

Sensors are cheap, but metabolism is still hard: the Promise and Pitfalls of Measuring River Metabolism

By: The StreamPULSE team

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So you found a DO dataset or you are about to collect one and you'd like to calculate metabolism?

A bit of time thinking carefully about your stream or river you are studying before you begin may save you a lot of wasted effort.

If you have data from a single point, you will have to use a 1-station model. This is what StreamMetabolizer is built to do.

In this case, StreamMetabolizer will do a great job for you as long as your site and your data meet the following model assumptions. If they don't (or if you don't know) you might rescue the situation if there are data from two stations. If not, this is not going to be an option for you. Two station metabolism requires a different computational approach and is more difficult than one-station because probes need to be intercalibrated closely and distances between sondes need be neither too long or too short ($0.7 \cdot V/K$ is the sweet spot).

Assumptions:

(1) Flow is unidirectional (if your river is tidal - this is not the right model for you)

A principal assumption of the single station model is that you are considering oxygen changes on a diel basis that occur due to net biological processes and variation in temperature. Tidal rivers can have distinct water bodies with different physical properties that pass over the sensor at varying time intervals. This complication can make it difficult to distinguish changes in oxygen occurring due to biological processes versus those occurring to the differential expression of water masses moving past the sensor. In effect, your sensor is measuring a reach that is not well mixed (assumption 2) and has non-homogenous GPP, ER, K (assumption 3).

(2) Your river is well mixed, both laterally and with depth.

If your river is slow and occasionally stratifies, the oxygen will remain in this stratified layer and may not flow past the sensor. Or if your sensor is in this layer mean river depth will decline throughout the day to that of the stratified layer. Find a new river because this situation will require data and physical modeling approaches way beyond that of streamMetabolizer.

(3) Rates of GPP, ER and K are distributed homogeneously throughout your reach

Really large discontinuities within your reach (e.g., Niagara Falls, a hydroelectric dam, major tributaries, large wastewater point sources) are going to severely violate this assumption (Reichert et al. 2009, Demars et al. 2015). Experimental reaches (say a nutrient addition or fish exclusion) by definition are discontinuities and therefore need to be really long or you need a two station approach

Small discontinuities, that occur regularly throughout your reach (e.g. riffle - pool sequences, debris dams, a series of rapids) are far less problematic because they occur a spatial scale much smaller than the O₂ turnover distance.. The key is that they are occurring multiple times within your reach length.

Okay great, but how long is the reach in which you are measuring metabolism?

You need to think really carefully about the 'footprint' over which you are making inferences. A rule of thumb is that your measurement 'reach' length = $3v / K_{O_2}$ where v is velocity ($m\ min^{-1}$) and K_{O_2} is the rate of O₂ exchange between the water column and the atmosphere (min^{-1}). This distance is the length of river required for 95% turnover of dissolved O₂.

Of course if you have no measure of K for your reach (which most people don't) this advice doesn't help very much. So what can you do?

→ use the empirical model of Raymond et al. (2012) to get a first guess at K (note their model predicts gas exchange velocity ($k\ m/d$), so you will need to divide by estimated mean depth to estimate K ($1/d$))

→ Conduct a gas tracer test (Wanninkhof et al. 1990, Marzolf et al. 1994) and estimate an empirical estimate of gas exchange

(remember that this may only be a good estimate for the Q of the day you make the measurement)

(4) The oxygen sources in the reach derive from only atmosphere and photosynthesis and the water only from upstream.

The model relies on detecting the difference between measured O₂ concentrations and the O₂ concentration that would be predicted at equilibrium (in the absence of biological activity). If you have O₂ depletion imported from outside the reach, this assumption is violated.

This will be particularly problematic for:

- reaches that have significant inputs of undersaturated deep groundwater (this will inflate your estimates of ER). The degree of bias is easily calculated, but the correction is difficult because groundwater O₂ concentrations are difficult to measure. (Hall and Tank 2005)
- reaches with some other source of strongly undersaturated water source contributing more than 5% of the water delivered to the channel within your reach (e.g water

upstream reservoir or wastewater). This problem is linked to the homogeneity assumption above.

(5) Physical and biological attributes of the reach allow estimating both metabolism and gas exchange

There are several phenomena that make it difficult to detect instream metabolic activity that do not actually violate any of the model assumptions above. The model has a detection limit for rates of GPP, ER, and K, when signal strength (diel O₂ amplitude) is low or gas exchange rates are so high the signal is hard to detect. A combination of high K and low GPP is thus extremely difficult for the model to accurately estimate parameters (Appling et al. in prep). If you have a combination of high K or low GPP, you may be able to overcome this challenge (and lower your model detection threshold) by getting empirical estimates of K using gas tracers (Wanninkhof et al. 1990, Marzolf et al. 1994). These estimates can then serve as prior probabilities for K in streamMetabolizer (Holtgrieve et al. 2015).

We do not have a magic formula for K and GPP needed to estimate metabolism well, because process error (i.e. the error caused by the O₂ in stream metabolizer not capturing all the processes that control variation in streams) can strongly lower your ability to measure metabolism and this error will vary from stream to stream.

In general high gas exchange rates makes estimating metabolism very difficult because the O₂ signal to noise ratio approaches zero, so we recommend that you not install sensors on steep sloped streams or in whitewater (K > 100/d is very difficult). A further complication of steep streams is that they will be oversaturated due to bubble mediated gas exchange thus rendering ER inestimable by using diel O₂ models (Hall et al. 2015).

Still think it's a good idea to move ahead?

Great, now here are some other things to be careful about. Do these right and you will maximize your ability to derive solid metabolism estimates. Do them poorly and you could introduce significant bias or error into your data and models.

- (1) You really need to calibrate your sensors well, especially if you care about ER. Small but continuous errors add up to big biases in your aggregate estimates of metabolic activity. Ideally sensors are calibrated within 2% of accuracy. We use bubbling buckets of air-saturated water to calibrate sensors. Be aware that these can increase the saturation concentration slightly (2%) due to unequal exchange between bubbles and the water. Air calibrations can work well if held in a constant temperature for long enough that the air inside the sensor and the temperature are exactly the same. Some sensors, e.g. PME, come precalibrated. Our experience is that these sensors are close to calibration, but you should check them anyway with a bubbling bucket and airstone. See PME website.

- (2) Your sensor needs to be installed in a well mixed part of your channel but not so energetic that it beats up the sensor. If the stream is really energetic, then you will need to bolt the sensor housing to something solid.
- (3) Your per m² rates will only be as good as your ability to estimate the average reach depth. We recommend salt tracer tests over a range of discharges to estimate velocity and then solve for depth using the continuity equation ($Q = \text{width} * \text{velocity} * \text{depth}$) so that you have depth at every v. That means you need accurate Q, velocity and width for the stream, We recommend at least 20 wetted-width cross sections to provide estimates of width. If you are estimating a time series of metabolism, you will need to estimate Q, width, velocity, and thus depth across a range of Q to generate a rating curve of these parameters.

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