Stream and Groundwater Exchange at a Large Fluvial Island

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INTRODUCTION AND OBJECTIVE

Channel bars are a common feature in fluvial river systems. The Truckee River has 321 bars over 192 km., which cover nearly 10% of the total river surface area and more than double the stream length.

Channel bars induce near stream exchange through: streambed topography, streambed obstructions, position in fluvial plain, hydraulic conductivity magnitude and distribution, velocity distribution in the stream channel, and stage relative to groundwater level.

To date, there has been limited quantitative investigation of flow and transport through channel bar systems. The objective of this investigation was to quantify GW/SW flux differences between a channel bar, streambed, and streambank. In addition, temporal water level and heat transport dynamics were investigated to assess the effect of channel bars on long-term GW/SW exchange.

STUDY AREA

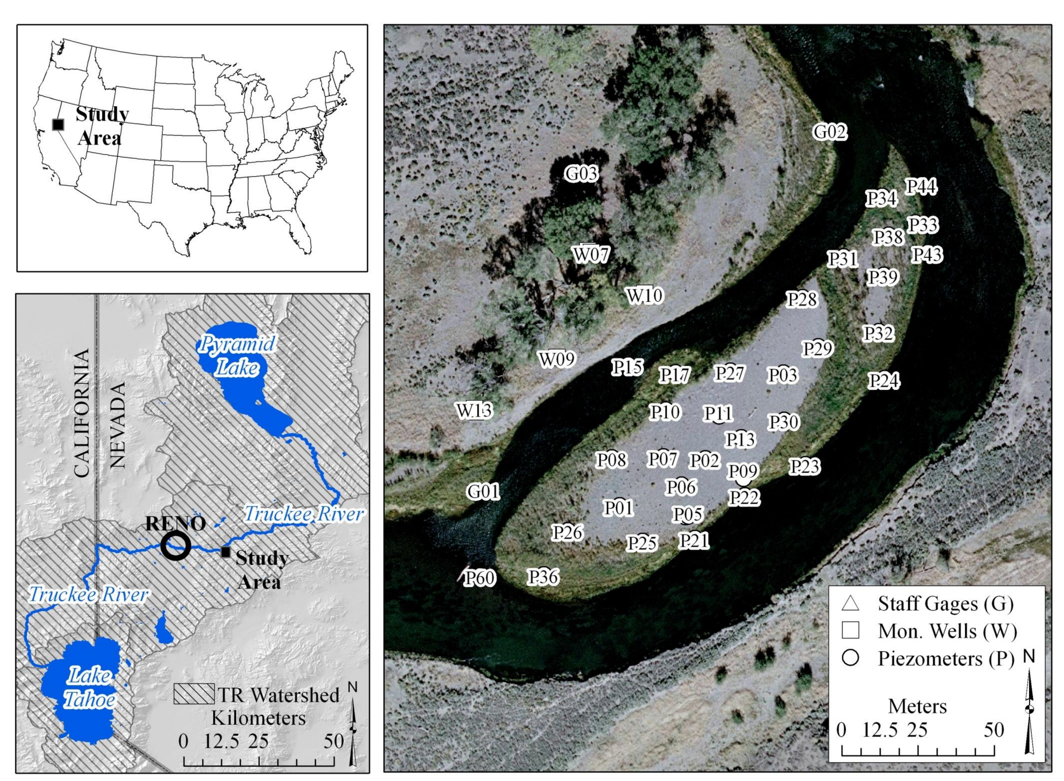

Fig. 1 – The study location is 27 km east of Reno, NV (39.5469, -119.5585). Piezometer, monitoring well, and staff gage locations provided. Streamflow is from lower left to upper right.

- •Average discharge 12.5 $m^3 s^{-1}$.
- •Average air temperature 10.4 C.
- •Average precipitation 178 mm yr^{-1}.
- •6th order generally losing stream.
- •Average streambed gradient 0.185%.
- •Mixed cobble, gravel, and sand.
- •200 m × 60 m × 1.2 m average channel bar dimensions (Fig. 1).
- •Stage difference across bar 0.7 m.
- •30% Cottonwood, Willow, and Alder surrounding bar.

METHODS AND EQUIPMENT

- •51 piezometers and wells installed and monitored between 2003 and 2009.
- •Multiple slug tests with variable volume injections analyzed by the Bouwer and Rice methodology.
- •In-stream discharge monitored with velocity/area method and ADCP cross sections at 28 locations between 2003 and 2009. Verified by USGS gage.
- •Precipitation and other micrometeorological measurements collected nearby in Fallon, NV.
- • Temperature corrected I-Button temperature dataloggers at 30- or 60-min intervals.
- •Water levels/stage monitored with MicroDiver pressure transducers at 30- or 60-min intervals. Verified with manual measurements.
- •Using heat as a tracer to quantify groundwater/surface water exchange.

ANALYSES

1D Vertical Flux Estimates

- •Vertical hydraulic conductivity assumed constant in time and space and10% of horizontal conductivity.
- •Vertical hydraulic gradient (VHG) used to estimate vertical seepage velocity with Darcy's Law.
- •Typically, downward flux at head, of channel bar and upward flux at tail (Fig. 2).
- •Temporally variable flux based on seasonal and event-based antecedent moisture conditions and hydraulic gradient.

ANALYSES

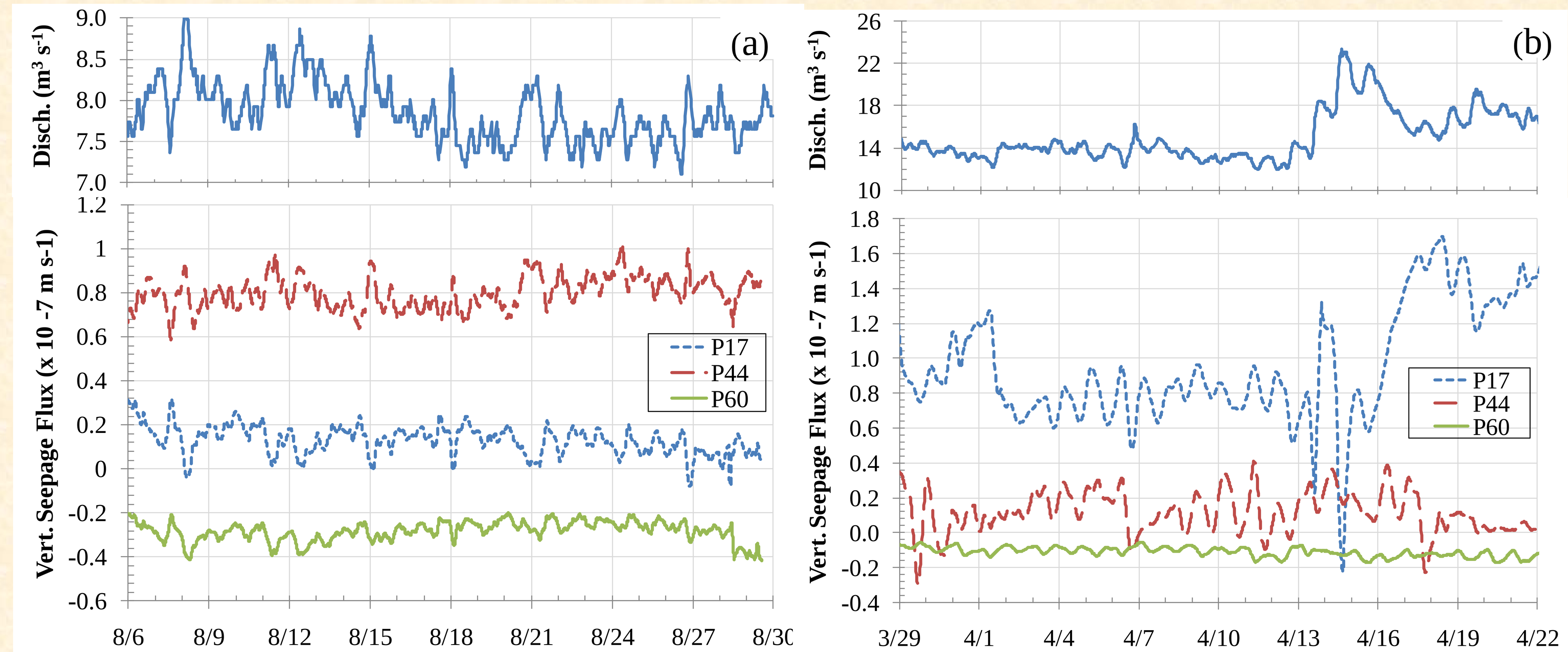

Fig. 2 – Vertical-flux time series at three streambed locations during (a) August 2007 and (b) April 2008. Positive values indicate upward flux and negative values indicate downward flux. Discharge measured at USGS gage 10350340. P60, P17, and P44 are located at the head, middle, and tail of the channel bar, respectively.

2D Horizontal Flux Estimates

- •Interpolated for 15 periods between 2005 and 2007 at 149 locations throughout the channel bar.
- •Horizontal hydraulic gradient coupled with field-based hydraulic conductivity to estimate horizontal seepage fluxes (Fig. 3).
- •Highest fluxes near channel bar/ streambed interface.
- •Median channel bar flux was an order of magnitude less than the channel bar/ streambed interface.

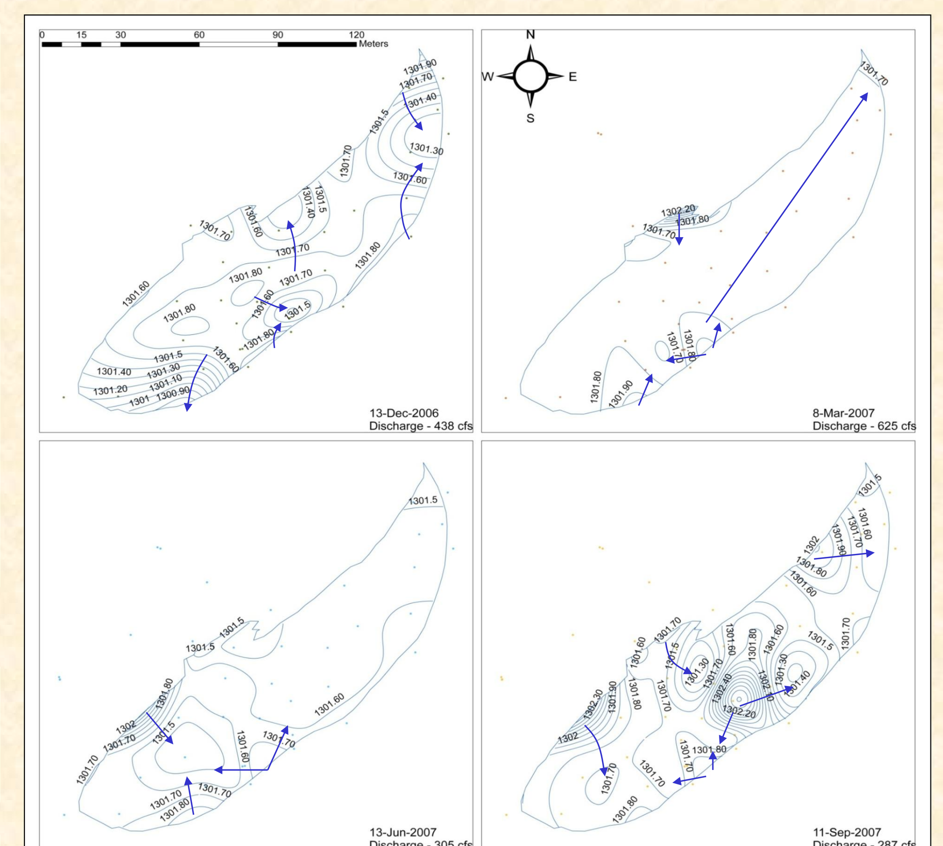

Fig. 3 –Channel bar potentiometric surface and horizontal flux transects. Potentiometric surface variability through four periods. Surface flow is from lower left to upper right

3D Simulated Flux Estimates

- •Correlate ambient air temperature with ground surface temperature (GST).
- •ET assumed minimal in February and no precipitation during the study or 10 days prior.
- •1D vertical heat diffusion equation to project GST time-series to water table as a function of vadose zone depth , time, and water content.
- •Van-Genuchten soil water content –pressure head model.
- •MODFLOW/MT3DMS used to numerically simulate 3D fluid flow and heat transport in saturated media. Fluid flow and temperature boundaries (Fig. 4).
- •Assumed fully decoupled temperature and density dependant fluid flow.
- •Inversely estimated K between simulated and observed head and temperature differences.
- •Head and temperature model fit quantified by spatial and temporal RMSE.

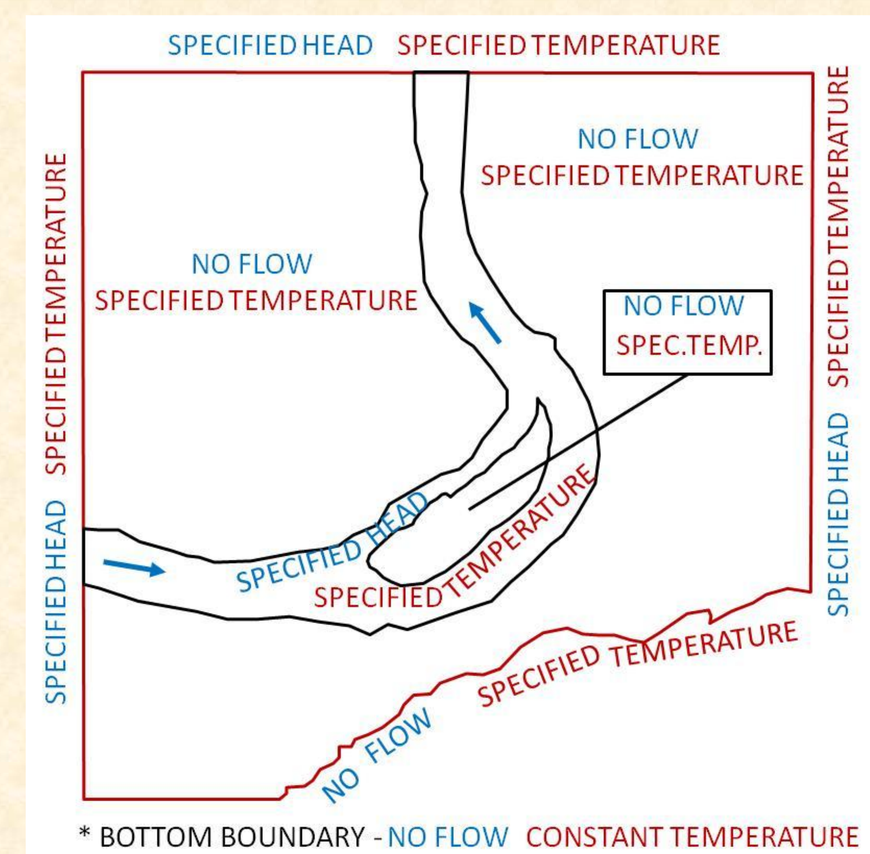

Fig4– Fluid flow boundary conditions (blue) and temperature boundary conditions (red) for the 3D simulated domain. Streamflow direction, as indicated by the arrows, is from lower left to the top of domain.

RESULTS AND DISCUSSION

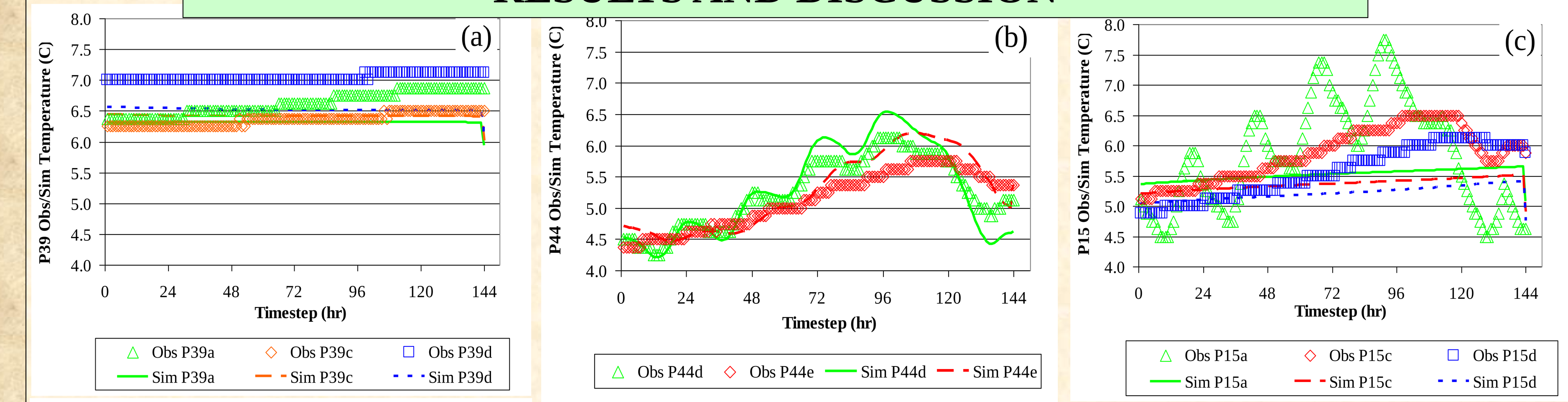

Fig. 5– (a) example channel bar thermograph (P39) located at the downstream end of the channel bar. Example streambed thermographs for piezometers (b) P44 near the downstream end of the channel bar and (c) P15 in a pool below a series of riffle pool sequences in the western channel.

- •Reasonable 3D simulations. Channel bar and streambed simulated values typically within 5% of observations.
- •Flux and hydraulic conductivity from 3D simulations agree well with field based methods (Table 1).

Table 1 – Comparison of the median hydraulic conductivity and seepage flux for vertical 1D, horizontal 2D, and numerically-simulated 3D).

1D Vertical Field-Based Seepage Flux Summary ($m s^{-1}$)

	Hydraulic Conductivity[a] ($m s^{-1}$)			Seepage Flux Lateral ($m s^{-1}$)		Seepage Flux Vertical ($m s^{-1}$)	
Location	Lateral		Vertical	Median	Range	Median	Range
entire streambed	-	-	2.23E-06	-	-	2.40E-07	8.70E-08 to 1.10E-06

2D Horizontal Field-Based Seepage Flux Summary ($m s^{-1}$)

	Hydraulic Conductivity[b] ($m s^{-1}$)			Seepage Flux Lateral ($m s^{-1}$)		Seepage Flux Vertical ($m s^{-1}$)	
Location	Lateral	Range	Vertical	Median	Range	Median	Range
Streambed	-	-	-	-	-	-	-
Channel bar edges	5.29E-05	3.18E-06 to 2.15E-04	-	1.24E-06	1.10E-07 to 8.80E-06	-	-
Channel bar central	4.24E-05	3.53E-07 to 5.29E-05	-	3.84E-07	4.55E-09 to 1.14E-06	-	-
Stream bank	-	-	-	-	-	-	-

3D Numerical Model Seepage Flux Summary (m s-1)

	Hydraulic Conductivity ($m s^{-1}$)			Seepage Flux Lateral[e] ($m s^{-1}$)		Seepage Flux Vertical[e] ($m s^{-1}$)	
Location	Lateral[c]		Vertical[d]	Median	Range	Median	Range
Streambed	5.68E-04	-	1.70E-04	1.42E-07	3.13E-08 to 2.78E-06	8.28E-07	1.09E-07 to 2.78E-06
Channel bar edges	6.48E-05	-	1.94E-05	9.87E-07	5.79E-07 to 1.85E-06	3.23E-09	2.20E-09 to 3.47E-08
Channel bar central	6.48E-05	-	1.94E-05	5.68E-07	2.78E-07 to 1.85E-06	2.46E-09	2.20E-09 to 3.47E-08
Stream bank	3.36E-06	-	1.01E-06	1.50E-07	3.13E-08 to 1.27E-06	1.95E-10	1.19E-13 to 4.28E-09

[a] vertical 1D hydraulic conductivity calculated as 10% of slug test geometric mean (2.23x10-5 m s-1)
[b] lateral 2D hydraulic conductivity estimated as the nearest neighbor slug test value
[c] 3D lateral hydraulic conductivity value inversely optimized from both global head and temperature measurements
[d] 3D vertical hydraulic conductivity value estimated as 30% of optimized horizontal hydraulic conductivity
[e] 3D seepage flux calculations represent net flux magnitude summed along boundary of interest

CONCLUSIONS

- •Optimized 3D hydraulic conductivity estimates similar to field-based values (Table 1).
- •Simulation results suggests that the channel bar increases fluxes six times, predominately near the edges.
- •Comparison of vertical and 3D results suggests that multi-dimensional flow patterns dominate.
- •Temporal vertical flux response suggests seasonal and event-based storage are important to flow patterns.
- •Channel bars are an important contributor to groundwater/surface water exchange, potentially impacting several hundred cubic meters of water per day.

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