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Watershed water balance changes as furrow irrigation is converted to sprinkler irrigation in an arid region

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Abstract: Irrigation is the largest water use in the western United States. The Upper Snake Rock Conservation Effects Assessment Project in southern Idaho began in 2005 to quantify the impacts of conservation practices in this irrigated watershed. The objective of this study was to determine the changes in the watershed water balances as farmers converted furrow irrigated fields to sprinkler irrigation from 2006 to 2016. More than 75% of annual watershed inflow was irrigation water diverted into the watershed from the Snake River and distributed through canals to 82,000 ha of cropland, while annual precipitation was only 10% to 23% of the annual inflow. Approximately 30% of the annual watershed inflow flowed back to the Snake River as irrigation return flow. Water balances showed that irrigation exceeded evapotranspiration (ET) in the spring and fall, indicating that irrigation diversions could be reduced early and late in the irrigation season. Annual irrigation project efficiency, defined as ET divided by the amount of diverted irrigation water, varied from 61% to 73%, but project efficiency did not increase as the amount of cropland that was sprinkler irrigated increased from 46% in 2006 to 59% in 2016. The only significant trends indicating that increasing sprinkler irrigation impacted the water balances were increasing irrigation project efficiency in July and increasing irrigation return flow during the irrigation season. Farmers may be applying less irrigation water with sprinkler irrigation compared to furrow irrigation, which could have caused return flow to increase since irrigation diversions did not change with the supply-based water allocation. Irrigation scheduling based on soil moisture measurement or daily ET would help irrigation application match crop water needs on individual fields. For the entire irrigation project, irrigation efficiency could improve if irrigation diversions into the watershed could be adjusted to more closely match ET in the spring and fall, which may require structural changes to the canal system and policy changes for the Snake River reservoir system.

Key words: Conservation Effects Assessment Project (CEAP)—irrigation efficiency—irrigation return flow—surface irrigation

Irrigation is the largest water use in the western United States. In 2015 irrigation accounted for 37% of the total freshwater withdrawal in the United States; however, in the 11 western states, irrigation withdrawals were 82% of the total freshwater withdrawals (Dieter et al. 2018b). Many private and public irrigation projects were developed in the western United States more than 100 years ago to divert water from streams and reservoirs for irrigation to develop arid land. Currently, off-farm water supplies are used on 55% of the irrigated land in the 11 western states (USDA NASS 2012). Most of these irrigation projects were designed with supply-based allocation systems that uniformly distributed irrigation water to fields that were primarily surface irrigated.

Improving irrigation efficiency is a typical goal for most irrigation projects. There are many terms used (and sometimes misused) to describe how effectively or efficiently irrigation water is used for crop production (Evans and Sadler 2008), such as irrigation efficiency, application efficiency, water use efficiency, and crop water productivity. It is important to know how the term is defined when evaluating irrigation (Lankford 2012). Irrigation efficiency is the ratio of the average depth of irrigation water that is beneficially used to the average depth of irrigation water applied (ASABE 2015). It is also important to note that increasing "efficiency" does not always result in more water available for another use, and sometimes the inefficient or lost water is beneficially used downstream (Grafton et al. 2018). Seepage from irrigation canals, for example, may return to streams or rivers by subsurface flow (natural or man-made), so reducing canal seepage will keep more water in the canal but could decrease flow in the stream. Increased irrigation efficiency can occur from (1) greater consumptive use by crops for the same amount of irrigation water diverted, (2) less applied water for the same consumptive use, or (3) a combination of both (Grafton et al. 2018). Consequently, increasing irrigation efficiency does not necessarily result in less water being used for irrigation.

Converting from surface irrigation to sprinkler irrigation generally increases irrigation efficiency at the field scale because water is distributed in the field through pipes rather than by flowing across the soil. Application times and rates are controlled with sprinkler irrigation whereas application rate for surface irrigation is a function of soil infiltration rate. Textbooks and irrigation manuals typically consider field-scale irrigation efficiency as 40% to 60% for surface irrigation and 60% to 90% for sprinkler irrigation (Howell 2002; Huffman et al. 2013). Within large irrigation projects (e.g., >20,000 ha), increasing irrigation efficiency on individual fields may not result in greater overall efficiency for the project because many projects were designed based on water supply, not crop water needs. Delivering irrigation water by gravity through canals is energy efficient but may not be water efficient because it can be difficult for irrigation diversions to match crop irrigation needs when water must flow for several days from the source to fields. Clemmens (2006) described many factors that cause poor performance in irrigation projects, mainly that water delivery is not tied to crop productivity. Irrigation in

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the Grand Valley of Colorado, for example, was estimated to consumptively use only 20% of the diverted irrigation water in the 1970s (Keys 1981). Most of the unused irrigation water returned to rivers from which it was diverted. Other studies have shown that 20% to 80% of the diverted water was used by crops (Ahadi et al. 2013; Bondurant et al. 1978; Zalidis et al. 1997). In Spain, average irrigation efficiency was 53% for surface irrigated areas with highly permeable and shallow soils and 94% for automated and well-managed sprinkler irrigated areas (Causape et al. 2006).

The Upper Snake Rock (USR) Conservation Effects Assessment Project (CEAP) is focused on measuring changes in water quality and quantity as conservation practices have been implemented on the Twin Falls Canal Company (TFCC) irrigation project (Bjorneberg et al. 2008). The TFCC diverts water from the Snake River in southern Idaho to irrigate 82,000 ha. The main conservation practice implemented on cropland in this irrigation project during the last 30 years was converting from furrow irrigation to sprinkler irrigation. State and federal agencies provided funding to replace furrow irrigation with sprinkler irrigation to reduce soil erosion and improve irrigation efficiency. Farmers converted to sprinkler irrigation to reduce labor, improve water management, and reduce tillage. Previous studies have documented the reductions in sediment and phosphorus (P) losses from this watershed (Bjorneberg et al. 2015, 2008). The objective of this paper was to determine the changes in water balances for the TFCC irrigation project from 2006 to 2016 as furrow irrigated fields were converted to sprinkler irrigation.

Materials and Methods

The TFCC irrigation project is located along the south side of the Snake River in south central Idaho, United States. The TFCC canal forms the east and south borders of the watershed, and the Snake River and Salmon Falls Creek canyons form the north and west borders, respectively (figure 1). Soil is predominantly silt loam. Irrigation water is supplied from the Snake River and flows by gravity in 180 km of main canals and 1,600+ km of laterals, ephemeral streams, and coulees as it is delivered to fields or flows back to the Snake River. Rock Creek is the only natural stream that flows into the watershed. It is ephemeral upstream from the watershed, typically flowing in spring and early summer from snowmelt in the mountains as rain seldom causes runoff in this arid area. Thus, unlike many watersheds, the USR watershed has two inflow streams (the main irrigation canal and Rock Creek) and numerous outflow streams. Many streams only flow during the irrigation season (April through October), while others flow all year due to relief drains located sporadically throughout the watershed to drain deep percolation water. The relief drains are tunnels (1.2 m wide by 1.8 m that were constructed by digging horizontally into the basalt bedrock) or tiles (connected to relief wells drilled through the bedrock) to remove excess groundwater that accumulated after irrigation started in 1905 (Carter et al. 1971). These tunnels and tiles are essentially man-made springs that flow throughout the year and drain a shallow aquifer (<20 m).

Irrigation water delivery in USR watershed is based primarily on a natural flow water right rather than water stored in a reservoir. Reservoir water supplements natural flow in the summer; however, both may be limited when snow pack in the mountains is below normal. The TFCC is designed to uniformly distribute the natural flow of the river to cropland on a flow rate basis rather than allocating a volume of water per hectare. Irrigation water is continually available at 52 L min^{-1} ha^{-1} during the irrigation season if supply is sufficient. Irrigation water delivery to fields is measured at 3,000 outlets (headgates). These gates are locked and only adjusted by TFCC employees on daily basis as needed. While a flow rate is available during the entire irrigation season, it is not practical to continually use this flow rate, especially in the spring and fall. However, this flow rate allocation is equivalent to 7.5 mm d^{-1}, which does not meet peak daily evapotranspiration (ET) for many crops in the summer. Consequently, farmers grow a variety of crops to spread peak crop ET throughout the irrigation season and rely on stored soil water to meet peak crop ET demand.

The water balance for this study was calculated as the sum of inflows equals the sum of the outflows plus change in storage and any errors:

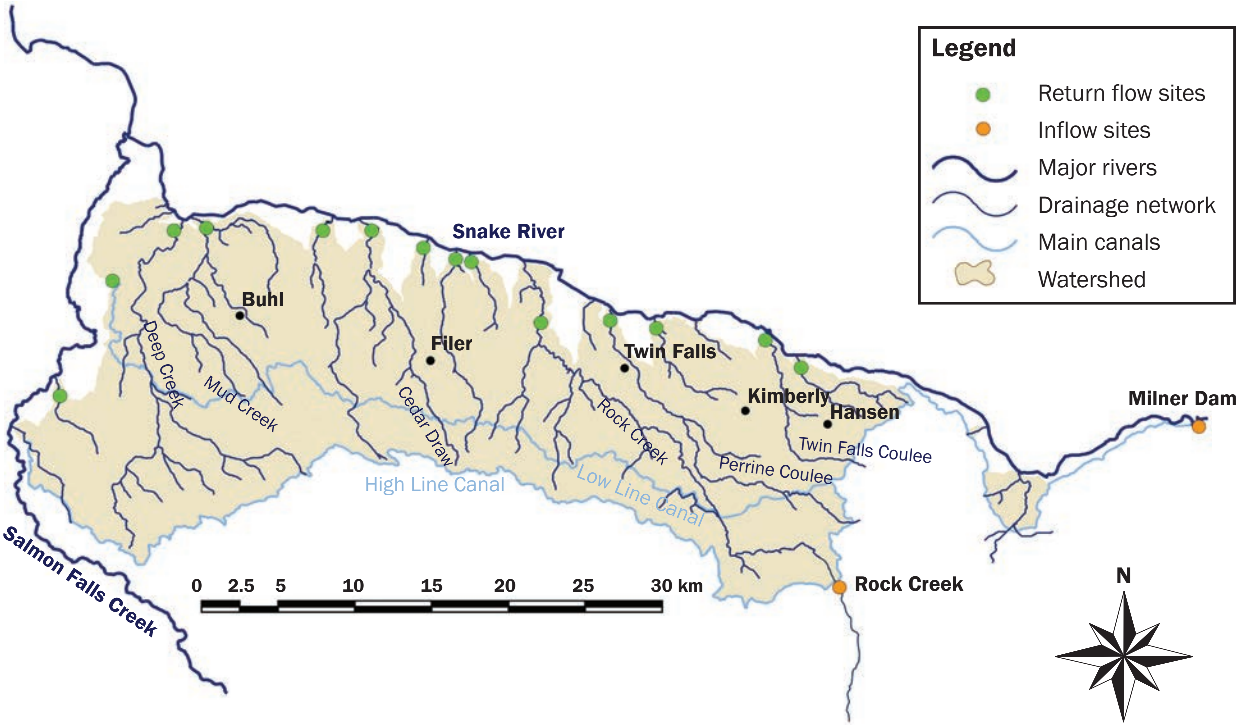
$$\text{Irrigation} + \text{Precipitation} + \text{Rock Creek} = \text{ET} + \text{Return Flow} + \text{remainder}\ . \quad (1)$$

Irrigation was the amount of water diverted into the watershed in the main irrigation canal. Rock Creek was the amount of water that flowed into the watershed in Rock Creek. ET was the potential crop evapotranspiration and bare soil evaporation when crops were not growing. Return flow was the amount of water flowing from the watershed in the 14 return flow streams that were measured during this study. Twelve of these streams flowed all year while two only flowed during the irrigation season. Return flow included unused irrigation water, tailwater from furrow irrigated fields, and subsurface drainage from the tunnels and tiles. The remainder accounted for all measurement and calculation errors plus unmeasured parameters such as small return flow streams, evaporation losses from the canals, wind drift and evaporation from sprinkler irrigation, and changes in soil water and groundwater storage. Some deep percolation from irrigated fields and seepage losses from canals and laterals will flow to shallow groundwater and eventually become return flow through the drain tunnels and tiles.

Flow rates in the main canal, Rock Creek, and 14 return flow sites were measured with weirs or calculated from stage-discharge relationships. Flow stage was automatically recorded at 15 minute intervals on data loggers (Campbell Scientific, Inc., Logan, Utah) at all sites in cooperation with Idaho Department of Water Resources (IDWR) or the TFCC. Daily average flow rates were calculated for each site. Daily averages were summed to calculate total monthly and annual flow volumes.

Precipitation was measured at the Twin Falls AgriMet site near Kimberly, Idaho (USBR 2018). The Twin Falls AgriMet site also provided data for calculating potential ET for crops grown in the watershed using ETIdaho (Allen and Robison 2017). ETIdaho used the American Society of Civil Engineers (ASCE) standardized Penman-Monteith method to calculate reference ET and a procedure to calculate crop coefficients that considers the impact of surface wetting by irrigation and precipitation on total evaporation from the soil surface. Daily ET values for each crop were summed monthly and annually and multiplied by crop areas to calculate total crop water use for the watershed. Area in the watershed planted to specific crops was determined using the cropland data layer in CropScape (USDA NASS 2018). ET for the growing season

Figure 1
Watershed area and monitoring sites for the Twin Falls Canal Company irrigation tract.



was also obtained from IDWR, which used the METRIC model to compute and map ET for irrigated land in Idaho. METRIC is an energy balance model that uses Landsat satellite thermal imagery and ground-based weather data to map ET (Allen et al. 2007, 2011). METRIC ET was available for April through October for 2006, 2008 through 2011, 2013, and 2016 (IDWR 2018).

Water balances were calculated for each year, irrigation season, and month from 2006 to 2016. Irrigation project efficiency was defined as the ratio of water beneficially used to the amount of water delivered to the irrigated area (ASABE 2015) and calculated as equation 2:

$$\text{IPE} = (\text{ET} \div \text{Irrigation}) \times 100, \qquad (2)$$

where IPE was the irrigation project efficiency (%), ET was evapotranspiration for the watershed (mm), and Irrigation was the amount of irrigation water diverted into the watershed (mm). IPE was calculated for each irrigation season and each month of the irrigation season (April through October) using ET estimates from both ETIdaho and METRIC.

The amount of land that was furrow or sprinkler irrigated was estimated from aerial images. One section (approximately 260 ha) was randomly chosen from each of the 17 townships in the TFCC irrigation project. This follows the same technique that was initially used for field surveys in this watershed (Bjorneberg et al. 2008). Total area surveyed was 3,500 ha or about 4% of the total land area in the TFCC irrigation project. The type of irrigation system in each field was visually identified from the aerial images for 2006, 2011, 2013, and 2016.

Linear regression was used to determine if two water balance parameters were correlated. Kendall trend analysis was used to determine if there was a 95% probability that parameters were increasing or decreasing during this study period (SAS Institute 2014).

Results and Discussion

Annual Results. Irrigation was by far the largest factor impacting hydrology in this watershed. Irrigation water diverted from the Snake River was 75% to 89% of the total annual inflow into the watershed (table 1). Precipitation was only 10% to 23% of the inflow. Rock Creek, an ephemeral stream, contributed less than 35 mm annually to the watershed or 0.5% to 2% of the total inflow. Annual ET was 57% to 67% of watershed inflow and ranged from 857 to 974 mm (table 1). Annual irrigation diversion only varied 170 mm during the study period, from 1,120 to 1,290 mm, while annual precipitation varied from 130 mm to 370 mm (table 1). The amount of irrigation water diverted into the watershed was generally limited by TFCC water rights and the available water supply (i.e., accumulated snow in the mountains), not by the relatively small annual differences in crop irrigation requirements or precipitation within the watershed. There was no linear correlation between total irrigation diversion and annual ET or precipitation ($R^2 < 0.001$ for both). TFCC will only make adjustments to irrigation diversions if cool and/or wet conditions persist since it takes several days for flow in this large canal system to respond to changes in irrigation diversions.

Return flow back to the Snake River was 27% to 34% of the total annual watershed inflow. Annual return flow increased as annual precipitation increased ($R^2 = 0.50$, $p = 0.01$). The greatest return flow occurred in 2016 and the least in 2007 (table 1). Irrigation diversion was almost equal during these two

Table 1

Annual water balances for the Twin Falls Canal Company irrigation project. Evapotranspiration (ET) was obtained from ETIdaho.

Year	Irrigation diversion (mm)	Precipitation (mm)	Rock Creek (mm)	Total inflow (mm)	ET (mm)	Return flow (mm)	Total outflow (mm)	Remainder (mm)
2006	1,117	312	34	1,462	919	463	1,382	80
2007	1,182	173	14	1,369	913	376	1,289	81
2008	1,236	211	11	1,457	899	395	1,294	164
2009	1,170	272	17	1,460	876	439	1,315	145
2010	1,176	284	9	1,469	891	450	1,341	128
2011	1,189	234	34	1,457	882	496	1,377	80
2012	1,240	269	7	1,516	906	489	1,396	120
2013	1,198	134	8	1,340	857	411	1,268	71
2014	1,262	371	10	1,643	948	491	1,439	204
2015	1,288	252	10	1,550	887	496	1,383	167
2016	1,186	358	27	1,571	974	502	1,476	95
Average	1,204	261	17	1,481	905	455	1,360	121

years, but precipitation was 185 mm greater in 2016. The additional precipitation could have increased return flow because of runoff from fields or because farmers reduced irrigation, and unused irrigation water returned to the Snake River. Since most precipitation events were small, increased return flow was likely due to unused irrigation water rather than runoff. Only 10 precipitation events from 2006 to 2016 were greater than 20 mm, and 41 events were between 10 and 20 mm. These 51 events accounted for 30% of the total precipitation, so events <10 mm accounted for 70% of the precipitation during this study. A large irrigation project like the TFCC cannot quickly adjust irrigation diversions in response to small, infrequent precipitation events, so irrigation water will flow back to the Snake River if it is not needed for irrigation. In order to take advantage of precipitation during the growing season, TFCC would need additional water storage within their system or farmers would need on-farm storage to store irrigation water during precipitation. It is also important to note that unused irrigation water returns to the Snake River where the water can be beneficially used by downstream water users.

The remainders for the annual water balances were 71 to 204 mm, or 5% to 12% of the total inflow (table 1). A 5% balance error is reasonable considering the precision of measurements and estimations; however, the annual water balance remainders were always positive, which means that the sum of measured inflow parameters was always greater than the sum of measured and calculated outflow parameters. Skhiri and Dechmi (2012) had −2.8% and +8.1% balance errors for a two-year study on a much smaller, 1,865 ha watershed. A 10% flow measurement error would be about 100 mm for irrigation diversion and 45 mm for return flow, but flow measurement errors should be both positive and negative. The 14 return flow streams measured for this study did not encompass all return flow streams. From 2005 to 2008, return flow was measured at nine additional sites (Bjorneberg et al. 2008), but these nine sites only contributed an additional 5% of the annual return flow during that study period, which would reduce the water balance remainder by only 20 to 25 mm. ET from ETIdaho was likely greater than actual crop water use because reference ET equations and crop coefficients were developed for nonstressed crop conditions. If actual ET was less than estimated ET, the water balance remainder would be greater.

The largest portion of the water balance remainder was likely the change in storage of water in the soil and shallow aquifer. Abrahao et al. (2011) calculated that the change in storage in the soil and aquifer was 32 to 77 mm y^{-1} in a sprinkler and drip irrigated basin. While the soil cannot continually store more water, the predominate soil in the watershed is silt loam with a water holding capacity of about 180 mm m^{-1}, which could be a substantial short-term buffer for the water balance. Likewise, the shallow aquifer would store water that eventually contributed flow to the drain tunnels, recharged a deeper aquifer, or was a source for domestic wells. According to US Geological Survey (USGS) estimates, self-supplied domestic groundwater withdrawals were 23,000 m^3 d^{-1} in Twin Falls County (Dieter et al. 2018a), which was about 8 mm annually in this watershed, and not a major factor in the water balance. Groundwater was not used for irrigation within the TFCC irrigation project with the exception of some lawn irrigation from domestic wells. TFCC supplies irrigation water to most rural subdivisions within the TFCC irrigation project for landscape irrigation.

The annual water balance remainder was not correlated with annual precipitation (R^2 = 0.17, p = 0.20) even though the lowest remainder occurred in 2013 and the highest in 2014, corresponding to the lowest and highest annual precipitation (table 1). Precipitation in 2014 was unusual because rain in August (120 mm) was 12 times the monthly normal. Much of this precipitation may have been stored in the soil in harvested wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) fields (about 20% of cropland) that had not been irrigated since July. Excess rain also could have caused deep percolation in fields that were still being irrigated.

Irrigation Season Results. Approximately 90% of the annual watershed inflow and more than 80% of the annual watershed outflow occurred during the seven-month irrigation season (April to October). Irrigation was 83% to 93% of the total watershed inflow during the irrigation season, and precipitation was 5% to 16% of inflow (table 2). More than 70% of the annual irrigation return flow occurred during the irrigation season. The water balance remainder for the irrigation season was 11% to 18% of the watershed inflow. The remainder for the irrigation sea-

Table 2

Irrigation season water balances (April through October) for the Twin Falls Canal Company irrigation project. Evapotranspiration (ET) was obtained from ETIdaho.

Year	Irrigation diversion (mm)	Precipitation (mm)	Rock Creek (mm)	Total inflow (mm)	ET (mm)	Return flow (mm)	Total outflow (mm)	Remainder (mm)
2006	1,117	139	26	1,282	808	335	1,143	139
2007	1,176	113	8	1,297	829	259	1,088	209
2008	1,228	82	8	1,318	793	283	1,076	242
2009	1,170	170	14	1,353	781	327	1,109	244
2010	1,176	131	6	1,312	777	327	1,104	209
2011	1,188	130	30	1,347	782	356	1,138	210
2012	1,231	69	5	1,305	808	355	1,164	141
2013	1,191	78	7	1,277	795	293	1,088	188
2014	1,255	194	9	1,458	828	369	1,198	260
2015	1,273	112	4	1,389	776	365	1,141	248
2016	1,181	220	19	1,420	860	377	1,236	184
Average	1,199	131	12	1,342	803	331	1,135	207
Trend*	Increase	No trend	No trend	Increase	No trend	Increase	Increase	No trend

*Kendall trend test ($p < 0.05$).

son was always greater than the remainder for the annual water balance because outflow from the watershed continued during the winter, mainly return flow from drain tunnels, while inflow (precipitation and Rock Creek) was minimal.

ET from ETIdaho was 4% to 13% greater than METRIC during the seven irrigation seasons that were available from IDWR (table 3). The energy balance model used by METRIC may provide a better estimate of ET since it estimates actual crop conditions with satellite thermal images approximately every two weeks. ETIdaho uses crop coefficients that were defined for well-watered conditions that typically do not occur everywhere in production fields. If actual ET was 4% to 13% less than ETIdaho, the water balance remainder would increase by 30 to 90 mm. However, both methods should be considered an estimate of ET because energy balance models also have discrepancies from ET calculated based on soil water balance (Evett et al. 2012).

There was no correlation between irrigation diversion and precipitation ($R^2 = 0.03$) or ET from ETIdaho ($R^2 = 0.01$) or METRIC ($R^2 \leq 0.01$) during the irrigation season. As stated previously, irrigation diversion in the large TFCC canal system cannot be easily adjusted especially when precipitation is infrequent and minimal during the summer. IPE based on ETIdaho varied from 61% to 73% (table 3) and averaged 67% for the 11-year study period. IPE based on METRIC was slightly lower than ETIdaho-based IPE, varying from 57% to 65% (table 3). If it was possible to capture all return flow during the irrigation season and use that return flow to reduce irrigation diversions, average IPE for 2006 to 2016 would have been 93%. This is not realistic, however, because major changes to the TFCC distribution system would be required, including substantial water storage within the irrigation project and numerous pumps to transfer the tunnel drainage water to cropland where it could be used. Eliminating return flow would also have a negative impact on power generation from the nine hydropower plants on return flow streams that generate electricity from water flowing back to the Snake River.

In 1995, about 10% of the cropland within the TFCC irrigation project was sprinkler irrigated (Bjorneberg et al. 2008). Since then, farmers have steadily converted from furrow irrigation to sprinkler irrigation to improve water management, reduce tillage and labor, and participate in cost-share programs. According to the survey of aerial images, sprinkler irrigation was used on 46% of the cropland in 2006. The amount of sprinkler irrigation increased almost 1.5% per year to 52% in 2011, 54% in 2013, and 59% in 2016.

Table 3

Evapotranspiration (ET) for the irrigation season and irrigation project efficiency (IPE) calculated by remote sensing with METRIC or by reference evapotranspiration from ETIdaho.

Year	METRIC (mm)	METRIC IPE (%)	ETIdaho (mm)	ETIdaho IPE (%)
2006	717	64	808	72
2007	na*	na	829	70
2008	706	57	793	65
2009	739	63	781	67
2010	698	59	777	66
2011	749	63	782	66
2012	na	na	808	66
2013	759	64	795	67
2014	na	na	828	66
2015	na	na	776	61
2016	766	65	860	73
Trend†	Increasing	No trend	No trend	No trend

*Not available.

†Kendall trend test ($p < 0.05$).

While the amount of sprinkler irrigation steadily increased, there was no increasing trend in IPE (figure 2). For IPE to increase, ET needed to increase and/or irrigation diversion needed to decrease. Irrigation diversion actually tended to increase during this study (table 2). Since crop water use calculated by ETIdaho represents potential crop ET based on weather parameters and crop type, it is understandable that ETIdaho was not affected by irrigation type. Even if farmers would use less water with sprinkler irrigation, irrigation diversion may not decrease because the canal system was not designed to adjust or redirect canal flow when individual sprinkler systems are turned on and off. Furthermore, farmers do not have an incentive to reduce water use with the flow rate allocation scheme, so irrigation water may have continued to be delivered to the farm while the sprinkler system was off. This unused irrigation water flowed to return flow streams where it could be used on other farms or return to the Snake River. If farmers had sufficient water storage on their farms, they could better utilize irrigation water by storing their allocated flow rate when their irrigation systems were off, which only occurs when the TFCC allocation exceeds irrigation needs on the farm.

Grafton et al. (2018) noted that irrigation diversion may increase as more cropland in an irrigation project is sprinkler irrigated because consumptive use could be greater with sprinkler irrigation than surface irrigation. While there was variation in crop types among years, the amount of high water use crops (e.g., alfalfa [*Medicago sativa* L.] and sugar beet [*Beta vulgaris* L.]) did not increase during this study (figure 3). METRIC ET for the irrigation season had an increasing trend during the study period while ETIdaho did not (table 3). The increasing trend for METRIC ET could indicate that consumptive use increased with increasing sprinkler irrigation. IPE calculated with METRIC ET, however, did not increase (table 3) because irrigation diversion also increased during the study (table 2).

Monthly Results. Monthly water balances show the seasonal impact of irrigation on hydrology in this watershed (figure 4). Average monthly inflow into the watershed was <50 mm until irrigation diversion began in April and ended in October. Irrigation diversion was 93% to 97% of the total monthly inflow from June to September

Figure 2

Irrigation project efficiency based on ETIdaho and relative amount of sprinkler irrigated cropland for the Twin Falls Canal Company irrigation project.

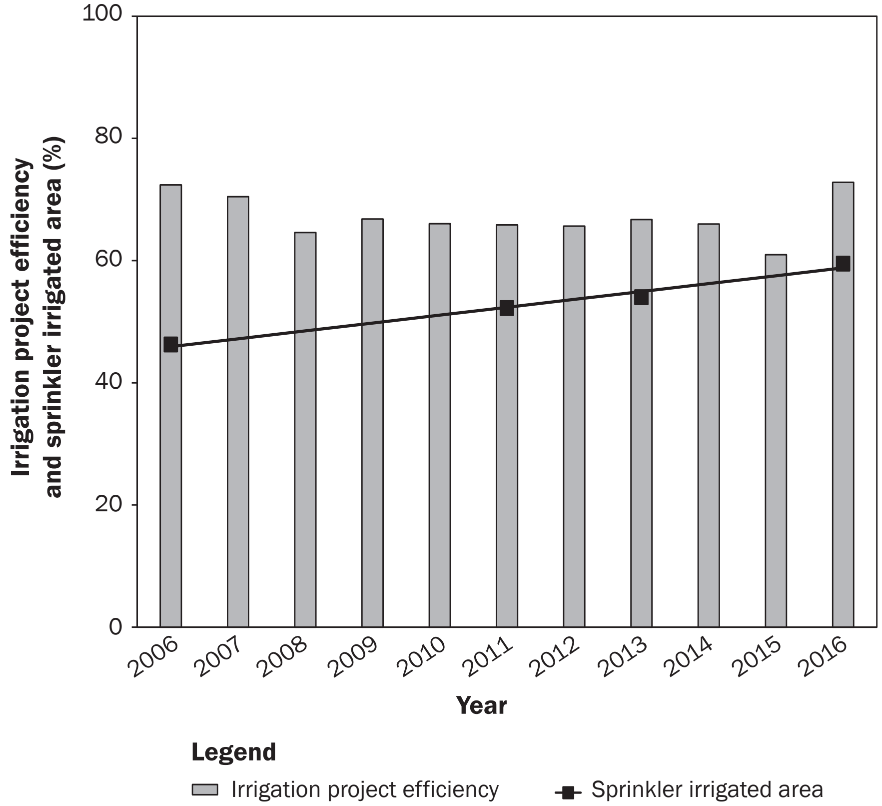
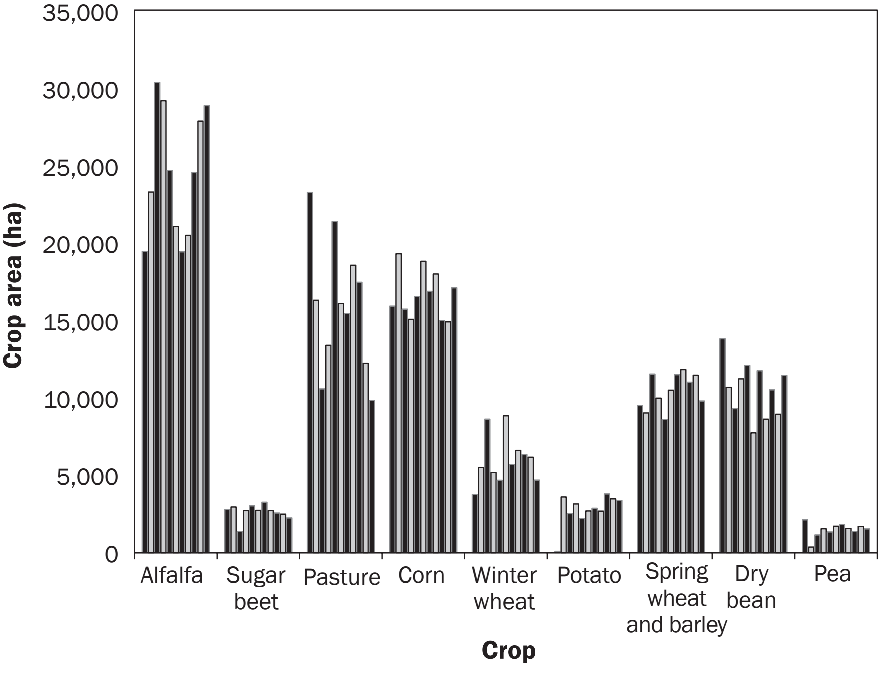


Figure 3

Crops grown in the watershed for each year of the study. Crops are arranged from high to low water use (left to right). Black bars are even years and gray bars are odd years from 2006 to 2016.

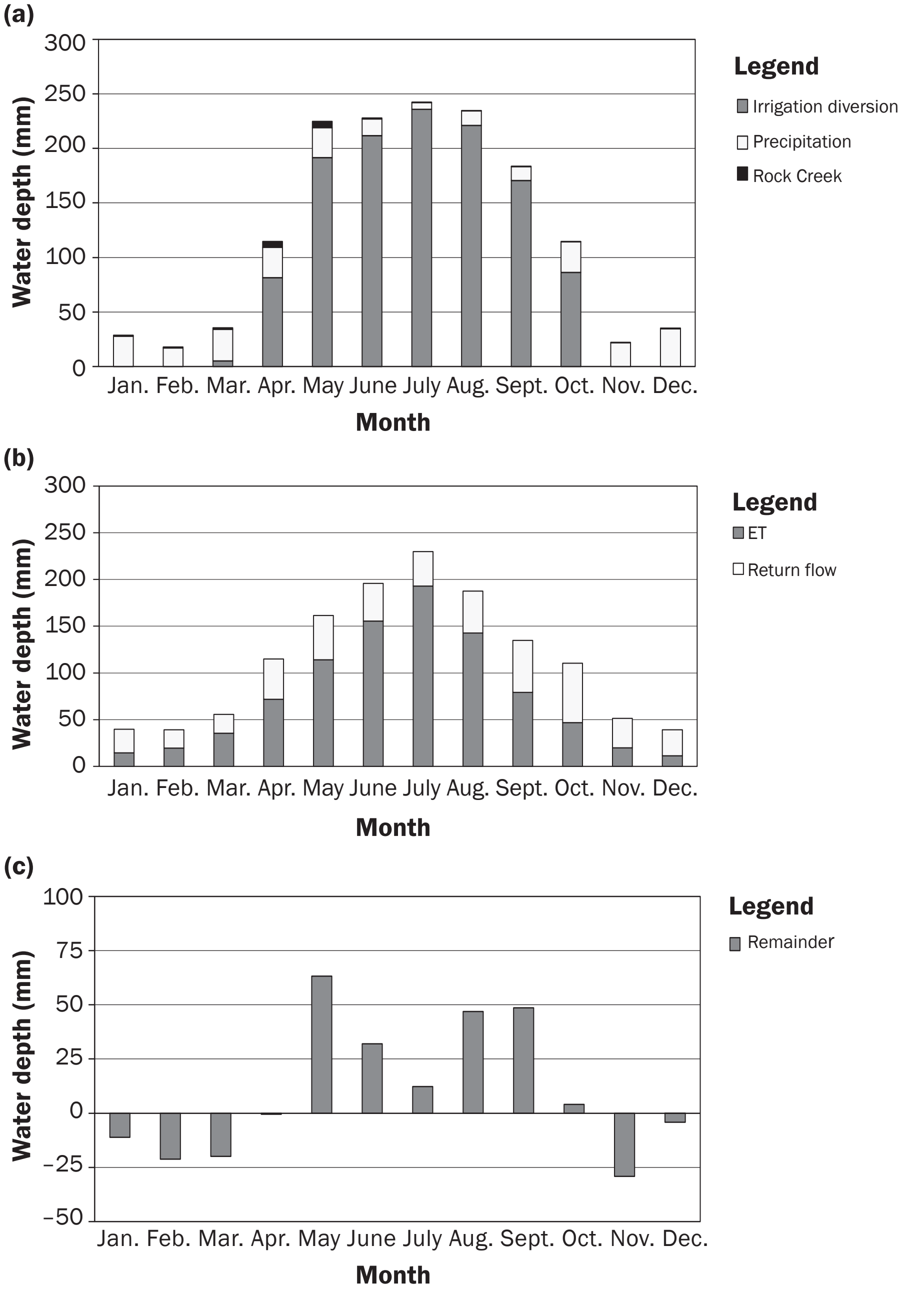


when average monthly precipitation was <15 mm and irrigation diversion was >170 mm. Monthly irrigation return flow was 40 to 60 mm during the irrigation season and 20 to 30 mm from November through March, resulting in 25% to 30% of the annual return flow occurring during the nonirrigation season due to flow from the drainage tunnels and tiles. ET from ETIdaho gradually increased from April until July, then decreased until October. Ideally, irrigation diversion plus precipitation would match ET. However, irrigation diversion was substantially greater than ET in April, May, September, and October. The TFCC canal system required a minimum flow rate to deliver irrigation water throughout the project area, resulting in excess irrigation diversions in the spring and fall. For example, average diversions in May and September were 190 and 170 mm, respectively, while ET was only 115 and 80 mm for these months. In 2018, TFCC installed an inflatable weir in a canal to allow water deliveries near the weir to be made with a lower flow rate in the canal. If this project is successful and feasible, TFCC could install more weirs, which could improve flexibility for irrigation diversions.

The monthly water balance remainders were negative from November to March because drainage tunnels continued to flow during the winter when Rock Creek and precipitation contributed little inflow to the watershed (figure 4). Water balance remainders were greatest in May (63 mm), August (47 mm), and September (49 mm). Assuming that the greatest portion of the remainder was the change in water stored in the soil or shallow aquifer, the large remainders indicate that irrigation applied to fields exceeded ET during these months. Excess irrigation in May can be used to bring the water content in the soil profile to field capacity before peak ET occurs during the summer. Irrigating in excess of ET in August and September has little potential to be beneficially used by a crop except for some fall seeded crops. These trends indicate that farmers could benefit from scheduling irrigation based on soil water content or calculated ET such as AgriMet (USBR 2018). According to the 2013 Farm and Ranch Irrigation Survey, 71% of Idaho farmers with irrigation decided when to irrigate based on crop condition, 42% based on soil feel, 37% based on the water delivery organization, and 29% based on personal calendar (USDA NASS 2013). Only 4% used soil moisture sensing and 6% used daily ET reports. (Farmers could select more than one method so percentages will total more than 100.) Irrigation water management would be an important conservation practice to be implemented in this watershed, especially as more cropland is converted to sprinkler irrigation, which is more conducive to irrigation scheduling than furrow irrigation.

Figure 4

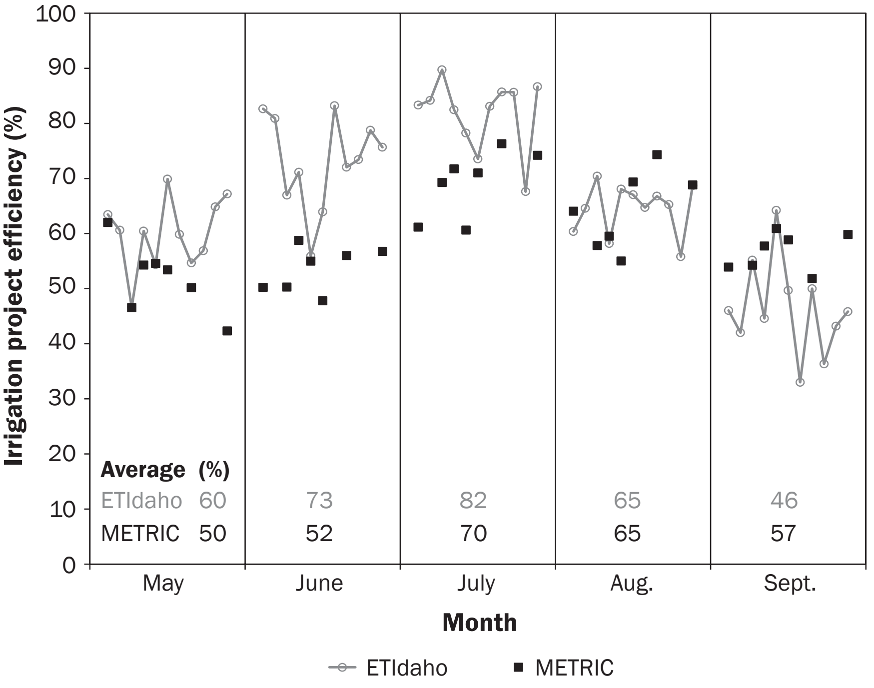
Average monthly water balances for 2006 to 2016 for the Twin Falls Canal Company irrigation project.



Precipitation had a substantial impact on the water balance in August of 2014. Annual precipitation in 2014 was above normal almost entirely because August precipitation was 120 mm compared to normal August precipitation of 9 mm. Irrigation diversion in August of 2014 was similar to the other 10 years of this study, but August return flow was 10 mm greater than the average, and the water balance remainder was 121 mm

Figure 5

Monthly irrigation project efficiency (IPE) calculated with ETIdaho or METRIC evapotranspiration (ET) for 2006 to 2016. Each data point is the monthly IPE for an individual year. METRIC ET was only available for 2006, 2008 to 2011, 2013, and 2016.



compared to <8 mm for the other years. The unusually high rainfall directly increased irrigation return flow by runoff during rain events and indirectly by farmers stopping irrigation, so unused irrigation water continued to flow in ditches and canals to return flow streams before TFCC could adjust irrigation diversion. The additional water balance remainder was probably increased storage of water in soil and shallow aquifer.

Monthly IPE values were calculated with ET from both ETIdaho and METRIC (figure 5). IPE was not shown for April and October because it was highly variable depending on when irrigation diversion began or ended. Differences in ETIdaho and METRIC IPE values reflect differences in the two ET calculation methods since the amount of irrigation water diverted into the watershed was the same. ETIdaho was greater than METRIC for six of seven years in both June and July. As stated previously, the crop coefficients used in ETIdaho were based on well-watered conditions while METRIC uses satellite thermal imagery to determine variations in crop growth. METRIC and ETIdaho were similar for three of seven years in both May and September, and quite different for the other four years. Crop coefficients were developed for typical crop conditions whereas METRIC can account for differences in crop growth that may occur early or late in the growing season.

Both methods follow the same trend of higher IPE in July and lower in May and September. Average IPE values were 60% or less for both methods in May and September (figure 5), which matches the large differences between ET and irrigation diversions (figure 4). IPE based on METRIC ET would increase to 65% in May and 71% in September if the TFCC could reduce irrigation diversions by 20% in these two months. Average IPE was greatest in July when irrigation diversion and ET were greatest and return flow and water balance remainder were lower than any other month during the irrigation season (figure 4). The IPE based on ETIdaho did not have an increasing or decreasing trend for any month during this study. Using METRIC ET, however, the IPE was decreasing in May ($p = 0.93$) and increasing in July ($p = 0.93$) (figure 5). The increasing IPE trend in July gives some indication that irrigation efficiency has increased with the greater amount of sprinkler irrigation.

Another significant trend was increasing monthly return flow for each month of the irrigation season except June. Increasing return flow could indicate that less irrigation water was being applied to fields, so unused irrigation water increased return flow to the Snake River. This increase, however, was only 5 to 10 mm over 10 years, which is equivalent to 2% to 5% of the monthly irrigation diversions. Return flow as a percentage of irrigation diversion also had an increasing trend for July, August, and September, which is another indication that irrigation application was decreasing since irrigation diversions were not changing, and that TFCC could consider strategies to reduce irrigation diversions.

Summary and Conclusions

Water balances for the TFCC irrigation project showed that irrigation water diverted from the Snake River contributed more than 75% of the annual inflow to this watershed. Annual ET equaled approximately 60% of the inflow while about 30% of the inflow flowed back to the Snake River. Annual irrigation diversions or return flow did not decrease, and annual ET or irrigation project efficiency did not increase even though 25% of the furrow irrigated cropland was converted to sprinkler irrigation during this study. TFCC was developed with a flow rate water allocation scheme to uniformly distribute their natural flow water right within the project. It was not designed to deliver irrigation water based on daily irrigation needs on individual farms. Farmers with a supply-based allocation also do not have an incentive to reduce delivery of irrigation water to their farm because the reduction cannot be saved for later use and their assessment is not based on the amount of water used. The only indications that the increasing amount of sprinkler irrigation impacted the water balance was increasing IPE in July (when calculated with METRIC ET) and the increasing irrigation return flow during the irrigation season. Farmers may be applying less irrigation water with sprinkler irrigation compared to furrow irrigation, which could have caused return flow to increase since irrigation diversion did not change. Additional on-farm irrigation water storage would allow farmers to store their allocation until they started irrigating again or they contacted TFCC to stop irrigation delivery. Irrigation water management is an important conservation practice to be implemented in this watershed so irrigation water is applied based on crop water needs rather than availability of irrigation water. This study also demonstrated that a supply-based policy can have a larger impact on irrigation project efficiency than converting individual fields from furrow irrigation to sprinkler irrigation.

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