How Much Does Stream-Groundwater Exchange Influence Whole-Stream Metabolism in a Small Mountain Stream?

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Abstract

To estimate whole-stream metabolism, the open-channel oxygen method has traditionally provided underlying assumptions for modeled estimates of gross primary productivity (GPP) and ecosystem respiration (ER). The open-channel oxygen method employs the diel dissolved oxygen (DO) curve, which attributes stream metabolism to four processes: photosynthesis by primary producers, oxidative respiration, reaeration, and groundwater flux. Of these processes, groundwater flux is often assumed to be negligible when modeling whole-stream metabolism, which may introduce bias in estimates of GPP and ER. For example, if net groundwater flux is into the main channel, we may expect an overestimation of modeled ER due to dissolved oxygen dilution effects from influent groundwater. Although this error is recognized, there is a lack of continuous and spatial data that quantifies the extent of bias that is introduced by not including groundwater flux in model parameters. To investigate this bias, we measured whole-stream metabolism and groundwater flux in Como Creek, a headwater catchment 26 km west of Boulder, CO. DO sensors were deployed in the stream and groundwater wells in June 2018 at 3 sites along 500 m of the reach. BASE (Bayesian Single-station Estimation), a package available through R, was used for modeling whole-stream metabolism between peak streamflow and baseflow. BASE also optimizes the reaeration coefficient, which was estimated both including and neglecting groundwater discharge and DO concentration. Preliminary results indicate that Como Creek has a net groundwater flux out of the stream, resulting in higher rates of GPP in the groundwater-corrected model output, and indicating the potential for bias in uncorrected models.

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1 Introduction

1.1 Background

- The open-channel oxygen method is used to estimate whole-stream metabolism [1].
- Change in concentration by: photosynthetic primary producers, organism respiration, atmospheric oxygen exchange, and influent groundwater [2] **(Fig 1)**.
- Groundwater assumed negligible in many models; introduces bias to metabolism estimates.
- If stream gains anoxic groundwater, ER and GPP expected to be higher and lower, respectively, in uncorrected model estimates because model will address change through metabolism, and not flux (*H1*).

1.2 Question

- What is the relationship between model bias and groundwater flux?
- Greater bias = greater influence on biogeochemical processes.

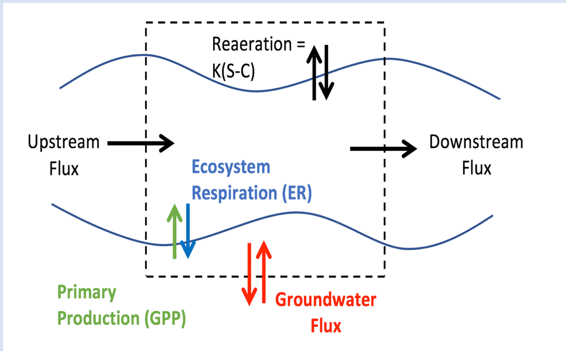


Fig 1. Dissolved oxygen mass balance, adapted from Hall and Tank (2005).

2 Study Site

- Como Creek, ~ 26 km west of Boulder, Colorado.
- Alpine stream affiliated with Boulder Creek Critical Zone Observatory (CZO) and CU Mountain Research Station.
- Watershed area is 6.64 km^2; maximum elevation is 3560 m.
- Three transects installed along 300 m.
- Main channel instrumentation and groundwater wells installed.
- Deployment period from June 25th, 2018 - September 4th, 2018.

Fig 2. Groundwater wells were installed at each transect.

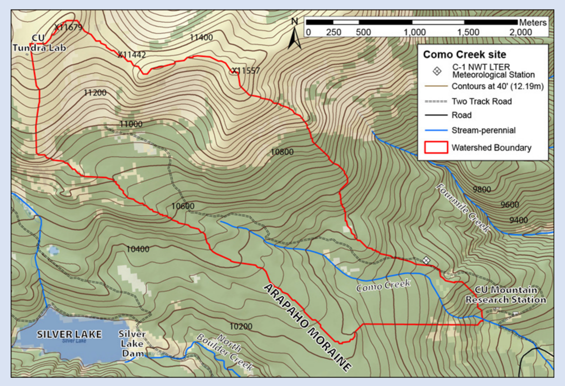


Fig 3. Map of Como Creek Watershed. *Source:* Boulder Creek CZO [3]

Fig 4. Como Creek during baseflow facing upstream.

3 Methods

- Continuous measurements of:
  - •Temperature
  - •Electrical Conductivity
  - •Dissolved Oxygen
  - •Stage and Pressure
  - •Photosynthetic Active Radiation
- Groundwater Flux through rating curve from conservative tracer injections.
- Input parameters into BASE (Bayesian Single-Station Estimation) model [4]; runs with and without groundwater flux.

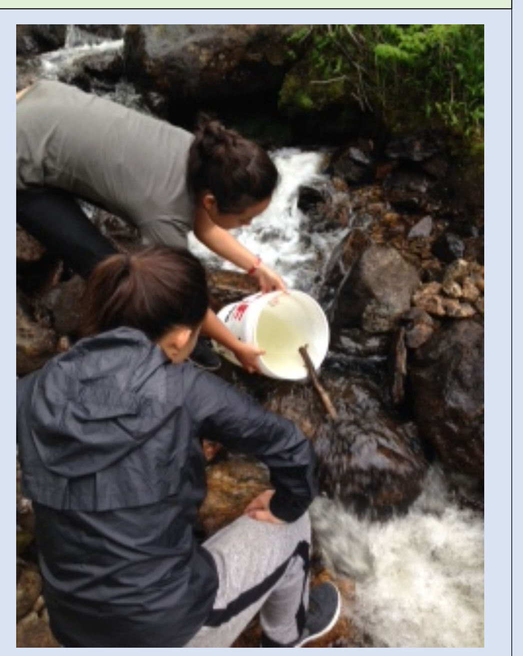


Fig 5. Students injecting conservative salt tracer for discharge computation.

Uncorrected Mass Balance:

$$C = C_0 + \left[\frac{M}{z} + k(S - C)\right]\Delta t$$

Groundwater-Corrected Mass Balance:

$$C = C_0 + \left[\frac{C_g Q_g}{Az} - \frac{Q_g C}{Az} + \frac{M}{z} + k(S - C)\right]\Delta t$$

4 Results

4.1 BASE Model Sensitivity

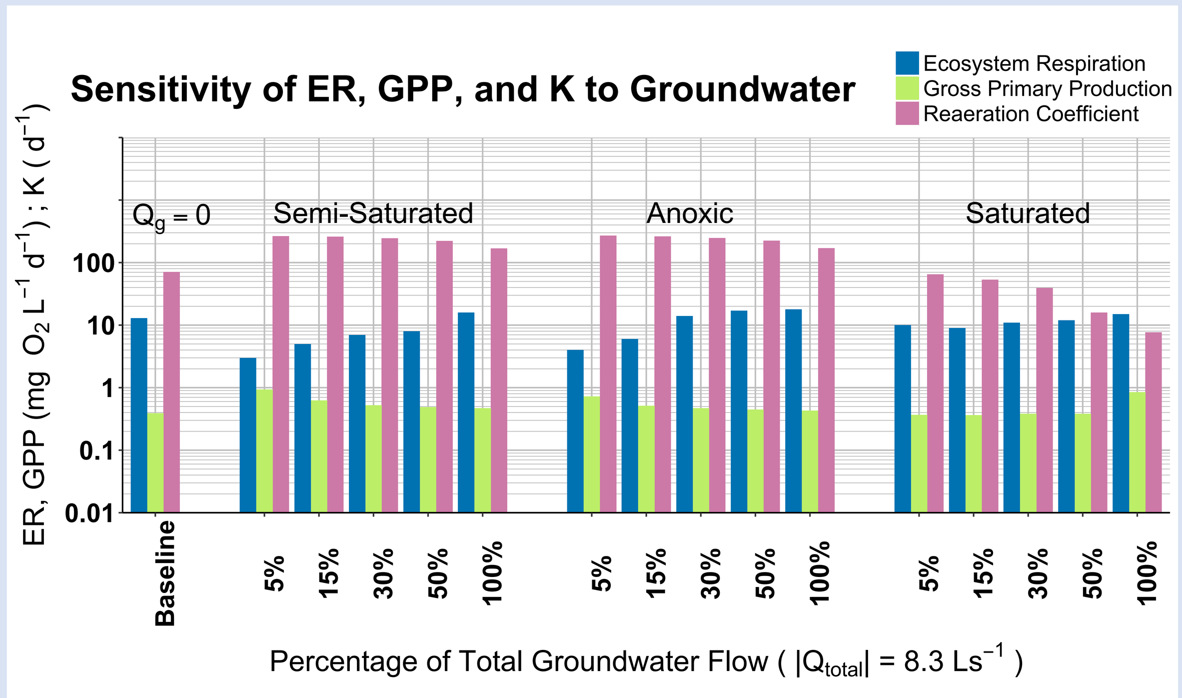


Fig 6. Model sensitivity to groundwater inflow. Semi-saturated and saturated concentrations input as 4 mg/L and ~8 mg/L. Reaeration responds to anoxic conditions by increasing DO concentrations through the reaeration coefficient.

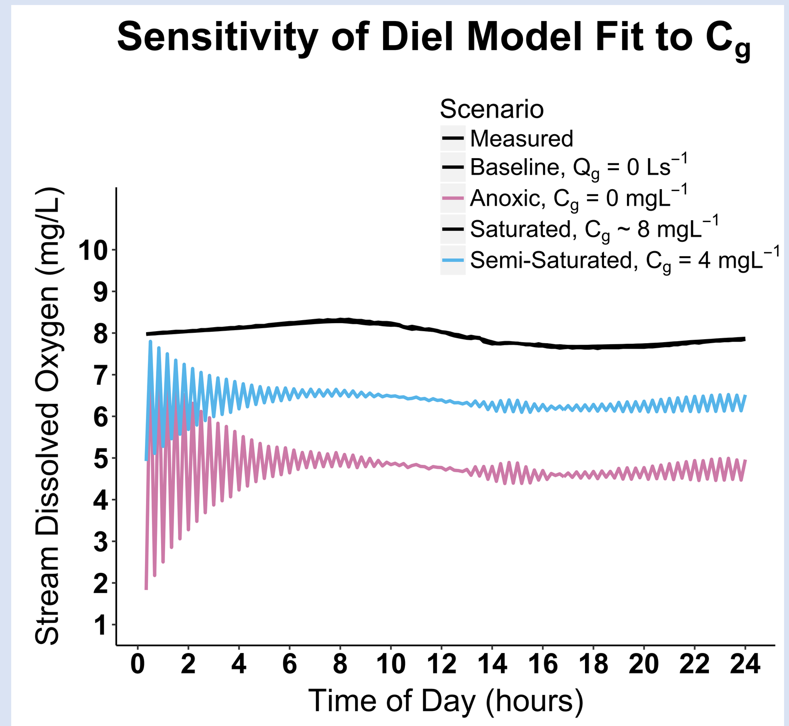


Figure 7. Data modelled for diel fit on 8/10/18. Measured, baseline, and saturated conditions do not vary significantly, while lower concentrations introduce noise from reaeration optimization.

4.2 Environmental Parameters During Deployment

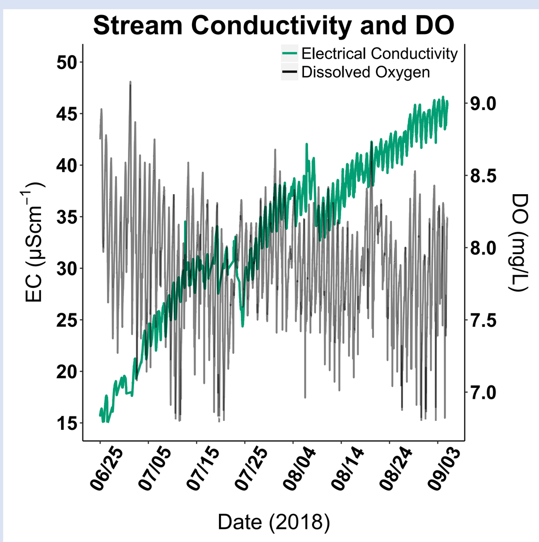


Fig 8. Stream conductivity and discharge increase and decrease with time, respectively.

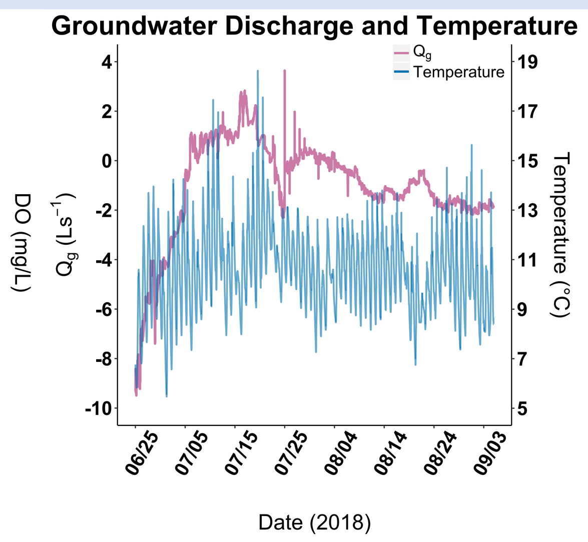


Fig 9. Calculated groundwater discharge through flow balance plotted with temperature.

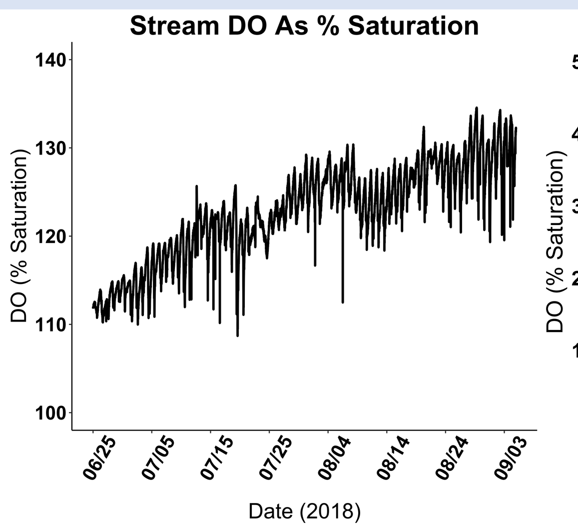


Fig 10. The reach is oversaturated with DO, making the reaeration term negative, with flux out of the stream.

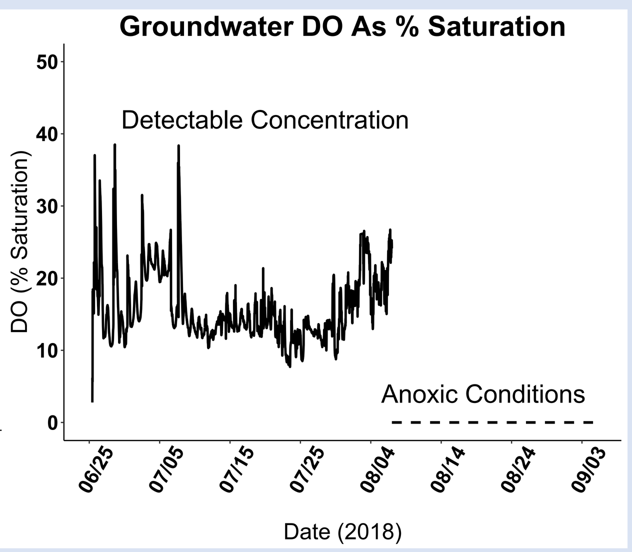
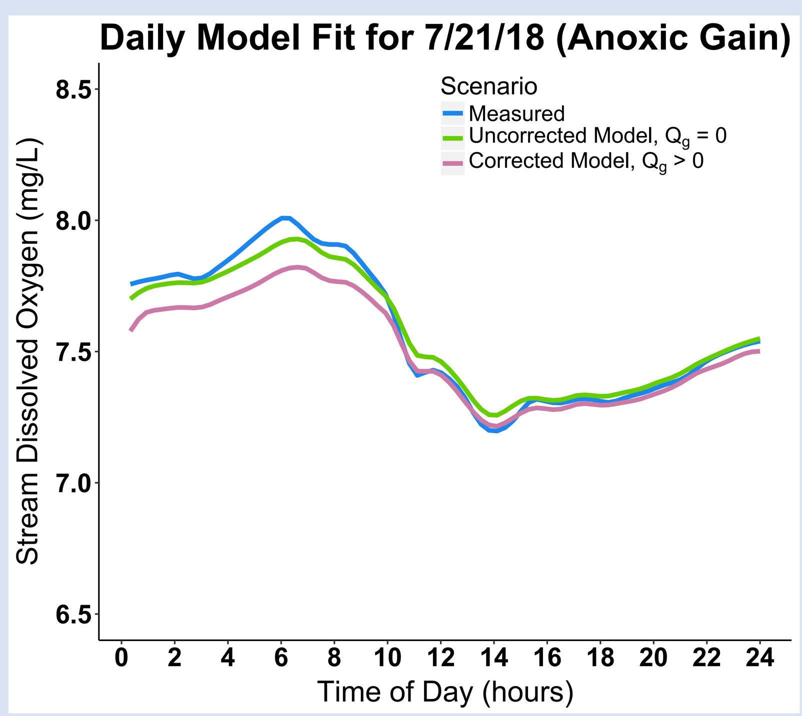
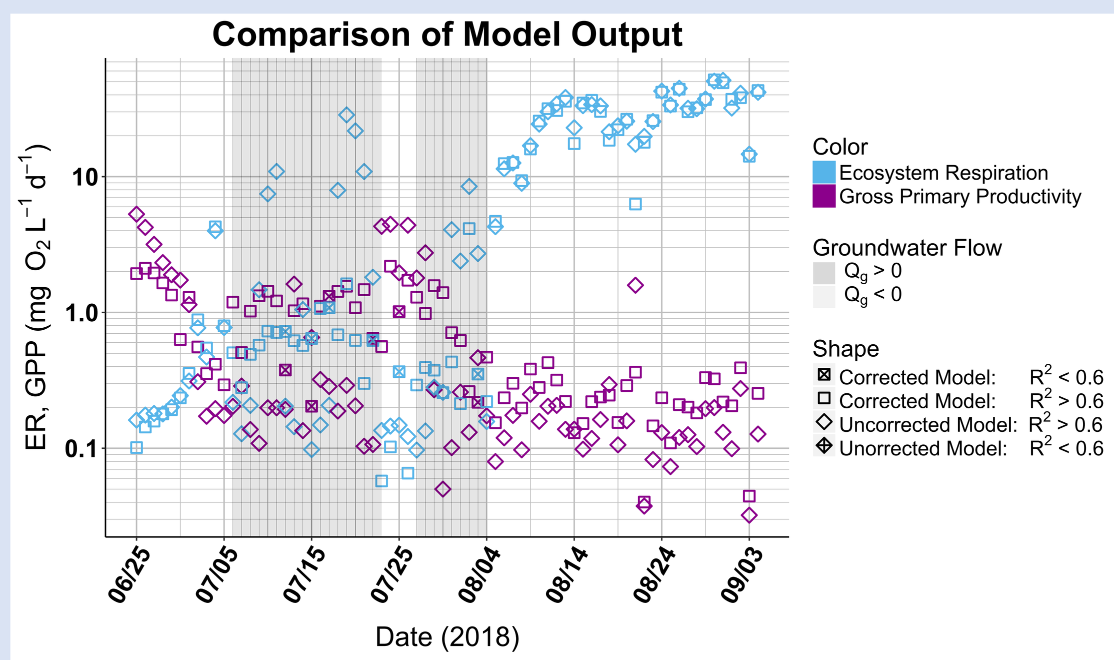
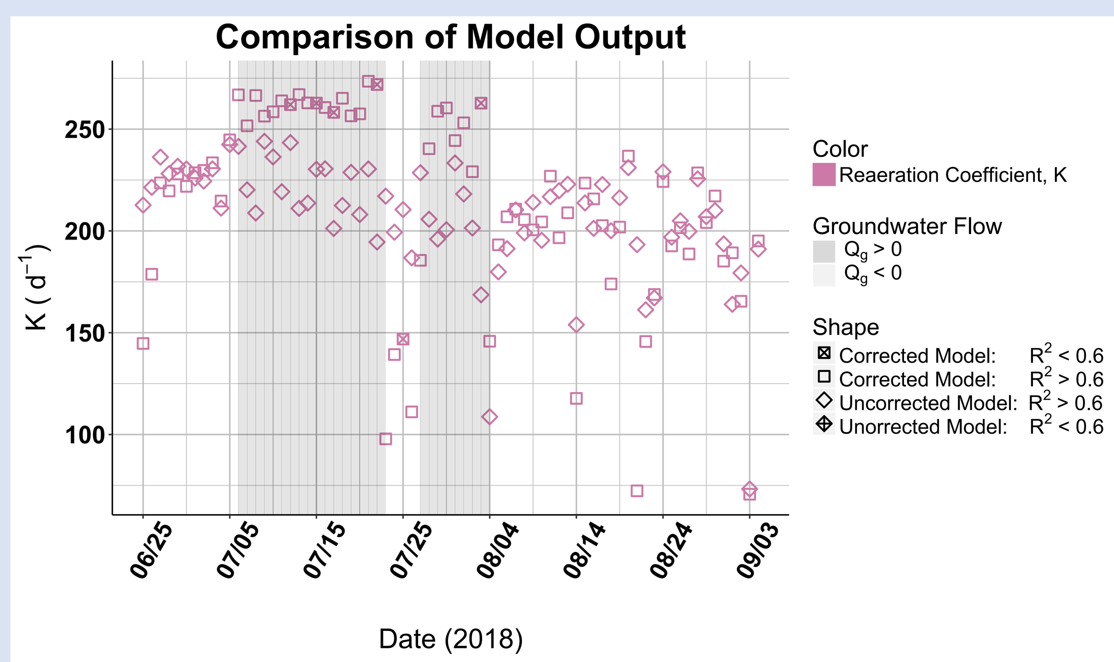


Fig 11. Groundwater concentrations are undersaturated, with anoxic conditions late in deployment.

4.3 Total Model Results







From top left to bottom right: **Figures 12-14** show model results for entire period of deployment. **Fig 12.** Diel model fit for groundwater influx of average concentration equal to 0.85 mg/L. Smoothing function applied to all cases, with uncorrected model fit yielding an R^2 value of 0.97. Fit improves during the day when GPP is accounted for. **Fig 13.** Shaded region indicates groundwater with lower concentration entering the stream. ER for the uncorrected model is higher than the baseline at this time, providing evidence for overestimation of ER when failing to account for hyporheic exchange. **Fig 14.** When groundwater flux is positive, reaeration increases from the baseline, with a decreasing seasonal trend as discharge decreases and a net loss is observed in the stream.

5 Discussion

5.1 Night Versus Day

- Bias defined as: $\frac{ER, GPP, K_{uncorrected}}{ER, GPP, K_{corrected}}$
- Greater bias observed at night **(Fig 12)** when GPP is negligible.
- If groundwater is anoxic, ER and K must either decrease or increase, respectively, to observe same concentration in stream.
- If prior is not defined, and K is limited, modelled GPP will instead increase rapidly, so that daytime model fit increases from low nightly concentrations.

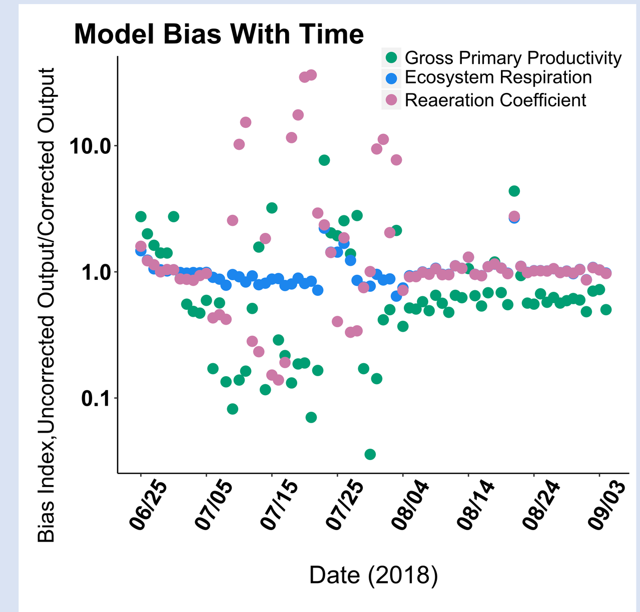


Fig 15. BASE model is sensitive to priors initiated, with reaeration increasing to offset anoxic inflows.

5.2 Groundwater Flux

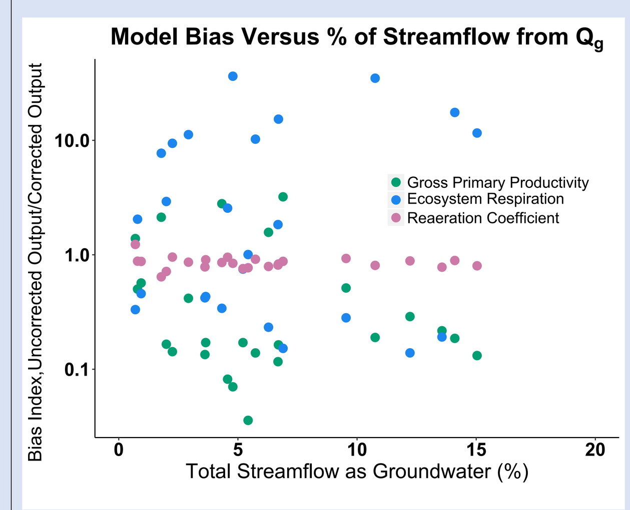


Fig 16. As source water transitions to baseflow, greater bias is observed for GPP and ER, with uncorrected modelled rates of GPP and ER less than and greater than corrected modelled rates, respectively.

- When gaining groundwater, the model is more sensitive to concentration, which is then amplified by discharge **(Fig 6)**.
- Model may fail in the heterogeneity of the timing and location of this input, while model assumes even mixing and distribution.
- As higher proportions of groundwater make up the main channel, GPP underestimated and ER overestimated due to metabolic compensation of dilution.

6 Conclusions

- Bias increases with decreasing concentration faster than discharge, even though both parameters affect model performance.
- Reaeration becomes important when anoxic groundwater is introduced because it compensates for nighttime conditions when GPP is assumed to be equal to zero.
- Groundwater should not be negligible in model development, as rates of ER and GPP decrease and increase, respectively with anoxic dilution.

7 References

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