People in Ecosystems/Watershed Integration: A web-based learning tool for evaluating ecosystem service tradeoffs from watersheds

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FEATURE

People in Ecosystems/Watershed Integration: A web-based learning tool for evaluating ecosystem service tradeoffs from watersheds

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Society is increasingly demanding outcomes from our agricultural landscapes that include but extend well beyond crop production (Arbuckle et al. 2015; National Research Council 2010). In shifting to manage for a multifunctional agriculture, the agricultural community is developing and using innovative knowledge, information, and expertise to restore valuable ecological functions to the agricultural landscapes while also supporting vibrant farmer and rural livelihoods (Jordan et al. 2013; Liebman and Schulte 2015). Still, gaps persist in advancing a more comprehensive, applied understanding of how agriculture can become more multifunctional in character and produce the broader outcomes that society desires.

We suggest that an integrated ecosystem service tradeoffs framework provides an educational opportunity to demonstrate to various agricultural stakeholders how landscape designs can enhance multifunctional agriculture, mitigate risks to farmers and society, and help farmers maintain solid financial performance over longer time scales. At present, however, few accessible tools exist to guide the broader landscape design learning process and aid in the evaluation of how various changes to land management can affect the types and levels of goods and services that support humans. We created the People in Ecosystems/Watershed Integration tool (PEWI) to help fill this educational gap.

PEWI is a new, open source web application and instructive tool that facilitates the visualization of multifunctional agricultural outcomes, both market and nonmarket, over parcel and watershed scales. PEWI integrates research on agricultural production and environmental services to calculate these outcomes within an interactive web-based interface. As an educational tool, PEWI simulates complex tradeoffs associated with agricultural land use and management but does not require guidance from expert modelers. This web-based application is a new generation of an original spreadsheet-based PEWI model (Schulte et al. 2010).

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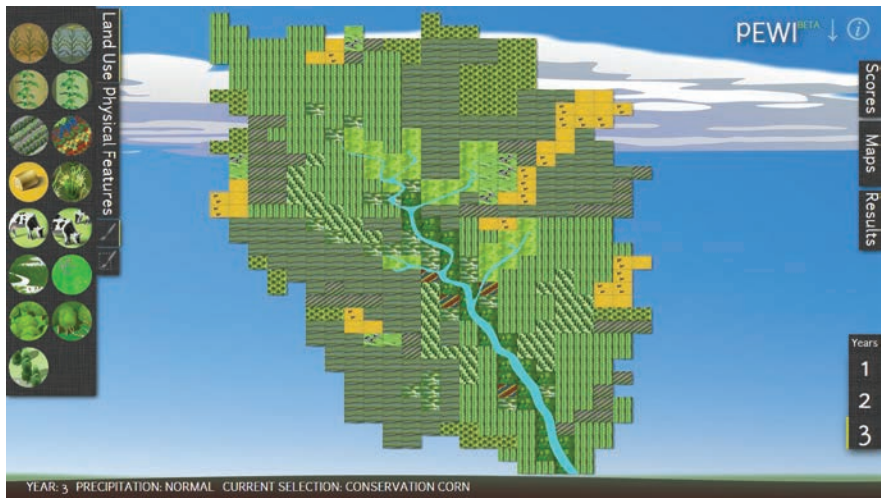
Figure 1

People in Ecosystems/Watershed Integration (PEWI) interface: controls (left), interactive watershed (center), download and info tabs (upper right), ecosystem service indicators (middle right), and design years (bottom right).



PEWI utilizes a simple approach: users design and evaluate patterns of agricultural land use on a virtual US Corn Belt watershed across multiple years and variable weather conditions. PEWI provides instant feedback to users, revealing both relative and absolute tradeoffs among ecosystem services. The tool allows users to consider the relationship between agricultural land uses; biophysical features of a watershed (e.g., topography and soils); and exogenous factors, such as variable weather. In doing so, users can weigh production outcomes (crop yields and livestock numbers) with environmental outcomes, such as nutrient and sediment levels in water, habitat provision for biodiversity, soil erosion, and carbon (C) management.

HOW PEOPLE IN ECOSYSTEMS/ WATERSHED INTEGRATION WORKS

PEWI uses components visible in the user interface—including the watershed area, land use options, varying annual weather conditions, and a sequence of three years—to calculate outcome indicators. PEWI also incorporates real-world data on soil properties and the effects of temporal and climate sequences, and reflects other recent advances in agronomic and watershed-scale scientific understanding.

Users interact with a fictitious watershed through PEWI's interface controls to create land use designs for Years 1, 2, and 3 (figure 1). This interaction creates a land use data set that users may download, save, share, and later reupload in PEWI. PEWI does not require any user-supplied data. The tool includes a main watershed interface, 5 predefined physical feature maps, 15 land use options, 7 weather conditions, an interactive plot of 16 ecosystem service indices, 3 environmental service maps, and summary numerical results. User-created land use designs, in conjunction with predefined physiographic characteristics and randomized annual weather conditions,

Table 1

People in Ecosystems/Watershed Integration (PEWI) 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.
Mixed fruits and vegetables	Mixed fruits and vegetables	Mixed fruits, including grapes and strawberries, and mixed vegetables, including green beans and squash.
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 (nonpasture)	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*	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.

*Arbuckle and Pease (1999)

serve as inputs for calculating ecosystem service outcomes.

We based the PEWI interactive watershed on two Iowa landform regions, the Des Moines Lobe and the Southern Iowa Drift Plain (Prior 1991), representing the western and eastern halves of the PEWI watershed, respectively. We designed the watershed as a collection of 593 grid cells configured around a vector-graphic stream to approximate a 2,383 ha (5,886 ac) watershed. By incorporating data from the Iowa Soil Properties and Interpretations Database (ISPAID) (Iowa State University Extension and Outreach 2010), PEWI represents realistic soil conditions. To simulate weather variability across years, the program randomly assigns annual weather conditions based on historical annual precipitation data from Iowa.

Users spatially manipulate land use within the watershed by selecting one of 15 annual or perennial land use types (table 1) on a PEWI grid cell by grid cell basis for each year. PEWI allows users to apply land use types that incorporate various in-field and edge-of-field conservation-oriented practices such as no-till, cover crop, prairie/wetland restoration, and riparian zone buffer practices on a cell-by-cell basis. Maps of predefined physical features (topographic relief, flood frequency, strategic wetland locations, subwatershed boundaries, and drainage class) further inform land use selection.

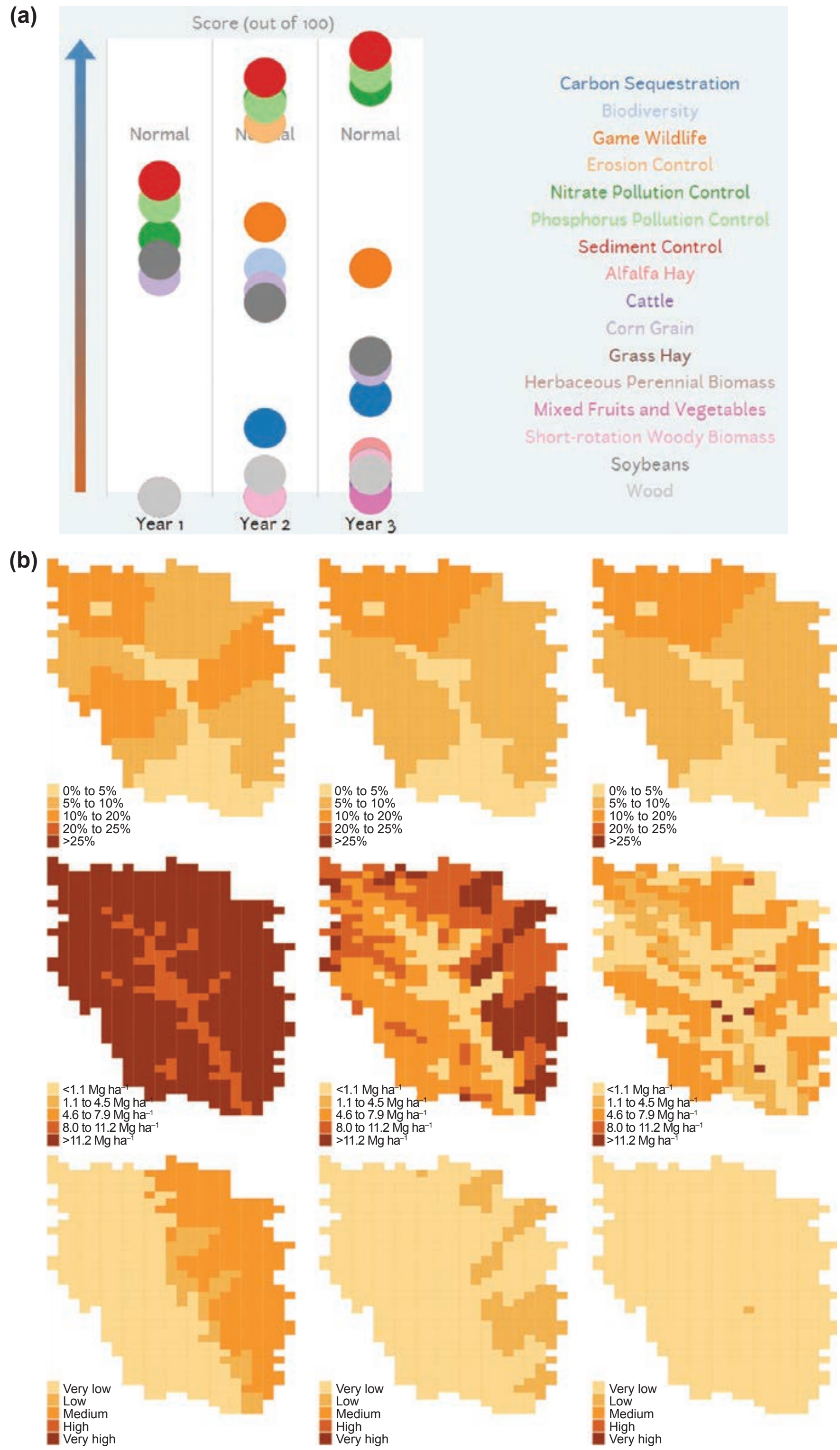
Based on user-determined designs of land use, the PEWI model calculates and presents levels of 16 ecosystem service outcomes using appropriate unit measures for each indicator. Provisioning ecosystem service indicators include yields of 9 crop and livestock production types (alfalfa hay [*Medicago sativa* L.], cattle, corn grain [*Zea mays* L.], grass hay [*Bromus inermis* Leyss. and *Dactylis glomerata* L.], herbaceous perennial biomass [*Panicum virgatum* L.], mixed fruits and vegetables [*Cucurbita pepo*, *Fragaria* × *ananassa*, *Phaseolus vulgaris,* and *Vitis riparia*], short-rotation woody biomass [*P. alba* × *P. grandidentata*], soybeans [*Glycine max* (L.) Merr.], and wood). Regulating ecosystem service indicators fall into two groups: surface water quality indicators include control of nitrate (NO_3-N), sediment, and phosphorus (P) pollution; and the soil quality indicators of soil erosion control and C sequestration. Habitat for overall biodiversity, and for game wildlife more specifically, serve as supporting ecosystem service indicators. Note that various indicators can inform cultural ecosystem service outcomes. For example, habitat and the water quality indicators present opportunities to experience cultural services such as hunting, birdwatching, and water-based recreation.

For every watershed design, PEWI translates each of the 16 ecosystem service indicators into 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 2). Scores appear together in a graphic plot that provides a comprehensive visualization of tradeoffs; users may highlight individual or sets of ecosystem services to custom-tailor feedback to individual preferences.

Users also can view outcome maps displaying soil erosion, P loss, and subwatershed percentage contribution to watershed NO_3-N concentration in each of three years. To demonstrate, we provide three-year simulation results from a user-designed landscape; the maps target the upper left-hand subwatershed for improvements in water quality management for NO_3-N (figure 2). In addition to index scores and plots, PEWI results include numerical summaries of area in

Figure 2

Visualizations of ecosystem service indicators. (a) Example indicator scores for 16 ecosystem services for years 1 through 3; indicators are assigned to a unitless index with a lowest possible score of 0 (bottom) to a highest possible score of 100 (top). (b) Example indicator maps for nitrate watershed percentage contribution (top), gross erosion (middle), and phosphorus index (bottom) from years 1 through 3 (left to right).



each land use type, index scores, and biophysical values for each ecosystem service indicator. Ecosystem service outcomes in PEWI, presented graphically, spatially, and numerically, communicate results in multiple ways, thereby enhancing users' ability to evaluate tradeoffs and overall experience. Chennault (2014) provides a comprehensive overview of the computational framework and data used for PEWI.

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." PEWI 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.

PEWI facilitates scenario creation, allowing users to explore and understand complex social-ecological relationships without necessarily delving into details underlying those relationships. We intend for PEWI 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 2). This process fosters multidimensional and integrative thinking by allowing learners to visualize results across space and time and to modify land use types to meet desired goals for the watershed.

As an educational tool, PEWI provides a platform for myriad teaching and learning opportunities. For example, instructors or facilitators may use PEWI to engage users in exploring the model's scientific and land management principles, which include the following range of topics:

- Land physiography
- Landscape ecology
- Watershed hydrology
- Biodiversity and habitat
- Weather and climate
- Forestry
- Agroforestry
- Agronomy
- Soils
- Agricultural best management practices

Yet PEWI can also inform users exploring pertinent socioeconomic principles or investigating policy design, implementation, and impact. For example, consider the following options:

- Use ecosystem service outcomes 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 N and P reduction (IDALS 2013)

We developed several exercises to help users get started with PEWI's basic learning concepts. Users can download these exercises and activities, including the basic PEWI exercises that we cover here, from the PEWI lesson plans library (http://www.nrem.iastate.edu/pewi/lessonplans). The five lessons in the basic PEWI 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 the following:

- How do spatial patterns of land use affect ecosystem service outcomes?
- How does variation in annual precipitation affect ecosystem service outcomes?
- How do we maximize ecosystem service cobenefits?
- When and where on the landscape can we minimize land use tradeoffs?

Users can answer these questions because PEWI helps people understand how agricultural production and associated tradeoffs vary across space and time.

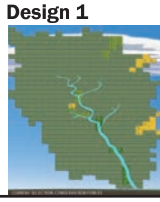
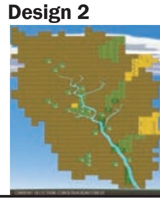
To demonstrate how our exercises help users achieve learning objectives, we present three landscape designs for the spatial targeting exercise for water quality (Basic PEWI Exercise 3b), which aims to teach the concepts of increasing cobenefits and decreasing tradeoffs. The exercise prompts users to design an agricultural watershed and then alter it to improve water quality scores, with minimal production loss. There is no single correct design, and several designs accomplish the exercise's objectives of maximized cobenefits and minimized tradeoffs. Furthermore, the designs are more or less effective depending on different annual precipitation scenarios (table 2). In the following illustration, we consider the outcomes of example watershed designs compared to a baseline scenario land use of 100% conventional corn–soybean rotation. We present the watershed designs, strategies, and results under two precipitation scenarios (table 2), along with each design's land use types and annual precipitation levels (table 3) for reference.

The three designs in this example incorporate management and land use practices with an objective of dramatically improving water quality with minimal production loss. Although users completing this exercise may set their own goals for water quality improvement, designs in this example aim to meet goals for nutrient reduction set forth in the Iowa Nutrient Reduction Strategy (Iowa 2013). Users may implement environmentally beneficial strategies that reflect real-world best practices for managing ecosystem function, including in-field conservation practices, edge-of-field practices, NO_3-N and erosion control practices, and land use change. Conservation corn and conservation soybean land uses in PEWI incorporate a broad set of in-field conservation practices (contouring, cover crops, no-till farming, and terracing) and edge-of-field practices (grassed waterways and riparian buffers). Based on information provided in the physical feature maps, users also can restore wetlands in strategic locations and identify other strategic locations for land use change.

In the first design, all productive areas of the watershed for annual row crops are placed into conservation row crops; yet the NO_3-N reduction goal is not met for dry–wet cycles (design 1 in table 2). This outcome reflects real world watershed management challenges. Based on the Iowa Nutrient Reduction Strategy science assessment, we know that widespread adoption of a broad suite of in-field conservation best management practices (e.g.,

Table 2

Basic People in Ecosystems/Watershed Integration (PEWI) exercise: results from spatial targeting to improve water quality under "normal" and "dry-wet" annual precipitation scenarios.

Designs	Design 1 	Design 2 	Design 3 
Strategies			
Conservation annual row crops	Yes	No	Yes
Alternative crops where annual row crop yields are lower	Yes	Yes	Yes
Alternative crops where slopes >9%	No	Yes	Yes
Strategic wetlands	No	Yes	Yes
Results: normal precipitation			
% Max annual row crop production	100%	90%	90%
% N reduction from baseline	36%	43%	59%
% P reduction from baseline	75%	31%	79%
Results: dry–wet precipitation			
% Max annual row crop production	85%	76%	76%
% N reduction from baseline	−7.8%	3.6%	31%
% P reduction from baseline	71%	14%	75%

grassed waterways, cover crops, and no-till farming) provide important incremental benefits but are not enough to achieve the strategy's goals for all pollutants (Iowa 2013). Rather, it is likely that a spatially targeted approach that mixes conservation row crop management with land use change, such as from annual row crops to perennial land uses, will be required to exact the desired outcomes at watershed scales (Tomer and Locke 2011).

To this end, PEWI would help users test the effect of spatially targeted water quality management by establishing perennial plant cover in environmentally sensitive landscape positions (e.g., steep slopes, shallow soils, and 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 et al. 2008).

Thus the second strategy places areas with negligible annual row crop production or with steep slopes into perennial land uses (design 2 in table 2). It also restores wetlands in strategic locations. In doing so, the second strategy has a tradeoff of reduced annual row crop yield by 10%. Still, PEWI shows that this strategy also fails to meet nutrient reduction goals for dry–wet cycles.

Strategies one and two together highlight the important takeaway that, as in the real world, strategies that are effective under average weather conditions may not work well in years with extreme weather cycles. Only incorporation of all four strategies in design three—conservation best practices, perennial land uses in low annual row crop production areas, perennial land uses in areas with steep slopes, and restoration of strategic wetlands—effectively mitigates nutrient pollution in sequential years with extreme weather cycles (table 2 design 3).

CONCLUSION

Few existing tools provide the type of learning platform that PEWI offers: a broadly accessible, yet comprehensive framework for considering multiple ecosystem service tradeoffs. In initial uses, we have seen PEWI's ability to fundamen-

Table 3

Basic People in Ecosystems/Watershed Integration (PEWI) exercise: land use percentage area and "normal" and "dry-wet" annual precipitation scenarios from spatial targeting to improve water quality designs in table 2.

	Percentage Area Design 1			Percentage Area Design 2			Percentage Area Design 3		
Scenario	Y1	Y2	Y3	Y1	Y2	Y3	Y1	Y2	Y3
Land use types									
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 scenarios									
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 (year 0 = 62.4 cm)	114.6	71.6	92.6	114.6	71.6	92.6	114.6	71.6	92.6

tally alter people's frameworks for land use management and decision making. We see an enormous future potential for PEWI to help people understand how commodities might be coproduced with other ecosystem services; to allow land managers, land owners, and communities develop a shared understanding of watershed processes and foster multistakeholder, watershed-scale decision making; and to help agricultural stakeholders develop effective strategies to mitigate economic and social risks associated with climate change, biodiversity loss, and natural resource impairment. The 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.

TO FIND OUT MORE

PEWI is available online at http://www.nrem.iastate.edu/pewi/app. The companion website, http://www.nrem.iastate.edu/pewi, provides informational materials, including a user guide, a library of learning exercises and lesson plans, publications, and postings of upcoming events. We encourage educators and other PEWI users to contribute to the developing library of exercises or continued development of the tool. To find out more about PEWI's open source development, visit https://github.com/nrem/pewi.

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