CONTAM 02 Observations in Rivers and Urban Streams: San Joaquin River Mixing Dynamics and Mass Balances

CONTAM 02.1 People

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CONTAM 02.2 Overview

In streams and rivers, primary production and community respiration are important determinants of ecosystem biomass and trophic structure as well as important drivers of nutrient cycling and other ecosystem processes. Metabolism in streams and rivers typically varies longitudinally from upstream to downstream, but less research has addressed metabolism variation at higher spatial resolution. Past reports have summarized the results from high resolution characterization efforts on the San Joaquin and Merced Rivers in Central California. The main goal of this project over the past year was to continue to develop this multiscale sensing and modeling approach in the context of understanding metabolism (primary production and community respiration) in complex river systems. Specific objectives include:

- Characterize the spatial variation of primary production and respiration in complex hydrodynamic regimes, such as a river confluence
- Developing and testing an inexpensive, easily deployed groundwater-surface water monitoring device (temperature javelins)
- To utilize high resolution river data to calibrate and provide initial data for a 2-D hydrodynamic model

CONTAM 02.3 Approach

A combination of computational and experimental approaches was employed. To quantify primary production and respiration (PP/R), repeated NIMS RD-actuated dissolved oxygen (DO) scans of the San Joaquin-Merced River confluence zone were decomposed to yield local DO histories at multiple locations in a cross-section. These time series were modeled to yield spatially distributed PP/R estimates. Next, an inexpensive groundwater-surface water sensor system (temperature javelin) was designed to provide vertical temperature profiles in river sediments, and a simple heat transfer model was used to translate these profiles into groundwater-surface water discharge rates. Finally, a two-dimensional hydrodynamic model was parameterized and used to simulate the hydrodynamics in the mixing zone using NIMS RD-facilitated velocity profiles to parameterize the boundary conditions.

CONTAM 02.4 System Description

**High Resolution Metabolism Estimates.** DO levels in a river with no groundwater inputs and clear sky conditions vary on a diel cycle as a combination of (1) the release of oxygen during photosynthesis by both benthic organisms and phytoplankton, (2) the uptake of oxygen as a result of autotrophic and heterotrophic respiration, and (3) the exchange of oxygen between the water and the atmosphere:

\[ Q = P - R + D \]

where, \( Q \) is the rate of change of DO, \( P \) is the rate of Gross Primary Productivity (GPP), \( R \) is Community Respiration (\( CR_{\text{a}} \)), and \( D \) is the diffusion rate, all of them expressed in units of mass per unit area, per unit time.
The open-system oxygen change approach is one of the methods used to estimate GPP and CR_{24} and it is usually preferred as it appears to be more accurate at determining the rate of stream metabolism since it accounts for the spatial heterogeneity in the system (including all components of the benthic, water column, and hyporheic communities). Field measurements lead to the calculation of GPP as:

\[
GPP = PR + NOL
\]

\[
NDM = GPP - CR_{24}
\]

In these equations, the parameters directly measurable by the gas change procedure are the net oxygen change in the light (NOL) being a balance of photosynthesis and respiration, and the respiration in the dark (CR) being a combination of autotrophic and heterotrophic respiration, \( R_a \) and \( R_h \), respectively. The latter, CR, calculated as the average nighttime respiration rate is then extrapolated through the daily hours to generate estimates of photoperiod respiration (PR) and total daily respiration (CR_{24}). NDM, the net daily metabolism, is the net O_2 change per day resulting from biological activity.

Within a low-gradient river confluence, where riparian effects are assumed to be negligible, spatial and temporal gradients were expected to be found according to the physicochemical characteristics of each confluent river and the transient conditions of the incoming flows. To investigate the cross-sectional variability of river metabolism at the confluence of the Merced and San Joaquin rivers, a multi-day experiment involving 30 cross-sectional runs using the NIMS-RD technology were developed, each one mapping distributed stream flow and water quality properties (temperature, pH, LDO, and Specific Conductivity). The whole-stream, one-station approach was selected to calculate river metabolism. In this method DO values from subsequent time stamps are used to calculate the rate of change of DO. A spline interpolation technique was used to obtain 1-min daily DO and temperature data both from the actual sampling points and from the averaged DO values for the Merced, mixing, and San Joaquin zones of the cross section (see Figures 1 and 2).

The reaeration-corrected rate of change of DO was calculated using the mass transfer coefficient \( f \) (cm/h), according to the surface renewal model (SRM) by means of the following equations, where \( V \) is the average water velocity (cm/s), \( H \) is the mean depth (cm), and \( f(t^\circ C) \) is the corrected mass transfer coefficient to stream water temperature at a given time during the diel cycle:

\[
f(t^\circ C) = f(20^\circ C) * 1.024^{(t-20)}
\]

Values of community respiration, \( CR_{24} \), gross primary productivity, \( GPP \), and net daily metabolism, \( NDM \), in g m^{-2} day^{-1}, and the \( P/R \) ratio, were obtained according to published methods for an open-system with one-station.

Groundwater-Surface Water Interactions. Temperature Javelins were composed of thick walled PVC measuring 1.25 inches in diameter and 10 feet in length. Holes were drilled through both sidewalls of the pipe to accommodate small self
Logging temperature probes (Thermocron iButton). The holes were tapped on one side and counter bored on the other sidewall. Large set screws threaded into the sidewall secure the temperature probes in place.

Proof of concept testing of the temperature javelins was performed near Livingston, California. Temperature javelins were tested to determine their accuracy in monitoring groundwater discharge/recharge velocities into the river. A steady state one dimensional groundwater transport model was used to determine vertical groundwater discharge/recharge through the use of surface water, groundwater, and streambed temperatures.

**Hydrodynamic Modeling.** For the 2-D hydrodynamic modeling effort, four datasets are typically required: upstream volumetric flow rate(s), downstream water surface elevation (WSE), water bathymetry, and water side boundaries. These datasets are now routinely determined using CENS techniques outlined in prior reports. To validate the results, the NIMS-RD and ADV setup was used downstream of the confluence near a US Geological Survey (USGS) gauging station whose data is ported both to the California Data Exchange Center (CDEC) and the USGS National Water Information System.

**CONTAM 02.5 Accomplishments**

High Resolution Metabolism Estimates. With the analysis of metabolism at the confluence of the Merced and San Joaquin Rivers, we were able to demonstrate the presence of temporal and spatial variations in the transverse dimension (i.e., not related to the continuum concept). The variation appears to be caused by local factors determining metabolism (biological differences in the two rivers, water temperature, incident light or nutrients present in water, etc.). The following table presents averaged metabolism values calculated for the three diel cycles and for the three zones within the confluence cross-section: Merced, mixing and San Joaquin. The complex dynamics within the confluence zone accompanied by transient conditions in flow and water quality are reflected in spatial and temporal variations of CR24, GPP, NDM and P/R. Temporally, for the three zones the P/R ratio indicates a switch from heterotrophic to autotrophic character between the first and the last day represented in a P/R ratio changing from <1 to >1. Spatially, for values within the same day, there is a clear gradient in all the calculated parameters as we move from the Merced to the San Joaquin zones.

<table>
<thead>
<tr>
<th></th>
<th>CR24 (g m⁻² day⁻¹)</th>
<th>GPP (g m⁻² day⁻¹)</th>
<th>NDM (g m⁻² day⁻¹)</th>
<th>P/R (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1 (August 8/2007)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Merced zone</td>
<td>-6.17</td>
<td>5.03</td>
<td>-1.14</td>
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<td>0.78</td>
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<td>-2.33</td>
<td>0.73</td>
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<tr>
<td>Day 2 (August 9/2007)</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>-----------------------</td>
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<td>------------------------</td>
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</tr>
<tr>
<td>Merced zone</td>
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<td>9.87</td>
<td>2.92</td>
<td>1.42</td>
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<tr>
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<tr>
<td>San Joaquin zone</td>
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<td>15.02</td>
<td>3.40</td>
<td>1.29</td>
</tr>
</tbody>
</table>

**Figure 3** - Calculated vertical groundwater-surface water discharge (positive indicates flow from groundwater into the river) based on javelin temperature data and 1D heat transfer modeling results.

**Groundwater-Surface Water Interactions.** Groundwater-surface water exchanges were successfully quantified and mapped at the reach scale at the UCM Flow Path site on the Merced River. Groundwater velocities were shown to be heterogeneous about each transect with a small range (-1.82 – 4.80 cm/day) (Figure 3). Higher rates of groundwater discharge are found on the right side of the river in both transects. Groundwater discharge velocities were within range of previous studies at this site giving credence to the instrumentation, and method.

Diurnal temperature cycling is seen at all depths with varying degree of magnitude as a response to the surface water releases. Diurnal variations are amplified during the transitional period in October and November. Surface water temperature influences are evident in the variability of the groundwater velocity at the shallowest depth (0.5 meters). With an increase in depth, diurnal cycles are less evident, thus validating our method with findings from previous investigations. As surface water flows stabilize in late November to early December, groundwater velocities also show smaller magnitudes in diurnal cycling.

**Hydrodynamic Modeling.** Employing the Surface water Modeling System (SMS) GUI for FST2DH, we are able to develop hydrodynamic simulations quickly which capture the dynamics of the mixing process semi-quantitatively (Figure 4). We are working to finalize the digital elevation map (DEM) and water boundary surface elevations (for various flows) in order to create a more quantitatively sound calibration.
CONTAM 02.6 Future Directions
In the upcoming year, we propose tasks in three main areas: (1) continuing installation and development of a flow path-reactive transport sensing platform by linking soil pylons, groundwater nodes, and static river nodes through software based on environmental process models, (2) extending the timeframe of the river metabolism inquiry to encompass inter-seasonal variation and the effects of reservoir operation (e.g., rapid flow changes), and (3) refinement of the hydrodynamic mixing model, including incorporation of a metabolism sub-model.

Figure 4 – Sample FST2DH model simulation; inputs were volumetric flow calculated from cross-sectional velocity magnitudes (T1, T2, and T3 designate locations of downstream, and two upstream NIMS RD transects which constitute the model flow boundaries).