Evaluating the Impacts on Runoff of Landscape-based Best Management Practices in a Rain-fed Agroecosystem of the U.S. Midwest (EP41B-0706)

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Summary: Conversion of the natural prairie-forested landscape in U.S. Midwestern states to a corn-soybean crop rotation has altered the runoff condition and stream hydrology throughout the region by creating more dynamic surface water flow regimes and increasing the likelihood of severe floods. Flooding and the associated water quality issues in the region adversely affect crop yields, downstream ecosystem health, and water availability. In response to these concerns, Midwestern agricultural producers have adopted Best Management Practices (BMPs) to increase runoff retention and reduce sediment delivery. Common BMPs in the region are Grassed WaterWays (GWWs), which have been found to effectively reduce runoff/sediment conveyance by slowing water flow and increasing infiltration rates. This study examined the storm-event based efficiency of GWWs at reducing runoff within an agricultural watershed of the U.S. Midwest using the Water Erosion Prediction Project (WEPP). Reductions in runoff volume in a representative field increased by 9 times as the length of the GWW increased. GWW efficiency was governed by the hydrology, expressed as Q_{peak}. The GWWs were more efficient during events with smaller Q_{peak} values, while the efficiency decreased during larger events. Building on these simulations for a single hillslope, a standardized hydrologic analysis was conducted in the watershed using established hydrologic modeling techniques (i.e., WIN TR-20) to quantify and mitigate potential flooding impacts for the entire watershed. The outcome of this study was to identify and quantify the management practices (e.g., conversion to grass or no-till) needed to mitigate large flood events in the watershed. The results suggested that the landscape changes are best used as secondary efforts. A high level of land use conversion was needed to produce significant runoff reductions. Average reductions in runoff volumes of about 12% were observed for a 25% conversion of agricultural land to grasslands, with about an average 15% reduction for a 50% conversion. However, these land conversions will likely decrease sediment and contaminant loads in the streams, which has other significant benefits.

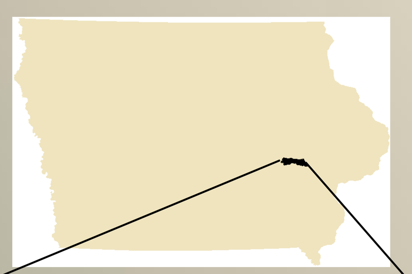
Goal: To determine the types of landscape-based Best Management Practices and the degree of their implementation needed to limit excess runoff in agriculture watershed.

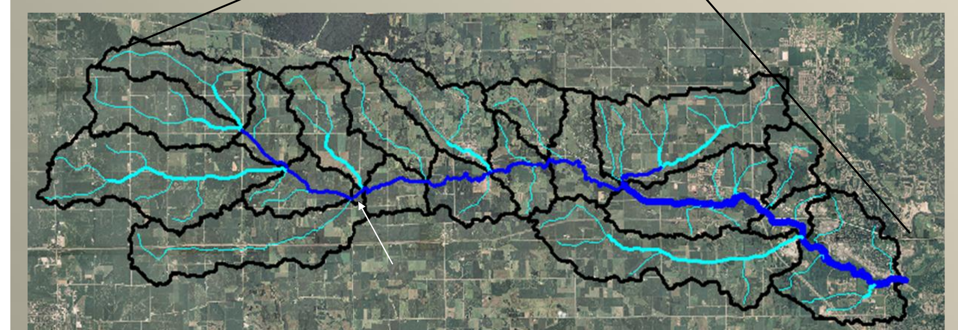
Excess runoff is defined as the volume that cannot be carried within channel boundaries.

Study Site:

Clear Creek, IA (260 km²) is located in the rolling hills of the southeastern Iowa.

Average annual precipitation is ~ 900 mm/yr. The average gradient is ~ 4%. Soils are mostly silty clay loam and have moderate infiltration rates (i.e., consist of moderately to well drained soils.

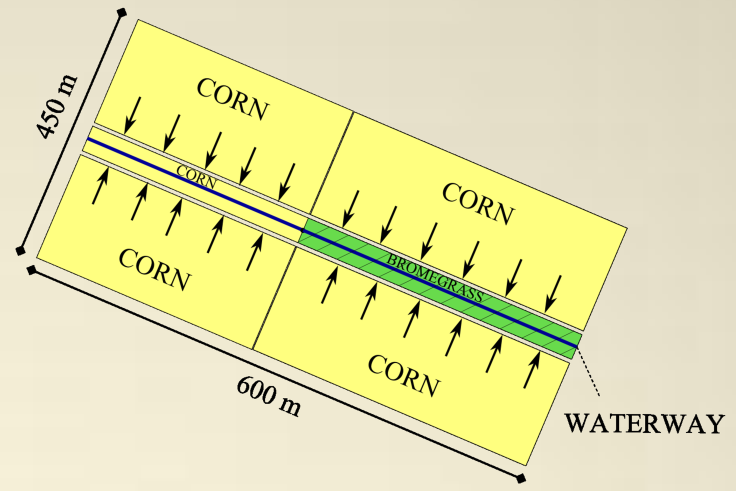




Land use transitions from predominantly agriculture in the western sub-watersheds to grasslands and forests in the central sub-watersheds to an urban environment on the eastern most edge of Clear Creek.

Methodology:

Step 1: Determine the efficiency of GWWs at reducing runoff for single storm events in representative test fields of the Clear Creek watershed. Different GWWs were examined with different dimensions (e.g., length) for different magnitude events, as represented with the peak runoff rate (Q_{peak}).



The Watershed Erosion Prediction Project (WEPP) model was used to simulate runoff for 8 storm events (4 events for calibration and 4 events for validation). Runoff was primarily controlled by the hydraulic conductivity. See table below.

Event	Date	Rainfall (mm)	Runoff (mm)	Q_{peak} (m^3/s)
1*	6/22/07	74	55	5.02
2a	8/19/07	24	2	0.56
4	7/7/08	51	5	1.52
5*	7/12/08	13	2	0.40
6a*	7/17/08	43	16	2.28
6b	7/19/08	30	16	1.82
6c*	7/21/08	19	13	1.06
8	9/12/08	62	30	3.39

*Calibration events; remainder used for verification

Model simulations:

(i) Assess the effects of GWW length on reducing runoff, by altering GWW length between 100 m - 600 m and planting corn the remaining length.

(ii) Examine the effects of the gradient of the contributing hillslope area on GWW efficiency by changing the hillslope gradient between 0.5 – 6.0%.

Step 2: Quantify runoff volumes in Clear Creek sub-watersheds for large storm events where excess runoff is produced. Storm events ranged from the 2-year, 24-hour (83 mm) to the 100-year, 24-hour Natural Resources Conservation Service (NRCS) design storm (171 mm). Calculate reduction in runoff volume by implementing GWWs.

The Win TR-20 is a Windows-based version of the NRCS Technical Release-20 and was used to calculate runoff volumes and peak flow rates (NRCS, 2004a).

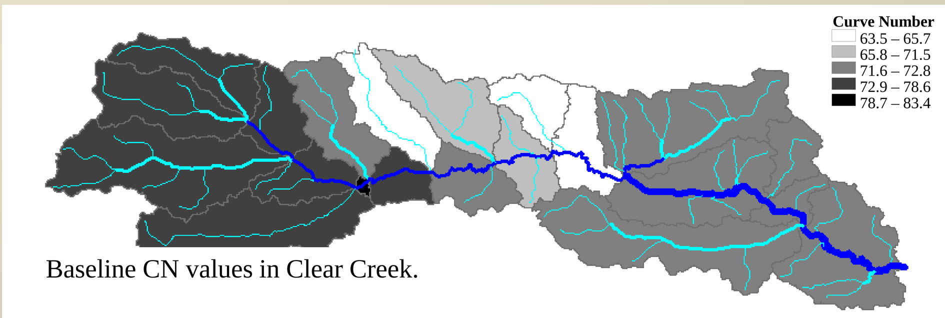
The runoff curve number (CN; NRCS, 2004b) is used by Win TR-20 to calculate runoff. It is a non-dimensional index that reflects a soil's response to a rain event through runoff and infiltration. The CN has a value between 0 (no runoff) and 100 (no infiltration). It is based on a specific combination of soil properties, tillage regimes, and land covers. Here a weighted average was calculated for each sub watershed.

$$S = \frac{1000}{CN} - 10 \qquad Q = \frac{(P - I_a)^2}{P - I_a + S}$$

where S is the potential maximum soil moisture retention after runoff begins (in.); Q is runoff (in.); P is rainfall (in.); I_a is the initial abstraction (in), or the amount of water before runoff, such as infiltration, or rainfall interception by vegetation; and it is generally assumed that $I_a = 0.2S$.

CURVE NUMBERS				
Land Cover	Hydrologic Soil Group (HSG)			
	A	B	C	D
Roads	98	98	98	98
Industrial	89	92	94	95
Residential	61	75	83	87
Row Crops	71	80	87	90
Pastures	49	69	79	84
Forests	36	60	73	79

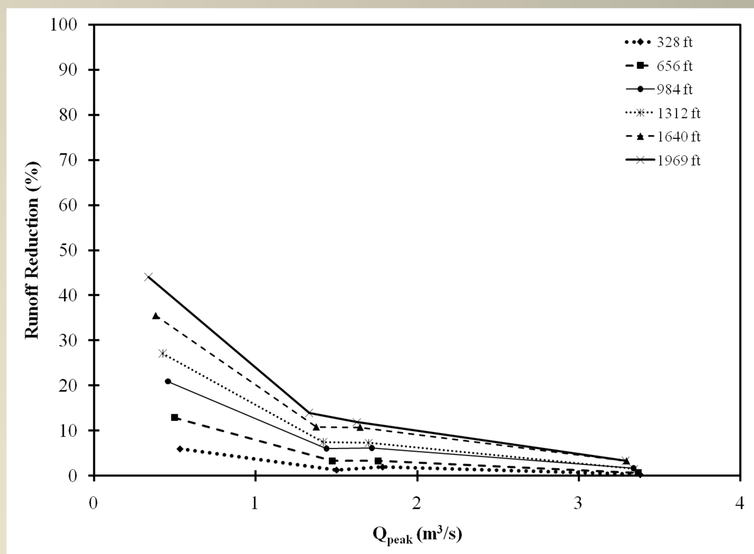
The HSG is a reflection of the runoff potential for a particular soil. Soils are divided into four groups ranging from well drained, little runoff (A) to poorly drained, low runoff (D).



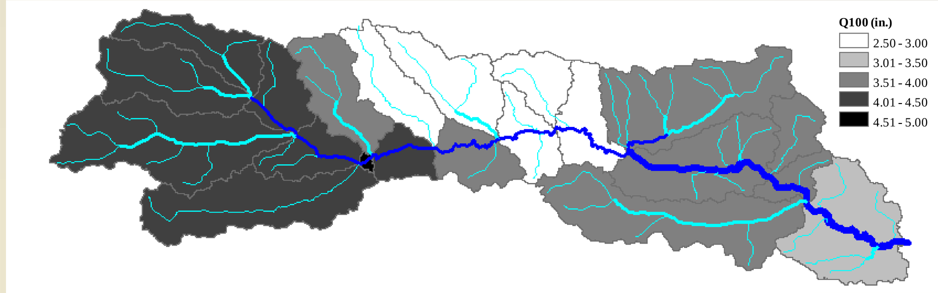
Baseline CN values in Clear Creek.

The predominantly agriculture western sub-watersheds had the highest average CN, while the grassland-forest central sub-watersheds had the lowest average CN.

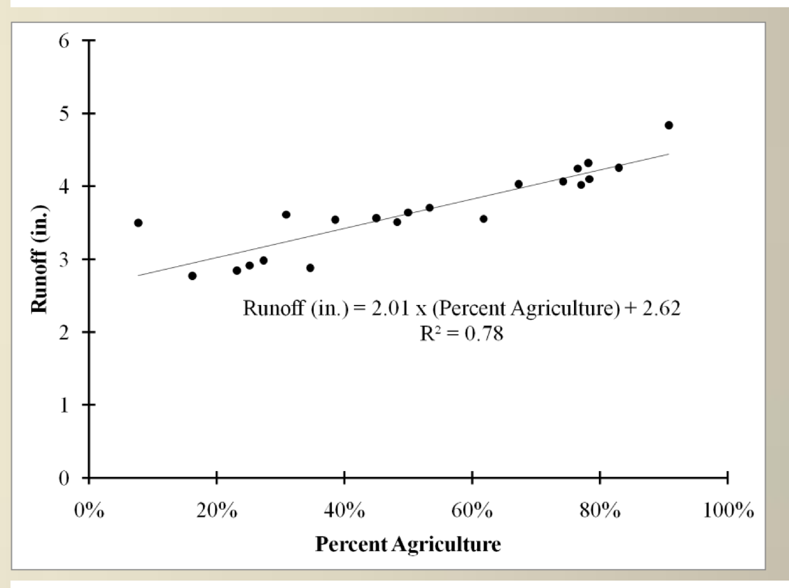
Results:



Runoff reductions from the contributing hills increased with the length of the GWW. The reduction increases about 9 times by increasing the length from 328 ft. to 1969 ft. The GWW's ability to reduce runoff decreased dramatically at higher Q_{peaks} (see left); thus, GWWs are more efficient at lower events. See Dermisis et al. (2010) for more discussion.

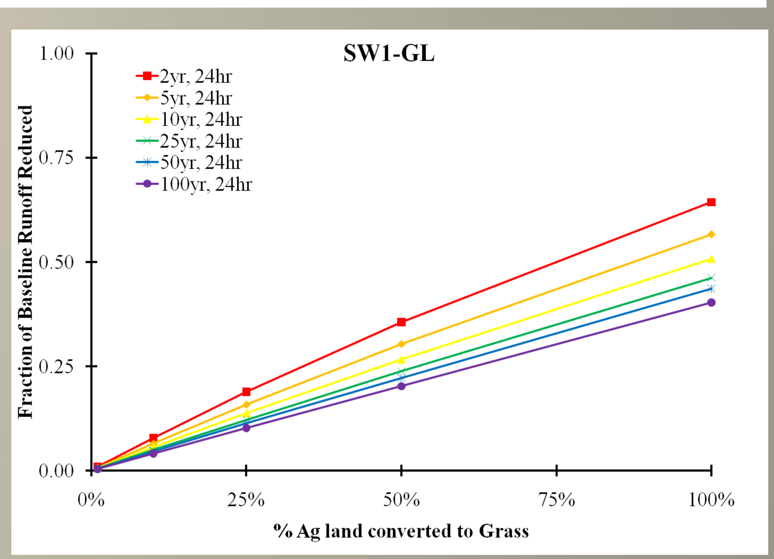


Runoff volumes in the Clear Creek sub-watersheds for the 100-year, 24-hour rain event are in the figure to the left.

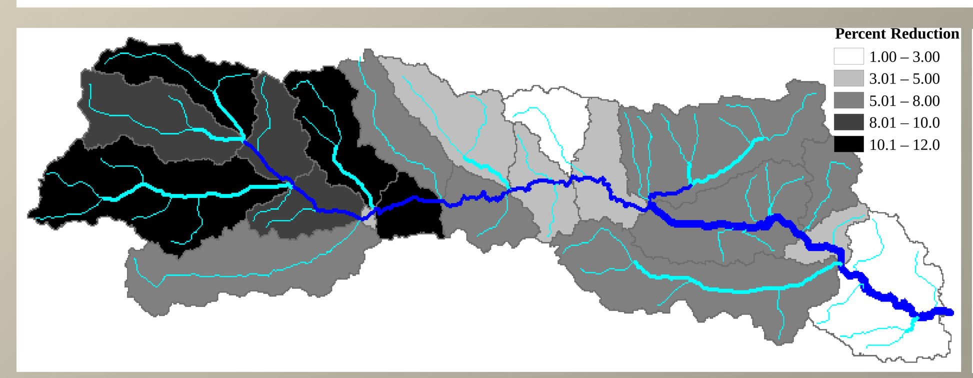


Runoff volumes were strongly related to the percentage of agricultural land in each sub-watershed, which is due to the agricultural land use having a relatively high CN and covering considerable area in each sub-watershed. The highest runoff volumes are in the western agricultural sub-watersheds, with the lowest in grassland-forest watersheds.

Different percentages (from 1% to 100%) of agricultural land in each sub-watershed were converted to grassland by lowering the CN. A 1% conversion would simulate the addition of approximately 20 GWWs, while a 100% conversion would simulate return to native prairie conditions.



The graph above shows an example of the runoff reductions for different levels of grassland conversion for a predominantly agriculture sub-watershed. A conversion of 25% of the agricultural lands to grasslands would only produce a runoff reduction of ~5 to 12% depending on the event size. These results correspond to the results of the WEPP simulations, which showed higher runoff reductions for smaller events.



Runoff reductions throughout the watershed ranged up to 15%. Thus, for large events, additional measures are needed for substantial runoff reductions.

References: Dermisis, D., O. Abaci, A.N. Papanicolaou, C.G. Wilson. 2010. Evaluating grassed waterway efficiency in southeast Iowa using WEPP. Soil Use & Management. 26(2):183-192.
Natural Resources Conservation Service (NRCS). 2004a. Win TR-20: Users Guide. U.S. Department of Agriculture. Washington, DC.
Natural Resources Conservation Service (NRCS). 2004b. Estimation of direct runoff from storm rainfall. Ch. 10, Part 630, Hydrology, *National Engineering Handbook*. 210-VI-NEH. USDA, Washington, DC.