The WEPP Model for Runoff and Erosion Prediction Under Center Pivot Irrigation

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Abstract

The USDA Water Erosion Prediction Project (WEPP) Hillslope model was tested with data taken under traveling lateral irrigation in Southern Idaho. The main parameter affecting infiltration and runoff was the effective hydraulic conductivity. The model was found to predict average runoff and soil loss reasonably well for small slope areas (<40m) and can be used to analyze for potential runoff problems on steep critical areas within a larger field.

Keywords. Sprinkler irrigation, Center pivots, Runoff, Erosion models, WEPP.

Introduction

The USDA Water Erosion Prediction Project (Flanagan and Nearing, 1995; Flanagan and Livingston, 1995) model was developed to predict runoff and erosion primarily on rain-fed cropland and rangeland. Laflen et. al. (1991) and Nearing et.al. (1989) describe the model and its processes. The sprinkler irrigation component allows users to input irrigation amount and application rate for specified days or to specify an irrigation schedule based on soil water depletion level. Since WEPP was designed to simulate uniform rainfall, the irrigation component can simulate constant application rate sprinkler irrigation over an entire hillslope, such as solid set systems or stationary individual laterals placed parallel to the slope. Kincaid (1999) evaluated WEPP for the case where sprinkler laterals were oriented parallel to the slope direction.

A center pivot is a traveling lateral which pivots about one end, irrigating a circular area. The system capacity (often expressed in mm/day or gpm/acre) and the length of lateral determines the application rates, which increase in direct proportion to the distance from the pivot. Thus, the greatest potential for runoff occurs near the outer edge of the field. Pivot laterals are commonly 400 m (1/4 mi) in length and irrigate about 52 ha (130 acres). The type of sprinkler used on the lateral also affects the application rates, which are inversely proportional to the width of the sprinkler pattern. Lower pressure sprinklers are increasingly popular, and these have reduced pattern widths. Sprinkler droplet sizes are affected by the nozzle pressure, nozzle size and sprinkler type. Large drops with large impact energy striking the soil surface, produce splash erosion, which, in turn affects infiltration and runoff.

Sprinkler systems, particularly center pivots, operate on variable topography. The slope direction relative to the lateral determines how runoff can accumulate and cause erosion. If the lateral is perpendicular to the slope, runoff will tend to move away from the lateral, reducing concentrated flow and thus reducing the distance surface runoff will travel before it infiltrates. However, if the slope is parallel to the lateral, runoff can accumulate downslope sufficiently to cause erosion. If crop ridges are present, the row direction relative to the slope and lateral also affects the runoff flow direction. It is common practice to ridge and plant row crops perpendicular to a traveling lateral or in a circular pattern under a pivot to help direct runoff away from the lateral. The pivot wheel tracks themselves (about 40m apart) provide runoff channels, further complicating the process. If the lateral is traveling upslope, runoff will move onto a previously wetted area, whereas with downslope travel, runoff can move onto dry soil. Thus a complete runoff-erosion model for center pivot sprinkler systems must be able to handle both the rainfall-runoff situation and furrow-rill flow with infiltration or any combination thereof.

Although the model should give best results for center pivots where the lateral is parallel to the slope so that the entire hillslope receives water simultaneously at a relatively high rate, it may also give reasonable results for the case where the lateral is perpendicular to the slope for short (probably less than a span length) hillslopes where the slope is watered in a short time. The main objective of this paper was to test whether WEPP would predict reasonable runoff and soil loss where a traveling lateral is moves up or down slope.

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Model Processes and Parameters

The WEPP Hillslope Model was designed for continuous simulation of the hydrologic process using a daily time step, and can handle only one rainfall or irrigation event per day. Input data files describe the climate, slope, soil properties, crop and tillage management, and irrigation. The hillslope can be divided into several sections (Overland Flow Elements) which can have different soil properties and management practices. The model calculates infiltration with the Green-Ampt model (Mein and Larson, 1973). The key parameter which the user can alter is the effective hydraulic conductivity, K_b. The user inputs a "baseline" K_b, (an initial high value representing conditions after tillage on a fallow soil), and the model will then decrease K_b to account for management practices. If the user has no initial estimate for K_b, the model will calculate a value based on soil texture alone. Before runoff can begin, rainfall excess is reduced by depression storage or water ponded on the surface which eventually infiltrates (Onstad, 1984). A random roughness parameter is user adjustable. Surface runoff is modeled using a simplified kinematic wave procedure (Woolhiser and Liggett, 1967). The rill width (0.15m used here) and spacing (0.76 m) are also user-adjustable parameters, and we found the model to be relatively insensitive to these parameters. The model predicts the amount and duration of runoff, peak runoff rate, and soil loss (Foster et.al., 1981; Foster, 1982).

Experimental Procedures

Field experiments were conducted near Kimberly in Southern Idaho, during the 1999-2000 irrigation seasons. A traveling lateral with six 41-m (135-ft) spans was used. The lateral was nozzled uniformly at 7.58 L/min/m (0.61 gpm/ft), with rotating spray heads spaced at 3.05 m (10 ft), and 138 kPa (20 psi) nozzle pressure. The droplet kinetic energy for the spray heads was about 8 J/kg (Kincaid, 1996). The spray pattern width was about 18m (60 ft). The average application rate was about 25 mm/hr. The soil was Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcids), which had a bulk density of about 1.35 g/cm^3. The soil holds about 32% water by volume at field capacity and 14% at wilting point. The 1999 crop was spring wheat, and the straw was shredded and disked into the surface. The 2000 crop was corn, planted on ridges spaced at 0.76 m (30 inch) perpendicular to the lateral. The plot area is located at the south end of the field, and slopes to the south. The slope direction is perpendicular to the lateral. The slopes were fairly uniform, averaging 3 percent for spans 5-6 and 2.5 percent for spans 3-4. The plot (hillslope) length was 37 m (120 ft). Six runoff plots were located under each of four spans (3-6). Each plot consisted of 4 adjacent furrows, whose runoff was combined and measured with a small trapezoidal flume. Sediment samples (1 L) were collected from each flume at approximately 5, 15, 30, 30... minute intervals after runoff began. Imhoff cones were used to determine sediment concentration. Antecedent soil water was measured by neutron probe. Four large irrigations were applied and monitored for runoff (Table 1). For the first two tests, the lateral traveled upslope, and for the second two, downslope. Additional smaller irrigations supplied crop water needs.

Model Simulations

The model runs reported here were made with WEPP hillslope version 98.4 (April, 1998 release). The model was run using a 2 year continuous simulation, with the first year (1999 wheat) simulation used to set up the soil management parameters. The second year simulated the actual fixed-date irrigations, which we monitored. Daily weather data for Kimberly were used in the climate file. Input files were constructed for running the simulation as a single OFE hillslope. Comparisons were made between measured and model-predicted total runoff, peak runoff rate, soil loss, and volumetric soil water content. The WEPP USER MANUAL (Flanagan and Livingston, 1995) was consulted for suggested values of the soil parameters. The baseline soil water conductivity, K_b , was initially set at the model-calculated value of 3.2 mm/hr. Subsequently, K_b was adjusted upward to reduce predicted runoff as discussed later.

Results and Discussion

Table 1 gives results for the field tests and model predictions for four irrigation dates. Measured runoff, peak runoff rate and soil loss are averages for 6 plots under each span. Field observations indicated that for downslope travel, significant runoff did not begin until the lateral had traversed about half the plot length. Therefore, runoff depths are calculated based on a plot length of 18 m, i. e. the width of the spray pattern. Runoff depths were much higher from span 6 than from the other spans. This is attributed to soil property differences rather than slope, since the predictions did not vary significantly with slope. Compared to the average of the four monitored spans, the

Hillslope model (with K_b=3.2 mm/hr) tended to overestimate runoff, peak runoff rate and soil loss. With the initial value of K_b=3.2 mm/hr, the model predicted runoff and soil losses reasonably close to measured amounts from span 6, but it was necessary to increase K_b to 5 mm/hr to bring predictions closer to those measured from the other spans. This shows the sensitivity of the model to the hydraulic conductivity estimate.

Table 1. Runoff, peak rate and soil loss for 2000 corn plots

		Measured				:	Model Predicted			
Irrig. Date	Span	Gross depth	Runoff	Std. Dev.	Peak rate	Soil Loss	K_b	Runoff	Peak Rate	Soil Loss
		mm	mm	mm	mm/hr	kg/m^2	mm/hr	mm	mm/hr	kg/m^2
22 Jun	3	27	1.6	1.0	1.8	0.001	5.0	2.3	7.8	0.027
	4		1.4	0.8	2.6	0.002				
	5		2.6	1.2	2.8	0.004				
	6		6.4	4.2	7.2	0.016	3.2	6.1	12.6	0.073
Avg			3.0	1.8	3.6	0.005				
29 Jun	3	38	1.0	1.0	1.6	0.002	5.0	0.6	4.4	0.01
	4		0.8	0.6	1.2	0.002				
	5		5.2	3.2	5.6	0.030				
	6		11.0	7.0	10.2	0.068	3.2	6.9	11.7	0.113
Avg			4.5	3.0	4.7	0.025				
12 Jul	3	50	6.0	5.2	5.0	0.008	5.0	13.2	13.1	0.157
	4		4.0	1.4	4.0	0.008				
	5		8.2	5.2	6.2	0.074				
	6		22.4	15.4	12.0	0.338	3.2	20.0	15.8	0.245
Avg			10.2	7.5	6.8	0.107				
18 Jul	3	40	4.8	3.8	5.2	0.012	5.0	11.4	13.8	0.111
	4		2.6	0.8	3.6	0.004				
	5		4.6	3.2	4.0	0.036				
	6		14.0	11.6	9.6	0.284	3.2	16.6	16.3	0.166
Avg			6.5	4.9	5.6	0.084				

If the measured runoff was based on the full slope length of 36 m, the measured amounts would be reduced by half. The model simulation could then be run using an effective intensity of 13 mm/hr, based on the time necessary for the lateral to traverse the entire slope. For example, the third test gave an average runoff of 10.2 mm, or 5.1 mm for the full slope. The model (with K_b =3.2 mm/hr) predicted 7.8 mm of runoff with the reduced intensity of 13 mm/hr. This approximation may be realistic for slope lengths up to twice the pattern width of the sprinklers.

Conclusions

The WEPP Hillslope Model should give reasonable runoff predictions for center pivot irrigation on slopes where the runoff direction runs nearly parallel to the lateral. This is a worst case scenario for center pivot irrigation, since runoff tends to concentrate and create erosive streams. For cases where the slope is perpendicular to the lateral, the model may still be used with some reservations. The upper portion of the slope where no run-on occurs may be handled normally. The effective application rate could be adjusted to account for partial-area rainfall. Since wheeltracks often become concentrated flow channels, disrupting the normal runoff direction, the overall slope could be divided into smaller span-length (30-50m) hillslopes, and combined in the WEPP watershed model. However, for use with center pivot type irrigation, the model probably should be limited to analyzing small, critical slope areas within a field.

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