American Society of Agricultural and Biological Engineers
2950 Niles Road | St. Joseph MI 49085-9659 | USA
269.429.0300 | fax 269.429.3852 | hq@asabe.org | www.asabe.org

An ASABE Meeting Presentation
DOI: https://doi.org/10.13031/aim.202400678
Paper Number: 2400678

Water Erosion Prediction Project (WEPP) Model 2024 Status

Dennis C. Flanagan[1], James R. Frankenberger[1], Chris S. Renschler[1], Chris B. Coreil, Jr.[2], Olaf David[3], Anurag Srivastava[4], Sadia A. Jame[5], Ryan P. McGehee[6]

[1]USDA-Agricultural Research Service, National Soil Erosion Research Laboratory, West Lafayette, Indiana
[2]USDA-Natural Resources Conservation Service, Central National Technology Support Center, Fort Worth, Texas
[3]Colorado State University, Department of Civil & Environmental Engineering, Fort Collins, Colorado
[4]University of Idaho, Soil & Water Systems Department, Moscow, Idaho
[5]Purdue University, Agricultural & Biological Engineering Department, West Lafayette, Indiana
[6]Iowa State University, Agricultural & Biosystems Engineering Department, Ames, Iowa

Written for presentation at the
2024 ASABE Annual International Meeting
Sponsored by ASABE
Anaheim, CA
July 28-31, 2024

Abstract. *The Water Erosion Prediction Project (WEPP) model has been developed by the United States Department of Agriculture since 1985. WEPP is a physical process-based simulation technology to estimate runoff, soil loss, and sediment yields from hillslope profiles, small watersheds, and fields. In this paper we will provide current science model status, recent updates including water quality capabilities, and newest model web-based interfaces and databases. A cooperative project between the USDA Agricultural Research Service (ARS) and the USDA Natural Resources Conservation Service (NRCS) has resulted in development of new web-based interfaces for model applications to hillslope profiles (https://brenton.nserl.purdue.edu/wepp/) and user-defined field polygon areas. These utilize the new NRCS Conservation Resources - Land Management Operations Database (CRLMOD) that provides consistent information for crop growth, tillage operations, and management operations for WEPP as well as the Wind Erosion Prediction System (WEPS), and the Revised Universal Soil Loss Equation version 2 (RUSLE2). An updated version of GeoWEPP has also been developed that functions with open-source QGIS instead of the proprietary ArcGIS. In addition to ARS and NRCS WEPP interfaces, other groups have also developed their own technologies utilizing WEPP for erosion predictions and watershed soil loss and sediment delivery applications. The USDA Forest Service together with the University of Idaho has created numerous web-based tools (https://forest.moscowfsl.wsu.edu/fswepp/), most recently WEPPcloud (https://wepp.cloud/weppcloud/). Iowa State University utilizes WEPP and observed radar precipitation data in their Daily Erosion Project, that provides near real-time daily estimates of runoff and soil loss across 7 Midwest states and reported in a web-based interface on a HUC-12 basis (https://www.dailyerosion.org/). Current WEPP efforts and future plans will also be discussed.*

Keywords. *Water Erosion Prediction Project, soil erosion, erosion prediction, computer modeling.*

Introduction

The Water Erosion Prediction Project (WEPP) was initiated in 1985 by the USDA-Agricultural Research Service to develop a new generation of soil erosion prediction technology, based upon fundamental physical processes driving soil detachment, sediment transport, and sediment deposition in croplands, forest lands, and rangelands (Foster and Lane, 1987). The WEPP model, first publicly released in 1995, is a spatially distributed, process-based, continuous simulation computer model that predicts infiltration, runoff, soil detachment by raindrops, soil detachment by concentrated water flows, sediment transport, sediment deposition, and sediment delivery (Flanagan et al., 2007). It is meant to be applied to hillslope profiles up to about 100-m in length, and small field and farm watersheds up to about 260 ha in size. WEPP was developed to be a replacement for mature older empirical technologies such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978). The model was targeted implementation on personal computers, and designed to be used by field office personnel of the Soil Conservation Service (SCS, now the Natural Resources Conservation Service – NRCS), Forest Service (FS), and Bureau of Land Management (BLM), with substantial user recommendations on types of applications and science inclusion (Foster and Lane, 1987).

When first released in 1995, the WEPP model was provided with a rudimentary DOS-based interface (Flanagan et al., 1994), created prior to the widespread availability of Windows operating systems, and mainly developed for internal ARS testing and validation studies. Once Windows became available, a standalone Windows graphical user interface was developed to make editing, organizing, and managing WEPP model simulations and inputs very easy (Flanagan et al., 1998). Additionally, geospatial model application approaches and interfaces for WEPP were formulated to allow for much easier watershed simulation setups and evaluations (Cochrane and Flanagan, 1999; Renschler et al., 2002; Renschler, 2003; Flanagan et al., 2013). Web-based interfaces were developed by both ARS (Flanagan et al., 2004), and the FS (Elliot, 2004).

Since 2013, ARS and NRCS have been working cooperatively on a project to develop updated web-based interfaces and databases, specifically designed for NRCS field users and technical service providers. ARS has led the web interface development and WEPP science model updates, while NRCS has led the development of an updated land management and operations database that can be applied with WEPP, WEPS (Wind Erosion Prediction System), and RUSLE2 (Revised Universal Soil Loss Equation version 2.

The Forest Service working cooperatively with the University of Idaho and ARS has developed additional geospatial web-based watershed interfaces for WEPP, most recently WEPPcloud. Initially created to allow assessment of wildfire impacts on runoff and soil losses, WEPPcloud can also be applied to other land uses anywhere within the U.S., and also to a number of foreign locations (Lew et al., 2022).

The Iowa Daily Erosion Project (IDEP) utilized the WEPP model, NexRAD radar precipitation data, NRCS National Resource Inventory (NRI) field slope, soils, and cropping/management information to allow for near real-time estimates of runoff, soil loss, and sediment yields across all of Iowa's 1,599 townships (Cruse et al., 2006). IDEP was a cooperative project led by Iowa State University faculty that also included scientists from ARS, the University of Iowa, and South Dakota State University. More recently, the Daily Erosion Project (DEP) by the same group of researchers and additional cooperators has produced an improved product reporting estimates of runoff, and sheet and rill erosion across all or part of seven Midwestern states (Gelder et al., 2018). The DEP uses WEPP along with NOAA Multi-RADAR Multi-Sensor (MRMS) radar precipitation data available at two-minute time resolution and 1 km^2 spatial resolution, NRCS SSURGO soils, the USDA-NASS cropland data layer and remotely-sensed residue cover estimates, and 3-m LiDAR-derived elevation data for hillslope topographic inputs (Gelder et al., 2018).

This paper provides an update and details on the most recent WEPP model developments, including newest science model improvements, new and updated interfaces, and updated databases.

WEPP Science and Database Updates

Climate database and tools

When the WEPP model was first publicly released in 1995, the CLIGEN (CLImate GENerator; Nicks et al., 1995) weather generator as well as a nationwide database of 2,642 National Weather Service (NWS) climate station parameters were also included. CLIGEN could then be used to generate a series of daily synthetic weather inputs for WEPP to use in its erosion predictions. However, in addition to being considerably outdated by 2013, the years of record at the stations varied from 9 to 117 years, and 2,111 stations had more than 44 years of data (Srivastava et al., 2019). Unfortunately, this could lead to different climate statistics for stations located very near each other, resulting in considerably different runoff and erosion predictions. These inconsistencies could lead to lower user confidence in the erosion model predictions.

To address these known concerns and problems, observed precipitation and temperature data from 2,765 NWS stations for the 40-yr period from 1974-2013 were used to create a temporally consistent CLIGEN parameter database (Srivastava et al., 2019). This updated database is now being distributed and/or used with all model releases. When the original CLIGEN database was compared to the updated one, Srivastava et al. (2019) noted several important trends, including increases in annual precipitation and minimum temperatures across the U.S., increases in annual maximum temperatures in the western U.S. and decreases in the eastern U.S., and increases in minimum daily temperatures across the entire country in all seasons. Use of the same time period for the weather station records assures that climate parameter statistics are more consistent between closely adjacent locations, and runoff and soil loss predictions are also more spatially consistent.

WEPP is also commonly used in research settings where model users or developers may have their own observed climate data they wish to use to drive WEPP simulations. This is particularly common when conducting model validation studies or model calibration using other plot, field, or channel measurements. In cases such as these, users may opt to use CLIGEN and daily observations of precipitation and temperature to further constrain the daily CLIGEN climate output, or they may use a relatively recent WEPP Climate File Formatter (WEPPCLIFF) program and daily or finer climate observations (down to 1-minute resolution) to obtain breakpoint or daily format climate inputs with the most accurate representation possible for WEPP (McGehee et al., 2020). The ability to force WEPP with breakpoint precipitation inputs is critical for erosion applications (Flanagan et al., 2020), and this is where the development of both WEPP (Laflen et al., 1987) and erosivity-based applications is rooted (Wischmeier and Smith, 1958; Wischmeier, 1959; McGehee et al., 2021).

Channel erodibility temporal updating

WEPP watershed simulations include configurations of hillslopes providing runoff and sediment to channels and impoundments. As released in 1995, channel erodibility and critical shear stress were constant values input by the user, which could not vary through time as field conditions changed. This shortcoming of the model could lead to either possible underestimations of channel erosion (if the input critical shear stress was too great and/or the erodibility was too low) or overestimations (if input critical shear stress was too low and/or erodibility was too large).

The newest WEPP model version now allows for temporal updating of channel erodibility and shear stress using the same algorithms as in hillslope simulations for rill erodibility parameters (Guo et al., 2021). Thus, channels are now most erodible immediately after a tillage operation occurs on them, and become less erodible with time and consolidation, as well as root and plant development. When exercising this option, users should input baseline erodibility conditions in the channel parameter and soil input files, representing a freshly-tilled soil with no residue or roots present. There are also options to calculate the baseline values using detailed soil information from the NRCS SSURGO soil database and the WEPP model parameterization equations for rill erodibility and critical hydraulic shear stress.

Tile drainage improvements

Many soils in the world, especially in the Midwest U.S., have poor internal drainage that can result in wet field conditions, delay of tillage and planting operations, crop stress, soil compaction, and delayed or difficult harvesting. To alleviate these problems, many landowners install subsurface drainage tile in their fields, usually consisting of perforated plastic tile buried 1 to 2 meters below the soil surface, which collects subsurface water and directs it off-site, usually to a large ditch or larger main tile. When the WEPP model was released in 1995, it included the ability to simulate subsurface drainage (Savabi, 1993). However, subsequent evaluations indicated variable performance. Recently, updates to the WEPP tile drainage component were made, and tested with field experimental data from Ohio and Indiana (Revuelta-Acosta et al., 2021). Model performance was substantially improved in the new modified version compared to v2012.8. Additional work is underway to further improve the tile drainage component of WEPP to account for winter hydrologic conditions as well as new tile system management practices, such as controlled drainage.

WEPP-CO_2 version

With concerns over changing climate due to increasing greenhouse gas emissions and carbon dioxide concentrations in the atmosphere, a modified WEPP version was created that can account for CO_2 levels and stomatal resistance, and their impacts on plant growth and biomass/residue production (Srivastava et al., 2023). When combined with future climate scenarios obtained from General Circulation Models (GCMs), this version of the model can be used in comprehensive evaluations of the potential effects of changing climate and atmospheric CO_2 levels on predicted runoff, soil loss, and crop yields. For example, Yuan et al. (2022) applied this modified version of the WEPP model to agricultural conditions at Weatherford, Oklahoma, and evaluated 100 climate scenarios from 25 GCMs and 29 cropping and tillage systems for the periods 2021–2050 and 2051–2080. They found that future temperatures were predicted to increase and precipitation decrease to the end of this century, and all crop yields except for cotton were estimated to decrease by 10-18%. Overall predicted future average annual runoff and soil loss were only minimally projected to decrease by 1-3%, and no-till systems and cropping systems including small grains and alfalfa were the best at minimizing soil losses.

WEPP-Water Quality (WEPP-WQ) model

Substantial efforts have recently been made to improve and enhance earlier attempts to enable the WEPP model to simulate losses of soluble and sediment-bound nutrients or pesticides. Prior to 2020, Savabi et al. (2011) and Wang et al. (2017) incorporated SWAT model (Arnold et al., 1998) chemical transport routines into WEPP, and conducted validation for single overland flow element (OFE) hillslope profiles (i.e., uniform hillslope conditions). The coupled model version performed well in simulating nitrogen and phosphorus losses in single storm events when calibrated using data from rainfall simulation studies near Lafayette, Indiana and Waterloo, Indiana (Wang et al., 2017).

McGehee et al. (2023) evaluated, improved, and expanded the functionality of the WEPP-WQ model to correctly account for chemical transport down spatially complicated hillslopes composed of multiple OFEs, as well as chemical transport from hillslopes through channel networks and impoundments in small agricultural watersheds. In an initial validation study using data from rainfall simulation experiments in Indiana and Nebraska, McGehee et al. (2024) found that Nash-Sutcliffe Efficiencies (NSE) for uncalibrated uniform condition simulations were greater than 0.6 except for soluble nitrogen losses. Model performance for nonuniform hillslope conditions was typically unsatisfactory for sediment and nutrient loss predictions; however, runoff predictions were quite good (NSE = 0.78). WEPP-WQ model performance greatly improved with calibration. Additional work on improving the water quality components is ongoing, as well as a search for additional high quality validation data sets. Interface and database development are also required before this model functionality becomes easily available and applicable by users.

Crop, Management, and Operations Database

NRCS national, regional, and state agronomists have conducted extensive work over the past ten years on developing an extensive Conservation Resources - Land Management Operations Database (CRLMOD) that is now available for utilization with the WEPP model, the Wind Erosion Prediction System (WEPS) model (process-based wind erosion simulation tool comparable to WEPP), and the Revised Universal Soil Loss Equation version 2 (RUSLE2) model. Kucera and Coreil (2023) provide details on the CRLMOD content and development. In 2023, CRLMOD version 4 contained 164 unique crop types, 471 unique harvest, spraying, construction, planting, tillage, and other operations, 17 manure/residue types, and 25,575 management system templates (i.e. residue management and cropping options). Subsequently, an updated CRLMOD version 5 became available in late 2023. The database also contains numerous default crop rotation templates for single crops and multiple crop rotations, organized by Cropping Management Zones (CMZs) in the U.S. NRCS staff have take care so that parameter values for plant growth, tillage, and residue operations produce similar effects on plant biomass, cover, and residue production for both WEPP and WEPS, and are comparable to those from RUSLE2.

Model changes to meet specific NRCS needs

NRCS staff have worked closely with ARS scientists and computer engineers in development of new web-based interfaces for their field office staff to use in soil conservation planning activities, and during that process identified certain needs of functionality that the interface and model needed to have. Many items could be handled in interface software, however, some items also required changes to the WEPP science model, often working together with the interface. Some of these model and interface updates include:

1. Multiple tillage operations - users can now use more than a single tillage operation on a simulation day.
2. Crop yield calibration – the web-based NRCS interface runs the WEPP model before actual simulation in a calibration mode for 15 years/crop to determine plant growth parameters needed to reach user input crop yield levels (within 10% tolerance). The user can modify the default calibration years and tolerance level if a closer agreement between target and simulated average crop yields is desired.
3. Irrigation specification and utilization – for irrigated locations with a cropping/management system having irrigation active, the interface will direct the model to assume depletion level scheduling and sprinkler irrigation water is applied at a very low intensity over 24 hours (no erosion from irrigation application is simulated).
4. Residue management options – multiple residue operations are now allowed within a yearly cropping period. For annual crops these operations include shredding/cutting, burning, removal & addition of residue; and silage harvesting, herbicide application (killing live biomass), and cutting with or without removal of above ground live biomass. A grazing option has been added to simply remove a specified percent of live biomass removal on a day or during a period when grazing animals are present.
5. Contouring changes – utilizes tracked ridge height and ridge spacing to determine contour failure. If fail – then soil loss computed up-and-down the slope until a tillage operation with ridge height 2"+ occurs to reset (contour) ridges. (NRCS web interface – defaults contour row length to 50 feet, contour row slope is an input from user).
6. Maximum growing degree days (GDDMAX) adjustment – Crops reaching maturity vary by climate. In the NRCS web WEPP version, the GDDMAX value is defaulted to zero to allow the model to internally calculate a value based on planting and harvest/kill dates and monthly temperatures. This allows crops to reach maturity as a function of the climate location, and this can also vary the live biomass and the crop surface residue after harvest through the use of PRISM adjustments to the climate location input.
7. Interseeded cover crops – the web interface and the model now contain a "release cover crop" option, that allows for cover crop canopy to be present immediately after the previous row crop harvest. A cover crop broadcast seeded into a growing cash crop can now better match conditions where it has germinated and started growth.
8. PRISM adjustments to model climate inputs - The web-based interface now allows the use of PRISM Parameter-elevation Regressions on Independent Slopes Model) 4-km grid information (precipitation, temperatures, etc.) to spatially adjust the base weather station parameter files, if desired, when building the climate input files for a WEPP model run. In the NRCS web-based interface a 100-yr synthetic climate input is created with the CLIGEN v5.3 weather generator.

USDA WEPP Interfaces

NRCS web-based hillslope profile interface

A web-based WEPP hillslope profile interface for NRCS field applications has been developed from 2013-2023, and was released in June 2023. Web site is: https://brenton.nserl.purdue.edu/wepp/. This interface provides an easy way to simulate soil loss from agricultural systems at any location in the U.S. The example shown in Figures 1-4 are for a simulation in a field in northwestern Ohio on a Blount silt loam, 5% uniform slope, with a fall chisel corn (200 bu/A) and no-till soybean (60 bu/A) cropping system. More details on this interface are provided in Flanagan et al. (2023).

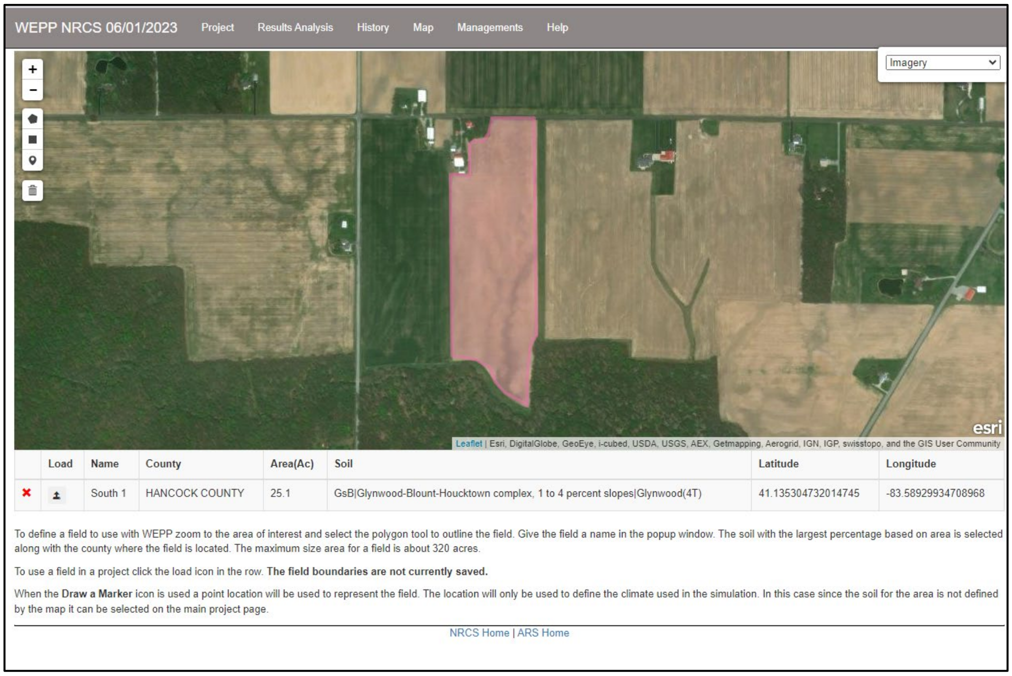

Figure 1. Web-based interface for NRCS field office soil conservation applications. Map screen shown with a field polygon drawn by the user (in light pink).

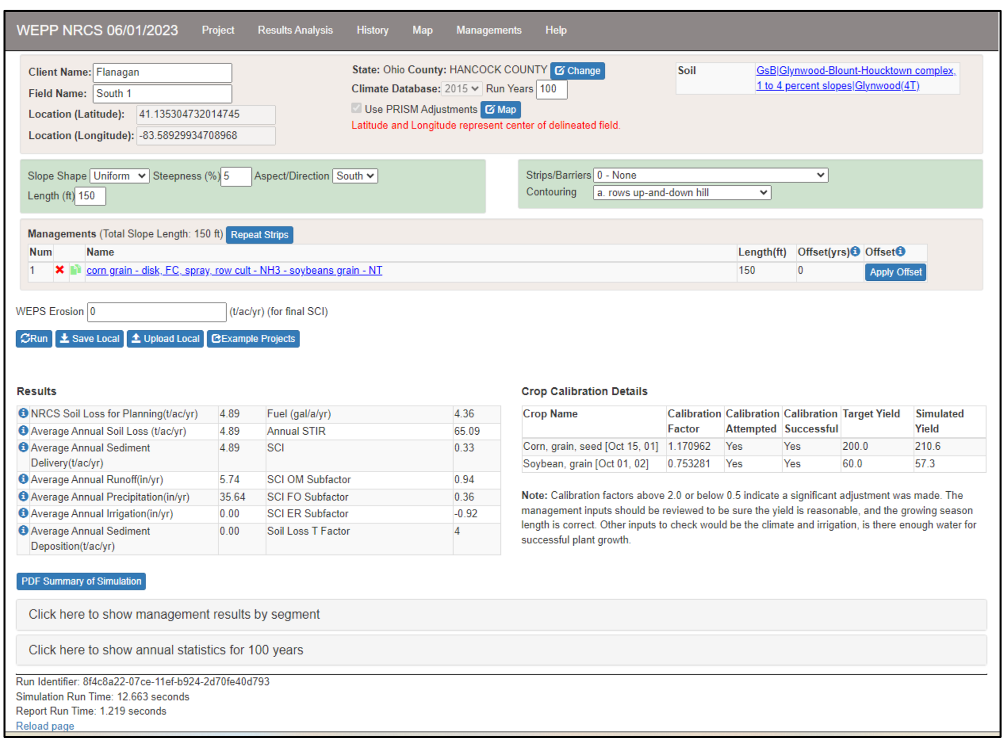

Figure 2. Main screen of web-based interface for NRCS field office soil conservation applications. Simulation inputs shown in top part of window, and output results from 100-yr model run shown in bottom half of screen.

Figure 3. Some of the graphical outputs from web-based interface for NRCS field office soil conservation applications. Results shown here highlight results from 100-yr simulation and recurrence interval values. Notice the much greater soil loss predicted during the corn part of the rotation where substantial tillage occurs (top center figure).

Figure 4. Numerous other graphical and text outputs are also available in the web-based interface for NRCS field office soil conservation applications. Results here also show greater soil loss during the corn crop grown with substantial tillage and lower soil loss predicted in the second year of the rotation during the no-till soybean period (bottom right graph).

Windows interface update in 2024

Prior to 2024, the most recent public WEPP Windows model release was from 2012 (v2012.8). Due to the extensive development work on the NRCS web-based hillslope interface, the Windows version became out-of-date and did not contain all of the functionality available in the new NRCS tool. So, during 2022-2024, the Windows interface for WEPP was updated to be compatible with the newest model version. Figure 5 shows the new Windows interface main hillslope profile screen with some simulation results visible. Large soil loss rates are predicted and shown in shades of dark red in the center of the profile displayed. Figure 6 shows results from an example watershed simulation in the updated WEPP Windows interface.

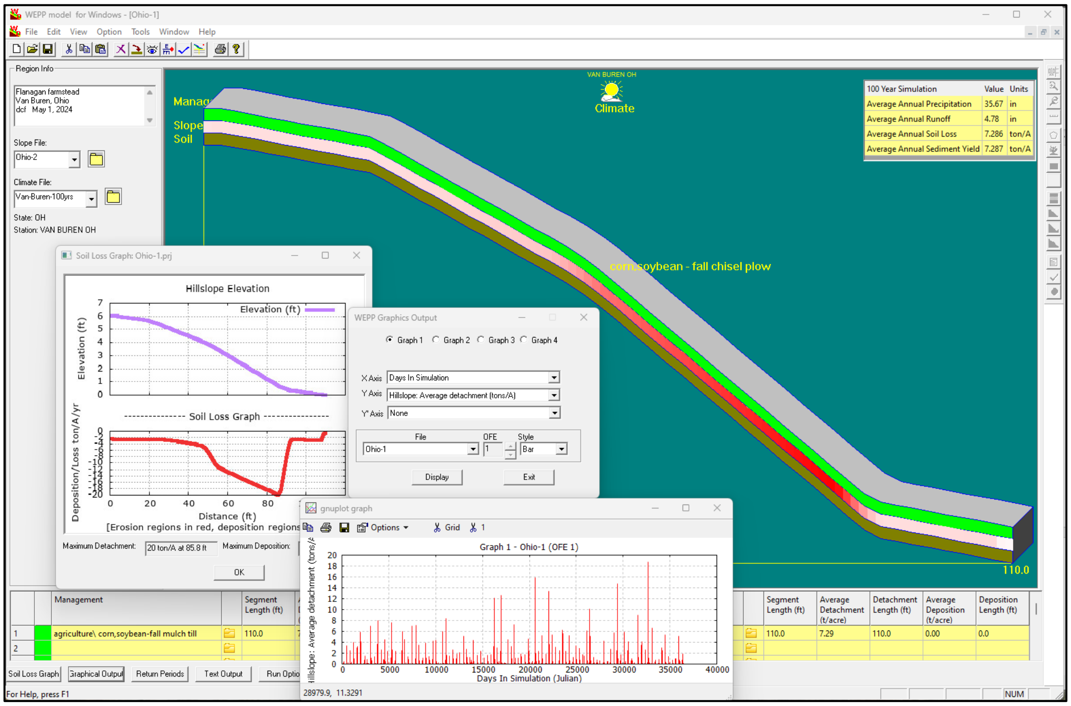

Figure 5. Updated 2024 WEPP Windows interface showing hillslope profile and some of the graphical outputs for a simulation run in northwestern Ohio.

Figure 6. Updated 2024 WEPP Windows interface showing results from an example watershed simulation. Shades of red indicate greater soil loss rates (above T) and green indicate soil loss between 0 and T. The upper hillslope in permanent grass vegetation had extremely low predicted soil loss (appears white in the figure).

Some of the updates in the new Windows interface include the updated CLIGEN database using National Weather Service weather station data from 1974-2013 to provide a temporally consistent set of climate inputs to the model. Only stations having a complete or nearly complete set of data for this time period were included. There is also the ability to utilize the NRCS CRLMOD management information and data, and the ability to download SSURGO soils from NRCS via the interface. This updated interface provides support for all new WEPP model management options and parameters. It also allows for users to utilize the new channel parameter temporal updating by Guo et al. (2021), described earlier in this paper. The new installation also includes all the hillslope model validation data used by Wang et al. (2023) in their journal publication. Many of the underlying software tools in the interface had to be updated due to changes in Windows operating systems over the past 10 years, which made some of the earlier tools obsolete or incompatible. The updated Windows interface and all other WEPP model ARS software and documentation are available via the main WEPP webpage at: https://www.ars.usda.gov/midwest-area/west-lafayette-in/national-soil-erosion-research/docs/wepp/research/

NRCS web-based field area of interest interface

Cooperative efforts between USDA-ARS, USDA-NRCS, and Colorado State University have been ongoing for the past six years on development of a field area of interest that performs hillslope and watershed simulations, and allows for soil loss predictions from any user identified area of interest. This interface allows the user to draw a polygon, circle, or other shaped region, and the interface will determine the interrill/rill soil loss for entire field region, as well as identify channel inlets and outlets for estimation of ephemeral gully erosion and effects of grass waterways or other channel types, and incorporation of impoundments in the field. This interface is still in a development prototype stage, but can be reached for evaluation at: https://wepp.erams.com/. Figures 7 and 8 show a couple of screen captures of this tool.

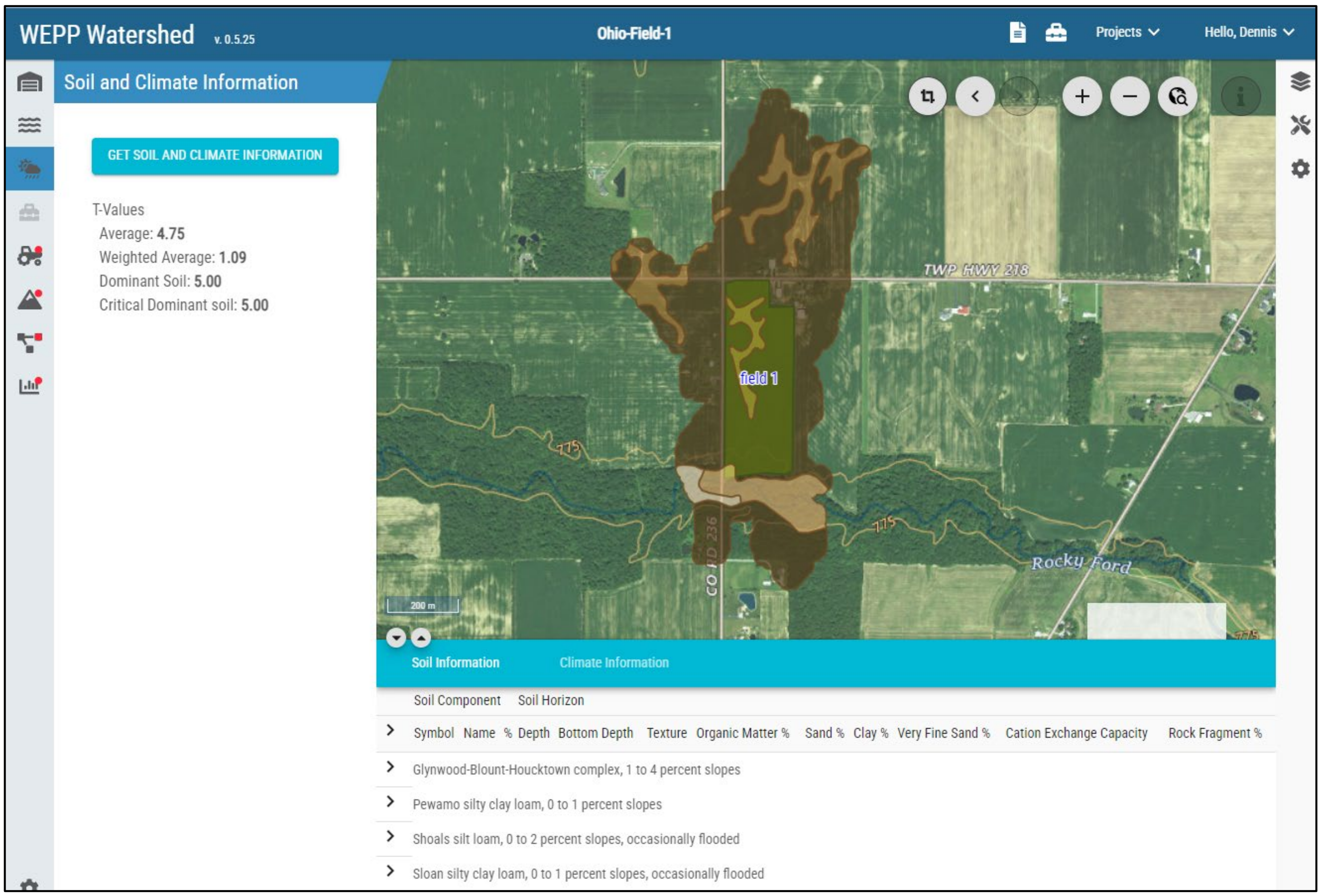

Figure 7. WEPP web-based field area of interest (and watershed) interface prototype, with an example field polygon drawn in the center of the image, and the contributing watershed areas delineated around it, with soil types identified from SSURGO shown in shades of brown.

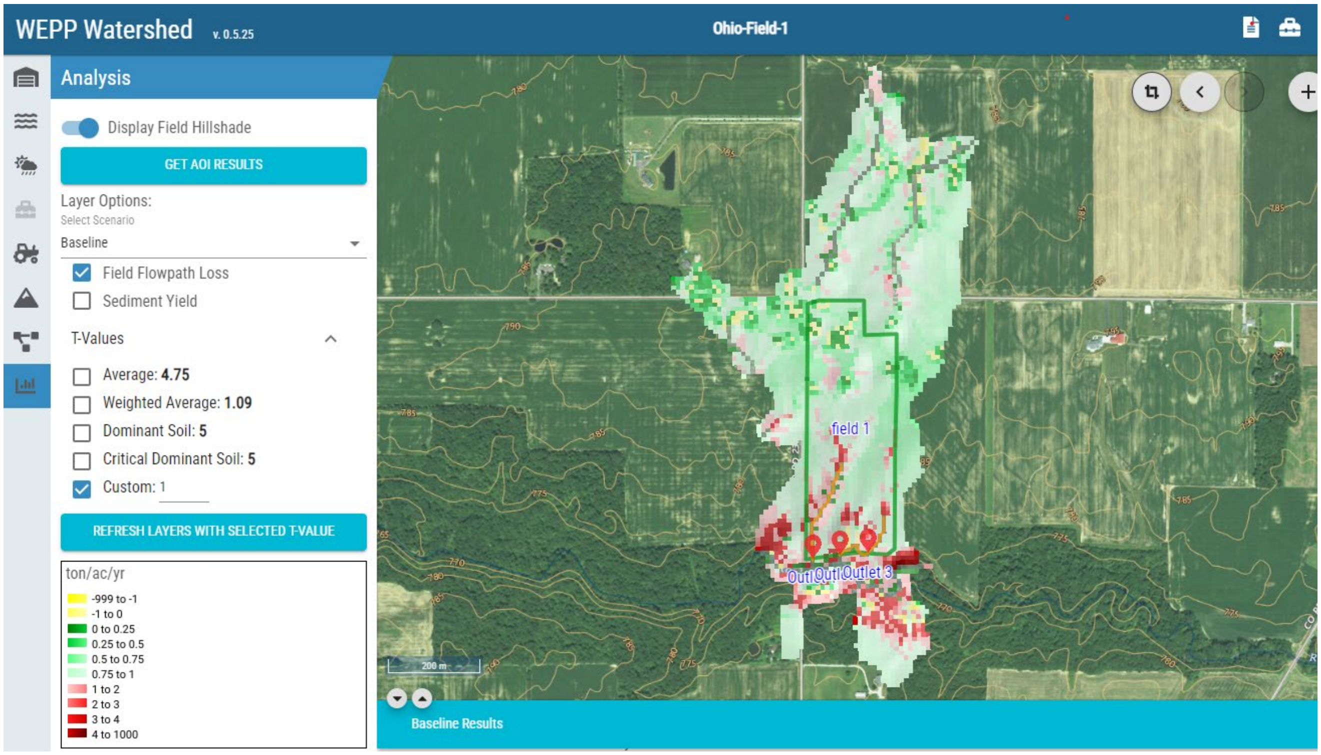

Figure 8. Spatial soil loss results from a ten-year simulation run with the WEPP web-based field area of interest (and watershed) interface prototype. Average annual soil loss values greater than 1 ton/A are shown in shades of red, values between 0 and 1 ton/A are in shades of green, and deposition cells are shown in yellow. The field area of interest polygon is outlined in the center within the bold green line. Numerical results (not shown here) summarize the overall average soil loss for the raster cells contained within the polygon. Note the greater soil loss at the south part of the field where slopes are greater. There are also three channel outlets identified here with the small red circles, and soil loss predicted from these channels is also calculated and reported.

QGeoWEPP

GeoWEPP is the geospatial interface to WEPP, originally developed as an ESRI ArcView extension (Renschler et al., 2002; Renschler, 2003), that requires the WEPP Windows interface installation as well. GeoWEPP allows a user to utilize their own site-specific GIS data for topography, soils, and land management, and conduct detailed erosion and sediment loss analyses for small watersheds within fields and landscapes. A comprehensive GeoWEPP validation study was conducted to demonstrate the spatial and temporal capabilities of the WEPP model to simulate event-based runoff and sediment yields and long-term soil loss and redistribution in a series of nested rangeland watersheds (Renschler and Zhang, 2020; Zhang et al., 2021). With updates of the ESRI GIS platform over the years from ArcView to ArcGIS versions it was a challenge to keep up with the latest ESRI GIS releases. An updated version of GeoWEPP has been developed that functions as a plug-in for the open-source QGIS v3.0 and greater (Zhang and Renschler, 2023), and enables WEPP users to stay or adjust to an evolving GIS platform. GeoWEPP and QGeoWEPP software are available from: https://fargo.nserl.purdue.edu/geowepp/.

Other WEPP Interfaces

Daily Erosion Project

The Daily Erosion Project (DEP) is a multi-state and location cooperative project led by faculty at Iowa State University, and utilizes the WEPP model, radar precipitation data, SSURGO soil data, and remotely-sensed land management information to provide near real-time estimates of runoff, interrill/rill soil loss, and hillslope sediment losses, aggregated to a HUC-12 watershed reporting scale (Gelder et al., 2018; Cruse et al., 2006). Efforts continue on the DEP to expand it to allow for channel erosion estimates as well. The DEP website is at: https://www.dailyerosion.org/.

USDA-Forest Service WEPP interfaces

The USDA-Forest Service (FS) has been an integral part of the WEPP model development team since 1985. Most FS activities relate to the use of erosion prediction technologies to estimate soil erosion and sediment loss risks from forested regions, usually after some type of disturbance (road construction, timber harvesting, wildfires, etc.). With increasing wildfires due to climate change, large emphasis has been placed on utilizing WEPP model predictions to assess the risk of burned areas producing runoff and sediment, and where to target remediation efforts to minimize potential damages from rainstorm and runoff events. The FS has created a suite of targeted web-based WEPP interfaces, available via their website at: https://forest.moscowfsl.wsu.edu/fswepp. Most recently, the FS has worked in a cooperative project with the University of Idaho, Washington State University, and USDA-ARS on creating WEPPcloud, which is a web-based interface allowing WEPP model simulations for any location in the U.S. (Lew et al., 2022; Dobre et al., 2022). Originally developed for forested regions impacted by wildfires, it can be applied to any land use if the appropriate management inputs are provided. There are also versions of WEPPcloud available for Australia and the European Union. Information and access to the web interfaces is available at: https://wepp.cloud/weppcloud/.

Summary and Conclusions

The WEPP model continues to be applied and used throughout the United States and the world, and interest continues to grow. It was the third most applied soil erosion prediction model in the world, according to the records reported in the GASEMT database in 2021 (Borrelli et al., 2021), ranking only behind the USLE and RUSLE technologies (which have been available for much longer periods of time). Efforts continue at the USDA-ARS National Soil Erosion Research Laboratory on WEPP model development and enhancement, with current efforts focused on completion of the NRCS web-based field area of interest interface, and cooperative projects with the Forest Service and multiple universities. Efforts also continue to validate WEPP for soil erosion during freeze-thaw cycles. New laboratory and field experimental studies are planned over the next five years to provide more data for model testing and validation, and development of better relationships to quantify effects of long-term high residue and cover crop systems on soil organic matter and soil erodibility parameters and temporal adjustments. Additional data and modeling approaches are also needed to better simulate ephemeral gully erosion and control practice effects.

References

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large-area hydrologic modeling and assessment: Part I. Model development. *JAWRA, 34*(1), 73-89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

Borrelli, P., Alewell, C., Alvarez, P., Ayach Anache, J. A., Baartman, J., Ballabio, C., … Panagos, P. (2021). Soil erosion modelling: A global review and statistical analysis. *Science of The Total Environment, 780*, 146494. https://doi.org/10.1016/j.scitotenv.2021.146494

Cochrane, T. A., & Flanagan, D. C. (1999). Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. *JSWC, 54*(4), 678-685.

Cruse, R., Flanagan, D., Frankenberger, J., Gelder, B., Herzmann, D., James, D., … Todey, D. (2006). Daily estimates of rainfall, water runoff, and soil erosion in Iowa. *JSWC, 61*(4): 191-199.

David, O., Carlson, J. R., Yaege, L. A., Kipka, H., Flanagan, D. C., & Frankenberger, J. R. (2023). WEPP-GIS: Detailed assessment of soil erosion, runoff, and sedimentation in farm fields and small watersheds. In (Flanagan, D.C. & Thompson, A.M., eds.): *Proceedings Soil Erosion Research under a Changing Climate International Symposium*, Abstract No. 23059. St. Joseph, Mich.: ASABE. https://doi.org/10.13031/soil.23059

Dobre, M., Srivastava, A., Lew, R., Deval, C., Brooks, E. S., Elliot, W. J., & Robichaud, P. R. (2022). WEPPcloud: An online watershed-scale hydrologic modeling tool. Part II. Model performance assessment and applications to forest management and wildfires. *J. Hydrol., 610*, 127776. https://doi.org/10.1016/j.jhydrol.2022.127776

Elliot, W. J. (2004). WEPP internet interfaces for forest erosion prediction. *JAWRA, 40*(2), 299-309. https://doi.org/10.1111/j.1752-1688.2004.tb01030.x

Elliot, W. J., & Flanagan, D. C. Estimating WEPP cropland erodibility values from soil properties. *J. ASABE, 66*(2), 329-351. https://doi.org/10.13031/ja.15218

Flanagan, D. C., Whittemore, D. A., Livingston, S. J., Ascough, J. C. II, & Savabi, M. R. (1994). Interface for the Water Erosion Prediction Project model. ASAE Meeting Paper No. 94-2105. St. Joseph, Mich.: ASAE. 16 pp.

Flanagan, D. C., Fu, H., Frankenberger, J. R., Livingston, S. J., & Meyer, C. R. (1998). A Windows interface for the WEPP erosion model. ASAE Meeting Paper No. 98-2135. St. Joseph, Mich.: ASAE. 14 pp.

Flanagan, D. C., Frankenberger, J. R., Renschler, C. S., & Engel, B. A. (2004). Development of web-based GIS interfaces for application of the WEPP model. Paper No. 419, *Proc. ISCO 2004 – 13th Intl. Soil Conserv. Org. Conf.*, 4-9 July 2004, Brisbane, Australia. 6 pp. https://topsoil.nserl.purdue.edu/isco/isco13/PAPERS%20F-L/FLANAGAN.pdf

Flanagan, D. C., Gilley, J. E., & Franti, T. G. (2007). Water Erosion Prediction Project (WEPP): development history, model capabilities, and future enhancements. *Trans. ASABE, 50*(5), 1603-1612. https://doi.org/10.13031/2013.23968

Flanagan, D. C., Frankenberger, J. R., Cochrane, T. A., Renschler, C. S., & Elliot, W. J. (2012). Geospatial application of the Water Erosion Prediction Project (WEPP) model. *Trans. ASABE, 56*(2), 591-601. https://doi.org/10.13031/2013.42681

Flanagan, D. C., McGehee, R. P., & Srivastava, A. (2020). Evaluation of different precipitation inputs to WEPP. Paper #2000740. St. Joseph MI: ASABE, 18 pp. https://doi.org/10.13031/aim.202000740

Flanagan, D. C., Frankenberger, J. R., Srivastava, A., Kucera, M. J., & Coreil, C. B. (2023). Water Erosion Prediction Project model for NRCS use. In (Flanagan, D.C. & Thompson, A.M., eds.): *Proceedings Soil Erosion Research under a Changing Climate International Symposium*, Paper No. 23002. St. Joseph, Mich.: ASABE. https://doi.org/10.13031/soil.23002

Foster, G. R., & Lane, L. J. (1987). *User Requirements: USDA – Water Erosion Prediction Project (WEPP)*. NSERL Report No. 1. National Soil Erosion Research Laboratory. West Lafayette, IN: USDA-Agricultural Research Service. 43 pp. https://www.ars.usda.gov/ARSUserFiles/50201000/WEPP/docs/wepp-user-requirements.pdf

Frankenberger, J. R., Dun, S., Flanagan, D. C., Wu, J. Q., & Elliot, W. J. (2011). Development of a GIS interface for WEPP model application to Great Lakes forested watersheds. In (Flanagan, D.C., Ascough, J. C. II, & Nieber, J. A., eds.): *Proceedings International Symposium on Erosion and Landscape Evolution (ISELE)*, Paper No. 11139. St. Joseph, Mich.: ASABE. 8 pp. https://doi.org/10.13031/2013.39195

Gelder, B., Skelnar, T., James, D., Herzmann, D., Cruse, R., Gesch, K., & Laflen, J. (2018). The Daily Erosion Project – daily estimates of water runoff, soil detachment, and erosion. *Earth Surf. Proc. & Landforms, 43*, 1105-1117. https://doi.org/10.1002/esp.4286

Guo, T., Srivastava, A., & Flanagan, D. C. (2021). Improving and calibrating channel erosion simulation in the Water Erosion Prediction Project (WEPP) model*. J. Environ. Mgmt., 291*, 112616. https://doi.org/10.1016/j.jenvman.2021.112616

Kucera, M. J., & Coreil, C. B. (2023). Overview of USDA-NRCS erosion prediction technology and Conservation Resources – Land Management Operations Database and use. In (Flanagan, D.C. & Thompson, A.M., eds.): *Proceedings Soil Erosion Research under a Changing Climate International Symposium*, Paper No. 23007. St. Joseph, Mich.: ASABE. https://doi.org/10.13031/soil.23007

Laflen, J. M., Thomas, A. W., & Welch, R. (1987). Cropland experiments for the WEPP project. ASAE Paper No. 87-2544. St. Joseph, MI, USA: American Society of Agricultural Engineers.

Lew, R., Dobre, M., Srivastava, A., Brooks, E. S., Elliot, W. J., Robichaud, P. R., & Flanagan, D. C. (2022). WEPPcloud: An online watershed-scale hydrologic modeling tool. Part I. Model description*. J. Hydrol., 608*, 127603. https://doi.org/10.1016/j.jhydrol.2022.127603

McGehee, R. P., Flanagan, D. C., Srivastava, P., & Nearing, M. A. (2021). Chapter 16 - Rainfall erosivity: essential historical, conceptual, and practical perspectives for continued application. In (J. Rodrigo-Comino, ed.): *Precipitation*. Amsterdam: Elsevier. pp. 373–394. https://doi.org/10.1016/B978-0-12-822699-5.00014-8

McGehee, R. P., Flanagan, D. C., & Srivastava, P. (2020). WEPPCLIFF: A command-line tool to process climate inputs for soil loss models. *J. Open Source Softw., 5*(49), 2029. https://doi.org/10.21105/joss.02029

McGehee, R. P., Flanagan, D. C., & Engel, B. A. (2023). A WEPP-Water Quality model for simulating nonpoint source pollutants in nonuniform agricultural hillslopes: Model development and sensitivity. *Intl. Soil & Water Conserv. Res., 11*(3), 455-469. https://doi.org/10.1016/j.iswcr.2023.02.002

McGehee, R. P., Flanagan, D. C., Engel, B. A., & Gilley, J. E. (2024). A validation of WEPP-Water Quality in uniform and nonuniform agricultural hillslopes*. Intl. Soil & Water Conserv. Res. (In-Press).* https://doi.org/10.1016/j.iswcr.2023.11.005

Renschler, C. S., Flanagan, D. C., Engel, B. A., & Frankenberger, J. R. (2002). GeoWEPP – the Geo-spatial interface to the Water Erosion Prediction Project. ASAE Paper No. 022171. St. Joseph, MI: ASAE. 10 pp.

Renschler, C. S. (2003), Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. *Hydrol. Process., 17*, 1005-1017. https://doi.org/10.1002/hyp.1177

Renschler, C. S., & Zhang, H. (2020). Long-term, process-based, continuous simulations for a cluster of six smaller, nested rangeland watersheds near Tombstone, AZ (USA): Establishing a baseline for event-based runoff and sediment yields. *Science of The Total Environment, 717*, 137089. https://doi.org/10.1016/j.scitotenv.2020.137089

Revuelta-Acosta, J. D., Flanagan, D. C., Engel, B. A., & King, K. W. (2021). Improvement of the Water Erosion Prediction Project (WEPP) model for quantifying subsurface drainage flow at field scale. *Agric. Wat. Mgmt., 244*, 106597. https://doi.org/10.1016/j.agwat.2020.106597

Savabi, M. R. (1993). Modeling subsurface drainage and surface runoff with WEPP. *J. Irrig. & Drainage, 119*(5), 801-813. https://doi.org/10.1061/(ASCE)0733-9437(1993)119:5(801)

Savabi, M. R., Flanagan, D. C., Frankenberger, J. R., Hubbard, R. K., Bosch, D. D., & Potter, T. L. (2011). Development of a WEPP-Water Quality (WEPP-WQ) model. In: (Flanagan, D.C., Ascough, J. C. II, & Nieber, J. A., eds.) *Proceedings International Symposium on Erosion and Landscape Evolution (ISELE)*, Paper No. 11146. St. Joseph, Mich.: ASABE. 5 pp. https://doi.org/10.13031/2013.39201

Srivastava, A., Flanagan, D. C., Frankenberger, J. R., & Engel, B. A. (2019). Updated climate database and impacts on WEPP model predictions. *JSWC, 74*(4), 334-349. https://doi.org/10.2489/jswc.74.4.334

Srivastava, A., McGehee, R. P., Flanagan, D. C., Frankenberger, J. R., & Engel, B. A. (2023). Modeling the impacts of climate change on crop yield, runoff, and soil loss using the Water Erosion Prediction Project (WEPP) model. In (Flanagan, D.C. & Thompson, A.M., eds.): *Proceedings Soil Erosion Research under a Changing Climate International Symposium*, Paper No. 23075. St. Joseph, Mich.: ASABE. https://doi.org/10.13031/soil.23075

Wang, L., Flanagan, D. C., & Cherkauer, K. A. (2017). Development of a coupled water quality model. *Trans. ASABE, 60*(4), 1153-1170. https://doi.org/10.13031/trans.12002

Wang, S., McGehee, R. P., Guo, T., Flanagan, D. C., & Engel, B. A. (2023). Calibration, validation, and evaluation of the Water Erosion Prediction Project (WEPP) model for hillslopes with natural runoff plot data. *Intl. Soil Water Conserv. Res., 11*(4), 669-687. https://doi.org/10.1016/j.iswcr.2022.10.004

Wischmeier, W. H. (1959). A rainfall erosion index for a Universal Soil-Loss Equation. *SSSAJ, 23*(3), 246–249. https://doi.org/10.2136/sssaj1959.03615995002300030027x

Wischmeier, W. H., & Smith, D. D. (1958). Rainfall energy and its relationship to soil loss. *Eos Trans. AGU, 39*(2), 285–291. https://doi.org/10.1029/TR039i002p00285

Yuan, L., Zhang, X. -C., Busteed, P., Flanagan, D. C., & Srivastava, A. (2022). Modeling surface runoff and soil loss response to climate change under GCM ensembles and multiple cropping and tillage systems in Oklahoma. *Soil & Tillage Res., 218*, 105296. https://doi.org/10.1016/j.still.2021.105296

Zhang, H., & Renschler, C. S. (2023). Steps towards the validation of process-based long-term soil redistribution at the watershed scale using QGeoWEPP. In (Flanagan, D.C. & Thompson, A.M., eds.): *Proceedings Soil Erosion Research under a Changing Climate International Symposium*, Paper No. 23044. St. Joseph, Mich.: ASABE. https://doi.org/10/13031/soil.23044

Zhang, H., & Renschler, C. S. (2024). QGeoWEPP: An open-source geospatial interface to enable high-resolution watershed-based soil erosion assessment. *Environmental Modelling and Software*. (In Review).

Zhang, H., Renschler, C. S., Nichols, M. H., & Nearing, M. A. (2021). Long-term, process-based, continuous simulations for a small, nested rangeland watershed near Tombstone, AZ (USA): Extending model validity to include soil redistribution. *Science of The Total Environment, 792*, 148403. https://doi.org/10.1016/j.scitotenv.2021.148403