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IM3 INTEGRATED MULTISECTOR MULTISCALE MODELING

For more information contact:
Stephen Ferencz
sbferen@sandia.gov

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Exploring Irrigation Return Flows and their Implications for Water Availability

Stephen B. Ferencz[1], Vincent C. Tidwell[1]
[1]Sandia National Laboratories, Albuquerque, New Mexico, USA

Motivation and Background:

Diverting flow from streams for irrigation is a large-scale, anthropogenic modification of surface water—groundwater (SW-GW) exchange.

Return flow is used to describe the additional groundwater discharge to a stream resulting from irrigation recharge. Return flows are especially relevant to surface water availability in agricultural regions that rely on streamflow from seasonal snowmelt to supply irrigation, such as the Western United States.

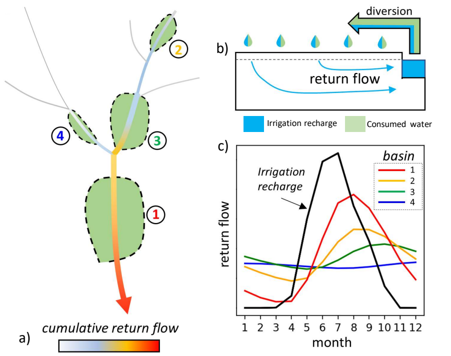
In snowmelt-dominated hydrologic regimes, diversions during the first half of the growing season (April-June) when flows are plentiful generate return flows that can supplement stream flow during the remainder of the growing season and also into the fall and winter after irrigation has ceased.

Because of the heightened importance of return flows providing supplemental flow in regions with highly variable annual streamflow, this study is designed around assessing return flows under conditions of seasonally variable streamflow, irrigation, and natural recharge, representative of a snowmelt hydrographic regime.

Local basin properties control timing and magnitude of return flows compared to the irrigation recharge signal (figures a, c)

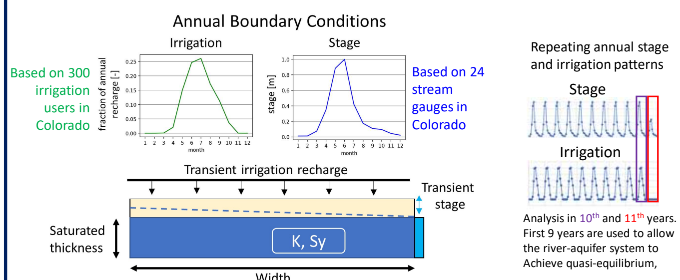
The amount of additional stream flow from irrigation returns can be substantial over a large basin, especially along high order stream segments that accumulate return flows from many upstream users (figure a).

To date, there has not been a sensitivity analysis to generalize return dynamics over a range of common conditions.



Simplified conceptual illustration of return flows at the local scale (b). Local return flows aggregate over basins and stream networks (a). Basin properties control the return flow timing (c).

Methods: Groundwater modeling of return flow dynamics



Groundwater modeling of surface water-groundwater exchange in hypothetical irrigated alluvial valleys using United States Geological Survey (USGS) MODFLOW 6 code. The modeling experiments varied alluvial aquifer dimensions (width and depth), aquifer hydraulic properties (K, Sy), and boundary conditions with transient recharge and stream stage.

Methods: Groundwater modeling scenarios

	Aquifer Width (m)	Initial Saturated Thickness (m)	K (m/d)	Sy (-)	River Stage (m)	Irrigation Recharge (cm/yr)	# of simulations
Group 1							
	500, 1000, 2000	10, 20, 30	3, 10, 30, 100	0.2, 0.3	1	20	72
Group 2							
	500, 1000, 2000	20	3, 10, 30, 100	0.3	0, 0.5, 1, 2	10, 20, 30	144

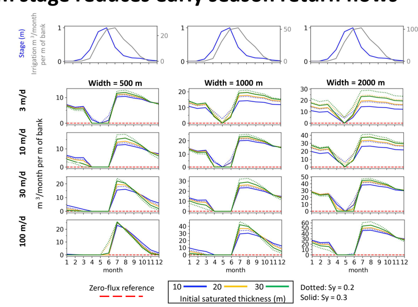
Aquifer dimensions (width, saturated thickness) and hydraulic properties (K, Sy) based on typical values for mountainous alluvial aquifers in the Upper Colorado Basin.

Group 1 Results: Stream stage reduces early season return flows

Additional groundwater discharge to stream during the 10th year.

Units are m³ per m of downstream length per month.

For context, over a 10 km Downstream distance, 20 m³/m of bank equates to 324 acre-feet of flow in a month!



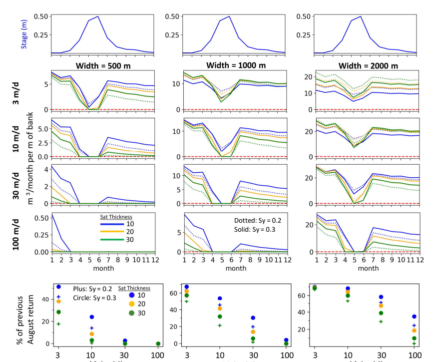
Return flows are suppressed or entirely absent for the April-June period during rising limb of the snowmelt hydrograph. During this period, the river stage counters the head gradient between the aquifer and river.

Group 1 Results: Return flows during hypothetical drought

Simulated drought:
11th year of simulation
Stage halved
No irrigation recharge

Return flows during drought year are from accumulated recharge from previous years.

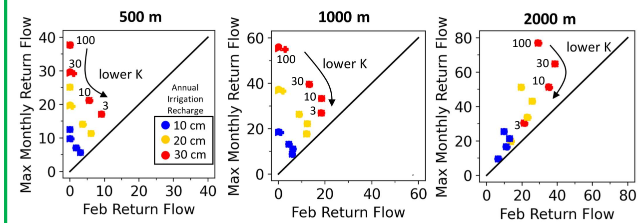
Wider and lower K aquifers provide more Buffering during drought.



Return flows during the critical late-summer low flow period shown as a percentage of the previous August's return flows. Narrower alluvial aquifers with higher Ks have less of a buffering capacity during a drought year when irrigation recharge is reduced or in the case of our extreme example, are entirely absent.

Group 2 Results: Seasonality and peak magnitude

Control of valley width, K, and irrigation recharge on return flow magnitude and variability

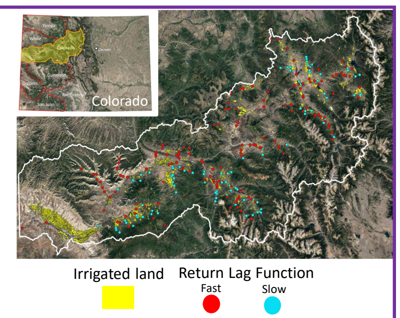


Each K and recharge combination has four stream stage scenarios (Group 2 in Table) represented by circle, cross, square, and triangle. In almost all cases, they plot on top of each other meaning that hydrograph amplitude did not affect max return flow or February baseflow.

From a water management perspective it is valuable to understand whether return flows tend to be highly seasonal or provide more consistent year-round supplemental flow to streams. February is selected to be representative of the long-term baseflow contribution from return flows as it is several months since irrigation has ceased and only two months before irrigation resumes. The 1:1 line provides a reference for how consistent return flows are annually.

Next steps:

- Evaluate the effect of irrigation efficiency and return flow parameterization for a large basin in Colorado.
- Generate unique return flow lag functions for each user based on proximity of irrigated land to streams and estimated aquifer K.
- Characterize user-level sensitivity to irrigation return flows.
- Explore implications of shifts in irrigation towards more efficient methods such as flood to sprinkler.



Only Two Return Flow Patterns Used In the StateMod Colorado Model

Key findings:

Stream stage fluctuations suppress return flows during the rising limb of the snowmelt hydrograph, suggesting that return flows in many Western US streams may be reduced during the spring snowmelt runoff period when water is plentiful and released during the receding limb of the snowmelt hydrograph.

Aquifers that have the capacity to accumulate and store irrigation recharge can provide supplemental return flow during years when irrigation recharge is reduced or even when it is absent.

Wider alluvial valleys with lower K sediments result in more attenuated return flows that provide more constant year-round baseflow.

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