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People in Ecosystems/Watershed Integration: Visualizing ecosystem services tradeoffs in agricultural landscapes

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People in Ecosystems/Watershed Integration:
Visualizing ecosystem services tradeoffs in agricultural landscapes

by

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DEDICATION

I dedicate this thesis to my loving grandmothers, Louise Young and Carlene Chennault. Their childhood stories of farming, family, and delicious home-grown food inspire me to rekindle in our communities all that we love about agriculture.

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NOMENCLATURE

CRP	Conservation Reserve Program
EPA	United States Environmental Protection Agency
IDNR	Iowa Department of Natural Resources
ISPAID	Iowa Soil Properties and Interpretations Database
MLRA	Major Land Resource Area
NRCS	United States Department of Agriculture Natural Resources Conservation Service
NRS	Iowa Nutrient Reduction Strategy
PE/WI	People in Ecosystems/Watershed Integration
P-Index	Iowa Phosphorus Index
RUSLE	Revised Universal Soil Loss Equation
STP	Soil Test Phosphorus

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ABSTRACT

Educational modeling in agricultural and environmental sciences provides access to the scientific knowledge needed to address local and global challenges that affect human wellbeing. Ecosystem services tradeoffs frameworks can enhance wellbeing by facilitating agricultural landscape design to produce multiple ecosystem services while maintaining farmer profitability and mitigating risk to farmers. At present, few broadly accessible tools evaluate how changes to land management affect the types and levels of ecosystem services delivered to humans. I developed a tool, People in Ecosystems/Watershed Integration version 2 (PE/WI or PE/WI v2), to fill this gap and foster multidimensional and integrative land-management decisions.

PE/WI is an online educational watershed simulation that allows users to design land-use configurations and evaluate ecosystem services tradeoffs. PE/WI creates a novel learning environment with visualizations that simplify complex land-use and ecosystem services relationships. Its ecological modeling framework aims to teach concepts of minimized tradeoffs and maximized co-benefits across spatial and temporal watershed dimensions. This approach allows users to simultaneously consider agricultural land use, climate conditions, production outcomes, and environmental outcomes such as nutrient levels in water, habitat provision for biodiversity, soil erosion, and carbon management.

As an educational tool, PE/WI has enormous flexibility. Initial use with students in age groups from middle through graduate school covered multiple, diverse learning objectives. PE/WI enhances lessons involving discussion of ecological principles; economic valuation of ecosystem services outputs and discussion of payments for ecosystem services; consideration of tradeoffs and societal constraints to land-use change; and design of landscape scenarios to meet assigned goals. In initial uses, I have seen PE/WI's ability to fundamentally alter people's frameworks for land use and management.

Beyond classrooms, I see an enormous future potential for PE/WI to help people understand how commodities might be co-produced with other ecosystem services; develop shared understanding of watershed processes; foster multi-stakeholder, watershed-scale decisions; and develop strategies to mitigate economic and social risks associated with climate change, biodiversity loss, and natural resource impairment. PE/WI combines the best available science with an appealing, interactive platform that I hope will engage groups such as students, farmers, and policy makers in the US Corn Belt and beyond.

CHAPTER 1

GENERAL INTRODUCTION

Educational modeling in agricultural and environmental sciences provides students and decision makers access to the scientific knowledge needed to address local and global challenges that affect human wellbeing. As individuals and societies consider issues wrought with complexity, uncertainty, and societal urgency, researchers including Biggs et al. (2010) have called for "new ways of thinking" that "reframe the relationship between science and decision making" (p. 267).

Beginning in 2004, a team of researchers at Iowa State University, with funding support from the US Forest Service Northern Research Station, developed a Microsoft Excel-based educational modeling tool, People in Ecosystems/Watershed Integration, version 1 (PE/WI or PE/WI v1), to teach complex tradeoffs among ecosystem services in agricultural landscapes (Schulte, Donahey, Gran, Isenhart, & Tyndall, 2010). The tool, primarily used in university instruction, alters the learning environment by using visualizations to simplify complex relationships between land uses and ecosystem services. PE/WI's ecological modeling framework encourages new ways of scientific thinking. Users take on decision-making roles through personalized scenario creation, and scenario outcomes allow users to qualitatively and quantitatively consider land-use tradeoffs among ecosystem services. Outside of a PE/WI type model, evaluations of land-use tradeoffs tend to be complex abstractions (de Groot, Alkemade, Braat, Hein, & Willemen, 2010).

While the initial spreadsheet-based PE/WI filled a critical niche in educational modeling within environmental and agricultural contexts (Schulte et al., 2010), the PE/WI research team identified several opportunities to re-evaluate and expand the PE/WI science model, add new components, and improve the user interface. Starting in 2013 with funding support from The McKnight Foundation, work began on People in Ecosystems/Watershed Integration, version 2 (PE/WI or PE/WI v2). We developed PE/WI v2 as an open source, web-based application using current web technologies with front-end (client-side) programming in JavaScript. I served on the team as graduate researcher and project manager. Other collaborators included seven consulting faculty members, three computer programmers, and a graphic designer.

We developed the PE/WI v2 model through a rigorous process of synthesizing the best available scientific research and conducting expert model reviews by scientists spanning multiple disciplines. Throughout development of the model, we emphasized simplification of inputs and modeling with a preservation of the complex relationships (Garcia-Barrios, Speelman, & Pimm, 2008; Long et al., 2014). To reach a broader user group beyond academic and research professionals, we synthesized existing research on watershed land use, dynamics, and outcomes—often too complex and detailed for general user groups—into an interactive, dynamic model that teaches concepts through user experimentation and comparison of results.

Creating a tool that integrates the science on agricultural production and social-ecological processes is not enough to reach the broader public. To encourage user adoption, we created a tool without burdensome user-supplied knowledge or data requirements. Motivating users to adopt and use an educational tool also requires that the tool be engaging, fun, simple, accessible, reliable and computationally accurate. PE/WI v2 incorporates this dual approach to transforming knowledge of land-use impacts.

User perspective and feedback played an important role in PE/WI's development. Upon release of the new version in beta, we encouraged educators and students using PE/WI v2 in classrooms at several universities nation-wide to provide suggestions for improvement. They found the web-based user interface appealing and fun, with attractive graphic illustrations, interactive features, and user-designated layouts. They also identified opportunities to enhance PE/WI's model and design. For example, one user suggested adding the ability to save and share land-use designs in PE/WI. We implemented this feature, which benefits students working in groups and allows teachers to collect land-use design data sets as part of the assignment. We received numerous additional ideas, which we anticipate developing in future versions of the tool.

In summary, the new version of PE/WI addresses critical needs for educational modeling of ecosystem services from landscapes. I see PE/WI v2 as a stepping stone to many future versions or adaptations of the tool. While we base the current PE/WI in an Iowa agricultural landscape, future possibilities for the tool's content and model components are numerous and, for example, could include a montane forest landscape in Colorado, a tropical forest landscape in Indonesia, a costal landscape in Belize, or an urban landscape in Europe. With its open source development platform and simple modeling approach, I envision collaboration from researchers, students, practitioners, and other stakeholders with a wide range of backgrounds and interests.

The remainder of this chapter outlines the organization of this thesis. Chapter 2, entitled "People in Ecosystems/Watershed Integration: Visualizing ecosystem services tradeoffs in an agricultural landscape," begins with an in-depth discussion of ecosystem services frameworks, ecological modeling, and technology-based educational tools. The main focus of Chapter 2 details the four components of the PE/WI tool including:

- DATA: Land-use configurations, pre-defined physiographic characteristics, and climate conditions of the watershed;
- CONTROLS: User controls for design of land-use configuration, download and upload of land-use configurations, review of selected pre-defined physiographic characteristics, review and modification of climate conditions, and evaluation of outcomes;
- OUTCOMES: Interactive graphic, spatial mapping, and numerical results; and

- MODULES: Model calculations using pre-defined physiographic characteristics data, published or expert-reviewed model parameters, and land-use configurations as inputs to produce outcomes data.

Chapter 3, entitled "People in Ecosystems/Watershed Integration: A web-based learning tool for evaluating ecosystem services tradeoffs from watersheds" updates publication of the first PE/WI model in 2010 in the *Journal of Soil and Water Conservation* (Schulte et al., 2010). As an outreach paper with an intended audience of conservation-oriented researchers and practitioners, Chapter 3 reviews the historical challenges of managing agricultural ecosystems for multiple services, overviews updates to the new PE/WI model, and presents a learning exercise with example land-use scenarios and discussion of ecosystem service outcomes in PE/WI. Chapter 4 provides a general conclusion.

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CHAPTER 2

PEOPLE IN ECOSYSTEMS/WATERSHED INTEGRATION: VISUALIZING ECOSYSTEM SERVICES TRADEOFFS IN AGRICULTURAL LANDSCAPES

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Carrie M. Chennault, Lisa A. Schulte, and John C. Tyndall

2.1 Introduction

The percentage of Earth's human-dominated ecosystems continues to increase and disrupt natural ecosystem function even while common metrics of human wellbeing rise at the global scale (Daily, 1999; Mendenhall, Karp, Meyer, Hadly, & Daily, 2014; Raudsepp-Hearne et al., 2010). This environmentalist's paradox persists with increased food production enhancing human wellbeing, although at more local scales the costs of ecosystem degradation can exceed benefits (Raudsepp-Hearne et al., 2010). To resolve this apparent paradox and enhance human wellbeing, Raudsepp-Hearne et al. (2010) and others suggest directing research to more fully elucidate human dependence on ecosystems.

Identifying, designing, and improving public understanding of multifunctional landscapes across spatial and temporal scales is a critical strategy for sustainable ecosystem management on a "crowded planet" (Lovell & Johnston, 2009b; Palmer et al., 2004). With a focus on terrestrial ecosystems, Wu (2013) proposed that landscapes or regions, which he defined as "multiple ecosystems over a watershed or a geopolitically-defined area" (p. 1000), are the operational scale at which humans can interact with nature to improve ecosystem functioning, provision of multiple ecosystem services, and human wellbeing. Landscape ecology as a discipline has advanced understanding of the impacts of landscape pattern on biodiversity and ecological processes, and therefore on ecosystem services and human wellbeing (Lovell & Johnston, 2009a, 2009b; Wu, 2013).

While opportunity exists to broaden land-management decision criteria to include a suite of economic, environmental, and social factors, our experience with land managers, students, policy makers, and agricultural and natural resource professionals indicates that people in general do not fully or accurately understand the link between land use and multiple ecosystem service outcomes. By combining the best available research with a simple, accessible modeling approach, we argue that ecological modeling provides an effective mechanism for exploration and communication of landscape-scale ecosystem services tradeoffs.

We present a model for an educational watershed simulation tool that allows users to design alternative land-use configurations and evaluate tradeoffs in ecosystem service indicator outcomes. People in Ecosystems/Watershed Integration, version 2 (PE/WI or PE/WI v2) accomplishes our educational objectives by making more transparent the complex relationships between land use and land-use outcomes, without requiring a high level of user-supplied knowledge and information common to more advanced decision-making tools. Members of our team led the development of an initial Microsoft Office Excel-based version of PE/WI v1 (Schulte, Donahey, Gran, Isenhart, & Tyndall, 2010). PE/WI v2 updates included migration to a more user-friendly, web-based format, an expanded watershed area, additional land-use options, varying climate conditions, a temporal component, expanded model components, an expanded set of ecosystem service indicators, improved graphics, and enhanced interaction with watershed tools and indicator outputs.

PE/WI works through user manipulation of land use across 593 grid cells in a 2,383 hectare watershed across three years of play (Figure 2-1). Based on spatial-temporal designs of land use and random interannual climate variability, the PE/WI model calculates levels of 16 ecosystem service indicators. We report ecosystem services indicators in PE/WI that include both well-known, short-term measures of land-use productivity and indicators of environmental benefits associated with both shorter-term and longer-term ecological processes. Ecosystem services indicators in PE/WI are intermediate services needed to produce “final” services enjoyed by humans (Ringold, Boyd, Landers, & Weber, 2013), though PE/WI does not report “final” services. Beneficiaries of ecosystem services directly experience “final” services as specific private and public outcomes (Kroeger & Casey, 2007). As in real life, the PE/WI decision maker determines the perceived value of outcomes based on social mores and individual motivations, and similarly may determine the best land-use configuration to achieve desired outcomes.

We designed PE/WI and its model in an agricultural ecosystem context to create a tool with direct relevance to agriculture and natural resource students at Iowa State University, as well as to decision makers in the US Corn Belt region.

However, PE/WI's model, its conceptual framework, and its general relationships between land use and ecosystem services teach lessons that apply more broadly to other ecosystem and landscape management contexts. Thus, US Corn Belt agriculture is one case of land use, and PE/WI has transformative potential for landscapes well beyond the Midwest region. PE/WI has the potential to impact short-term land-use transformation among decision makers who value co-production of economic goods and environmental services, but previously lacked information regarding how to implement co-production on the landscape. The potential for long-term land-use transformation lies in the feedback effect of broadened information and understanding of ecosystem services on individual and societal values and constraints.

In the sections below we elaborate on the history of the US Corn Belt landscape, connecting historical and potential land use in the region with relationships between social-ecological science and society. We also discuss the role of educational tools in addressing current and future land-use challenges.

2.1.1 Multifunctional Land Use and Tradeoffs in Social-Ecological Systems

Land use is a human manifestation complicated by social, economic, and environmental pressures and constraints. It influences and is influenced by individual and societal values, assumptions, knowledge, and evaluation criteria (Costanza et al., 2014; Janssen, 2013; Sorice, Kreuter, Wilcox, & Fox, 2014). Land use generally reflects individual and collective human decisions and represents a choice among alternative options, though members of society do not equally share in the ability to influence or design land use (Jackson, 2008).

The landscape design in the Midwest Corn Belt region of the United States provides ecosystem services in the form of fuel, feed, food, and fiber from row crop agriculture. Emphasis on short-term individual economic gains and cultural norms developed over generations of intensive, row-crop production have led to the region's large-scale corn and soybean monocultures. Alternative land use and practices outside of corn and soybean production have not gained significant momentum because, as Jackson (2008) noted, "the current economic structure of our food system will not permit farmers to use it" (p. 32).

While a corn and soybean production system provides high levels of a small number of provisioning ecosystem services, commodity production externalizes high real and opportunity costs to producers and society. As Tallis and Polasky (2009) noted: "a single sector approach that ignores the multitude of connections among components of natural and social systems generally fails to provide as high a value to society…as would management that accounted for the complete range of services" (p. 266). To account for the full value of ecosystems, researchers have developed alternative approaches to evaluate broader sustainability criteria by taking monetary and nonmonetary factors, both in the present and future, into account (Power, 2010). These criteria may include economic productivity, ecosystem resilience, and human adaptability.

Multifunctional agriculture has the potential to achieve numerous ecosystem service benefits in addition or as alternatives to short-term maximization of commodity products (Boody et al., 2005). In practice, challenges in accounting for the costs and benefits of multifunctional agriculture have deterred its adoption on the landscape (Swinton, Lupi, Robertson, & Hamilton, 2007). For example, short-term, private outcomes often are directly visible, whereas longer-term, more broadly distributed benefits and costs may be less well-known or less certain to the decision maker. Robertson et al. (2014) noted that farmers are more likely to provide environmental services that are direct and local, and found that farmers perceive provision of widespread benefits as unfairly "shouldering a perceived public burden" (p. 8). Provision of ecosystem services therefore depends on the local importance of a particular service or on payments for those services. Transitioning to multifunctional agricultural systems also depends on the objectives that decision makers adopt, as well as their understanding of multiple spatially and temporally-driven outcomes.

Applying social science frameworks, such as the reasoned action approach (Fishbein & Ajzen, 2011), to ecosystem services suggests that decision-making models and tools have the potential to alter land-use patterns to the extent that new information better equips decision makers to meet current objectives or guides formation of new objectives. Conversely, dynamic social-ecological systems can place external pressure on decision makers to shift production of ecosystem services. The shift in production may create additional demand for ecosystem services tools and alter land-use patterns.

Yet, how these factors will affect the landscape is uncertain. Complex interrelationships exist among decision-maker objectives due to technological changes, ecosystem dynamics, social mores, individual motivations, economic and political factors, and understanding of associations between land-use decisions and ecosystem service outcomes. Efforts to steer land-use on an environmentally sustainable trajectory depend on social action (Daily, 1999). Part of that social challenge is communicating the existing science that supports a correct understanding of associations between land-use decisions and outcomes. Communicating science to decision makers and the public entails synthesizing research from multiple disciplines to inform complex land-use and land-management decisions in agricultural systems (Coiner, Wu, & Polasky, 2001).

An ecosystem services framework can serve as a starting point to communicate how changes in land use and agroecosystem management produce changes in the types and levels of services that benefit humans. To illustrate flows of ecosystem services and disservices in and out of agricultural ecosystems, Zhang, Ricketts, Kremen, Carney, and Swinton (2007) illustrated flows of ecosystem services and disservices in and out of agricultural ecosystems, which we adapted to show how the PE/WI model fits within such a framework (Figure 2-2).

Changes in land use, for example, may entail tradeoffs in short-term production of commodity grain crops and associated revenue by taking land out of production to install conservation practices (Robertson et al., 2014). Strategic placement of alternative land uses and conservation best management practices (BMPs), however, may replace decreases in provisioning services with increases in other ecosystem services. The Iowa Nutrient Reduction Strategy (NRS) (Iowa, 2013) quantified these types of ecosystem services tradeoffs for the state of Iowa. Their analyses compared the effects of BMPs such as in-field nutrient management, edge-of-field and erosion control practices, and land-use changes in terms of decreases in provisioning services, namely lost corn and soybean production, and increases in other ecosystem service indicators, namely nitrogen and phosphorus loads in surface waters.

Connecting theory to practice, designers of alternative agricultural system approaches aim to produce multiple ecosystem services. Various approaches describe their operations and practices as sustainable, multifunctional, agroecological, organic, or diversified (Boody et al., 2005; Kremen & Miles, 2012). However, few information and evaluation tools exist for producers to explicitly incorporate ecosystem services frameworks like the one presented by Zhang et al. (2007) into management decisions. The PE/WI setup enables users to simulate a range of real-world land-management options, including conventional practices, conservation practices, and alternative land uses. Users may implement spatially and temporally driven strategies by designing configurations of various land-use types—each associated with specific management practices—and rotating land-use types across multiple years of play. Each strategy and management option uniquely impacts ecosystem function. By evaluating ecosystem service indicators, users then may compare how well each strategy across different climate scenarios accomplishes their desired objectives.

Research studies and tools to date have typically focused on a small number of ecosystem services (Power, 2010). Researchers, including Power, have called for spatially and temporally explicit frameworks that cover a wider range of ecosystem service outputs. We developed PE/WI as a tool to bridge the informational gap between land-use design and ecosystem services outcomes, designed to be accessible to land managers, producers, students, and the general public without guidance from an expert modeler.

2.2 Materials and Methods

The PE/WI watershed is static in its physiographic properties, but interactive and variable in terms of climate and land use. The tool provides an interface for users to visualize five of the pre-defined physiographic characteristics of the watershed and configure land use—15 land-use types—across each cell grid location in the watershed annually across three years. Land-use selection, in conjunction with pre-defined physiographic characteristics and annual average climate conditions, serve as inputs for modeling ecosystem services outputs.

PE/WI presents outputs both to users both as biophysical ecosystem service indicator numerical values and converted to a unitless index score ranging between 0 and 100. Users may compare index scores for all outputs across three years through an interactive graphic plot. Additionally users may evaluate outputs maps to identify source areas for three ecosystem service indicators across each year and review numerical results that include area in each land-use type, annual precipitation levels, and number of utilized strategic wetlands.

2.2.1 Model Specification

PE/WI users directly or indirectly interact with the four components of the PE/WI tool:

- DATA: Land-use configurations, pre-defined physiographic characteristics, and climate conditions of the watershed;
- CONTROLS: User controls for design of land-use configuration, download and upload of land-use configurations, review of selected pre-defined physiographic characteristics, review and modification of climate conditions, and evaluation of outcomes;
- OUTCOMES: Interactive graphic, spatial mapping, and numerical results;
- MODULES: Model calculations using pre-defined physiographic characteristics data, published or expert-reviewed model parameters, and land-use configurations as inputs to produce outcomes data.

The following sections specify the PE/WI model according to its data, controls, outcomes, and modules. The Modules section presents the core science model.

2.2.2 Data

The first component of PE/WI is data, which consists of inputs into the PE/WI model. The PE/WI watershed is a fictitious watershed based on two Iowa landform regions, the Des Moines Lobe and the Southern Iowa Drift Plain (Prior, 1991). Rather than use an actual watershed for PE/WI, we created a fictitious watershed to 1) provide users unique land-use and management challenges from multiple regions, and 2) encourage use of PE/WI as a general educational tool to inform decision making, rather than use as a location-specific decision tool. However, PE/WI makes extensive use of real-world data. The PE/WI watershed—which we represented spatially in the application as a collection of 593 grid cells configured around a vector-graphic stream to approximate a 2,383 hectare watershed—pulls in data from the Iowa Soil Properties and Interpretations Database (ISPAID) (Iowa State University, 2010). Each grid cell has an area of approximately 4 ha, though we reduced the land area for grid cells containing portions of the stream (Table 2-1). We nested each grid cell within one of 20 subwatersheds, which are nested in the PE/WI watershed (Table 2-1). We additionally mapped each grid cell to a specific soil map series, and its associated data set, from one of two Iowa counties—Boone County in the Des Moines Lobe and Jasper County in the Southern Iowa Drift Plain.

When users open the PE/WI application, they see a watershed map loaded with a pre-defined initial land-use data set to represent Year 0 land-use configuration. We created a generic land-use data set for Year 0 with land-use options available in PE/WI. However, the initial land-use data set does not represent a realistic or intentional land-use configuration, nor does it impact temporally-driven ecosystem service indicator outcomes. We deliberately chose an arbitrary configuration to emphasize user imagination in creating PE/WI scenarios. Because PE/WI results in a given year depend on prior year precipitation, we pre-defined climate conditions for Year 0 to use as model inputs. Upon starting PE/WI, the program randomly assigns annual climate conditions based upon historical annual precipitation data from Iowa to simulate climate variability across years. The PE/WI model consists of seven annual precipitation levels, occurring with varying frequency (Table 2-1).

By interacting with PE/WI controls to change land-use types, users start their designs for Year 1, followed by Years 2 and 3. This creates a land-use data set that users may download, save, share, and later re-upload in PE/WI. PE/WI contains 15 land-use types (Table 2-3).

Either initially, during, or after creating land-use designs, users may evaluate maps of important watershed physiographic characteristics and take climate information into consideration in order to direct land-use decisions for production of desired ecosystem services. The pre-defined physiographic characteristics data visible to users in PE/WI include topographic relief (Table 2-4), flood frequency, and drainage class data for each soil map series from ISPAID (Iowa State University, 2010); as well as realistically-delineated subwatershed boundaries and strategic wetland location data. Additional physiographic characteristics from ISPAID serving as model inputs include corn suitability rating (an index rating soil type suitability for row-crop production); yields for corn, soybean, and alfalfa-brome; slope range; hydrologic group; soil texture (surface horizon); subsoil group (B horizon only); permeability; and an erodibility factor (Kw).

2.2.3 Controls

Controls in PE/WI include a design control to interactively create land-use configurations on the virtual watershed and multiple display controls to evaluate input and outcome data. Through the design control, users may click any of the land-use icons to activate their computer input device (typically a mouse, stylus, or touchpad finger contact) as one of 15 land-use and land-management options. Navigating on the screen to individual cell grids and using a point, click, and drag sequence, each selected cell grid takes on the active land use. Next, users navigate to different years to create future land-use designs, which they access by clicking on Year tabs labeled “1,” “2”, and “3.”

The display controls provide informational functionality, allowing users to navigate to maps of physiographic characteristics by clicking on the “Physical Features” icons, and view PE/WI outcomes by clicking on the “Scores,” “Maps,” and “Results” tabs.

We created two additional controls to enhance usability, especially in classroom or group settings: a download and upload control to save, re-upload and/or share land-use data sets, and a hidden control—accessed by a keyboard short-cut “Control + p”—to set precipitation levels rather than use random climate conditions.

2.2.4 Outcomes

Inputs to the PE/WI model—land-use types, physical features, and climate—interact through the model to produce outcomes for users to evaluate. PE/WI presents its outcomes as interactive graphic, spatial mapping, and numerical summary results. Specifically, PE/WI displays interactive graphic results as a plot of 16 unitless index scores for all three years, in which 0 indicates the lowest attainable score in PE/WI and 100 indicates the highest attainable score in PE/WI (Figure 2-3). The 16 outcomes consist of nine crop and livestock production indices, three water quality indices, one soil quality index, one greenhouse gas index, one game wildlife habitat index, and one biodiversity index. The conversion of each model output to an index allows users to compare relative performance among ecosystem service indicators and assess tradeoffs across multiple years or previous designs. We adapted a Data Driven Documents (D3) (Bostock, Ogievetsky, & Heer, 2011) open source template to create the interactive index plot, which allows users to highlight their ecosystem service indicators of interest.

PE/WI additionally provides spatial mapping of three ecosystem service indicators: nitrate watershed percent contribution (Figure 2-4), gross erosion, and phosphorus index risk assessment. In the nitrate watershed percent contribution example (Figure 2-4), the upper left subwatershed contributes most heavily to nitrate-N concentration levels in the first year. In subsequent years, the nitrate percent contribution becomes more even across all watersheds. Although this map does not indicate whether overall nitrate-N concentration is low or high relative to some standard, spatial mapping of percent contribution indicates locations for users to target land-use changes to lower concentration overall. The other two maps—gross erosion and phosphorus index risk—show absolute levels of erosion and P-index for each grid cell in the watershed. Similar to the nitrate contribution map, these two ecosystem service indicators maps enable users to identify and target areas for improvement in the watershed.

Finally, PE/WI presents users with numerical summary results for all three years. These results include annual area and percent area of the PE/WI watershed in each land-use type; annual value for each ecosystem service indicator; annual index score for each ecosystem service indicator; annual number of strategic wetland areas in a wetland land-use type; and annual precipitation. Area, ecosystem service indicator values, and annual precipitation appear in metric and English units.

2.2.5 Modules

PE/WI models ecosystem and supporting services through seven modules: biodiversity, game wildlife, carbon sequestration, nitrate concentration, phosphorus loading, sediment delivered, and yield. These seven categories further break down into 16 ecosystem service indicators reported as outcomes to users.

Biodiversity

The biodiversity model in PE/WI presents a relative measure indicating how well a landscape pattern maintains habitat suitability at the watershed scale for native species (Fischer, Lindenmayer, & Manning, 2006), based upon landscape configuration and composition (Fahrig et al., 2011). We developed the biodiversity model to reflect habitat suitability for a suite of native species, with emphasis on native bird species due to the relatively greater scientific understanding of this taxon compared to others.

The importance of biodiversity on the landscape scale is important to humans because, according to Robertson et al. (2014), it “affects the capacity of agriculture to deliver ecosystem services, especially those related to biocontrol and water quality”(p. 4). To provide one example of how biodiversity supports ecosystem services, research and experimentation conducted by Costamagna and Landis (2006) at the Kellogg Biological Station Long Term Ecological Research site shows the importance of ladybird beetles in controlling soybean aphids, which in turn reduces the risk of decreased crop production. Details for each component of the biodiversity calculation follow.

PE/WI users receive between 0 and 10 biodiversity points annually, with 10 indicating a PE/WI landscape that best maintains habitat quality. The biodiversity score breaks down into five calculations with associated rules to form a point system (Table 2-5). The landscape composition component calculates the percent area of native vegetation land-use types and land-use types with high diversity and low input relative to conventionally row-cropped systems. Calculations of landscape composition and configuration include stream buffering and wetland percent area and strategic location. Together, the biodiversity score calculations account for the effects of land-use type, land management, and landscape pattern on native species habitat (Fischer et al., 2006).

PE/WI also provides users with an index to evaluate all indicators on a relative basis. To assign an index score for biodiversity, PE/WI converts biodiversity points to the index score on a straight-line basis with scores ranging between 0, the lowest score attainable in PE/WI, and 100, highest score attainable in PE/WI. For example, 5.5 biodiversity points in PE/WI equals an index score of 55 out of 100.

The first biodiversity calculation in PE/WI considers landscape composition of native vegetation. Fischer, Lindenmayer, and Manning (2006) presented 10 guiding principles for biodiversity in agricultural landscapes. They concluded that placing large areas into native vegetation "tends to support higher biodiversity than structurally simple or degraded vegetation" (p. 81). More recently, ecologists studying biodiversity in suburban and rural landscapes have developed and tested countryside biogeography frameworks that predict the ability of agricultural landscapes to support biodiversity, if managed appropriately for habitat and if species have access to proximate reserve areas of native vegetation such as forests (Mendenhall et al., 2014). We classified three land-use types offered in the PE/WI model as structurally complex, native vegetation: conservation forest, prairie, and wetland. Users receive between 0 and 4 biodiversity points based on the amount of the watershed in native vegetation (Table 2-5).

Fischer, Lindenmayer, and Manning's (2006) principles noted that "a matrix that has a similar vegetation structure to patches of native vegetation (i.e. that has a low contrast) will supply numerous benefits to ecosystem functioning"(p. 81). Additionally, non-native perennial land uses may provide habitat for different species, particularly when, as Fahrig et al. (2011) described, "production areas have structural similarities to extant natural areas in the same landscape" (p. 107). Accordingly, in addition to native vegetation, we allocated biodiversity points to agricultural land-uses that better support wildlife richness and abundance compared to conventionally row-cropped systems. To conceptualize our model, we adapted to PE/WI a framework that categorizes suitability of agricultural bioenergy landscapes to support wildlife richness and abundance according to two gradients: levels of agricultural inputs and plant diversity (Schulte, Ontl, & Larsen, 2013), (Figure 2-5). Like Schulte et al. (2013), we categorized land use as supporting low or high diversity and as using low or high inputs. Additionally, we designed the PE/WI biodiversity model to award points for each land use with high-diversity and/or low-input land uses relative to a conventional row-cropped system. The point system has a hierarchical structure that awards greater overall points to land-use types that incorporate relatively higher diversity and lower inputs.

The second biodiversity calculation considers the percent area in all three native vegetation land uses and three high-diversity land uses. We included the three land-use types in the first biodiversity calculation as native vegetation, and three additional land-use types offered in the PE/WI model as high-diversity: conventional forest; mixed fruit and vegetables; and rotational grazing. Users receive between 0 and 1.5 biodiversity points for this calculation (Table 2-5).

The third biodiversity calculation considers the percent area in all three native vegetation land uses; three high-diversity land uses; three low-diversity, high input land uses; and three low diversity, low-input land uses. Native vegetation and high-diversity land uses are identical to land uses from the first and second biodiversity calculations. The addition of three low-diversity, high-input land uses and three low diversity, low-input land uses represent land-use types that are not as beneficial as any of the six land-use types in the second calculation. Nevertheless, these land-use types rank higher in the matrix than conventional row-cropped systems (Figure 2-5). The additional low-diversity, high-input land uses include: conservation corn, conservation soybean, and permanent pasture. We selected conservation corn and conservation soybean for inclusion in this category because we defined management practices for conservation row crops to include winter cover crops, no-till, and grassed waterways, and/or buffers. Low diversity, low-input land uses include: grass hay, herbaceous perennial bioenergy, and short-rotation woody bioenergy. Users receive between 0 and 1.5 biodiversity points for this calculation (Table 2-5).

The fourth biodiversity calculation in PE/WI subdivides into two calculations: percent area in wetland and strategic placement of wetlands. Wetlands provide invertebrate and amphibian habitat, with prairie pothole wetlands being especially important for birds (Best, Freemark, Dinsmore, & Camp, 1995; M. L. Hunter, 2005). Users receive between 0 and 1.5 biodiversity points for wetlands (Table 2-5).

The fifth biodiversity calculation in PE/WI is percent of buffered stream. Based on Fischer, Lindenmayer, and Manning's (2006) principle that stream buffers protect sensitive aquatic ecosystems and that corridors connect patches of native vegetation, users receive between 0 and 1.5 additional biodiversity points based upon the percent of stream-adjacent cells placed in one or more land uses that function as a stream buffer and corridor for native species (Table 2-5). Streams and riparian areas provide habitat for diverse and abundant wildlife, and land managers can use strips of vegetation in these zones to protect against agricultural runoff and conserve these sensitive ecosystems (M. L. Hunter, 2005). To receive points for buffering, users must create stream buffers using the following land-use types: conservation corn, conservation forest, conservation soybean, conventional forest, grass hay, herbaceous perennial bioenergy, mixed fruit and vegetables, prairie, rotational grazing, short-rotation woody bioenergy, and wetland. We assume conservation corn and conservation soybean best management practices include stream buffering.

<u>Game Wildlife</u>

The game wildlife model in PE/WI, similar to the biodiversity model, presents a relative measure indicating how well a landscape pattern maintains habitat quality for game species (Fischer et al., 2006) based upon landscape configuration and composition (Fahrig et al., 2011). Game species include deer, ducks, turkey, pheasant, quail, and sport fish. Users receive between 0 and 10 game wildlife points annually, with 10 indicating a PE/WI landscape that best maintains game habitat quality. Although the game wildlife index is similar to the biodiversity index, we adjusted it to reflect less sensitivity to need for natural habitats and greater need to reach a minimum threshold area for land-use types that support each game species. The game wildlife score breaks down into six calculations (Table 2-6). The first two calculations consider the percent area of native vegetation land-use types and land-use types with high diversity and low input relative to conventionally row-cropped systems. The remaining calculations consider the percent area in conservation forest, grassland, and wetland, as well as the percent of stream buffered. Together, the game wildlife score calculations account for the effects of land-use type, land management, and landscape pattern on native species habitat (Fischer et al., 2006).

PE/WI also provides users with an index to evaluate all indicators on a relative basis. To create an index score for game wildlife, PE/WI converts game wildlife points to the index score on a straight-line basis with scores ranging between 0, the lowest score attainable in PE/WI, and 100, highest score attainable in PE/WI. For example, 5.5 game wildlife points in PE/WI equals an index score of 55 out of 100.

Similar to biodiversity calculations, we considered land-use type suitability for game wildlife habitat along two gradients: agricultural inputs and level of plant diversity (Schulte et al., 2013), (Figure 2-5).

The first game wildlife calculation considers the percent area in all three native vegetation land uses and three high-diversity land uses. We classified the three land-use types as native vegetation: conservation forest, prairie, and wetland, and three additional land-use types offered in the PE/WI model as high diversity: conventional forest; mixed fruit and vegetables; and rotational grazing. Users receive between 0 and 4.0 game wildlife points for this calculation (Table 2-6).

The second game wildlife calculation considers the percent area in all three native vegetation land uses; three high-diversity land uses; three low-diversity, high input land uses; and three low diversity, low-input land uses. Native vegetation and high-diversity land uses are identical to land uses from the first game wildlife calculation. The addition of three low-diversity, high-input land uses and three low diversity, low-input land uses represent land-use types that are not as beneficial as any of the six land-use types in the first calculation. Nevertheless, these land-use types rank higher in the matrix than conventional row-cropped systems (Figure 2-5). The additional low-diversity, high-input land uses include: conservation corn, conservation soybean, and permanent pasture. We selected conservation corn and conservation soybean for inclusion in this category because we defined management practices for conservation row crops to include winter cover crops, no-till, and grassed waterways, and/or buffers. Low diversity, low-input land uses include: grass hay, herbaceous perennial bioenergy, and short-rotation woody bioenergy. Users receive between 0 and 1.5 game wildlife points for this calculation (Table 2-6).

The third game wildlife calculation in PE/WI is percent area in conservation forest. Forests provide important habitat for game wildlife, including nesting birds (Best et al., 1995; M. L. Hunter, Jr. & Schmiegelow, 2010). Incorporating at least some forest into an agricultural landscape supports game wildlife including northern bobwhite quail, wild turkey, and white-tailed deer (Brennan, 1999; McRoberts, Wallace, & Eaton, 2014). Users receive between 0 and 1 game wildlife points; more specifically, a user receives 1.0 point when placing at least five percent of the watershed in conservation forest (Figure 2-6).

The fourth game wildlife calculation in PE/WI is percent area in grassland. Incorporating at least some grassland into an agricultural landscape supports game wildlife including northern bobwhite quail and ring-necked pheasant (Brennan, 1999; Giudice & Ratti, 2001). Users receive between 0 and 1 game wildlife points; more specifically, a user receives 1.0 point when placing at least five percent of the watershed in a combination of herbaceous perennial bioenergy, prairie, and/or rotational grazing (Table 2-6).

The fifth game wildlife calculation in PE/WI is percent area in wetland. Prairie pothole wetlands are important for birds, especially water nesting bird species (Best et al., 1995; M. L. Hunter, 2005). Incorporating at least some wetland into an agricultural landscape supports game wildlife such as mallards (Drilling, Titman, & Mckinney, 2002). Margins of wetlands also provide good winter habitat for ring-necked pheasants (Giudice & Ratti, 2001). Users receive between 0 and 1 game wildlife points; more specifically, a user receives 1.0 point when placing at least five percent of the watershed in wetland (Table 2-6).

The sixth game wildlife calculation in PE/WI is percent of buffered stream, and users receive between 0 and 1.5 game wildlife points (Table 2-6), based on Fischer, Lindenmayer, and Manning's (2006) principle that stream buffers protect sensitive aquatic ecosystems and that corridors connect patches of native vegetation. To receive points for stream buffering, users must create stream buffers using the following land-use types: conservation corn, conservation forest, conservation soybean, conventional forest, prairie, rotational grazing, and wetland. We assume conservation corn and conservation soybean best management practices include stream buffering.

Carbon

Soil carbon sequestration serves as a potential strategy to offset atmospheric carbon dioxide (CO_2) emissions linked to climate change (Fissore, Espeleta, Nater, Hobbie, & Reich, 2010). Soil carbon sequestration can play an especially important role in mitigating emissions because incremental changes in land-management practices are inexpensive and easily adoptable/adaptable compared to other climate mitigation technologies (W. M. Post et al., 2004). The vulnerability of agriculture to climate change—decreased production resulting from extreme weather events, climate shifts, increased risks of soil erosion, and reduced soil fertility—makes adoption of mitigation and adaptation strategies important both to local producers in the US Corn Belt and to global producers and consumers (J. G. Arbuckle, Jr., Morton, & Hobbs, 2013).

While agricultural activities primarily generate greenhouse gases such as nitrous oxide (N_2O) and methane (CH_4) (US EPA, 2014) that would provide important ecosystem disservice indicators to PE/WI users, we did not include these parameters in PE/WI v2. We instead selected soil carbon sequestration for its potential for landscape-scale mitigation. As Fissore et al. (2010) noted, "Because cultivated agricultural lands are often C-depleted, they have the potential to sequester C when converted to other land-cover types that positively affect their net C balance" (p. 410). Other considerations for selecting a carbon model included potential for increasing participation of land owners and managers in carbon credit markets (Jiang & Koo, 2014), and potential irreversibility of climate change due to carbon dioxide's especially long falloff time after anthropogenic emissions have ceased (Solomon, Plattner, Knutti, & Friedlingstein, 2009). As future research findings further our understanding of biological sources and sinks of nitrous oxide and methane, and carbon equivalent conversion mechanisms gain acceptance in carbon credit markets, the potential will exist to expand the PE/WI carbon model to a more general greenhouse gas model.

Currently, the carbon model in PE/WI presents a measure of potential sequestered carbon resulting from vegetation conversion of an annual conventional row-crop land use to alternative land-use or land-management practices. A meta-analysis conducted by Fissore et al. (2010) summarized available empirical data on carbon sequestration rates to obtain mean "C sequestration rates in plant biomass and soil for alternative land-use/land-cover changes" (Supplemental Information, WebPanel 1). These summary figures serve as the primary source for PE/WI carbon model calculations (Table 2-7). Because the Fissore et al. (2010) meta-analysis did not provide results specific to two PE/WI land-use types—alfalfa and herbaceous perennial bioenergy crops—we based calculations for those land-use types on empirical data from Iowa (Al-Kaisi, Yin, & Licht, 2005), (Table 2-7).

The PE/WI model for annual carbon sequestration, C, of the watershed equals the sum, as land-use type i goes from 1 to n, of the product of land-use type area, A, and sequestration rate. We based sequestration rates on Fissore et al. (2010) and Al-Kaisi, Yin, and Licht (2005), (Table 2-7). Additionally, PE/WI reports an index score between 0 and 100 that indicates how well a given watershed performs relative to both the lowest amount of annual carbon sequestration attainable in PE/WI, indexed to 0, and the highest amount of annual carbon sequestration attainable in PE/WI, indexed to 100. PE/WI calculates the index score on a straight-line basis.

To illustrate carbon tradeoffs, the highest carbon sequestration attainable in PE/WI equals 11,176.7 Mg yr^{-1} and occurs in a scenario of 100% area in short-rotation woody bioenergy at a rate of 4.69 Mg ha^{-1} yr^{-1}. The lowest carbon sequestration attainable in PE/WI equals 0.0 Mg yr^{-1} and occurs in a scenario of 100% area in a combination of conventional corn, conventional soybean, and/or mixed fruit and vegetables at a rate of 0.0 Mg ha^{-1} yr^{-1}. If a user places 75% of the area, 1788.5 ha, in conservation corn and the 25%, 594.6 ha, in rotational grazing, the following calculation computes total carbon sequestration for the year, equal to 887.8 Mg yr^{-1}.

$$C = \sum_{i=1}^{n} A * r$$

$$= 594.6\ ha * 0.40\ Mg\ ha^{-1} yr^{-1} + 1788.5\ ha * 0.29\ Mg\ ha^{-1} yr^{-1}$$

$$= 887.8\ Mg\ yr^{-1} \quad [3]$$

To calculate the index score, PE/WI divides carbon sequestered, *C,* by the difference between the highest and lowest attainable values and multiplies by 100. In this example, the index score equals 7.9 out of 100.

While carbon sequestration in the PE/WI model presents exact figures to users, the best available research has noted the high degree of uncertainty regarding carbon sequestration and land use. The availability of published empirical data also presented challenges in estimating carbon sequestration values for PE/WI. For the mixed fruit and vegetable land-use type, we found no literature citing results from experiments measuring sequestered carbon, though the literature did suggest potential to increase carbon sequestration in organic fruit and vegetable systems. We consulted Cynthia Cambardella (USDA Agricultural Research Service, personal communication, 2014), who is conducting research on carbon sequestration in fruit and vegetable production systems. She advised us based on her preliminary understanding of potential carbon sequestration to not report increases in carbon sequestration relative to annual row crop systems.

Nitrate

PE/WI reports nitrate-N concentration levels from the outlet of the model watershed. Nitrate-N concentrations in drinking water negatively affect human health as levels increase and exceed a contamination level of 10 mg/L ("National Primary Drinking Water Regulations," 2010). At broader spatial scales, multiple subwatersheds contribute nitrate-N to a given body of water, highlighting the relationship in PE/WI between subwatershed and watershed. Beyond drinking water and human health, nitrate-N loading affects aquatic ecosystems and human activity downstream by creating hypoxic zones in gulf regions (US EPA, 2008). Although PE/WI reports nitrate-N concentration rather than total nitrate-N load, reduced concentration implies reduced loading for a given volume of water.

The nitrate-N calculation in PE/WI presents mean nitrate-N concentrations in surface water for the modeled watershed. Estimates are based on Schilling and Libra's examination (2000) of watershed characteristics and nitrate-N concentrations in Iowa. Schilling and Libra approximated mean nitrate-N concentrations in Iowa surface waters as 11% of the percent area of a watershed in row crops ranging in area from 47 to 2,774 km^2. They also concluded that watershed size "affects the relationship of nitrate concentrations in surface water to percent row crops in watersheds" (p. 1849), finding nitrate-N concentration relationships of 14% of the percent area of a subwatershed in row crops, 11% for small and large watersheds, and 7% for large interior basins.

Because the PE/WI watershed is less than half the size of the watersheds that Schilling and Libra (2000) associated with the 11% multiplier, we used the 14% multiplier for subwatersheds in PE/WI nitrate model calculations. To calculate subwatershed nitrate-N concentration, we first assigned one of two multipliers, 14% or 0%, to each grid cell in PE/WI and weighted each grid cell's multiplier by the area of the grid cell as a percent of the subwatershed area. We assigned a 14% multiplier to conventional corn, conservation corn, conventional soybean, conservation soybean, and mixed fruit and vegetables, as row-crop land-use types. We assigned all other land-use types a 0% multiplier, and in the final step of the calculation restricted nitrate-N concentration to a minimum concentration of 2 mg/L in line with empirical data of nitrate-N concentration in surface waters of fully perennial ecosystems (Randall et al., 1997). Calculating concentration using the row-crop multiplier, R_{ij}, produces a baseline nitrate-N concentration based on land use (Table 2-8). Other factors—climatic cycles and management decisions—alter this baseline by reducing or temporally redistributing nitrate-N release into surface water. We accounted for these factors in the model by creating three additional multipliers (Table 2-8), which we describe in detail below.

The PE/WI model for watershed annual mean nitrate-N concentration, *N*, averages subwatershed nitrate-N concentration, weighted by subwatershed area, $A_{i..}$, proportional to watershed area, $A_{..}$. Because we restricted nitrate-N concentration to a minimum of 2 mg/L in line with data on fully perennial systems (Randall et al., 1997), subwatershed nitrate-N concentration, in mg/L, equals the maximum of: 2 or 100 multiplied by the product of: 1) precipitation multiplier, *P*; 2) strategic wetland multiplier, W_i; 3) row crop multiplier, R_{ij}, a weighted average by grid cell area proportional to subwatershed area; and 4) conservation row-crop multiplier, C_{ij}, also a weighted average by grid cell area proportional to subwatershed area. The formula for watershed annual mean nitrate-N concentration appears below (Table 2-8).

$$N = \sum_{i=1}^{n} \left[\max\left\{ 100 * PW_i \sum_{j=1}^{m_i} R_{ij}\, C_{ij}, 2 \right\} * \frac{A_{i.}}{A_{..}} \right] \qquad [4]$$

We selected nitrate-N concentration as an indicator of water quality to PE/WI users. To reflect how well each year's land-use configuration controls for nitrate pollution, we created a unitless nitrate pollution control index score, N_{index}, ranging between 0 and 100. High nitrate-N concentration translates to low pollution control, and thus a low index score, and vice versa. The highest nitrate-N concentration value attainable in PE/WI occurs in a 100% conventional row-crop scenario during a wet year that follows a dry year. Because of interannual variability in precipitation, users are not able to generate the scenario with PE/WI's highest concentration value in every year. The highest attainable nitrate-N concentration value equals 29.52 mg/L, calculated as 100 times the product of 0.14, the row crop multiplier, and 2.11, the precipitation multiplier. Conservation and wetland multipliers both equal 1.00 in this scenario. The lowest attainable *N* value in PE/WI equals the pre-defined minimum concentration of 2 mg/L. Suppose *N* for a given year equals 14 mg/L; then the index score equals 56.42 out of 100, with its formula as follows.

$$N_{index} = 100 * \left(1 - \frac{N-2}{29.54-2}\right) \quad [5]$$

In addition to a nitrate pollution control index score, PE/WI generates a map for users to evaluate the percent contribution of each subwatershed to the overall watershed nitrate-N concentration, PC_i. PE/WI calculates the percent contribution of each subwatershed, *i*, as the product of subwatershed nitrate-N concentration and the ratio of subwatershed area to watershed area. The formula for percent contribution follows.

$$PC_i = \frac{1}{N}\left(\max\left\{100 * PW_i \sum_{j=1}^{m_i} R_{ij}\, C_{ij}, 2\right\} * \frac{A_{i.}}{A_{..}}\right) \quad [6]$$

Detailed model assumptions and rules in the nitrate-N concentration calculation follow. The nitrate-N concentration calculation first evaluates each grid cell in PE/WI to determine its relative contribution to the overall watershed annual nitrate-N concentration level. PE/WI users can alter baseline contribution of each grid cell R_{ij} by selecting a conservation row crop—conservation corn or conservation soybean. The conservation multiplier, C_{ij}, reduces baseline concentration of a grid cell by either 31% or 39%, depending on the Major Land

Resource Area (MLRA) to which a grid cell belongs—the Des Moines Lobe (103) or Southern Iowa Drift Plain (108C) (Iowa, 2013).

According to the Iowa Nutrient Reduction Strategy (NRS) (Iowa, 2013), reducing nitrogen-N application rates and planting cover crops are the most effective in-field methods by which to reduce nitrate-N losses from corn and soybean systems. We did not vary nitrogen application form or rates between conventional and conservation row crops. Rather, nitrogen application rates vary only by MLRA based on Iowa NRS figures (Iowa, 2013, Section 2.2 Table 11). Thus, we did not include a concentration reduction factor based upon reduced fertilization rates between conventional and conservation corn and soybean land-use types. In PE/WI we assumed that two land-use types, conservation corn and conservation soybean, incorporate cover crops as a management practice. For those land-use types, we apply a nitrate-N reduction factor based on Iowa NRS estimates in which a winter cereal rye cover crop exhibits a 31% mean reduction in nitrate-N concentration (Iowa, 2013).

In the Des Moines Lobe grid cells, the conservation multiplier C_{ij}, equals 100% minus a 31% cover crop reduction, totaling 69% or 0.69. To calculate the conservation multiplier for the Southern Iowa Drift Plain grid cells, we added together the effect of each of the two practices, 31% cover crop reduction plus a 7% edge-of-field buffer reduction, and subtracted from 100%, totaling 62% or 0.62 (Iowa, 2013). The Iowa NRS listed edge-of-field buffers as another potential practice to reduce nitrate-N concentration in Iowa waters (Iowa, 2013). While the Iowa NRS science team estimated a 91% concentration reduction from the water that flows through the soil below the buffer, they noted that this percentage accounts for an overall reduction of 7% because only a very small portion of the water moves through the active buffer zone. In the model, we assumed conservation best management practices include adoption of edge-of-field buffers only in the Southern Iowa Drift Plain grid cells, which is consistent with land-use practices in the region (Brown & Schulte, 2011).

The precipitation multiplier, *P*, represents the effects of interannual patterns of precipitation on mean nitrate-N concentrations in surface water (Table 2-8). Randall and Mulla (2001) cited three previous studies to establish a relationship between precipitation and annual flow-weighted nitrate-N concentration (Randall, 1998; Randall et al., 1997; Randall & Iragavarapu, 1995). These studies illustrated climate cycles of dry years with relatively low concentrations and buildup of residual soil nitrate-nitrogen, followed by wet years with very high concentrations and transport and delivery of residual soil nitrate-nitrogen to streams. Elevated concentrations returned to baseline levels in subsequent years of normal and above-normal precipitation.

Using the five data sets from these studies we created precipitation multipliers in the PE/WI nitrate model as follows. We chose to designate a precipitation multiplier for each of the climate cycles with which Randall and Mulla (2001) established a relationship to annual flow-weighted nitrate-N concentration. We used the authors' descriptions of precipitation levels in each year as dry, normal, above-normal, and wet to label their data from each year in relationship to one of four climatic cycles: (a) dry year, (b) initial wet or above normal precipitation year after a dry year, (c) initial normal precipitation year after a dry year, or (d) background year (i.e. any year not falling into the first three groups). Next, for each data set we calculated the mean of the reported mean flow-weighted annual nitrate-N concentration values within each climate cycle group. We then indexed the calculated mean of each climate cycle group as a percentage of the background climate cycle group mean. Finally, we calculated the mean of indexed values for each climate cycle group across all five data sets. This resulted in multipliers of 0.86 for dry year, 2.11 for an initial wet or above normal precipitation year after a dry year, 1.69 for a normal precipitation year after a dry year, and 1.00 for background years. To assign multipliers in the PE/WI model, we classified PE/WI's seven precipitation levels as dry, normal, or wet (Table 2-2).

The final factor to reduce baseline nitrate-N concentration, the strategic wetland multiplier, W_i, depends on whether the user places the wetland land-use type on pre-defined strategic wetland locations (Table 2-8). We created a static strategic wetland data set in PE/WI that users may view by navigating to the physical feature maps. The strategic wetland map helps users to identify optimal locations for restoring a wetland, which we based upon physiographic features of the watershed. Twenty strategic wetland locations exist in PE/WI, and we assigned subwatersheds containing strategic wetlands a potential nitrate-N concentration reduction of 52% (Iowa, 2013). More precisely, if a subwatershed contains one or more strategic wetlands, and PE/WI users designate at least one strategic wetland in a wetland land-use type, then PE/WI calculates a strategic wetland multiplier of 0.48 for the subwatershed.

The remainder of the nitrate section presents a discussion of additional factors that we did not incorporate into the PE/WI nitrate model. We decided not to include these and other factors to minimize model complexity in terms of land use, management practices, and spatial scale influences on nitrate-N concentration estimates and nitrate as an ecosystem services indicator.

The PE/WI nitrate model simplifies land use into two categories, as either annual row crop or perennial vegetation. Schilling and Libra (2000) did not explicitly consider the impact of land uses such as pasture, alfalfa, hay, or bioenergy crops on nitrate-N concentration levels. Because corn and soybean dominate land use in Iowa, the model may not estimate nitrate-N concentration in watersheds with low annual row crop composition. Consequently, PE/WI concentration results account for the contribution of annual row crop and perennial vegetation land uses to the extent that a given scenario is similar in composition to data from the Schilling and Libra analysis. PE/WI scenarios with a large percentage of perennial vegetation in a subwatershed may underestimate concentration levels because the model does not account for factors within perennial vegetation systems that have potential to elevate nitrate-N concentration levels above 2 mg/L. As one example, Russelle (2004) discussed leaching potential from alfalfa without proper management. The dearth of data on perennial systems limits the PE/WI nitrate model; the Iowa Nutrient Reduction Strategy science assessment (Iowa, 2013) pointed to “little pertinent data about nitrate-N concentrations coming from pasture in Iowa” (p. 12). The science team assumed that grazed pasture functions similarly to Conservation Reserve Program (CRP) land covers. Based upon available data—and scientific judgment where data were lacking—the science team concluded that Iowa will achieve reductions in concentration levels upon conversion of row-crop production to other land uses. This includes CRP and grazed pasture concentration reductions of 85%.

The Iowa Nutrient Reduction Strategy science assessment (Iowa, 2013) also suggested several nutrient management practices that we did not incorporate into the PE/WI model. For example, the assessment pointed to use of denitrification woodchip bioreactors to treat tile-drained water, with 43% mean nitrate-N concentration reduction for treated water (Iowa, 2013). The option of placing bioreactors is not included in PE/WI at this time to minimize model complexity.

Gross Erosion

Erosion is the process of “detachment and transport of soil and rock by moving water, wind, and other geologic agents” (USDA NRCS, 1998, p. 1) and, in excess, has documented negative soil and water quality impacts such as diminished crop productivity and impaired aquatic stream habitat (Lyons & Courtney, 1990; Smith, Lerohl, Messele, & Janzen, 2000). Details for each component of the calculation and parameters follow.

We used the 2004 Iowa Phosphorus Index (P-Index) guidelines (Mallarino, Stewart, Baker, Downing, & Sawyer, 2005; USDA NRCS, 2004a) to inform calculations of water erosion in PE/WI. P-index guidelines defined gross erosion as rill and interrill erosion, ephemeral gully erosion, and classical gully erosion. Due to lack of published data on classical gully erosion, PE/WI only provides figures for rill and interrill erosion, based on the Revised Universal Soil Loss Equation (RULSE) (Renard, Foster, Weesies, McCool, & Yoder, 1997), and ephemeral gully erosion, based on statewide estimates for Iowa (USDA NRCS, 1997). USDA NRCS (1998) listed other common sources of erosion, including streambank, landslides, roads, roadbanks, construction sites, and feedlots, that we did not incorporate into the PE/WI erosion model due to a lack of published data, in some instances, and to stay within scope of our modeling objectives.

PE/WI quantifies gross erosion, E, in PE/WI as the amount of soil loss per year in the fictitious watershed from ephemeral gully erosion, rill erosion, and interill erosion. Using results from E, we created a unitless erosion control index score, E_{index}, ranging between 0 and 100, with 0 corresponding to the highest erosion quantity attainable in PE/WI and 100 corresponding to the lowest erosion quantity attainable in PE/WI. High gross erosion translates to low erosion control, and thus a low index score, and vice versa. The highest erosion value attainable in PE/WI occurs in a year with maximum precipitation in which land use is a 100% continuous conventional soybean scenario, i.e. all conventional soybean in the current year and all conventional soybean in the preceding year. The lowest erosion value attainable in PE/WI occurs in a year with minimum precipitation in which land use is 100% combination of herbaceous perennial bioenergy and/or prairie.

The two subcomponents in the gross erosion calculation are ephemeral gully erosion and RUSLE, the latter of which describes rill and interill erosion. Ephemeral gully erosion has only recently received attention, and a precise ephemeral gully erosion model does not currently exist for Iowa (Eller, 2014). Thus we created a simple ephemeral gully erosion model for PE/WI, in which we modified USDA NRCS (1997) estimates of 6.7 Mg/ha for Iowa upward by 50% to 10.1 Mg/ha for conventional annual row-crop practices, and downward by 50% to 3.4 Mg/ha for conservation annual row-crop practices (Thomas Isenhart, Iowa State University, personal communication, 2014). Because published research has not quantified relationships between ephemeral gully erosion and row-cropping practices, the 50% upward and downward adjustments reflect directionally accurate models based our understanding of the effects of conservation practices on ephemeral gully erosion.

The RUSLE soil loss calculation takes the product of five factors: rainfall erosivity factor, R, soil erodibility factor, K, slope length steepness factor, LS, cover management factor, C, and practice support factor, P (Renard et al., 1997), (Table 2-9). We converted RUSLE factors between SI units and US customary units using USDA Agricultural Handbook 703 (Renard et al., 1997, Table A-2).

Rainfall erosivity, R-factor, estimates account for climate effects on erosion. Typically, RUSLE calculations use a static R-factor value set for a location or region based on historic average storm erosivity values. PE/WI instead varies *R*-factor values by annual precipitation levels, according to an equation provided by Renard and Freimund (1994). We selected this model to emphasize the relationship between climate variability and interannual differences in erosion rates.

Soil erodibility, *K*-factor, accounts for soil susceptibility to erosion, or as USDA Agricultural Handbook 703 (Renard et al., 1997) states, the "ease with which soil is detached by splash during rainfall or by surface flow or both" (p. 68). The measurement unit for the *K*-index is the rate of soil loss per unit of rainfall erosivity. ISPAID (Iowa State University, 2010) provides K-factor values for each soil type, which we incorporated within PE/WI.

For slope length-steepness, *LS*-factor, estimates we assumed a relationship between slope steepness, *S*-factor, and slope length, *L*-factor, similar to values that Iowa NRCS Technical Note 29 (USDA NRCS, 2008b) presented in a plot entitled "Slope length related to slope gradient" (p. 5).

We derived cover management, *C*-factor, values based on estimates for Squaw Creek Watershed in Boone, Hamilton, Story and Webster Counties, Iowa (Wendt, 2007). Cover management depends not only on current year land use but also on prior year land use. We found one challenge in deriving appropriate *C*-factor values in that year 1 PE/WI erosion depends on prior land-use type. Currently, the erosion model assumes that a hypothetical year 0 did not have the following annual row crop land-use types: conventional corn, conservation corn, conventional soybean, conservation soybean, mixed fruit and vegetables. This contrasts with the carbon model, which assumes conversion from a conventional corn and/or conventional soybean system. It also contrasts with the initial land-use types displayed on the watershed upon users opening the PE/WI application.

We calculated practice support, *P*-factor, as the product of a contour subfactor and a terrace subfactor. We assumed that only conservation corn and conservation soybean land-use types incorporate contouring and terracing, and only at downhill slopes greater than 2%. RUSLE instructions (Renard et al., 1997) suggested to modify estimates of soil loss with contouring when the slope length, *L*-factor, exceeds the critical slope length at which contouring fails and permits rill erosion. For PE/WI, we defined critical slope lengths based upon Iowa NRCS USLE Erosion Prediction (USDA NRCS, 2002, Table IIIa), which resulted in no *L*-factors exceeding critical lengths. We selected contour subfactors for 10 year EI (storm intensity) equal to 80 and low (1-3”) ridge or oriented roughness height, and assumed median row grades for each downhill slope category (USDA NRCS, 2002, Table IIIe), as well as terrace subfactors (Table IIId). We selected closed outlet terrace values for PE/WI, which vary based on horizontal terrace intervals that we set equal to Iowa NRCS terrace standards recommendations on maximum terrace spacing for each slope category (USDA NRCS, 2008a).

Sediment

Sediment delivery describes the quantity of eroded soil that arrives at a specific location in a body of water, such as a lake, river, or stream (USDA NRCS, 1998). High levels of sediment delivery contribute to water quality impairment both locally and downstream (Alexander et al., 2008; Iowa, 2013; Lyons & Courtney, 1990; Vache, Eilers, & Santelmann, 2002). Sediment and phosphorus are tightly linked because phosphorus moves with sediment. Details for each component of the calculation and parameters follow.

We used the 2004 Iowa Phosphorus Index (P-Index) guidelines (Mallarino et al., 2005; USDA NRCS, 2004a) to inform calculations of sediment delivery in PE/WI. According to Mallarino et al. (2005) the erosion component of the index is "an approximate (proportional) estimate of the total amount of sediment-bound P (excluding dissolved P) delivered to a stream…that is likely to become available to aquatic ecosystems" (p. 5). The erosion component of the Iowa P-Index calculates the product of five factors: buffer factor, enrichment factor, gross erosion, sediment delivery ratio, and soil test P (STP) erosion factor. The PE/WI model modifies the erosion component calculation to arrive at an estimate of eroded sediment delivered to the stream. We removed two factors from the product, enrichment factor and STP erosion factor. These factors serve as multipliers to convert sediment to phosphorus for the P-Index. The enrichment factor adjusts the erosion component to account for soils with higher concentrations of phosphorus, and the STP erosion factor converts sediment delivery to sediment-bound phosphorus based on estimates of soil P concentration. The remaining three multiplicative factors—buffer factor, gross erosion, and sediment delivery ratio—provide the

PE/WI estimate of the total amount of sediment delivery to a stream. Thus, we used the following equation:

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij}\left(B_{ij} * E_{ij} * SDR_{ij}\right) \quad [7]$$

The Iowa P-Index sets the buffer factor, B_{ij}, equal to 0.5 for vegetative buffers that meet the USDA NRCS practice standard 393 for a filter strip (USDA NRCS, 2004a). For PE/WI, we assumed that conservation corn and conservation soybean land-use types include vegetative buffers. Additionally, we assumed that the following PE/WI land-use types function as vegetative buffers: conservation forest, conventional forest, grass hay, herbaceous perennial bioenergy, prairie, short-rotation woody bioenergy, and wetland.

As described previously, Gross erosion, E, provides estimates of total rill and interrill erosion using RUSLE (Renard et al., 1997) and ephemeral gully erosion, based on Iowa statewide estimates (USDA NRCS, 1997). Detailed explanations of RUSLE subcomponent calculations are in the preceding section, Gross Erosion (Table 2-9 and Table 2-11).

Sediment delivery ratio (SDR) converts gross erosion into sediment yield and "represents the efficiency of the watershed in moving soil particles from areas of erosion to the point where sediment yield is measured" (USDA NRCS, 1998, p. 6). SDR functions for each landform region in Iowa estimate SDR as a function of drainage area because of its close relationship with sediment delivery (USDA NRCS, 1998). PE/WI uses "SDR 2" ratios for the Southern Iowa Drift Plain and "SDR 4" ratios for the Des Moines Lobe (Table 2-10 and Figure 2-6). For PE/WI, we derived SDR as a function of drainage area according to "Chart 1" and calculated two SDR values for the PE/WI watershed. These values equal 4.4% for the Des Moines Lobe and 27.8% for the Southern Iowa Drift Plain (Table 2-11).

Phosphorus

Phosphorus delivery to stream in PE/WI estimates phosphorus transport from sources across the watershed to surface waters. Loss of phosphorus from agricultural fields into surface waters has negative consequences at multiple scales—at local scales where producers incur expenses to apply phosphorus fertilizers to fields, at near and distant regional scales where freshwater eutrophication threatens aquatic species and human economy, and at more distant regional scales where Gulf Hypoxia also threatens aquatic ecosystems and human economy of the northern Gulf of Mexico (Alexander et al., 2008; Iowa, 2013; Jacobson, David, & Drinkwater, 2011; US EPA, 2008).

The PE/WI model uses the Iowa Phosphorus Index (P-Index) (USDA NRCS, 2004a) to calculate annual phosphorus loading. Iowa NRCS Technical Note 25, with P-Index calculation instructions, described three primary phosphorus delivery pathways to surface waters: 1) an erosion component, measuring delivery with sediment; 2) a runoff component, measuring delivery with runoff; and 3) a subsurface drainage component, measuring delivery with subsurface drainage (USDA NRCS, 2004a).

PE/WI calculates P-Index values for each grid cell, and a simple summation of grid cell values yields watershed annual in-stream phosphorus delivery. We selected index parameter values based upon sources including Iowa NRCS Technical Note 25 (USDA NRCS, 2004a), Iowa Nutrient Reduction Strategy (Iowa, 2013), expert consultation (Matthew Helmers and Thomas Isenhart, Iowa State University, personal communication, 2014), and data from other published sources. Details for each component of the calculation and parameters follow.

The erosion component is the product of five parameters: gross erosion (Table 2-9), sediment trap factor or sediment delivery ratio (SDR) (Table 2-11) buffer factor, enrichment factor, and soil test phosphorus (STP) erosion factor (USDA NRCS, 2004a). See Gross Erosion and Sediment sections above for further information. The enrichment factor adjusts the erosion component to account for soils with higher concentrations of phosphorus, and the STP erosion factor converts sediment delivery to sediment-bound phosphorus based on estimates of soil P concentration (USDA NRCS, 2004a). We used major landform region area (MLRA) average STP values of: Bray-1 P, Mehlich-3 STP of 30 ppm concentration for the Des Moines and 27 ppm concentration for the Southern Iowa Drift Plain (Iowa, 2013).

The runoff component of the Iowa P-Index measures phosphorus delivery with water runoff (USDA NRCS, 2004a). The runoff component consists of the product of a runoff factor, precipitation, and the sum of STP runoff factor and P application factor (Table 2-12). The runoff factor equation takes 50% of the observed weighted average percent of runoff in Iowa for Runoff Curve Number

(RCN) levels of 50, 60, 70, 80, 90, and 95, to account for approximately 50% of observed rain events in Iowa that fall below the limit for production of runoff (Mallarino et al., 2005). Our calculation uses runoff factor values converted from RCN (USDA NRCS, 2004b), (Table 2-12, Table 2-13).

PE/WI uses each modeled year's precipitation level to calculate that year's hypothetical P-Index value. We converted precipitation to units of million megagrams per unit area, in accordance with P-Index instructions.

The next runoff subcomponent, STP runoff factor, represents the concentration of dissolved phosphorus in runoff based on soil test P values. As with the erosion STP factor, we used average soil test P values of: Bray-1 P, Mehlich-3 STP of 30 ppm concentration for the Des Moines and 27 ppm concentration for the Southern Iowa Drift Plain (Iowa, 2013). The P application factor depends on P_2O_5 application rate and method of application. For conservation corn and conservation soybean land-use types, we assumed surface application with no incorporation. For conventional corn, conventional soybean, and mixed fruit and vegetable land-use types, we assumed management across the watershed with two methods occurring in equal proportion: surface application with no incorporation and incorporating within one week (Matthew Helmers and Thomas Isenhart, Iowa State University, personal communication, 2014). Mallarino et al. (2005) provided a time and method factor that we used in P application factor calculations.

The subsurface drainage component of the Iowa P-Index consists the product of precipitation, a flow factor, and an STP drainage factor (USDA NRCS, 2004a). The

P-Index again uses precipitation and STP concentrations to determine factor values. The flow factor takes on a value of 0.1 if subsurface flow is present, with 10% representing the observed average annual precipitation percentage that flows through the subsurface in Iowa; otherwise flow factor takes on a value of zero (Mallarino et al., 2005). Using P-Index guidelines, PE/WI assumes a flow factor of 0.1 when an ISPAID soil map unit has the following attributes: slopes of 5% or less; texture of 40% clay or coarser; and poor or very poor in natural drainage (Iowa State University, 2010; USDA NRCS, 2004a) (Table 2-12).

Yields

Yield calculations in PE/WI provide estimates of marketable crop and livestock production for several land-use types in the watershed (Table 2-14). In terms of ecosystem services, crop and livestock production provides primarily food, fuel, and feed for consumers, as well as a source of producer income that benefits individual and community livelihoods.

While the yield types (Table 2-14) include both existing and emerging agricultural products in Iowa, they do not exhaust possible markets for each land-use type. For example, corn yield includes only grain production and does not include stover for biofuel production. Additionally, two of the native perennial land-use types—prairie and wetland—do not have associated yields. Markets do exist, however, for prairie vegetation, with prairie seeds and native grasses for biomass production as two examples. Prairie, wetland, and conservation forest areas also produce marketable venues for tourism, recreation, and hunting that we did not report in PE/WI. Details for the calculation of each PE/WI yield type follow.

Annual yield on a per unit area basis equals production of a given crop or livestock for a year divided by watershed area. While PE/WI presents all production types on an annual basis, the number of cattle supported by grazing land accounts only for the grazing season.

The general formula for crop and livestock production, Y, is the sum total of production across the watershed for each yield type (Table 2-15). The yield index scales from 0-100 and equals 100 times the yield from a user-created scenario divided by the maximum attainable yield. The maximum attainable yield for each yield type occurs under the following conditions: 1) all productive areas have land-use types associated with that yield type, and 2) the yield precipitation factor equals 1.

Production for each grid cell equals the product of grid cell area, A_{ij}; yield base rate per unit area YB_{ij}, which is a function of yield type; and yield precipitation factor, YP_{ij} (Table 2-16).

The remainder of this section presents models of yield base rate per unit area for each yield type (Table 2-14). We derived corn (*Zea mays* L.) yield estimates for conventional corn and conservation corn from ISPAID (Iowa State University, 2010) data that modeled corn yield for each soil mapping unit based on “parent material, slope class, erosion class, natural drainage class, and nature of the subsoil in terms of rooting environment to include limiting layers, soil depth, and plant water capacity…[and] potential for periodic flooding and weather conditions" (Miller, Fenton, Oneal, Tiffany, & Burras, 2010, p. 6), (Table 2-17). They reported that ISPAID corn yield estimates assumed high-level management.

To show interannual variability in PE/WI, we multiplied this base corn yield level (Table 2-17) by a yield precipitation factor to reduce base yields in years of extreme climate conditions. For a given precipitation level, PE/WI applies a specific yield precipitation factor according to land-use type (Table 2-16). For model simplification, we further assumed no yield difference between conventional corn and conservation corn by making the following assumptions: conservation practices that take land out of production are located in unproductive areas of a field, conservation corn exhibits similar yield responses as conventional corn to extreme climate conditions, and yields do not decline as a result of cover crops or no-till practices. Because ISPAID reported corn yield in bushels (volume) per acre, we converted to metric units of Mg (mass) per hectare using a factor of value 0.0254 megagrams per bushel. We calculated the factor based on an approximate relationship of 56 lbs per bushel of corn (Johanns, 2013).

Similar to corn, we derived conventional and conservation soybean (*Glycine max* (L.) Merr.) yield estimates from ISPAID (Iowa State University, 2010) data of modeled soybean yield for each soil mapping unit based on a percentage of corn yield equivalent to 29%. We multiplied the soybean yield base rate (Table 2-17) by the yield precipitation factor for extreme climate conditions and assumed no yield differences between conventional soybean and conservation soybean. To convert between bushels in ISPAID and metric units, we used an approximate relationship of 60 lbs per bushel of soybeans (Johanns, 2013) to derive a factor of 0.0272 megagrams per bushel.

ISPAID (Iowa State University, 2010) also provided estimates of alfalfa-grass hay yields for stands of alfalfa (*Medicago sativa* L.) and either bromegrass (*Bromus inermis* Leyss.) or orchard grass (*Dactylis glomerata* L.). We used these estimates for two PE/WI land-use types: alfalfa and grass hay (Table 2-18). The ISPAID model estimated alfalfa-grass hay yields as a percentage of corn yields: 2.8% for excessively, somewhat excessively, well, and most moderately well drained soils; 2.6% for two moderately drained soil associations and all somewhat poorly drained soils; and 2.1% for poorly and very poorly drained soils. However, we set minimum base yield rates of 8.07 megagrams of alfalfa and grass hay per hectare based on expert consultation (Emily Heaton and Matt Liebman, Iowa State University, personal communication, 2014). To arrive at total yield, we multiplied both alfalfa base yield rate and grass hay base yield rate by the yield precipitation factor for extreme climate conditions.

Permanent pasture and rotational grazing land-use types both have potential to support a wide range of ruminant livestock. We used PE/WI alfalfa and grass hay yield potentials to estimate the number of cattle that each ISPAID soil mapping unit supports; however, note that the PE/WI model does not use production from areas in alfalfa or grass hay land-use types to support cattle, only production from areas in permanent pasture and rotational grazing land-use types.

Although ISPAID reports animal unit months (AUM) for three different forage types (Miller et al., 2010), we chose an alternative production unit. Based on expert consultation (Devan McGranahan, North Dakota State University, personal communication, 2014), we instead calculated the number of grazing cattle supported on permanent pasture and rotational grazing land per grazing season, which we approximated at 200 days per year in Iowa based on a survey of Iowa beef production in which most respondents reported a grazing season of April 15 through November 1 (Iowa Beef Center, 2007), (Table 2-19). This unit of measurement is more familiar than AUM to a general PE/WI user outside of the livestock industry.

The PE/WI model assumes daily intake of 3% of 0.544 Mg bodyweight and seasonal forage utilization rates of 35% for permanent pasture and 55% for rotational grazing, based upon Iowa NRCS Technical Note 32 (USDA NRCS, 2008c). We implicitly assumed that cattle outside of grazing season require additional inputs including feed, water, and shelter. However, we did not include those factors in the model nor report them alongside results to maintain focus on ecosystem service benefits produced by the watershed landscape. Users of PE/WI could separately create economic analyses and operational budgets that utilize non-grazed alfalfa or grass hay yields as feed inputs for the non-grazing season.

The formula for yield base rate for permanent pasture and rotational grazing land-use types equals yield base rate for alfalfa multiplied by the percentage of seasonal utilization of forage production, *SU*, and divided by total intake over the grazing season per animal, which is the product of grazing season length, *GS*, and daily intake, *DI* (Table 2-19).

For mixed fruit and vegetable crops, we selected grapes (*Vitis riparia*), green beans (*Phaseolus vulgaris*), squash (*Cucurbita pepo*), and strawberries (*Fragaria × ananassa*) as examples of crops that are increasingly popular among Iowa fruit and vegetable producers and have high demand in local and regional metropolitan markets (Bregendahl & Enderton, 2013; Iowa State University News Service, 2014; Swenson, 2011). For green beans, squash, and strawberries, we used yield values published by Iowa State University Extension and Outreach (Taber, 2009). Due to a lack of grape yield information from Iowa, we are using regionally similar data (New York state), which indicated 'Elvira' grape yields of 17.6 megagrams per hectare (Delate & Friedrich, 2004; R. M. Post & Robinson, 1995). To calculate yield, we further allocated one-quarter of each grid cell in a mixed fruit and vegetable land-use type to each of the four crops (Table 2-20).

Although we assigned separate yield values for each crop, PE/WI only reports one final quantity for mixed fruit and vegetable yield. Additionally, we created a soil texture multiplier to downward adjust yields for unfavorable soil textures (Taber, 2009), (Table 2-20). We created multiplier values based upon general relationships between soil types and crop adaptation from the Iowa State University Extension and Outreach commercial vegetable production publication (Taber, 2009).

PE/WI also estimates wood production for conventional forest and conservation forest land-use types based on soil mapping unit yield ranging from the 2007 Iowa Woodland Suitability Composite (IDNR & USDA NRCS, 2007), (Table 2-21). Yield estimates assume selection of tree species suitable for a given location, as recommended in the Iowa Woodland Suitability Composite. These estimates serve as base yield amounts of wood production for conventional forest. To account for yield differences due to management practices in conservation forest land-use types, we applied a 30% reduction to wood production estimates from the Iowa Woodland Suitability Composite for conservation forest yield.

Bioenergy crops are an emerging market in the US Corn Belt (Heaton et al., 2013). For PE/WI, we selected herbaceous perennial crops and short-rotation woody crops to represent the potential of the watershed to produce bioenergy. For the land-use type herbaceous perennial bioenergy, switchgrass (*Panicum virgatum* L.) biomass yields range between 4.39 and 6.61 megagrams per hectare, which we scaled based on a modification to ISPAID corn suitability ratings (CSR) (Emily Heaton, Iowa State University, personal communication, 2014), (Table 2-22).

We chose switchgrass as the PE/WI herbaceous perennial bioenergy crop since it is the most developed perennial dedicated energy crop in the region (US DOE, 2011), although other possible options included miscanthus or other native warm-season grasses. We further assumed no added inputs of nitrogen and phosphorus fertilization, based on expert consultation, even though general guidelines for switchgrass production typically recommend high levels of fertilizer application after an establishment year. Unlike corn and soybean production systems in the US Corn Belt, which focus almost exclusively on maximized production, we developed the herbaceous perennial bioenergy crop model in PE/WI to balance production of multiple ecosystem services benefits.

Finally, PE/WI provides biomass yield estimates for production of short-rotation woody bioenergy crops based on 10-year aspen (*P. alba x P. grandidentata*) biomass figures of 224 Mg/ha (Manatt et al., 2013). For annual production figures, we made an assumption of temporally spaced plantings such that one-tenth of an area in production becomes ready for harvest each year. Thus, annual production equals 22.4 Mg/ha of biomass.

2.3 Examples and Outcomes

We constructed four scenarios in PE/WI to illustrate tradeoffs in ecosystem services indicator outcomes (Table 2-23). The four scenarios represent a combination of two spatial configurations: 1) corn-soybean-corn rotation or 2) two-thirds conservation corn-soybean-corn rotation with one-third strategically placed perennial land uses; with two temporal sequences: 1) normal climate or 2) interannual climate variability.

Analysis of outcomes allows users to answer questions such as, "How well do conventional corn and conventional soybean provide for multiple ecosystem services?" Additionally, "Is a conventional corn and soybean system as resilient to extreme climate swings as a conservation row crop system with strategically placed perennial land-use types?" The results from PE/WI also provide inputs for financial analyses associated with alternative crop production versus traditional crop production systems.

Users completing this exercise will find that negative yield responses to extreme climate conditions are less severe for perennial land-use types, such as herbaceous perennial bioenergy or grass hay, than for annual row crop production. This strategy provides one form of risk mitigation to producers and society. Annual row crop systems are more sensitive to dry-wet climate cycles, which lead to large spikes in stream nitrate-N concentration. Heavy rainfall years also elevate phosphorus loading, erosion, and sediment delivered to stream. Other ecosystem service indicators also perform better in systems incorporating perennial land uses, and include carbon sequestration levels, biodiversity, and game wildlife habitat.

At the same time as the indicator values for an array of ecosystem benefits increase, the systems incorporating perennial land-use types lose a substantial amount of annual row-crop yield due to land taken out of production. In turn, producers gain other marketable agricultural products. In the real world, decision makers may consider whether such a combined annual-perennial crop and livestock system fulfills societal demands for agricultural goods and environmental services and whether it also supports farmer economic wellbeing.

2.4 Discussion

Continued engagement with PE/WI gives users the opportunity to synthesize outcomes and identify reoccurring patterns between land use and outcomes. In conjunction with in-classroom lessons and discussion, learning materials provided through the PE/WI website, or guidance from conservation professionals or other educators, we expect users to develop better understanding and demonstration of learning objectives.

Ecosystem service indicators in PE/WI also provide inputs for further analyses. PE/WI users may convert production of marketable quantities into monetary values for economic analyses and, more generally, production of ecosystem service indicators into levels of final ecosystem services. In addition to analyses of total productive capacities of various landscape scenarios, users may reflect on outcomes in terms of spatial and temporal scales. The number of beneficiaries, where they are located, and when they experience each of the services or disservices on a landscape varies by service. Tradeoffs do not occur solely among ecosystem services, but also among beneficiaries.

Few existing tools provide a broadly accessible, yet comprehensive framework for consideration of ecosystem services. PE/WI has transformative potential to fundamentally alter people's frameworks for land-use decision making (Schulte et al., 2010). With future development of PE/WI, opportunity exists to expand and improve the model to better support enhanced decision making. Next, we discuss the main areas for future refinement and enhancement of the PE/WI model.

2.4.1 Final Ecosystem Services

While this version of PE/WI contains indicators of many ecosystem services, future versions of PE/WI may conceivably model how biophysical indicators translate into final services. Final services such as clean drinking water and human nutrition provide more meaning to the broader public than biophysical indicators. Daily et al. (2009) depicted relationships between ecosystems, ecosystem services, values, institutions, and decisions (p. 23). They noted that the relationships are particularly complex because any factor can directly influence another. The following examples demonstrate the importance of final ecosystem services for analyzing tradeoffs.

Nitrate-N contamination of drinking water provides an example that underscores the importance of integrating both biophysical indicators of ecosystem services and final ecosystem services into decision models. The federal limit on nitrate-N concentration in drinking water is 10 mg/L ("National Primary Drinking Water Regulations," 2010). A concentration level that exceeds the limit therefore indicates a final ecosystem disservice of unsafe drinking water. Rural and metropolitan municipal water suppliers that utilized contaminated water must bring the nitrate-N concentration to a safe level before it enters the public system, and this process often entails high costs associated with treating or securing alternative sources of water. When volume demand rises, a community may experience a non-linear increase in ecosystem disservice as the nitrate-N concentration level increases. This non-linear relationship occurs when safe water supplies are increasingly difficult and expensive to obtain. If contamination levels regularly exceed the ability of municipal water suppliers to find additional sources, municipalities have fewer options and may spend considerable resources building and operating nitrate removal facilities. Such non-linearity between a biophysical indicator level and final service or disservice level warrants consideration as society evaluates tradeoffs with other ecosystem services. Providing direct measures of final ecosystem services will enable evaluation and decision processes that are more in line with people's needs, values, desires, and demands from ecosystems.

Another example illustrating how tradeoffs differ between intermediate and final ecosystem services is human health and nutrition. A number of land-use types in PE/WI generate crops or livestock production for human food consumption. However, yield measures alone are not adequate to quantity the level of final services that benefit humans. For instance, PE/WI includes mixed fruit and vegetables for human food and beverage consumption. Other commodity crops such as corn enter a variety of fuel and feed markets, and enter food markets to a less extent, with less than 12% of corn grown domestically for food, seed, and other industrial uses (USDA ERS, 2014). Comparing final service levels would likely entail consideration of calories, nutritional benefits, demand for food products, and other factors. Creating a human nutrition index in a future version of PE/WI would provide users one type of final service, though there are numerous other indices that also measure final services related to food production.

Modeling final ecosystem services, while valuable, presents challenges because of a lack of methodologies to evaluate final service levels and impacts to human wellbeing (Ruckelshaus et al., 2013). Modeling final ecosystem services also is prone to greater subjectivity than modeling biophysical indicators. Future versions of PE/WI that incorporate final ecosystem services will require careful examination of what services people use, who uses them, how various users benefit from them, and how they interact with other socioeconomic implications of land use.

2.4.2 Uncertainty

Uncertainty in selection of model parameters and values also presented an interesting challenge in developing PE/WI. As future research on alternative crops and environmental services in the US Corn Belt fills gaps in current understanding of biophysical functioning at watershed and landscape scales, we can improve the accuracy of several PE/WI parameter estimates. For example, we do not fully understand the relationship between perennial land-use types, such as alfalfa, pasture, and herbaceous bioenergy, and nitrate-N concentration levels at a watershed or landscape scale. Further, we do not precisely understand how variability in management, including fertilization, affects that relationship. The team that conducted the Iowa Nutrient Reduction Strategy science assessment evaluated research on crops such as alfalfa in the context of a rotation with annual row crops, and used data from CRP land to represent the performance of pasture land-use types. Neither the Lawlor curve (Lawlor, Helmers, Baker, Melvin, & Lemke, 2008) used in the Nutrient Reduction Strategy model (Iowa, 2013) nor the Schilling and Libra estimate (Schilling & Libra, 2000), which we incorporated into PE/WI, evaluated crops other than corn and soybean.

Uncertainty also exists in PE/WI due to variations in existing literature. For example, Fissore et al.'s (2010) meta-analysis published on carbon sequestration potential in the Midwest US found large standard deviations in published carbon sequestration data, especially for certain land uses and management practices. Subsequent literature review by Cambardella, Johnson, and Varvel (2012) pointed to a "relatively poor understanding of the mechanisms that determine SOC changes in response to land management practices" (p. 52).

Research gaps such as these exist for each PE/WI module and indicate need for additional research and further refinement of the model as continued research supports more informed models. For the current version of PE/WI, when possible, we consulted subject expert advice to estimate model relationships and parameter values; otherwise, we excluded models, such as classical gully erosion and streambank erosion, from PE/WI altogether.

2.5 Conclusion

PE/WI serves as a framework around which users may conceptualize relationships between land use and ecosystem services to devise alternative scenarios with potential to satisfy collective societal needs while also maintaining individual needs of agricultural producers. The current PE/WI model fills an enormous gap, both conceptually and as a functioning tool, with potential to change how people approach land-use decisions in agricultural landscapes. The tool combines the best available science with an appealing, interactive platform that we hope will engage user groups ranging from students to farmers to policy makers in the US Corn Belt and beyond.

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Table 2-1. PE/WI Watershed Area

Description	**Notation**	**Rule**	**Value**
Grid cell area	A_{ij}	Area of individual grid cell, *j*, in subwatershed *i*	$\leq 4\ ha$
Subwatershed area	$A_{i.}$	Sum of m_i grid cell areas, A_{ij}, in subwatershed *i* $\sum_{j=1}^{m_i} A_{ij}$	$Varies$
Watershed area	$A_{..}$	Sum of $n * m_i$ grid cell areas, A_{ij}, in the watershed $\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij}$	2,383.1 ha

Table 2-2. Climate Type and Percent Frequency Distribution of Annual Precipitation Values in PE/WI

Precipitation (*pr*) (cm yr^{-1})	**Climate Type**	**Frequency**
62.4	Dry	5%
71.6	Dry	15%
77.2	Normal	15%
81.7	Normal	15%
87.2	Normal	15%
92.6	Wet	15%
114.6	Wet	5%

Table 2-3. PE/WI Land-use Category, Type, and Description

Land-use Category	**Land-use Type**	**Description**
Perennial legume	Alfalfa	Perennial forage crop harvested primarily for hay or silage; may be included in long-term rotations with other crops.
Annual grain	Conservation corn	Annual grain crop managed using conservation practices, such as no-till, cover crops, grassed waterways, and/or buffers. Contouring and/or terracing where location-appropriate.
	Conventional corn	Annual grain crop managed using conventional tillage.
Annual legume	Conservation soybean	Annual legume crop managed using conservation practices, such as no-till, cover crops, grassed waterways, and/or buffers. Contouring and/or terracing where location-appropriate.
	Conventional soybean	Annual legume crop managed using conventional tillage.
Pasture	Permanent pasture	Forage (alfalfa and/or grass) grazed by cattle throughout the typical grazing season.
	Rotational grazing	Forage (alfalfa and/or grass) grazed by cattle through the typical grazing season; managed by strategically rotating cattle across paddocks to promote even grazing.
Perennial herbaceous (non-pasture)	Grass hay	Perennial forage crop harvested primarily for hay or silage.
	Herbaceous perennial bioenergy	Perennial herbaceous crop (switchgrass) harvested as biomass for biopower and biofuel generation. Low levels of management.
	Prairie	Diverse mix of tallgrass prairie vegetation native to Iowa.
	Wetland[a]	Constructed pooled water areas designed to include water, soil, and plant features that restore ecological functions and processes of native, naturally occurring wetlands. Managed for habitat for biodiversity, controlling nitrate flow to streams, or both.
Perennial woody	Conservation forest	Managed for historically relevant compositional and structural diversity using uneven-aged (gap or patch cuts) or even-aged (shelterwood, crop tree release) techniques and other management (timber stand improvement, prescribed burning and/or tactical grazing, removal of invasives). Management of coarse woody debris, mast-bearing trees, and sensitive areas such as riparian zones, ephemeral ponds, and rock outcrops.
	Conventional forest	“Managed” on an ad hoc basis, in which the forest is periodically high-graded (most valuable trees periodically removed, uneven-aged/gap cuts) or clearcut. No attention to composition or structure of forests/woodlands historically present in the region.
	Short-rotation woody bioenergy	Short-rotation aspen crop with 10-year rotation, harvested as biomass for biopower and biofuel generation.

[a](K. Arbuckle & Pease, 1999)

Table 2-4. PE/WI Topographic Relief Ranges

Topographic relief (*tr*)
0-1%
1-2%
2-5%
5-9%
9-14%
14-18%
114.6

Table 2-5. Biodiversity Point System

Calculation	Land-use Type	Metric	Points	Thresholds
Native vegetation	Conservation forest, Prairie, Wetland	Percent of watershed area	0.0	Less than 10% area
			1.0	At least 10%, less than 25% area
			2.0	At least 25%, less than 50% area
			3.0	At least 50%, less than 100% area
			4.0	100% area
Native vegetation and other high-diversity land uses	Conservation forest, Conventional forest, Mixed fruits and vegetables, Prairie, Rotational grazing, Wetland	Percent of watershed area	0.0	Less than 10% area
			0.5	At least 10%, less than 50% area
			1.0	At least 50%, less than 100% area
			1.5	100% area
Native vegetation, and comparatively high-diversity and/or low-input land uses*	Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Mixed fruits and vegetables, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	Percent of watershed area	0.0	Less than 10% area
			0.5	At least 10%, less than 50% area
			1.0	At least 50%, less than 100% area
			1.5	100% area
Wetland	Wetland	Percent of watershed area and strategic location	0.0	Less than 5% area and less than 50% of strategic wetland locations in wetland land-use type
			0.5	At least 5% area and at least 50% of strategic wetland locations in wetland land-use type
			1.0	At least 5% area and at least 75% of strategic wetland locations in wetland land-use type
			1.5	At least 5% area and 100% of strategic wetland locations in wetland land-use type

Table 2-5. (Continued)

Calculation	**Land-use Type**	**Metric**	**Points**	**Thresholds**
Stream buffer	Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Mixed fruits and vegetables, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	Percent of stream-adjacent cells	0.0	Less than 10% stream-adjacent cells
			0.5	At least 10%, less than 50% stream-adjacent cells
			1.0	At least 50%, less than 100% stream-adjacent cells
			1.5	100% stream-adjacent cells

Note:
*In this calculation, PE/WI awards up to 1.5 biodiversity points for land uses that include native vegetation and other high-diversity land uses, as well as both low-diversity, high-input and low-diversity, low-input land uses that provide higher diversity support and require fewer inputs than conventionally row-cropped systems.

Table 2-6. Game Wildlife Points

Calculation	Land-use Types	Metric	Points	Thresholds
Native vegetation and other high diversity land uses	Conservation forest, Conventional forest, Mixed fruits and vegetables, Prairie, Rotational grazing, Wetland	Percent of watershed area	0.0	Less than 10% area
			1.0	At least 10%, less than 25% area
			2.0	At least 25%, less than 50% area
			3.0	At least 50%, less than 100% area
			4.0	100% area
Native vegetation and comparatively high-diversity and/or low-input land uses*	Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Mixed fruits and vegetables, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	Percent of watershed area	0.0	Less than 10% area
			0.5	At least 10%, less than 50% area
			1.0	At least 50%, less than 100% area
			1.5	100% area
Conservation forest	Conservation forest	Percent of watershed area	0.0	Less than 5% area
			1.0	At least 5% area
Grassland	Herbaceous perennial bioenergy, Prairie, Rotational grazing	Percent of watershed area	0.0	Less than 5% area
			1.0	At least 5% area
Wetland	Wetland	Percent of watershed area	0.0	Less than 5% area
			1.0	At least 5% area

Table 2-6. (Continued)

Calculation	**Land-use Types**	**Metric**	**Points**	**Thresholds**
Stream buffer	Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Mixed fruits and vegetables, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	Percent of stream-adjacent cells	0.0	Less than 10% stream-adjacent cells
			0.5	At least 10%, less than 50% stream-adjacent cells
			1.0	At least 50%, less than 100% stream-adjacent cells
			1.5	100% stream-adjacent cells

Note:
*In this calculation, PE/WI awards up to 1.5 game wildlife points for land uses that include native vegetation and other high-diversity land uses, as well as both low-diversity, high-input and low-diversity, low-input land uses that provide higher diversity support and require fewer inputs than conventionally row-cropped systems.

Table 2-7. Carbon Sequestration Rates by Land-use Type: Values in PE/WI

Source	**From Annual Row Crop Types[a] to**	**Measured Unit**	**PE/WI Land-use Types**	**Values (Mg ha^{-1} yr^{-1})**
Fissore et al. (2010)	Forests	Total biomass and soils	Conservation forest, Conventional forest	3.67
	Incorporation of cover crops	Soils	Conservation corn, Conservation soybean	0.40
	Perennial grassland	Soils	Prairie	1.07
	Pasture or hay land	Soils	Grass hay, Permanent pasture, Rotational grazing	0.29
	Prairie potholes	Soils	Wetland	3.05
	Short-rotation woody crops	Total biomass and soils	Short-rotation woody bioenergy	4.69
Al-Kaisi et al. (2005)	Switchgrass	SOC, 0-15 cm soil depth[b]	Herbaceous perennial bioenergy	1.20
	Corn-soybean-alfalfa rotation	SOC, 0-15 cm soil depth[b]	Alfalfa	0.50

[a]Conventional corn, Conventional soybean, Mixed fruit and vegetables
[b]Al-Kaisi (2005, p. 642) reported soil organic carbon (SOC) content increases during a 10-year period compared with initial SOC content; measurements were taken at the 0-15 cm soil profile.

Table 2-8. Nitrate-N Concentration: Range of Possible Values in PE/WI

Description	**Notation**	**Rule**	**Possible Values**
Watershed nitrate-N concentration	N	$\sum_{i=1}^{n}\left[\max\left\{100 * PW_i \sum_{j=1}^{m_i} R_{ij}\, C_{ij}, 2\right\} * \frac{A_{i.}}{A_{..}}\right]$	$2\ mg\ L^{-1} \leq N \leq\ 29.54\ mg\ L^{-1}$
Nitrate pollution control index	N_{index}	$100 * \left(1 - \frac{N-2}{29.54-2}\right)$	$0 - 100$
Subwatershed nitrate-N percent contribution	PC_i	$\frac{\max\left\{100 * PW_i \sum_{j=1}^{m_i} R_{ij}\, C_{ij}, 2\right\} * \frac{A_{i.}}{A_{..}}}{N}$	$0 - 100\%$
Precipitation multiplier[a]	P	Dry: Precipitation current year ≤ 71.6 cm	0.86
		Normal after dry: Precipitation current year = 77.2 cm, 81.7 cm, or 87.2 cm; and Precipitation prior year ≤ 71.6 cm	1.69
		Wet after dry: Precipitation current year ≥ 92.6; and Precipitation prior year ≤ 71.6 cm	2.11
		Background: All other climate cycles	1.00
Wetland multiplier[b]	W_i	At least one strategic wetland in the subwatershed with wetland land-use type	0.48
		No strategic wetland locations in the subwatershed with wetland land-use type	1.00
Row crop multiplier[c]	R_{ij}	Land-use types: Conservation corn, Conservation soybean, Conventional corn, Conventional soybean, Mixed fruit and vegetables	$0.14 * \frac{A_{ij}}{A_{i.}}$
		Land-use types: Alfalfa, Conservation forest, Conventional forest, Hay, Herbaceous bioenergy, Permanent pasture, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	0.00
Conservation row crop multiplier[d]	C_{ij}	Land-use types in Des Moines Lobe: Conservation corn, Conservation soybean	$0.69 * \frac{A_{ij}}{A_{i.}}$
		Land-use types in Southern Iowa Drift Plain: Conservation corn, Conservation soybean	$0.62 * \frac{A_{ij}}{A_{i.}}$
		Land-use types: Alfalfa, Conservation forest, Conventional corn, Conventional forest, Conventional soybean, Hay, Herbaceous bioenergy, Permanent pasture, Prairie, Rotational grazing, Short-rotation woody bioenergy, Wetland	$1.00 * \frac{A_{ij}}{A_{i.}}$

[a](Randall & Mulla, 2001)
[b](Thomas Isenhart, Iowa State University, personal communication, 2013)
[c](Schilling & Libra, 2000)
[d](Iowa, 2013)

Table 2-9. Gross Erosion: Range of Possible Values in PE/WI

Description	Notation	Rule	Possible Values
Gross erosion[a]	E	$\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij}E_{ij}$	1.36 exp 2 − 1.10 exp 5 $Mg\ year^{-1}$
Gross erosion index	E_{index}	$100 * \left(\frac{109{,}844 - E}{109{,}844 - 135.7}\right)$	$0 - 100$
Gross erosion rate[a]	E_{ij}	$RI_{ij} + EG_{ij}$	4.03 exp 2 − 1.37 exp 2 $Mg\ ha^{-1}\ year^{-1}$
RUSLE rill and interrill erosion rate[b]	RI_{ij}	$R * K_{ij} * LS_{ij} * C_{ij} * P_{ij}$	4.03 exp −2 − 1.27 exp 2 $Mg^{-1}\ ha^{-1}$
Ephemeral gully erosion rate[c]	EG_{ij}	Land-use types:, Conventional corn, Conventional soybean, Mixed fruit and vegetables	1.01 exp 1 $Mg\ ha^{-1}\ year^{-1}$
		Land-use types: Alfalfa, Conservation corn, Conservation soybean	3.36 $Mg\ ha^{-1}\ year^{-1}$
		Land-use types: All others	0 $Mg\ ha^{-1}\ year^{-1}$
Rainfall erosivity factor[d]	R	$(4.83 \exp -2)\ (10 * pr)^{1.61}, \quad pr \leq 85$ $(5.878 \exp 2) - 1.219(10 * pr)$ $+(4.105 \exp -3)(10 * pr)^2, \quad pr > 85$	1.53 exp 3 − 4.58 exp 3 $MJ\ mm\ ha^{-1}\ h^{-1}\ year^{-1}$
Soil erodibility factor[e]	K_{ij}	Soil series in Des Moines Lobe: Boone County (B); and Southern Iowa Drift Plain: Jasper County (J) 0.0263, *Buckney* 1636 (B) 0.0316, *Clarion* 138B (B) 0.0316, *Coland* 135 (B) 0.0316, *Nicollet* 55 (B) 0.0369, *Canisteo* 507 (B) 0.0369, *Tama* 120B (J) 0.0369, *Tama* 120C2 (J) 0.0369, *Muscatine* 119 (J) 0.0421, *Okoboji* 90 (B) 0.0421, *Downs* 162D2 (J) 0.0421, *Gara − Armstrong* 993E2 (J) 0.0487, *Ackmore − Colo* 5B (J) 0.0487, *Nodaway* 220 (J)	2.63 exp −2 − 4.87 exp −2 $Mg\ ha\ h\ ha^{-1} MJ^{-1}\ mm^{-1}$

Table 2-9. (Continued)

Description	Notation	Rule	Possible Values
Slope length steepness factor[b]	LS_{ij}	Land-use types: Alfalfa, Conservation corn, Conservation soybean, Conventional corn, Conventional soybean, Mixed fruit and vegetables 0.05, $0\% \leq tr_{ij} < 1\%$ 0.31, $1\% \leq tr_{ij} < 2\%$ 0.67, $2\% \leq tr_{ij} < 5\%$ 1.26, $5\% \leq tr_{ij} < 9\%$ 1.79, $9\% \leq tr_{ij} < 14\%$ 2.20, $14\% \leq tr_{ij} < 18\%$	$0.05 - 2.20$
		Land-use types: Permanent pasture, Rotational grazing 0.05, $0\% \leq tr_{ij} < 1\%$ 0.28, $1\% \leq tr_{ij} < 2\%$ 0.58, $2\% \leq tr_{ij} < 5\%$ 1.12, $5\% \leq tr_{ij} < 9\%$ 1.69, $9\% \leq tr_{ij} < 14\%$ 2.18, $14\% \leq tr_{ij} < 18\%$	$0.05 - 2.18$
		Land-use types: All others	1
	L_{ij}	200, $0\% \leq tr_{ij} < 5\%$ 150, $5\% \leq tr_{ij} < 9\%$ 100, $9\% \leq tr_{ij} < 14\%$ 75, $14\% \leq tr_{ij} < 18\%$	$75 - 200$
	S_{ij}	0.2%, $0\% \leq tr_{ij} < 1\%$ 2%, $1\% \leq tr_{ij} < 2\%$ 4%, $2\% \leq tr_{ij} < 5\%$ 8%, $5\% \leq tr_{ij} < 9\%$ 12%, $9\% \leq tr_{ij} < 14\%$ 16%, $14\% \leq tr_{ij} < 18\%$	$0.2 - 16\%$
Cover management factor[f]	C_{ij}	Conventional corn preceding annual row crop: 0.085, *Conservation corn* 0.116, *Conservation soybean* 0.150, *Conventional corn* 0.200, *Conventional soybean* 0.200, *Mixed fruit and vegetables*	$0.085 - 0.200$
		Conservation corn preceding annual row crop: 0.020, *Conservation corn* 0.031, *Conservation soybean* 0.085, *Conventional corn* 0.116, *Conventional soybean* 0.116, *Mixed fruit and vegetables*	$0.020 - 0.116$

Table 2-9. (Continued)

Description	**Notation**	**Rule**	**Possible Values**
		Conventional soybean or mixed fruit and vegetables preceding annual row crop: 0.156, $Conservation\ corn$ 0.178, $Conservation\ soybean$ 0.260, $Conventional\ corn$ 0.300, $Conventional\ soybean$ 0.300, $Mixed\ fruit\ and\ vegetables$	$0.156 - 0.300$
		Conservation soybean preceding annual row crop: 0.052, $Conservation\ corn$ 0.055, $Conservation\ soybean$ 0.156, $Conventional\ corn$ 0.178, $Conventional\ soybean$ 0.178, $Mixed\ fruit\ and\ vegetables$	$0.052 - 0.178$
		All land-use types except Conventional corn, Conservation corn, Conventional soybean, Conservation soybean, and Mixed fruit and vegetables preceding annual row crop: 0.020, $Conservation\ corn$ 0.031, $Conservation\ soybean$ 0.085, $Conventional\ corn$ 0.116, $Conventional\ soybean$ 0.116, $Mixed\ fruit\ and\ vegetables$	$0.020 - 0.116$
		Any land-use type preceding the following land-use types: 0.001, $Herbaceous\ perennial\ bio.$ 0.001, $Prairie$ 0.004, $Conservation\ forest$ 0.004, $Conventional\ forest$ 0.004, $Short-rotation\ woody\ bio.$ 0.005, $Alfalfa$ 0.005, $Grass\ hay$ 0.005, $Wetland$ 0.020, $Rotational\ grazing$ 0.030, $Permanent\ pasture$	$0.001 - 0.030$
Support practice factor[bg]	P_{ij}	Land-use type: Conservation corn, Conservation soybean $1, \quad 2\% > tr_{ij}$ $CS_{ij} * TS_{ij}, \quad 2\% \leq tr_{ij} < 18\%$	$0.4375 - 1$
		Land-use type: All others	1
Contour subfactor[g]	CS_{ij}	$1.000, \quad S_{ij} < 4\%$ $0.925, \quad S_{ij} = 4\%$ $0.875, \quad S_{ij} = 8\%$ $0.900, \quad S_{ij} = 12\%$ $1.000, \quad S_{ij} = 16\%$	$0.875 - 1$

Table 2-9. (Continued)

Description	**Notation**	**Rule**	**Possible Values**
Terrace subfactor[g]	TS_{ij}	0.5, $100 * 0.305 > TI_{ij}$ 0.6, $100 * 0.305 \leq TI_{ij} < 140 * 0.305$ 0.7, $140 * 0.305 \leq TI_{ij} < 180 * 0.305$ 0.8, $180 * 0.305 \leq TI_{ij} < 225 * 0.305$ 0.9, $225 * 0.305 \leq TI_{ij} < 300 * 0.305$ 1.0, $300 * 0.305 \leq TI_{ij}$	$0.5 - 1$
Terrace interval[h]	TI_{ij}	$300 * 0.305$, $S = 0.2\%$ $240 * 0.305$, $S = 2\%$ $180 * 0.305$, $S = 4\%$ $150 * 0.305$, $S = 8\%$ $120 * 0.305$, $S = 12\%$ $105 * 0.305$, $S = 16\%$	$32.0 - 91.5\ m$

[a](USDA NRCS, 2004a)
[b](Renard et al., 1997)
[c](USDA NRCS, 1997)
[d](Renard & Freimund, 1994)
[e](Iowa State University, 2010)
[f](Wendt, 2007)
[g](USDA NRCS, 2002)
[h](USDA NRCS, 2008a)

Table 2-10. Sediment Delivery Ratio (SDR) by Iowa Landform Region and Drainage Area, from Iowa NRCS Erosion and Sediment Delivery (USDA NRCS, 1998).

Hectares	**SDR1**	**SDR2**	**SDR3**	**SDR4**
0.4	97.0	94.0	88.0	80.0
4.0	84.5	68.0	44.0	25.5
25.9	75.0	50.0	25.0	10.0
40.5	73.0	47.0	23.0	9.0
404.7	65.0	35.0	17.5	6.0
4,046.9	57.0	26.0	13.0	4.0

Table 2-11. Sediment Delivery to Stream: Range of Possible Values in PE/WI

Description	**Notation**	**Rule**	**Possible Values**
Sediment delivery to stream[a]	S	$\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij}\left(B_{ij} * E_{ij} * SDR_{ij}\right)$	1.08 exp 1 − 2.12 exp 4 $Mg\ year^{-1}$
Sediment control index	S_{index}	$100 * \left(\frac{21{,}171.6 - S}{21{,}171.6 - 10.8}\right)$	0 − 100
Buffer factor[b]	B_{ij}	Land-use types: Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Prairie, Wetland, Short-rotation woody bioenergy	0.5
		Land-use types: All others	1
Gross erosion rate[a]	E_{ij}	$RI_{ij} + EG_{ij}$ (see Table 2-9)	4.03 exp −2 − 1.37 exp 2 $Mg\ ha^{-1}\ year^{-1}$
Sediment delivery ratio[c]	SDR_{ij}	Grid cells in Des Moines Lobe: $\frac{10^{\log\frac{4}{6} * \log(0.4047 A_{..}) + \log 4 - 4\log\frac{4}{6}}}{100}$	0.044
		Grid cells in Southern Iowa Drift Plain: $\frac{10^{\log\frac{26}{35} * \log(0.4047 A_{..}) + \log 26 - 4\log\frac{26}{35}}}{100}$	0.278

[a](USDA NRCS, 2004a)
[b](Matthew Helmers and Thomas Isenhart, Iowa State University, personal communication, 2014)
[c](USDA NRCS, 1998)

Table 2-12. Phosphorus Delivery to Stream: Range of Possible Values in PE/WI

Description	Notation	Rule	Possible Values
Phosphorus delivery to stream[a]	P	$\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij}P_{ij}$	$1.31 \exp -1 -$ $1.10 \exp 1$ $Mg\ year^{-1}$
Phosphorus control index	P_{index}	$100 * \left(\frac{11.0 - P}{11.0 - 0.131}\right)$	$0 - 100$
Iowa P-Index[a]	P_{ij}	$EC_{ij} + RC_{ij} + SDC_{ij}$	$2.45 \exp -5 -$ $1.80 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
Erosion component[a]	EC_{ij}	$\frac{B_{ij} * E_{ij} * SDR_{ij} * EF_{ij} * STPE_{ij}}{2{,}000}$	$4.77 \exp -7 -$ $1.73 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
Runoff component[a]	RC_{ij}	$RF_{ij} * PF * (STPR_{ij} + PA_{ij})$	$2.26 \exp -5 -$ $9.24 \exp -4$ $Mg\ ha^{-1}\ year^{-1}$
Drainage component[a]	DC_{ij}	$FF_{ij} * PF * STPD_{ij}$	$0 - 1.14 \exp -4$ $Mg\ ha^{-1}\ year^{-1}$
Buffer factor[ab]	B_{ij}	Land-use types: Conservation corn, Conservation forest, Conservation soybean, Conventional forest, Grass hay, Herbaceous perennial bioenergy, Prairie, Wetland, Short-rotation woody bioenergy	0.5
		Land-use types: all others	1
Enrichment factor[a]	EF_{ij}	Land-use types: Conventional corn, Conventional soybean, Mixed fruit and vegetables	1.1
		Land-use types: All others	1.3
Soil test P erosion factor[c]	$STPE_{ij}$	$0.7 * (500 + STP_{ij}) * (2{,}000/1{,}000{,}000)$	$0.82 - 0.83\ ppm$
Soil test P concentration[d]	STP_{ij}	Soil series in Des Moines Lobe	$30\ ppm$
		Soil series in Southern Iowa Drift Plain	$27\ ppm$
Runoff factor[a*]	RF_{ij}	$(7.99 \exp -7) * RCN_{ij}^{3}$ $- (4.84 \exp -5) * RCN_{ij}^{2}$ $+(2.65 \exp -3) * RCN_{ij} - 8.50 \exp -2$	$1.90 \exp -2 -$ $3.57 \exp -1$
Precipitation factor[a]	PF	$(1.00 \exp 4) * pr$	$6.24 \exp -3 -$ $1.15 \exp -2$ $million\ Mg\ ha^{-1}$
Soil test P runoff factor[c]	$STPR_{ij}$	$0.05 + 0.005 * STP_{ij}$	$0.19 - 0.20\ ppm$
P application factor[c]	PA_{ij}	$\frac{PAR_{ij}}{4.58} * 0.5 * TM_{ij} * 0.005$	0 $- 3.61 \exp -5\ ppm$
P application rate, as P_2O_5[defgh*† ‡]	PAR_{ij}	Des Moines Lobe with land-use types: Conservation corn, Conventional corn	$6.61 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Southern Iowa Drift Plain with land-use types: Conservation corn, Conventional corn	$6.50 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Des Moines Lobe with land-use types: Conservation soybean, Conventional soybean	$3.92 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Southern Iowa Drift Plain with land-use types: Conservation soybean, Conventional soybean	$4.26 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$

Table 2-12. (Continued)

Description	**Notation**	**Rule**	**Possible Values**
		Land-use type: alfalfa $13 * YB_{ij}[Alfalfa]$	$5.25 \exp -2 -$ $1.01 \exp -1$ $Mg\ ha^{-1}\ year^{-1}$
		Land-use types: Permanent pasture, Rotational grazing $0.053 * 0.001 * 2.29 * SU * DI * YB_{ij}[Alfalfa]$	$3.44 \exp -3 -$ $1.04 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Des Moines Lobe with land-use type: Grass hay	$3.81 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Southern Iowa Drift Plain with land-use type: Grass hay	$4.37 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Land-use type: Mixed fruit and vegetables $0.25 * [(2.50 \exp -3) GBY + (1.40 \exp -3)\ SQY]$	$1.60 \exp -2$ $Mg\ ha^{-1}\ year^{-1}$
		Land-use types: All others	$0\ Mg\ ha^{-1}\ year^{-1}$
Time and method factor[bc]	TM_{ij}	Land-use types: Conservation corn, Conservation soybean, Grass hay, Permanent pasture, Rotational grazing	1
		Land-use types: Alfalfa	0.9
		Land-use types: Conventional corn, Conventional soybean, Mixed fruit and vegetables	0.8
Flow factor[a]	FF_{ij}	Soil map series meeting conditions for one of the following options: Option 1 • Slope range no greater than 5%; • Drainage class of 60, 65, or 70 (Poor, Poor-Very poor, or Very poor); • Subsoil group of 1 or 2 (Clay less than 40%) Option 2 • Permeability code no greater than 35 or equal to 58, 72, or 75 (Coarse texture subsoil/substrate)	0.1
		Soil map series: All others	0
Soil test P drainage factor[c]	$STPD_{ij}$	0.1, $STP_{ij} \leq 100$ 0.2, $STP_{ij} > 100$	0.1 ppm

Table 2-12. (Continued)

Description	Notation	Rule	Possible Values

[a](USDA NRCS, 2004a)
[b](Matthew Helmers and Thomas Isenhart, Iowa State University, personal communication, 2014)
[c](Mallarino et al., 2005)
[d](Iowa, 2013)
[e](Goolsby et al., 1999)
[f](Jacobson et al., 2011)
[g](Laboski, Peters, & Bundy, 2006)
[h](Sawyer, Mallarino, Killorn, & Barnhart, 2008)

Notes: *
Runoff Curve Number (RCN_{ij}) estimates (Table 2-13).
†Yield rates for alfalfa ($YB_{ij}[Alfalfa]$)(Table 2-18); and green beans (*GBY*), and squash (*SQY*) (Table 2-20)
‡ Seasonal utilization rate (SU) and average daily intake (DI) (Table 2-19).

Table 2-13. Runoff Curve Numbers (USDA NRCS, 2004b)

Land-use Type	**Topographic relief**	**Hydrologic Group**	**Flow Factor**	**Value**
Alfalfa	< 9%	A	-	58
		B, C, D, B/D	> 0	72
		C	0	81
		D, B/D	0	85
Alfalfa	≥ 9%	A	-	55
		B, C, D, B/D	> 0	69
		C	0	78
		D, B/D	0	83
Conservation corn, Conservation soybean	< 9%	A	-	64
		B, C, D, B/D	> 0	74
		C	0	81
		D, B/D	0	85
	≥ 9%	A	-	61
		B, C, D, B/D	> 0	70
		C	0	77
		D, B/D	0	80
Conservation forest, Conventional forest, Short-rotation woody bioenergy	-	A	-	30
		B, C, D, B/D	> 0	55
		C	0	70
		D, B/D	0	77
Conventional corn, Conventional soybean, Mixed fruit and vegetables	-	A	-	72
		B, C, D, B/D	> 0	81
		C	0	88
		D, B/D	0	91
Grass hay, Herbaceous bioenergy	-	A	–	30
		B, C, D, B/D	> 0	58
		C	0	71
		D, B/D	0	78
Permanent pasture	-	A	–	68
		B, C, D, B/D	> 0	79
		C	0	86
		D, B/D	0	89
Prairie, Wetland	-	A	–	30
		B, C, D, B/D	> 0	48
		C	0	65
		D, B/D	0	73
Rotational grazing	-	A	–	49
		B, C, D, B/D	> 0	69
		C	0	79
		D, B/D	0	84

Table 2-14. Crop and Livestock Production

Yield Type	PE/WI Land-use Types	Units
Alfalfa hay (*Medicago sativa* L.)	Alfalfa	Megagrams
Cattle	Permanent pasture, Rotational grazing	Animals
Corn grain (*Zea mays* L.)	Conventional corn, Conservation corn	Megagrams
Grass hay	Grass hay	Megagrams
Herbaceous perennial biomass (*Panicum virgatum* L.)	Herbaceous perennial bioenergy	Megagrams
Mixed fruit and vegetables	Mixed fruit and vegetables	Megagrams
Short-rotation woody biomass	Short-rotation woody bioenergy	Megagrams
Soybeans (*Glycine max* (L.) Merr.)	Conservation soybean, Conventional soybean	Megagrams
Wood	Conservation forest, Conventional forest	Cubic meters

Table 2-15. Yield

Description	Notation	Rule	Values
Yield	$Y[Yield\ Type]$	$\sum_{i=1}^{n}\sum_{j=1}^{m_i} A_{ij} * YB_{ij}[Yield\ Type] * YP_{ij}$	$Varies$
Yield index	$Y[Yield\ Type]_{index}$	$100 * \frac{Y[Yield\ Type]}{Y[Yield\ Type]_{max}}$	$0 - 100$

Table 2-16. Yield Type Precipitation Factor at Different Precipitation Levels

Land-use Types	Precipitation (cm) Factors						
	62.4	71.6	77.2	81.7	87.2	92.6	114.6
Alfalfa, Grass hay, Herbaceous Perennial bioenergy, Permanent pasture, Rotational grazing	0.75	0.90	1.00	1.00	1.00	0.90	0.75
Conservation corn, Conservation soybean, Conventional corn, Conventional soybean	0.95	1.00	1.00	1.00	1.00	1.00	0.95
Mixed fruit & vegetables	1.00	1.00	1.00	1.00	1.00	0.90	0.75
All others	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 2-17. Yield Base Rate: Corn and Soybean[a]

County	ISPAID Soil Type	Yield Base Rate (Mg ha^{-1} year^{-1})	
		Corn	**Soybean**
Boone County	Clarion 138B	14.0	4.37
	Buckney 1636	0	0
	Canisteo 507	13.4	4.17
	Coland 135	13.2	4.10
	Nicollet 55	14.3	4.44
	Okoboji 90	11.2	3.49
Jasper County	Downs 162D2	12.9	4.03
	Gara-Armstrong 993E2	0	0
	Ackmore-Colo 5B	12.6	3.90
	Tama 120C2	13.9	4.30
	Tama 120B	14.7	4.57
	Muscatine 119	15.1	4.70
	Nodaway 220	13.1	4.10

[a](Iowa State University, 2010)

Table 2-18. Yield Base Rate: Alfalfa and Grass Hay[a]

County	ISPAID Soil Type	Yield Base Rate (Mg ha^{-1} year^{-1})
Boone County	Clarion 138B	14.1
	Buckney 1636	8.07
	Canisteo 507	9.64
	Coland 135	9.42
	Nicollet 55	14.4
	Okoboji 90	8.07
Jasper County	Downs 162D2	12.6
	Gara-Armstrong 993E2	8.07
	Ackmore-Colo 5B	9.19
	Tama 120C2	14.6
	Tama 120B	15.5
	Muscatine 119	15.0
	Nodaway 220	14.1

[a](Iowa State University, 2010)

Table 2-19. Yield Base Rate for Cattle: Range of Possible Values in PE/WI

Description	Notation	Rule	Possible Values
Cattle supported yield base rate[a]	$YB_{ij}[Cattle]$	$YB_{ij}[Alfalfa] * SU/(DI * GS)$	$0.87 - 2.61$ $animals\ ha^{-1}\ year^{-1}$
Seasonal utilization rate[a]	SU	Land-use type: Permanent pasture	0.35
		Land-use type: Rotational grazing	0.55
Average daily intake[a]	DI	3% of live bodyweight $0.03\ day^{-1} * 0.544\ Mg$	1.63 exp -2 $Mg\ day^{-1}\ animal^{-1}$
Grazing season length[b]	GS	April 15 – November 1	200 $days$

[a](USDA NRCS, 2008c)
[b](Iowa Beef Center, 2007)

Table 2-20. Yield Base Rate: Mixed Fruit and Vegetables: Range of Possible Values in PE/WI

Description	Notation	Rule	Possible Values
Mixed fruit and vegetable yield base rate	$YB_{ij}\begin{bmatrix} Mixed\ fruit \\ and\ vegetable \end{bmatrix}$	$0.25 * STM * (GRY + GBY + SQY + STY)$	$6.58 - 16.4$ $Mg\ ha^{-1} year^{-1}$
Grape yield[ab]	GRY	-	17.6 $Mg\ ha^{-1}\ year^{-1}$
Green bean yield[c]	GBY	-	6.73 $Mg\ ha^{-1}\ year^{-1}$
Squash yield[c]	SQY	-	33.6 $Mg\ ha^{-1}\ year^{-1}$
Strawberry yield[c]	STY	-	7.85 $Mg\ ha^{-1}\ year^{-1}$
Soil texture multiplier[c]	STM	Fine sandy loam	1.00
		Silt loam	0.90
		Loam	0.85
		Clay loam, Mucky silt loam, Silty clay loam	0.40

[a](Delate & Friedrich, 2004)
[b](R. M. Post & Robinson, 1995)
[c](Taber, 2009)

Table 2-21. Yield Base Rate: Wood[ab]

County	ISPAID Soil Type	Yield Base Rate (m^3 ha^{-1} $year^{-1}$)
Boone County	Clarion 138B	1.630
	Buckney 1636	0.741
	Canisteo 507	0.504
	Coland 135	0.504
	Nicollet 55	1.040
	Okoboji 90	0.504
Jasper County	Downs 162D2	1.630
	Gara-Armstrong 993E2	1.560
	Ackmore-Colo 5B	0.771
	Tama 120C2	1.630
	Tama 120B	1.630
	Muscatine 119	1.040
	Nodaway 220	1.631

[a](IDNR & USDA NRCS, 2007)
[b]Yield Base Rate figures are for conventional forest.
We apply a 30% reduction factor for conservation forest wood yield.

Table 2-22. Yield Base Rate: Herbaceous Perennial Bioenergy[a]

County	ISPAID Soil Type	Yield Base Rate (Mg ha^{-1} $year^{-1}$)
Boone County	Clarion 138B	5.77
	Buckney 1636	4.39
	Canisteo 507	5.65
	Coland 135	5.65
	Nicollet 55	6.25
	Okoboji 90	4.39
Jasper County	Downs 162D2	4.39
	Gara-Armstrong 993E2	4.39
	Ackmore-Colo 5B	4.81
	Tama 120C2	5.29
	Tama 120B	6.31
	Muscatine 119	6.61
	Nodaway 220	5.83

[a](Emily Heaton, Iowa State University, personal communication, 2014)

Table 2-23. PE/WI Example Scenarios

Scenario Number	Scenario Description
1	Conventional corn-soybean-corn rotation with normal climate, i.e. precipitation equals 81.7 cm in all years.
2	Conventional corn-soybean-corn rotation with interannual climate variability, i.e. precipitation equals 81.7 cm in year 0, 62.4 cm in year 1, 114.6 cm in year 2, and 81.7 cm in year 3.
3	Two-thirds area in conservation corn-soybean-corn rotation and one-third in strategically placed marketable perennial land-use types with normal climate, i.e. precipitation equals 81.7 cm in all years.
4	Two-thirds area in conservation corn-soybean-corn rotation and one-third in strategically placed marketable perennial land-use types with interannual climate variability, i.e. precipitation equals 81.7 cm in year 0, 62.4 cm in year 1, 114.6 cm in year 2, and 81.7 cm in year 3.

Figure 2-1. PE/WI Interface: Controls (left), Interactive Watershed (center), Download and Info Tabs (upper right), Ecosystem Service Indicators (middle right), and Design Years (bottom right).

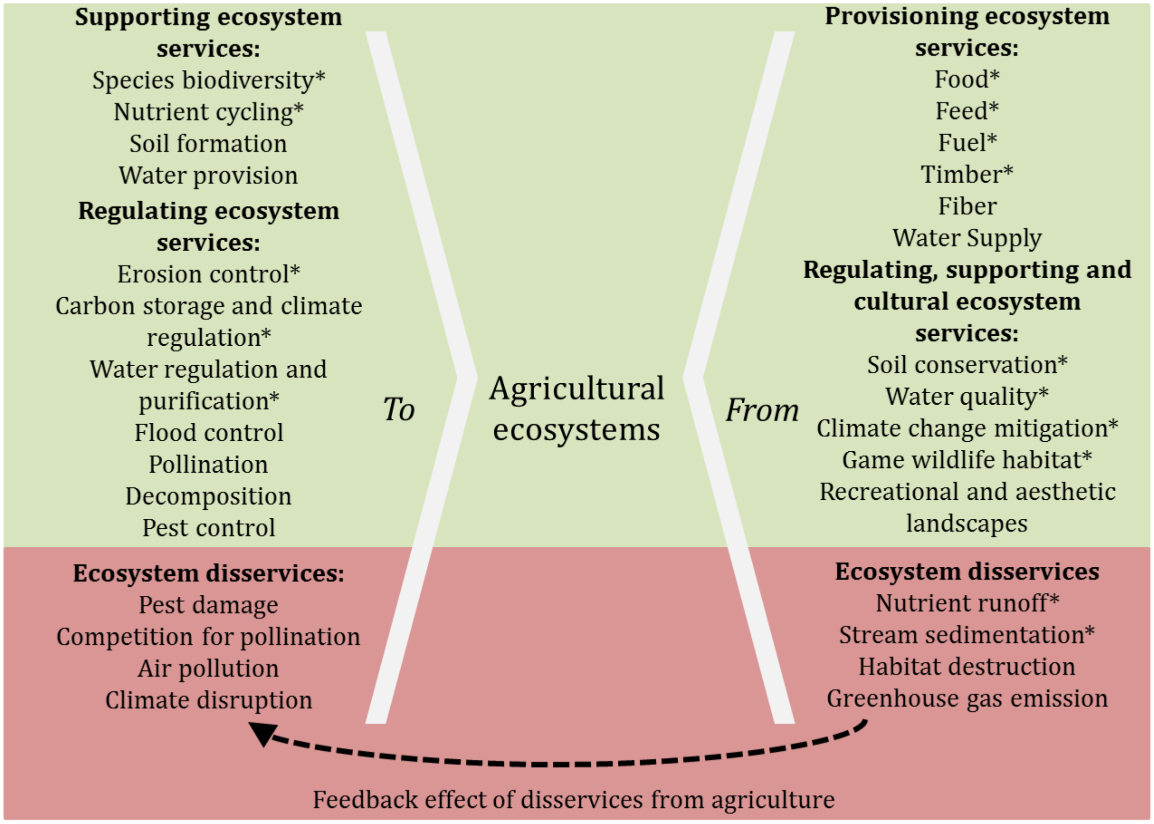

Figure 2-2. Ecosystem services and disservices to and from agriculture, adapted from Zhang et al. (2007). Asterisks (*) represent services and disservices either indirectly or directly reported in PE/WI.

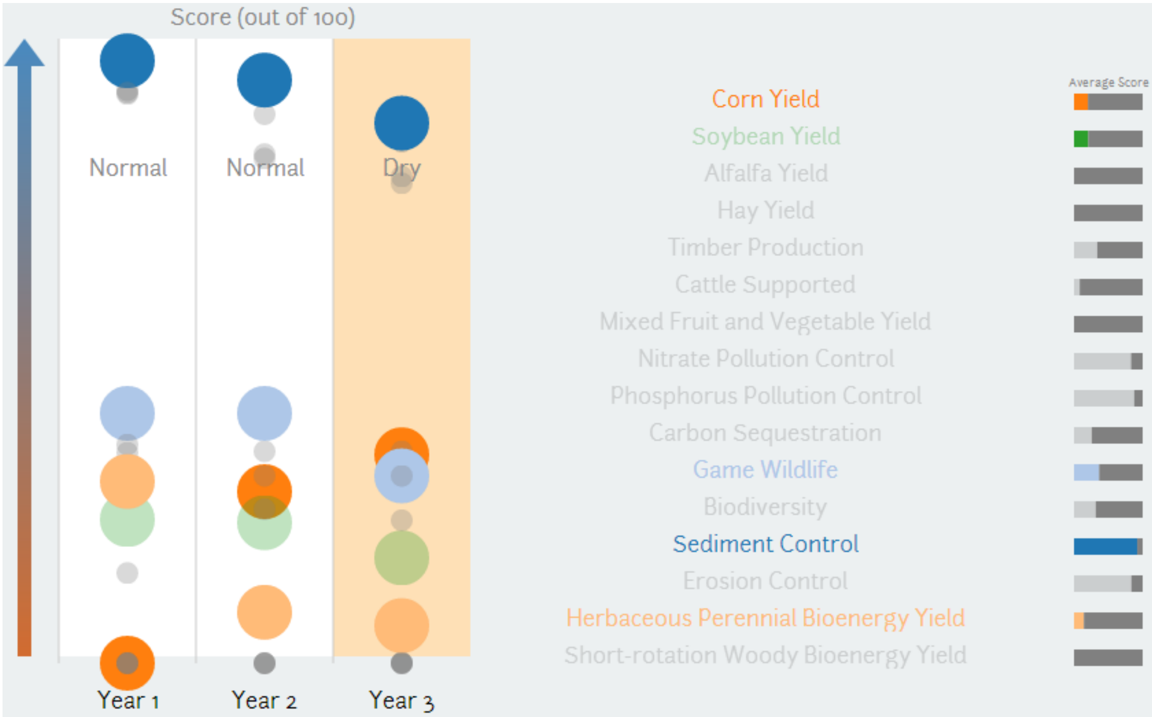

Figure 2-3. PE/WI Index Score Results

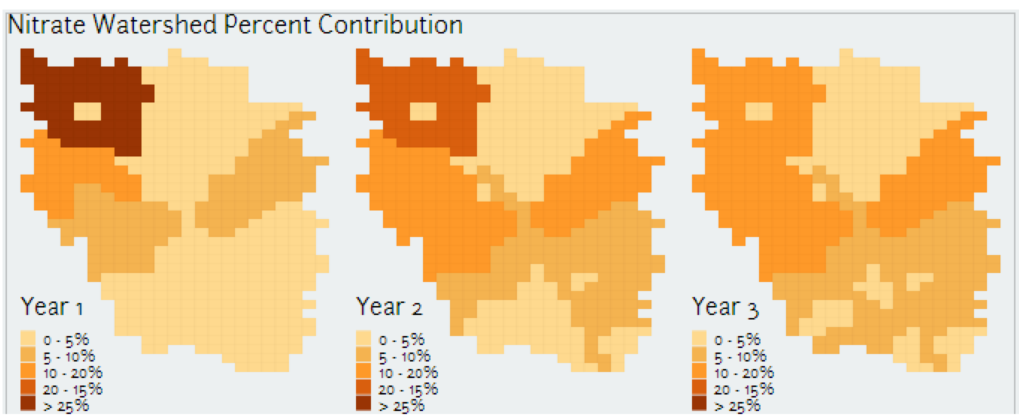

Figure 2-4. PE/WI Spatial-Temporal Maps of Ecosystem Service Indicators

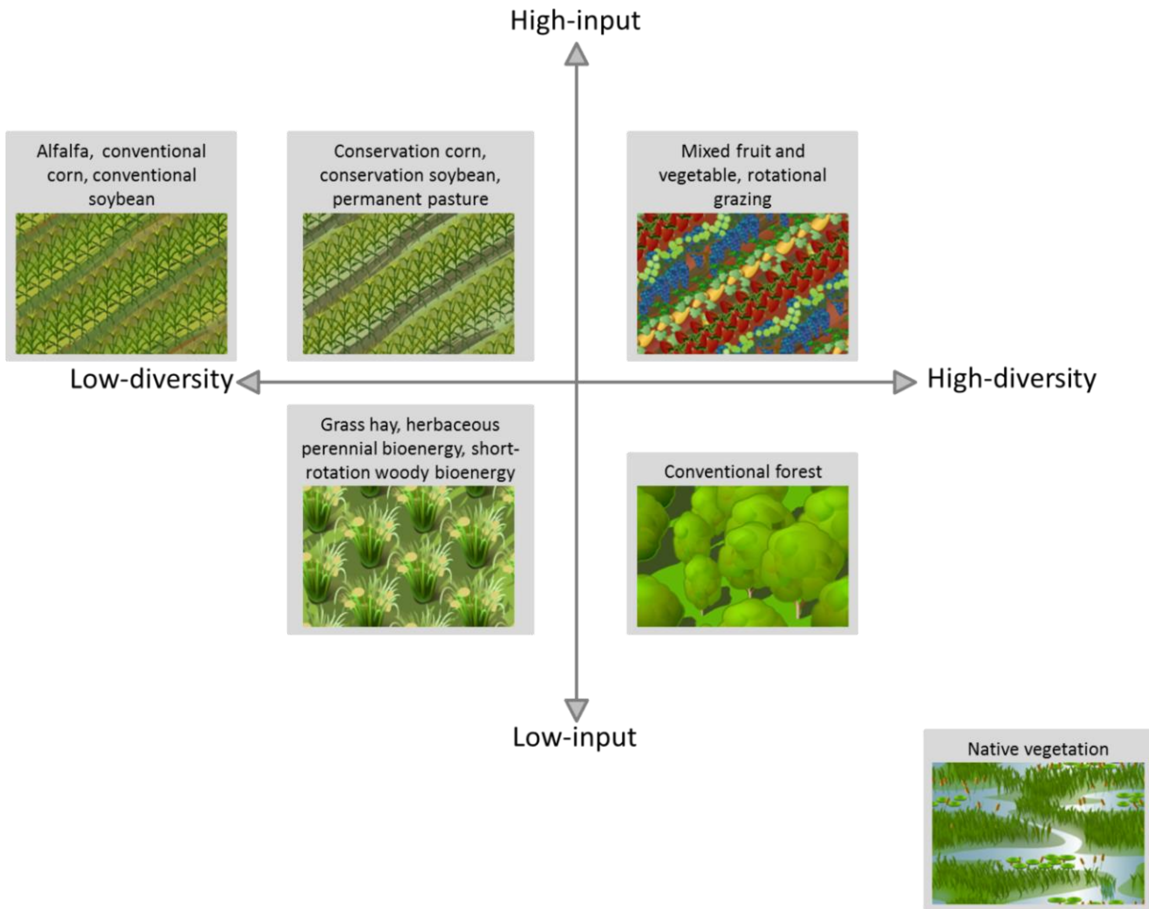

Figure 2-5. Diversity and input matrix for managed ecosystems, with native vegetation included (lower right) for reference; adapted from Schulte, Ontl, and Larsen (2013).

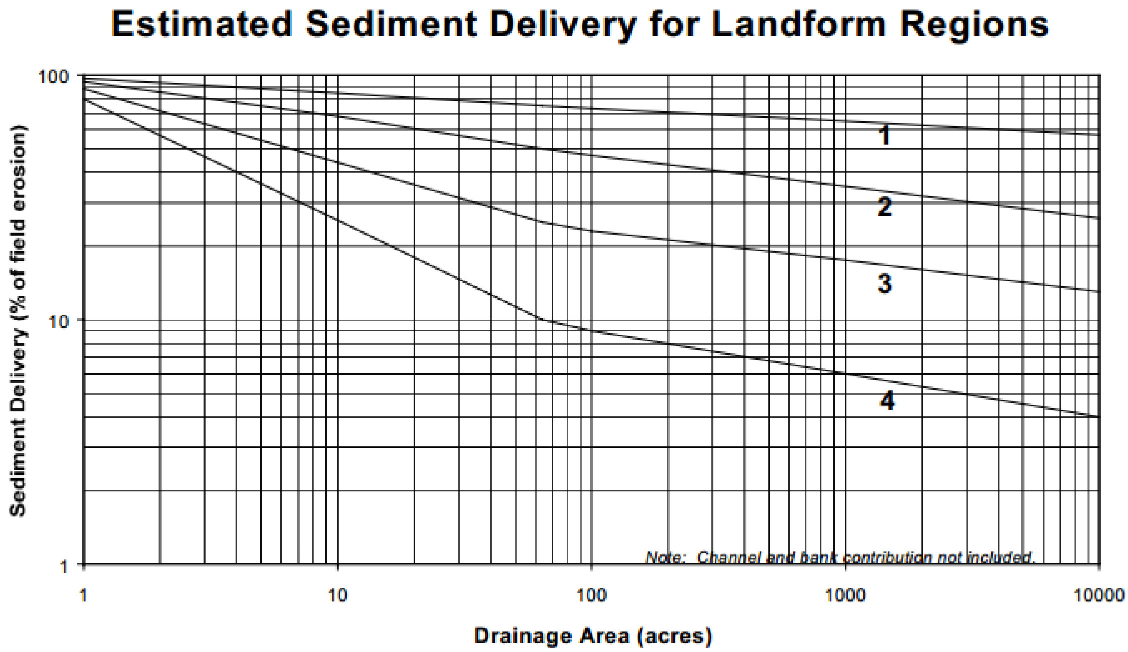

Figure 2-6. Sediment Delivery Ratio; from Iowa NRCS Erosion and Sediment Delivery (USDA NRCS, 1998).

CHAPTER 3

PEOPLE IN ECOSYSTEMS/WATERSHED INTEGRATION: A WEB-BASED LEARNING TOOL FOR EVALUATING ECOSYSTEM SERVICES TRADEOFFS FROM WATERSHEDS

A paper to be submitted for publication to the *Journal of Soil and Water Conservation*

Carrie M. Chennault, Lisa A. Schulte, and John C. Tyndall

Introduction

Society has the knowledge, information, and expertise to provide valuable ecological functions from agricultural landscapes while supporting vibrant farmer and rural livelihoods, but that potential remains largely untapped. While intensive production systems common to the United States Corn Belt and other agricultural regions provide high levels of a small number of provisioning ecosystem services, these systems externalize high costs to producers and society. Farmers face a host of environmental and societal pressures that threaten operations, profitability, and community livelihoods, including volatile markets; extreme weather; soil degradation; surface water impairment; and groundwater contamination (Robertson et al., 2014). By managing for multiple ecosystem services, farmers can help mitigate such risks to themselves and society.

The aim of agricultural modernization is to support a growing human population with limited resources. We suggest that an integrated ecosystem services tradeoffs framework provides an opportunity to design landscapes that enhance the production of multiple services while maintaining farmer profitability or mitigating risk to farmers. At present, however, few tools exist to evaluate how changes to land management affect the types and levels of services delivered to humans.

People in Ecosystems/Watershed Integration, version 2 (PE/WI or PE/WI v2) is a new tool that integrates research on agricultural production and environmental services with a virtual interactive watershed. In designing PE/WI v2, our objective was to allow users to better visualize market and non-market environmental outcomes of land-use decisions. PE/WI v2 is an online tool with a simple approach: users design and evaluate patterns of land use on a virtual US Corn Belt watershed across multiple years and variable climate conditions.

PE/WI illustrates agronomic, watershed, and biodiversity management principles important for sustainable land use and land management. The tool also teaches complex principles key to human livelihoods, including resilience and adaptation during periods of climate and political-economic uncertainty. The web-based PE/WI v2 improves upon the original spreadsheet-based PE/WI v1 tool (Schulte, Donahey, Gran, Isenhart, & Tyndall, 2010) with new and intuitive modeling and graphic user-interface features.

Our goal with PE/WI is to foster multidimensional and integrative thinking regarding land-management decisions. PE/WI is an educational tool with the capacity to broadly inform users on the consequences of land-use choices (Schulte et al., 2010). It differs from other models that simulate the complex tradeoffs associated with land use in that it does not require guidance from expert modelers.

PE/WI provides instant feedback to any user, reveals both relative and absolute tradeoffs among ecosystem services, and does not require user-supplied data. This innovative approach allows stakeholders to simultaneously consider agricultural land use, climate conditions, production outcomes (e.g., crops and livestock), and environmental outcomes such as nutrient and sediment levels in water, habitat provision for biodiversity, soil erosion, and carbon management.

Overview of Model Updates

The PE/WI v2 tool is a fully-contained, open source web-based application that does not require user-supplied data. Updates from the first version include a more user-friendly, web-based format, an expanded watershed area, additional land-use options, varying climate conditions, a temporal component, expanded model components, an expanded set of output indicators, improved graphics, and enhanced interaction with watershed tools and indicator outputs. PE/WI v2 model update incorporates additional real-world data on soil properties and the effects of temporal and climate sequences, and reflects other recent advances in scientific understanding. While the current model represents a hybrid of real-world data within a fictitious US Corn Belt watershed, we see enormous potential to eventually adapt the model structure to real-world watersheds.

Users interact with the PE/WI model through interface controls to create land-use designs for Year 1, followed by Years 2 and 3 (Figure 3-1). This interaction creates a land-use data set that users may download, save, share, and later re-upload in PE/WI. The tool includes a main watershed interface, five predefined physical feature maps, 15 land-use options, seven climate conditions, an interactive plot of 16 ecosystem service indices, three environmental service maps, and summary numerical results. User-created land-use designs, in conjunction with predefined physiographic characteristics and randomized annual climate conditions, serve as inputs for modeling ecosystem services outputs.

The PE/WI v2 interactive watershed is a fictitious watershed based on two Iowa landform regions, the Des Moines Lobe and the Southern Iowa Drift Plain (Prior, 1991, p. 30), representing the western and eastern halves of the PE/WI watershed, respectively. The PE/WI v2 watershed—which we represented spatially in the application as a collection of 593 grid cells configured around a vector-graphic stream to approximate a 2,383 hectare watershed—uses data from the Iowa Soil Properties and Interpretations Database, ISPAID (Iowa State University, 2010). To simulate climate variability across years, the program randomly assigns annual climate conditions based on historical annual precipitation data from Iowa.

Users manipulate land use in each PE/WI grid cell by selecting one of 15 land-use types for each year (Table 3-1). PE/WI also allows users to apply in-field, prairie/wetland restoration, and riparian zone conservation practices on a cell by cell basis. Maps of predefined physical features (e.g. topographic relief, flood frequency, strategic wetland locations, subwatershed boundaries, and drainage class) further inform user land-use selection.

Based on the user-supplied designs of land-use, the PE/WI model calculates levels of 16 ecosystem service indicators. Provisioning ecosystem service indicators include nine commodity crop and livestock production types (alfalfa, cattle, corn, grass hay, herbaceous perennial bioenergy, mixed fruit and vegetable, short-rotation woody bioenergy, soybean, and wood). Regulating ecosystem service indicators fall into three groups: stream water quality indicators include control of nitrate, sediment, and phosphorus pollution; the soil quality indicator of soil erosion control; and the climate regulation indicator of carbon sequestration. Habitat for biodiversity serves as a supporting ecosystem service indicator. Cultural ecosystem service indicators include habitat for game wildlife; water quality indicators may also represent opportunities to provide cultural services.

Each of the 16 ecosystem service indicators translates to a unitless index score ranging between 0 (lowest level of ecosystem service attainable in the simulation) and 100 (highest level of ecosystem service attainable in the simulation) (Figure 3-2). Scores are represented by a graphic plot that allows users to select which ecosystem services to highlight and provides a comprehensive visualization of tradeoffs.

Users also may view output maps of source areas for three indicators across each year: soil erosion, watershed phosphorus contributions, and nitrate watershed percent contributions. The example map (Figure 3-3) resulted from a user manipulation over the three-year period of simulation that targeted the upper left-hand subwatershed for improvements water quality management. In addition to index scores and plots, PE/WI results include numerical summaries of area in each land-use type, index scores, and biophysical values for each ecosystem service indicator. The ecosystem service indicator outputs in PE/WI, presented graphically, spatially, and numerically, enrich the user experience and ability to evaluate tradeoffs.

Learning Concepts and Exercises

As individuals and societies consider issues of high complexity, uncertainty, and societal urgency, researchers including Biggs et al. (2010) call for “new ways of thinking” that “reframe the relationship between science and decision making” (p. 267). PE/WI supports this new way of thinking through multiple learning opportunities, including scenario planning, which Biggs et al. (2010) heralded as pivotal for teaching students and society how to address environmental challenges.

PE/WI has enormous flexibility as an educational tool. We briefly present four learning opportunities here. We then expand on one example, allowing users to explore PE/WI learning opportunities, exercises, and concepts. Although we mention four opportunities here, PE/WI supports many other learning opportunities. Instructors or facilitators may use PE/WI to engage users to:

- Discuss ecological principles underlying the PE/WI model;
- Use ecosystem service indicator outputs as inputs for economic valuations and broader discussion of payments for ecosystem services;
- Consider tradeoffs and societal constraints to land-use change;

- Design landscape scenarios that meet assigned goals and objectives, such as Iowa Nutrient Reduction Strategy goals for nitrogen and phosphorus reduction (Iowa, 2013).

The remainder of this section focuses on the fourth learning opportunity, scenario design to meet goals and objectives. PE/WI facilitates scenario creation, allowing users to explore and understand complex social-ecological relationships without delving into details underlying those relationships. We intend for PE/WI learning exercises to help users explore how different land uses, as well as landscape configuration, lead to different ecosystem service outcomes and tradeoffs. To understand the connections between landscape designs and results, users iteratively create designs and review indices, maps, and summary results for ecosystem service indicators (Figure 3-2 and Figure 3-3). This process aids learners in multidimensional and integrative thinking by allowing people to visualize results across space and time and to modify land-use types to meet desired goals for the watershed.

We provide example basic learning concepts and exercises to help users get started with PE/WI (Table 3-2). The exercises range in level from beginner to advanced learner and may be completed individually or in a group setting. Each exercise builds upon concepts in the previous exercise. General questions for reflection include: "When and where on the landscape are land-use tradeoffs minimized? How are ecosystem service co-benefits maximized? How do spatial patterns of land use affect ecosystem service outcomes? How does variation in annual precipitation affect ecosystem service outcomes?" Users can answer these questions because PE/WI helps people understand how production and associated tradeoffs vary across space and time.

To demonstrate how our exercises help users achieve learning objectives, we present three scenario designs created by PE/WI users during the "Targeting for Water Quality" exercise (Table 3-3), which aims to teach users the concepts of minimized tradeoffs and maximized co-benefits. There is no single correct design, and users created several designs that accomplished the exercise's objectives of minimized tradeoffs and maximized co-benefits. Furthermore, designs were more or less effective depending on different climate scenarios. In the following illustration, we consider tradeoffs in user designs compared to a baseline scenario land-use of 100% conventional corn-soybean rotation.

The three user designs in this example incorporated management and land-use practices with an objective of dramatically improving water quality with minimal production loss. Users aimed to create designs that would meet goals for nutrient reduction set forth in the Iowa Nutrient Reduction Strategy (Iowa, 2013). The user-selected suite of environmentally beneficial strategies reflects real-world practices for managing ecosystem function, including in-field conservation practices, edge-of-field and erosion control practices, and land-use change. PE/WI, for example, helps users test the effect of targeted water quality management by establishing perennial plant cover in environmentally sensitive landscape positions (e.g., steep slopes, shallow soils, adjacencies to water bodies), where the physical structure of perennial plant systems can have a greater impact on reducing nutrient and sediment losses compared to a more arbitrary placement of the same practices (Secchi, Tyndall, Schulte, & Asbjornsen, 2008).

Strategies that are effective under average climate conditions may not work well in years with extreme climate cycles (Table 3-3, scenarios 1 and 2). Further, adoption of a broad suite of conservation practices alone is not enough to achieve Iowa Nutrient Reduction Strategy goals for nitrogen and phosphorus reduction (Iowa, 2013). In the second and third PE/WI watershed designs, users made tradeoffs that reduced agricultural production of corn and soybean by approximately 10%, and only by incorporating all four strategies did they effectively mitigate nutrient pollution in years with extreme climate cycles.

Conclusion

Few existing tools provide the type of learning platform that PE/WI offers: a broadly accessible, yet comprehensive framework for considering ecosystem services tradeoffs. In initial uses, we have seen PE/WI's ability to fundamentally alter people's frameworks for land-use management and decision making. We see an enormous future potential for PE/WI to help: people understand how commodities might be co-produced with other ecosystem services; land managers, land owners, and communities develop shared understanding of watershed processes and foster multi-stakeholder, watershed-scale decision making; and agricultural stakeholders develop effective strategies to mitigate economic and social risks associated with climate change, biodiversity loss, and natural resource impairment. The updated tool combines the best available science with an appealing, interactive platform that we hope will engage user groups such as students, farmers, and policy makers in the US Corn Belt and beyond.

User Instructions

PE/WI is available online at http://www.nrem.iastate.edu/landscape/pewi. The supporting website, http://www.nrem.iastate.edu/landscape/content/pewi, provides supporting materials, including links to a user guide and lesson plans. We are currently collecting a library of learning exercises and lesson plans for public use, to be made available on the PE/WI supporting website. We encourage educators and other PE/WI users to contribute to the library. For a comprehensive overview of the computational framework and data used for PE/WI, see Chennault (2014, Ch. 2).

Acknowledgement

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Jordan, Lisa Mandle, Taylor Ricketts, students in their classrooms, and students at Iowa State University, who used PE/WI v2 during its initial beta release and provided invaluable feedback for its development.

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Table 3-1. PE/WI Land-use Category, Type, and Description

Land-use Category	**Land-use Type**	**Description**
Perennial legume	Alfalfa	Perennial forage crop harvested primarily for hay or silage; may be included in long-term rotations with other crops.
Annual grain	Conservation corn	Annual grain crop managed using conservation practices, such as no-till, cover crops, grassed waterways, and/or buffers. Contouring and/or terracing where location-appropriate.
	Conventional corn	Annual grain crop managed using conventional tillage.
Annual legume	Conservation soybean	Annual legume crop managed using conservation practices, such as no-till, cover crops, grassed waterways, and/or buffers. Contouring and/or terracing where location-appropriate.
	Conventional soybean	Annual legume crop managed using conventional tillage.
Pasture	Permanent pasture	Forage (alfalfa and/or grass) grazed by cattle throughout the typical grazing season.
	Rotational grazing	Forage (alfalfa and/or grass) grazed by cattle through the typical grazing season; managed by strategically rotating cattle across paddocks to promote even grazing.
Perennial herbaceous (non-pasture)	Grass hay	Perennial forage crop harvested primarily for hay or silage.
	Herbaceous perennial bioenergy	Perennial herbaceous crop (switchgrass) harvested as biomass for biopower and biofuel generation. Low levels of management.
	Prairie	Diverse mix of tallgrass prairie vegetation native to Iowa.
	Wetland[a]	Constructed pooled water areas designed to include water, soil, and plant features that restore ecological functions and processes of native, naturally occurring wetlands. Managed for habitat for biodiversity, controlling nitrate flow to streams, or both.
Perennial woody	Conservation forest	Managed for historically relevant compositional and structural diversity using uneven-aged (gap or patch cuts) or even-aged (shelterwood, crop tree release) techniques and other management (timber stand improvement, prescribed burning and/or tactical grazing, removal of invasives). Management of coarse woody debris, mast-bearing trees, and sensitive areas such as riparian zones, ephemeral ponds, and rock outcrops.
	Conventional forest	"Managed" on an ad hoc basis, in which the forest is periodically high-graded (most valuable trees periodically removed, uneven-aged/gap cuts) or clearcut. No attention to composition or structure of forests/woodlands historically present in the region.
	Short-rotation woody bioenergy	Short-rotation aspen crop with 10-year rotation, harvested as biomass for biopower and biofuel generation.

[a](Arbuckle & Pease, 1999)

Table 3-2. Example PE/WI Learning Concepts and Exercises

Concepts	Objectives	Exercises
Ecological Functions	Understand how watershed ecosystem service indicators are linked to land use and land cover.	Create two scenarios: 1) All corn and soybean 2) All perennial vegetation Questions: 1) Which scenario has the highest potential to produce the following ecosystem goods: crops, timber, cattle? 2) Which scenario has the highest potential to produce the following ecosystem service indicators: habitat for biodiversity, carbon storage, water quality? 3) Which land-use types are perennial types? 4) How does the presence of perennial vegetation in the watershed relate to the delivery of services?
Targeting	Understand how some locations in watersheds have greater positive or negative impact on watershed ecosystem service indicators than others, due to their environmental configuration.	Create three scenarios: 1) Agricultural production landscape 2) Scenario 1 altered to dramatically improve water quality, with minimal production loss 3) Scenario 2 altered to dramatically improve habitat for biodiversity, with minimal production loss Questions: 1) Why are each of the five physical feature maps (topographic relief, flood frequency, subwatershed boundaries, strategic wetland areas, and drainage class) are important? 2) How does spatial placement of perennial vegetation impact the following ecosystem services: water quality, biodiversity, game wildlife, crop productivity, carbon sequestration?
Tradeoffs	Understand that tradeoffs exist among land-use types and their location in achieving multiple outputs from watersheds. Understand how to enhance co-benefits (multiple ecosystem goods and services) from land-use types and their locations.	Create one scenario: 1) Maximize all watershed ecosystem goods and services Questions: 1) What are the characteristics of the scenario in terms of land-use composition and placement? 2) What are the key decisions for developing this scenario? 3) What are two economic, two ecological, and two social challenges to achieving this design in the real world?

Table 3-3. Learning Exercise: Targeting to Improve Water Quality with Minimal Production Loss

	Design 1	**Design 2**	**Design 3**
Landscape Design			
Conservation Annual Row Crops	**Yes**	No	**Yes**
Alternative Crops: locations where annual row crop yields are lower	**Yes**	**Yes**	**Yes**
Alternative Crops: locations where slopes >9%	No	**Yes**	**Yes**
Strategic Wetlands	No	**Yes**	**Yes**
% Max Annual Row Crop Production: normal precipitation	100%	90%	90%
% N Reduction: normal precipitation	36%	43%	59%
% P Reduction: normal precipitation	75%	31%	79%
% Max Annual Row Crop Production: extreme dry-wet cycles	85%	76%	76%
% N Reduction: dry-wet cycles	-7.8%	3.6%	31%
% P Reduction: dry-wet cycles	71%	14%	75%

Table 3-4. "Targeting Water Quality" Exercise: Percent Area in each Land-use Type and Precipitation Levels for Normal and Dry-Wet Cycle Scenarios

	Percent Area Design 1			**Percent Area Design 2**			**Percent Area Design 3**		
Land-use Type	**Y1**	**Y2**	**Y3**	**Y1**	**Y2**	**Y3**	**Y1**	**Y2**	**Y3**
Conservation Corn	93.8	-	93.8				83.5	-	83.5
Conservation Forest	1.3	1.3	1.3	1.8	1.8	1.8	1.8	1.8	1.8
Conservation Soybean	-	93.8	-	-	-	-	-	83.5	-
Conventional Corn	-	-	-	83.5	-	83.5	-	-	-
Conventional Soybean	-	-	-	-	83.5	-	-	-	-
Grass Hay	2.7	2.7	2.7	4.9	4.9	4.9	4.9	4.9	4.9
Herbaceous Perennial Bioenergy	2.2	2.2	2.2	6.4	6.4	6.4	6.4	6.4	6.4
Wetland	-	-	-	3.4	3.4	3.4	3.4	3.4	3.4
Precipitation									
Normal (year 0 = 81.7 cm)	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7
Dry-wet cycle (year 0 = 24.58 cm)	114.6	71.6	92.6	114.6	71.6	92.6	114.6	71.6	92.6

Figure 3-1. PE/WI Interface: Controls (left), Interactive Watershed (center), Download and Info Tabs (upper right), Ecosystem Service Indicators (middle right), and Design Years (bottom right)

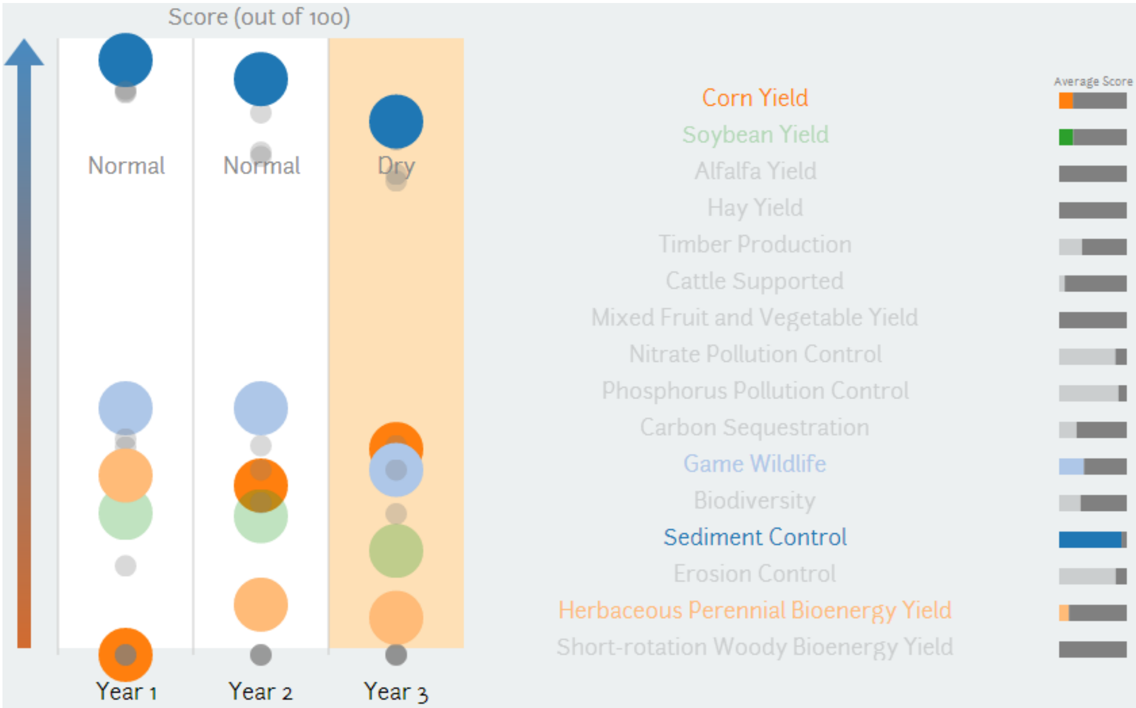

Figure 3-2. Example Index Scores for Three Year Scenario with Normal-Normal-Dry Climate Sequence

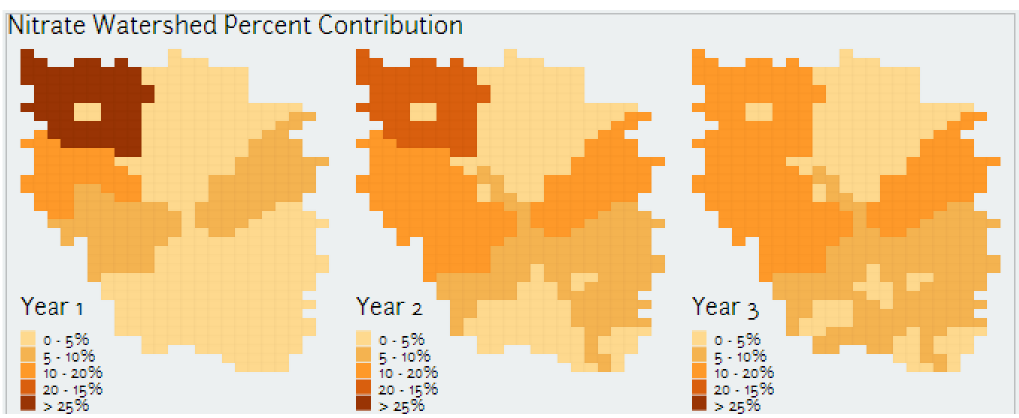

Figure 3-3. Example Watershed Maps of Results for Nitrate Watershed Percent Contribution by Year

CHAPTER 4

GENERAL CONCLUSION

The People in Ecosystems/Watershed Integration (PE/WI) project provided me with opportunity to explore and synthesize research on ecosystem management of agricultural watersheds from a range of academic disciplines. The science supporting PE/WI is rich, complex, rigorously developed and reviewed, often well-established, and sometimes uncertain.

Synthesis research enables scientists to communicate their work to the broader public, and PE/WI-like modeling tools provide effective mechanisms to distribute scientific knowledge. Throughout development of PE/WI, our team repeated a mantra of “Keep it simple” to remind ourselves that the detailed intricacies of scientific data can translate into a simple, yet comprehensive and computationally accurate framework. In retrospect, few aspects of PE/WI are truly simple beyond its user interface. The science illuminating the relationship between land use, climate, ecosystem functions, and ecosystem services requires a vast body of knowledge and expertise that, in sum, is beyond my intellectual attainment or that of any single scientist. To communicate science, even among scientists, we translate, summarize, conclude, and generalize. Communicating research to the public challenges us further to disseminate clear messages that enhance rather than cloud understanding. Whether the lessons and nuanced concepts embedded in PE/WI easily translate into acquired knowledge for its users remains an important question to investigate.

After the initial phase of PE/WI v2 development and model publication, I will transition directly into doctoral research in sustainable agriculture. At present, opportunities for continued research and expansion on PE/WI remain promising. I plan to seek funding support to test PE/WI's effectiveness as an educational tool with multiple stakeholder groups, primarily focusing on university students in agricultural and environmental sciences; farmers; land managers; and land owners. While the scope of testing for educational effectiveness may remain narrow, I hope to gain insight into multiple educational dimensions of the tool, such as: PE/WI's ability to promote new ways of scientific thinking and its capacity as a scenario planning tool to influence decisions; whether PE/WI's technological platform, including visualizations and interactions, enable users to more effectively process information and draw connections among complex system components; and how well PE/WI enables users to analyze ecosystem service relationships spatially and temporally.

Concurrent with educational testing of PE/WI, I also plan to pursue opportunities to present at conferences and share PE/WI more broadly with multiple stakeholder groups. PE/WI has enormous potential for us to adapt the model structure to other contexts, including real-world watersheds. Collaborating with other scientists and research teams creates potential to take PE/WI in numerous, exciting and new directions.