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

Soil Survey Decision Support Tools for Water Resources Sustainability and Agricultural Productivity

Principal Investigators:

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Project Summary

Groundwater banking: Groundwater pumping chronically exceeds natural recharge in many agricultural regions in California. A common method of recharging groundwater — when surface water is available – is to deliberately flood an open area, allowing water to percolate into an aquifer. However, open land suitable for this type of recharge is scarce. Flooding agricultural land during fallow or dormant periods has the potential to increase groundwater recharge substantially, but this approach has not been well studied. Using data on soils, topography and crop type, we developed a spatially explicit index of the suitability of soils for groundwater recharge in all agricultural cropland regions in California.

We identified 3.6 million acres of agricultural land statewide as having Excellent or Good potential for groundwater recharge and 5.6 million acres of suitable land (Figure 1). The index provides preliminary guidance about the locations where groundwater recharge on agricultural land is likely to be feasible. A variety of institutional, infrastructure and other issues must also be addressed before this practice can be implemented widely.

SAGBI group	Extent (acres)
Excellent	1,557,035
Good	2,020,921
Mod. Good	1,984,414
Mod. Poor	1,364,066
Poor	4,586,645
Very poor	6,084,142

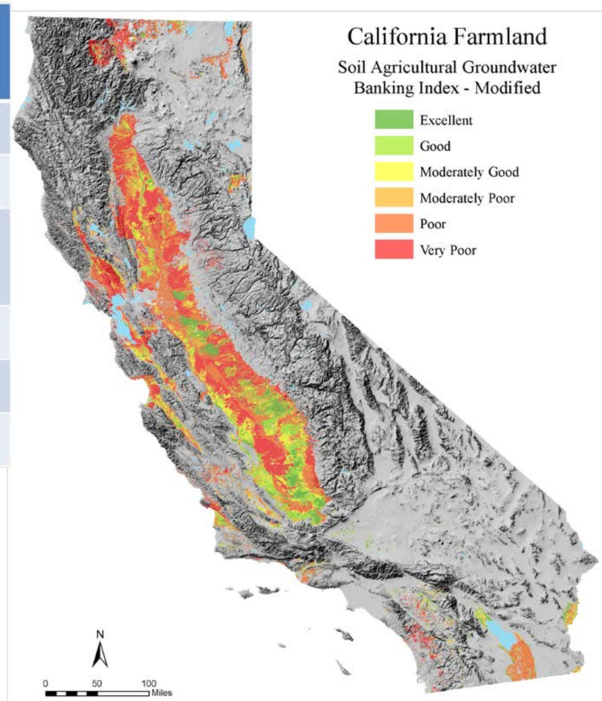

Fig. 1. Suitability index for on farm groundwater recharge, the Soil Agricultural Groundwater banking Index (SAGBI).

Maximizing use of green water: *Green water*, soil stored water from rainfall, can reduce agricultural reliance on *blue water,* applied irrigation water. The FAO-56 daily soil water balance model was used to simulate irrigation for major perennial crops in CA (alfalfa, almonds, grapes, pistachios, and walnuts), comprising ~4.1 million acres. We tested a gradient of crop rooting depths (0.5-3.0 m) and crop water stress irrigation management thresholds (30-80% allowable depletion of plant available water) to explore how varying the size of the soil water reservoir impacts the green water resource and, consequently, blue water demand. We found that green water ranged from 0.8-3.9 million-acre feet (MAF) yr^{-1} across the 30-50% allowable depletion (no crop water stress) and 0.5-3.0 m rooting depth scenarios.

Annual variability in the green water resource was driven by a threefold range in annual precipitation (2.1-6.0 MAF yr^{-1}). 60% of total green water was available in the wettest 5 of 12 years. Wet years tended to be low potential evapotranspiration years, such that the annual blue water demand was reduced more than the increase in available green water. The green water resource decreased from north-to-south, but with complicated topographic and soil property effects (Fig. 2). An opposite potential evapotranspiration gradient further meant that when combined with consideration of available green water, an even stronger blue water demand gradient exists. In total, green water cumulatively met 7-15% of growing season ET in the no crop water stress scenarios with a maximum 25% of growing season ET demand met by green water in a single year. On average, assuming 2.0 m rooting depth, 20% of the landscape can meet 20% or more of its crop water needs with green water.

Larger soil water storage reservoirs led to a higher estimate of green water availability. Surprisingly, blue water demand was reduced more than the increase in green water availability from enlarging the soil reservoir because larger soil water reservoirs allow for less frequent but deeper irrigations. This decreases the frequency of surface wetting and reduces the surface soil evaporative loss. Thus, managing the soil storage reservoir is a way to reduce reliance on blue water by delaying time to first irrigation to maximize green water and minimize evaporation. Optimizing green water use in irrigated agriculture is a formidable adaptive management challenge. But managing for green water is an attractive strategy to adapt to a more water-limited future. The total difference in blue water reliance on 4 million irrigated acres in CA could be tens of millions of acre-feet over decadal scales.

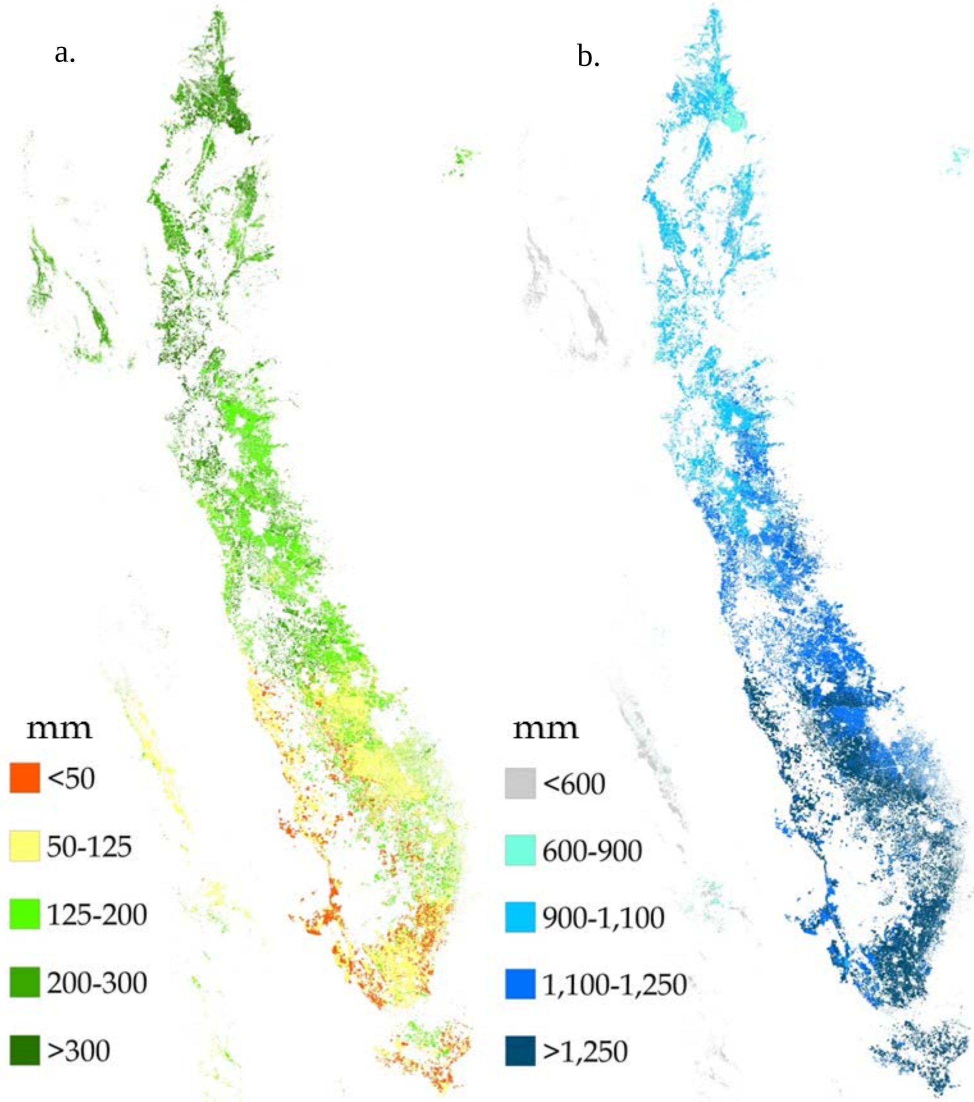

Fig. 2. Average green water (a.) and blue water (b.) utilization over a 12 year simulation using the FAO 56 model for almonds, pistachios, grapes and alfalfa.

Rangeland erosion potential: We used the Revised Universal Soil Loss Equation (RUSLE) to evaluate how low, moderate and high residual forage dry matter (RDM) levels affect erosion potential in rangelands across California. The model was adapted to operate in a Geographic Information System (GIS) to model 14.8 million of land. Average erosion potential was low among all RDM scenarios and increased from an estimated 0.05 tons ac^{-1} yr^{-1} with the high RDM scenario to 0.12 tons ac^{-1} yr^{-1} with the low RDM scenario (Fig. 3). Considering all RDM scenarios, less than 174,733 acres (0.012%) of land had erosion potential that exceeded soil loss tolerance values. Although achieving a uniform RDM target across a landscape may be an over simplification of reality, simulations suggest that sheet and rill erosion potential on average, is low in California's annual rangelands across high, moderate and low RDM recommendations.

Findings indicate that grazing management (maintaining moderate or high RDM) to mitigate erosion can be effective when targeted at areas of high vulnerability. This study shows that sheet and rill erosion on rangeland is low, but emphasizes the importance of focusing on point sources of erosion that form gulley erosion such as roads, culverts, cattle trails and stream banks.

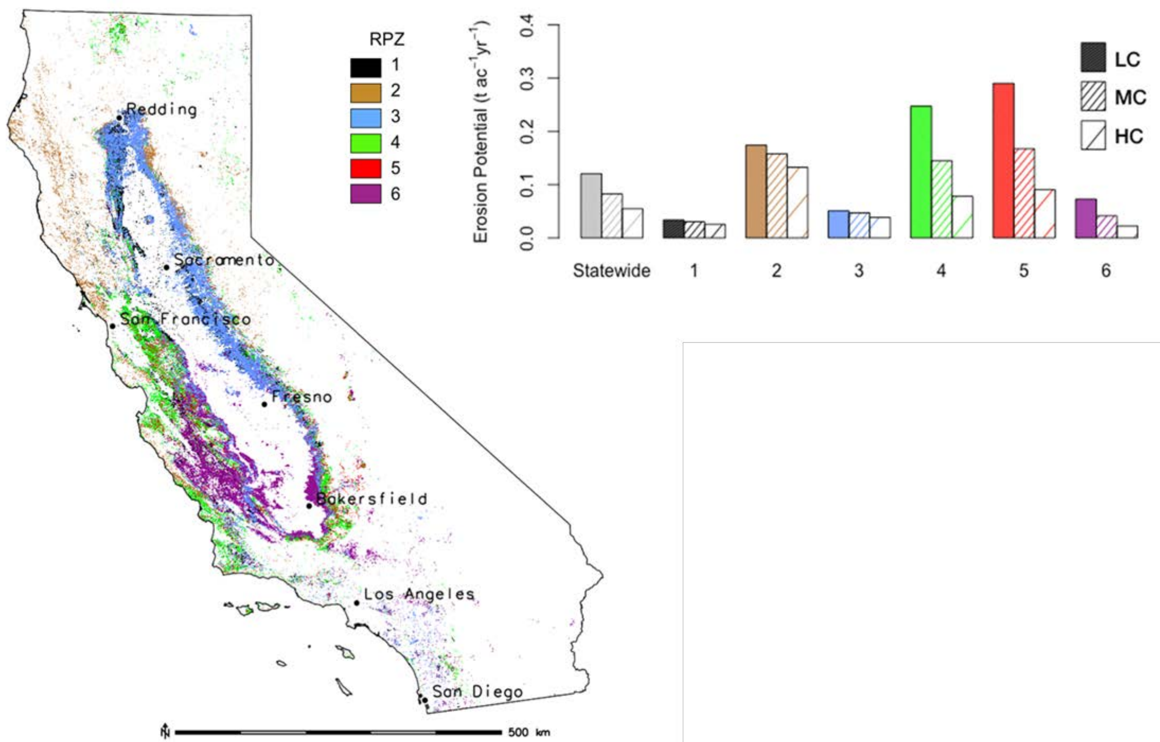

Fig. 3. Modeled soil erosion potential using the revised universal soil loss equation (RUSLE) under low, moderate and high residual dry matter. Erosion potential is reported statewide and by different rangeland management zones.

Nitrate leaching index: We created a user friendly decision support tool to predict nitrate leaching for all agricultural soils in California. The tool is place-based simulating the effects of climate zones, all agricultural soils and 58 different crops (i.e. rooting depths). It enables users to evaluate changes in management by considering different irrigation efficiencies and nitrogen application rates and times (Fig. 4). The app simulates nitrate leaching over a 12 year period delivering output which includes: nitrate leached (lbs/ac), nitrate concentration in leachate (ppm), nitrate leaching index, deep percolation (in), runoff (in) and leaching fraction (%). We anticipate that this new tool can be used to evaluate the ideal crop for a given soil and location. It can also be used to evaluate how improvements to irrigation efficiency and/or fertilizer application (rate and timing) can influence the magnitude of nitrate leaching.

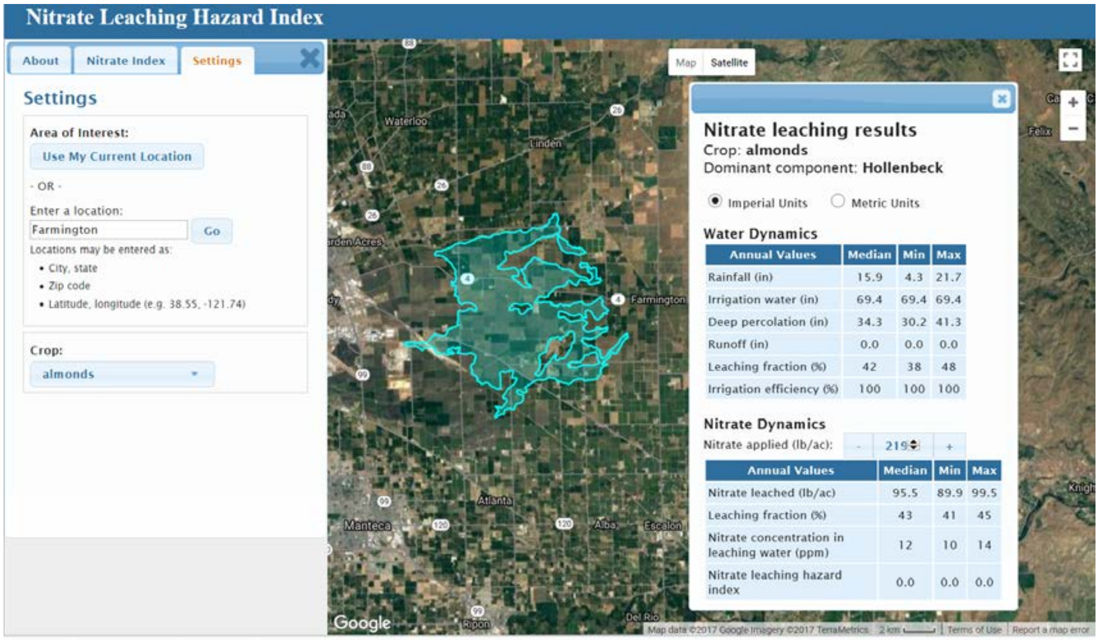

Fig. 4. Example of the beta version of the nitrate leaching hazard index app.

Phosphorus availability: A predictive map of available P and P sorption (PSI) for vineyard soils in California was created for use as a decision support tool for agriculture. We used the Random Forest algorithm, as well as environmental covariates, namely climate data (PRISIM), terrain attributes (DEM), radiometric proxies for lithology (Gamma Radiometric Data), and vegetation (NDVI-Landsat 8), coupled with SSURGO derived rasters of soil properties, to predict distribution of P availability and sorption in vineyard soils in California (Fig. 5).

The RF model was able to explain 85% of variation in P-saturation, and 83% of variation in PSI. Values for RPD, a method to standardize RMSE in the context of SD, were also very good, with RPD greater than 2.4 for P-saturation and PSI, indicating an accurate model. Results from 3 iterations of 10-fold CV were similarly promising, with R^2 of 0.74 and 0.75 for P-saturation and PSI respectively. This new tool will help to guide fertilizer management in a way that identifies which soil landscape require P regularly vs soils that may not require P at all.

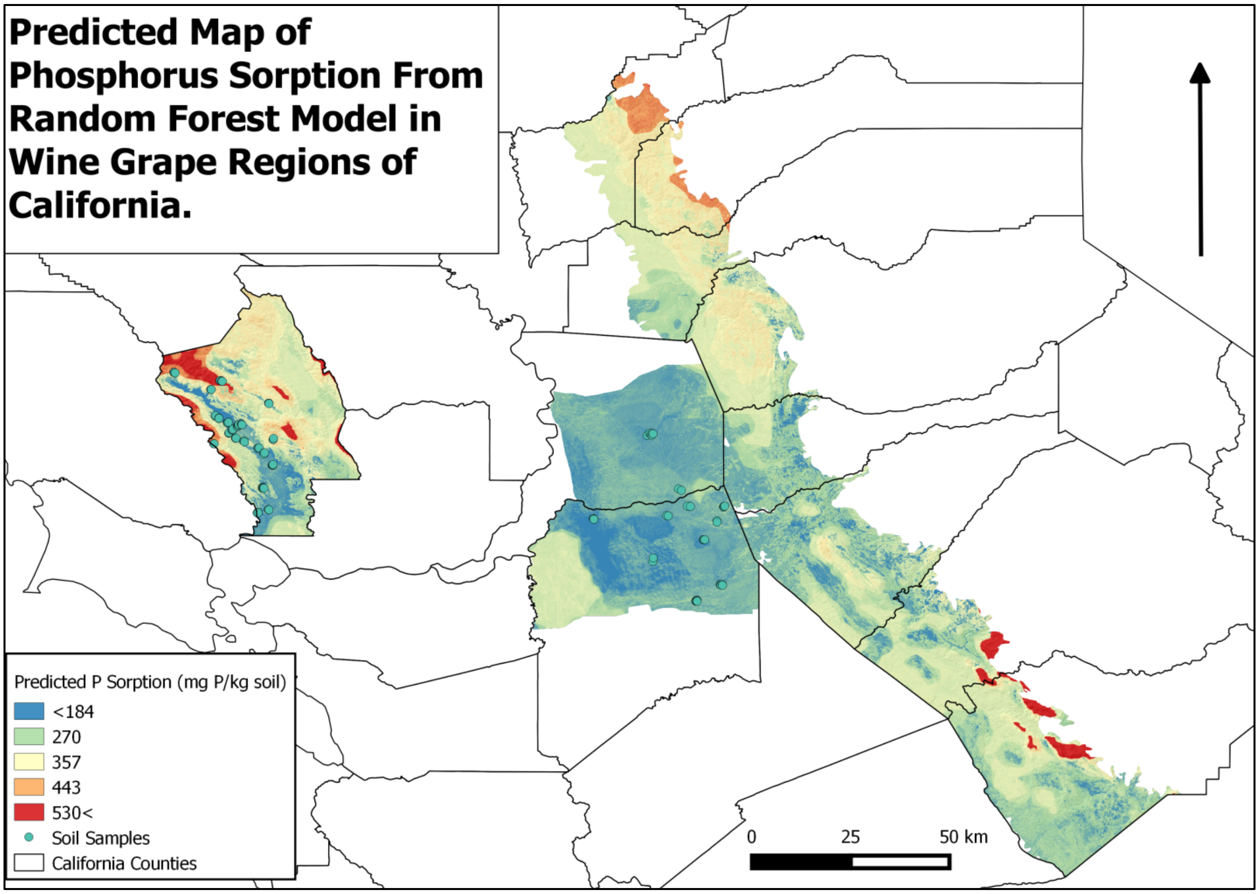

Fig. 5. Predicted phosphorus sorption from a Random Forest model in winegrape regions of CA.

Research Program

Our project had three general objectives some having multiple specific milestones. Obj. 1. Develop a suitability index for agricultural groundwater banking for the maintenance and protection of groundwater resources in CA; Obj. 2. Develop soil-landscape specific nutrient management guidelines and BMP placement tools that account for differences in nutrient transformations and losses; and, Obj. 3. Develop drought tolerance decision support tools.

The project completed six milestones that involve repackaging of soil survey for land use and policy decision-making. SoilWeb was completely redesigned and repackaged to include a suite of apps that make soil survey information more readily available for users. A nitrate leaching hazard index was created for all agricultural soils in California to establish place based nitrogen management practices. An interpretive map of erosion potential was created for annual rangelands in California simulating three different residual dry matter conditions. An interpretive map of fate of phosphorus was created for winegrapes. A time to first irrigation tool was created for walnuts, almonds, alfalfa, grapes and pistachios in order to maximize utilization of green water and reduce reliance on blue water (applied water). An agricultural groundwater banking index was created for all agricultural land in CA.

PROJECT OUTCOMES

Changes in Learning:

Soil survey information is critical to water resource management and agricultural sustainability. Unfortunately, this information is presented in ways that are difficult to understand and use by non soil scientists. We repackaged this information into a variety of decision support tools that are easy to use and understand. The raw soils data was integrated into models to create new knowledge explaining suitability for groundwater banking, nitrate leaching, maximizing green water utilization, understanding fate of phosphorus and documenting erosion. This information did not exist previously but is essential to sustainable water and land management. SoilWeb apps receive 500-1000 hits per day totaling 246,883 unique page visits since October 2015. The SAGBI app is viewed by about 16 people per day and has had almost 7,154 unique page visits since October 2015. The tremendous media coverage of SAGBI has resulted in extremely large, yet unquantifiable dissemination of knowledge on the subject.

Changes in Behavior/Practice:

Wide spread use of apps documented above indicates that this new information is changing behavior and practice. The impact of the groundwater banking study has been staggering, resulting in multiple interviews via news articles, radio and television. Scientific American highlighted this study and collaborators in its December 2015 issue: **World Changing Ideas: 10 big advances that will improve life, transform computing and maybe even save the planet.** Moreover, soils information is being actively used in water resource decision making. We have delivered 68.15 GB of geospatial data to stakeholders to characterize their basins for the new groundwater regulations. We anticipate the nitrate leaching hazard index will have equal impact given the need to characterize sustainable groundwater resource basins for SIGMA.

Change in Policy or Decision-making:

The groundwater banking project has changed how water resource managers think about flood water. According to a recent (2017) survey of local agricultural water districts by the PPIC, 75% of respondents were actively engaged in groundwater recharge on agricultural land. The main constraint to applying flood water to agricultural land was identified as infrastructure. Our three high level briefings to the Governor's office of Science and Technology and California's Secretary of Agriculture indicate that policy makers are listening. We expect equal interest in the nitrate leaching hazard index and the green water index will emerge from these new tools. Much of this will directly relate to policy and decision making given the new SIGMA requirements for groundwater management. Our erosion study will ideally lead to erosion control efforts that focus on point sources of sediment such as roads, culverts, trails and stream channels since we indicate that sheet and rill erosion is relatively low across RDM scenarios.

Changes in Conditions:
The tools created from this project are timely. Our initial product (SAGBI) was completed when the drought ended with a very wet season, which stimulated a lot of consideration of this practice. As such this practice will lead to improved infrastructure and social will to manage flood waters to promote groundwater recharge in agricultural lands across the state. Groundwater banking is currently being practiced or evaluated in over 7 different counties in California. This research will improve the sustainability of our groundwater supply.

The nitrate leaching tool is expected to have equally large impact given the new Sustainable Groundwater Management Act. Groundwater basins will need to develop Groundwater Sustainability Plans and the type of information delivered by SAGBI and the nitrate leaching tool is critical to this process saving money and providing important information. The green water tool will also help groundwater basin groups manage their water resource.

Encouraged collaboration:
This project has expanded the partnership between university of California and the National Cooperative Soil Survey (NCSS). The NCSS is a group of agencies, (NRCS, BLM, USFS, land grant institutions, and BIA) that work to develop and promote the use of soil resource inventories. Specifically, this project has identified new ways to promote the use of soil survey information. This is a key mission of the NCSS that historically has not been adequately addressed by NRCS. We have identified highly relevant issues that soil survey can directly address for water and land-use decision making. This partnership has resulted in new opportunities to integrate soils information in climate change assessments.

The nitrate leaching hazard index evolved from a partnership with CDFA-FREP. The output is also being used to evaluate regional modeling project on nitrate loss from agricultural land performed by the consulting group Planterra in a USDA-NRCS Conservation Innovation Grant.

A partnership with DWR resulted in a new data delivery tool where SAGBI is integrated with the new land use data https://gis.water.ca.gov/app/cadwrlanduseviewer/. This tool is expected to be utilized in response to SIGMA.

We provided consultation and data to the Nature conservancy and Point Blue. Its scientists are generating tools to evaluate multiple outcomes and benefits associated with on farm flooding for habitat, production, water supply and carbon sequestration in the California delta region.

This project partnered with Monterey County UCCE to host a workshop and blog designed to convey current information to maximize capture of runoff to promote groundwater recharge and minimize nitrate leaching.

Strengthened the research-extension network:
The ideas for this project were initiated by extension specialists. The specialists where informed by stakeholders and UCCE advisors of the need for these types of tools. Some arose through

personal conversations. Other projects arose with detailed planning among workgroups consisting of UCCE advisors, growers, agency staff, ngo's and policy makers. Findings have been extended through media (news and trade magazines), 63 presentations invited talks initiated by UCCE advisors and other stakeholders, web-based apps, Radio interviews, and TV interviews.

Additional resources leveraged:
This work leveraged a successfully funded grant from CDFA-FREP ($225,000) to help build the nitrate leaching hazard index. It also leveraged two CESU agreements ($80,000 each) from USDA-NRCS to build a new soil climate app that serves as a repository and data delivery mechanism for soil climate data. The SAGBI project stimulated funded studies from the Almond Board and UCANR strategic initiatives to support on farm research activities by project collaborators.

Information Transfer/Outreach Program

Policy Briefs:
On farm groundwater banking, CA Secretary of AG. State leaders in CDFA, DWR, SWRCB, Ag. Industry, Legislators, Corporations, Municipalities and Water Managers On-Farm Recharge, Sacramento, CA 10/30/2015.

Opportunities to promote sustainable groundwater resource through soil and aquifer characterization,Director of the Office of Planning and Management (OPR) and Senior Policy Advisor to Governor Jerry Brown and OPR's Community and Rural Affairs Advisor. Sacramento, CA, 10/3/2016.

Opportunities for groundwater banking. Wide variety of state, local and municipal leaders. California Economic Summit Davis, CA 10/5/2017.

Article/paper:
O'Geen, A.T., M.B.B. Saal, H. Dahlke, D. Doll, R. Elkins, A. Fulton, G. Fogg, T. Harter, J.W. Hopmans, C. Ingels, F. Niederholzer, S. Sandovol Solis, P. Verdegaal and M. Walkinshaw. 2015. Soil suitability index identifies potential areas for groundwater banking on agricultural lands. California Agriculture 69:75-84.

O'Geen, A.T., M. Walkinshaw and D.E. Beaudette, 2017. SoilWeb: A Multifaceted Interface to Soil Survey Information. Soil Science Society of America Journal 81:853-861.

Salls, W. et al., **Accepted**. Modeled Soil Erosion Potential is Low Across California's Annual Rangelands. California Agriculture Journal.

O'Geen, et al., **In Review**. Techniques to Evaluate and Modify Soils with Root and Water Restrictive Conditions. Almond production manual.

Two more papers are in progress.

Website: https://casoilresource.lawr.ucdavis.edu/

Data made available: Soil Agricultural Groundwater Banking Index geospatial data has been delivered to multiple users totaling 68.15 GB of information delivered. Groups: irrigation districts, USGS, DWR, local governments, consultants, NGOs.

We expect similar amounts of data will be distributed for the green water project, erosion project and the nitrate leaching project.

New tools/model/technology: 1. SoilWeb: http://casoilresource.lawr.ucdavis.edu/soilweb/ ; **2.** SoilWeb Earth: http://casoilresource.lawr.ucdavis.edu/soilweb-apps; **3.** California Soil Properties App: http://casoilresource.lawr.ucdavis.edu/ca-soil-properties/; **4.** Soil Series Extent Explorer: http://casoilresource.lawr.ucdavis.edu/see/; **5.** Soil Agricultural Groundwater Banking Index: http://casoilresource.lawr.ucdavis.edu/sagbi/; **6.** Nitrate leaching hazard index: https://soilmap2-1.lawr.ucdavis.edu/nitrate/ (beta version). **7.** Random Forest model of phosphorus availability and sorption in soil; **8.** Physically based model (HYDRUS 1-D) of hydrology and nitrate leaching for all agricultural soils in CA; **9.** FAO-56 hydrologic model to evaluate green water and blue water resources in CA agricultural soils.

Visual images (such as photo, GIS map, streaming video): 1. Twelve Statewide maps of the amount of green water used for 4 different crops and 3 different rooting zones; **2.** Two Statewide suitability maps for groundwater banking on agricultural soils; **3.** Two maps (phosphorus availability and phosphorus sorption) for winegrape growing regions in CA; **4.** 580 statewide maps of nitrate leached, runoff, deep percolation, leaching fraction, ET, Rainfall, nitrate concentration in leachate and nitrate leaching hazard for 58 different crops. **5.** Three statewide maps of erosion potential under high, moderate and low residual dry matter cover scenarios in CA annual rangeland. 6. One video Available tools for estimating soil suitability for groundwater banking https://www.youtube.com/watch?v=b9jd7Wt3lRE.

Extension activities: During the project period 63 educational presentations about soil survey decision support tools were delivered across the state. Most of these were about groundwater banking and using soil survey to promote informed decsions.

Other (media): Twenty eight concreate media events where soil survey decision support tools (primarily groundwater banking) were discussed on radio, newspaper, trade magazines and TV. This information has been picked up by hundreds of online and print media sources. Scientific American highlighted this study and collaborators in its December 2015 issue: **World Changing Ideas: 10 big advances that will improve life, transform computing and maybe even save the planet.**

Notable Achievements

The Issue

California does not have a sustainable groundwater supply. State-wide, estimates of groundwater overdraft are estimated to be between 500,000 to over 1.5 million acre-feet per year. To compensate for this loss, groundwater recharge must be encouraged, yet these opportunities can only occur during times of water excess such as during flood events. Considering its vast acreage, agricultural land may be ideally suited to receive flood waters to recharge groundwater. This process is termed agricultural groundwater banking.

What Has ANR Done?

We developed a soil agricultural groundwater banking index (SAGBI) to evaluate the suitability of soils to accommodate flood water for recharge, while maintaining healthy soils, crops, and a clean groundwater supply. The index rates the suitability of soils and certain cropping systems for this practice in map form across most agricultural regions in the State.

The Payoff

We found that 5.6 million acres of agricultural land could be suitable for groundwater banking. This decision support tool can be a powerful aid to decision makers and stakeholders when considering the tradeoffs associated with the implementation of groundwater banks utilizing agricultural land for direct recharge. Moreover, it can be used to inform growers of the potential hazards associated with this practice.

Include a photo.