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Nutrient Losses from an Irrigated Watershed in Southern Idaho

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Abstract. *Water, sediment and nutrients flowing into and out of the 82,000 ha Twin Falls, ID irrigation tract were measured from 2005 to 2008. Approximately 80% of the water flowing into the watershed was irrigation water diverted from the Snake River. About 40% of the watershed inflow returned to the Snake River. Much of this return flow was water from subsurface drain tiles and tunnels that drain shallow groundwater. Converting from furrow to sprinkler irrigation, improved irrigation management, and constructed sediment ponds have reduced sediment loss from 460 kg ha*$^{-1}$ *in 1971 to <100 kg ha*$^{-1}$*in 2005. In 2007 and 2008, more sediment and phosphorus entered the watershed than returned to the Snake River. Diverting irrigation water into the watershed removed 6300 Mg of sediment, 21 Mg of dissolved P, and 32 Mg of total P from the Snake River on average each year. However, the watershed contributed almost 900 Mg of nitrate-N annually to the Snake River. Conservation practices have effectively reduced sediment and phosphorus losses from the watershed, emphasis now must shift to reducing nitrate loss from the watershed.*

Keywords. *Irrigation, Sediment Loss, Phosphorus, Nitrate*

Introduction

Irrigation is important for stable production of high quality food and fiber. Surface irrigation is used on about 85% of the 299 Mha of irrigated land in the world (ICID, 2013). In the United States, surface irrigation is only used on 39% of the 22 Mha of irrigated land as sprinkler irrigation has steadily increased from 2 Mha in 1969 to 12 Mha in 2008 (USDA NASS, 2013). Sprinkler irrigation allows farmers to apply water more precisely than surface irrigation and eliminates irrigation runoff that is often required with surface irrigation for uniform water application. Surface irrigation runoff often transports sediment and nutrients in irrigation return flow to rivers or streams. The main objective of the Upper Snake Rock (USR) Conservation Effects Assessmnet Project (CEAP) was to quantify the water quality effects of converting from surface irrigation to sprinkler irrigation.

Watershed research for the USR CEAP began in 2005 by monitoring inflow and outflow on the 82,000 ha watershed irrigated by the Twin Falls Canal Company (TFCC). Hydrology in the USR watershed is driven by irrigation, which supplies more than 80% of the water input to the watershed (Bjorneberg et al., 2008). Irrigation water flows in canals, ephemeral streams and coulees as it is delivered to fields or flows back to the Snake River (figure 1). Many streams only flow during the irrigation season (April through October), while others flow all year due to subsurface drain tiles and tunnels that were installed to remove excess groundwater that accumulated after irrigation started in 1905. Rock Creek is the only stream that flows into the watershed and supplies <2% of the water to the watershed.

Irrigation-induced soil erosion has been the predominant natural resource concern in this watershed. Irrigation return flow monitoring from 1968 to 1971 showed that the TFCC watershed had a net loss of sediment, nitrate, and total salts, and a net gain of soluble phosphorus (Brown et al., 1974; Carter et al., 1971, 1974). Water flowing in irrigation furrows detaches and transports soil. Eroded sediment and associated nutrients are then transported back to the Snake River with irrigation return flow. It is impractical to contain irrigation runoff on furrow irrigated fields in this area because field slopes are typically 1% to 2% and some irrigation runoff is desired to achieve acceptable irrigation uniformity. Berg and Carter (1980) found that 20% to 50% of applied irrigation water ran off fields in the TFCC watershed. Soil loss from these fields varied from 1 to 141 Mg ha^{-1} annually. In a more recent study, annual soil loss of 2 to 33 Mg ha^{-1} was measured on six production furrow irrigated fields (Bjorneberg et al., 2007).

The objective of this study was to calculate sediment and nutrients loads entering and leaving the TFCC watershed to determine the net input or removal of these parameters. Sediment and nutrient concentrations will also be compared to monitoring results from 1968 to 1970 when 95% of the land was furrow irrigated compared to 60% in 2005.

Materials and Methods

Twenty-three monitoring sites were established in 2005 to measure the quantity and quality of water returning to the Snake River (figure 1). Two additional return flow sites were added in 2006. Two inflow sites measured water flowing into the watershed in the Mainline Canal and Rock Creek. Flow rates were measured with weirs or calculated from stage-discharge relationships. Flow rates were automatically recorded on data loggers at 17 sites that had higher flow rates. Flow stage was manually recorded once per week at the remaining locations. Flow rates at 10 minor sites were measured once a week when a water sample was collected. Automatic water samplers were used at primary sites to collect time-composite water samples (0.2 L sub-sample every 5 h in 2 L bottles). The three or four 2-L composite samples from each site were combined into a weekly composite sample. The 5 h interval was chosen so samples were not collected at the same time each day. A 2 L grab sample was collected once per week at the remaining sites.

Water samples were refrigerated until processed within 24 h of collection. During sample processing, samples were stirred for 1 to 2 min before measuring pH and electrical conductivity (EC). A 50 ml aliquot was taken for total nitrogen (N) and phosphorus (P) analysis. 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 before and after sediment collection. 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 and by FIA for NH_4-N for total N.

The volume of flow at each site was calculated for each sample interval. This volume was multiplied by parameter concentrations from laboratory analysis to calculate mass loads. Loads were summed over appropriate intervals (e.g. yearly or monthly) to determine net input or output of a parameter. Flow-weighted concentrations were calculated by dividing the mass load for a time period by the total flow volume for the same period. Total soluble salt concentration was calculated by multiplying EC (μS cm^{-1}) by 0.64. Statistical differences in parameter concentrations were determined with the Mann-Whitney U-Test.

Results and Discussion

Annual return flow from the watershed was 37 to 53% of the surface water flowing into the watershed (table 1). The net water remaining in the watershed varied from 600 to 870 mm, not including precipitation which was 170 to 310 mm y^{-1}. Mean potential crop water use for the last twenty years was 990 mm for alfalfa, 630 mm for corn, and 590 mm for spring small grain (USBR, 2013), indicating that crops probably did not use all of the water remaining in the watershed. Since the TFCC watershed is an irrigated watershed, inflow was greatest during June, July and August when irrigation demand was greatest (figure 2). Only water from one small perennial stream (Rock Creek) flowed into the watershed from November to March. Return flow, however, continued during the winter due to flow from subsurface drain tiles and tunnels.

Table 1. Flow, sediment and nutrients loading flowing into and out of the TFCC watershed.

Year	Flow[a]	TSS	DP	TP	Nitrate-N
	(mm)	----------------------------------	(kg/ha)	----------------------------------	
Inflow					
2005	1149	327	0.88	1.01	0.6
2006	1269	537	0.47	1.00	0.1
2007	1249	443	0.56	1.31	0.3
2008	1384	662	0.47	1.03	0.4
Average	1263	492	0.59	1.09	0.3
Outflow					
2005	428	419	0.36	0.64	7.4
2006	667	591	0.38	0.89	14.7
2007	523	307	0.28	0.72	14.0
2008	515	344	0.30	0.53	11.5
Average	533	415	0.33	0.70	11.9
Net					
2005	720	-92	0.51	0.37	-6.8
2006	602	-54	0.08	0.11	-14.6
2007	726	136	0.28	0.59	-13.6
2008	869	318	0.16	0.50	-11.2
Average	730	77	0.26	0.39	-11.5

[a] Inflow includes the main irrigation canal and Rock Creek and does not include precipitation which averaged 220 mm y^{-1} for 2005 to 2008.

Sediment loss from the watershed has been a major concern that the TFCC, NRCS and conservation districts have worked to address. The current study shows that there was net deposition of sediment within the watershed in 2007 and 2008 (table 1). This is a great improvement from 1971 when Brown et al. (1974) measured a 460 kg ha^{-1} net loss during the irrigation season (May to September). Converting from furrow irrigation to sprinkler irrigation and improving water management have reduced irrigation-induced soil erosion. The TFCC has also installed wetlands and sediment ponds to remove sediment from return flow before it reaches the Snake River. In 2006-2008, more sediment entered the watershed with diverted irrigation water than returned to the river during the irrigation season (figure 3). Although the sediment concentrations were low during the winter, return flow continued to transport some sediment to the river (table 2). The greatest monthly loss of sediment occurred in April when the irrigation canals were initially filled and irrigation demand was low so most of the initial water returned directly to the Snake River.

More dissolve P and total P entered the watershed with irrigation water than returned to the river for all four years (table 1). Approximately 0.3 kg ha^{-1} of dissolved P and 0.4 kg ha^{-1} of total P were deposited within the watershed each year. While these amounts were small in agronomic terms, diverting irrigation water into the watershed removed 21 Mg of dissolved P and 32 Mg of total P from the Snake River on average each year. The monthly load of dissolved P in return flow was fairly consistent compared to the load entering the watershed (figure 4). Although dissolved P concentration was greater in watershed outflow than inflow (table 2), dissolved P was retained in the watershed because most of the water was retained in the watershed. Most of the dissolved and total P that entered the watershed during the irrigation season was deposited within the watershed (figures 4 and 5). Net losses of P only occurred in the winter when more water flowed from the watershed than flowed into the watershed.

The irrigation water diverted from the Snake River contained almost no nitrate (maximum concentration=0.4 mg L^{-1}). Return flow with water from subsurface drain tunnels, however, contained nitrate so monthly return flow loads always exceeded the inflow loads (figure 6). Annual net nitrate-N losses were 7 to 15 kg ha^{-1} (table

1), resulting in return flow contributing 560 to 1,200 Mg of nitrate-N to the Snake River annually.

Winter and summer flow-weighted concentrations showed the effects that irrigation had on sediment, nutrient and soluble salt concentrations (table 2). Median concentrations for all parameters were significantly greater in outflow than inflow in both winter and summer. The only water that flowed into the watershed during the winter is Rock Creek, which originated from snow melt and springs with low sediment, nutrient and salt concentrations. Flow from drain tunnels and tiles increased nitrate-N and soluble salt concentrations in outflow in both winter and summer. Inflow and outflow sediment concentrations were greater in the summer than the winter, however, nitrate-N and soluble salt concentrations were greater in the winter than the summer. Sediment and phosphorus entered return flow from field runoff while nitrate and soluble salts entered return flow from subsurface drain tiles and tunnels. Field runoff was greatest during the summer when fields were furrow irrigated, causing increased sediment and phosphorus concentrations in summer watershed outflow. This same irrigation water, however, dilutes the nitrate and soluble salts from the subsurface drains, causing lower concentrations in the watershed outflow in the summer.

Table 2. Flow-weighted sediment, nutrient and soluble salt concentrations in return flow in winter and summer.

	TSS		Dissolved Phosphorus		Total Phosphorus		Nitrate-N		Soluble Salts	
Year	inflow	outflow	inflow	outflow	inflow	outflow	inflow	outflow	inflow	outflow
Winter[a]					mg L^{-1}					
2005	11	28	0.02	0.06	0.03	0.09	0.11	3.50	90	549
2006	15	28	0.02	0.07	0.04	0.11	0.06	4.15	93	553
2007	3	22	0.01	0.07	0.01	0.10	0.00	4.56	106	584
median[b]	5*#	24#	0.02*#	0.06	0.02*#	0.09#	0.00*	4.16#	101*#	564#
Summer										
2005	28	114	0.08	0.09	0.09	0.16	0.05	1.29	288	414
2006	42	93	0.04	0.05	0.08	0.13	0.01	1.68	252	406
2007	36	58	0.05	0.06	0.11	0.15	0.03	2.08	289	450
2008	48	74	0.03	0.06	0.07	0.10	0.03	1.70	272	432
median	33*	84	0.04*	0.06	0.08*	0.14	0.02*	1.80	282*	444

[a] winter is November through March.
[b] median of monthly flow-weighted concentrations.
* inflow was significantly different from outflow for winter or summer based on Mann-Whitney U-test ($P<0.05$).
# winter concentration was significantly different from summer for inflow or outflow based on Mann-Whitney U-test ($P<0.05$).

From 1968 to 1970, flow and water quality were measured on four main return flow streams and the main irrigation canal (Carter et al., 1973). These four streams accounted for about 80% of the total return flow back to the Snake River from 2005 to 2008. Dissolved P concentrations have not changed at three of the four return flow sites during the last 40 years (table 3). Dissolved P only decreased in the main irrigation canal and where Rock Creek flows into the Snake River. The decrease in the main canal indicates that phosphorus concentrations in the Snake River have decreased in the last 40 years. Lower dissolved P concentrations in the irrigation water, however, have not resulted in lower concentrations in three of the return flow streams. This may be due to water maintaining an equilibrium soluble P concentration when in contact with soil and suspended sediment within the watershed.

Median nitrate-N concentrations have also decreased in the main irrigation canal. However, nitrate-N concentrations have increased at all four return flow sites (table 3). Since nitrate in the return flow comes from subsurface drain tunnels and tiles, this indicates that nitrate concentrations in shallow groundwater have increased and/or the relative amount of subsurface drainage water in the return flow was greater in 2005-2008 than 1968-1970 (i.e. less dilution with irrigation water). Prior to 1972, a small amount of water was diverted into the irrigation canals in the winter for livestock water. The diverted water would have diluted the nitrate in the return flow. Soluble salt concentrations have also increased at all four return flow sites, further indicating that a greater portion of the return flow currently originated from subsurface drainage than in the past.

Summary

Measuring inflow and outflow in the TFCC watershed from 2005-2008 showed that about 40% of the watershed inflow returned to the Snake River. Much of this return flow was water from subsurface drain tiles and tunnels that drain shallow groundwater. Converting from furrow to sprinkler irrigation, improved irrigation management, and constructed sediment ponds have reduced sediment loss from the watershed. In 2007 and 2008, more sediment and phosphorus entered the watershed than returned to the Snake River. Diverting irrigation water into the watershed removed 6300 Mg of sediment, 21 Mg of dissolved P, and 32 Mg of total P from the Snake River on average each year. However, the watershed contributed almost 900 Mg of nitrate-N annually to the Snake River. Conservation practices have effectively reduced sediment and phosphorus losses from the watershed, emphasis now must shift to reducing nitrate loss from the watershed.

Table 3. Median dissolved phosphorus, nitrate-N and soluble salt concentrations for the current study compared to historic data.

	Dissolved Phosphorus		Nitrate-N		Soluble Salts	
Location	1968-1970[a]	2005-2008	1968-1970	2005-2008	1968-1970	2005-2008
	mg L^{-1}					
Cedar Draw	0.07	0.07	1.37	2.82 *	525	763 *
Deep Creek	0.04	0.05	0.96	2.47 *	448	760 *
Mud Creek	0.06	0.06	1.33	2.86 *	602	870 *
Rock Creek	0.09	0.05 *	0.60	2.43 *	542	762 *
Main Canal	0.06	0.03 *	0.20	0.00 *	316	430 *

[a] 1968-1970 data are from Carter et al. (1971 and 1973).

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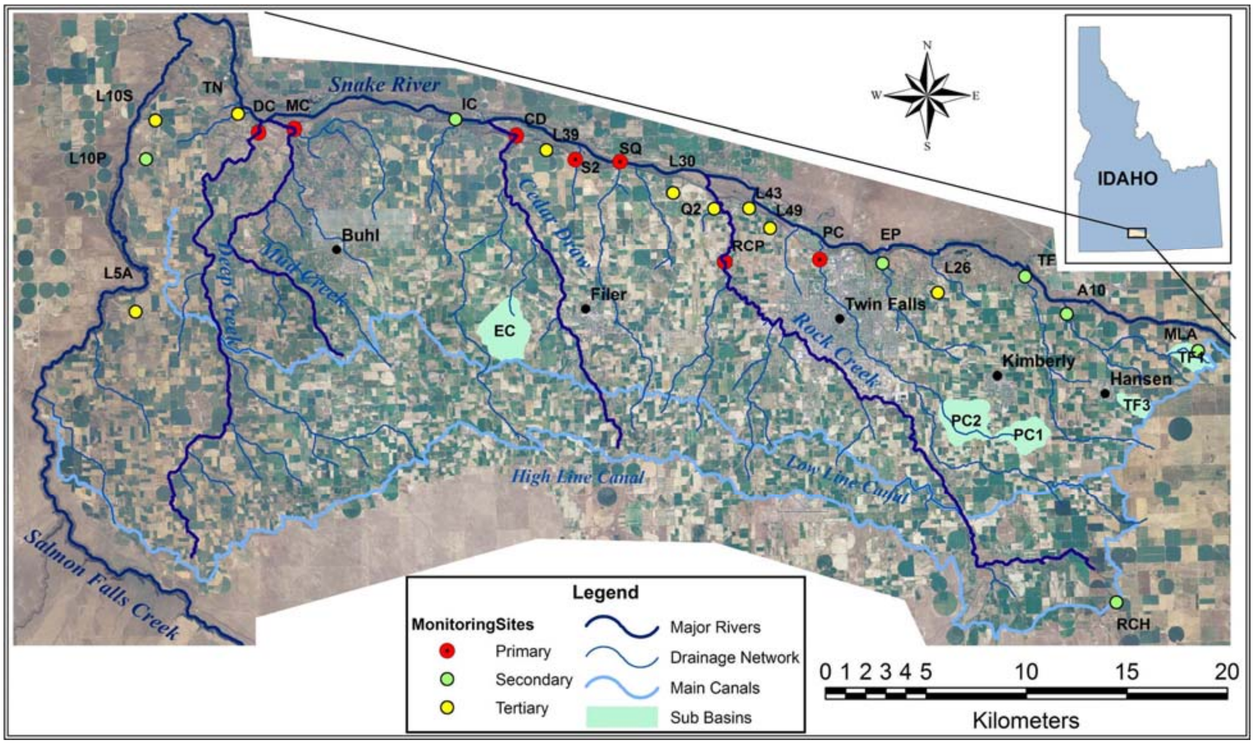

Figure 1. Aerial photograph of the TFCC watershed showing monitoring locations. The two inflow locations are the main irrigation canal (MLA, upper right) and Rock Creek (RCH, lower right). Rock Creek is also a return flow site where it enters the Snake River (RCP).

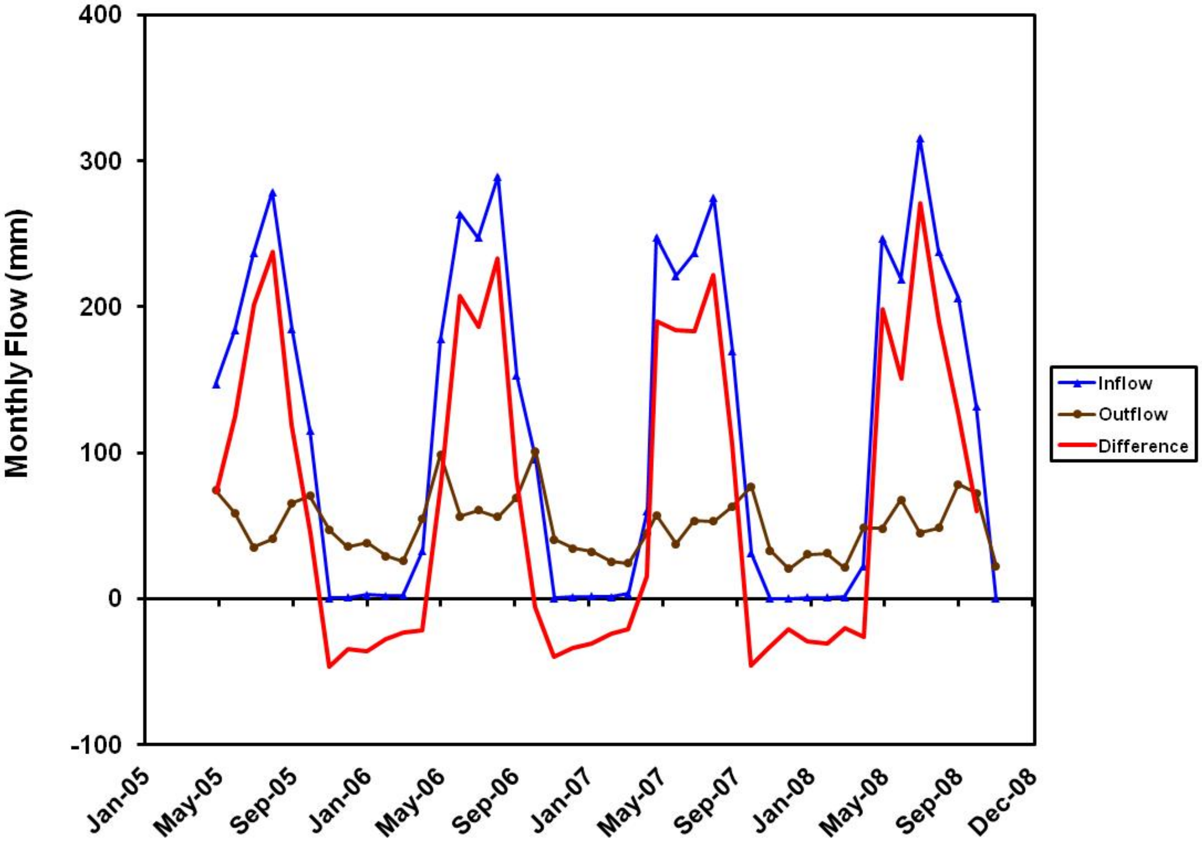

Figure 2. Monthly water inflow, outflow and difference (inflow-outflow). A negative difference indicates that more water left the watershed than flowed into the watershed.

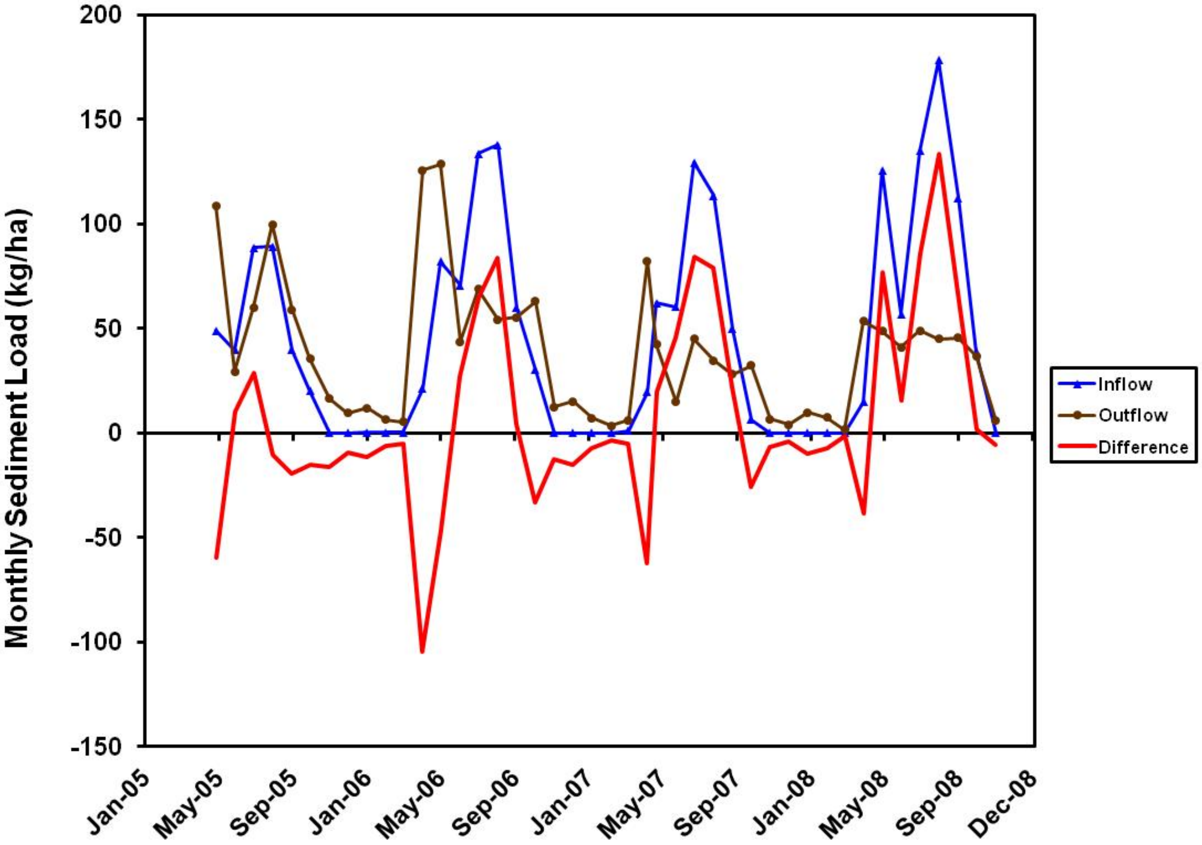

Figure 3. Monthly sediment loads flowing into and out of the watershed. A negative difference indicates a net loss of sediment from the watershed.

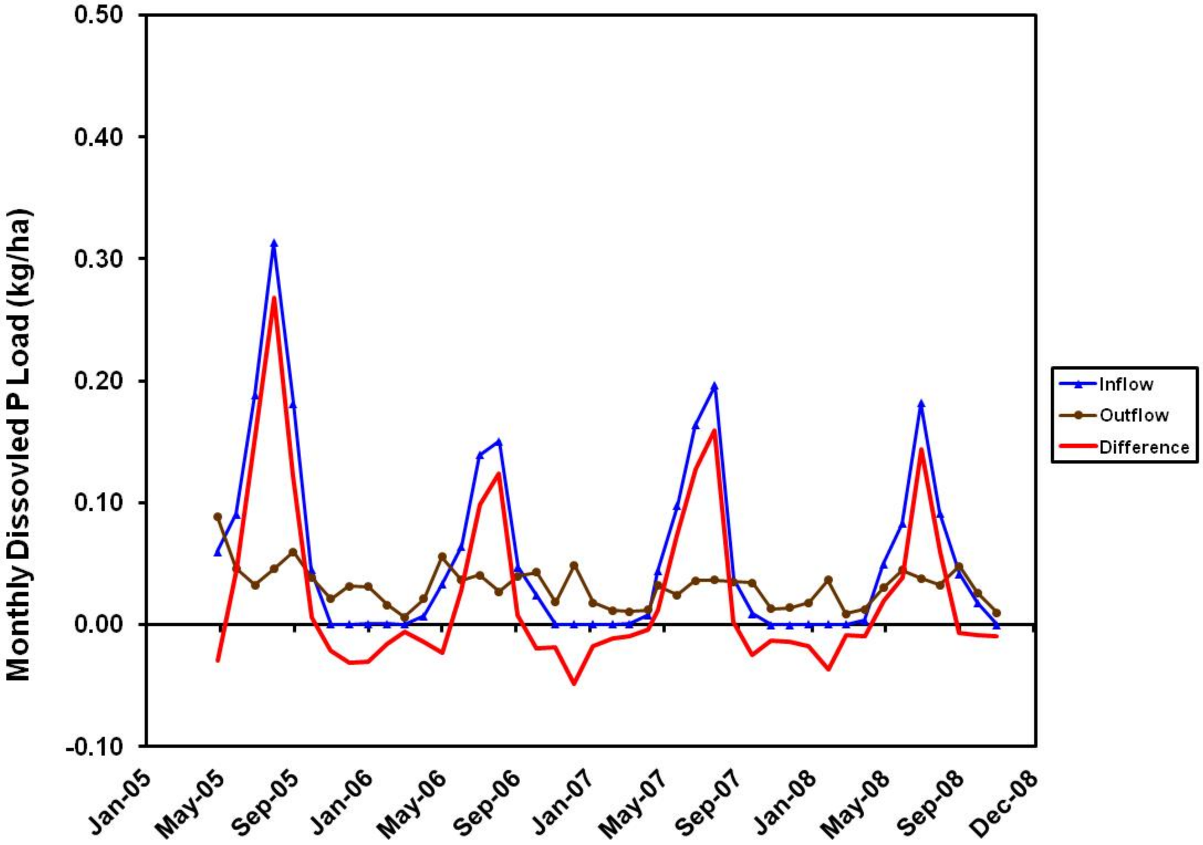

Figure 4. Monthly dissolved phosphorus loads flowing into and out of the watershed. A negative difference indicates a net loss of dissolved phosphorus from the watershed.

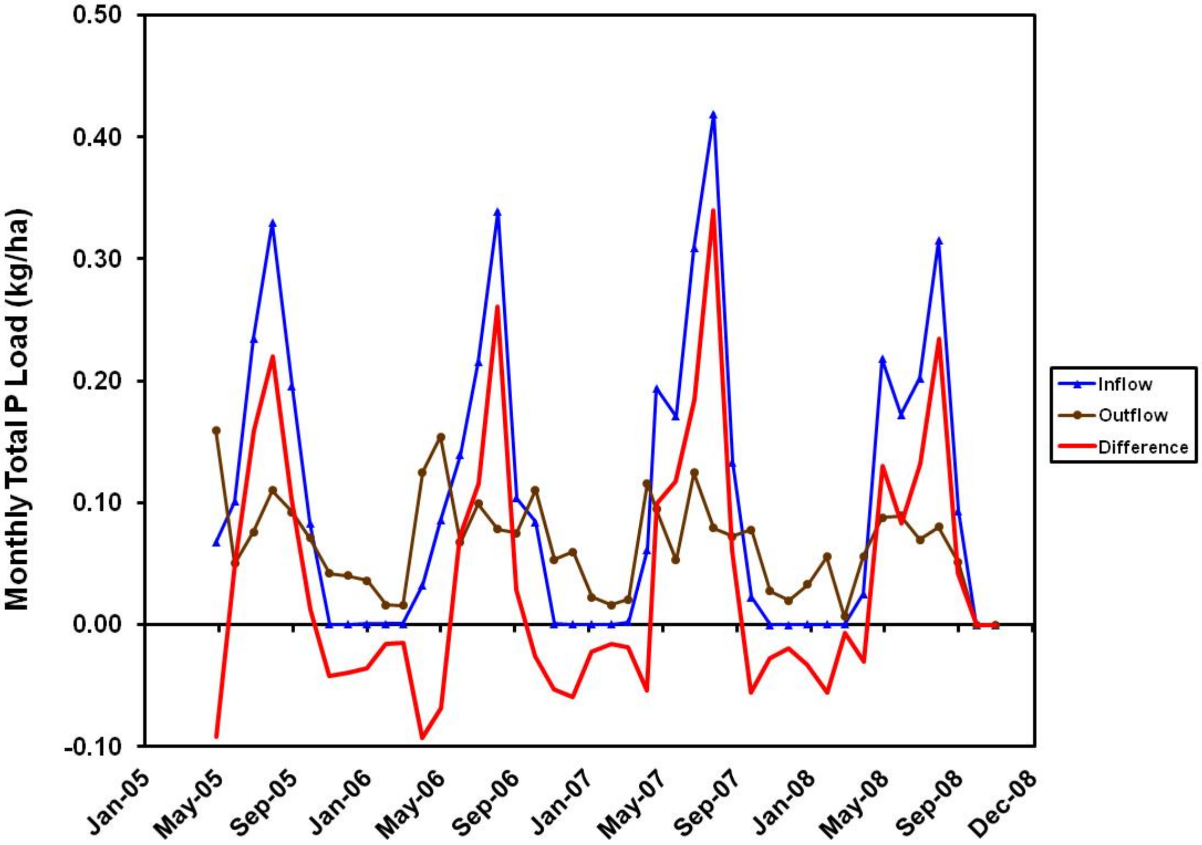

Figure 5. Monthly total phosphorus loads flowing into and out of the watershed. A negative difference indicates a net loss of total phosphorus from the watershed.

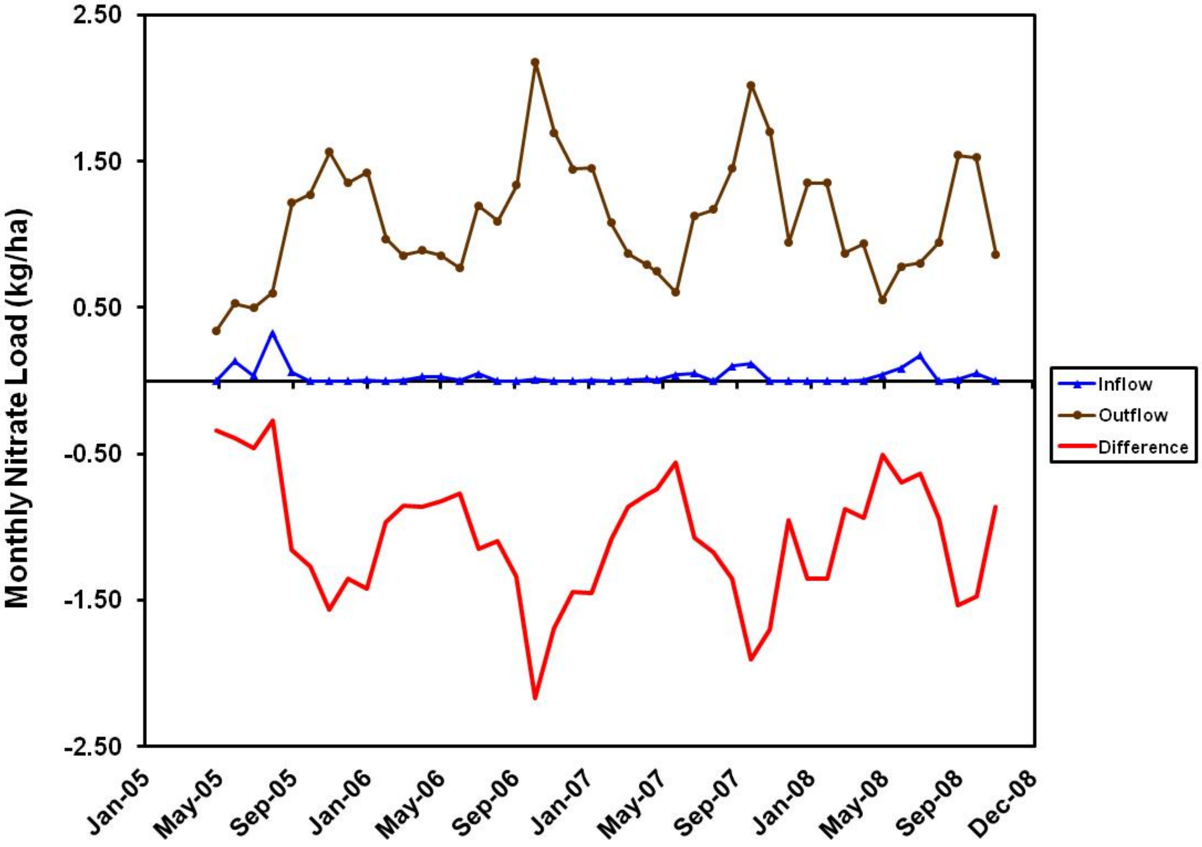

Figure 6. Monthly nitrate-N loads flowing into and out of the watershed. A negative difference indicates a net loss of nitrate-N from the watershed.