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Sprinkler and Surface Irrigation Effects on Return Flow Water Quality and Quantity

D.L. Bjorneberg[1], D.T. Westermann[1], N.O. Nelson[2]
[1]USDA ARS, Kimberly, ID [2]Kansas State University, Manhattan, KS

Abstract. A major conservation practice in the Upper Snake-Rock (USR) watershed is the conversion from furrow irrigation to sprinkler irrigation. We compared the effect of irrigation system type on water quality and quantity at the watershed scale. Six small watersheds (150-700 ha) were identified with 5 to 70% of the cropland sprinkler irrigated and the remaining fields surface or furrow irrigated. Other agricultural land uses, cropping practices and soils were similar among watersheds. Water quality and quantity entering and exiting each watershed were measured with automated samplers during the irrigation season. Irrigation inflow to watersheds and outflow from watersheds did not decrease as sprinkler irrigated area increased. This probably results from the flow rate allocation system used on the Twin Falls irrigation tract. Annual sediment loss (r=-0.19, P=0.40) and concentration (r=-0.38, P=0.30) also did not correlate with the relative amount of sprinkler irrigated area. Annual sediment loss (r=0.87, P=0.03) and concentration (r=0.84, P=0.05) correlated with irrigation inflow–the more irrigation water delivered to a watershed the greater the outflow sediment concentration and loss. These preliminary results indicate that irrigation water delivery should be managed in addition to converting to sprinkler irrigation to improve water quality in this irrigated watershed.

Keywords. Sprinkler Irrigation, Surface Irrigation, Water Quality.

Introduction

The Conservation Effects Assessment Project (CEAP) was initiated to assess the effectiveness of cost-shared practices following increased conservation program funding in the 2002 Farm Bill. The Upper Snake-Rock (USR) watershed is one of eight special emphasis watersheds in the CEAP effort. This 6300 km^2 watershed, which includes irrigated cropland, rangeland and forest in southern Idaho, was chosen specifically to assess the effects of conservation practices in irrigated agriculture. The USR project focuses on the Twin Falls irrigation tract, an 820 km^2 agricultural area supplied with irrigation water from the Snake River by the Twin Falls Canal Company (TFCC). All cropland in the Twin Falls irrigation tract is irrigated because annual precipitation is less than 250 mm, most of which occurs during the winter months. Irrigation is the primary hydrologic input to the Twin Falls irrigation tract, generally 2 to 4 times greater than annual precipitation.

Conversion from furrow irrigation to sprinkler irrigation is the primary Natural Resources Conservation Service (NRCS) funded conservation practice in the Twin Falls irrigation tract. Sprinkler irrigation is typically more efficient than furrow irrigation because water is distributed in the field through pipes rather than flowing over the soil. Water flowing over soil detaches and transports sediment, which negatively impacts water bodies receiving irrigation return flow. Berg and Carter (1980) measured soil loss from 49 fields in southern Idaho during two irrigation seasons (1978 and 1979) and found that 20 to 70% of the irrigation inflow ran off the fields and annual soil loss varied from 0.5 to 141 Mg ha^{-1}. A more recent study reported annual soil loss of 2 to 33 Mg ha^{-1} from six furrow irrigated, row crop production fields in southern Idaho (Bjorneberg et al., 2007) Converting to sprinkler irrigation conceptually should reduce runoff and soil loss from fields. The objective of this study was to conduct a preliminary assessment of the water quality and quantity effects, at a small watershed scale, of converting from furrow to sprinkler irrigation using data collected during the first year (2005) of the USR CEAP.

Materials and Methods

A multiple watershed approach is being used to assess the water quality and quantity effects of converting from furrow to sprinkler irrigation. Six small watersheds within the Twin Falls irrigation tract were chosen for monitoring based on each having a well defined inflow boundary and a single outlet. It is common within the Twin Falls irrigation tract for unused irrigation water and field runoff to be diverted from drainage channels to other fields, making the surface water hydrology very complicated in some areas.

The six watersheds vary from 150 to 710 ha and have 5 to 69% of the cropland sprinkler irrigated (Table 1). Soils in all watersheds are silt loam, predominantly Portneuf silt loam. Two of the watersheds, EC and S2, contain subsurface drains that continue to flow after the irrigation season.

Table 1. Watershed Characteristics in 2005.

Watershed	Size	Sprinkler Irrigated Area	Slope	Irrigation Inflow	Potential Crop Water Use	Watershed Outflow
	ha	%	%	mm	mm	mm
EC	600	15	2 to 8	807	575	411
PC1	350	5	0 to 2	821	597	112
PC2	450	38	0 to 2	1001	635	485
S2	710	69	0 to 2	505	633	318
TF1	170	19	2 to 4	1106	603	230
TF3	150	51	2 to 4	1091	561	239

Inflow to each watershed was calculated from TFCC records for all headgates in each watershed. Outflow from each watershed was measured with a flume or weir. A datalogger and pressure transducer measured water stage every minute and recorded the hourly average stage and flow rate. An automatic sampler, controlled by the datalogger, collected flow proportional samples with a goal of 4 to 5 sample bottles per week. Ten subsamples were composited in each sample bottle. The dataloggers also recorded cumulative flow volume associated with each subsample and sample.

The TFCC diverts water from the Snake River into canals and laterals in mid-April. Most farmers did not begin irrigating until June 2005 because precipitation in April and May were approximately 250% of normal. Monitoring equipment was installed and operating in May for all watersheds. Monitoring continued until flow stopped in early October in the watersheds without subsurface drains. For EC and S2, data through Dec. 31, 2005 are included in this paper.

Monitoring sites were visited weekly during the irrigation season to collect water samples and download flow data. Grab samples were also collected weekly from one or two inflow sites in each watershed. Water samples were refrigerated until processed the day after collection. During sample processing, samples were stirred for 1 to 2 min before measuring pH and electrical conductivity. A 50 ml aliquot was taken for total nutrients and salts analysis (N, P, K, Ca, Mg, and Na). A second 20 ml aliquot was filtered (0.45 micron) and analyzed for dissolved nutrients and salts (NO_3, NH_4, P, K, Ca, Mg, Na, Al, Fe, Mn, Zn, S, and Cl). A third aliquot was used to determine sediment concentration by filtering a known volume (approximately 100 ml) through 0.45 micron filter paper and weighing the dried filter paper.

The filtered water sample was analyzed by inductively coupled plasma optical emission spectroscopy (ICP-OES) for P, K, Ca, Mg, Na, Al, Fe, Mn, Zn, and S concentrations, and by flow injection analysis (FIA) for NO_3-N, NH_4-N, and Cl concentrations. An aliquot (~25 ml) of the unfiltered water sample was digested with a Kjeldahl procedure (USEPA, 1983) and analyzed by ICP-OES for total P, K, Ca, Mg, Al, Fe, Na, and Zn, and by FIA for NH_4-N for total N.

Precipitation data from three National Weather Service sites in the Twin Falls irrigation tract were used to estimate average precipitation for the six watersheds. Each watershed was also surveyed to determine irrigation system type and crops grown on each field for calculating potential crop water use. Cropped areas were multiplied by the potential water use for 2005 calculated by AgriMet (http://www.usbr.gov/pn/agrimet/) for the Kimberly, ID site to estimate potential crop water use for each watershed. The U.S. Bureau of Reclamation uses AgriMet to calculate potential water use for crops in the Pacific Northwest. The potential water use for each crop was the average water use for all AgriMet emergence dates because detailed records of crop emergence were not recorded. We assumed no water use for the area attributed to farmsteads.

Watershed inflow and outflow volumes were divided by total watershed area to calculate inflow and outflow water depths. The mass of a constituent flowing from a watershed was calculated by multiplying the concentration by flow volume that occurred during each sample period. The mass for each sample period was summed to determine season total loss. Total season mass loss was divided by total watershed outflow to calculate flow weighted annual concentrations. Regression was used to compare relationships between watershed characteristics and water quality/quantity measurements. With six watersheds, the coefficient of determination must exceed 0.66 to be significant at $P=0.05$ and 0.53 at $P=0.10$.

Results

A simple water balance showed that irrigation inflow plus precipitation exceeded outflow plus potential crop water use by >200 mm for three watersheds (Figure 1). The net gain of water in these three watersheds was likely lost to deep percolation, which could reappear in the Twin Falls irrigation tract via subsurface drainage. The amount of water gained or lost in a watershed did not correlate with the relative amount of sprinkler irrigation in each watershed ($r=-0.44$, $P=0.26$). For example, TF1 had a net gain of 394 mm with

19% sprinkler irrigation while TF3 had a net gain of 414 mm with 51% sprinkler irrigation. The one watershed with a net loss of water (S2) has a subsurface drain that contributed to the outflow. The net loss of water indicates that water from outside the watershed may be contributing flow to the subsurface drain. There could also be some fields in the S2 watershed that are irrigated with water pumped from a headgate outside the watershed. Excluding flow data and precipitation occurring after the irrigation season reduced the net water loss from 250 mm to 208 mm for S2. The water balance for the EC watershed was nearly zero. This could indicate that the subsurface drain captured any deep percolation that occurred within the watershed and returned it as surface flow that was measured at the watershed outlet. Note that this discussion assumes that actual crop water use was not substantially different from the calculated potential crop water use. A 20% difference between actual and potential crop water use would change the water balance about 100 mm.

Irrigation inflow did not decrease as sprinkler irrigated area increased (r=-0.33, P=0.32) even though sprinkler irrigation is usually more efficient than surface irrigation. Although crop distributions varied among the watersheds, the differences were not related to the amount of sprinkler irrigation. Therefore potential crop water use was not correlated with sprinkler irrigated area (r=0.32, P=0.33).

Watershed outflow tended to increase with the relative amount of sprinkler irrigation in a watershed (Figure 2). Although the correlation was not significant (P=0.20), it indicates that watershed outflow will not decrease with sprinkler irrigation in this irrigated tract. One possible reason is that the TFCC allocates water on a flow rate basis, not water volume basis. Farmers are able to receive a flow rate of irrigation water for the entire season, typically 50 to 60 Lpm per hectare. Their flow rate cannot be stored for later use so there is little incentive for farmers to stop diverting irrigation water even if a field is not being irrigated. Therefore water typically flows directly from the headgate to the drainage channel when a sprinkler system is turned off. Removing the two watersheds with subsurface drainage did not improve the correlation between watershed outflow and sprinkler irrigated area.

Net annual sediment loss (outflow sediment mass minus inflow sediment mass) from watersheds did not decrease as the relative amount of sprinkler irrigation increased (r=-0.19, P=0.40). S2 watershed actually gained 6 kg ha^{-1} of sediment with 69% sprinkler irrigation and PC1 lost 138 kg ha^{-1} of sediment with only 5% sprinkler irrigation. Net annual sediment loss varied from 1000 to 2000 kg ha^{-1} for the other four watersheds. The lack of correlation may be due to location and management of furrow irrigated fields within each watershed. Essentially all of the soil eroded from a furrow irrigated row crop field near the watershed outlet could be transported from the watershed. Conversely, sediment deposition could occur if the outlet for the furrow irrigated fields is located some distance from the watershed outlet. Furthermore, excessive erosion from one furrow irrigated field could overwhelm the erosion control benefits of sprinkler irrigation. Berg and Carter (1980) and Bjorneberg et al. (2007) measured 2 to 57 Mg ha^{-1} annual soil loss from 17 dry bean fields, with an average annual soil loss of about 17 Mg ha^{-1}. One 10-ha field with 30 Mg ha^{-1} soil loss would contribute 300 Mg of sediment to the return flow, assuming no deposition within the watershed. This additional sediment would raise the average annual soil loss in each watershed 420 to 1900 kg ha^{-1}, depending on watershed size.

Net sediment loss was significantly correlated (r=0.87, P=0.03) with irrigation inflow depth (Figure 3). The more water that was delivered to a watershed, the greater the sediment loss regardless of the percentage of sprinkler irrigation. This sediment may be eroded from the fields or the channels and ditches in the watershed. Flow weighted sediment concentration was similarly correlated with irrigation inflow (r=0.84, P=0.05). Since watershed outflow did not correlate with irrigation inflow (r=-0.06, P=0.47), the increased sediment loss was caused by increased sediment concentration not additional flow from the watershed.

Flow weighted total P concentration had similar correlations with sprinkler irrigation percentage and irrigation inflow (Figure 4) as sediment concentration because total P was directly related to sediment concentration (r=0.91, P<0.01). Soluble phosphorus (P) concentration tended to decrease as the relative amount of sprinkler irrigated area increased (r=-0.54, P=0.21), and tended to increase irrigation inflow depth increased (r=0.65, P=0.15). Although these correlations were not statistically significant, it is reasonable that soluble P concentration would decrease with sprinkler irrigation because water is not flowing over the soil in the fields, assuming that the soluble P comes from the fields not the channels. It is also expected that soluble P concentration would increase with irrigation inflow depth because increasing irrigation inflow increased sediment concentration in watershed outflow.

Only looking at season total losses and flow weighted concentrations could lead to the conclusion that sprinkler irrigation has little effect on water quality. Analyzing the data for only July, when irrigation demand is greatest, shows that increasing the relative amount of sprinkler irrigation in a watershed tends to decrease sediment concentration (r=-0.70, P=0.12), total P concentration (r=-0.76, P=0.09) and soluble P concentration (r=-0.82, P=0.05). However, characteristics and management within each watershed effect the quality of water flowing from the watershed. TF1, for example, with 19% sprinkler irrigation seemed to have a disproportionately high sediment loss compared to the other watersheds (Figure 5). Removing TF1 from the regression analysis increased the correlation coefficients to -0.97, -0.96, and -0.84 for sediment, total P, and soluble P, respectively.

Conclusions

Preliminary analysis of data from these six small watersheds indicates that annual irrigation inflow and annual watershed outflow did not decrease as the relative amount of sprinkler irrigated land increased. The greater the depth of irrigation water delivered to a watershed, the greater the sediment loss and concentration in watershed outflow. Sediment losses and concentrations for the entire irrigation season were not significantly correlated with the relative amount of sprinkler irrigated area, although there was a decreasing trend. These preliminary results suggest that irrigation water delivery should be managed in addition to converting to sprinkler irrigation to improve water quality in this irrigated tract.

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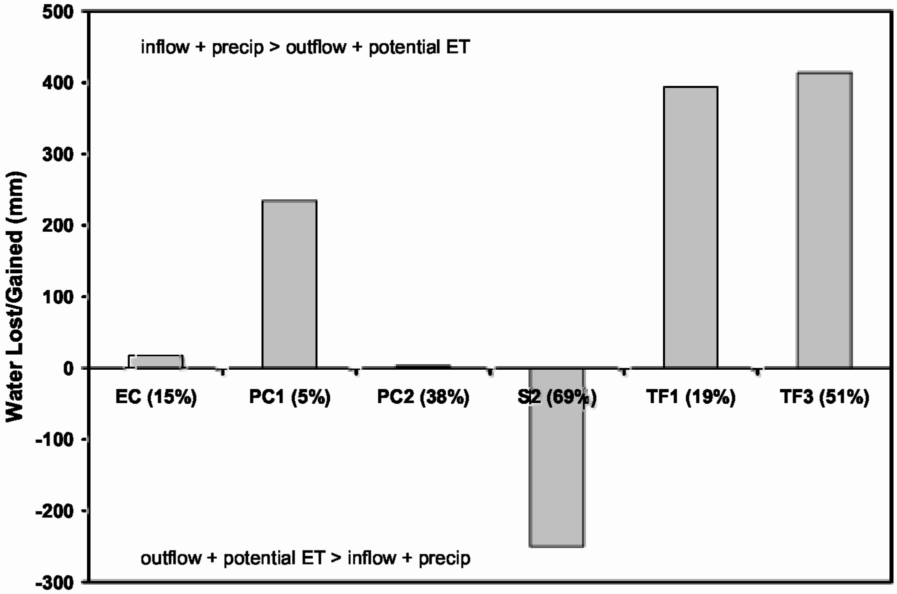

Figure 1. Water balance for the six watersheds. Water lost is the result of inflow plus precipitation minus outflow minus potential crop water use. EC and S2 watersheds have subsurface drains. Numbers in parenthesis are percent sprinkler irrigated area in each watershed.

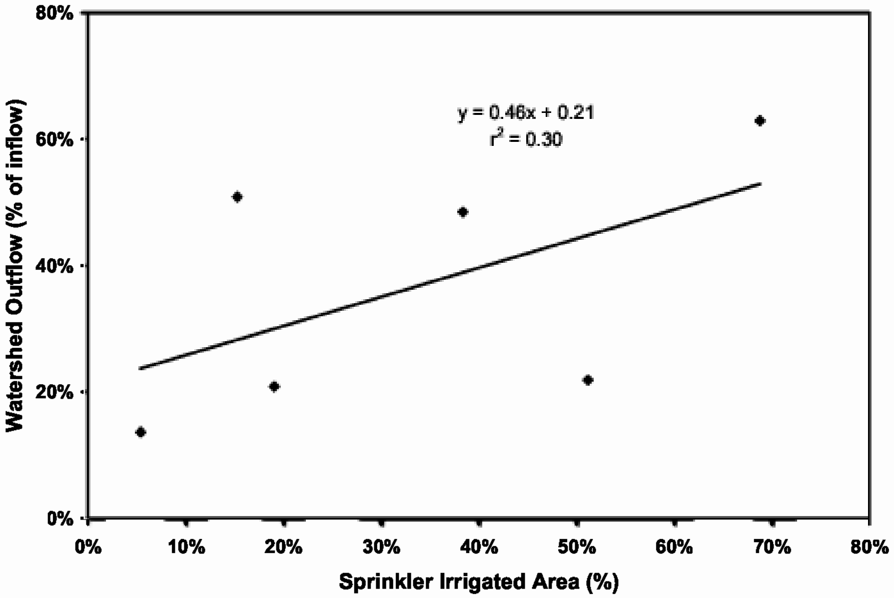

Figure 2. Relationship between watershed outflow and relative amount of sprinkler irrigated area in each watershed.

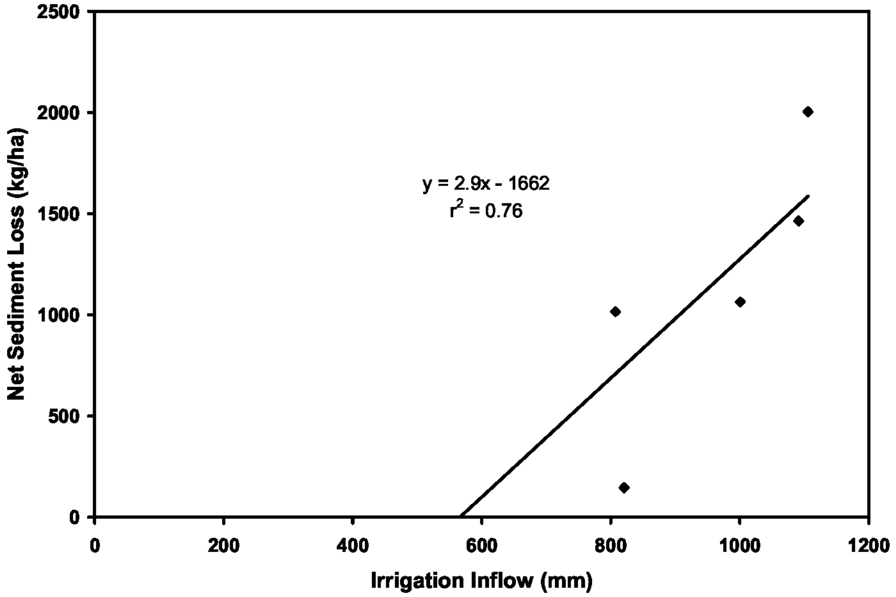

Figure 3. Relationship between net sediment loss and irrigation inflow for each watershed.

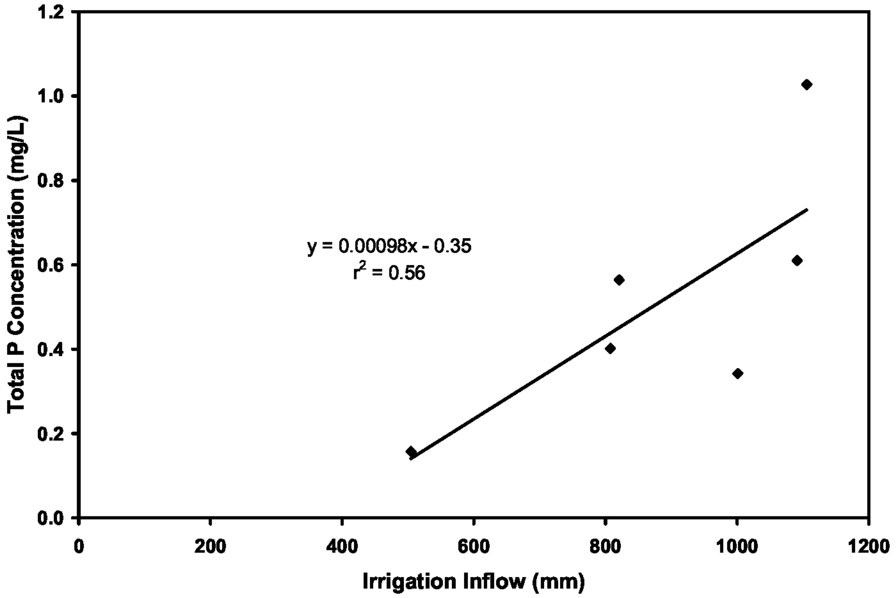

Figure 4. Relationship between flow weighted total phosphorus concentration and irrigation inflow for each watershed.

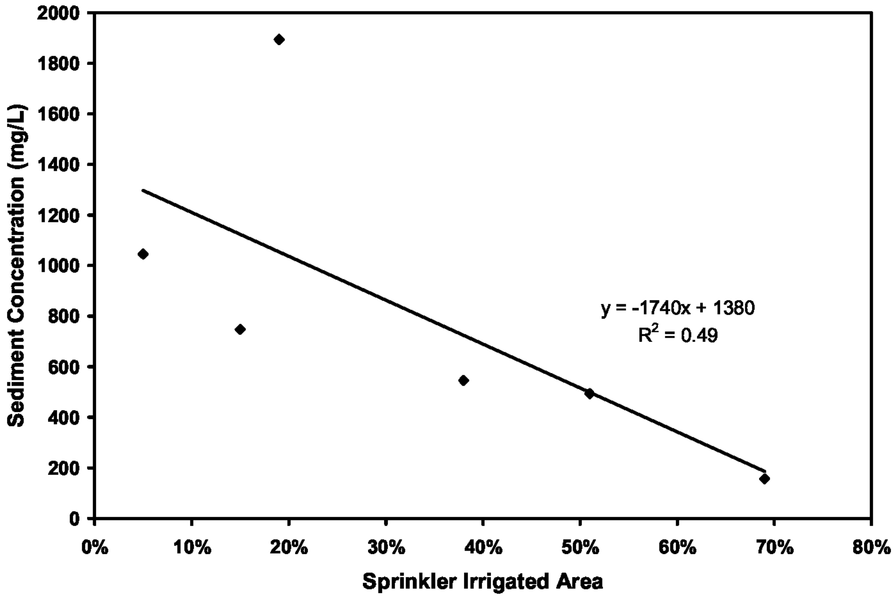

Figure 5. Relationship between flow weighted sediment concentrations for July 2005 and relative amount of sprinkler area in each watershed.