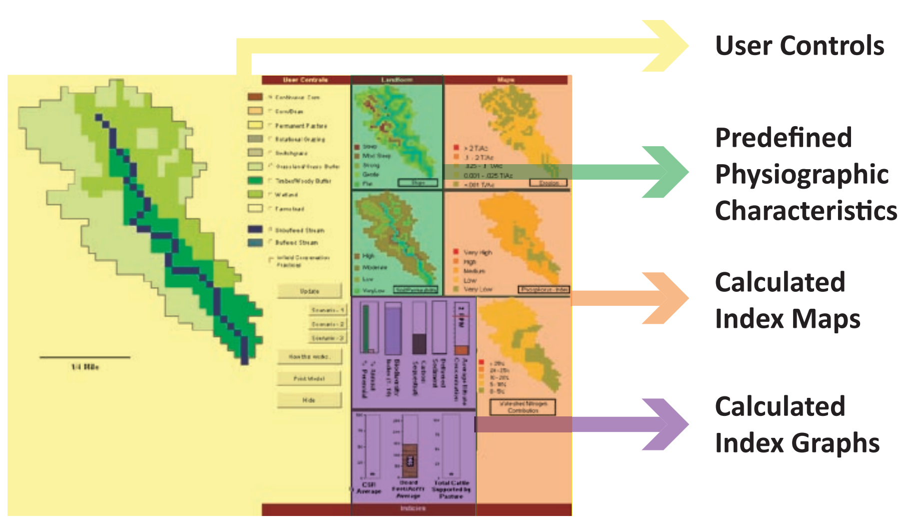
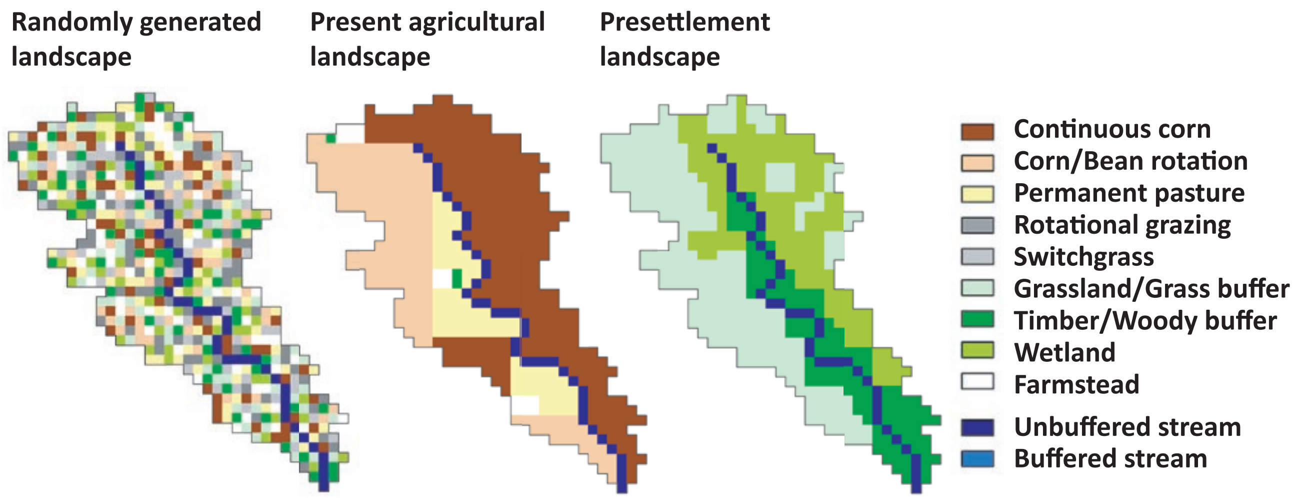


Figure 2

Three predefined scenarios included in People in Ecosystems/Watershed Integration tool user controls.



variables that can be manipulated include the following:

- The land-cover composition of a parcel in one of nine land-cover types (i.e., continuous corn, corn/bean rotation, permanent pasture, rotationally grazed pasture, switchgrass, grassland, forest, wetland, and farmstead)
- Whether or not the land adjacent to the stream has an established riparian buffer
- Whether or not in-field conservation practices (i.e., terracing, contour farming) are implemented.

Controls allow unique watershed designs and outputs to be saved or printed for later referral or comparison. The interface also includes links to three preprogrammed, contrasting scenarios designed to introduce users to the range of variability in the tool's inputs and outputs. The predefined scenarios represent (1) a random distribution of land-cover types, (2) a row crop–dominated watershed with some area in perennial cover types such as occurs in much of the Corn Belt today, and (3) a grassland-dominated watershed such as existed in the Corn Belt prior to Euro-American settlement (figure 2).

The predefined physiographic characteristics of the watershed—topographic relief and soil permeability—are based on two different physiographic regions of Iowa that present unique challenges in achieving agricultural sustainability:

- The eastern portion of the watershed represents the topography and soil permeability typical of the Des Moines Lobe landform, which is characterized by subtle topography, poorly drained soils, and poorly developed stream networks (Prior 1991). Specific values for topographic relief and soil permeability were derived from the Montgomery Creek watershed in Story County, Iowa.
- The western portion of the watershed represents the topography and soil permeability typical of the Southern Iowa Drift Plain landform, which is characterized by relatively steep slopes, well-drained plains, and a developed stream network (Prior 1991). Specific values were derived from the Walnut Creek watershed in Jasper County, Iowa.

Values for topographic relief are given in accessible and relative terms, ranging from "steep" to "flat;" however, these descriptors translate to the actual slope percentage values of 14% to 18% and 1% to 2%, respectively, in model calculations. The soil permeability map displays soil hydrologic groups for the watershed. These groups are described along the range of "high" to "very low" and translate to "Hydrologic Group A—Deep, well drained sands and gravels" and "Hydrologic Group D—Clay soils or soils with high water table," respectively (USDA NRCS 2009).

Based on user inputs, PE/WI calculates and spatially displays output maps of source areas for soil erosion and watershed phosphorus and nitrate-nitrogen contributions. Soil erosion is calculated according to the widely employed Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). Phosphorous contribution is based on the Iowa Phosphorus Index, which was developed and utilized by the USDA Natural Resources Conservation Service to assess the risk of phosphorus delivery to surface waters (USDA NRCS 2004). Nitrate-nitrogen contributions are calculated according to Schilling and Libra (2000), who showed that nitrate concentrations in Iowa streams and rivers could be estimated based on land cover. The relative nitrogen contribution from each of 18 subwatersheds comprising the full watershed is shown in the index map, while the nitrate-nitrogen concentration in downstream surface waters is given in parts per million through a nonspatial indicator bar. Values represent annual averages and do not represent peak concentrations, which can be much higher than the annual average.

PE/WI also calculates and graphically outputs several other nonspatial indices, including delivered sediment, carbon storage, habitat provision for biodiversity, cattle number supported, timber output, and corn suitability rating. Delivered sediment is calculated over the entire watershed using RUSLE, and the sediment delivery ratio for each of the subwatersheds is considered in the calculations. Carbon storage is based on estimated carbon sequestration values from Tufekcioglu et al. (2003) for each of the general cover types: corn, soybeans, cool season grass, warm season grass, and trees. The biodiversity index is composed of six calculations that consider the impacts of landscape pattern on biodiversity, as derived from Fischer et al. (2006): the amount of overall perennial habitat, wetland habitat, grassland habitat, forest habitat, and riparian forest habitat and a measure of landscape heterogeneity and connectivity. The number of cattle supported is calculated based on the area in rotational and continuous pasture cover types. The area is multiplied by an estimated likely carrying capacity—or the total amount of forage consumed per season divided by the daily feed requirements per animal during the grazing season—under local conditions (USDA NRCS 2008). Timber output estimates the productivity of lands designated as forest. Values are based on the Iowa Woodland Suitability Composite and the soils common for each of the two physiographic regions represented by the model (IDNR and USDA NRCS 2007). Corn Suitability Rating (CSR) is a relative ranking of all soils in Iowa for their productivity at producing corn (Miller 2005). The scale ranges from 0 to 100 and has been estimated for each soil type within the state of Iowa. Within PE/WI, we averaged the CSR for each soil hydrologic group and slope category within the two watersheds represented within PE/WI. The model index averages the CSR from all user-defined areas in corn or soybean land-cover types and indicates the average productivity of the land devoted to row crop agriculture.

The interworkings of PE/WI are entirely transparent and can be amended to fit the conditions of other locations. The second worksheet in the Microsoft Office Excel workbook provides a flow map of the model with links to companion worksheets that store baseline data and are used in calculating output indices. These worksheets can be shown for the advanced user or hidden to avoid unnecessary complication.

EXAMPLES OF USES OF PE/WI IN EDUCATIONAL SETTINGS

We designed PE/WI to be used in diverse classroom or workshop settings, particularly with college students and watershed stakeholders. We have also designed a series of exercises, ranging from simple to complex and that build on one another, to work with these groups. These could be contracted or expanded depending on the expertise of the group and time available. Exercises 1 and 2 alone may be most appropriate for groups with limited knowledge of basic ecology and land management. Groups with more expertise in these areas may be asked to quickly complete Exercises 1 and 2 to familiarize themselves with PE/WI, but skip formal responses; they would then be asked to spend more time with Exercises 3 and 4. With such advanced users, we have expanded upon Exercise 4 by asking students to propose, discuss, and evaluate methods of economic valuation that may be used to overcome the challenge of delivering societal benefits such as water quality and habitat for biodiversity from private lands. Please see http://www.nrem.iastate.edu/landscape/projects/pewi/pewi.html for exercises.

We have tested PE/WI's ability to enhance learning with junior and senior students in natural resources classes at Iowa State University. In comparing student answers to a brief pre- and postexercise questionnaire, students offered more specific discussion on the spatial placement of land-cover types to achieve particular results (i.e., targeting) following the use of PE/WI (table 1). For example, when asked to describe their ideal watershed in Iowa, most students stated in pretests that they would prefer a mixture of crops, forests, and a farm pond. By comparison, posttest responses to the same question largely described corn placed on land with high CSR, switchgrass and pasture on lower productivity soils, forests on steep slopes, and a buffer along the stream. When asked what their ideal watershed would produce or provide, students commonly included general statements about food, wildlife, and recreation or specific statements about corn, soybeans, beef, and pheasants in pretests. While student posttests also listed these traditional outputs, they additionally included clean water, habitat for biodiversity, and/or carbon storage in their responses. A specific student response to PE/WI is illustrative: one student responded to a question about his/her ideal Iowa landscape in the pretest with "farmed as much as possible while maintaining as much soil as possible" and posttest with "optimized crop ground with minimal environmental impact." Students also verbalized that they enjoyed using the model. Overall, we feel the use of PE/WI provides a rigorous, scientifically-based challenge to student preconceptions of linkages between land

Table 1

A summary of student responses to pre- and posttest questions used along with PE/WI in a classroom in April, 2008; test results were categorized according to major themes emerging from qualitative analysis of 40 students responses.

Questions and thematic responses	Pretest (%)	Posttest (%)	Change (%)
Describe your ideal Iowa landscape			
Rolling hills	50.0	5.0	-45.0
Wildlife habitat	70.0	52.5	-17.5
Farm pond	20.0	15.0	-5.0
Native ecosystems	0.0	7.5	7.5
Targeted perennial plants	25.0	37.5	12.5
What are some of things that this Iowa landscape would produce or provide?			
Recreational opportunities (i.e., hunting, fishing)	35.0	17.5	-17.5
Corn and beans	20.0	30.0	10.0
Water	2.5	17.5	15.0
Wildlife	25.0	55.0	30.0
What is the role of perennial vegetation within the Iowa landscape?			
Soil conservation	60.0	55.0	-5.0
Store carbon	2.5	5.0	2.5
Protect biodiversity	0.0	15.0	15.0
Buffer stream	27.5	60.0	32.5
Purify water	20.0	60.0	40.0

cover and watershed outputs. The model also formalizes student consideration of the trade-offs among the multiple, often conflicting objectives they hold for agricultural landscapes. We additionally expect that the educational power of PE/WI can extend well beyond the classroom and have broad application in Cooperative Extension education programs and other activities designed to promote landowner education and land-use dialog among watershed stakeholders.

In conclusion, we perceive a need for science-based tools that allow students and watershed stakeholders to directly evaluate the many trade-offs associated with managing our land, air, and water resources. By providing a formal platform for evaluating the multiple consequences of land-use and land-cover change, our classroom experience has shown that PE/WI can be effectively used to facilitate discussions on designing agricultural watersheds to achieve multiple outcomes. We hope that PE/WI will be used to improve decision-making now and in the future by clarifying the consequences of alternative land-cover and land-use choices.

INSTALLATION INSTRUCTIONS

Interested in using PE/WI? The file PEWI.v1.1.xls can be downloaded from our website at http://www.nrem.iastate.edu/landscape/projects/pewi/pewi.html. More information on model parameterization and use can be found in the User's Guide, also available for download from our website.

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