Developing WEPP-Mine: A Management Tool for Western Alkaline Surface Coal Mines

OSM cooperative agreement S09AP15470

Final Report

Reporting period - 8/1/09 to 10/31/12

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Date of submission: November 2012

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Abstract

This project was designed to develop WEPP-Mine, a practical computer simulation tool for evaluating site-specific sediment control and reclamation plans for the National Pollutant Discharge Elimination System (NPDES) Western Alkaline Coal Mining Subcategory by EPA. The main objectives were: (1) to develop WEPP-Mine, a user-friendly computer package for evaluating site-specific sediment control and reclamation plans in western alkaline coal mining operations; (2) to develop templates containing datasets pertinent to climate, topography, soil, and land management for representative western US surface coal mines (Rosebud and Big Sky Mines, southeast Montana); (3) to assess the performance of the WEPP-Mine through comparison with field-observed streamflow and sediment data; and (4) to disseminate the developed WEPP-Mine tool through various technology transfer venues, including workshops for regulatory authorities, consultants, and the mining industry, presentations at professional meetings, and scientific publications.

WEPP-Mine (http://wepponlinegis.bsyse.wsu.edu/osm) was developed based on the USDA's Water Erosion Prediction Project (WEPP) model and the recently developed WEPP Watershed Online GIS interface. During the model development, we carried out extensive literature review and synthesized data pertaining to soil properties and vegetation parameters for surface coal mines in western US and other regions in the country and the world. We also compiled and analyzed relevant topographic, climatic, soil, vegetation and streamflow data for two representative surface coal mines in western US, the Rosebud and Big Sky Mines, Colstrip, MT, for testing and refining the WEPP-Mine model. Additionally, we conducted field sampling and performed laboratory experiments to determine soil hydraulic properties as impacted by surface mining.

New functions developed in this study and incorporated in WEPP-Mine allow (i) the use of user-specified DEMs and reclamation maps to properly characterize the changes in topographic, land cover, and soil conditions in mined and reclaimed areas, and (ii) the assessment of Best Management Practices (BMPs), such as sediment pond, silt fence, and revegetation, for erosion and sediment control. The default input templates in WEPP-Mine were all customized to properly represent the dry climate and landuse and soils typical of western US conditions. WEPP-Mine performance was evaluated by comparing the model simulation results with field observations at the Big Sky Mine. Commonly applied reclamation practices for erosion and sediment control were simulated and contrasted, and recommendations on future research work were provided.

As the primary product of this project, WEPP-Mine is developed as a user-friendly web-based computer package for use by regulatory authorities, consultants, the mining industry, and other practitioners and researchers. WEPP-Mine can be used to simulate watershed discharge and sediment yield under pre- and post-disturbance conditions, and to assess the effectiveness of reclamation activities and alternative management practices for erosion and sediment control, as required by OSM, EPA, and state regulations. WEPP-Mine can also be used as a cost-effective prediction tool for general planning and management, e.g., in determining cumulative watershed hydrologic and erosion effects of future climate change. With the customization functions and newly developed data templates in the package, WEPP-Mine can be readily applied to common alkaline coal mines in western US and other regions in the country.

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Introduction

The federal Surface Mining Control and Reclamation Act (SMCRA) of 1977 provides the framework for regulating the planning and scheduling of mining operations for erosion and sediment control, as well as for maintenance activities on a mine site to reduce erosion and sediment. Specifically, SMCRA established effluent discharge limits on surface discharges from mine sites for total iron, total manganese, total suspended solids, and pH. The National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act (CWA) of 1985 also stipulates effluent limitations for direct discharge from a mine site.

In 2002, EPA established the Western Alkaline Coal Mining Subcategory to encourage the use of Best Management Practices (BMPs) to control erosion and sediment from coal mining reclamation and other non-process areas in the arid and semi-arid western US (EPA, 2002). The arid west has considerably different environmental conditions compared to other coal mining areas in the US. In most western coal mining areas, the natural vegetation is sparse and runoff events are localized and of high intensity and short duration (EPA, 2000). However, the current effluent guidelines require all reclamation areas throughout the US to meet the same discharge limits, regardless of climate, soil and topography, or the type of mine drainage (acid or alkaline), which often leads to the construction of unnecessarily large sediment ponds. These large sediment ponds are costly to build and maintain, and furthermore, they cause disturbance of natural hydrologic balance, groundwater flow, and water availability. To reduce these adverse impacts, EPA has established a new regulatory subcategory that requires coal mine operators to design and implement BMPs to control the average annual sediment yield below the pre-mined, undisturbed level (EPA, 2001). To meet this requirement, the coal mine operators must develop site-specific sediment control and reclamation plans.

Computer models have been developed to predict erosion and sediment yield under different geographic and land management conditions. These models, once developed, are cost-efficient tools for evaluating watershed responses to various BMPs for sediment control and reclamation prior to their implementation. Currently used models by regulatory authorities, consultants, and the mining industry include RUSLE (Revised Universal Soil Loss Equation; Renard et al., 1997) and SEDCAD (Sediment, Erosion, Discharge by Computer Aided Design; Warner and Schwab, 1998).

RUSLE is a revised form of the empirical USLE equation (Wischmeier and Smith, 1978). Both USLE and RUSLE are restricted to annual simulations for simple field conditions, and cannot provide erosion predictions for individual storm events or for a study area with any hydraulic structures. A variation of the USLE, the Modified USLE (MUSLE), is used in SEDCAD to estimate single-storm erosion as a function of precipitation and runoff (Williams, 1975). A more critical limitation of the USLE, MUSLE, and RUSLE lies in that, due to their empirical nature, they cannot be used to predict the temporally and spatially varying soil detachment and transport, and thus the actual paths of flow and sediment transport. This limitation becomes vital when using these models in assessing the impact of erosion on stream water quality in a watershed.

SEDCAD has physically-based runoff and sediment routing routines for hydraulic structures (sediment basins, check dams, silt fence, straw bales, dikes, and small sumps and berms). However, its overland flow simulation is based on the empirical SCS curve number method (USDA, 1986) for runoff generation. In addition, SEDCAD simulates erosion and sediment yield based on MUSLE and RUSLE, thus sharing the same limitations as these two empirical approaches.

Additionally, using RUSLE and SEDCAD for assessment of site-specific sediment control and reclamation plans for western alkaline coal mines can lead to erroneous results due to the following reasons. First, snowmelt runoff can cause significant erosion and sediment in high-elevation areas in the arid and semi-arid western US (McCool et al., 2000). The highly dynamic and complicated snowmelt process cannot be properly described by RUSLE and SEDCAD. Second, RUSLE cannot model the various sediment control BMPs, including the different hydraulic structures recommended by the US EPA (2002). SEDCAD can simulate these hydraulic structures yet it is limited in evaluating the spatial distribution of the BMPs (e.g., regrading, revegetation, mulching) due to its lumped-parameter approach to overland flow. The ability to model spatial distribution of BMPs and their effects is important to optimize the additive watershed cumulative effects (MacDonald, 2000). For example, sediment yield from a watershed can vary depending on the locations where silt fences are installed (upslope vs. downslope). Third, topography in many surface coal mining areas is complex and changes from pre-mining to post-mining. RUSLE and SEDCAD use an average slope steepness for the entire watershed and are thus limited in describing complex topography and associated soil detachment and deposition. Studies show that non-uniform hillslopes in different shapes have different soil loss rates (Meyer and Romkens, 1976) and the order of soil loss in accord with a hillslope profile is: complex < concave < uniform < convex (Toy and Foster, 1998).

The Department of Environmental Quality (DEQ) of Montana, a state regulatory authority, has identified the needs for adapting a physically-based and distributed-parameter model to better evaluate sediment yield in surface mining areas. The Montana DEQ has also expected that the new model should be able to evaluate the Montana Pollutant Discharge Elimination System (MPDES) sediment control and reclamation plans in initial application assessment and final bond release determinations (Neil Harrington and Tom Golnar, Montana DEQ, e-mail circulation, 2008).

WEPP (Water Erosion Prediction Project) is a physically-based model built on the fundamentals of hydrology, plant science, hydraulics, and erosion mechanics (Laflen et al., 1991; 1997). WEPP was developed by the USDA ARS to replace the empirical USLE approach and has been widely used by various federal agencies, including EPA, BLM, NRCS, and US Forest Service. WEPP is applicable for a wide range of geographic, landuse, and management conditions, and is capable of predicting spatial and temporal distributions of soil detachment and deposition on an event or continuous basis at both small (hillslopes, roads, small parcels) and large (watershed) scales (Flanagan and Livingston, 1995). The hydraulic structure routines in WEPP and SEDCAD were originally developed by the same team (Lindley et al., 1998a; 1998b), and those in WEPP have been further improved (Wu and Dun, 1998). WEPP has been parameterized for various benchmark soils across the US and the model performance has been assessed under a wide variety of land cover and management conditions. In addition, daily or single-storm climatic data can be generated based on statistical data with CLIGEN, an auxiliary stochastic climate generator (Nicks et al., 1995), when weather data are not available or when future prediction or frequency analyses are desired. WEPP can provide sediment output categorized into five particle-size classes: 2-, 10-, 40-, 200-, and 600-µm median diameters, allowing calculation of fine (suspended) sediment fractions.

WEPP conceptualizes a watershed as hillslopes, channels, and hydraulic structures, such as check dams and sediment ponds (Flanagan and Livingston, 1995). GIS tools have been developed to build input files for WEPP to determine the spatial distribution of erosion within a watershed, and the delivery of sediment to any point within a channel network (Cochrane and Flanagan, 1999; Renschler, 2003). Hence, the details of the topography both before and after mining can be evaluated to determine changes in sources of sediment, and sediment delivery. The effectiveness of BMPs for erosion and sediment control can also be evaluated, e.g., by considering different depths of storage or different shapes and slopes in case of sediment ponds.

The overall goal of this study was to develop WEPP-Mine, a practical computer simulation tool for evaluating site-specific sediment control and reclamation plans for National Pollutant Discharge Elimination System (NPDES) Western Alkaline Coal Mining Subcategory by EPA. The main objectives were: (1) to develop WEPP-Mine, a user-friendly computer package for evaluating site-specific sediment control and reclamation plans in western alkaline coal mining operations; (2) to develop templates containing datasets pertinent to climate, topography, soil, and land management for representative western US surface coal mines; (3) to assess the performance of the WEPP-Mine through comparison of model simulations with field observations; and (4) to disseminate the developed WEPP-Mine tool through various technology transfer venues, including workshops for regulatory authorities, consultants, and the mining industry, presentations at professional meetings, and scientific publications.

Executive Summary

The ultimate goal of this study was to develop an easy-to-use, cost-effective, and reliable computer simulation package for evaluating site-specific sediment control and reclamation plans in surface coal mine operations in the western US.

Developed based on the USDA's WEPP model and the recently developed WEPP Watershed Online GIS interface, WEPP-Mine is a user-friendly web-based computer package (http://wepponlinegis.bsyse.wsu.edu/osm) for use by regulatory authorities, consultants, the mining industry, and other practitioners and researchers. A user needs only a computer and a web-browser to access WEPP-Mine and to simulate watershed discharge and sediment yield under pre- and post-disturbance conditions, to evaluate and contrast the effectiveness of reclamation activities and BMPs for erosion and sediment control, and to predict cumulative watershed hydrologic and erosion responses to changing climatic and management conditions. The customization functions and newly developed input data templates allow WEPP-Mine to be applied to common alkaline coal mines in western US and other regions in the nation.

The performance of WEPP-Mine was assessed by comparing model simulation results and field observations using data collected at two western US alkaline surface coal mines, the Rosebud Mine and Big Sky Mine in Colstrip, MT. In collaboration with the Montana Department of Environmental Quality, we compiled and analyzed topographic, climatic, soil, vegetation, streamflow and sediment data. In addition, we carried out extensive literature review and synthesized data pertaining to soil properties and vegetation parameters for other surface coal mines in western US as well as other regions in the country and the world. (Detailed literature review and data synthesis were presented in a sequence of our quarterly progress reports.) As a case application of WEPP-Mine, we also evaluated commonly implemented reclamation practices for erosion and sediment control, and provided recommendations for future research work.

As another important effort of the study, we conducted field sampling and performed laboratory experiments to determine soil hydraulic properties, a major factor affecting soil erosion, as impacted by surface mining. Soil samples from undisturbed areas, roughly graded mine spoil, replaced topsoil before seeding, and revegetated areas at the Rosebud Mine were sampled from the field and tested in the laboratory. Measurements were made of particle-size distribution, organic matter content, and saturated hydraulic conductivity. The results showed significant differences in the hydraulic properties of the soils from the different sampling areas due to the mining and reclamation practices at the mine. WEPP simulations and risk analyses using these soil hydraulic property data indicated that the potential for soil erosion increases due to mining activities disturbing the soils. WEPP simulations also suggest that the potential for erosion may return to pre-mining levels over time with effective revegetation practices.

This project was aimed to develop a tool for use by regulatory authorities, coal mine operators, and others in evaluating watershed discharge and sediment yield in response to mining operations and post-mining reclamation activities. As such, efficient and effective project results dissemination and technology transfer was one of the key project objectives. During the past three years, we have regularly communicated with the funding agency and collaborating scientists, engineers, and staff at the MT DEQ and Rosebud Mine through teleconferencing, electronic exchanges, and in-person visits. We have submitted a series of quarterly progress reports, and presented our project results at the 2011 Annual Meeting of the Society for Mining, Metallurgy & Exploration, and the 2011 International Symposium on

Erosion and Landscape Evolution. Additionally, we conducted a half-day workshop on developing and applying the WEPP-Mine modeling technology in Helena, MT, on August 14, 2012. The workshop was attended by a broad audience of MT DEQ staff, OSM personnel, WSU researchers, and private consultants. A MS thesis has been completed from this project. A manuscript derived from the thesis assessing the impact of surface coal mining on soil hydraulic properties has been developed and submitted to the SME Mining Engineering Magazine.

Experimental Description and WEPP-Mine Development

Field sampling and laboratory experiments were a part of this comprehensive research project to develop a modeling technique for use as a management tool for assessing the hydrologic and erosion impacts of mining operations and reclamation practices. A series of soil sampling were conducted at the Rosebud Mine during 2009–2010. Analyses of soil hydraulic properties were made on the soil samples in the Soil Physics Laboratory at Washington State University. Measurement and analysis were made of soil particle-size distribution (ASTM, 1963), soil organic matter content (ASTM, 2007), and saturated hydraulic conductivity (Klute and Dirksen, 1986). Subsequent WEPP simulations were made with the field- and laboratory-measured soil property data to assess the hydrological and water erosion potential of different reclamation. The detailed description of the field work and laboratory experimentation as well as the study findings and results can be found in the MS thesis of Liu (2012). In the following we shall focus on the methods and material used in developing WEPP-Mine.

WEPP-Mine uses WEPP as its core model for watershed hydrology and erosion and builds upon the recently developed WEPP Watershed Online GIS interface (Frankenberger, 2011). WEPP-Mine was intended to address the specific conditions pertaining to mining areas, including substantially altered landuse, topography, and soil. Additionally, hydraulic structures may be constructed for runoff and sediment control in compliance with state and federal regulations. In this project, we developed new functions and incorporated them into WEPP-Mine to allow (i) the use of user-specified DEMs and reclamation maps to properly characterize the changes in topographic, land cover, and soil conditions in mined and reclaimed areas, and (ii) the assessment of BMPs (e.g., sediment pond, silt fence, and revegetation) for erosion and sediment control. (See Appendices A and B for detailed descriptions of the newly developed functions in WEPP-Mine.)

In developing the WEPP-Mine data templates, we carried out extensive literature review and synthesized data pertaining to soil properties and vegetation parameters for surface coal mines in western US and other regions in the country and the world. In collaboration with the Montana Department of Environmental Quality, we compiled and analyzed relevant topographic, climatic, soil, vegetation and streamflow data for the Rosebud and Big Sky Mines, Colstrip, MT, for testing and refining the WEPP-Mine model. In addition, we conducted field sampling and laboratory experiments to determine soil hydraulic properties as affected by mining operations and reclamation activities.

The default input templates in WEPP-Mine were customized to adequately represent the dry climate and landuse and soil conditions typical of alkaline surface coal mines in western US. Default soil and land management inputs for post-mining conditions were developed based on data collected at the Rosebud and Big Sky Mines, Colstrip, MT (Appendix A). Default data for sediment pond and other small hydraulic structures were customized to the arid or semi-arid climatic conditions (Appendix B). In addition to these newly developed data templates, WEPP-Mine provides options for a user to further customize WEPP inputs (see Appendices A and B; Frankenberger, 2011.) An example of applying WEPP-Mine to a representative western alkaline surface coal mine, the Big Sky Mine (Area A, "demo" watershed), is presented in Appendix A. The user-specified DEM and the reclamation map, intended to describe the post-mining conditions, were used in this application. For comparison, WEPP-Mine simulation for pre-mining conditions was made using the default inputs, i.e., the USGS DEM and land cover and the SSURGO soil data, presumed to represent pre-mining conditions. The results from both simulations were contrasted.

To test the default impoundment setting in WEPP-Mine, we chose three small nested watersheds (areas of 10, 20, and 50 ha) upstream the "demo" watershed in Area A, Big Sky Mine. The hydraulic structures, all presumed located at the watershed outlet and simulated for 30 years, included (1) culvert in sediment pond, (2) drop spillway with circular riser and barrel, (3) drop spillway with rectangular riser and circular barrel, (4) emergency spillway, (5) filter fence, (6) perforated riser, (7) rock-fill check dam, (8) straw bales, (9) culvert in forest road, and (10) sediment pond. The simulation results were compared with those with no impoundment in the watershed (Appendix B).

WEPP-Mine performance was further evaluated by comparing the model simulation results with field observations from seven watersheds with long-term daily streamflow data in Areas A and B, Big Sky Mine (Appendix C). Among the seven watersheds, one is in Area A and the other six in Area B. The default inputs, the USGS DEM and land cover and the SSURGO soil data, were used in the simulations since post-mining topographic and reclamation maps were not available at the time of completing this report. In all WEPP-Mine testing efforts, alternative reclamation practices for erosion and sediment control were simulated and contrasted, and recommendations of future research work were provided (Appendices A, B, and C).

Results and Discussion

WEPP-Mine (Fig. 1) is developed as a user-friendly web-based computer package for use by regulatory authorities, consultants, the mining industry, and other practitioners and researchers to evaluate site-specific sediment control and reclamation plans for alkaline surface coal mines in western US and other regions. A user only needs a computer and an internet browser to access WEPP-Mine and simulate watershed hydrology and erosion anywhere at any time. Furthermore, an authorized user can upload and use user-specified DEMs (Fig. 2) and reclamation maps (Fig. 3) to properly characterize the changes in topographic, land cover, and soil conditions in mined and reclaimed areas. Post-mining landuse map is then created by merging the reclamation map and the USGS land cover map, and, post-mining soil map is derived from intersecting the reclamation map with the SSURGO soil map. Post-mining soil inputs for disturbed areas consist of three parts; surface soil hydraulic and erosion parameters from the WEPP soil database (Table 1), soil texture data for the top 0.6 m as averages of the corresponding SSURGO soil data for the top 0.6 m, and the soil texture data for the remaining soil profile being from site-specific mine spoil data. Management inputs can be adapted from those in the WEPP database (Table 1).

Table 1. Land management and soil data in relation to reclamation conditions in WEPP-Mine

Index	Description	WEPP Management	WEPP Soils
0	Undisturbed or NoData	Poor grass	Shrub
1	Disturbed—facilities	Poor grass	Paved or bare rock
2	Not reclaimed	Bare	Mine spoil
3	Prior reclamation	Bare	Regraded mine spoil
4	Natural re-vegetation	Poor grass	Top soil
5	Seed phase I	Good grass	Sod grass
6	Seed phase II	Good grass	Bunch grass
7	Trail-complete	Low traffic road	Skid

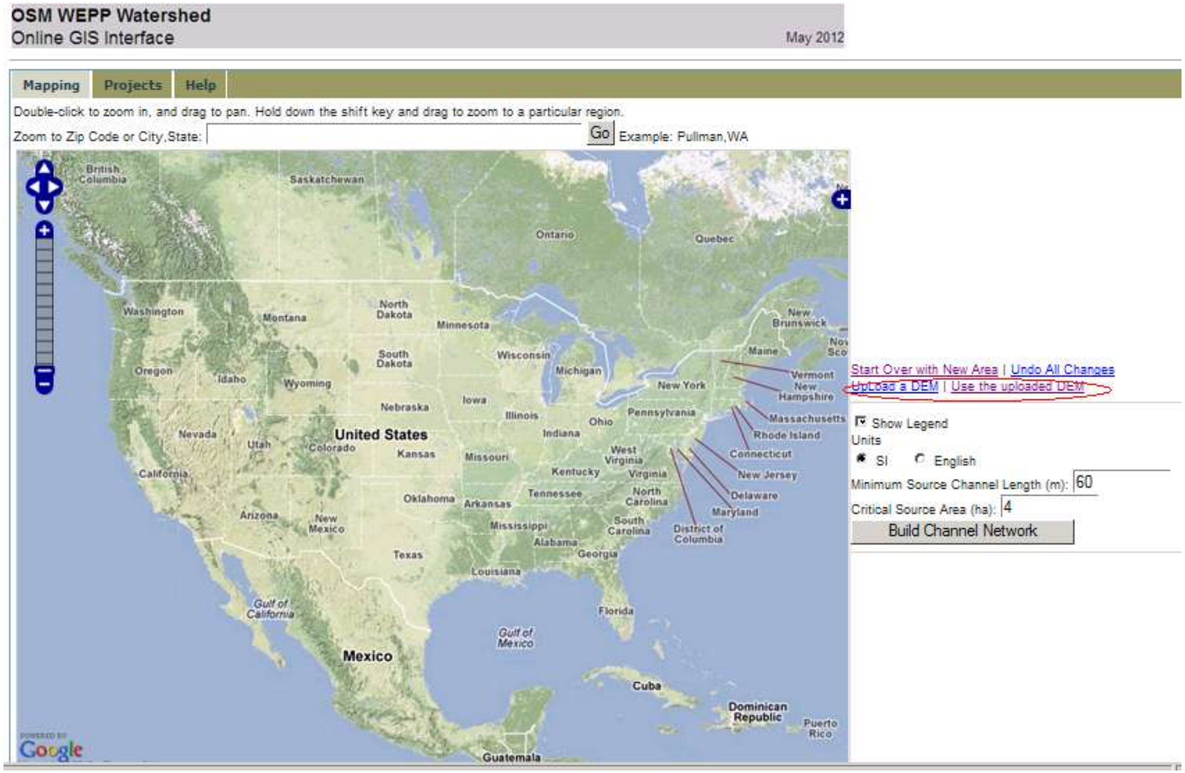

Figure 1. WEPP-Mine front page

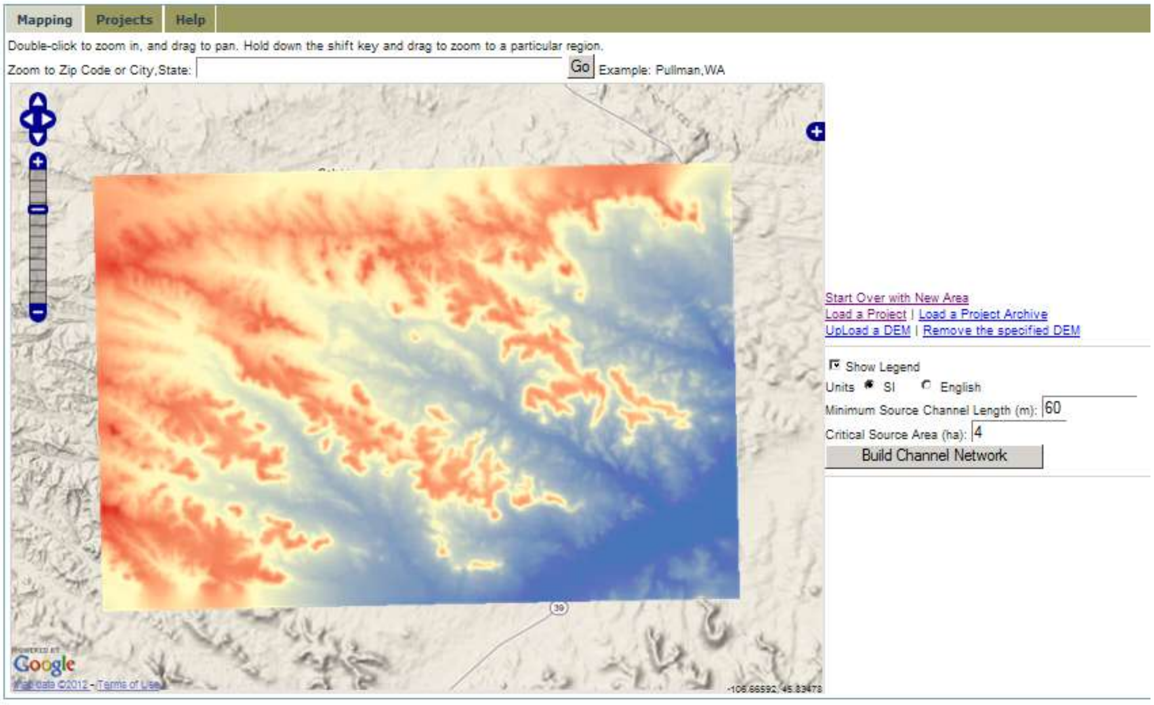

Figure 2. Using a user-specified DEM

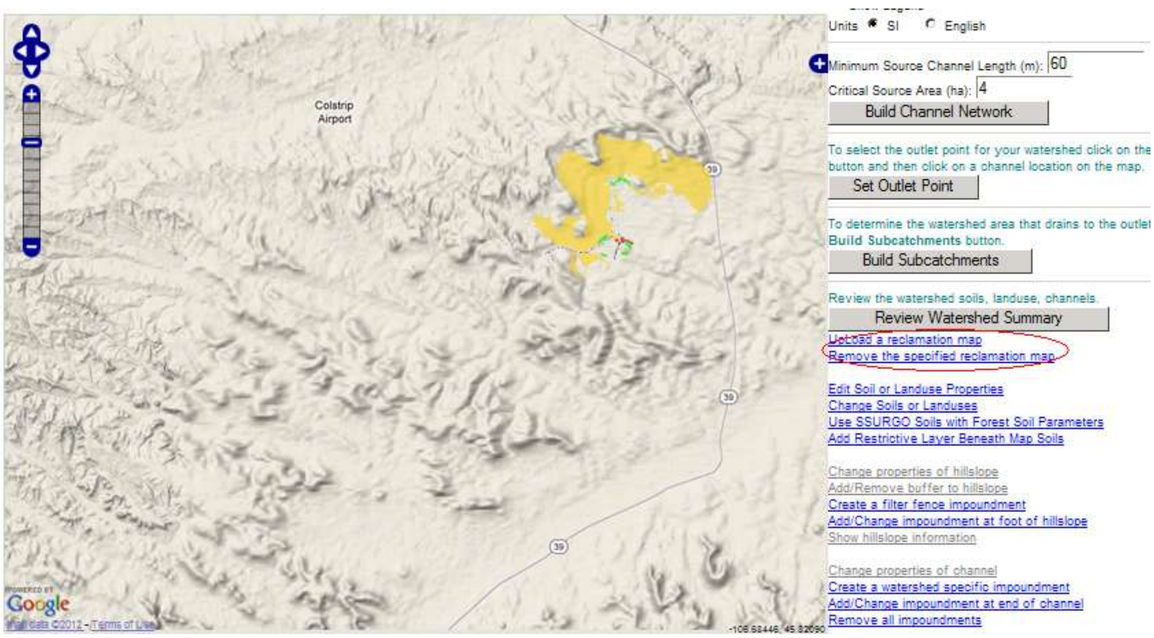

Figure 3. Using a user-specified reclamation map

WEPP-Mine provides options for selecting climatic inputs and WEPP simulation type (Fig. 4). By default, WEPP-Mine uses stochastic weather inputs generated with CLIGEN (Nicks et al., 1995) based on long-term statistical climate parameters from the nearest weather station included in the WEPP climate database. A user can choose to use the statistical parameters from other weather stations in the database and to further adjust the statistical parameters for precipitation and temperature using PRISM (PRISMCG, 2010). WEPP-Mine also allows uploading of user-specified climate files. Two types of simulations, watershed and flowpaths and "watershed only", can be made, and the number of simulation years can be specified. The maximum number of simulation years is 10 for a flowpath-type simulation and 100 for a "watershed only" run as the former requires much longer run time than the latter. A user can also choose to use a single soil or management for the whole watershed or to use the soil and landuse data determined from the GIS maps. WEPP-Mine simulation results are presented in the forms of text outputs, return-period analysis, and summary as well as maps of runoff, soil loss, and sediment yield.

Figure 4. WEPP simulation options

The application of WEPP-Mine to the “demo” watershed in Area A, Big Sky Mine, reveals that post-disturbance runoff and sediment yield are increased (Table 2, Figs. 5 and 6).

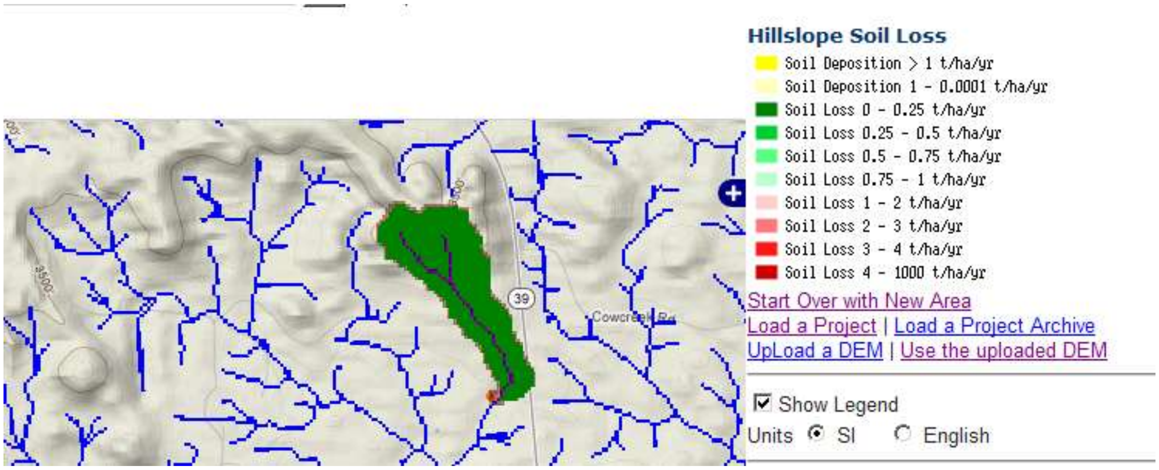

Figure 5. WEPP-simulated soil loss using default inputs presumed for pre-mining conditions

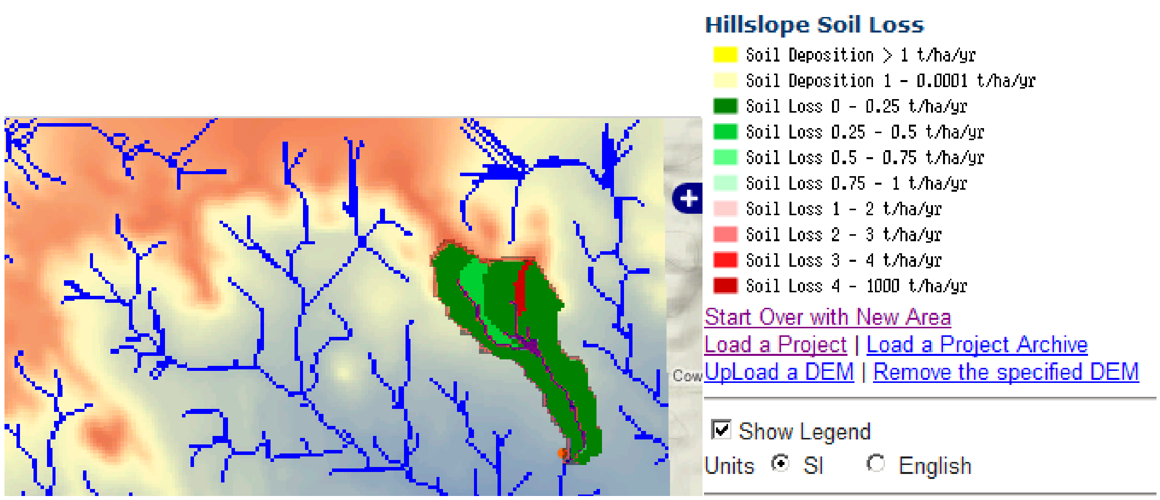

Figure 6. WEPP-simulated soil loss using user-specified DEM and reclamation map for post-mining conditions

Table 2. WEPP-simulated runoff and sediment yield for different return periods

Return Period (yrs)	With Default Inputs		With User-specified DEM and Reclamation map	
	Runoff (mm)	Sediment Yield (t/ha)	Runoff (mm)	Sediment Yield (t/ha)
2	0	0	0	0
5	0.04	0	0.57	0.29
10	0.24	0.03	0.91	0.48
20	1.33	0.19	1.67	0.88
25	1.64	0.30	1.67	0.92

The test results of WEPP-Mine performance using observed streamflow data from the seven watersheds in Areas A and B, Big Sky Mine, are presented in Table 3.

Table 3. Study watersheds in Areas A and B, Big Sky Mine

Obs. Point	BPSFL	BRTFL	BMMFL	BS33FL	BLFFL	BBBFL	AFL50-1
Longitude	−106.717	−106.692	−106.675	−106.633	−106.674	−106.641	−106.603
Latitude	45.824	45.815	45.806	45.79	45.802	45.8	45.835
Stream	Lee Coulee, Area B	Lee Coulee, Area B	Lee Coulee, Area B	Lee Coulee, Area B	Fossil Fork, Lee Coulee, Area B	Bad Bob Gulch, Lee Coulee, Area B	Area A
Collection Area, ha	581	992	1308	4067	760	794	168
Obs. Start	10/18/1984	3/14/1985	10/18/1984	2/17/1984	2/28/1985	3/15/1985	8/9/2000
Obs. End	12/31/2006	5/16/2001	6/15/2003	12/31/2006	5/11/1999	9/30/1989	12/31/2006
Obs. Year	22	17	19	23	15	5	6
Observed Runoff at Specified Recurrence Interval, mm							
2-yr	0.57	0.11	0.07	0.05	0.77	0.62	0.00
5-yr	1.31	0.38	2.06	0.98	2.15	2.16	0.01
10-yr	1.63	0.77	9.03	2.28	3.83		1.06
20-yr		0.88	9.33				
25-yr	9.38			3.83			
WEPP-simulated Runoff at Specified Recurrence Interval, mm							
2-yr	0.02	0.01			0	0	0.06
5-yr	0.76	0.39			0.03	0.06	1.11
10-yr	2.81	1.57			0.07	0.09	2.67
25-yr	15.9	12.2			0.34	0.64	8.97
WEPP-simulated Sediment Yield at Specified Recurrence Interval, t/ha							
2-yr	0	0			0	0	0
5-yr	0.02	0.02			0	0	0.12
10-yr	0.11	0.13			0	0.01	0.52
25-yr	0.95	1.24			0.02	0.07	2.41

Figure 7 shows the newly developed WEPP-Mine function of simulating hydraulic structures that can be placed at the end of a channel segment or the foot of a hillslope (Fig. 7). Templates were developed for 10 different types of commonly used hydraulic structures for erosion and sediment control and were customized to the dry climatic conditions of the western US. These templates are default impoundment settings in WEPP-Mine. Site-specific hydraulic structures with customized configurations and hydraulic parameters can be created and simulated in WEPP-Mine (Fig. 8). The results testing the hydraulic structures in WEPP-Mine are presented in Tables 4−6. From the simulation results, the large hydraulic structures, i.e., the drop spillway and emergency spillway may be unnecessary for the small (10-ha) watershed with the extremely low sediment delivery ratios (< 10%); they appear most efficient for the 20-ha watershed. Small hydraulic structures all lead to similar sediment trapping efficiency for both the 10- and 20-ha watersheds, but they become overtopped in the 50-ha watershed.

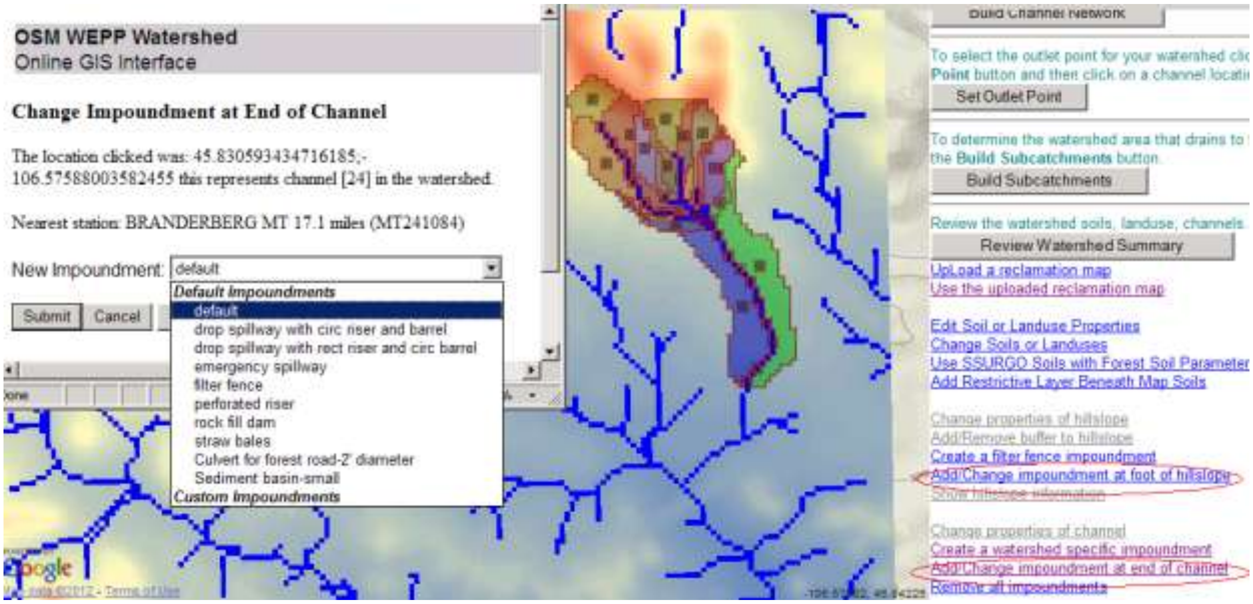

Figure 7. Adding a hydraulic structure at the end of a channel segment or at the foot of a hillslope

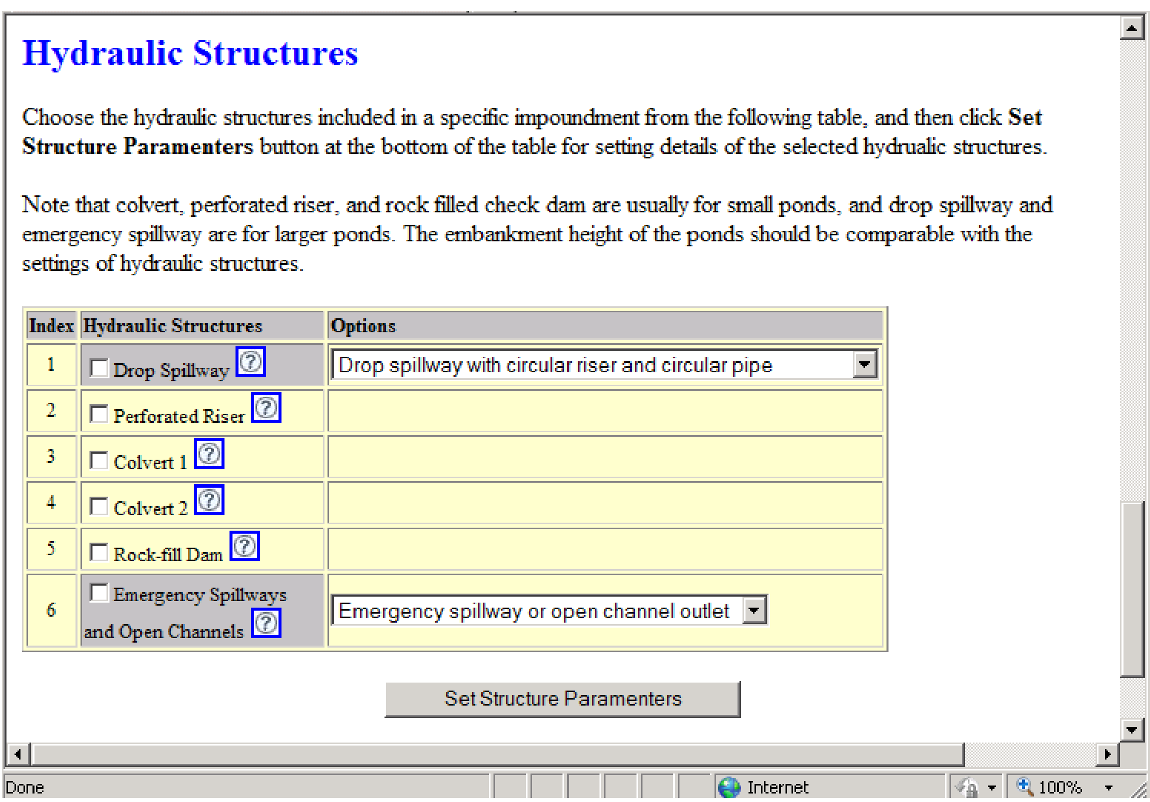

Figure 8. Customizing hydraulic structures

Table 4. Simulated runoff and sediment yield from the 10-ha watershed

Impoundments	Sediment				Runoff Discharge	
	Yield		Delivery Ratio		m^3/yr	mm/yr
	ton/yr	t/ha/yr				
No impoundment	0.8	0.10	1.017	1.00	48.4	5.76
Culvert in sediment pond	0.5	0.06	0.551	0.54	47.3	5.63
Drop spillway with circ riser and barrel	0.1	0.01	0.070	0.07	16.1	1.92
Drop spillway with rect riser and circ barrel	0.0	0.00	0.058	0.06	15.9	1.89
Emergency spillway	0.0	0.00	0.006	0.01	6.1	0.73
Filter fence	0.5	0.06	0.638	0.63	48.4	5.76
Perforated riser	0.6	0.07	0.727	0.71	48.3	5.75
Rock-fill dam	0.4	0.05	0.456	0.45	48.1	5.73
Straw bales	0.4	0.05	0.519	0.51	48.4	5.76
Culvert in forest road	0.4	0.05	0.471	0.46	47.6	5.67
Sediment pond	0.4	0.05	0.475	0.47	48.3	5.75

Table 5. Simulated runoff and sediment yield from the 20-ha watershed

Impoundments	Sediment				Runoff Discharge	
	Yield		Delivery Ratio		m^3/yr	mm/yr
	ton/yr	t/ha/yr				
No impoundment	5.2	0.23	0.977	1.00	158.6	7.08
Culvert in sediment pond	3.9	0.17	0.718	0.73	156.5	6.99
Drop spillway with circ riser and barrel	1.6	0.07	0.299	0.31	119.0	5.31
Drop spillway with rect riser and circ barrel	2.0	0.09	0.369	0.38	118.9	5.31
Emergency spillway	1.0	0.04	0.193	0.20	96.3	4.30
Filter fence	2.7	0.12	0.512	0.52	158.6	7.08
Perforated riser	4.7	0.21	0.871	0.89	158.5	7.08
Rock fill dam	2.8	0.13	0.523	0.54	158.4	7.07
Straw bales	2.7	0.12	0.512	0.52	158.6	7.08
Culvert in forest	3.1	0.14	0.574	0.59	156.8	7.00
Sediment pond	3.4	0.15	0.630	0.64	158.5	7.08

Table 6. Simulated runoff and sediment yield from 50-ha watershed

Impoundments	Sediment				Runoff Discharge	
	Yield		Delivery Ratio		m^3/yr	mm/yr
	ton/yr	t/ha/yr				
No impoundment	2.7	0.05	0.375	1.00	331.6	6.14
Culvert in sediment pond	2.7	0.05	0.371	0.99	328.5	6.08
Drop spillway with circ riser and barrel	2.1	0.04	0.288	0.77	281.2	5.21
Drop spillway with rect riser and circ barrel	2.1	0.04	0.288	0.77	280.5	5.19
Emergency spillway	1.7	0.03	0.236	0.63	254.8	4.72
Filter fence	2.7	0.05	0.367	0.98	331.5	6.14
Perforated riser	2.7	0.05	0.370	0.99	331.5	6.14
Rock fill dam	2.7	0.05	0.365	0.97	330.7	6.12
Straw bales	2.7	0.05	0.364	0.97	331.6	6.14
Culvert in forest road	2.7	0.05	0.369	0.98	328.6	6.09
Sediment pond	2.7	0.05	0.371	0.99	331.3	6.14

The assessment of WEPP-Mine performance shows that the simulated runoff amount generally falls in the range of the field-observed, though the occurrence of the observed runoff events was not reproduced in most cases. The ten hydraulic structures simulated by WEPP-Mine have different effects in runoff and sediment control, with the larger structures, i.e., emergency spillway and drop spillway being the most efficient. By and large, these structures are more efficient for smaller watersheds. Future efforts may include continuous monitoring of sediment yield, which is crucial for evaluating the effectiveness of different BMPs and for assessing the adequacy and reliability of the WEPP-Mine model. In WEPP-Mine applications, break-point precipitation data may be used to more properly reproduce the observed runoff and erosion events. Finally, the soil and management inputs can also be refined to better describe pre- and post-mining conditions.

Conclusions

WEPP-Mine is developed as a user-friendly web-based computer package for use by regulatory authorities, coal mine operators, consultants, and other practitioners and researchers to evaluating site-specific sediment control and reclamation plans for National Pollutant Discharge Elimination System (NPDES) Western Alkaline Coal Mining Subcategory by EPA. A user needs only a computer and a web browser to access WEPP-Mine to simulate watershed discharge and sediment yield under pre- and post-disturbance conditions, and to assess the effectiveness of reclamation activities and alternative management practices for erosion and sediment control. WEPP-Mine can also be used as a cost-effective prediction tool for general planning and management, e.g., in determining cumulative watershed hydrologic and erosion response to changing climatic and management conditions. With the customization functions and newly developed data templates in the package, WEPP-Mine can be readily applied to common alkaline coal mines in western US and other regions in the country.

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