CONTAM 01 Multi-Scale Soil Sensor Network in Support of Groundwater Quality Protection

CONTAM 01.1 Overview
This project has previously focused on moisture and chemical propagation in the soils undergoing irrigation. This aspect of the project has shifted primarily toward modeling and resource management questions, which are now being addressed in a separate project (see CONTAM-03 report). While some of these aspects of the project remain, the main emphasis of the CONTAM-01 project has shifted to the opposite end of the land use-to-waterway flow path, where agriculturally impacted groundwater discharges into a river.

Progress in this year’s CONTAM-01 report was primarily in three areas:

• In a new direction, we extended the multi-scale soil sensor systems to the study of groundwater-surface water discharges. The quantification of groundwater discharge/recharge from surface water is poorly understood due to the heterogeneity of these processes within a given reach and a deficiency of instrumentation needed to obtain a high resolution for these interactions.

• We tested the response of potentiometric nitrate sensors to monitor nitrate impulses under controlled laboratory conditions. We have tested these sensors previously in the field, but all results to obtained to date have been ambiguous.

• We continued to add to the Palmdale soil moisture, temperature, and salinity data set with uninterrupted operation of this wireless sensor network since May 2008 (for typical results, see CONTAM-04 portion of the annual report).

Specific Objectives
The objective of this project was to evaluate inexpensive groundwater-surface water monitoring devices (temperature javelins) used to calculate groundwater-surface water discharge in a high spatial resolution. In addition, the response of low power, potentiometric electro-chemical sensors for nitrate sensing was further evaluated in a laboratory setting to determine whether groundwater-surface water chemical fluxes might also be determined using this approach.

CONTAM 01.2 Approach
Groundwater-Surface Water Discharge Mapping
We installed several of the previously developed temperature javelin sensor platforms at a site on the Lower Merced River. Temperature Javelins were composed of thick walled (schedule 80) PVC measuring 3 cm diameter and 3 m in length. Holes were drilled through both sidewalls of the pipe to accommodate small self-logging temperature sensors (Thermocron i Button). The holes were tapped on one side and counter bored on the other sidewall. Large set screws threaded into the sidewall secure the temperature probe in place (see Figure 1).

Initial testing took place at a known gaining reach of the lower Merced River near Livingston, California. Temperature javelins were tested to determine how accurately they are capable of gathering temperature data for interpreting groundwater discharge/recharge 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.

Laboratory Testing of Nitrate Sensors in Soil Columns
Large soil columns were fabricated at the Civil & Environmental Engineering Lab at Loyola Marymount University (LMU). Ion-selective sensors have proven effective in the laboratory using liquid solutions. However, sensor reliability is often affected in soil environments, which offer challenging conditions that include: saturated/unsaturated conditions affecting probe’s moisture and non-uniform contact among sensor-water-soil-air. Experiments
were conducted to test sensors’ reliability and to help overcome these challenges. The experiment entailed injecting an instantaneous slug of nitrate in a 1-D steady up-flow field created inside a Plexiglas column packed with soil and equipped with up to 6 nitrate sensors (Figure 2). Sensors were pushed into low-moisture soil to simulate common “push-probe” field techniques. Sensors were calibrated in known nitrate solutions before and after the experiments to assess drift in calibrations. The sensors’ temporal responses were assessed to determine whether or not the sensors captured the nitrate spike, and to study applicable principles of solute transport in saturated soil.

CONTAM 01.3 Systems/Experiments

Groundwater-Surface Water Discharge Mapping

From October 16, 2008 through January 14, 2009 15 temperature javelins installed along two existing hyporheic piezometer transects approximately 100 meters apart. The Javelins were installed 5 meters apart and 4 meters on each side of the existing piezometer transects (see Figure 1). Streambed temperatures were measured in 30 sampling intervals at three depths below the streambed-surface water interface;

Groundwater temperatures were measured using Hobo water level loggers (U20-001-01) and found to be constant (19°C). Surface water temperature was assumed to identical to a downstream gauge station (MST). Upon retrieval of the temperature javelins it was found that there was an extremely high mortality rate (68%) of the Thermocron iButtons. Redundancy in the experimental setup ensured a minimum loss of data.

Vertical discharge velocities were calculated using an analytical solution to the convection-conduction equation for a saturated porous medium, allowing for the interpretation of discharge/recharge velocities through the use of surface and groundwater, and streambed temperatures. Uncertainty involved with this set up is less than 12 percent for the reasonably large temperature differences observed (>2°C), however, when groundwater and surface water are not more than 2°C different, the uncertainty increases significantly (see Figure 4).

Laboratory Testing of Nitrate Sensors in Soil Columns

Sensors captured the injected nitrate spike in terms of signal strength and arrival time. Other sensors (not shown) exhibited similar responses. Results are promising in that the sensors may prove effective in detecting sudden nitrates spikes (e.g., as part of an alarm system in a field installation). Despite improvements, quantification of nitrate mass is not optimal due to sensor drift and uncertainty in background levels. Long-term use of sensor data for
quantification remains a challenge not only due to harsh field conditions, but also because newer sensors behaved better than older sensors.

**CONTAM 01.4 Accomplishments**

*Groundwater-Surface Water Discharge Mapping*

Groundwater velocities were shown to be spatially heterogeneous about each transect with a small range (-1.82 to 4.80 cm/day) (Figure 5). 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.

Figure 5 shows groundwater discharge data for each depth of a selected temperature javelin over the monitoring period. After November 22, surface water temperatures diverge sufficiently from the groundwater temperature (2°C) to allow for groundwater discharges to be accurately calculated. Prior to November 22, the groundwater and surface water temperatures are too similar to utilize this model to calculate groundwater velocities, as is evident by the extreme noise in Figure 4. Small diurnal variations in groundwater discharge are evident from this point, and are in sync with surface water temperature cycling after December 22. Discharge values during this period are shown to be relatively small (~0.5 to 2 cm/day), which are consistent with findings by previous investigations in the region.

*Laboratory Testing of Nitrate Sensors in Soil Columns*

The nitrate sensors captured the injected nitrate spike in terms of signal strength and arrival time (Figure 6). Other sensors (not shown) exhibited similar responses. Results are promising in that the sensors may prove effective in detecting sudden nitrates spikes (e.g., as part of an alarm system in a field installation). Despite improvements, quantification of nitrate mass is not optimal due to sensor drift and uncertainty in background levels. Table 1 shows considerable uncertainty for the best two among six sensors tested.

**CONTAM 01.5 Future Directions**

Temperature Javelins as currently designed have proved effective in determining groundwater discharge or recharge. Future steps include the implementation of less expensive and higher resolution thermocouples in place of self
logging thermistors, and the pairing of a more robust groundwater-surface water model capable of calculating both groundwater recharge and discharge. In addition, the integration of loggers, and radio modems connected to on-site wireless sensor networks will allow for real-time groundwater-surface water discharge monitoring. Long-term use of sensor data for quantification remains a challenge not only due to harsh field conditions, but also because newer sensors behaved better than older sensors. From a broader perspective, the results and systems developed in this aspect (CONTAM 01) of the contaminant transport observation and management research thrust area will be integrated into synergistic projects (CONTAM 02 and SEN 04). The overall goal of these projects is to link water and chemical transport pathways from agricultural land uses, through groundwater, and into rivers.