University of California
Agriculture and Natural Resources | California Institute for Water Resources

Improving aquifer storage recovery operation to reduce nutrient load and benefit water supply

Principal Investigators:

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Project Summary

Our research project focused on how improvements can be made to water supply and water quality during managed aquifer recharge (MAR). We collaborated on this research with a local water agency, researchers at other academic institutions and the U.S. Geological Survey, the Resource Conservation District of Santa Cruz County, the Community Water Dialog (a grassroots community group involved in water issues) and numerous landowners, growers, and other regional stakeholders. The review period included in this summary of results includes the second half of the 2012 water year and the first half of the 2013 water year.

The first several years of this project focused on a MAR project that is operated by the Pajaro Valley Water Management Agency (PVWMA). This project includes an infiltration pond that is used to recharge fresh water into a shallow, perched aquifer (Figure 1). This water is used by local growers in lieu of pumping groundwater from a regional aquifer that is impacted by overdraft and resulting seawater intrusion. The water put into the pond is diverted from a nearby wetland system during the wet (rainy) season, when flows are sufficient high and water quality is good.

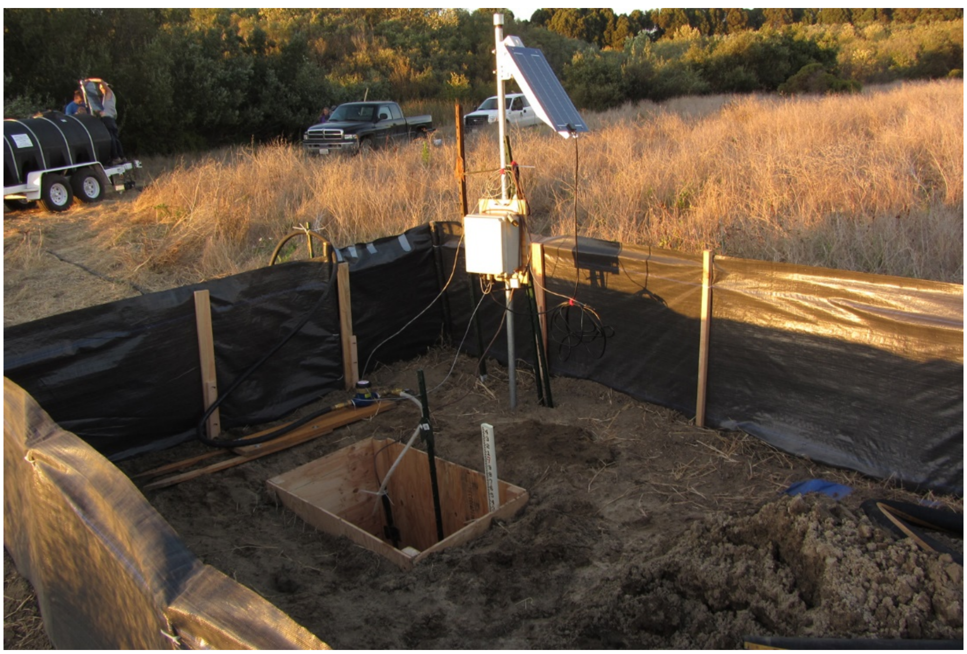

Figure 1. Site configured for infiltration testing, Monterey County.

The first three years of this effort focused on this MAR system, but in the last two years, we have extended these results by transitioning the project to two additional settings: a recharge basin established by a local grower to capture stormwater, and a field site owned by the State of California being considered for managed recharge using recycled waste water. We also extended this work regionally through use of a Geographic Information System (GIS) and a sophisticated regional groundwater model. All of these developments have helped to bring research results into a phase of water supply project implementation.

At field sites, our work involves monitoring the rates of shallow infiltration using mass balance techniques, and determining rates of infiltration at specific locations using heat as a tracer. This last technique involves innovative use of time-series analysis to resolve changes in diurnal temperature changes in shallow soils below the pond, developed in the first three years of our research program. We monitor groundwater levels and quality using local monitoring wells.

We deployed water content, pressure, and thermal sensors in the infiltration pond, allowing us to assess rates of infiltration at different locations. We sampled shallow soils before each recharge season, and again at the end of each recharge season to evaluate the influence of recharge on soil grain size, soil carbon content, and hydraulic properties. This also helps us to assess the influence that sediment transport and deposition may have for project maintenance, a topic of considerable concern to growers and land owners who are considering putting projects like these on their property.

In past two years, we focused on write up and publication of several papers in top-tier journals resulting from work at our initial field site. Full pond infiltration rates were typically 1–5 m/day during the initial 2–3 weeks after the MAR pond was filled, but decreased rapidly to 0.2–0.4 m/day and remained at this rate for the next 6–8 weeks. In addition, we documented large spatial and temporal variations in infiltration rates that shifted during a 6–8 week period. The greatest rates of infiltration were initially at the northwestern end, but the center of the highest rate of infiltration swept across the pond to the southeast, as the magnitude of infiltration rates decreased with time.

Grain size analyses of samples collected before and after each recharge season suggest that initial periods of infiltration caused the loss of fine grained material from the upper 50 cm of the subsurface. Later in the season, a thin layer of fine sediment accumulated at the base of the pond, causing a reduction in hydraulic conductivity. The net result is that the overall rate of infiltration slowed, and the extent of saturation decreased in the shallow subsurface because the rate of inflow could not keep up with the rate of drainage from below.

Evaluation of fluid chemistry showed that there was a 30-60% load reduction during the passage of water from the pond through the upper 1 m of subsurface soils, and low nitrate water arrived at the monitoring wells surrounding the recharge pond at different times as a function of distance and direction. Nitrate isotopic analyses showed that the primary mechanism of nitrate removal was denitrification. Comparison of denitrification rates apparent from our data, based on combined chemical and thermal results, are at the high end of denitrification rates detected in soil and groundwater systems in other settings. It may be that this system is especially efficient at denitrification because of the high availability of organic carbon in the diverted fluids, and the availability of particulate carbon in subsurface soils.

We have also found that high rates of denitrification were maintained even at some of the greatest infiltration rates, but that eventually (at the highest infiltration rates), we see the expected decrease in denitrification efficiency.

In the last two project years, we instrumented a new field site in the southern Pajaro Valley, a three-acre infiltration basin designed to capture stormwater runoff from a 122 acre area. We deployed sediment collection systems, pressure gauges, a rain gauge, and thermal probes. Unfortunately, the last two rainy seasons were both relatively dry, with only 60-70% of "normal" precipitation falling, and much of this falling during a small number of precipitation events. In the 2011-12 water year, we documented only about 5-10 acre-feet of water entering the infiltration basin. In the 2012-13 water year, most of the rain fell during a one-month period (December 2012), and it appears that considerably more recharge benefit was achieved. The field site was instrumented with thermal probes, pressure gauges (for water) level and discharge, and sediment collection systems.

Two week ago, we recovered all of our instruments and samples collection devices that were deployed for the 2012-13 rainy season. All instruments returned usable samples/data, and we are currently processing these results and samples; this work will comprise part of a PhD thesis for a UCSC graduate student. We also have two new undergraduate students working on thesis projects as part of this work.

We completed a GIS and modeling study of regional MAR opportunities, and are have a draft manuscript that is almost ready for submission to a peer-reviewed journal. The GIS analyses used topographic, land use, surficial geology, soil infiltration capacity, aquifer and associated confining layer locations, properties, thicknesses, and historical changes in water levels. A map of MAR site suitability and comparison with an existing project suggests that about 8% of the basin may be highly suitable for MAR (Figure 2).

Model results show simulated MAR projects in locations identified as “highly suitable” for MAR reduce seawater intrusion more than projects simulated in “unsuitable” locations, supporting the GIS analysis results. Results from the model also illustrate the variability in seawater intrusion reduction and head level changes throughout the basin and over time, as simulated MAR project locations vary. Collectively, these studies help to evaluate management options for improving long-term groundwater conditions, both supply and quality.

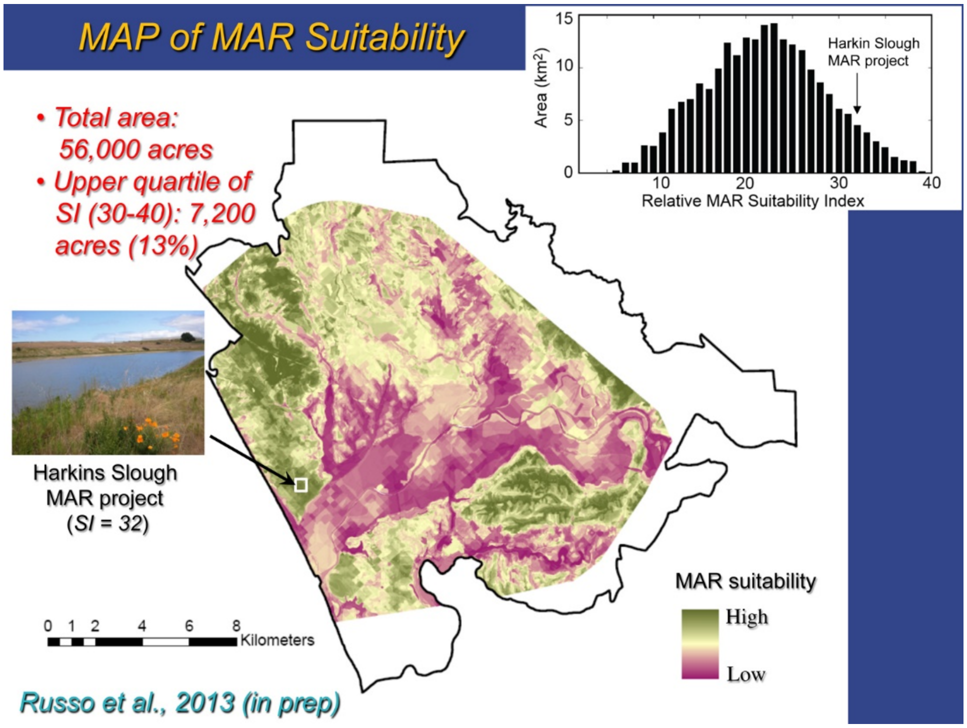

Figure 2. MAR suitability map for the Pajaro Valley

We completed a statistical analysis of historic data from over 600 precipitation stations in the San Francisco Bay Area (SFBA), California, to assess whether there have been statistically significant changes in extreme precipitation between 1890 and 2010. This issue is important for assessing groundwater recharge because there is expected to be less recharge if more precipitation falls during a smaller number of intense events. An annual exceedance probability analysis of extreme precipitation events in the SFBA, coupled with a Markov chain Monte Carlo algorithm, reveals an increase in the occurrence of large events.

The depth-duration-frequency characteristics of maximum annual precipitation events having durations of 1 h to 60 days indicate on average an increase in storm intensity in the last 120 years, with the intensity of the largest (least frequent) events increasing the most. Mean annual precipitation (MAP) also increased during the study period, but the relative increase in extreme event intensity exceeds that of MAP, indicating that a greater fraction of precipitation fell during large events. Analysis of data from subareas within the SFBA region indicates considerable heterogeneity in the observed Q2 nonstationarity; for example, the 5 day, 25 year event exceedance depth changed by +26%, +16%, and –1% in San Francisco, Santa Rosa, and San Jose, respectively. These results emphasize the importance of analyzing local data for accurate risk assessment, emergency planning, resource management, and climate model calibration.

Information Transfer/Outreach Program

We have presented results of this work at numerous public meetings and, as a result, there is growing interest regionally in applying what we have learned to other settings.

Invited presentations were made during the reporting period to the following groups, including scientific and engineering personnel and the public at large:

- Program in Environmental Fluid Dynamics and Hydrology, Stanford University (invited department seminar).
- Department of Geological Sciences, SF State University (invited department seminar)
- Two meetings of the Pajaro Valley Water Dialogue
- Salinity Management conference of the Groundwater Resources Association of CA (invited presentation)
- Santa Clara Valley Water District (lunchtime seminar for engineering and water quality staff)
- Science and Environmental Policy seminar, California State University, Monterey Bay (invited department seminar)
- Santa Cruz Water Forum (public presentation on groundwater recharge)
- American Geophysical Union Fall Meeting (one poster, one talk presented)
- American Geophysical Union Hydrology Days (one poster)
- Webcast on Application of Tracer Studies to Managed Recharge, part of an online series developed by the Groundwater Resources Association of California, focusing on recharge (invited webinar).

We were interviewed by the following media groups, generating stories that were published in regional newspapers:

- Santa Cruz Sentinel (newspaper), Santa Cruz, CA

Students supported with NIWR and associated funds, in part, during the project:

- Calla Schmidt, Ph.D., Fall 2011 (CA SeaGrant Postdoc, now tenure track faculty in Environmental Science at the University of San Francisco)
- Tess Russo, Ph.D., Fall 2012 (Postdoc with the Earth Institute at Columbia University)
- Andrew Racz, Graduate Student (anticipated graduation in Summer 2013)
- Sarah Beganskas, Ph.D. student, began Fall 2012
- Katie Earp, B.S., Spring 2011
- Susanna Bird, B.S., Spring 2011 (Env. Chemistry)
- Devon Stewart, B.S. Spring, 2011
- Christina Richardson, B.S., Spring 2012
- Barbara Montgomery, B.S., Winter 2013
- Emily Edwards, B.S., expected Spring 2013
- Eric Lujan, B.S., expected Winter 2014
- Anna Weisenberger, B.S., expected Spring 2014