CENS **Center for Embedded Networked Sensing**

Understanding of Flow, Mixing and Groundwater Accretion on Large-Scale Rivers Using Integrated Modeling and Multiscale Embedded Networked Sensing

Sandra Villamizar Amaya[1], Thomas Harmon[1], William Kaiser[2], Jason Fisher[1], Henry Pai[1], Amarjeet Singh[2], Maxim A. Batalin[2], Michael Stealey[2], Victor Chen[2]

[1]School of Engineering, University of California, Merced; [2]Electrical Engineering Department, UCLA

Introduction: Understanding distributed water quality in rivers - San Joaquin River Case Study

Water Quality estimates in the San Joaquin River

- **What has been done so far**

The single modified Kratzer equation relating EC to flow at Vernalis has been replaced by ***salt balance calculations*** at different points from Lander Avenue to Vernalis. Significant improvement has been reached through the disaggregation of the flow model representation of the western side of the river basin. However, for the current model, the EC-flow scatter plots (rating curves) for Vernalis overestimate EC for the months of February and March.

- **Efforts needed to improve the understanding**

Incorporation of ***more accurate inputs*** from the Eastside tributaries and agricultural drains, and ***groundwater-surface water*** fluxes will help to refine the water quality estimates along the river.

Multiscale Embedded Networked Sensing

- **NIMS RD – robotic "scanning" of river cross-sections**
  - Provide the possibility of getting efficient and high granularity ***two-dimensional*** mapping.
  - Facilitate the ***high spatial-temporal resolution*** data acquisition by doing real-time data collection with autonomous motion of the mobile system.
  - Reduce considerably the sampling time by using an ***adaptive sampling approach*** (instead of doing dense scan raster sampling).
  - Allow collection of samples in the field from any desired location in the cross section.
- **Javelins – quantifying chemical inputs from groundwater**
  - Allow the observation of groundwater-surface water exchanges of nitrate and other species in river bed sediments.

Problem Description: Poor predictability of water quality impairment by non-point sources

Understanding and changing the impact of non-point source pollution

Degraded water quality has been the norm for many years in the western U.S. and other parts of the world due to upstream impoundments and the impaired quality of return flows from agricultural drainage, managed wetlands, groundwater inputs and other distributed sources. In essence, environmental engineers and scientists have successfully reduced the impact of point source pollution on receiving water quality, but have thus far failed to ***fully understand and change the impact of non-point source pollution***. This project will leverage early successes in the ***NIMS RD river assessment*** program to launch a distributed river observation campaign which will focus on several important water quality issues in Central California. In the future, we anticipate on building on knowledge gained in these river systems to test our technology and extend our understanding of non-point source pollution processes over a broad range of river and pollution conditions.

Proposed Solution: Multiscale observational network on the main stem of the SJR

Multiscale Observational Network

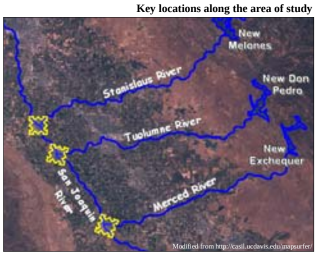
Deployment of NIMS RD and Javelins

- Located at key locations of the main stem of the SJR focused on several water quality issues.
- Acquiring greatly refined estimates for water quality based on flow and mixing conditions as well as groundwater accretion along the main stem of the primary river.
- Collecting and synthesizing data in a manner consistent with agency needs.

Key locations

- Merced River confluence
- Tuolumne River confluence
- Stanislaus River confluence
- Sites of groundwater accretion into the San Joaquin River identified by the USGS.

Key locations along the area of study



Salt Mixing Study

Starting point of theory

All waters in rivers contain salts or total dissolved solids (TDS). The salts dissolved are usually dominated by the carbonates, chlorides and sulfates of calcium, magnesium and sodium. ***Electrical Conductivity (EC in $\mu S/cm$)*** is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids.

Proposed Regression Technique:

A ***sediment rating curve*** describes the average relation between discharge and suspended sediment concentration (important fraction of the TDS in lowland rivers) for a certain location. The most commonly used sediment rating curve has the form:

$$C = aQ^b$$

As a starting point, we proposed testing the same mathematical form to describe a TDS rating curve by:

(1) Collecting synoptic (cross-sectional) data sets upstream, within, and downstream of three confluences (Merced, Tuolumne, and Stanislaus Rivers) to improve our ability to forecast transport in these zones.

(2) Developing salt-flow rating curves using different ***statistical regression strategies*** to characterize ***5 different flow conditions*** based on flows reported in prior (low precision) EC-flow rating curves and avoiding monitor stage conditions.
   (1) Merced confluence: from ~500 cfs to 8000 cfs
   (2) Tuolumne confluence: from ~3000 cfs to 15000 cfs
   (3) Stanislaus confluence from ~3000 cfs to 25000 cfs

Groundwater Accretion Study

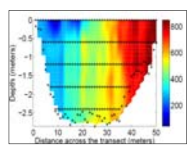
Quantify and sample groundwater-surface water interactions

- By deploying immediately upstream and downstream of a suspected "hot spot" with velocity, temperature, salinity, and nitrate sensors, we will create flow and mass balances over the hot spot reach as an additional line of evidence as to the quantity of the groundwater, salt, and nitrate fluxes into the river segment.

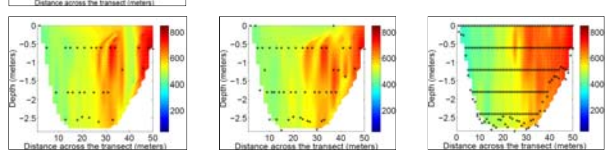
Sampling Algorithms, Data Analysis and Modeling

Develop multiscale modeling and data fusion approaches

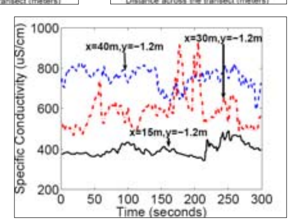
- NIMS RD software allows the user to specify raster scans of ***variable granularity*** or a variety of ***adaptive sampling algorithms***. Preliminary tests at the Newman station indicate that horizontal variability in the mixing zone is greater than that in the vertical direction, an observation consistent with river mixing theory.



Testing process of an adaptive approach for a raster scan of a cross section at the confluence of the Merced and San Joaquin rivers on August 23. Top left: measured specific conductivity at the transect during the raster scan with 250 points (time of sampling: 2 hours 40 minutes). Bottom left: predicted surface when only 30 out of 250 locations, selected greedily based on the Mutual Information criterion are sampled (time of sampling: 20 minutes). Bottom center: predicted surface when only 50 out of 250 locations, selected greedily based on the Mutual Information criterion are sampled (time of sampling: 31 minutes). Bottom right: distribution of specific conductivity using the raster scan for the same cross section at the same time during the previous day.
Source: Singh et.al., 2006.



- **Adaptive sampling routines** are available for focusing larger numbers of NIMS RD sampling points in the regions of the cross-section with the greatest variability, and where velocities and/or EC values are greatest. Using these algorithms, we will be able to glean the necessary information from a deployment more efficiently than raster scanning allows for maximizing the useful information gathered from regional (remote sensing) scales to local (NIMS RD, river javelin) scales.



Temporal variation of specific conductivity at three different points along the cross section (15, 30 and 40 m) at the confluence of the Merced and San Joaquin rivers. Since bigger variations are shown in the center of the cross section (mixing zone), longer dwelling time should be required in this area than at the edges.
Source: Singh et.al., 2006.