Final Report

Hydrologic Impacts of Improved Irrigation Efficiencies and Land Use Changes

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Abstract:

Stream flows that originate in the mountainous areas of Wyoming are receiving increased interest in relation to allocation of water rights. The primary objective of this study was to examine hydrologic impacts, including changes in instream flows, resulting from changes in irrigation practices and land use. The study area was the Salt River drainage basin (Star Valley). The methodology used incorporated comparing flows in the Greys and Salt Rivers. The Greys River, due to lack of agriculture in it's drainage area, was used as a control and flows in the Greys River were compared to flows in the Salt River where changes in land use and irrigation had occurred. Comparing flows in the Greys and Salt Rivers allowed effects due to changes in land use and irrigation practices to be quantified.

The overall irrigation efficiency in the study area increased from an assumed value of 50% for flood irrigation to 70% for sprinkler irrigation. The conversion to sprinkler irrigation resulted in major hydrologic impacts to the Salt River basin, including an estimated 9% increase in average annual flow. Estimated changes in return flow timing were even greater. Stream flows increased an estimated 34% in May and 50% in June, while decreasing 14% and 15% for August and September.

Problem and Research Objectives:

The conversion from flood irrigation to sprinkler irrigation provides many benefits to farming communities including savings in water, energy, and labor, which are supplemented with the farmer's ability to produce increased crop yields (Guitjens and Goodrich 1994). With the conversion to sprinkler irrigation, farmers can place more acreage into production, and adjust harvest dates to best fit market conditions. Perhaps the greatest benefit to farmers resulting from changing irrigation practices is the increase in total irrigation efficiency. Irrigation efficiency is defined as the ratio of net volume of water beneficially used by the crops to the volume of water applied to the crops (Burt, Clemmons et al. 1997). Delivery systems and many climatic and geologic factors, such as wind, soil type, solar influences and precipitation influence irrigation efficiencies. Irrigation efficiencies reported for flood irrigation systems range from 45% to 60%, while sprinkler irrigation efficiencies range from 60% to 80% (Wolter and Bersisavlijevic 1991; Zalidis, Dimitriadis et al. 1997). In most case studies, average irrigation efficiencies increase from approximately 50% to 70% after converting from flood to sprinkler irrigation.

While improvements in irrigation efficiency are well documented when changing from flood to sprinkler irrigation, impacts to the watershed are not well known. The resulting impacts to a river basin hydrology are the focus of this study.

Objectives of this study were to quantify the potential hydrologic impacts to a watershed when irrigation systems are converted from flood to sprinklers and to relate these impacts to the various hydrologic components through which they occur. Specific objectives included the determination of changes in: (1) return flow timing, (2) irrigation efficiencies, (3) total annual river flow, (4) land use; including agricultural production, (5) surface water and groundwater quality, and (6) groundwater levels in the unconfined aquifer impacting river recharge.

Methodology:

Because of its physical characteristics, the Star Valley presents a unique opportunity to study the hydrologic impacts of irrigation changes and differences in irrigation efficiencies. The Salt River and many of its tributaries flowing through the Star Valley provide as much as 95% of the water used for irrigation. The Greys River flows through a narrow drainage basin of approximately 1160 km^2 (448 mi^2) on the other side of the Salt River Mountain Range adjacent to the Salt River. The Greys River is in close proximity to the Salt River and it contains nearly the same flow as the Salt River. However, unlike the Salt River, the Greys River has not been significantly impacted by changes in irrigation practices since the river only provides water to about 200 ha (500 acres) of irrigated agriculture. As such, a comparison of flows in the two rivers before and after the application of sprinkler systems provides an excellent method to investigate impacts associated with the change from flood irrigation to sprinkler irrigation.

Double mass balance plots were created for analyzing the flow consistency of the Salt River, utilizing the Greys River as a control. The period of record analyzed was from 1954 through 2000. United States Geological Survey (USGS) stream gages were used as the primary data resources. USGS station 13027500 located near Etna, Wyoming above the Palisades Reservoir (latitude 43 – 04', longitude 111 – 02') was used to represent the Salt River flows. USGS station 13023000 located near Alpine, Wyoming above the Palisades Reservoir (latitude 43 –08', longitude 110 – 58') was used to represent the Greys River flows. The slopes of the double mass balance plots represent ratios of cumulative monthly flow in the Greys River to cumulative monthly flow in the Salt River. This ratio for each month was calculated for flows prior to the change to sprinkler irrigation and another ratio was calculated for flows after sprinkler irrigation. The difference in ratios between the pre-sprinkler and post-sprinkler periods for a month multiplied by the average monthly flow in the Salt River for that month represents the change of average stream flow in the Salt River for that month. Annual conservation of water was calculated by summing the average monthly values of the months considered to be statistically significant. Annual conservation of water and an assumed prior flood irrigation efficiency were used to estimate changes in irrigation efficiencies.

Conservation of water resulting from different irrigation practices is associated with changes in hydrologic mechanisms acting in the drainage basin. One mechanism affecting the river basin hydrology is canal evaporation. Canal evaporation losses during conveyance that occurred with the flood irrigation systems are eliminated with sprinkler systems. Based upon monthly evaporation losses for reservoirs and estimates of surface area of water in the canals, evaporation loss calculations for the open canals were made for two of the larger irrigation districts, the Cottonwood Irrigation District and the Dry Creek Irrigation District. These calculations were then extrapolated to estimate the canal evaporation for the entire drainage basin.

The groundwater hydrology is also impacted by changes in irrigation practices. Direct impacts to groundwater hydrology, such as changes in groundwater elevation, aquifer capacity, and the hydrologic cycle occur due to changes in seepage and deep percolation. Well logs obtained from the Groundwater Division at the Wyoming State Engineer's Office for every well installed in the Star Valley area were analyzed to try to determine any impacts to the groundwater elevation. The well logs contained information on the owner of the well, the type of water use, initial static level of the groundwater, initial groundwater depth, the depth of the well, the main water bearing zone, the approximate location of the well, the geology of the soils enclosing the well, and the drilling date of the well.

The changes in irrigation practices may also have impacts upon the water quality within the watershed. The Star Valley contains large saline deposits (Walker 1965), and the leaching of salts during irrigation may cause water quality concerns with respect to domestic and agricultural use. The gaging station, USGS stream gage #13027500, utilized for stream flow analysis on the Salt River contained data on water quality, including salinity, total dissolved solids, and conductance for the period of 1965-1975. Fortunately, the period of record contains data years before and after the change in irrigation techniques

Principal Findings and Significance:

Objectives of this study were to quantify the potential hydrologic impacts to a watershed when irrigation systems are converted from flood to sprinklers and to relate these impacts to the various hydrologic components through which they occur. Specific objectives included the determination of changes in: (1) return flow timing, (2) irrigation efficiencies, (3) total annual river flow, (4) land use; including agricultural production, (5) surface water and groundwater quality, and (6) groundwater levels in the unconfined aquifers impacting river recharge. Return flow timing was impacted by the conversion to sprinkler irrigation. Stream flows increased 34% in May and 50% in June, while decreasing 14% and 15% for August and September. These changes are related to how on-field application efficiency of irrigation water increases with sprinkler irrigation. Because conveyance for sprinkler irrigation now occurs in a pipe network, deep percolation, seepage, and groundwater recharge related to the former flood irrigation practices are eliminated. The change in timing of return flows has the potential to hamper irrigators in the lower end of the valley, because the river flow has decreased during the time of the irrigation season when the irrigation water is under its greatest demand. Practical solutions for reducing the impacts of the return flow timing include installation of catchments. The early spring runoff could be stored and utilized more beneficially to alleviate the 15% decrease in available in-stream flow at the end of the irrigation season.

The overall irrigation efficiency in the study area increased from an assumed value of 50% for flood irrigation to 70% for sprinkler irrigation. The 20% increase in irrigation efficiency resulted in major hydrologic impacts to the Salt River basin, including an increase in average annual flow of 65.62 MCM (53,200 acre-ft). The average annual Salt River Flow is approximately 722 MCM (575,000 acre-ft), and the 65.62 MCM of excess flow represents 9% of the average annual Salt River flow. The increased flow is substantial as it represents approximately 55% of the average annual consumptive use requirement in the study area.

The excess flow occurred even with an increase in crop yields. After the conversion from flood irrigation to sprinklers, average crop yields increased from 1.6 ton/acre to 2.1 ton/acre. Crop yields increased because farmers can now more evenly distribute irrigation water to their fields and irrigate higher reaches of their fields. Since 1990, population increased in the area by about 17%. This increase in population has yet to show any significant impact upon river basin hydrology.

The surface water quality appears unaffected by the conversion in irrigation practices. Dissolved solids concentrations within the Salt River for the sprinkler period maintained quantities within 10% of the concentrations measured for the pre-sprinkler period. The results of the limited groundwater quality data indicate that TDS values are lower in sprinkler irrigated areas.

The observed impacts to the river basin hydrology are mainly due to canal evaporation, ET, phreatophytic consumption, unlined canal seepage, and changes to the aquifer system. Unlined canal evaporation estimates account for approximately 1.25 MCM/year (1,500 acre-ft/year) of the increased annual flow. Unlined canal seepage losses were estimated to be 50 MCM/year (40,000 acre-ft/year). The volume of water conserved through reduction in seepage can account for 80% of the increased flow in the Salt River. However, this estimate cannot be directly applied as true savings, because it is assumed that a large fraction but not all of the seepage water eventually returned to the Salt River later in the year. The water table appears to have decreased in sprinkler irrigated areas since 1971. Unlined canal evaporation and irrecoverable groundwater losses account for 2% and 65% respectively of the increased stream flow in the Salt River. Approximately 32% of the observed increased stream flow remains unaccounted for in this study. The unaccounted for water in the water balance may be due to conservative estimates and/or other mechanisms not quantified in this study including phreatophytic vegetation consumption, ET, and additional evaporation from soil surfaces.

Conclusions of this study are based on limited groundwater information. In the future, a more in depth study of the changes in groundwater hydrology is necessary. Lysimeters in the study area have been installed in the last five years, which should provide additional information on the impacts to the groundwater hydrology.

Water in the semi-arid western U.S. is a vital resource. In an attempt to conserve this valuable commodity, irrigation practices in the Star Valley in western Wyoming were converted from flood to sprinkler irrigation to improve application and conveyance efficiencies. The conversion from flood to sprinkler irrigation increased overall irrigation efficiencies and agricultural production, but other impacts to the river basin hydrology also occurred, including changes in groundwater storage, groundwater quality, and return flow timing.

Project Publications:

Venn, B. J., 2002. Hydrologic Impacts Due to Conversion from Flood to Sprinkler Irrigation Practices. MS Thesis. Dept. of Civil and Architectural Engineering, UW, Laramie, WY.

Venn, B. J., D. W. Johnson, and L. Pochop, 2004. "Hydrologic Impacts Due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices." Journal of Irrigation and Drainage Engineering, ASCE, Vol. 103, No. 3, May/June, pgs 192-200.

Student Support and Training:

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