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Water Balance for a West and a Midwest Watershed

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Abstract. *Water use efficiency is a term often applied to irrigated conditions to determine the amount of applied water that is used by crops. Water use in irrigated watersheds can be managed by adjusting irrigation diversions to meet irrigation needs. Precipitation is often the only source of water input in many watersheds, and its rate and timing cannot be controlled. Excess water is often drained from the watershed through surface or subsurface drains to provide suitable conditions for crop growth. The objective of this paper is to compare water balances for the irrigated Upper Snake-Rock (USR) watershed in southern Idaho and the subsurface drained Upper Big Walnut Creek (UBWC) watershed in central Ohio.*

Irrigation water diverted from the Snake River supplied 80% of the water input into the USR watershed. Precipitation only supplied 10 to 20% of the water in the USR compared to 100% in the UBWC watershed. Potential crop ET was estimated to use 37 to 51% of the total annual water input in the USR watershed and 30 to 55% in the UBWC watershed. The relative volume of water potentially used by crops in these two watersheds was quite similar on an annual basis even though the hydrology throughout the year is quite different.

Keywords. Irrigation, Subsurface Drainage, Upper Snake-Rock watershed, Upper Big Walnut Creek watershed.

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Introduction

Water is often a limiting factor in crop production with either too much or too little available for optimum crop growth. In some areas, irrigation is used to supplement precipitation. In other areas, drainage is needed to remove excess water, and sometimes a combination of drainage and irrigation are needed. As competition for finite water resources increases, it is important to understand how much water is used by crops in agricultural watersheds to be able to maintain food production.

Water use efficiency is usually applied to irrigated situations to quantify the amount of applied water that is used by crops. Water application can be controlled with irrigation unlike precipitation. The objective of this paper was to compare potential crop water use and water balances between an irrigated watershed in southern Idaho and a non-irrigated watershed in central Ohio.

Methods and Materials

The two watersheds used for this study are the Upper Snake-Rock (USR) watershed in southern Idaho and the Upper Big Walnut Creek (UBWC) watershed in central Ohio. Agricultural crop production is the primary land use in both of these watersheds, which are ARS benchmark watersheds for the Conservation Effects Assessment Project (CEAP) (Mausbach and Dedrick, 2004). Additional details about these watersheds are provided by Bjorneberg et al. (2008) and King et al. (2008). Data from 2005 to 2008 were used for this study for the USR and 2005 to 2010 for the UBWC.

Upper Snake-Rock (USR) watershed

Research in the USR watershed focused on the 82,000 ha watershed irrigated by the Twin Falls Canal Company (TFCC). The TFCC supplies irrigation water from the Snake River to about 3000 deliver points through approximately 180 km of main canal and 1600 km of laterals (Figure 1). Approximately 85% of the study area was used for crop production. All crop production in the USR was irrigated because average annual precipitation was 270 mm, with only 90 mm occurring from May through September. Typical crops were alfalfa (Medicago sativa L.), barley (Hordecum vulgare L.), spring and winter wheat (Triticum aestivum L.), dry bean (Phaseolus vulgaris L.), sugar beet (Beta vulgaris L.), potato (Solanum tuberosum L.), and corn (Zea mays L.) (Table 1). Soils in the watershed are well drained silt loams.

The USR is categorized as cold semi-arid climate with average low temperature in January of -6.7°C and average high temperature in July of 30°C. Hydrology in the USR watershed is driven by irrigation. Irrigation water flows in ephemeral streams and coulees as it is delivered to fields or flows back to the Snake River. Many streams only have water 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. Most of these drains flow continuously through the year. Rock Creek is the only stream that flows into the watershed.

Table 1. Crop areas in USR watershed.

Crop	Year 2005	2006	2007	2008
	--	ha	--	
Corn	21938	14399	15839	13951
Alfalfa	21702	17593	17746	34467
Dry Bean	14306	12500	7060	9027
Wheat/Barley	13641	12001	14105	18054
Pasture	4367	3563	4027	2462
Potato	2528	90	0	1641
Sugar Beet	1333	2527	4105	821
Pea	156	1922	709	821

Upper Big Walnut Creek (UBWC) watershed

Upper Big Walnut Creek (UBWC) watershed is a 49,200 ha USGS 10-digit (HUC 05060001-13) watershed located in central Ohio (Figure 2). UBWC is characterized by 686 km of perennial and intermittent streams that drain to Hoover Reservoir. Hoover Reservoir is the primary water supply for approximately 800,000 residents in Columbus and surrounding communities. The reservoir was completed in 1955 and has a surface area of approximately 1200 ha at normal pool elevations and 1860 ha at maximum capacity. The reservoir is 13.7 km in length with a residence time of 180 days.

The study watershed is 26227 ha. Crop production comprises the largest land use classification within the watershed (Table 2). The primary agricultural crops are corn, soybean and winter wheat (Table 3). Management primarily includes conservation tillage, fertilization and pesticide applications. An extensive portion of the watershed used for agricultural production is systematically tile drained, especially in the southern half of the watershed. Soils in the watershed are mostly moderately fine-textured, moderately well drained to very poorly drained, and consist primarily of Cardington (10%), Centerburg (20%), Bennington (35%) silt loams, and Pewamo (17%) silty clay loam. Approximately 18% of the watershed is comprised of other minor soils and water.

Table 2. Land use classification in the UBWC watershed.

Land Use	Year 2005	2006	2007	2008	2009	2010
	-----------------------------		percent of watershed area		-----------------------------	
Agriculture	54.8	54.6	NA	NA	54.2	54.2
Scrub	0.8	0.9	NA	NA	0.8	0.8
Urban	21.4	22.0	NA	NA	22.5	22.6
Woodland	22.9	22.5	NA	NA	22.5	22.5

UBWC is located in the humid continental-hot summer climatic region of the United States. The climate provides for approximately 160 growing days per year, generally lasting from late April to mid-October. Average daily temperatures range from a minimum of -9.6 °C in January to a maximum of 34 °C in July. Thunderstorms during the spring and summer produce short duration intense rainfalls. Moisture in the form of frozen precipitation or snow averages 500 mm annually and occurs primarily from December to March. The 30-year average rainfall near the southwest portion of the watershed is 985 mm. Monthly distribution of rainfall exhibits a bimodal distribution with a primary peak in late spring and early summer and a secondary peak in late fall and early winter.

Table 3. Crop areas in UBWC watershed

		Crop	
Year	Corn	Soybean	Winter Wheat
	------------	ha	------------
2005	5,130	8,022	2,610
2006	4,746	8,148	3,073
2007	6,358	8,061	3,160
2008	5,505	8,831	3,517
2009	5,497	8,999	3,197
2010	6,066	9,179	2,294

Water Balance Calculation

The water balances were calculated as:

Precipitation + Irrigation + Stream Inflow = Stream Outflow + Potential Crop ET + Remainder

Precipitation, irrigation and stream inflow were the only watershed inputs considered. Pumping groundwater was not considered. Evapotranspiration (ET) was only calculated for agricultural crops because the focus of this study is agricultural crop water use. The remainder includes all measurement or estimation errors and unestimated losses like change in soil water content, deep percolation, surface water evaporation, and water use by non-agricultural crops. In the USR, water use by non-agricultural crops was minor with the possible exceptions of lawns and landscaping that were usually irrigated with groundwater, which was not included as inflow to the watershed. Non-agricultural water use was likely a significant component of ET in the UBWC watershed because only 55% of the watershed area is cropland.

Precipitation and Flow Data

In the USR watershed, flow rate was measured at 23 sites–two sites where water flows into the watershed and 21 sites where water returns to the Snake River or Salmon Falls Creek, which is a tributary to the Snake River (Figure 1). The two inflow sources are the TFCC mainline canal and Rock Creek. Water stage was measured at weirs or rated sections with pressure transducer connected to data loggers at the inflow sites and 13 return flow sites. Eight additional return flow sites had less flow so flow rate was manually measured once per week by recording water depth from a staff gage on a weir or weir stick on a concrete structure.

Precipitation data were obtained from the US Bureau of Reclamation's AgrMet site at Kimberly, ID for the USR and from six tipping bucket rain gauges located in the UBWC. Flow data in the UBWC watershed were obtained from the USGS gage station on Big Walnut Creek and Sunbury, OH (USGS Site# 03228300).

Crop Water Use

In the USR watershed, crop areas were estimated by a single field survey each year of one randomly chosen section within each of the 17 townships in the watershed. Total area surveyed was 4,400 ha or about 5% of the total land area in the watershed. The relative area of each crop type identified by the survey was multiplied by the total area of the watershed to determine the total area of each crop. Potential crop water use was calculated by multiplying crop areas by the potential ET for those crops calculated by AgriMet (US Bureau of Reclamation, 2011) for Kimberly, Idaho. AgriMet used site-specific weather data and the ASCE standardized Penman-Monteith method to compute daily reference ET. Reference ET was multiplied by crop coefficients to estimate ET for crops grown in the vicinity of each weather station.

Alfalfa reference ET was computed by the ASCE standardized Penman-Monteith method (Allen et al., 2005) using climatic data from the UBWC watershed. Crop coefficients were determined by the FAO 56 method for corn, soybean and winter wheat (Allen et al., 1998). Crop coefficients were multiplied by reference ET to calculate potential crop ET. Crop area was determined from USDA NASS county data and weighted by watershed area in each county. Area for each crop was multiplied by potential crop ET to estimate the potential volume of water used for each crop. Total water volume used by the three crops was divided by the total watershed area to determine potential crop ET for the entire watershed. Potential crop ET was not adjusted for water stress conditions in either watershed.

Results and Discussion

Water diverted from the Snake River to irrigate the USR watershed was 80% of the water input to the watershed. Precipitation only supplied 10 to 20% of the watershed input in the USR compared to 100% in the UBWC watershed. On average for the study periods, the USR had 45% more water input to the watershed than UBWC and 55% more potential crop ET. Stream outflow was also 49% greater in the USR.

Potential crop ET was estimated to use 37 to 51% of the total annual water input in the USR and 30 to 55% in the UBWC. The lowest percentages occurred in the year with highest annual precipitation (2006) in both watersheds (Table 4). Increasing precipitation in either watershed does not result in greater crop water use. In the UBWC, precipitation must occur when water can be stored in the soil for crop use. In the USR, precipitation during the growing season can cause diverted irrigation water to be unused and flow back to the Snake River. The size the TFCC irrigation system does not allow irrigation delivery to be immediately reduced if irrigation demand decreases from atypical precipitation. The greatest crop ET occurred in the USR in 2008 when irrigation diversion was greatest and precipitation was similar to 2007 (Table 4). In the UBWC, there was a decreasing linear trend between annual precipitation and crop ET (R^2=0.73). There are two potential reasons for this trend. First, annual precipitation was at or above normal for every year except 2010. Second, calculated potential ET was not reduced for water stress conditions that may have occurred during growing seasons with less precipitation.

The remainder of the water balance was 18 to 24% of the annual inflow for the USR, and varied from 7 to 42% for the UBWC. The consistent values for the USR reflect the controlled input of irrigation water and presumably consistent seepage and evaporation losses in the watershed that were not included in the water balance. The greater variation in the UBWC indicates that the unestimated water uses/losses vary from year to year depending on precipitation patterns and amounts. There was an increasing linear trend between precipitation and the water balance remainder (R^2=0.67) indicating that non-estimated water uses/losses, such as non-crop ET or deep percolation, increased with precipitation.

Table 4. Water balance for USR and UBWC watershed.

Year	Irrigation	Stream Inflow	Precip.	Stream Outflow	Cropland ET	Remainder
USR	-------------------------------------			mm	-------------------------------------	
2005	1120	28	227	428	615	332
2006	1220	45	311	667	590	319
2007	1230	19	173	523	624	275
2008	1370	14	170	495	786	273
Average	1235	27	220	528	654	300
UBWC						
2005	NA	NA	1097	382	396	319
2006	NA	NA	1184	332	351	501
2007	NA	NA	1044	403	449	192
2008	NA	NA	979	450	459	70
2009	NA	NA	993	310	422	261
2010	NA	NA	839	244	462	133
Average			1023	354	423	246

Average monthly water balances are shown in Figures 3 and 4. Each bar represents total cumulative water input to the watershed for each month. The monthly trends reflect the hydrologic differences between the two watersheds. The USR has a large difference between summer and winter due to irrigation diversion (Figure 3). Total water inflow was only 24 mm in March compared to 270 mm in August. Winter months typically had a negative remainder because stream outflow was greater than precipitation and the inflow from Rock Creek. Flow from subsurface drains accounts for essentially all of the stream outflow after the irrigation season.

Precipitation was the only water input to the UBWC. Average monthly watershed input ranged from 45 mm in February to nearly 120 mm in June (Figure 4).The monthly remainder in the UBWC was negative in March and July. The negative remainder in March could have resulted from subsurface drain flow removing excess soil water in the spring. The negative balance in July likely resulted from potential crop ET exceeding precipitation and therefore reducing the soil water content.

Potential crop ET was 74 to 98% of precipitation in June, July and August in the UBWC. Actual crop water use was likely less than the potential ET because ET was not reduced for water stress conditions. In the USR, potential crop ET was only 52 to 68% of watershed input during the same months. Matching irrigation diversion with irrigation demand is not possible with large irrigation projects so some water essentially flows through the watershed and back to the river. As previously noted, annual average potential crop ET as a percentage of watershed input was similar between the two watersheds (37 to 51% for USR, 30 to 55% for UBWC). The lower values on an annual basis reflect the effect of non-growing season precipitation (USR and UBWC) and early and late season irrigation diversions (USR) that cannot be used by crops.

Summary

Annual potential crop ET as a percentage of water input to the watersheds was similar between the two watersheds (37 to 51% for USR, 30 to 55% for UBWC). Average monthly inflow and outflow trends are different due to irrigation diversion into the USR and precipitation patterns in the UBWC. Actual crop and non-crop ET should be estimated to improve the calculated water balances in these watersheds.

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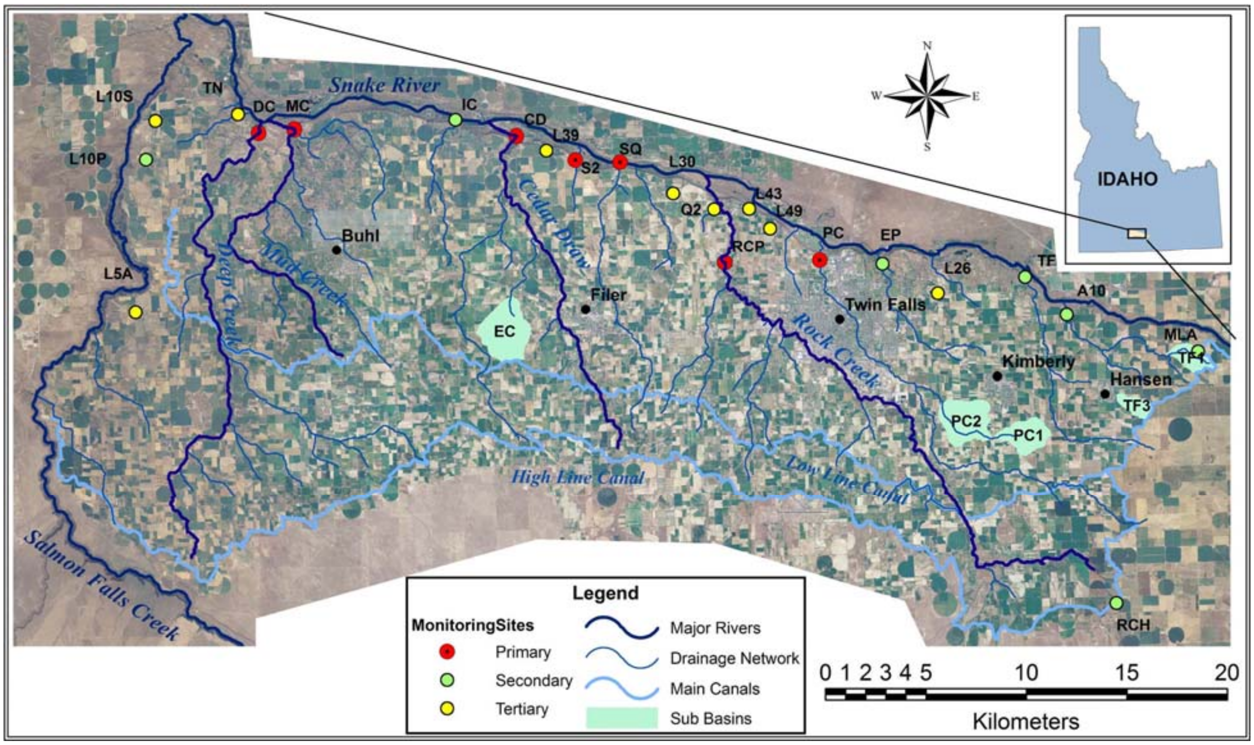

Figure 1. Aerial photograph of Twin Falls irrigation tract in the USR watershed showing monitoring locations where water leaves the watershed and two locations where water enters the watershed (MLA in upper right and RCH in lower right).

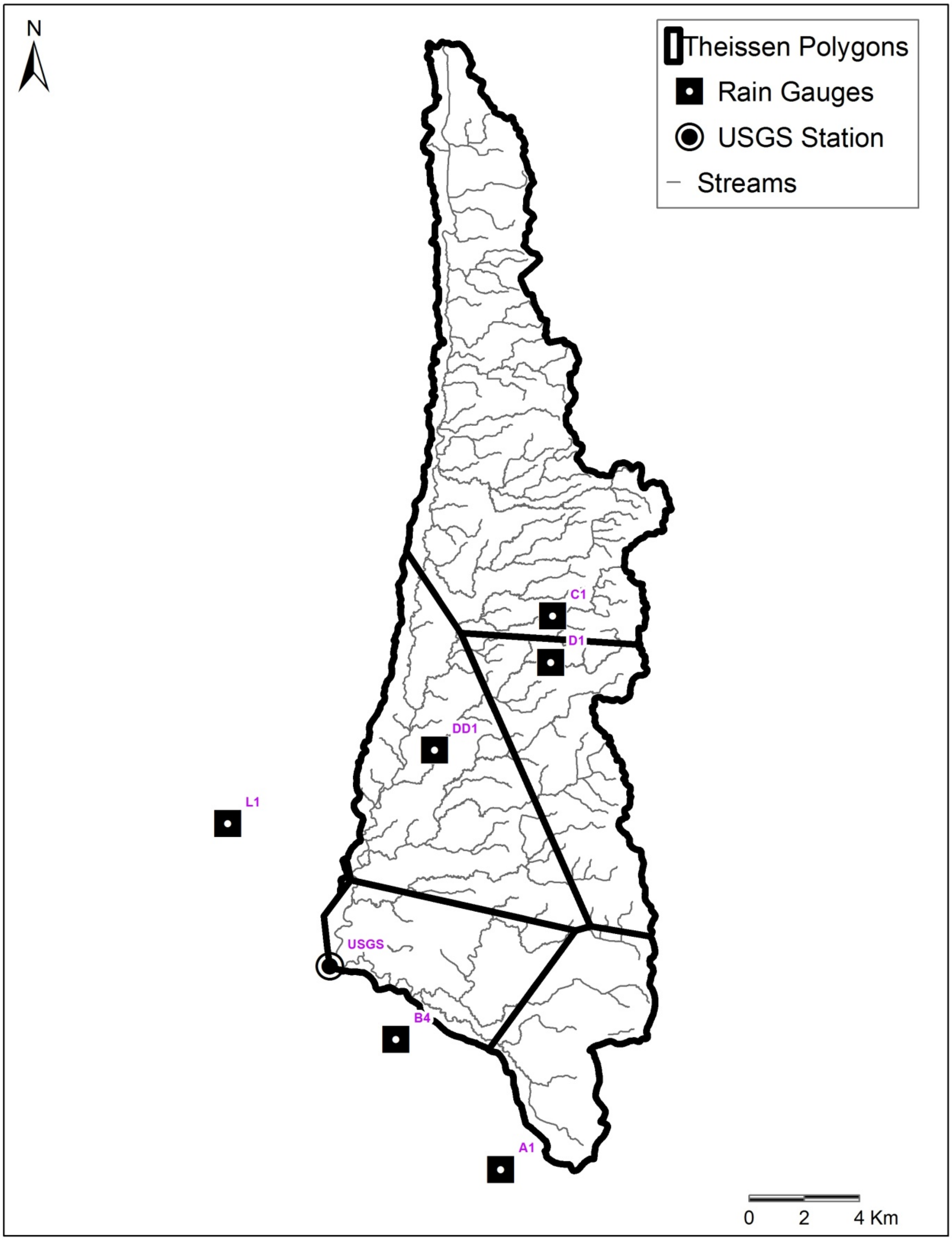

Figure 2. The UBWC watershed.

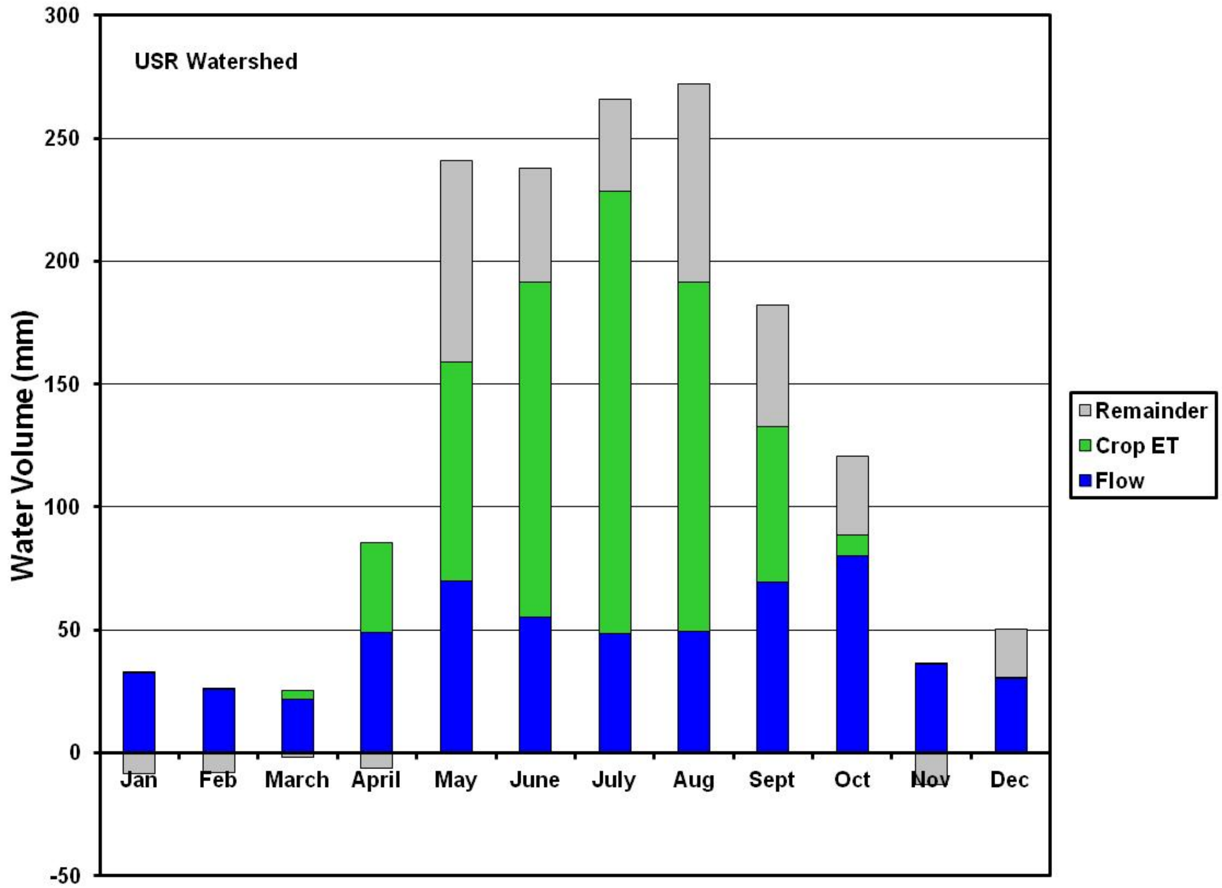

Figure 3. Average monthly water use or loss from the USR. The sum of bars equals total water input to the watershed (irrigation + precipitation + Rock Creek).

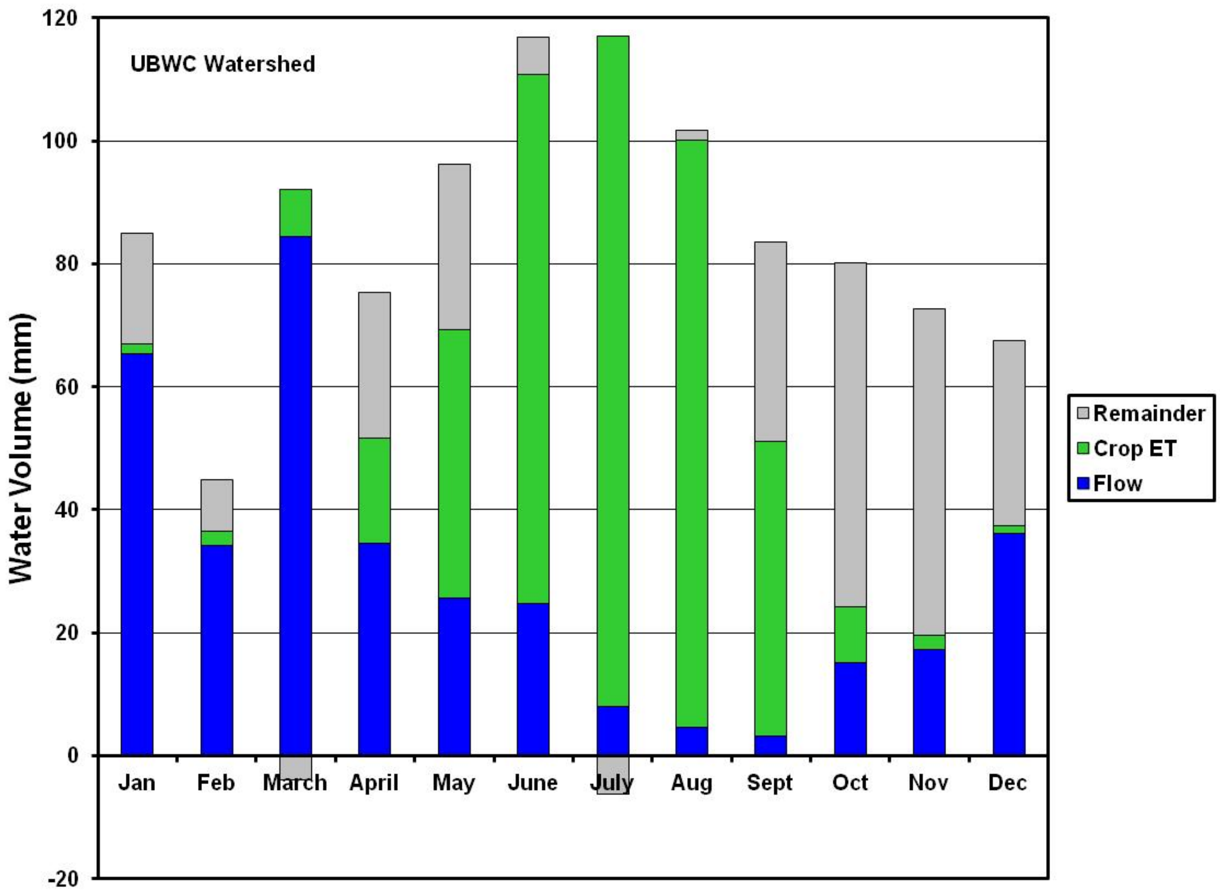

Figure 4. Average monthly water use or loss for the UBWC watershed. The sum of bars equals precipitation.