2.4 Contaminant Transport Assessment and Management (CONTAM)

The Contam research area focuses on developing technology to observe and manage mass and energy distributions and fluxes across a range of temporal and synoptic scales. In 2010–2011, the contaminant transport group continued its emphasis on integrated sensing and model-driven analysis. Projects continued to focus on high resolution river observation and modeling with respect to whole stream metabolism, groundwater-surface water exchanges, and hydrodynamic mixing. In addition, new emphases have emerged in the areas of (1) managed aquifer recharge aimed at increasing the sustainability of groundwater supplies and (2) integrating remote (aerial) sensing products with CENS embedded sensing strategies in order to extend our approaches to larger spatial scales (i.e., watershed).

The major accomplishment in the Contam application area for 2010–2011 was the installation of a major new observational network at a managed aquifer recharge site in Fresno, CA. After more almost 2 years of uninterrupted data from the Palmdale water reclamation and irrigation site, and the dairy wastewater irrigations sites near Merced, CA, we shifted sensing resources to the managed aquifer recharge site in Fresno, CA. This newest Contam site is called MARnet (managed aquifer recharge network). One of the observational nodes is shown Figure 3 during the initial flooding of the infiltration pond. At this site, we aim to successfully demonstrate integrated modeling and observational techniques which will enable managed aquifer recharge with reclaimed water to be used more readily in arid and semi-arid climates, thereby increasing the sustainability of water resources.

Overall the Contam group focused on three projects over the past year, including (1) the new managed aquifer recharge site, (2) continued development of high temporal resolution dissolved oxygen data collection and net daily metabolism estimation at high spatial resolution, (3) developing new approaches to integrating CENS’ embedded sensing approaches with larger scale remote sensing data.

After transitioning sensor to the MARnet site, we also focused effort on the interpretation of long-term data at the Palmdale and Merced dairy sites. Findings from these sites are summarized in one doctoral dissertation and two M.S. theses. These focus on the development and testing of long-term simulation models and data assimilation methods for forecasting the effects of irrigating with reclaimed water on groundwater quantity and quality in terms of nitrate and salinity levels, and on the long-term problem of soil salinization. Our results indicate that by hardening the demonstrated approaches we can build robust embedded sensing systems reporting higher level information than simply moisture changes over time, reporting instead on the sustainability of current practices and proposing modifications to improve upon the current approach. Furthermore, to enable scale up of the MARnet approach we have developed parsing algorithms that sort hydrologic and geospatial properties and socioeconomic features over large areas, such as counties, to identify the most promising areas for developing MAR operations. In the coming year this aspect of Contam research will continue to operate and assess the MARnet prototype while working with local water agencies to identify additional test sites. In particular, we are interested in identifying a floodwater diversion site to contrast with the existing wastewater reclamation site.

In the second project area, we have extended our aquatic sensing capabilities on the Lower Merced Rivers, having installed a long-term water quality monitoring station in September 2010. This station is enabling us to continuously examine water quality parameters at high temporal resolution in a critical agricultural reach of the river. In addition, we have continued our synoptic monitoring efforts over this river reach on a roughly quarterly basis, including both water quality and imagery to capture human influences in the form of inputs (canals, drain pipes) and outputs (pumps and diversions). By combining the temporal and synoptic data we are learning to separate the influences of human disturbances from natural background processes. At this time we are focusing mainly on temperature, dissolved oxygen (DO), and nitrate changes in the river, and using the ecosystem metrics associated with net daily metabolism (primary production, community respiration) as a method for quantifying the river’s response to natural
and anthropogenic disturbances. Most recently we have been able to autonomously detect changes in metabolism over a wide range of flow releases from upstream reservoirs.

The third Contam project area over the past year focused on the integration of embedded and remote sensing approaches in both terrestrial and aquatic systems. For terrestrial systems, we continued to pursue the objective of classifying ecosystem change over relatively short time periods. Our most successful approach to date involves modifying an existing algorithm (multivariate alteration detection or MAD) to include an object-based approach. The latter allows us to better filter false change detections. We tested the algorithm using high resolution aerial imagery of a managed wetland area in Central California. Our new approach enabled us to filter out false changes better than the MAD algorithm alone. The object-based aspect of our algorithm allows us, for example, to notice that certain vegetation objects (small trees or bushes) cannot spread or move over short time periods, and therefore identifies potential changes in such objects as spurious. Overall, the modified object-based MAD (OB-MAD) algorithm successfully classified relatively subtle changes in wetland plant community structure over a period of only one year.

By enabling ecosystem managers to identify the onset of change over shorter time periods, we can empower them to enact operational changes which have a better chance of preserving desirable ecosystem functions before the movement toward change become irreversible.
CONTAM 01 Multi-Scale Soil Sensor Network in Support of Groundwater Quality Protection

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Overview
This project is part of the ongoing CENS investigation into reclaimed wastewater infiltration into shallow soils and groundwater recharge. Groundwater resources are typically over-drafted during dry periods in arid and semi-arid climates. In states like California, the issue of groundwater depletion and degradation through pollution is growing dire and threatens sustainability.

Specific Objectives
The overall objective here is to identify and observe potential uses of reclaimed water both as substitutes or supplements to local groundwater, or to replenish groundwater. The project currently encompasses both exploratory and active lines of research, with specific research objectives as follows:

- Develop a strategy for identifying potential artificial recharge areas based on existing geospatial data (e.g., topography, soil type, aquifer type, current land use, etc.).
- Observe and quantify soil salinity propagation to groundwater as a result of irrigation with reclaimed water.
- Observe and quantify reclaimed wastewater artificial recharge and nitrogen species transport in an artificial recharge pond.

Progress in 2010-11
- We have completed observations over more than 2 years in a soil zone under high salinity flood irrigation.
- We have installed and are operating an observational network in an artificial recharge pond receiving municipal effluent.
- We have developed a hierarchical parsing algorithm which identifies potentially efficient artificial recharge zones and tested this for a large region in Central California.

Approach
This project includes work two field sites: (1) A sandy dairy pasture irrigated with reclaimed manure wastewater (dairy site) and (2) An infiltration pond receiving secondary effluent from the Fresno municipal wastewater treatment plant (Figure 1). Our approach is to characterize the surface land use and subsurface hydrology with respect to water infiltration and recharge rates, and water quality in terms of salinity and specific salts like nitrate and ammonium. We then collect data and model these observations in an effort to better understand the underlying processes and implications of these practices.

In addition to the field work, we have also begun to investigate the notion of large-scale managed aquifer recharge and are using geospatial analysis of existing data sets. By accessing and mining open data sources, including digital elevation models (DEMs), land use type, soil surveys, flood-prone areas, and aquifer sediment maps based on borehole logs, we are developing rules for identifying first estimates for potentially viable aquifer recharge sites in Central California. After secondary screening and selection, such sites could be instrumented and recharge assessed using the integrated sensing-modeling systems being developed at our field sites.
System Description and Experiments

The system at the dairy site (recently decommissioned) included three soil monitoring pylons situated across an elevational gradient in the flood-irrigated pasture. Each pylon included an array of soil temperature, moisture (volumetric) and salinity (electrical conductivity) sensors. Local weather conditions were monitored at the central pylon. These pylons were in place for nearly 2 years and experienced a wide range of natural precipitation and irrigation events. During the past year, these data were modeled using one-dimensional soil moisture flow, energy, and solute transport models, and then the calibrated models were used to project future implications with respect to soil salinization and groundwater contamination.

The Fresno infiltration pond system was installed in September 2010 and flooding of the pond began in October 2010. The system includes three vertical soil pylons with moisture, temperature and salinity sensors installed at 2, 5, 10, and 18 ft depths. The remainder of the sensor system includes an input flow meter, pressure transducers to measure pond depth, nitrate and dissolved organic matter instrumentation (intermittently), and a weather station. We are currently assessing the approach of the pond to steady infiltration status, and periodically measuring water quality samples with assistance by the Fresno WWTP laboratory.

Accomplishments

We completed the dairy study in December 2010, and all results are summarized in the M.S. thesis by Barnes (UCM). The plots in Figure 2 show long-term salinity observations together with the calibrated transport model simulation. The results indicated that soil salinization potential in the sandy soils was low given the climate and operating conditions. On the other hand, groundwater contamination by leaching salts appears to be unavoidable under these conditions. Although groundwater could not be directly assessed at the site (no wells were available near the pasture), predictions based on models calibrated with a year’s worth of data demonstrate that low levels of salt propagate to the water table.

We acquired additional funding through CITRIS, and successfully installed the new system in Fresno and have been collecting and analyzing infiltration data since October 2010, and have quantified the running infiltration rate which began at roughly 0.5 m/d and is approaching a steady value of about 0.3 m/d. We are currently watching for a reduction in infiltration which is likely to be caused by porous media clogging by suspended solids in the effluent.

Lastly, we have completed one parsing algorithm for spatial data sets and tested it on Madera County in Central California. Key results suggested that some underlying sediments in flood prone areas may have adequate infiltration characteristics and would provide economically viable options as combined flood control-aquifer recharge zones.

Figure 2. Long-term observations and calibrated model results for soil moisture electrical conductivity (as a surrogate for salinity) under a pasture under irrigation with blended manure water and groundwater.

Figure 3. Flood prone areas (red shading) and prospective areas (orange) identified for storm water diversion and artificial recharge in Madera County, CA.
**Future Directions**

As noted, we are interested in identifying more opportunity for safe wastewater reuse and aquifer recharge to help alleviate water stress in arid and semiarid regions of high population. In the upcoming year, we will:

- Continue to operate and assess water quantity and quality implications of artificial recharge with reclaimed wastewater at the Fresno site.

- Work with local water agencies to identify pilot test sites for assessing flood diversion sites in terms of their potential to recharge groundwater.

- Develop model-based engineering tools to optimize the selection, operation, and maintenance of artificial recharge operations.
CONTAM 02 Observations in Rivers and Urban Streams: Merced River Net Daily Metabolism Studies

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Overview
This project is part of the ongoing CENS investigation into whole stream metabolism (or net daily metabolism) in human-dominated watersheds. More specifically, we are focusing on assessing primary production and respiration at various spatial and temporal scales, motivated by the need to understand the connection between human land management activities and stream metabolism.

Specific Objectives
Continuing last year’s work, this project examined net daily metabolism (NDM) changes stemming from large human disturbances on the river. In this case, the disturbances were large, pulse-releases of cold water from upstream reservoirs. The specific research objectives were as follows:

- Developing and test a long-term water quality gauging station on the Merced River and use it to collect dissolved oxygen, temperature and other water quality data before, during and after large disturbance events.
- Estimate whole stream metabolism values on a daily basis and use these estimates to assess whether or not significant changes in metabolism occur as a consequence of such a disturbance.

Progress in 2010-11
- We successfully installed a semi-permanent station on private property along the Merced River and continue to collect water quality data (Figure 1). Several large disturbances have been captured and interpreted with respect to net daily metabolism changes.

Approach
We have installed a semi-permanent station for continuously estimating whole stream metabolism parameters, namely Gross Primary Productivity (GPP) and Community Respiration (CR) rates, or their ratio (P/R). Our approach is to use these to evaluate river ecosystem structure and function because it directly assesses the balance between energy supply and demand within the system. We are examining multiple scales of temporal variability in ecosystem metabolism rates including (1) seasonal, (2) daily, (3) episodic, and (4) inter-annual. Over the past year we have focused in episodic variability, which can also be described in terms of disturbance (an abrupt event that can drastically change ecosystem characteristics).

System Description and Experiments
The semi-permanent station is installed on the Lower Merced River approximately halfway between two government river gauging stations. While the government stations monitor stage and flow, the CENS station monitors stage and water quality. Specifically, the station houses a Hydrolab DSS unit and monitors water depth, water temperature, dissolved oxygen, specific conductance (salinity), and pH. Data from this station is transmitted wirelessly to the UC Merced campus, where CENS investigators can interpret it scientifically or identify signs that maintenance is necessary (e.g., the sensors typically require cleaning after major flood events).

The experiments entail monitoring dissolved oxygen and temperature before, during and after significant disturbance events on the river. Disturbance here is in the ecological context, and refers to substantial changes in flow or water...
quality as a result of natural processes or human activities. A specific example involves mandated seasonal releases from the upstream reservoir (Lake McLure) in support of anadromous fish migration. Each spring (May) and Fall (October or November), the reservoir operators send a large pulse of cold water down the Lower Merced River under this agreement. The flow disturbance for this release in Fall 2010 is shown in Figure 2 (top).

Accomplishments
We successfully installed the semi-permanent station with has been operational since September 2010. The system has enabled the observation and interpretation of several major disturbance events in 2010-11. In addition, we have identified but did not yet interpret numerous lesser disturbances. We presented our results at the Fall 2010 Meeting of the American Geophysical Union.

The data shown in Figure 2 depict the flow disturbance (top) and corresponding dissolved oxygen (middle-blue) and temperature (middle-red) signals before and after the disturbance. Note that the extreme nature of the disturbance disrupted data acquisition during its peak. We have since reinforced the system such that it should tolerate such disturbances in the future. The bottom plot in Figure 2 demonstrates the change in river metabolic rates due to the disturbance. This can also be seen in the change in amplitude of the dissolved oxygen pulses. The metabolism estimates yield daily averages of gross primary production (GPP) and community respiration (CR24). Consistent with the limited literature on disturbances, there is a clear decrease in GPP with the arrival of the cooler water, while CR24 values increase, most likely in response to the additional nutrients in the water as a result of the greater flows. These results validate that our system is providing useful important data on the nature of river ecosystem disturbances and resilience.

Future Directions
As noted above, we are interested in using our system to study disturbance and resilience phenomena across a variety of temporal scales. This will require automation of the metabolism calculations, and we are currently working with researchers at the USC Information Science Institute to develop work flow software supporting this goal. Automation will enable us to analyze potential disturbances which are smaller and more frequent, or of a different nature (e.g., salinity pulses) than the cold water pulses. Specifically, we intend to address the following questions:

- What magnitude of flow alteration constitutes an ecological disturbance over various seasons and water years?
• Under what conditions do chemical releases from agricultural drainage, wastewater treatment plants and other sources constitute disturbances?

• What role does non-point source pollution, as from groundwater seepage, play in river metabolism and its change?

In addition to addressing a wider range of temporal scales, we are interested in expanding our investigation to encompass greater spatial scales along the river and surrounding watershed. This will start with the installation of a duplicate station approximately 40 river-km upstream of the current station. We are also commencing a series of synoptic surveys between the two stations in an effort to learn how to integrate landscape processes (e.g., surface water runoff, groundwater-surface water discharges) into our interpretation of stream metabolism changes.
Overview
This project focuses on up-scaling the CENS embedded sensing approaches in terrestrial and aquatic systems to larger spatial scales by integrating embedded and remote sensing techniques. More specifically, we are focusing on identifying and testing remote sensing methods and algorithms for detecting changes in the environment.

Specific Objectives
Continuing last year’s work, this project continued to investigate terrestrial applications. New aspects of the project extended into the aquatic domain. Specific objectives included:

• Developing and testing of a high-resolution image classification method for mapping changing plant community structure over relatively short time periods (1 year).

Progress in 2010-11

• We successfully modified an existing change detection algorithm (Multivariate Alteration Detection or MAD) to address plant community structure changes, and tested this at our wetland field site.

 Approach
We developed an object-based (OB) change detection approach enhanced by its integration with Multivariate Alteration Detection (MAD) transformation and decision tree-based post-classification methods (Figure 1). Recent studies have found that MAD methods are promising in change detection analysis. However, MAD has not been well-studied in terms of reducing errors due to mis-registration and shadows. By incorporating object-based analysis with MAD, features such as object shapes and contrast could be used to improve change detection results. For example, mis-registration along rivers and roads often results in linear features that can be detected using object-based analysis. Our hypothesis is that the resulting OB-MAD method will better differentiate real from spurious changes in very high resolution images compared to conventional approaches. In the proposed approach, MAD transformation is first implemented to find the change and no-change pixels using spectral and spatial information. Then, MAD components are combined and used for image segmentation and object extraction. Finally, we apply a decision tree classification method to detect spurious change areas caused by mis-registration and shadow.

 System Description and Experiments
The study area is a wetland located in the Los Banos Wildlife Area (LBWA), which lies within the boundaries of the Grasslands Ecological Area (GEA) in Merced County, California (36° 57’ 40” N and 120° 43’ 58” (Figure 2). The wetland units of the GEA are managed and operated through canals and control structures, following a pattern of flooding in the late summer, maintaining water levels through the winter, and draining in the spring, typically mid- to late March. Climate in this area is characterized by hot, dry summers and cool, wet winters, with a mean annual temperature of 16.8°C. A publicly owned wetland pond with an area of 17 ha, Gadwall

Figure 1. Flowchart description of the proposed object-based multivariate alteration detection (OB-MAD) method.
North, is the subject of this work. Water in the ponds flows from south to north, following a swale that located along the edge of the pond. The land slopes gradually from west to east. Vegetation includes *Cyperus schoenoides*, *Rumex spp.*, *Eleocharis spp.*, *Scirpus maritimus*, *Scirpus acutus*, *Juncus balticus*, *Typha spp.*, and *Xanthium strumarium* and others. Some emergent vegetation (*rushes, tules, and cattails*) is left for wildlife cover. The wetland in Central California is important for biological conservation, wetland managers are striving to detect habitat changes as early as possible.

Aerial photographs of the drained pond (Figure 2) were taken on 10 May 2006 and 11 May 2007 minimizing discrepancies. The false color composite photographs were taken using a Zeiss RMK TOP 15 aerial survey camera system. Images were taken at noon, zero degrees off nadir to minimize shadow effects. Flights were flown and geo-rectified by HJW Geo-Spatial, Inc. (Oakland, California). Photographs responded to the green (G: 500 to 600 nm), red (R: 600 to 700 nm), and near-infrared (NIR: 700 to 900 nm) bands. The scanner produced an RGB digital image with 8-bit false color. Each image has 4,113 by 2,827 pixels and has a ground resolution of 0.15 m by 0.15 m.

**Accomplishments**

The proposed OB-MAD change detection method entails object-based post-classification of MAD components as a means of reducing the effects of mis-registration and shadow. Using imagery from managed wetland ponds subject to relatively modest but well-characterized changes over a one-year period, the OB-MAD approach was tested against the OB-traditional method, an exclusively MAD-based method (Threshold-MAD), and an analogous hybridized approach (PB-MAD). For the area associated with real vegetation changes, the OB-MAD method outperformed other methods and better detected mis-registration and shadow. The OB-traditional method overestimated the spatial extent of the change area, while the Threshold-MAD approach resulted in relatively severe local mis-classification, with the PB-MAD method exhibiting a lesser degree of mis-classification. Statistically significant differences were observed between all of the methods. The test results indicated the OB-MAD was superior to the other methods in excluding a larger portion of common mis-classification errors associated with mis-registration and shadow effects. This new method has the potential to be an important tool for minimizing the influence of inevitable mis-registration and shadow on applications of very high spatial resolution imagery.

**Future Directions**

There remain several issues which impede development of a more rapid and autonomous application of the method. First, the requirement for selection of training object samples representative of mis-registration, shadow, and other change classes from MAD components creates a need for a priori knowledge that is potentially laborious to obtain. Second, traditional change detection methods have relied mainly on image-derived variables. Ancillary variables can also provide useful information to improve the overall accuracy of change detection algorithms. In the wetlands of this study, for example, micro-topography plays an important role during pond drainage and is well correlated with moist soil plant community structure (in the absence of...
human manipulations).

In addition to the added OB-MAD developments, our future work will extend into the aquatic domain. Specifically, we will explore the use of hyperspectral reflectance and absorption as a means of quantifying water quality parameters. Others have used this approach to investigate water quality parameters like chlorophyll-a and suspended solids. We intend to develop novel approaches with the intent of expanding this approach to a broader set of parameters, including nitrate and phosphate species, natural organic matter and others.