Water Balance for a Predominantly Surface Irrigated District in Southern Idaho.

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Abstract

Water quantity and quality are being measured in an 82,000 ha irrigation district in southern Idaho to determine the effects of conservation practices, primarily conversion from furrow to sprinkler irrigation, for the Conservation Effects Assessment Project (CEAP). The percentage of sprinkler irrigated land has steadily increased from about 10% in 1990 to more than 30% in 2005. The objective of this study was to calculate a preliminary water and soluble salt balance for April through November, 2005. The water balance was calculated by subtracting measured outflow and estimated crop water use from measured inflow and precipitation. Precipitation was about 250% of normal in April and May, which delayed irrigation for many crops and probably increased the amount of return flow during these months. Water diverted for irrigation was 82% of the total water input to the irrigation district (inflow plus precipitation). Precipitation contributed 16% of the total input. Thirty-six percent of the diverted water left the irrigation district as surface return flow from April through November. This percentage will increase on an annual basis because return flow continues through the winter months after irrigation diversions have ceased. The irrigation district was a source of suspended sediment and a sink for soluble salts. April through November 2005 monitoring showed a net gain of 1620 kg ha^{-1} of soluble salts in the irrigation district, which could be a long-term concern if these salts accumulate in the root zone. Net sediment loss was 102 kg ha^{-1}, which is less than the 461 kg ha^{-1} measured during a similar study in 1971. These preliminary results indicate that converting to sprinkler irrigation, along with other conservation practices, has reduced sediment loss from this irrigation district. However, solid conclusions cannot be made until at least one year of monitoring is complete to adequately characterize annual trends, particularly the quantity and quality of non-irrigation season return flows.

Introduction

The conservation effects assessment project (CEAP) was initiated to evaluate the effects of conservation practices implemented through the 2002 Farm Bill programs.

Effects of conservation practices are being assessed on 24 watershed scale projects. The Upper Snake-Rock watershed in southern Idaho was chosen as a special emphasis watershed to focus on conservation practices in an irrigated watershed. Total drainage area of the Upper Snake-Rock watershed is 6300 km^2, which includes irrigated farmland, rangeland and forest. CEAP efforts in this watershed are limited to the Twin Falls Irrigation District (Figure 1). The Twin Falls Canal Company (TFCC) supplies water to this district from the Snake River to 82,000 ha through approximately 180 km of main canal (15 to 100 m^3/s [500 to 3500 cfs]), 1600 km of laterals (0.25 to 1.5 m^3/s [10 to 50 cfs]) and 3000 headgates. Conversion from furrow irrigation to sprinkler irrigation is the main conservation practice funded by USDA cost-share programs. Approximately 10% of the land in the Twin Falls Irrigation District was sprinkler irrigated in 1990. This percentage has increased to over 30% in 2005.

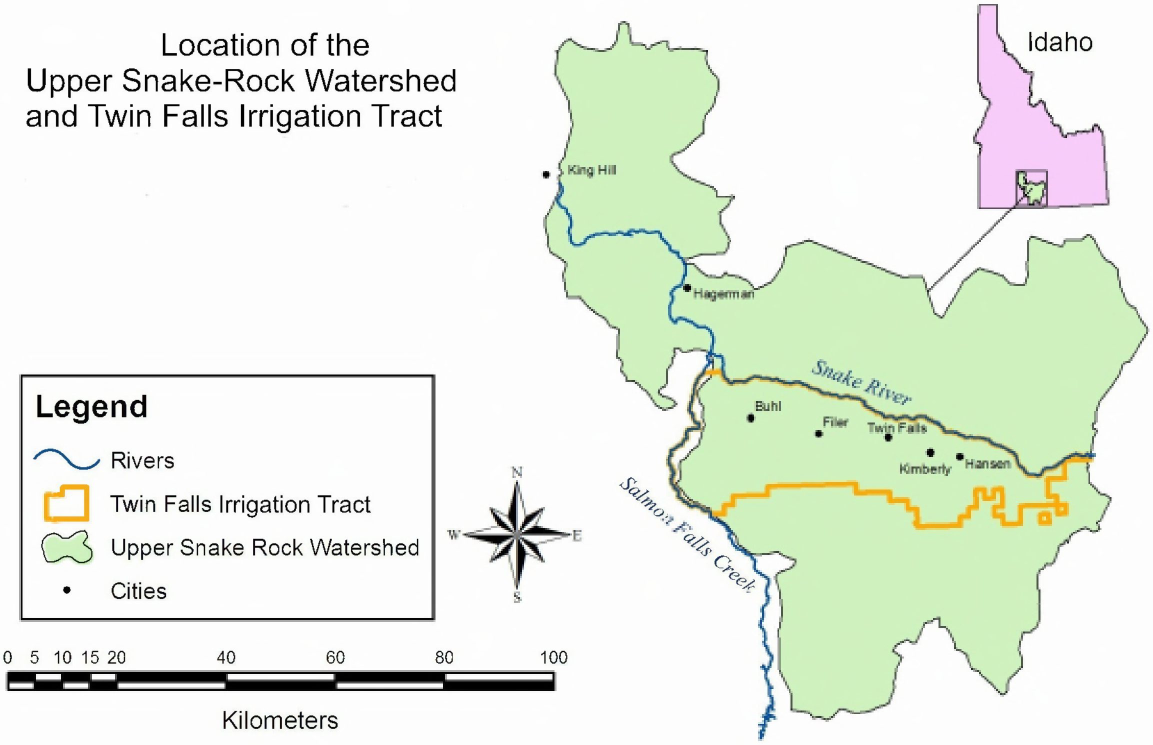

Figure 1. The Upper Snake-Rock watershed and the Twin Falls irrigation district in southern Idaho.

High water tables occurred in certain areas shortly after irrigation was initiated on the Twin Falls Irrigation District in 1905. Drainage tunnels and subsurface drain tiles were installed to convey water to natural surface drains, many of which flow all year due to subsurface drainage. A 1971 study on the Twin Falls Irrigation District found that 64% of the total water input to the tract returned to the Snake River (Carter et al., 1974). Water quality sampling indicated that 50% of the phosphorus diverted from the Snake River remained on the tract (Carter et al., 1974) but there was a net loss of 460 kg ha^{-1} of sediment (Brown et al., 1974).

A coordinated effort by landowners, Twin Falls county conservation districts and Twin Falls Canal Company to implement conservation practices reduced the average concentration of sediment in water returning to the Snake River from 190 mg L^{-1} in 1990 to 80 mg L^{-1} in 2001 (Bjorneberg et al., 2002). Water quality monitoring during this time period did not include water quantity data so mass loads cannot be compared. In addition to converting from furrow irrigation to sprinkler irrigation, other significant conservation practices include applying polyacrylamide (PAM) to reduce furrow irrigation erosion (Lentz et al, 1992) and installing sediment ponds to remove suspended sediment from irrigation return flow. From 1995 to 2001, the TFCC installed 98 sediment ponds ranging in size from 40 to 4000 m^2.

One objective of the Upper Snake-Rock CEAP is to determine a salt and water balance for the Twin Falls Irrigation District to compare with previous studies. The objective of this paper is to present a preliminary water and salt balance for the first year of monitoring on the irrigation district. Regular water quantity and quality monitoring started in April so the water balance for this study was limited to April through November. Water quality data were limited to filtered water samples because analysis of unfiltered samples were not completed.

Methods and Materials

Water Quantity and Quality Monitoring

Flow rate and water quality data were measured at 23 sites in the Twin Falls Irrigation District–two sites where water flows into the irrigation district and 21 sites where water returns to the Snake River or Salmon Falls Creek, which is a tributary to the Snake River. The two inflow sources are the TFCC mainline canal and Rock Creek. Flow rate in the mainline canal was measured at a gauging station operated by the TFCC. A datalogger and pressure transducer recorded canal stage at 15 min. intervals. Flow rate where Rock Creek enters the irrigation district was measured with a 3 m weir and a pressure transducer connected to a datalogger. Water depth was measured at 1 min intervals with the datalogger recording the hourly average depth. Two-liter water samples were collected once per week while water flowed at these sites. Water generally flows in the mainline canal from April 15 to October 15. Rock Creek typically does not flow into the irrigation district during the summer due to upstream irrigation diversions.

Irrigation return flow monitoring sites were categorized as primary, secondary or tertiary sites. The seven primary sites had continuous flow monitoring and automatic water samplers collecting time-composite water samples. The six secondary sites had continuous flow monitoring and 2-L water samples collected once per week. The eight tertiary sites had less flow than primary or secondary sites so flow rate was manually measured once per week when 2-L water samples were collected. Flow rates at primary and secondary sites were measured with weirs or calculated from stage-discharge relationships. Continuous flow monitoring involved measuring water depth with a pressure transducer and datalogger. Automatic water samplers at the primary sites collected 0.2 L samples every 5 h. These samples were combined into a weekly composite sample. The 5 h interval was chosen so samples were not always collected at the same time of day. Flow was measured at tertiary sites by recording water depth from a staff gage on a weir or weir stick on a concrete structure.

Water samples were refrigerated until being processed the day after collection. During sample processing, samples were stirred for 1 to 2 min before measuring pH and electrical conductivity (EC). A 50 ml aliquot was collected for total nutrients and salts analysis. A second 20 ml aliquot was filtered (0.45 micron) and analyzed for dissolved nutrients and salts. A third aliquot was collected 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 ICP-OES for P, K, Ca, Mg, Na, Al, Fe, Mn, Zn and S concentrations, and by FIA for NO_3-N, NH_4-N, and Cl concentrations (Lachat Instruments, Loveland, CO). 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. Only results from filtered samples were included in this study because analysis of unfiltered samples were not completed.

Concentration and Load Calculations

The volume of flow was calculated between each sample interval. This volume was multiplied by the parameter concentrations from laboratory analysis to calculate mass loads. Flow-weighted concentrations were calculated by dividing the mass load by the flow volume for the desired time interval (i.e. monthly or annual). Soluble salt concentration was calculated by multiplying EC (µS/cm) by 0.64.

Crop Water Use

Areas associated with each crop type were determined by driving seven transects across the Twin Falls Irrigation District and identifying crops grown in fields on each side of the road. These transects covered about 90 km and ran from the Snake River on the north to the south end of the irrigation district. This method sampled 8% of the land area in the irrigation district. There was some bias in this method because the average sprinkler irrigated field was larger than the average furrow irrigated field (15 vs 8 ha). However, we assumed that the relative area of each crop type was the same under sprinkler and furrow irrigation.

The relative area of each crop type identified by the driving survey was multiplied by the total area of the irrigation district to determine the total area of each crop (Table 1). Crop 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 total crop water use for the irrigation district. The US Bureau of Reclamation uses AgriMet to calculate potential water use for crops in the Pacific Northwest.

The potential water use for each crop is the average water use for all AgriMet emergence dates because detailed records of crop emergence were not recorded. Also, small grain was not differentiated into winter wheat, spring wheat and barley so the average of winter and spring grain was used for small grain. Corn was also the average of sweet corn and field corn. We assumed no water use for the area attributed to farmsteads. We also did not estimate non-growing season evapotranspiration or water use from urban areas, assuming that most urban water sources were deep groundwater (>25 m) that did not affect surface water return flows.

Table 1. Crop area and potential water use on the Twin Falls Irrigation District for 2005 crop year.

Crop	Crop Area		Annual Potential Crop Water Use	
	(%)	(ha)	(mm)	(ha-m)
Corn[†]	26.7	21900	598	13100
Alfalfa	26.4	21700	933	20200
Dry Bean	17.4	14300	449	6420
Small Grains[‡]	16.6	13600	509	6910
Pasture	5.3	4370	762	3330
Potatoes	3.0	2490	619	1540
Unplanted/Fallow	2.5	2030	295	599
Sugar Beet	1.6	1330	782	1040
Peas	0.2	160	304	48
Farmyard	0.1	64	0	0
Oats	0.1	57	498	28
Onion	0.0	31	650	20
total		82032		53235

[†] Field and sweet corn.

[‡] Barley, winter wheat and spring wheat.

Precipitation

Precipitation from three National Weather Service sites in the Twin Falls Irrigation District was used to calculate average total precipitation for the irrigation district. Total monthly precipitation from Buhl, Castleford and Kimberly was averaged to estimate average precipitation for the irrigation district.

Water and Soluble Nutrient Balance

The water balance was calculated by subtracting measured and calculated outputs from measured inputs by the following equation

Inflow + precipitation – outflow – crop water use = balance

Inflow was water diverted from the Snake River through the mainline canal and water flowing into the irrigation district in Rock Creek. Outflow is the cumulative flow from the 21 return flow monitoring sites, including the confluence of Rock Creek with the Snake River. The balance is the sum of the parameters that were not measured or calculated, such as deep percolation in fields, seepage and evaporation from canals, and water use from bare soil, farmsteads and urban areas. Much of the seepage and deep percolation will flow to surface drains through drain tiles and tunnels and thus be measured as return flow. Urban and residential area irrigation from groundwater was not considered, assuming that no runoff occurred from these areas and the groundwater source was deeper than the shallow groundwater that contributes to subsurface drainage to return flow streams.

Results

The 2005 irrigation season was not typical in southern Idaho. Precipitation was approximately 250% of normal in April and May (Figure 2). Annual precipitation for 2005 was about 20% greater than normal Above normal spring rain delayed irrigation

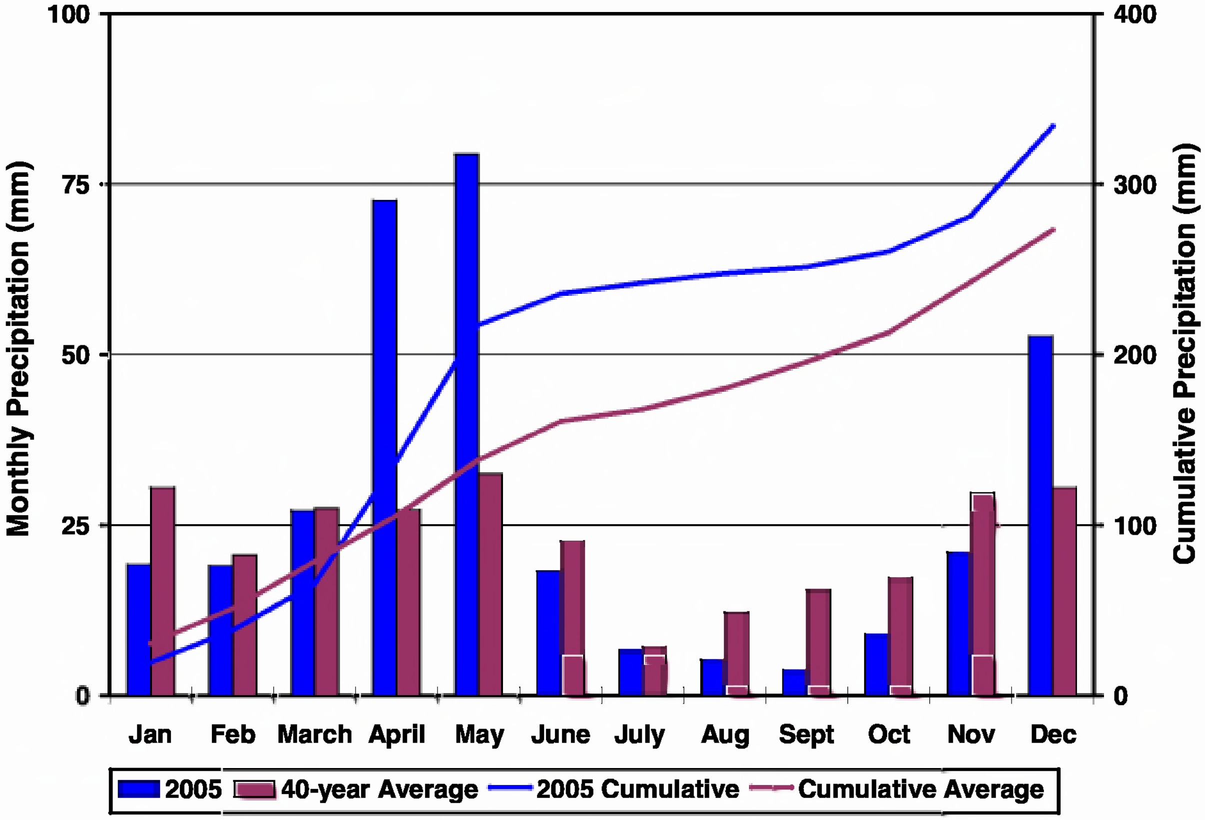

Figure 2. Monthly and cumulative precipitation for Kimberly, ID.

on many fields until middle or late June, probably causing a greater percentage of the diverted irrigation water to flow back to the river during that period. The TFCC has a “natural flow” water right, which precludes the canal company from storing natural flow water in the Snake River reservoir system after April 1. Thus the TFCC continued diverting water through the high rainfall period although irrigation demand was low.

April to November Water Balance

The TFCC diverted water into the mainline canal on April 4, 2005 and stopped on October 26, 2005. Flow in the mainline canal was the largest component to the water balance, contributing 82% of the total input (1390 mm) to the irrigation district (Table 2). Rock Creek contributed only 34 mm, or 2% of the total input. Precipitation supplied the remaining 16% of water to the irrigation district between April and November (Table 2).

Thirty-six percent of the water diverted into the mainline canal, or 29% of the total water input, was measured as surface flow back to the Snake River between April and November (Table 2). Crop water use was estimated at 648 mm, or 55% of the diverted water. The balance of the water budget was 335 mm, or 24% of the total input to the irrigation district. Much of the unaccounted for balance probably recharged shallow groundwater that will eventually flow into return flow streams. The percentage of diverted water returning to the Snake River will increase when the

Table 2. Water balance for the Twin Falls Irrigation District (82,000 ha) for April through November, 2005.

	Water Depth	
	------- (mm) -------	
Precipitation	216	
Mainline Canal	1141	
Rock Creek	34	
Total Surface Inflow	1175	
Total Input		1391
Primary	334	
Secondary	54	
Tertiary	20	
Total Return Flow	408	
Crop Water Use	648	
Total Output		1056
Balance[†]		335

[†] Includes parameters not measured or calculated such as seepage and evaporation from canals and deep percolation in fields.

water balance is calculated for an entire year because subsurface drainage continues to flow into some return flow streams throughout the year. Additional water flows to the Snake River as diffuse groundwater discharge. Water was still flowing at seven primary, three secondary and two tertiary sites on January 1, 2006.

The seven primary monitoring sites measured 82% of the 408 mm of recorded return flow (Table 2). The six secondary sites contributed 13% of the recorded return flow while the seven tertiary sites only contributed 5% of the recorded return flow. Flow could not be measured at one tertiary site where a power plant was under construction.

Monthly Balance

Calculating the water balance on a monthly basis shows that inflow to the irrigation district increased until August as irrigation demand increased to meet crop water use (Figure 3). The main input to the irrigation district each month, except April and November, was the mainline canal. In April, above normal precipitation (73 mm) exceeded inflow in the mainline canal (24 mm) and Rock Creek (8 mm). If precipitation was closer to normal, flow in the mainline canal would probably supply a similar amount of water as precipitation.

Rock Creek contributed less than 1 mm of water per month to the irrigation district from July to November due to upstream irrigation diversions and low runoff and baseflow in November. In April and May, Rock Creek contributed 8 and 9% of the input, respectively, to the irrigation district. Rock Creek was the only surface water flowing into the irrigation district in November because irrigation diversions had ceased.

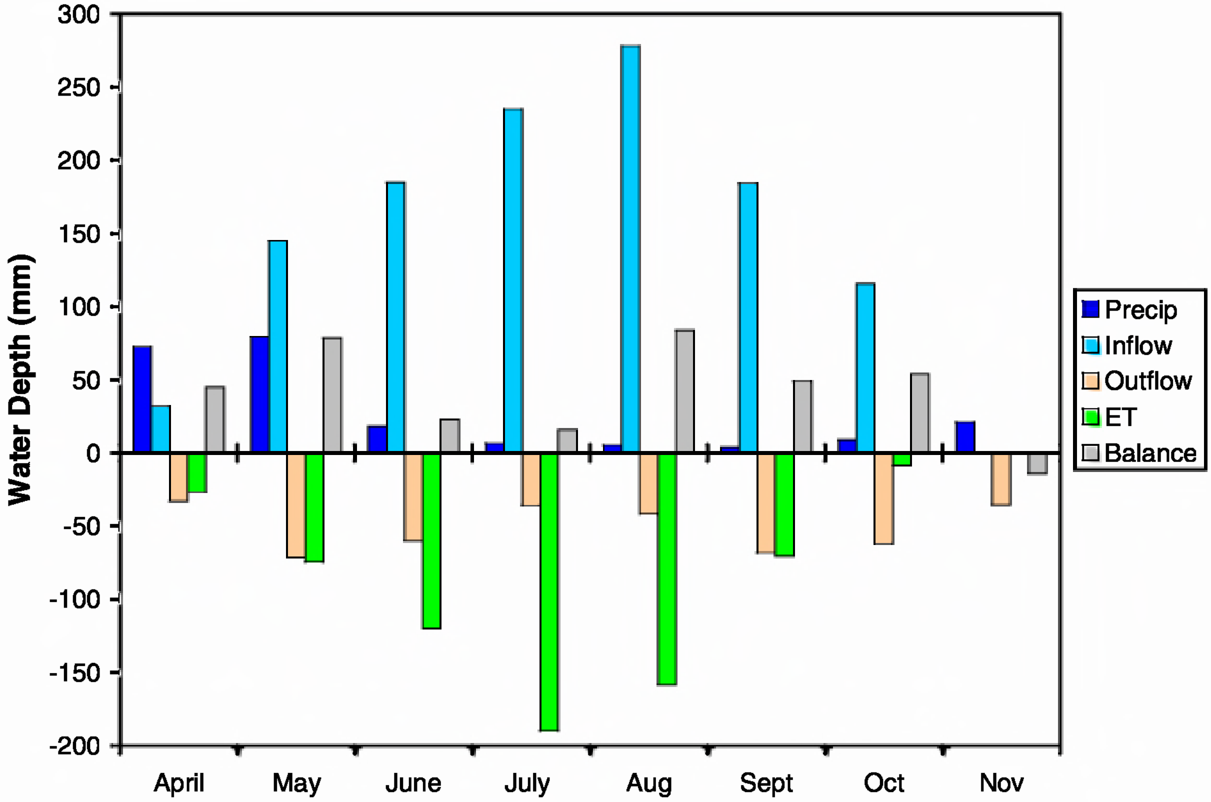

Figure 3. Monthly water balance for the Twin Falls irrigation district for April to November, 2005.

The unaccounted balance was positive for each month except November (Figure 3). The positive balance is likely due to seepage from canals and deep percolation on irrigated fields. The negative balance results from continued return flow from subsurface drainage of shallow groundwater. Negative monthly balances will probably continue until irrigation diversion begins again in April if precipitation remains near normal.

Sediment and Soluble Salt Balance

Concentrations for all parameters shown in Table 3 were greater in return flow than the inflow. The Twin Falls irrigation district, however, was a sink for soluble salts and a source for suspended sediment (Table 3), primarily because 65% of the inflow water remained within the irrigation district. Only 35% of the inflow water was measured as return flow to the Snake River from April through November. Therefore parameter concentrations must increase about 3-fold for a net loss to occur. Average flow-weighted soluble P concentration, for example, was only 10% greater in return flow than inflow, which resulted in only 39% of the inflow soluble P leaving the irrigation district with the return flow (Table 3). This is equivalent to applying 0.6 kg ha^{-1} of soluble P to the entire irrigation district. (Keep in mind that much of the total P is attached to sediment which is not included in this preliminary analysis.) Average flow-weighted soluble salts (EC) concentration was 290 mg L^{-1} in inflow compared to 430 mg L^{-1} in return flow. The net balance was 1620 kg ha^{-1} of salts deposited within

Table 3. Flow-weighted average concentrations and mass loads for selected parameters for April through November, 2005.

	Concentration		Mass Load		
Parameter	Inflow	Return Flow	Inflow	Return Flow	Difference
	------ mg/L ------		------------ kg/ha -------------		
Total Suspended Sediment	29	109	341	443	-102
Soluble Salts†	290	430	3370	1754	1616
Chloride	22	33	256	134	122
Sodium	44	59	523	240	283
Calcium	21	41	249	166	83
Nitrate-N	1.8	3.3	20.7	13.5	7.2
Soluble P	0.07	0.08	0.9	0.3	0.6

† Calculated from electrical conductivity.

the irrigation district (Table 3). Total suspended sediment (TSS) concentration increased 3.7-fold, presumably due to erosion from furrow irrigated land. Consequently, 102 kg/ha of sediment were lost from the irrigation district.

Soluble parameter loads measured at the primary monitoring sites accounted for 83 to 87% of the total TSS, soluble salts, chloride, sodium, calcium, nitrate-N and soluble P in return flow (data not shown). Secondary monitoring sites measured 11 to 13% of the loads in return flow. Only 3 to 5% of the mass loading was measured at tertiary sites.

Discussion

Estimated crop water use for 2005 compared reasonably well with previous evapotranspiration (ET) measurements on the Twin Falls Irrigation District by Allen and Robison (2004). They calculated ET for 2000 and 2003 using the METRIC satellite-based ET model (Mapping EvapoTranspiration at high Resolution and Internalized Calibration). They calculated 683 mm of ET for March through October in 2000 compared to 648 mm calculated for this study. ET was only calculated for April through August in 2003 due to unavailability of cloud-free satellite images for September and October. The April through August ET was 533 mm in 2003 compared to 596 mm calculated for this study.

In 1971 the TFCC diverted 1690 mm (Carter et al., 1974), or about 30% more than we measured in the mainline canal in 2005. Return flow volume measured in 1971 (456 mm) was similar to this study (408 mm), which indicates that Carter et al. (1974) may have under measured return flow and/or that seepage losses within the irrigation district have decreased. Although TSS concentrations in canal water were similar between these two studies (55 and 30 mg L^{-1}), diverting additional water in 1971 resulted in an additional 580 kg ha^{-1} TSS in inflow compared to 2005. However, the 18 drains monitored by Carter et al. (1974) returned 1834 kg ha^{-1} of sediment to the Snake River, resulting in a net sediment loss of 461 kg ha^{-1} in 1971, substantially greater than the 102 kg ha^{-1} measured in 2005 (Table 3). This indicates that converting to sprinkler irrigation, installing sediment ponds, and improving management practices have reduced sediment loss from the Twin Falls Irrigation District.

A salt balance for the Twin Falls Irrigation District was calculated with data collected in 1968 and 1969 (Carter et al., 1971). Monitoring sites and water balance calculations were slightly different from the current study. The same four main return flow streams were monitored for both studies, but Carter et al. (1971) used a hydrograph separation technique to estimate the contribution of subsurface drainage. They also included the unaccounted balance with subsurface drainage, presumably because this water and soluble salts do not remain in soil and eventually flow to the Snake River. Soluble salts (EC) concentrations in return flow of this study (430 mg L^{-1}) were greater than the 294 mg L^{-1} measured by Carter et al (1971). However, by including deep percolation with return flow, they calculated a net loss of 2400 kg ha^{-1} soluble salts from the irrigation district in one year compared to a net gain of 1616 kg ha^{-1} estimated from April through November, 2005 (Table 3). Changes in irrigation diversions and irrigation practices during the last 30 years may have caused the Twin Falls irrigation district to change from a source to a sink of soluble salts, which could be a long-term concern.

The net deposition of soluble salts will decrease when the water balance is calculated for the entire year. The only inflow to the irrigation district from November through March is Rock Creek, which has lower soluble salt concentrations than the Snake River. As subsurface drainage water continues to supply flow to surface drains, more salts will leave the irrigation district than enter until irrigation diversion begins again in April. Solid conclusions cannot be made until at least one year of monitoring is complete to adequately characterize annual trends, particularly the quantity and quality of non-irrigation season return flows.

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