SALINAS VALLEY IRRIGATION AND NUTRIENT MANAGEMENT PROGRAM (INMP)

12-414-553 FINAL PROJECT REPORT

Final Report

California's Proposition 84 Agricultural Water Quality Grant Program

Agreement No. 12-414-553

Total Grant Funds: $1,250,000

Coastal Conservation & Research

UCCE University of California Cooperative Extension

RESOURCE CONSERVATION DISTRICT

NATIONAL MARINE SANCTUARIES MONTEREY BAY

CCWG Central Coast Wetlands Group

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The following individuals played important roles in the inspiration, planning, management and implementation Salinas Valley Irrigation and Nutrient Management Program

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- MLML Volunteers:
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- Dayton Biological: Gage Dayton
- California Department of Water Resources (funding for planning/permitting)
- MLML: Dr. Kim Null
- CCC Watershed Stewards Program: Kyle Monper and Jenny Balmagia

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- PG&E: Jon Wilcox and Joyce Nichols
- Monterey County Water Resources Agency: Mark Foxworthy-
- Monterey County Mosquito Abatement: Ken Klemme and Jerry Rasmussen
- Durden Construction: Dodd Durden
- Pajaro Valley Laser Leveling: Bob and Chris Peixoto
- CC&R Field Team: Dr. John Oliver, Kamille Hammerstrom, Jane Echenique, Jasmine Ruvalcada, Sarah Jeffries, Dorota Szuta, Niko Oliver
- MLML, CSUMB and other Volunteers
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- California Ecological Analytics: Rob Burton and Kristy Uschyk
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Azevedo Bioreactor:

- Ag Land Trust: Sherwood Darrington,
- Stockman's Energy- Kirk Story, Alex Bugrov
- Contractor: Toni Oliveira

Spence Vegetated Treatment System:

- USDA Research Facility : Sharon Benzen
- Contractor: RDO Water
- Monterey Bay Analytical Services: David Holland

Soledad CIMIS Station

- DOLE: Joe Ferrari, Gabriel Diaz
- IDC Central Coast: Victor Ramos, Eder Tostado
- Superior Hydroseeding, Inc.
- CA Department of Water Resources: Andrew Isner, Jared Birdsall

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PROJECT BACKGROUND AND PURPOSE

The lower Salinas Valley is a 405 square mile area located on the Central Coast of California, composed of three watersheds (Lower Salinas River, Reclamation Canal and the Moro Cojo Slough) that drain into the Monterey Bay National Marine Sanctuary. The area has a Mediterranean climate that makes year round agriculture feasible, with mild temperatures and rainfall averaging approximately 14 to 16 inches per year in the farmed areas of the Valley. The highly productive land draws high lease rates with cropland renting from $350 - $3000 per acre depending on location (UCCE 2015), so growers are quite interested in maximizing crop production. Overall for Monterey County, agriculture is of enormous economic importance with crop production contributing $4.8 billion in 2015 (MCAC 2016).

Crop production is one of the four main land uses in the Lower Salinas area, representing 34% of the land coverage. Other land uses are grazing land (32%), undeveloped or forest (26%), and urban land (8%) (CCRWQCB 2013; Fig. 1). The lower elevation area of Salinas Valley is predominantly used for crop production and in this area, the hydrology and water quality is influenced by crop irrigation and artificial drainages (CCRWQCB 2013). Both surface and groundwater in the region are contaminated with nitrate and other non-point source pollutants. The addition of nitrogen fertilizer and animal wastes is the largest source of nitrate in groundwater (Harter and Lund 2012). Fertilization rates differ by crop type, with the estimated average application rate of 230 lb N/acre/crop for vegetables and berries on irrigated agricultural land in the Salinas Valley (Fig. 2, Harter and Lund 2016). To reduce groundwater nitrate loading to a sustainable level, Harter and Lund estimated a needed reduction of 70 lb N/acre/crop for vegetables and berries. Surface water is also contaminated by runoff from agriculture when applied nutrients cannot all be taken up by plants, as the water solubility of nitrate makes it easily transportable to waterbodies.

Figure 1: A) Land use in the Lower Salinas Valley and B) 303(d) listed water bodies. Used with permission (CCRWQCB 2013).

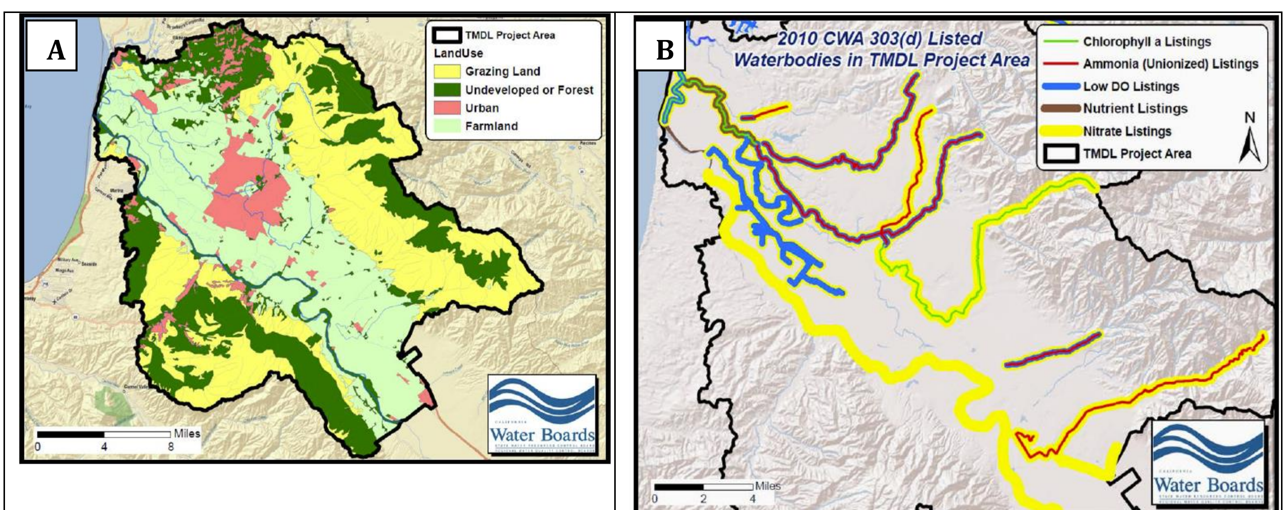
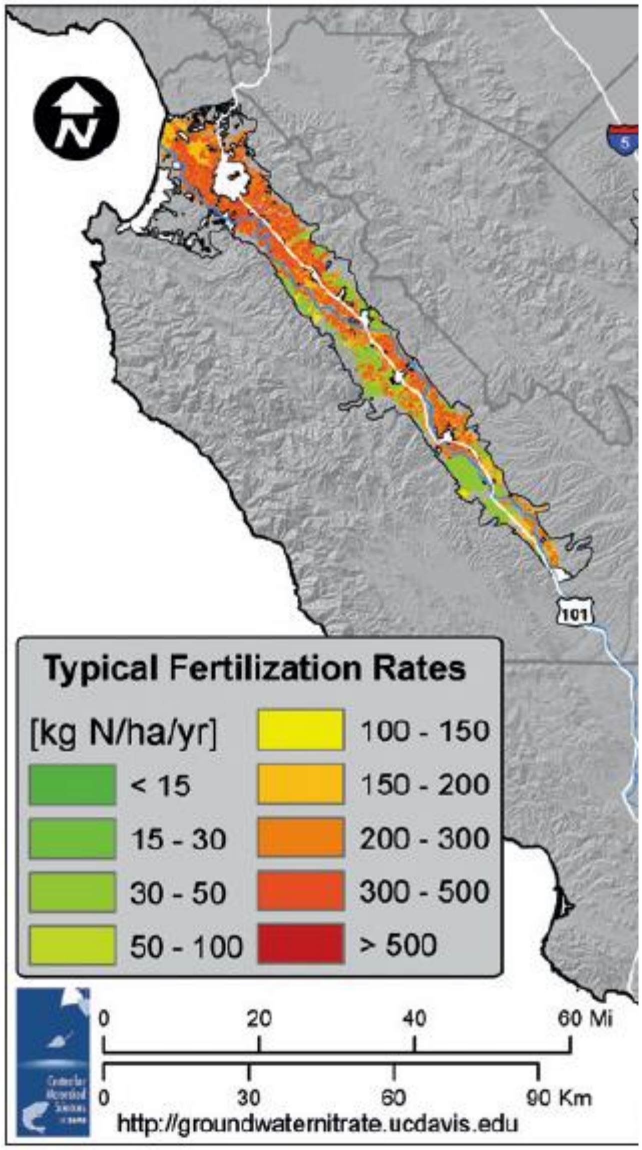


Figure 2: Typical fertilization rates in the Salinas Valley derived from literature and USDA Chemical Usage reports. Extracted from Harter and Lund 2016.



The poor water quality of many waterbodies in the Lower Salinas area has damaged their ecological condition and impaired their beneficial uses, resulting in several being placed on the 303(d) list (CCRWQCB 2013; Fig 1b). Nutrient contamination is one of the causes of impairment, and a TMDL evaluating the extent and severity of the problem was approved in March 2013 by the Central Coast Regional Water Quality Control Board (CCRWQCB). This TMDL identified that cropland constitutes over 88,000 acres comprising 34% of the three watersheds (Tembladero Slough, lower Old Salinas River, Moro Cojo Slough) included in the Lower Salinas region (CCRWQCB 2013). Seventeen surface water bodies (creeks, ditches, rivers or sloughs) in these watersheds have been identified as impaired for nutrient contamination by nitrate and/or unionized ammonia. Nitrate concentrations at one or more sampling sites in16 out of 22 waterbodies listed in the Salinas Nutrient TMDL exceeded the 10 mg N/ L drinking water standard in >50% of samples taken. Additionally, nitrate has contaminated groundwater in the Salinas area, causing a problem with drinking water obtained from wells. Unionized Ammonia concentrations in 2 out of 18 waterbodies listed in the Salinas Nutrient TMDL exceeded the 0.025 mg N/ L standard in =>50% of samples taken. Orthophosphate concentrations in19 out of 22 waterbodies listed in the TMDL exceeded the 0.3 mg P/ L standard in =>50% of samples taken (CCRWQCB 2013).

Due to the significance of agriculture to the local economy and the need to improve water quality, incorporating management practices into farming methodology is important to appropriately managing nutrient and water inputs and reducing polluted runoff. Precision management can reduce both the amount of runoff and the concentration of nutrients found in runoff. Further treatment of the remaining runoff through treatment structures such as wetlands and bioreactors can reduce or remove pollutants prior to their discharge to public water bodies. Through managing water and fertilizer inputs and treating runoff, the resulting improvements in water quality will strengthen the viability of agriculture and on the Central Coast.

Project Description

The efforts funded by this grant focused on reducing nutrient levels found in discharges from farm fields through two primary means: 1) improving the application efficiency of irrigation water and nutrients through education and direct technical assistance on the farm and 2) through nutrient treatment structures designed to remove nitrate and orthophosphate from irrigation runoff prior to discharging to public water bodies. With the high density of agricultural production found in the area and the importance of maintaining high yields to pay for agricultural rents, a combination of management practices and runoff treatment is often necessary to meet regional water quality objectives. Management practices are designed to help growers apply only the necessary amount of water and nutrients for plant growth and soil salinity management. Treatment structures, located on-farm or off-farm, remove excess nutrients remaining in the water to achieve the appropriate concentrations for beneficial uses determined by the State Water Quality Control Board prior to releasing water to a stream or other water body. Beneficial uses for the Salinas Valley waters include drinking water, groundwater recharge, agricultural supply, aquatic habitat and recreation. The overall goal of this program is to improve water quality and make progress toward restoring beneficial uses in waterbodies through education, assessment of irrigation systems and management practices, and implementation of projects.

Project Goals:

1) Provide growers with technical expertise to improve on-farm irrigation and nutrient management practices.
2) Provide growers technical and financial assistance in implementing on-site projects, infrastructures for water management, and/or sub-watershed nutrient treatment structures that can conserve water and reduce nutrient loads to water bodies or groundwater.
3) Make progress toward the achievement of the Lower Salinas Nutrient TMDL water quality targets for nitrate, unionized ammonia and orthophosphate.
4) Reduce nitrate load contributions to groundwater and surface water.

OUTREACH, EDUCATION AND RECRUITMENT

Outreach

Early in the grant process we developed an Outreach Strategy for Grower Participation and Implementation. Our strategy identified that in the first year of program outreach we would communicate to growers regarding the availability of funding for assessments and practices. We developed the goal of exceeding project maximum deliverables in terms of participation and number of assessments implemented through the following outreach activities:

- word of mouth through existing personal relationships
- direct communication with commodity group and industry contacts for solicitation of information through their networks
- presentations at commodity group meetings

We engaged in all three types of outreach activities (Table 1). The RCDMC and UCCE made personal connections with their grower contacts who are typically on the forefront of adopting management practices. These growers, termed early adopters, are typically larger growers with the means and motivation to develop their organization's skill base and the managing tools required to implement new management practices and systems. Several of these growers participated in irrigation and nutrient management assessments. Others received shorter consultations to provide technical advice and review whether the operation could benefit from further assessment. We also communicated with commodity groups and other industry contacts to solicit involvement. A notice was posted on the AWQA website that funding was available for assessments and projects through the Proposition 84 grant. Presentations were made and connections developed at commodity group meetings including Strawberry Commission meetings, an Aquaponics class, and the Salinas Valley Ag Tech summit.

As an aspect of outreach, we informed growers of the benefits of participating in the grant project, including potential for water and fertilizer N savings, complying with water quality regulations and improving the calibration of water and nutrient management tools. Growers were also informed of the grant phases (consultation, assessment and implementation) and the required shared information for each phase. This ensured that the grower had full knowledge of the reporting obligations prior to their involvement.

Education

The purpose of education was to improve the knowledge base of growers, their organizations and also technical service providers regarding technologies and practices available to aid their decision making for irrigation water and nutrient applications, so they can more reliably apply the right amount of water and nutrients at the right time to meet the needs of the plant through stages in its growth cycle. More precise application of water and nutrients affects water quality through minimizing leaching to ground water and reducing or eliminating runoff. Most training sessions were designed to provide growers and other members of their organizations with an understanding of the concepts of irrigation and nutrient management and with hands on use of the hardware and software tools to aid them (Fig. 3). The types of training sessions offered are listed below:

- ALBA training conducted in Spanish on basic irrigation
- ALBA training and direct assistance with developing a farm plan
- CropManage hands on workshops
- Nutrient budgeting workshops regarding the different forms of nutrient additions and their accounting, eg fertilizer, organic N mineralization rates, nitrate in water and soil.
- Annual UCCE Irrigation and Nutrient management meetings to convey the most recent research findings
- AWQA meetings to share information and review research related to innovative nutrient removal technologies
- Drought and Irrigation Conservation Training
- Strawberry Commission Irrigation Training
- Nitrogen Management Training for Certified Crop Advisors

Hands on training for pressure management of irrigation systems

Photo: Pam Krone on 3/11/14

AWQA meeting on Nitrate Removal Technologies including information on efficiency, footprint and cost.

Photo: Pam Krone on 4/20/16

Figure 3. Photos from Educational Events.

Education has a long lasting benefit because what is learned can be built upon and applied over several years of operation and support, as well as being shared with others. Relationships that are formed during training events are built upon and trust is gained through time and effort. After trust is built, the grower is ready to try implementing management changes in his operation. Some growers, who started by attending a training event, later asked for technical support or for an assessment. Other growers utilized internal consultants to aid them in adopting practices and tracking results. Consultants attended the training sessions and passed the knowledge on to others in their grower organizations. A hands on irrigation training event, in one case, lead to specific requests for in-house training for field managers in irrigation management. Another grant was obtained for doing this training.

Recruitment:

The purpose of recruitment was to rally growers to participate in on-farm consultations and assessments and also to garner interest in on-site or off-site treatment practices. Through our outreach activities we were able to recruit 14 growers in the region to participate in nutrient and/or irrigation management assessments, often on multiple farms and over several crop cycles. We reached out to growers and landowners where the potential for a treatment structure could be considered. Our strategy was to identify acreage within sub-watershed drainages sufficient to achieve measurable nutrient reduction and to target outreach activities to explore landowner willingness to participate in a project. Forming and developing land owner relationships requires an ongoing effort and the patience to progress at a pace that is comfortable to the land owner. Commitment of land to a conservation project and to maintaining that project for its useful life covers a long time horizon. Careful consideration by the landowner, especially on parcels where ownership is shared by multiple individuals or a large corporate entity, takes time and represents a substantial commitment. We were successful in gaining the agreement of one large non-farming corporation, a government owned research station, a nonprofit organization and two large farming operations for the installation of 5 different structural technologies. We also developed many relationships with additional growers and landowners that we hope will result in their agreement to install future practices on their land.

Table 1. Outreach, Education and Recruitment Activities

Date	Event	Number of Contacts
1/30/2014	UCCE Nutrient Budgeting Workshop	3
2/4/2014	2014 Annual Central Coast Strawberry Meeting	2
2/5/2014	Monterey Bay Conference on Water Quality	4
2/12/2014	UCCE 2014 Irrigation and Nutrient Management Meeting	1
2/25&26/14	Nitrogen Management Training for Certified Crop Advisers	5
3/11/2014	Strawberry Irrigation Management Educational Program	5
3/18/2014	Assessment of Soil Moisture and Irrigation Scheduling	3
3/27/2014	Salinas Valley Ag Technology Summit	1
1/29/2014	ALBA Basic Irrigation	29
2/7/2014	ALBA Developing a Farm Plan	26
1/1/14 to 3/31/14	Personal contacts with growers	6
4/10/2014	2014 Drought and Irrigation Conservation Conference	70
4/19/2014	Aquaponics Class & Tour	3
5/1/2014	CropManage Workshop	35
6/19/2014	Irrigation Efficiency& water conservation in Nurseries	3
7/9/2014	AWQA Meeting	25
12/3/2014	ALBA Grower Event Farm Lease & Mixer	30
11/12/2014	AWQA Meeting	4
12/10/2014	AWQA Meeting	20
1/14/15 - 1/15/15	Strawberry Commission Irrigation Training	30
1/14/2015	AWQA Meeting	8
2/19/2015	2015 Irrigation and Nutirent Management Meeting	35
3/11/2015	AWQA Meeting	10
3/26/2015	Salinas Valley Ag Technology Summit	4
4/2/2015	CropManage Hands On Workshop	45
4/2/2015	INM Workshop	18
4/8/2015	AWQA Meeting	30
6/10/2015	AWQA Meeting	20
Total	Number of Events = 28	475

Sharing and Building on Successes

Our outreach strategy included sharing project successes through commodity groups and UCCE grower meetings, partner newsletters, the RCDMC website, and local media so that we could build community awareness of the importance of these collaborative undertakings.

Website Presence: The RCDMC website and the Central Coast Action Tracker (CCAT, https://www.ccactiontracker.org/site/map) websites display the implementation projects accomplished through this grant. Information shared on these websites may provide inspiration to motivate other organizations to adopt nutrient management practices.

AWQA Meetings: Project progress was shared with AWQA partners throughout the course of the project in regular bi-monthly meetings. A presentation of each project and the resulting benefits to water quality will be presented at an AWQA meeting in early 2017.

Local Media: Local media covered the opening ceremony for the PG&E Treatment Wetland, advertised as the Castroville reflooding event in memory of the wetlands that once predominated the lower Salinas Valley. KSBW, Monterey's local television news station, covered the opening of the ceremony on their November 8, 2016 newscast: http://www.ksbw.com/article/moss-landing-project-aims-to-make-ag-runoff-water-cleaner/8341998. KION also covered the opening, available at http://www.kion546.com/news/18-acre-wetland-in-castroville-set-for-re-flood/171050256

The Monterey County Herald covered the story in their 11/18/16 article "Castroville wetland restoration project to help clean agricultural water" available at http://www.montereyherald.com/environment-and-nature/20161118/castroville-wetland-restoration-project-to-help-clean-agricultural-water.

The Santa Cruz Sentinel ran an article: http://www.santacruzsentinel.com/environment-and-nature/20161118/castroville-wetland-restoration-project-to-help-clean-agricultural-water

THE COMMUNITY CELEBRATES THE OPENING OF THE PG&E TREATMENT WETLAND

"We're really thrilled to be part of this project, this living classroom, to help show the benefits and the value of wetlands and naturally filtered water." Diane Ross-Leech, P,G&E

"This wetland will help clean up pollutants that would otherwise enter the Monterey Bay National Marine Sanctuary." Pam Krone, MBNMS

"Our local growers are really some of the most responsible when it comes to caring about what happens to their runoff." Mark Stone, CA Assembly

"Being part of the project was a good way to demonstrate commitment to improving agricultural practices." Dale Huss Co-owner of Sea Mist Farms.

Figure 4: Opening Day Ceremony at the PG&E treatment wetland. Photos: Pam Krone on 11/18/16.

Long Term Implementation Strategy:

The work undertaken through the support and funding of this Proposition 84 grant provided the opportunity for meaningful advancement of the regional effort to increase precision resource management of water and nutrients and to implement structural practices to reduce nutrient concentration and load from agricultural runoff. Despite the progress made, accomplishing the water quality objectives of the region remains a formidable goal that will require the ongoing collective and collaborative efforts of many individuals and organizations over a long time horizon. Project partners on this grant developed a long term implementation strategy that summarizes our ongoing efforts and long term strategy:

The reduction of nutrients in runoff to surface water and leachate to groundwater from irrigated agriculture on the Central Coast remains a commitment of all partners involved in this Proposition 84 grant project: Coastal Conservation and Research Inc., Central Coast Wetlands Group, Monterey Bay National Marine Sanctuary, California Marine Sanctuary Foundation, Resource Conservation District of Monterey County and UC Cooperative Extension. We intend to continue to provide outreach and training in management practices and technologies, to provide ongoing research and technical support to the grower community, and to develop remediation projects in the Lower Salinas Valley that enable more precisely controlled irrigation and nutrient management and that reduce the nutrient load reaching surface and groundwater. We feel that partnerships in grants and unfunded efforts, where each organization contributes their special talents and capabilities, can advance agriculture in the region toward more rapid attainment of objectives for water quality, environmental health, and agricultural sustainability.

Our long term implementation strategy is to continue partnering with one another as well as with other committed organizations in both unfunded efforts and grant projects that will allow us to further our efforts to improve water quality, environmental health and agricultural sustainability. We built a strong platform demonstrating many successes through our Proposition 84 grant, and we plan to build on this platform by continuing to lead and support similar activities in the future. This platform includes outreach, training, irrigation and nutrient management assessments, close working collaborations with growers, implementation projects that remove nutrients, and monitoring that demonstrates effectiveness.

Grant partner organizations are involved in organized and ad hoc relationships related to the joint efforts described below. Some of the unfunded or partially funded efforts that involve progress toward the goals represented by the Prop 84 grant include the following collaborations:

Agricultural Water Quality Alliance (AWQA): The mission of AWQA :

Working together we will protect and enhance water in the Monterey Bay National Marine Sanctuary and the adjacent watersheds while sustaining a world class production agriculture region through voluntary collaboration with managers of agricultural and rural lands.

All Prop 84 partners have led and participated in AWQA events in the past and plan to continue to do so in the future. The AWQA strategic plan includes objectives and strategies for improving water quality, providing technical support to growers, outreach and communications to the public and the ag community and being a forum for problem solving. AWQA partners determine specific AWQA events, collaborate on grants and develop close working relationships through monthly meetings.

Nutrient Cooperative Approach: The nutrient cooperative approach is a partner driven effort to work toward achieving water quality objectives with growers located in a common subwatershed through management practice improvement and the implementation of nutrient removal structures. By developing cooperation between growers in the subwatershed with technical and professional support from Prop 84 grant partner organizations, the Grower Shipper Association, and The Nature Conservancy, we anticipate we can better determine the types and location of practices that will provide the largest advancements in water quality using the most affordable strategies for growers. We also hope to reduce the regulatory burden and liability risks faced by growers, and thus provide incentives to participate in the cooperative.

CropManage: CropManage is an online decision-support tool developed by UCCE under the leadership of Michael Cahn, to provide suggestions for the amount and timing of fertilizer and water application through various stages in the plant growth cycle. Ongoing research involving field trials enables adding new crops to the CropManage system and demonstrates the effects on crop yield of following CropManage recommendations. CropManage technical support is regularly provided by UCCE in classroom training sessions and through individual relationships with growers. Technical support in using the CropManage system was part of the irrigation and nutrient assessment work accomplished through our Prop 84 grant. CropManage is a system supported and promoted by grant partners through outreach, training, technical support, and research.

Assessments: Continue work on assessments. Work with growers in the Blanco and Moro Cojo Slough subwatersheds to provide assessments and recommend management practices through funding provided by the NRCS Conservation Innovation Grant and Coastal Conservancy funds.

In addition to the collaboration mentioned above, partner organizations are undertaking or proposing the following grant projects to advance our objectives:

- Resource Conservation District of Monterey County:
    - Complete designs for Blanco Drain treatment wetlands projects and pursue non-SWRCB funding sources for their implementation (mostly likely options DWR/IRWMP or CDFA).
    - Develop Santa Rita Creek Stream Management Plan with Monterey County using Coastal Conservancy funds (Integrated Watershed Restoration Program) to support designs and permits for projects to improve water quality draining to and in Santa Rita Creek
    - Implement education and training and technical assistance projects as funded by CDFA Specialty Crop Block Grants Program and DWR Ag Water Use Efficiency Program.
    - Initiate NRCS Conservation Innovation Grant (CIG) nutrient management cooperative project starting in 2017.

- Central Coast Wetlands Group
    - Compare the effectiveness of multiple runoff treatment systems in parallel (CDFA Specialty Crop Block Grants Program)
    - Build bioreactor in the upper Salinas river near the town of King City (design and or permitting)
    - Initiate CIG nutrient management cooperative project starting in 2017.

- California Marine Sanctuary Foundation/ Monterey Bay National Marine Sanctuary
    - Seek future funding to take advantage of outreach potential of the Focus Projects for demonstrations to the ag community
    - Initiate CIG nutrient management cooperative project starting in 2017.
    - Assist NASA/CSUMB in the validation of NOAA's Forecast Reference Evapotranspiration (FRET) model.
    - Seek grants to continue on Assessment funding and the Equipment Loan program for recommended improvements.

- University of California Cooperative Extension
    - Continue to support strawberry growers in the use of CropManage and to lend equipment such as flow meters so growers can assess their effectiveness in regard to irrigation application.
    - Participate in Specialty Crop Block Grant as a partner with CDFA to demonstrate irrigation and nutrient best management practices on vegetable crops.
    - Continue work with large growers and their consultants in regard to field equipment installation, operation and maintenance for irrigation management.
    - Expand CropManage to new crops (celery, alfalfa, orchards) and to new regions (CA Central Valley).
    -
- Coastal Conservation and Research Inc.
    - CCR will continue to provide native plants, seeds, greenhouse facilities, biological expertise, long-term maintenance, and administrative support for many of the projects initiated by our partners

Six projects resulted from the Proposition 84 grant, two for improving the application efficiency of irrigation and nutrients and four projects designed to remove nutrients from field runoff. The 2 projects with the purpose of increasing application efficiency were 1) irrigation and nutrient management assessments, recommendations and implementation and 2) the installation of a CIMIS station near Soledad. The 4 nutrient removal projects were 1) the Spence vegetated treatment system, 2) the Oceanmist bioreactor, 3) the PG&E treatment wetland and 4) the Azevedo bioreactor.

The primary purpose of both application efficiency and nutrient removal projects was to reduce nutrient loads entering surface and groundwater from irrigated land. Load reductions were computed for each project based on and grower interviews for project 1 and monitoring data for projects 2-5 (Table 2A). For the Oceanmist bioreactor, we reported the percent load reduction and not the numeric reduction because we have an agreement with the landowner not to share actual numbers. The Azevedo bioreactor and CIMIS station did not have monitoring data and load reduction could not be computed.

Table 2A: Estimated load reduction for each of the 6 projects based on current monitoring data.

			Nitrate		OrthoPhosphate	
#	Project	Project Type	Percent Load Reduction	Estimated Annual Load Removal (kg/yr)	Percent Load Reduction	Estimated Annual Load Removal (kg/yr)
1	INM Assessment & Implementation	Application Efficiency	ND	191,400	ND	ND
2	CIMIS Station	Application Efficiency	ND	ND	ND	ND
3	PG&E Treatment Wetland	Nutrient Removal	44%	2912	66%	148
4	Oceanmist Bioreactor	Nutrient Removal	42%	NA	29%	NA
5	Azevedo Bioreactor	Nutrient Removal	ND	ND	ND	ND
6	Spence Vegetated Treatment System	Nutrient Removal	100%	0.2	100%	0.1

In the case of wetland and bioreactor projects, nitrate removal is likely to increase as maturation is approached and then level off once maturation is achieved. The performance of newly constructed wetlands improves through time as plants become established and microbial communities develop in the bottom sediments and on plant surfaces. We computed an anticipated mature removal rate for the PG&E wetland based on the median value found by Kadlec (2009) in his study of 205 surface flow wetlands. Using this rate, we computed the load reduction the PG&E Constructed Wetland is likely to achieve at maturity. Similarly the Oceanmist bioreactor performance will improve as biological denitrifying bacteria communities are established and flow issues are addressed. We estimated the likely removal rate at the Oceanmist bioreactor based on the median denitrification rate found by Leverentz et al. (2010) for 5 woodchip bioreactors. We also show the predicted annual nitrate load removal and the capital cost associated with the nitrate removal for each of the Projects in Table 2B.

Table 2B: Estimated load reduction for each of the 6 projects at maturation and capital cost of nitrate removal.

#	Project	Project Type	Nitrate: Predicted with maturation		Capital Cost of Nitrate Removal		
			Estimated Percent Load Reduction	Estimated Annual Load Removal (kg/yr)	Estimated Project Life	Asset or Service Cost (not including O&M)	Capital Cost per kg of Nitrate Removed* ($/kg)
1	INM Assessment & Implementation	Application Efficiency	ND	191,400	10	$323,485	$0.17
2	CIMIS Station	Application Efficiency	ND	ND	20	$143,100	ND
3	PG&E Treatment Wetland	Nutrient Removal	84%	5950	20	$600,000	$5.04
4	Oceanmist Bioreactor	Nutrient Removal	59%	NA	20	$93,000	$1.23
5	Azevedo Bioreactor	Nutrient Removal	73%	3.6	20	$32,000	$444.44
6	Spence Vegetated Treatment System	Nutrient Removal	100%	0.5	20	$85,615	$8561.50*

*** The capital cost of nitrate removal at the Spence VTS is higher than other projects due to the substantial decrease in fertilizer and water application the grower achieved through best practices. The VTS is capable of a much higher removal rate than was observed, however due to very low inputs of water and nitrate it was not operated to full capacity.**

Projects also provide ecosystem and human benefits beyond the removal of non-point source pollutants. These benefits include water conservation, reduced nitrate leaching, habitat restoration, outreach and education, beautiful open space, demonstration sites for consideration by other growers, and locations for further research (Table 2C). Specific examples of these benefits include the Spence Vegetated Treatment system, which was used to demonstrate how carefully calculated nutrient and irrigation water addition can result in almost no runoff to the VTS during the growing season. The grower at this location managed irrigation so precisely that only two runoff events occurred in both the summer of 2015 & 2016 generating an average of less than 5000 gallons of runoff per event, all of which completely infiltrated prior to reaching the outlet in the VTS. He managed fertilizer so precisely that this runoff only contained 3.3 mg/L of nitrate. UC Davis Granite Canyon lab also used the Spence VTS for pesticide removal trials and provided grower outreach at the site regarding trial results. The PG&E constructed wetland is another example of high value added beyond nutrient removal. It provides habitat value for fish, reptiles, amphibians, birds and small mammals as well as putting land into open space in perpetuity. This wetland restoration project has supported the implementation of a critical portion of the Moro Cojo management plan.

Table 2C: Project benefits to the ecosystem and human endeavors.

Project	Project Benefits
INM Assessment & Implementation	Nutrient removal, water conservation, education
CIMIS Station	Nutrient removal, water conservation
PG&E Treatment Wetland	Nutrient Removal, habitat restoration*, outreach and education, beautiful open space, demonstration site, location for further research
Oceanmist Bioreactor	Nutrient removal, location for further research
Azevedo Bioreactor	Nutrient Removal, outreach and education, demonstration site, location for further research
Spence Vegetated Treatment System	Nutrient Removal, outreach and education, demonstration site, location for further research

*** Habitat restoration at PG&E wetland is valued at $240.000**

IRRIGATION AND NUTRIENT MANAGEMENT ASSESSMENTS, RECOMMENDATIONS AND IMPLEMENTATION

The purpose of irrigation and nutrient management (INM) Assessments is to help growers effectively manage their irrigation water and nutrient additions to meet crop needs so that nutrient loads to ground water and surface water are reduced. Effective INM helps the region make progress toward several environmental objectives including reduced groundwater and surface water contamination, reduced groundwater use, agricultural sustainability, and healthier stream and ocean habitats. INM should also benefit the grower through reducing the cost of adding excessive fertilizer, reducing water and pumping costs and achieving regulatory compliance. Each grower faces a different set of circumstances that play a role in their choice of management practices that will work best for their organization, current irrigation system, crop type and geo-physical setting. For this reason, on-farm assessments are the most effective way to help growers accomplish INM goals.

Three types of INM assessments were offered through grant funding: irrigation distribution uniformity, irrigation scheduling and nutrient management.

> **Distribution Uniformity (DU)** is the cornerstone for irrigation management, because uniform water distribution means an even application of water across all plants in the field. In the absence of even water distribution, irrigation water addition must be sufficient to satisfy the plants receiving the least amount of water. This results in over watering of the plants receiving more water through the irrigation system. Once maximum possible distribution uniformity is achieved, precision management of the application of irrigation water can follow. The concepts of DU can be misunderstood so multiple visits and follow up are recommended to gain full organizational acceptance and ongoing implementation by the farming operation. Conducting initial meetings separately with the farm manager and the technical irrigation staff is an important first step for establishing a relationship and an information exchange based on what is relevant to each. Follow up and verification that practices are still in place after a time period can help accomplish the oversight and maintenance requirements to sustain even DU. Our work with farming operations typically followed several phases: Outreach > Assessment > Report > Follow Up Consultation > Implementation > Verification .
>
> **Irrigation Scheduling:** Irrigation scheduling relates to the time, rate and duration of the application of irrigation water to the crop. Irrigation scheduling can be accomplished through highly automated systems that monitor soil moisture and automatically apply water based on these measures or through a simple process of an irrigator turning a valve and timing the application for a given period. Our irrigation scheduling evaluations focused on the use of soil moisture sensors and evapotranspiration as the basis for scheduling irrigation and when appropriate, the use of CropManage as a system for tracking and recommending irrigation amounts and timing.
>
> **Nutrient Management:** Nutrient management plans document available nutrient sources, production practices, and other management practices that influence nutrient availability, crop productivity and environmental stewardship. CropManage was also used to recommend fertilizer amounts and timing of fertilizer applications. Fertilizer

recommendations were based on soil test values of nitrate-nitrogen and the crop growth stage using crop specific nutrient uptake models.

Consultation Summary

Consultations with growers sometimes precede more extensive irrigation and nutrient management assessments, and are a way to let growers know what benefits can be obtained through assessments. At other times they help growers obtain professional advice regarding specific issues or questions. A summary of consultations provided through this grant project is shown in Table 3.

Table 3: Consultations with growers included vegetable and berry growers managing over 1000 acres of production.

Quarter	Crop Type	Irrigation Type	Acreage Represented	Hours
Q1 2014	Strawberries & vegetables	drip/sprinkler	120	6
Q2 2014	Strawberries	drip/sprinkler	480	4
Q2 2014	Vegetables & strawberries	drip	30	4
Q4 2014	Strawberries, cane berries and vegetables	drip/sprinkler	10	4.5
Q4 2014	Strawberry	drip/sprinkler	6	30
Q4 2014	Cauliflower	drip/sprinkler	8.7	20
Q1 2015	Strawberries	drip	200	3
Q1 2015	Vegetables	drip/sprinkler	200	3
Q1 2015	Strawberry	drip/sprinkler	1	16
TOTAL			**1055.7**	**90.5**

Assessment Summary

Three types of assessments were offered to growers. Assessments of one or more types were conducted on 469 acres of land over 30 different fields related to 7 different crop types involving 12 growers (Table 4). All three types of assessments were performed on 8 fields. Assessments were performed for 4 large farming operations (> 1000 acres), for 2 operations between 500-1000 acres, for 3 operations between 50-500, and for 3 small operations (<50 acres).

Table 4: Three types of assessments were offered to growers covering 7 crop types and 3 types of irrigation systems, sometimes in combination for different parts of the growth cycle.

					Irrigation System			Assessment Start Dates		
Grower	Farming Operation Size (acres)	Region	Crop Type	Acres	drip	sprinkler	furrow	Irrigation System Evaluation	Irrigation Scheduling	Nutrient Management
A	> 1000	N Salinas	Iceberg Lettuce	8.2	x	x			3/20/2014	3/20/2014
A	> 1000	N Salinas	Iceberg Lettuce	9.2	x	x		4/20/2014	4/11/2014	4/11/2014
A	> 1000	N Salinas	Iceberg Lettuce	10.2	x	x			3/27/2014	3/27/2014
C	>1000	Soledad	Iceberg Lettuce	35	x	x		6/14/14		4/18/2014
C	>1000	Soledad	Iceberg Lettuce	32.8		x			4/24/2014	4/24/2014
E	>1000	Castroville	Iceberg Lettuce	15	x	x			4/10/2014	4/10/2014
G	<50	S Salinas	Winegrapes	13	x			1/31/2014		
H	103	Soledad	Winegrapes	28	x			5/16/2014		
I	<500	N.Salinas	Strawberry	5	x			6/29/2014	4/1/2014	4/1/2014
A	> 1000	N Salinas	Iceberg Lettuce	13	x	x			6/8/2014	6/8/2014
A	> 1000	N Salinas	Iceberg Lettuce	12.9	x	x		7/26/2014	6/7/2014	6/7/2014
C	>1000	Soledad	Iceberg Lettuce	10.8		x		8/1/2014	6/18/2014	6/18/2014
C	>1000	Soledad	Iceberg Lettuce	10.8		x		8/13/2014	6/18/2014	6/18/2014
C	>1000	Soledad	Iceberg Lettuce	19.4		x	x		6/25/2014	6/25/2014
C	>1000	Soledad	Iceberg Lettuce	8		x	x	5/8/2014		
C	>1000	Soledad	Iceberg Lettuce			x	x		6/30/2014	
C	>1000	Soledad	Iceberg Lettuce	20		x	x	8/12/2014		
A	> 1000	N Salinas	Iceberg Lettuce	8.2	x	x		5/11/2015	3/20/2015	3/20/2015
A	> 1000	N Salinas	Iceberg Lettuce	8.2	x	x			6/27/2015	6/27/2015
C	>1000	Soledad	Iceberg Lettuce	9.85	x	x			4/16/2015	4/16/2015
C	>1000	Soledad	Iceberg Lettuce	10		x	x		4/24/2015	4/24/2015
C	>1000	Soledad	Iceberg Lettuce	10.8		x			4/30/2015	4/30/2015
J	>1000	S Salinas	Cauliflower	8.7	x	x			11/26/2014	11/26/2014
J	>1000	N.Salinas	Spinach	16		x			4/21/2015	
C	>1000	Soledad	Broccoli	10.5	x	x			5/14/2015	5/14/2015
M	>500	Soledad	Broccoli	10		x		4/16/2015		
C	>1000	Soledad	Celery	51					7/9/2015	
B	< 500	N Salinas	Strawberry	12	x			3/26/2015	12/5/2014	12/5/2014
B	< 500	N Salinas	Strawberry	12	x			3/26/2015	12/1/2014	12/1/2014
I	>500	N.Salinas	Strawberry	6	x	x			11/6/2014	11/6/2014
J	>1000	N.Salinas	Celery	19	x	x	x		7/15/2015	
K	>500	S Salinas	Strawberry	6.48	x			3/27/2015	11/28/2014	11/28/2014
K	>500	S Salinas	Strawberry	4.5	x					11/29/2014
L	<50	N.Salinas	Strawberry	1	x	x		1/26/2015	11/12/2014	
L	<50	N.Salinas	Strawberry	1	x			2/1/2015		
N	<50	N.Salinas	Strawberry	3	x			4/26/2015		
C	>500	Gonzales	Broccoli	10	x				7/28/2015	7/28/2015
12 Growers	**9323**	**5 Areas**	**7 Crop Types**	**470**	**25**	**26**	**6**	**18**	**28**	**25**

Common Lessons Conveyed during Distribution Uniformity (DU) Evaluations:

Figure 5 shows photos of equipment used or reviewed during Distribution Uniformity evaluations. Assessments cover the benefits of using pressure regulators, how to measure pressure on drip lines in the field, and a review of the irrigation system and its performance. The grower is provided an irrigation efficiency report with findings and recommendations.

Figure 5: Irrigation Efficiency Evaluations. Photos Michael Cahn 2015.

Findings from DU Evaluations
Based on DU evaluations, the percent of DU was measured and recommendations were made to growers for improving DU (Table 5). Drip irrigation systems tend to have higher DU than do sprinkler systems, indicating that the entire field receives more even amounts of water. Greater uniformity enables more efficient irrigation because excess water does not need to be applied to the crop areas receiving a lower amount of water.

Table 5: DU evaluations completed on 18 fields show the spreads found in distribution uniformity.

Irrigation method	Number of fields	Distribution Uniformity		
		Average	Mininum	Maximum
		------------------------% Dulq ------------------------		
drip	11	85	64	94
sprinkler	5	66	56	76
Total	16	76	56	94

The following points were the major findings of issues that prevented uniformity in drip irrigation systems:

- Pressures varied between submains
- Pressure in the field lines was too low
- Pressure fluctuated during the irrigation set
- Emitters were plugged
- Pressure was lost at hose leads
- Organic and mineral material plugged the lines

Sprinkle irrigation systems had a different set of problems that prevented uniform water distribution. Below are the issues found with sprinkler systems:

- The nozzle discharge rate varied
- Spacing of sprinkler lines was uneven
- Significant ponded water occurred in some furrows
- The nozzle pressure varied.

Recommendations for improving DU on drip systems.
To overcome the issues commonly found for drip irrigation systems, a number of recommendations were provided. Many recommendations were similar across farms:

1. Add pressure reducing valve (PRV)
2. Install Schrader valves before and after PRVs.
3. Add or maintain a filter.
4. Flush drip lines regularly to reduce plugging.
5. Increase pressure in submain
6. Fix Tape Issues: same lot, right type, fix leaks
7. Use shorter & wider lead hoses,
8. Set all gate valves to a similar pressure

9. Add low pressure drain valves.
10. Change manifold design to allow flushing
11. Set all gate valves to same pressure

Recommendations for Distribution Uniformity on sprinkler systems.
Five sprinkler system DUs were performed and recommendations made included the following system maintenance and upgrade suggestions. Most recommendations were unique to each farm.

Drip Irrigation Recommendations:

1. Maintain nozzles
2. Investigate pressure losses in the main.
3. Increase pressure in laterals to 50 psi and make all laterals a uniform length.
4. Replace broken sprinklers and leaky gaskets.
5. Eliminate long laterals at field perimeter
6. Use a uniform nozzle size.
7. Irrigate sets of equal size and time.
8. Add pressure reducing valve
9. Set all gate valves to a similar pressure.

Drip System Recommendations Implemented
All growers who received DU evaluation reports were contacted by phone for a follow-up interview to find out whether the recommendations provided to them in the irrigation evaluation reports were implemented. Of the 18 fields where DUs were conducted, 13 reports were provided to growers with recommendations. In the DU Reports, a total of 48 practices were recommended and 36 practices were implemented. A barchart showing the recommended and implemented practices for drip irrigation systems is shown in Figure 6.

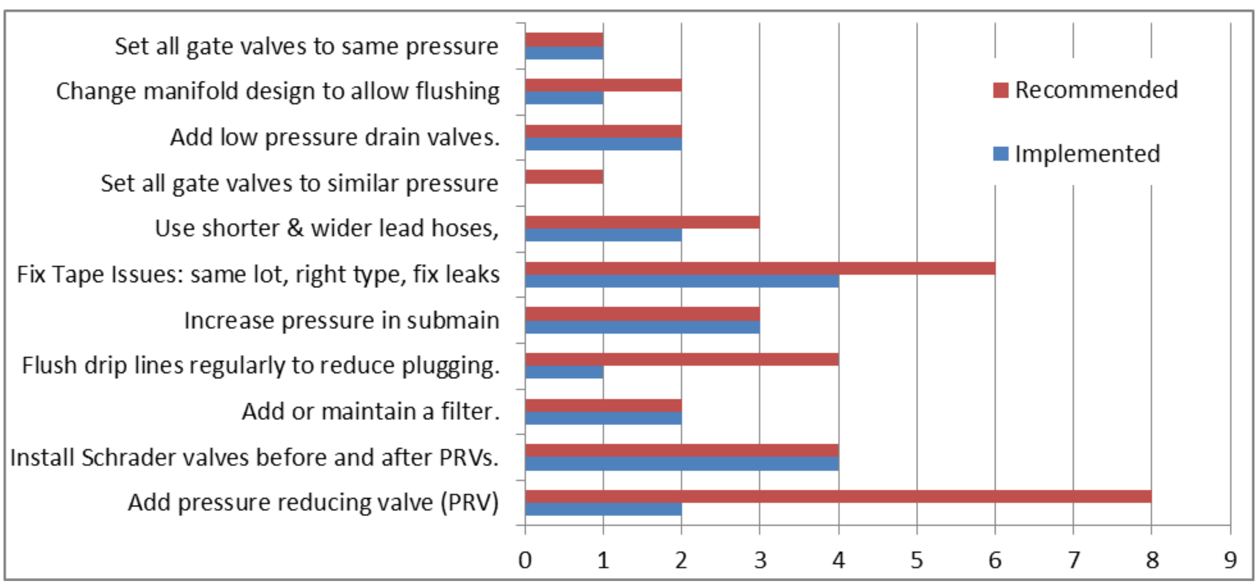


Figure 6: Common recommendations for improving DU in drip irrigation systems and the number of recommendations that were implemented, based on grower interviews.

On the 5 fields using sprinkler irrigation where DU evaluations were completed and reports provided, recommendations for improving sprinkler irrigation systems were unique for each field. Most recommendations (81%) for bringing about improvement were adopted. The recommendations adopted are bolded in the list below and those not adopted are in unbolded font:

Sprinkler System Recommendations:

1. **Irrigate sets that are equal in size and for the same amount of time**
2. **Irrigate during periods of low wind**
3. **Replace worn nozzles with new nozzles of uniform size**
4. **Replace broken sprinklers and leaky gaskets**
5. **Straighten leaning sprinklers**
6. **Increase pressure in laterals to 50 psi**
7. Make all laterals a uniform length
8. **Replace broken sprinklers and leaky gaskets.**
9. Increase diameter of submain
10. Eliminate long laterals at field perimeter
11. **Replace leaky gaskets.**
12. **Add a submain at the middle of the field**
13. **Continue maintenance of nozzles**
14. **Investigate pressure losses in mainline.**
15. **Add pressure reducing valve**
16. **Set all gate valves to similar pressure**

Irrigation Scheduling Assessments:
Irrigation scheduling is about placing the amount of water the plant needs in its root zone at the time it requires water to avoid stress. Irrigation scheduling assessments provided grower and irrigator assistance in the use of equipment for measuring soil moisture, tracking and transmitting water use, and incorporating the use of software decision support tools, such as CropManage (Fig. 7).

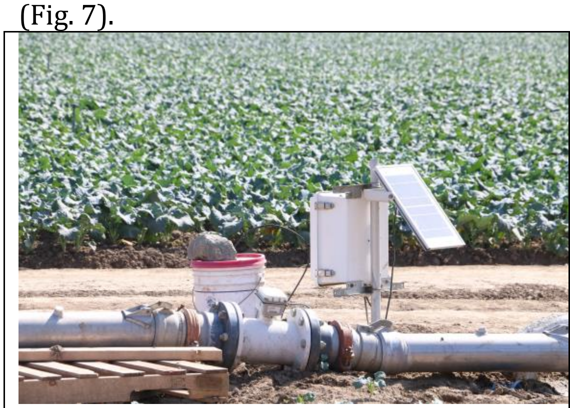


Photo: Michael Cahn 2015.

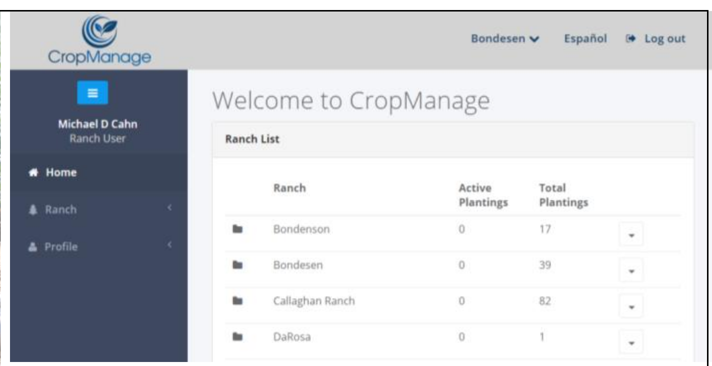


Figure 7. A) A water meter & data logger with a cell modem transmits water-use information to CropManage. B) CropManage provides recommendations for water and nutrient applications for use by growers in the decision making process and for tracking purposes.

Recommendations for Irrigation Scheduling.
Out of the 28 farm fields where irrigation scheduling assessments were performed, many farms received the same recommendations (Fig. 8).

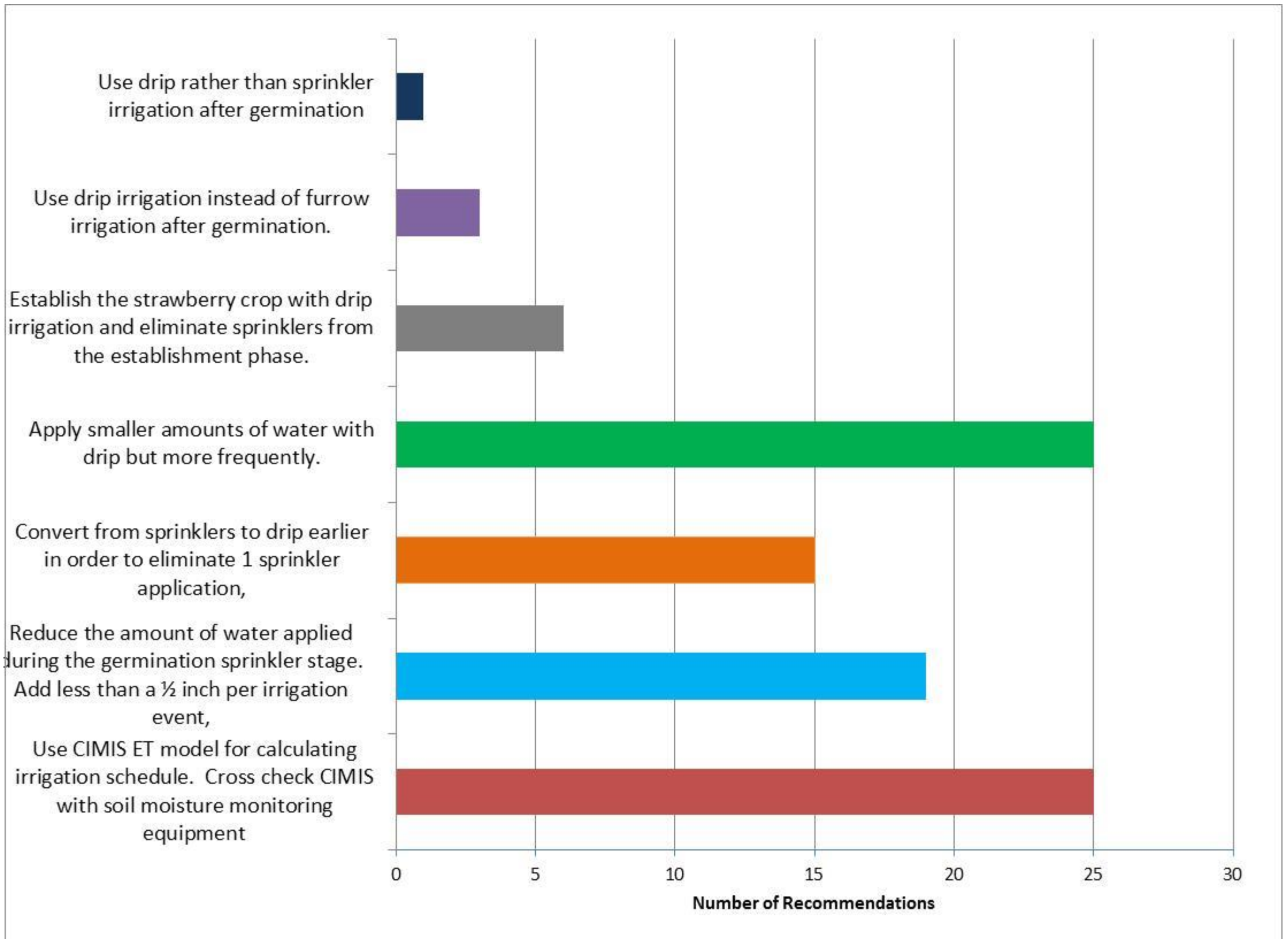


Figure 8. Common recommendations for irrigation scheduling.

Nutrient Management Assessments:
Nutrient Management Assessments included information on soil nitrate testing, computing nitrate application from irrigation water and creating a nitrogen budget (Fig. 9). They also include the 4 Rs (right nutrient, right amount, right location, right time) and how to avoid the common mistakes made with fertilizer addition.

Figure 9. A) Soil sample cores are removed from the field at multiple locations and combined. B) combined samples are tested for nitrate concentrations using quick nitrate test strips. Photo credits Michael Cahn 2015.

Recommendations for Nutrient Management.

Out of the 25 farm fields where nutrient management assessments were performed, most received the same recommendations as shown (Fig. 10).

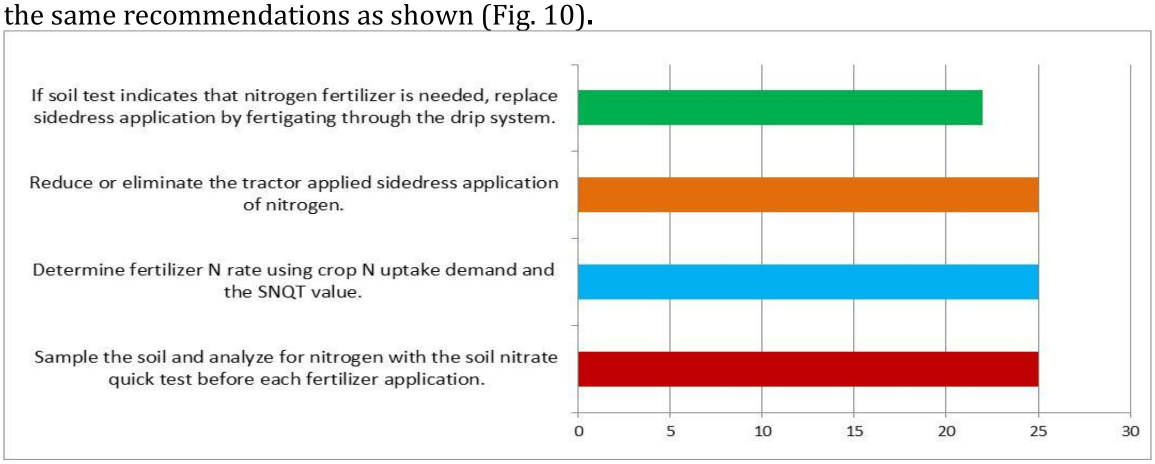


Figure 10. Common recommendations for nutrient management.

STATUS AND PERFORMANCE

Assessments were performed on a total of 469 acres on 35 fields (some fields were assessed twice during different plantings) that ranged in size from 1 acre to 51 acres. A total of 12 different growers managing 9323 acres were assisted. The benefits of performing an assessment typically exceed the actual acreage receiving assessment, as most participating growers manage large farm operations, some with more than 1000 acres of crops. Growers report that lessons learned through assessments are commonly carried over to multiple fields and the benefits extend to the entire operation, hopefully over a long time frame and multiple crop cycles. Growers demonstrated an investment in the assessments and recommendations made. They regularly asked their field staff to participate in DU evaluations, devoted staff to providing input so we could conduct thorough and complete assessments, and spent time understanding the results and recommendations from assessments. In one case, a grower hired a software development company to develop a tablet application for use by his field crew so that they could record water application information needed to utilize the CropManage system.

At the start of the Project we had a goal for the number of irrigation and nutrient management assessments set at 5 irrigation assessments and 5 nutrient management assessments. We surpassed our goal, accomplishing a total of 18 distribution uniformity assessments, 28 irrigation scheduling assessments and 25 nutrient management assessments. Many growers requested both irrigation and nutrient management assessments and some growers requested these assessments across multiple fields and crop types. Crop types where assessments were performed included strawberries, iceberg lettuce, spinach, celery, winegrapes, broccoli and cauliflower.

Assessments were held across multiple areas within the Lower Salinas Valley. The map in Figure 11 shows the number of fields where one or more assessment was conducted. On some fields, all three types of assessments were performed.

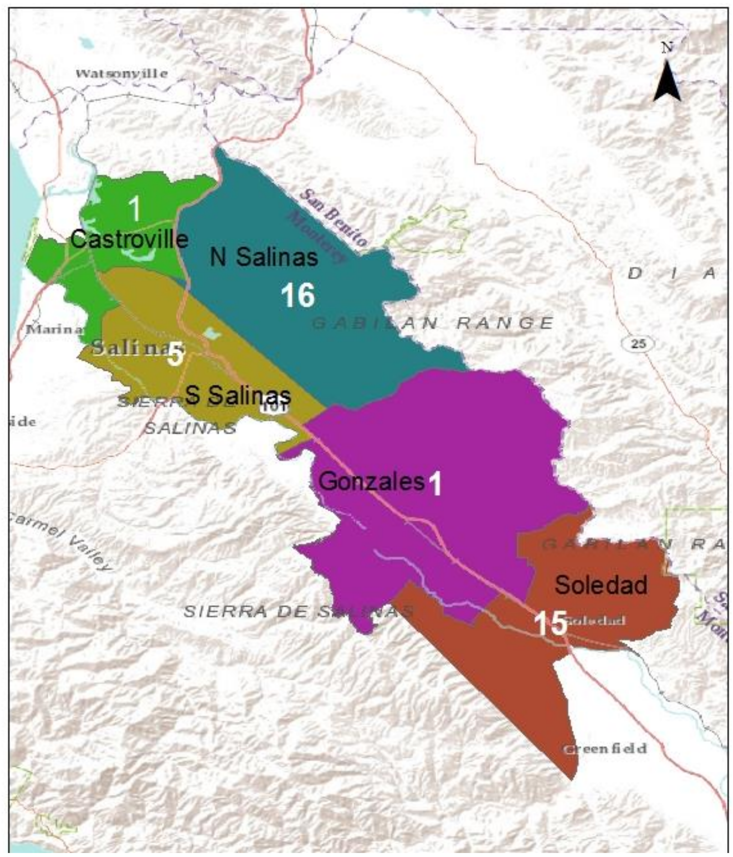


Figure 11: Map showing the number of fields where at least one type of .

Project Assessment and Evaluation Plan (PAEP): Goals and Accomplishments

We established a PAEP goal that between 50% to 75% of growers receiving assessments would independently, without the support of grant money, implement at least one BMP included on the assessment recommendation form. We conducted phone follow up interviews to discover whether recommendations were followed to obtain this information.

All 9 growers who received assistance with DU evaluations were contacted by phone and reported on the practices implemented on their farms based on recommendations in the DU Reports they received. All the growers (100%) who received DU assistance installed at least one practice. Of the 18 fields where DUs were conducted, one or more recommendations were implemented and funded by the grower except on 1 field. This field already had achieved a high DU of 93% and the benefit to the grower from another small incremental gain was not sufficient to warrant the change. Out of the 48 total practices recommended on DU Reports, 35 practices were implemented or 73%.

Of the 8 growers who received irrigation scheduling and nutrient management assessments, 5 growers were interviewed by phone to determine the water and nutrient savings estimated or measured from implementing practices. For irrigation scheduling assessments, they were asked for estimated or measured reductions in the irrigation water applied compared with past usage. For nutrient management assessments, they were asked for the measured or estimated reduction they achieved for fertilizer application. Some growers reviewed fertilizer purchases from previous years prior to receiving the recommendations of the nutrient assessment and compared these purchases with subsequent fertilizer purchases in order to estimate reduction in N applied to the field. Of those reached, all of them (100%) had implemented at least one recommendation. All growers interviewed stated they had implemented many recommendations extensively across their entire operation, not only in the fields assessed.

We estimated the total savings of water and nutrients to the Lower Salinas watershed from Irrigation Scheduling and Nutrient Management Assessments, however this did not include an estimate of water savings from DU improvements. We computed the average fraction saved as the actual decrease reported per acre of irrigation water over CropManage recommendations for water and nutrient applications from the 5 growers interviewed. We used these averages to extrapolate to the farming operations of the 3 growers who were not interviewed. Based the actual savings reported and the extrapolations, our estimated annual water and nutrient savings to the Lower Salinas Valley through this project is summarized below:

Estimated Water and Nutrient Savings

- ✓ Total acres managed by growers involved in irrigation scheduling and nutrient management assessments and DU Evaluations: 9323 acres
- ✓ Estimated water savings to the Lower Salinas Valley: 2704 acre-ft/yr
- ✓ Estimated fertilize N reduction in the Lower Salinas Valley: 211 tons N/yr
- ✓ Cost over 10 years: $0.37 /lb of N fertilizer reduced

Because CropManage is used to track water and fertilizer usage in comparison with recommended amounts, Table 6 also shows the reduction that would have occurred if all management recommendations had been fully implemented.

Table 6: Grower estimates or measurements of the reduction in irrigation water and nutrient application across their entire farming operation. Also shown are the potential savings based on CropManage recommendations. NR means not reached for an interview.

Grower	Farming Operation Size (acres)	Reduction in Irrigation (inches/acre/year)	Reduction in Fertilizer Application (lbs N/acre/year)	Irrigation Scheduling Potential	Nutrient Management Potential
		Grower measured or estimated irrigation water reduction as ___ inches per acre per year across his operation.	Grower measured or estimated fertilizer application was reduced by ___ pounds N per acre per year across his operation.	Following these irrigation management recommendations would have reduced the total amount of irrigation water applied to this crop by ___ inches.	Following these nutrient management recommendations would have reduced the nitrogen fertilizer application by ___ lbs N per acre.
A	2700	3	73	3	147
B	300	3	35	0	77
C	4000	3.6	52.5	9	198
E	600	NR	NR	0	0
I	540	3	0	0	0
J	160	NR	NR	5	16
K	200	NR	NR	3	50
L	40	12	28	18	50
Total* or Average	8540*	5	38	5	67

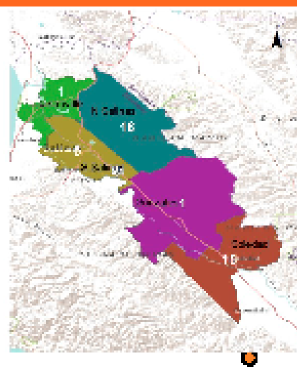
Irrigation and Nutrient Management

Description

The purpose of irrigation and nutrient management (INM) Assessments is to help growers effectively manage their irrigation water and nutrient additions to meet crop needs so that nutrient loads to ground water and surface water are reduced. Effective INM helps the region make progress toward several environmental objectives including reduced groundwater and surface water contamination, reduced groundwater use, agricultural sustainability, and healthier stream and ocean habitats. INM can benefit the grower through reducing the cost of over fertilizing, reducing water and pumping costs and achieving regulatory compliance. Each grower faces a different set of circumstances that play a role in their choice of management practices that will work best for their organization, current irrigation system, crop type and geo-physical setting. For this reason, on-farm assessments are the most effective way to help growers accomplish INM goal.

By involving growers, farm managers and irrigators in the evaluation & assessment, knowledge and skills are transferred. Although the assessment is applied to a single block, the learnings are commonly transferred across the entire grower operation.

PROJECT LOCATION



Three types of INM assessments were offered through grant funding:

Distribution Uniformity (DU) evaluates the uniformity of water distribution across the field and recommends improvements to the irrigation system so all plants will receive the same amount of water.

Irrigation Scheduling relates to the time, rate and duration of the application of irrigation water to meet crop water needs. Our irrigation scheduling evaluations focused on the use of soil moisture sensors and evapotranspiration as the basis for scheduling irrigation and when appropriate, the use of CropManage as a system for tracking and recommending irrigation amounts and timing.

Nutrient Management: Nutrient management plans document available nutrient sources, production practices, and other management practices that influence nutrient availability, crop productivity and environmental stewardship.

Practice Adoption

Assessments of one or more types were conducted on 469 acres of land over 30 different fields related to 7 different crop types involving 12 growers.

DU evaluations
Number Conducted: 18 total (13 drip, 5 sprinkler irrigation systems)
Recommendations: 48 recommendations, 36 implemented (75%)
Irrigation Scheduling & Nutrient Management Assessments
Conducted 28 Irrigation and 25 nutrient management assessments
12 growers involved
Farm water savings: 3-12 in/acre-ft/yr
Farm fertilizer savings: 0-73 lbsN/acre/yr
Estimated Salinas Valley Benefit
Area managed by 12 growers involved: 9323 acres
Estimated water savings to the Lower Salinas Valley: 2704 acre-ft/yr
Estimated fertilizer reduction: 211 tons N/yr

Partnerships

UC Cooperative Extension and RCDMC provided the technical assistance and the decision support software, CropManage. Grower organizations covered the cost of improvements and employee time. The project was funded by SWRCB Prop 84 grant # 12-414-553.

Prop 84 Grant Funding

State Water Resources Control Board's Proposition 84 Agricultural Water Quality grant paid for the technical assistance. Professional services match was provided by NRCS and UCCE.
Assessment Costs $323,500
Grower: Costs: time, upgrades & maintenance. Benefits: water & fertilizer savings, record keeping & tracking, and reduced risk of con-

FOR MORE INFORMATION

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STRUCTURAL PROJECTS

Six projects resulted from the Proposition 84 grant, five of which were structural (Table 7; Fig. 7). Structural projects were chosen based on defined criteria determined by the TAC and shown below. During the grant, a total of 9 projects were ranked against these criteria and the top 5 were chosen for development.

SITE SELECTION CRITERIA FOR STRUCTURAL PROJECTS

1. Growers:

a. Grower is willing to participate and accept grant requirements.

b. Grower shows willingness to maintain BMPs for their useful life.

2. Water Quality:

a. Select sites that will result in improvement to water quality (surface water or ground water) that either:

- Demonstrates load or concentration reduction
- Makes improvement towards attainment of the Basin Plan WQ objectives or compliance with the CCRWQCB Ag Order

b. Monitoring the WQ improvements resulting from the BMPs is feasible at a reasonable cost to demonstrate effectiveness.

3. Location/Geography:

a. Site is located where there is runoff or leeching of nitrate to an impaired water body or groundwater basin.

b. Site must be located within impaired, high priority areas of the Salinas River, Tembladero, or Moro Cojo watersheds.

<u>Ranking Considerations</u>

Give priority to:

a. Implementation projects in sub-watersheds where a cooperative downstream treatment project (eg VTS, wetland, bioreactor) is viable and incorporates multiple farm operations.
b. Sites with the largest potential to reduce nitrate concentration based on the On-farm assessments.
c. Sites where the project cost is economical and allows sufficient funding for 3 or more projects.
d. Sites that will address TMDLs or improve conditions for identified beneficial uses.
e. Sites where the grower is willing to participate in cost sharing.
f. Sites where the grower is willing to work cooperatively, to share and demonstrate the effectiveness of BMPs to other growers/ resource agencies either through tours and/or through the Central Coast Action Tracker.

g. Sites add to the cumulative effect that leads to a quantifiable improvement to water quality.
h. Sites that make up a variety of practices and structures that add diversity to the “tool box” in achieving water quality improvement
i. If two sites are exactly the same, but one grower will allow on farm monitoring, select that one for more quantifiable results.
j. Sites in a sub-watershed that have had assessments; a need is demonstrated (poor water quality); and there is opportunity for off farm treatment structures or a combined regional treatment.
k. Sites where upstream operations have incorporated best management practices related to irrigation and nutrient management.
l. Sites that are clustered in a subwatershed area to lead to increased measureable downstream results.

Table 7. Five structural projects showing the sub watershed, 303(d) listing, acreage treated or supported and crop types.

Project Name	Subwatershed	Acreage Impacted	Crops	CMP Site Downstream	Waterbody 303(d) nutrient Listing	CMP Site Nitrate Mean	CMP Site Ammonia Mean
PG&E Treatment Wetland	Moro Cojo, Castroville Slough	600	brussel sprouts, artichokes	306MOR	ammonia	1.56	0.3
Oceanmist Bioreactor	Moro Cojo	100	Burssel sprouts, artichokes	306MOR	ammonia	1.56	0.3
Soledad CIMIS Station	Salinas River, El Toro Creek	60,000	vegetables, grapes	309SAG	nitrate	2.28	0.08
Spence Vegetated Treatment System	Quail Creek	86	vegetables, strawberries	309QUI	nitrate, ammonia	30.62	1.82
Azevedo Bioreactor	Elkhorn Slough	10	strawberries	306ELK	none	1.77	0.09

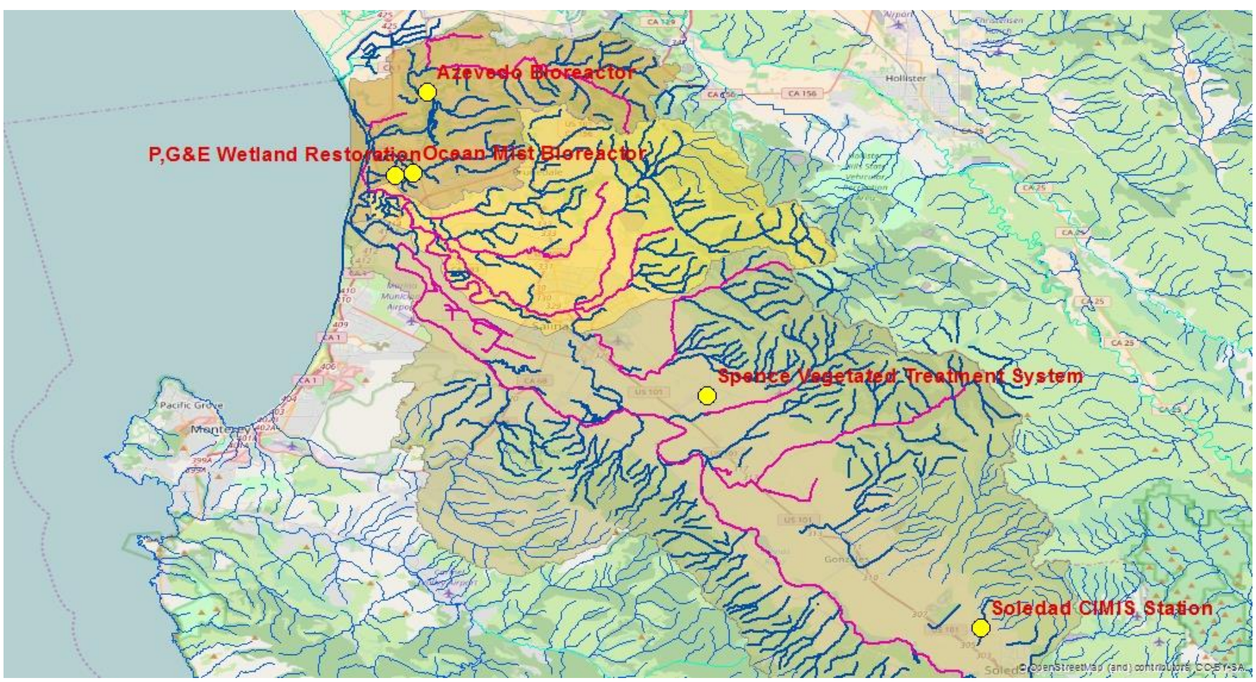


Figure 12. Map showing structural project locations. Pink lines represent 303(d) listed waterbodies.

SOLEDAD CIMIS STATION

DESCRIPTION

The Soledad CIMIS is a structural project related to improving application efficiency of water and nutrients. In order to determine the amount of irrigation water a plant needs, reference evapotranspiration is calculated based on meteorological data gathered by the CIMIS station. Through the use of both reference evapotranspiration data and crop coefficients, decision support tools used by growers calculate crop-specific plant water needs. Measuring locally representative climate data increases the accuracy of forecasting crop water needs and boosts the confidence of growers to utilize this information in their irrigation scheduling. By irrigating to match plant water needs, excess water is not applied and the potential for leaching nutrients to groundwater is reduced.

California Irrigation Management Information Systems (CIMIS) stations are a network of weather stations for use by California growers that provide evapotranspiration data for calculating crop water needs. Meteorological data including wind speed, temperature, solar radiation and other parameters are used to calculate reference Evapotranspiration (ET_0) and uploaded to an easily accessible website: http://wwwcimis.water.ca.gov/. The Soledad CIMIS Station will be included in this information network to provide localized ET_0 for farms representing approximately 60,000 acres of irrigated agriculture in Salinas Valley between Gonzalez and Greenfield. ET_0 in combination with crop coefficients can be used to estimate field (soil and plant) water loss and estimate crop water demands. Data is sent on an hourly basis to the CIMIS website, where ET_0 data can be accessed: www.cimis.water.ca.gov/ This information, along with other factors, augments growers' ability to determine irrigation water application amounts and timing.

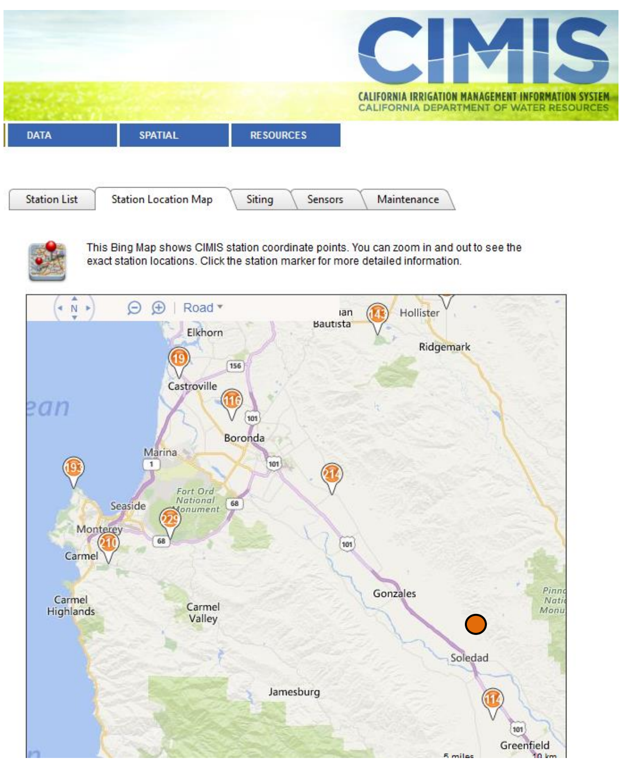


Figure 13: Location of Soledad CIMIS

Location: The Soledad CIMIS station is located between the North Salinas and Arroyo Seco stations in Salinas Valley (Fig. 13) . It monitors climate variables from atop irrigated fescue grass covering 2 acres of land. Having the grass coverage is important to creating the climate conditions found on irrigated crop land. With this grass as a controlled variable, the reference evapotranspiration data collected at different CIMIS stations corresponds to the same conditions and can be used in calculating crop water needs for corresponding local areas experiencing similar weather patterns. Wind speed is the most influential variable causing water loss in vegetation. Because of the spatial variability of wind in the Salinas Valley, having more accurate and locally relevant wind speed data can increase the confidence of growers in using this information to determine crop water needs.

Use in Decision Support Tools: CropManage is a decision support tool developed by UCCE to help growers estimate crop irrigation water and nutrient needs at different stages in the plant growth cycle (Fig. 14). Suggested amounts of water and nutrient addition provided by CropManage are based on the research done by UCCE in studies of crops including romaine and iceberg lettuce, broccoli, cauliflower, cabbage, spinach, celery, onions, and berries. As more research is consummated on different crops, these are added to the CropManage system. CIMIS ET_0 data is incorporated into the CropManage to recommend specific crop water needs based on other information added by the grower.

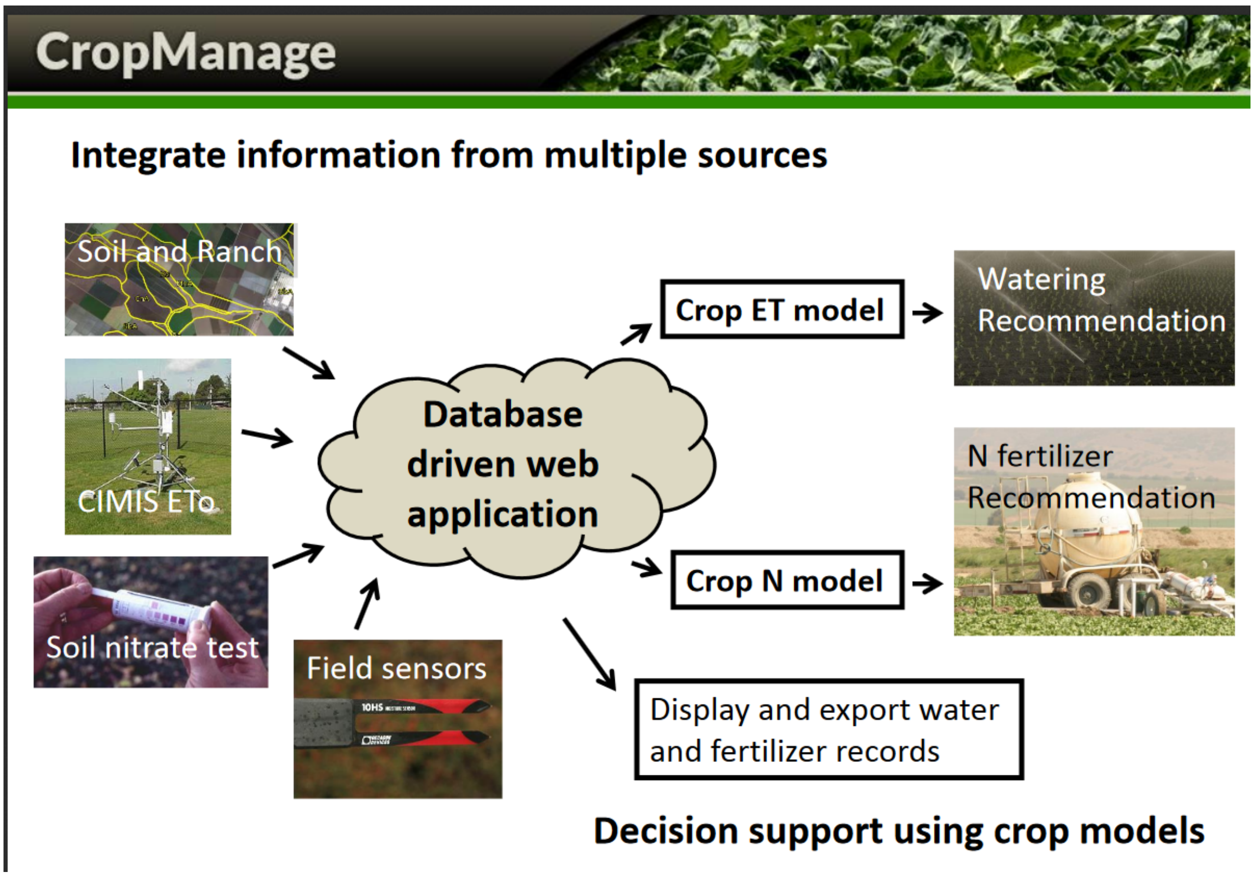


Figure 14: Information that is used by CropManage software to recommend irrigation and nutrient application amount and schedule.

As the importance of conserving water and avoiding nitrate leaching below the root zone has escalated, growers are increasingly concerned with precision irrigation practices. Growers can have increased confidence in ET data when a weather station is located in close proximity to their fields and measures the actual conditions where they are farming, especially in windy areas like the Salinas Valley. Multiple benefits for the region and the individual grower can be gained from precise irrigation to match crop needs, which include:

- avoiding the need to over-apply fertilizer due to leaching,
- reducing irrigation runoff,
- reducing contamination of groundwater with nitrate,

- reducing groundwater use and slowing aquifer depletion,
- cost savings,
- avoiding plant stress from under or over watering,
- and aiding with regulatory requirements.

STATUS AND PERFORMANCE

The Soledad CIMIS Station #252 is transmitting evapo-transpiration data, which is available on the CIMIS website for download (http://www.cimis.water.ca.gov/) and use by growers farming 60,000 acres of irrigated land in this area. The CIMIS station was fully installed in October 2016 with an irrigation system, weather station, cell tower for data transmission and planted grass. However there was a delay in getting it operational online due to grass establishment issues. The first grass was planted in October of 2016, but due to a substantial weed seedbank and early rains, excessive weed growth occurred and this vegetation did not provide a suitable base to meet DWR standards for a CIMIS station. CIMIS stations must be located on 4 inches of well- irrigated grass to create the right climactic environment for determining reference evapotranspiration. The irritant weeds were mowed and sprayed with herbicide and will be treated once more prior to replanting in late February or March once winter rains abate. In the meanwhile, the Soledad CIMIS Station began transmitting data to CIMIS on 2/20/17 and is available for use by growers and interested parties.

Operation and maintenance of the Soledad CIMIS station site will be the responsibility of DOLE. DOLE will provide the ongoing irrigation and maintenance of the grass. The Department of Water Resources will pay for the cell service to convey information and for any maintenance required for the weather station.

The PAEP objective for the CIMIS Station is to provide growers technical and financial assistance in implementing on-site projects and a water conservation infrastructure that can conserve water and reduce nutrient loads to water bodies or groundwater. Because of the importance of accurate evapo-transpiration (ET) data in managing irrigation scheduling, having locally measured climate information (temperature, windspeed, solar radiation, etc.) can improve the reliability and grower confidence in ET data. The Soledad CIMIS station will provide this localized data to growers farming about 60,000 acres in Soledad and surrounding areas. Our PAEP target for the CIMIS project was twofold: A) Compare CIMIS data to closest alternatives stations to evaluate increased accuracy of ET data, and B) Survey growers to evaluate the importance of increased confidence in using this data. Because the CIMIS station has only been operational for a short time (one week), we were not able to make comparisons to other nearby CIMIS station alternatives nor were we able to contact growers to find out if the more localized and more reliable ET data was increasing their confidence in using this data for irrigation scheduling.

Soledad CIMIS Station

Description

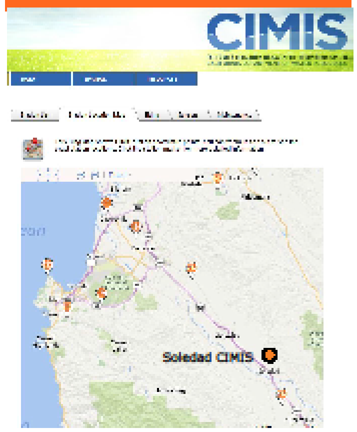
CIMIS stations provide meteorological data including wind speed, temperature, solar radiation and other parameters used for calculating reference Evapotranspiration (ET_0). The Soledad CIMIS Station will provide localized ET_0 to help growers' determine crop water needs for farms representing approximately 60,000 acres of irrigated agriculture in Salinas Valley between Gonzalez and Greenfield. ET_0 in combination with crop coefficients can be used to estimate field (soil and plant) water loss and crop water demands, which augments growers' ability to determine irrigation water application amounts and timing.

Significance

As the importance of conserving water and avoiding nitrate leaching below the root zone has escalated, growers are increasingly concerned with precision irrigation practices. Growers can have increased confidence in ET data when a weather station is located in close proximity to their fields and measures the actual conditions where they are farming, especially in windy areas like the Salinas Valley. Multiple benefits for the region and the individual grower can be gained from precise irrigation to match crop needs, which include:

- avoiding the need to over-apply fertilizer due to leaching,
- reducing irrigation runoff,
- reducing contamination of groundwater with nitrate,
- reducing groundwater use and slowing aquifer depletion,
- cost savings,
- avoiding plant stress from under or over watering,
- and aiding with regulatory requirements.

PROJECT LOCATION



The Soledad CIMIS station, located between the Salinas and Arroyo Seco stations, monitors local climate from atop irrigated fescue grass covering 2 acres of land. Data is sent on an hourly basis to the CIMIS website, where ET_0 data can be accessed: www.cimis.water.ca.gov/

Decision Support Tools

CIMIS ET_0 data is incorporated into decision support tools, such as CropManage, for use by growers and irrigators. CropManage quickly estimates water needs for vegetables and berries. Growers can also use CropManage to track water and nutrient applications.

Partnerships

DOLE provided the land for the CIMIS station as well as ongoing maintenance of the grass. University of California Cooperative Extension (UCCE) provided the CropManage model for utilizing reference ET to calculate crop water needs and irrigation timing. The Resource Conservation District of Monterey County (RCDMC) provided the conceptual design and oversaw the management and construction of the project. The engineering and construction contractor was Irrigation Design and Construction (IDC). The California Department of Water Resources installed the weather station and provides data on the CIMIS website. The project was funded by SWRCB Prop 84 grant # 12-414-553.

Prop 84 Grant Funding

State Water Resources Control Board's Proposition 84 Agricultural Water Quality grant paid for the engineering design and construction of the irrigation system, planting of the fescue grass, and the CIMIS weather station. Professional services match was provided by NRCS and UCCE.

Capital Costs $113,000
Land: $30,000

FOR MORE INFORMATION

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SPENCE VEGETATED TREATMENT SYSTEM

DESCRIPTION

The Spence vegetated treatment system (VTS) is a project designed to remove nutrients from field runoff. The Spence VTS is an 1800-ft long ditch vegetated with native grass *(festuca rubra)* that intercepts runoff from 86 acres of farm fields, removing nutrients and other pollutants (Fig. 15). Sediment ponds at the field edges capture large sand particles and then culverts transport water under the farm roads, emptying into a bed of rocks. Dense grass in the VTS slows the flow of run-off, settling out fine sediment. Plants uptake nutrients and also reduce the volume of run-off by increasing infiltration and evapotranspiration losses. During heavy storm events the vegetation prevents soil erosion. When sufficient run-off drains to the lowest end of the VTS, this water is collected in a sump and reapplied to the sides of the ditch using drip tape, thus maintaining the grass through the dry season and increasing the treatment surface area. During summer irrigation in 2016, all runoff was infiltrated prior to reaching the outlet.

The Spence ditch was manmade to carry field and storm runoff from the Spence farm and does not serve the beneficial uses identified by state water quality policy. Prior to implementation of this Project, the Spence ditch was previously vegetated with fescue grass. This project paid for the culverts, sediment basins and some grass seed for revegetation.

The Spence VTS is located on the USDA Research station in south Salinas on Spence Road and represents an ideal site for agricultural research, outreach and training. UCCE conducted monitoring to demonstrate nutrient removal. UC Davis explored organophosphate and neonicitinoid pesticide removal at the VTS, also adding carbon and plastic filters as treatments. A grower tour of the Spence VTS demonstrated nutrient and pesticide removal at a field day event on 2/19/15, which followed an Irrigation and Nutrient Management Meeting held at UCCE in Salinas.

Culvert from ditch under Road into VTS exiting on a bed of rocks to control erosion.	This weir was used for flow Monitoring	Peristaltic Pump for Composite Sampling	Completed VTS with red fescue as the vegetation.
 Photo: Ben Burgoa 6/9/15	 Photo: Ben Burgoa 8/27/15	 Photo: Bridget Hoover 4/14/16	 Photo: Bridget Hoover 4/14/16

Figure 15: Important elements of the Spence Vegetated Treatment System.

Crop irrigation scheduling is determined at this site using information from CropManage, a web based decision support tool for recommending irrigation and fertilization application amounts and schedule to match crop water and nutrient needs. Because the goal is to apply just as much water as is needed to replace water that is evaporated and transpired along with any needed leaching fraction, irrigation runoff from fields is minimal. During non-storm events throughout the growing season 2015-2016, all irrigation water entering the VTS was infiltrated prior to reaching the outlet. This will be of interest to growers pursuing on-site containment of runoff.

WATER QUALITY ISSUES

The Spence VTS is located within Quail Creek watershed, located south of Salinas. Quail Creek watershed is 11,000 acres with 2700 acres of farmland and 3700 of grazing land (CCRWQCB 2013). These land uses contribute to the nutrient water quality issues on Quail Creek, which is 303(d) listed for both ammonia and nitrate. The impaired beneficial uses are drinking water and freshwater habitat. The unofficial goal is a 65% nitrate load reduction. Nitrate load data provided by the Cooperative Monitoring Program indicated that nitrate load in Quail Creek was substantially reduced between 2005 and 2011 (CCRWQCB 2013).

STATUS AND PERFORMANCE

Irrigation scheduling at the Spence VTS is controlled to match recommendations from CropManage, a software decision support tool to help growers determine crop water needs. Due to the high level of control exercised to conserve water and irrigate efficiently, there were few irrigation runoff events and thus little opportunity for monitoring. Only two irrigation runoff events occurred during each summer (2015 and 2016) of monitoring. In all cases for irrigation runoff events, water entering the VTS had totally infiltrated or evaporated prior to reaching the outlet of the VTS (Fig. 16). This can be viewed as a success for growers seeking to eliminate tailwater from leaving the ranch. The irrigation runoff events in 2016 followed the addition of an anti-crustant that was high in phosphorus.

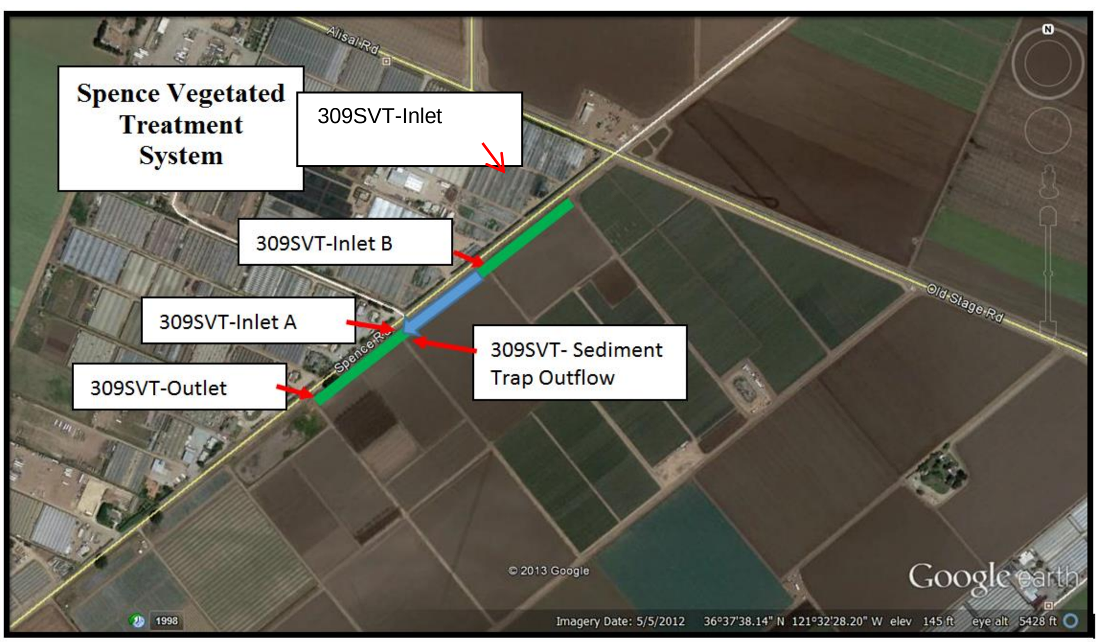


Figure 16: Monitoring locations for Spence VTS chemistry.

Monitoring results from these irrigation runoff events are shown in Tables 8. No samples were taken at the top Inlet of the VTS (309 SVT-Inlet) because there was no runoff into the ditch at this location. Samples were not taken at the outlet (309SVT-Outlet) in the summer as all water had infiltrated prior to reaching the outlet. Samples from only one irrigation event were tested for nitrate as N during irrigation runoff from both seasons, on 7/26/16. During this event, the concentration of nitrate as N dropped from 3.3 mg/L to 0.9 mg/L demonstrating a 73% reduction of the nitrate between Inlet B and Inlet A of the VTS (Appendix A, Table A1). This drop occurred over a distance of 615 feet representing 35% of the length of the ditch. A higher removal would have occurred over the entire ditch if water had travelled the entire length. Orthophosphate increased in the VTS between Inlet B and Inlet A during the two summer events in 2016, once from a non-detectable level to 0.5 mg/L on 8/2/16 and from 0.2 to 0.7 mg/L on 7/26/16. This sampling event occurred following the addition of a high phosphorous anticrustant and the increase could have been due to phosphorus on particles that had settled and then become re-suspended in the VTS. The PAEP stated that we would accomplish 75% of our nitrate concentration reduction projection by the end of year 1. We projected that the VTS would remove 75% of the nitrate. In year 2, our actual removal was 73% over only a 35% section of the VTS and complete infiltration prior to the outlet. Therefor we met or exceeded the PAEP target.

We averaged the concentrations for all summer irrigation runoff events in 2015 and 2016 to calculate percent concentration reduction (Table 8). We used flow information to calculate percent load reduction. During the summer runoff events, as all runoff had fully infiltrated prior to reaching the outlet, we assumed 100% load reduction. Nutrient concentrations entering the VTS were low during winter stormwater events. Computations show no change or an increase in concentration and load for nitrate and orthophosphate between the inlet and outlet during high flow conditions, which could be due to degradation of the vegetation in the ditch. During storm events, the VTS reduced the TSS load by 15%.

Table 8: Concentration and Load Reduction during summer irrigation runoff and winter stormwater events.

Analyte	Inlet Concentration (mg/L)	Outlet Concentration (mg/L)	Percent Concentration Reduction	Percent Load Reduction	# Sample Dates
	Summer Irrigation Runoff				
Nitrate as N	3.3	ns	NA	100%	1
Orthophosphate as P	0.6	ns	NA	100%	2
Total Phosphorus	1.9	ns	NA	100%	4
Total Suspended Solids	95.1	ns	NA	100%	4
	Storm Water Runoff				
Nitrate as N	0.85	0.91	-7%	0%	6
Orthophosphate as P	0.67	0.76	-13%	-15%	6
Total Phosphorus	5.93	5.65	5%	4%	6
Total Suspended Solids	2839	2526	11%	15%	6

***NA no concentration was measured at the outlet as all water had infiltrated**
***ns not sampled due to the absence of water**

Operation and maintenance of the Vegetated Ditch will be the responsibility of the property owner, the USDA. During winter storms in 2016-2017 the ditch was not compromised, and the sediment ponds worked well for keeping sediment from entering the VTS and causing plugging. The only anticipated maintenance is occasional reseeding of the vegetation as needed.

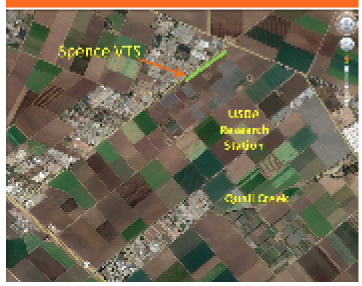
The careful management of irrigation water and nutrient addition at the Spence sites demonstrates that low nitrate concentrations in runoff can be achieved with careful management. Studies of this management strategy have also demonstrated that reduced irrigation was accomplished without sacrificing product yields. As an example case this project demonstrated that if careful management is not sufficient to achieve water quality objectives, further reduction in nutrient concentration in runoff can be accomplished through a treatment system such as this VTS. This ditch was constructed for agricultural purposes and is not a stream, thus it has no habitat or water use benefits. However, as an example, the nitrate as N concentration of 3.3 mg/L entering the VTS at Inlet B on the 7/26/16 sampling event was below the drinking water standard of 10 mg/L, however exceeded the CCAMP objective of 2.25 mg/L. The nitrate as N concentration observed downstream at Inlet A was 0.9 mg/L, below both objectives.

Spence Vegetated Treatment System

Description

The Spence Vegetated Treatment System (VTS) is an 1800-ft long ditch vegetated with native grass *(festuca rubra)* that intercepts runoff from 86 acres of farm fields, removing nutrients and other pollutants. Sediment ponds at the field edges capture large sand particles and then culverts transport water under the farm roads, emptying into a bed of rocks. Dense grass in the VTS slows the flow of run-off, settling out fine sediment. Plants uptake nutrients and also reduce the volume of run-off by increasing infiltration and evapotranspiration losses. During heavy storm events the vegetation prevents soil erosion. When sufficient run-off drains to the lowest end of the VTS, this water is collected in a sump and reapplied to the sides of the ditch using drip tape, thus maintaining the grass through the dry season and increasing the treatment surface area. During summer irrigation in 2016, all runoff was infiltrated prior to reaching the outlet.

PROJECT LOCATION



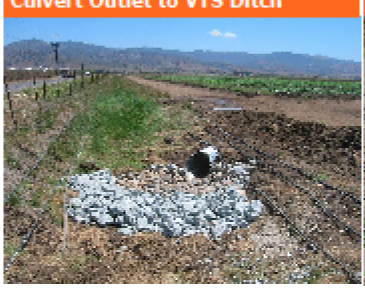
The Spence Vegetated Treatment System (VTS) is located at USDA Agricultural Research Station in the Quail Creek watershed south of Salinas. Quail Creek is 303(d) listed for ammonia and nitrate. The impaired beneficial use is drinking water and the goal is a 65% nitrate load reduction.

Load Reduction

Midpoint sampling over a distance of 615 feet (35% of the VTS) showed a concentration reduction in nitrate of 73% and sediment of 69% during summer irrigation on 7/26/16. Othophosphate removal over the course of the project was variable. Because all water was infiltrated, we surmised total removal of pollutants of 100%.

Date	Flow Rate m3/sec	Load Reduction Percent	Nitrate as N g/hr	Othophosphate as P g/hr	Total Susp. Solids g/hr
7/26/2016	0.00136	100%	16.13	0.98	1486.27
8/2/2016	0.00180	100%	nt	2.72	485.99

Culvert Outlet to VTS Ditch



Culvert Inlet from Sediment Basin

Demonstration Site

The VTS is used as a demonstration site for researchers, agricultural professionals and growers interested in nutrient and pesticide removal by vegetated ditches. UC Davis Granite Canyon Lab tested and demonstrated methods for organophosphate and neonicitinoid pesticide removal. UCCE demonstrated nutrient removal and small-seeded grass that does not provide rodent or bird habitat. The use of CropManage for irrigation water and nutrient application has resulted in low to no runoff during the irrigation season with complete infiltration of any field runoff within the VTS (except during storms).

Partnerships

UCCE provided the conceptual design and outreach to user groups. RCD Monterey County provided the technical design, and the USDA Agricultural Research Station provided the location and earth movement for the sediment basins . The project was funded by SWRCB Prop 84 grant #12-414-553.

Prop 84 Grant Funding

State Water Resources Control Board's Proposition 84 Agricultural Water Quality grant paid for culverts, monitoring equipment, sediment basins, plant establishment and irrigation. The ditch had been previously constructed. Matching funds were provided from UCCE as professional services.

Construction Costs $40,600
Land $45,000

FOR MORE INFORMATION

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PG&E TREATMENT WETLAND

DESCRIPTION

The PG&E treatment wetland covers 18 acres of land in the Moro Cojo watershed (Fig. 17). Of this 18 acres, 12 acres is a treatment wetland and 6 acres is road access and ponded habitat. The treatment wetland is designed to reduce nutrients and other NPS pollutants, provide wildlife habitat, and help with flood control. Inlet water is pumped from the Castroville Ditch, which drains approximately 800 acres of land farmed predominantly in artichokes and brussel sprouts. Water is gravity fed through a 1.25 km sinuous channel that includes depressions and ponds that support wetland plants and sediments that denitrify agricultural water. Approximately 140,000-300,000 gallons/day of water is treated, depending on water availability at the inlet ditch. The treated water then flows into the Castroville Slough about 200m downstream of the inlet, and out to the Moro Cojo Slough before joining Old Salinas River and flowing through the Moss Landing harbor and into the Pacific Ocean. The restoration site actively removes nutrient loading from the entire Castroville Slough watershed, including part of the City of Castroville. There is also a culvert that allows flow of water from agricultural fields on the west side of highway 1 to drain into the PG&E Treatment Wetland, increasing the amount of runoff treated. This project demonstrates the effective integration of wetland restoration as a portion of a regional water quality enhancement strategy.

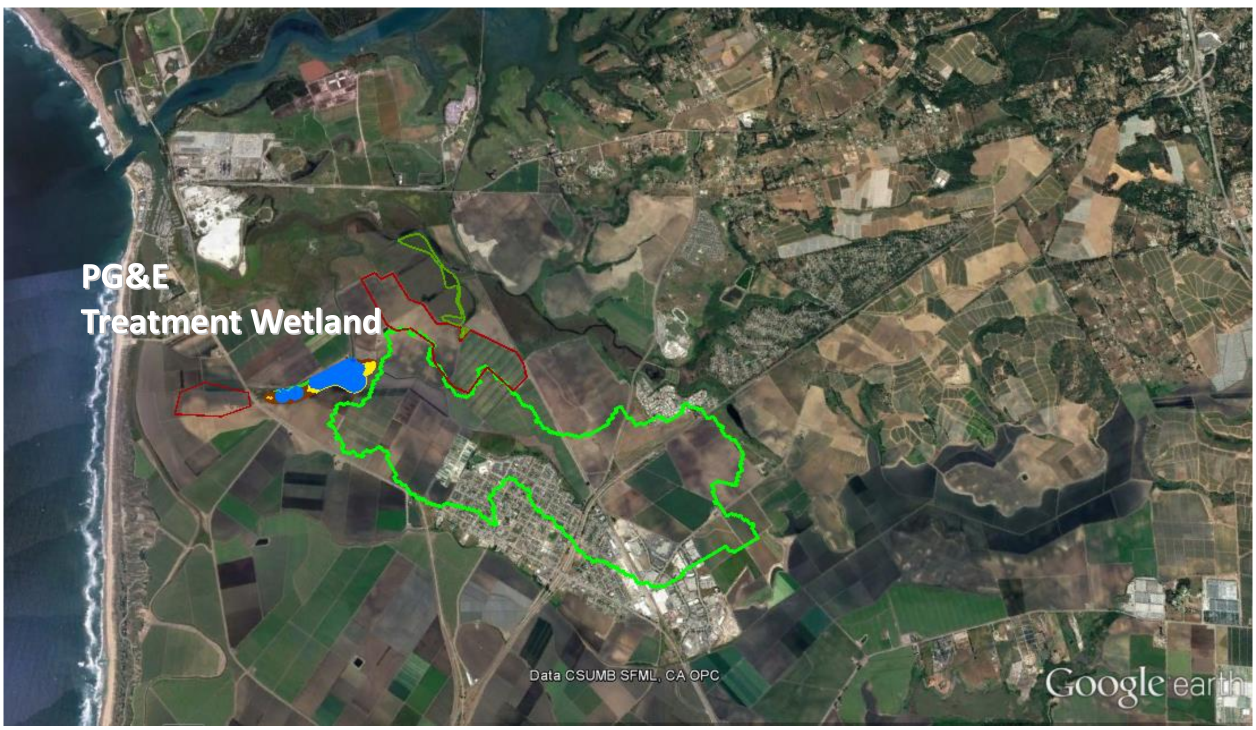


Figure 17: The watershed treated by the PG&E Treatment wetland is shown in highlighted green and also includes the highlighted red area on the west side of the Highway 1.

The PG&E treatment wetland holds approximately 18 acre-ft of water and the residence time is estimated at 7.5 days. Nitrate concentrations entering the wetland are quite variable as shown by our pre-implementation monitoring. Our current estimate is that the wetland will remove 80% of the nitrate when it reaches maturity with plant and microbial growth.

This location is available for tours and use as a demonstration site regarding the treatment results that can be achieved by a constructed wetland. It is an ideal site with easy access off of Highway 1 and arrangements can be made through the Central Coast Wetlands Group. Many people including researchers, regulators and the grower owning adjacent property spoke positively about the water quality benefits at the opening ceremony event conducted at the site on 11/16/2016.

WATER QUALITY ISSUES

The Castroville ditch flows into the Moro Cojo Slough. Downstream of this confluence, the Moro Cojo Slough joins the Old Salinas River and empties into the Moss Landing Harbor before exiting to the Pacific Ocean. Water from the Old Salinas River is entrained during flooding tides and enters the ecologically important and sensitive Elkhorn Slough estuary. The Elkhorn Slough is an important breeding ground for rock fish and provides important habitat for many kinds of birds, fish, invertebrates and marine mammals. The Elkhorn Slough Foundation awarded an "F" rating to the Moro Cojo Slough and Old Salinas River (at the bridge) for water quality (Mercado et al. 2014). The Elkhorn Slough Foundation is concerned with the addition of nutrients to the Elkhorn Slough via these water bodies and the effect on eutrophic conditions found in the Slough. Because most sites in the Elkhorn Slough are under severe nutrient stress, nutrient loading to the Elkhorn Slough estuary poses a serious threat to this ecosystems (Hughes 2010).

Nutrient concentrations within the Castroville Ditch were documented between 10-45 mg/L Nitrate as N. This is higher than the concentrations measured in the Moro Cojo Slough at Highway 1 where the nitrate concentration averaged 0.56 mg/L and the maximum concentration was 9.6 mg/L (CCAMP website). These differences could be due to the timing of samples and the highly variable nitrate concentrations typically found in areas where drainage has a high percent of water from irrigated agriculture, or could be due to the dilution of Castroville Ditch water with other water travelling in Moro Cojo Slough. The Castroville Ditch flows into the Moro Cojo Slough where the endanged tidewater goby is found along with rainbow trout and other fish species. The Moro Cojo Slough is on the 303(d) list for high ammonia, but not for nitrate. The TMDL target objective for unionized ammonia as N is 0.025 mg/L. We prioritized this site as important based on the high nitrate concentrations observed in the Castroville ditch as well as the importance of reducing nitrate load entering Elkhorn Slough and ammonia load entering Moro Cojo Slough.

The PG&E Treatment Wetland will provide habitat for amphibians and birds. The design deliberately excludes habitat for large waterfowl such as Canadian geese, as these would represent a food safety concern to neighboring growers. Wetland habitat is made less attractive to geese through the growth of native wetland plants along the edges and shallow areas of the wetland body. Deep pools were not included as part of the design in order to minimize the attraction to large waterfowl. Figure 18 shows the area of low water level that will grow with wetland plants through time.

Photo looking toward the wetland inlet after clearing weeds and prior to planting wetland plants. Photo Ross Clark 8/7/16.

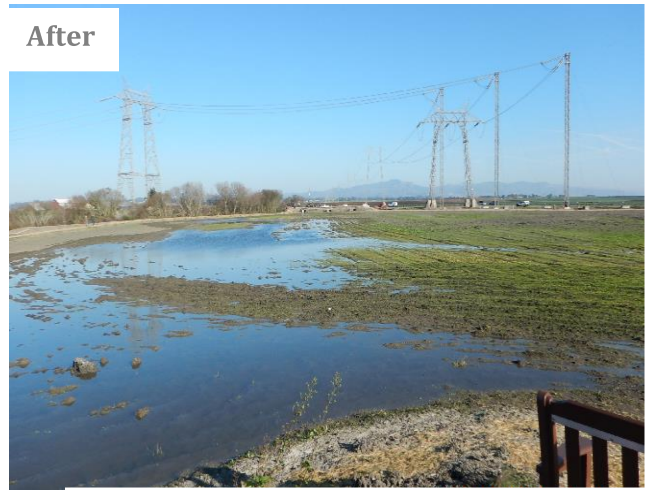


Photo looking toward the wetland inlet about a week after opening the inlet valve. Photo by Ross Clark 11/16/16.

Figure 18: Before planting and after planting at the PG&E treatment wetland.

STATUS AND PERFORMANCE

PG&E became operational in early November 2017. Because of project delays encountered due to unanticipated permitting requirements and the difficulties of working through the Monterey County permitting process (see Lessons Learned below), the implementation of the wetland and therefore the monitoring of this site was considerably delayed. The actual construction of the site took place in a remarkably short period of time over the month of October 2016 (Fig. 19). Project partners pulled together accomplishing an extraordinary job to make things happen quickly and provide resources where needed. CCWG oversaw the construction on a daily and hourly basis, quickly resolving any issues encountered so as not to increase project construction costs running approximately $1000 per hour during this period. Monterey County's mosquito abatement program provided euipment and personnel time for rerouting ag ditches around the wetland permiter. PG&E helped out by providing $54,000 to add a habitat portion to the west end of the project. The project engineer from Waterways Consulting remained onsite and recommended design modifications when field situations dictated the need for changes. Seamist farms allowed the use of water for wetting during construction and provided earth moving support. Coastal Conservation and Research grew the 30,000 native wetland plants that were planted by CCWG and by volunteers. The valve was opened and the wetland began importing water for treatment in early November 2016. The opening ceremony was publicized by local media (as described in the earlier part of the report).

Earth Moving Equipment	Sediment Basin	Near Castroville Slough
 Photo Credit Ross Clark 10/6/16	 Photo Credit Ross Clark 10/6/16	 Photo Credit Ross Clark 10/6/16
CCR started plants from native seeds and volunteers helped plant them.	**Some seeds were cast directly without pre-starting them.**	**Children helped seed the wetland at the opening ceremony.**
 Photo Credit Ross Clark 10/24/16	 Photo Credit Ross Clark 10/24/16	 Photo: Ross Clark 11/18/16
A CDFA grant funded the development of treatment chambers for research at the wetland inlet.	**Ross Clark described how the wetland removes pollutants and improves water quality.**	**P Krone emphasized the importance of cleaning water entering MBNMS.**
 Photo Pam Krone 11/18/16	 Photo Credit Katie McNeill 11/18/16	 Photo Katie McNeill 11/18/16

Figure 19. Construction at PG&E treatment wetland.

Early monitoring following construction demonstrated nitrate removal between the source and discharge site averaging 44%, even in the newly initiated wetland (Fig. 20). These measures were taken prior to the growth of plants in the wetland, thus removal rates are expected to increase as the plants populate the wetland and the microbial denitrifying bacteria proliferate. Samples were taken between 11/29/16 and 2/6/17 with an interval of 7 days between the inlet and outlet based on the estimated hydraulic residence time (HRT) of the wetland. This interval provides the best sample match, allowing for the travel of inlet water to the outlet. Even so, mixing occurs within the wetland body, and outlet samples are a combination of inlet waters entering over the course of several days. Thus there is not truly a one to one correspondence between inlet and outlet samples.

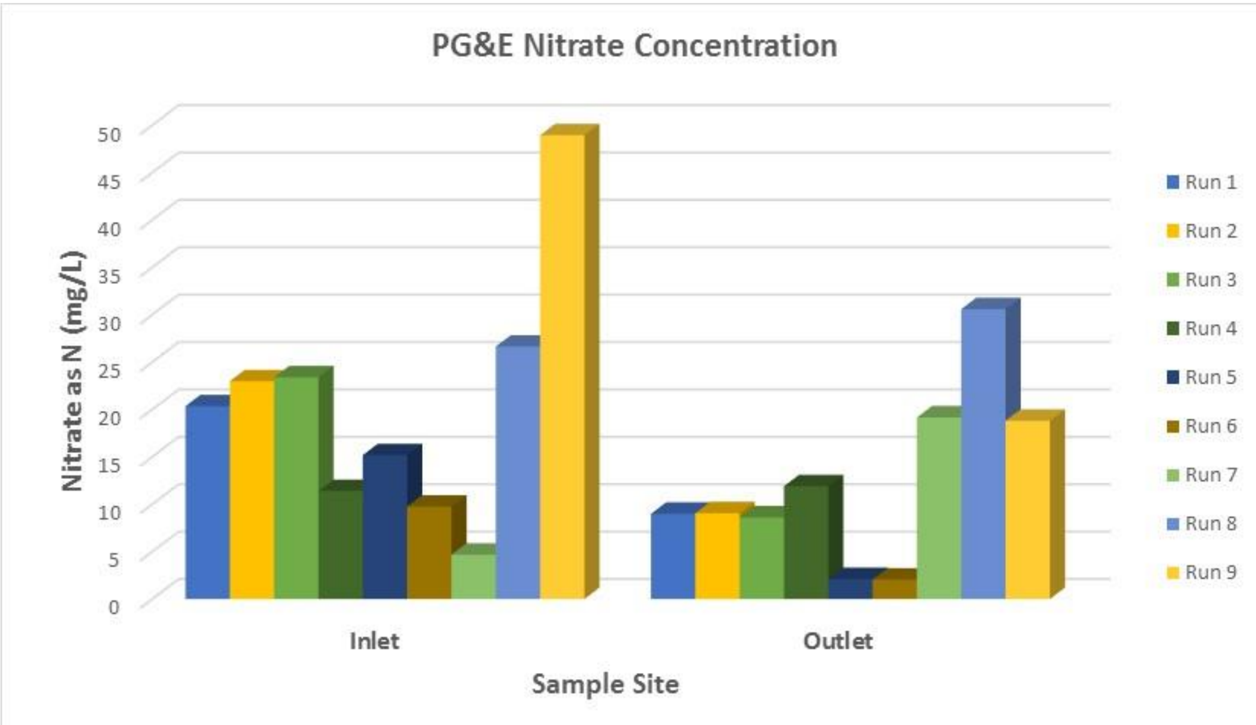


Figure 20. Nitrate as N monitoring results comparing the outlet to inlet water at the PG&E treatment wetland show an average reduction of 44%.

Based on current monitoring data from the new PG&E wetland, conservatively assuming no improvement in performance with wetland maturation, we calculated the estimates shown in Table 9 for nutrient removal and we also show the removal performance anticipated at maturity.

Table 9A: Nutrient Removal from PG&E treatment wetland based on monitoring data.

Estimated Nutrient Removal for PG&E Treatment Wetland based on monitoring:
Estimated Volume of Water Treated Annually: 51 million gallons
Concentration Reduction of Nitrate: 44%
Concentration Reduction of Ammonia: 34%
Concentration Reduction of OrthoPhoshate: 66%
Estimated Load Reduction for Nitrate as N: 2912 kg/yr
Estimated Load Reduction for Ammonia as N : 75 kg/yr
Estimated Load Reduction for OrthoPhoshate as P: 148 kg/yr
Estimated Nutrient Removal for PG&E Treatment Wetland based on mature wetland nitrate removal rates:
Estimated Concentration Reduction of Nitrate: 84%
Estimated Load Reduction for Nitrate as N: 5950 kg/yr

Mature wetlands perform better at nitrate removal than do newly constructed wetlands due to plant growth and the development of denitrifying microbial populations (Kadlec and Wallace 2009). As this grant project is over before the wetland plants have become established, we estimated the future nitrate load reduction potential for the PG&E treatment wetland based on the median value for wetland performance found by Kadlec (2009) in his review of 205 free surface flow wetlands. The computed value for the PG&E nitrate load removal as a mature wetland are shown in Table 9A.

Comparison of PAEP with Accomplishments:

The PAEP goal for nutrient removal projects was to reduce nitrate load contributions to surface water. The target for nutrient removal projects was to achieve a load reduction of 75% of the projected load reduction by the end of their first year of operation. Wetlands and bioreactors generally improve performance for a time period after their initiation, as plants and microbial populations become established. For this reason we did not expect 100% performance the first year, but targeted 75% performance. Although the wetland has only been operational for 3 months, not for a full year, performance has exceeded the year 1 performance target. Kadlec (2009) found a median aerial denitrification rate in constructed free surface wetlands of 27 m/yr based on the performance of over 200 wetlands, which we used to calculate a projected load removal rate. We used the tanks in series model for hydrology and first order removal to calculate projected percent removal:

$$\frac{C_o}{C_i} = \left(1 + \frac{k_a}{Nq}\right)^{-N}$$

where C_i is the inlet concentration (mg/L), C_o is the outlet concentration (mg/L), k_a is the areal reaction rate constant (m/yr), N is the number of tanks in series, and q is the hydraulic loading rate (m/yr). We also based k_a on temperature using the Arrhenius equation, as wetlands are known to perform better in warmer temperatures and worse during winter temperatures when microbial activity is lower.

Based on the projected outlet concentration derived from the above formula, the nitrate concentration reduction in the winter months is expected to be 76% and the winter projected load removal is 11.8 kg/day, whereas the observed concentration reduction was 44% and load removal rate was 7.9 kg/day. The performance accomplished after 3 months was 66% of the projected removal rate at maturity, thus not meeting the targeted 75% of the mature rate. Our estimate is that the 75% target will be met by the end of year one of operation.

Cost Benefit Analysis

The PG&E treatement wetland has multiple ecosystem benefits beyond the removal of non-point source pollutants from runoff. This wetland restoration project has supported the implementation of a critical portion of the Moro Cojo management plan. It will provide habitat for frogs, reptiles, small mammals, and birds. Bird counts have already shown an increase in the diversity and number of species present in the wetland. In addition, the property owner has agreed that the wetland can be a demonstration site that can be used for outreach and education as well as for further research on wetland performance and value. Not least, it will remain dedicated as beautiful open space adjacent to Highway 1.

Two benefits were analyzed for thePG&E treatment wetland. One was the benefit of improved water quality and the second was the benefit of improved habitat. Central Coast Wetlands Group (CCWG) estimated the water quality cost/ benefit ratio to be $5.21. CCWG estimated the habitat value at $240,000 and the overall cost benefit ratio to be $3.19.

Table 10: Cost benefit analysis for PG&E treatment wetland.

PGE Cost Benefit	
Capital Cost for 12 acre wetland:	$ 600,000
Maintenance Cost (20 years):	$ 20,000
Water Quality Cost /Benefit:	$ 5.21
Habitat Value	$ 240,000
Complete Cost Benefit	$ 3.19

Ecoli Monitoring

Surrounding growers were concerned with food safety and asked that we monitor E coli at the PG&E treatment wetland. We measured E coli concentrations at the outlet on 2/9/17 and 2/16/17 finding values of 30 MPN/100mL and 2420 MPN/100mL respectively. The Leafy Greens Marketing Association (LGMA) standard is a geometric mean of 126 MPN/100mL for foliar applications and a limit of 576 MPN/100mL for non-foliar applications. E coli samples taken at the outlet exceeded LGMA safety standards. However no intended application to crops is planned for water from the PG&E wetland.

Bird Monitoring

Bird species and abundance counts were conducted in August prior to construction and November subsequent to construction at the PGE treatment wetland (Table 10). In August the total number of species observed was 10 and the total bird count was 50. In November the total number of species observed was 13 and the total bird count was 249. The completed wetland is attracting bird species and numbers in quantities above previous scientific and casual observations at this site. The wetland was designed with shallower water to encourage smaller water fowl and discourage large ducks and geese.

Table 10. Bird count before construction and after planting for the PGE treatment wetland.

		Bird Counts	
Code	**Species**	**8/27/2016**	**11/29/2016**
AMCO	American Coot		1
AMGO	American Goldfinch	29	
AMPI	American Pipit		5
BARS	Barn Swallow	4	
BLPH	Black Phoebe	1	
BRBL	Brewers Blackbird		97
CLSW	Cliff Swallow	1	
COYE	Common Yellowthroat	1	
EUST	European Starling		5
GREG	Great Egret		1
GRYE	Greater Yellowlegs		4
HOLA	Horned Lark	1	
KILL	Killdeer	7	22
LBDO	Long-billed Dowitcher		40
LESA	Least Sandpiper		3
NOHA	Northern Harrier	1	
RTHA	Redtailed Hawk		1
RWBL	Redwinged Blackbird		48
SAVS	Savannah Sparrow	2	
SOSP	Song Sparrow	3	
WEME	Western Meadowlark		21
WTKI	White-tailed Kite		1
	Total	**50**	**249**

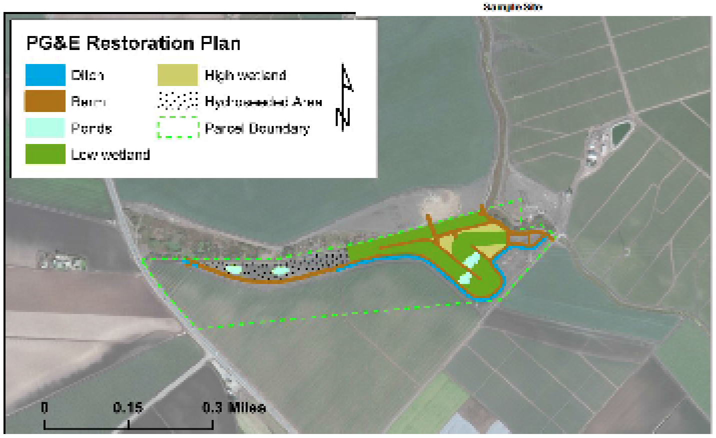
PG&E Constructed Treatment Wetland

Description

The PG&E treatment wetland covers 18 acres of land in the Moro Cojo watershed. It is designed to reduce nutrients and other NPS pollutants, provide wildlife habitat, and help with flood control. Inlet water is pumped from the Castroville Ditch which drains approximately 800 acres of land farmed predominantly in artichokes and brussel sprouts, as well as a portion of the stormwater runoff from Castroville. Water is gravity fed through a 1.25 km sinuous channel that includes depressions and ponds that support wetland plants and sediments that denitrify agricultural water. The treated water then flows into the Castroville Slough about 200m downstream of the inlet, and out to the Moro Cojo Slough before joining Old Salinas River and flowing the into the Pacific.

Water Quality Issues

Nutrient concentrations within the Castroville Ditch have been documented between 10-45 mg/L Nitrate as N. The Castroville Ditch flows into the Moro Cojo Slough where the endanged tidewater goby is found along with rainbow trout and other fish species. The Moro Cojo Slough is on the 303(d) list for high ammonia, sediment and low dissolved oxygen.

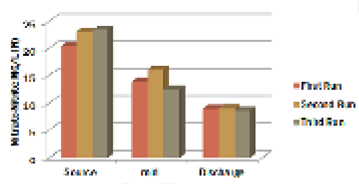


PROJECT LOCATION

Nutrient Removal

Load and concentration removal are estimates based on typical wetland performance and will be validated by monitoring:

Area contributing runoff: 800 acres
Wetland land area: 18 acres
Water volume: 12,000 yard^3
Capacity: 220,000 gal/day
Nitrate-N Load Reduction: 5950 lbs/yr
Nitrate Removal: 84%
Orthophosphate Removal: 86%
Ammonia Removal: 60%



Partnerships

The Central Coast Wetlands Group (CCWG) provided the conceptual design, coordinated with the owners and contractors, obtained permits and oversaw the construction. PG&E provided the land and project support. Waterways Consulting provided the technical design and Durden Construction Inc. completed construction. Coastal Conservation and Research grew the 30,000 native wetland plants that were planted. Monterey County Mosquito Abatement and SeaMist Farms provided earthmoving and on-site support to establish ditches around perimeter. The project was funded by SWRCB Prop 84 grant # 12-414-553.

Prop 84 Grant Funding

State Water Resources Control Board's Proposition 84 Agricultural Water Quality grant paid for biological monitoring, wetland construction, and water quality monitoring. A Department of Water Resources (DWR) Integrated Regional Water Management Plan Implementation grant covered the engineering designs and permitting costs. Matching funds were provided from NRCS and UCCE as professional services. PG&E dedicated land use and paid for west end Frog Ponds. Monterey County supported installation of new pumping infrastructure.

Design & Engineering: $82,000
Permitting & Planning: $45,000
Land: $92,000
Construction & Mgmt: $455,000
Total Cost: $674,000*

* Project costs could be reduced by $162,000 if prevailing wage and permitting were eliminated.

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OCEANMIST BIOREACTOR

DESCRIPTION

The Oceanmist bioreactor covers approximately half an acre of land and treats runoff from 100 acres of farmland growing predominantly artichokes and brussel sprouts. The bioreactor receives and treats drainage water flowing from three agriculture drainage ditches that support extensive tile drain systems. The bioreactor discharges to the Seamist wetland, previously restored by CCR under Proposition 13, and therefore serves as a pre-treatment system to improve water quality entering the wetland habitat. Water is pumped from a collection point where the three drainage ditches meet into the inlet of the bioreactor, which spreads the water across the breadth of the inlet (Fig. 21). This water then flows passively through the bioreactor to the outlet where it gravity feeds into the Seamist wetland and eventually flows into the Moro Cojo Slough, before joining the Old Salinas River and then flowing into Monterey Bay.

The original project proposed a one acre bioreactor and two basins were dug within this acre. The first larger basin was used to construct the bioreactor. For two primary reasons, the second basin has not been put into operation. First, the project team wanted to monitor and evaluate the performance of the first basin to find out if it could remove sufficient nitrate without the need for a second basin. This would leave open the option of designing and utilizing the second basin for some other purpose, such as pesticide removal. A second reason related to the escalated expense of completing the first basin, largely due to the need to pay for woodchips. When the project was originally conceived, woodchips could be obtained free of charge. However, the regional waste disposal site began charging for woodchips for use in boiler operations and was no longer willing to provide them free of charge at the time of construction. So in addition to not being certain a second basin was necessary, there was also insufficient funding available to construct a bioreactor within the second basin.

Three agricultural ditches converge at the inlet pump location. Runoff is treated by bioreactor denitrification processes.	The sinuated channel was created by draping pond liner over fencing.	Wood chips provide a carbon source for denitrifying bacteria and a colonization surface.	The outlet pipe in the photo forefront sends treated water to the Seamist wetland.
	 Photo Date: 1/22/16 Credit: Jason Adelaars	 Photo Date:4/14/16 Credit: Pam Krone	 Photo Date:4/14/16 Credit: Pam Krone

Figure 21. Location, construction and outlet at the Oceanmist Bioreactor

Water Volume

The transect method was used on 8/31/16 to measure and estimate total bioreactor volume and to identify possible "dead zone" areas in the bioreactor where water bypasses treatment. An in-situ porosity test was conducted to re-evaluate porosity now that wood chip settling has occurred. The total bioreactor capacity was measured at 127,110 gallons, with 80% porosity. Based on the high porosity discovered, more wood chips were subsequently added to the bioreactor in order to increase the carbon source available for denitrification and eliminate water flowing preferentially across the open bottom of the wetland beneath the floating wood chips. The water capacity at 55% porosity is 70,000 gallons. Dead zones in the corners were identified to represent approximately 13% of the bioreactor volume. Dead zones in treatment systems are not unusual, and this percent is within the norm.

Oceanmist Bioreactor Tracer Test 1:

A tracer test was performed at the Oceanmist Bioreactor with the goal of calculating the hydraulic residence time. On 8/14/16 the tracer test was performed by CCWG and CMSF by adding 400 pounds of salt dissolved in 275 gallons of water to the inlet of the bioreactor over a 2 hour period. A Eureka water probe was placed at the outlet and programmed to measure salinity at 10 minute intervals over a 7day period until the probe was removed the morning of 8/19/16. The pump operation was monitored on a daily basis and the number of hours pumped was recorded and converted to gallons of water and inlet discharge. The pump turns on and off based on a level in the ditch, so inlet pumping rate varies.

The primary finding from the tracer test was that pumping variability has a greater impact on the hydraulic retention time than does the hydraulic characteristics of the bioreactor. A chart was developed to display the hydraulic retention time and recommended time interval between samples based on the number of hours the pump operates.

STATUS AND PERFORMANCE

The Oceanmist bioreactor has been operational since April 2016 and continues to be operated and maintained. However, numerous technical issues have occurred that have prevented consistent operation and monitoring of the bioreactor. The outlet of the bioreactor was originally undersized and required modification. Gas emmitted from the soil caused the pond liner to lift and impaired water flow through the bioreactor. January and February 2017 storms caused flooding of the surrounding farm fields and roads, as well as record high water levels in the Seamist wetland. Operating the bioreactor under these high water conditions was not feasible.

The Oceanmist bioreactor is removing nutrients from the runoff it is treating (Tables 11 & 12). Per the monitoring plan, we disclosed percent concentration and load reductions but not numeric reduction. Nitrate removal in the new bioreactor was 42%, which will increase as the bioreactor microbial population matures. The nitrate-N reduction applies to both concentration and load as inlet and outlet discharge rates are approximately equal, because the lined pond does not permit infiltration and evaporation is minimal. Orthophosphate removal was 29% while ammonia increased by a factor of 4. Despite this increase, all concentrations of total ammonia at the outlet were less than 1.35 mg/L and of unionized ammonia were less than 0.007 mg/L, which are below the acute and chronic criterion set by the EPA. The addition of a pump to oxygenate water at the midpoint of the bioreactor is planned to remove ammonia.

Table 11. Oceanmist bioreactor parameters and performance in 2016.

Area contributing runoff	100 acres
Bioreactor land area	0.5 acres
Wetted treatment area	7500 ft^2
Water volume	76,000 gallons
Treatment capacity	30,000-144,000 gal/day
Nitrate concentration removal	42%
Nitrate-N load reduction	42%
Orthophosphate concentration removal	29%
Orthophosphate load reduction	29%

Table 12: Percent change in concentration and load between inlet and the outlet of the Oceanmist bioreactor. A positive number indicates a reduction in concentration. Although ammonia increased between the inlet and outlet, concentrations were below EPA chronic and acute toxicity criterion.

Date	Unionized Ammonia as N %	Total Ammonia as N %	Nitrate as N %	Orthophosphate as P %
8/29/2016	-526	-288	41	62
8/30/2016	-284	-417	48	41
8/31/2016	-505	-432	47	-30
9/1/2016	-87	-624	40	-17
9/2/2016	-1362	-854	40	-233
9/6/2016	-241	-244	33	74
Average*	-348	-410	42	29

Average* calculation is based on average concentrations at the inlet and outlet, not the average of the daily percentage removal.

Comparison of PAEP with Accomplishments:

The PAEP goal for nutrient removal projects was to reduce nitrate load contributions to surface water. The target for nutrient removal projects was to achieve a load reduction of 75% of the projected load reduction by the end of their first year of operation. Wetlands and bioreactors generally improve performance for a time period after their initiation, as plants and microbial populations become established. For this reason we did not expect 100% performance the first year, but targeted 75% performance. Hartz et. al 2017 found a maximum removal rate of 10 ppm per HRT day for the woodchip bioreactors they installed for research purposes in the lower Salinas Valley. With an observed HRT of 0.9 days for the bioreactor, therefore we estimated a removal of

9 mg/L nitrate as N as 100% performance. We observed an average removal 3 times this amount or 300%.

Cost Benefit Analysis

Two benefits were analyzed for thePG&E treatment wetland. Central Coast Wetlands Group (CCWG) estimated the water quality cost/ benefit ratio to be $1.49. CCWG estimated the habitat value at $0 and the overall cost benefit ration to be $1.49.

Table 13: Cost benefit of Oceanmist Bioreactor.

Oceanmist Bioreactor Cost Benefit	
Construction Cost for bioreactor:	$ 93,000
Maintenance Cost (10 years):	$ 20,000
Water Quality Cost /Benefit:	$ 1.49
Habitat Value	$ 0
Complete Cost Benefit	$ 1.49

Oceanmist Bioreactor

Description

The half acre Oceanmist bioreactor treats runoff from approximately 100 acres of farmland growing predominantly artichokes and brussel sprouts. The bioreactor receives and treats runoff from three agriculture drainage ditches that support extensive tile drain systems.

A sinuated channel was created to minimize bypass within the system and simulate plug flow conditions. The channel was excavated and lined with pond liner to create a containment basin, and then filled with woodchips from the local landfill. Woodchips provide a carbon source for denitrifying microbes, thus increasing the nitrogen removal rate.

The pumping rate into the bioreactor varies depending on water level in the drainage ditch collection point, which varies with field runoff and stormwater. The higher the flow rate into the bioreactor, the more nitrate load is removed; however concentration reduction is less at higher flow. The bioreactor discharges to the Seamist wetland restoration site, serving as a pre-treatment system to remove contaminants and clean up water prior to entry into the wetland habitat.

PROJECT LOCATION

Water is pumped into the bioreactor from a collection point of three agricultural drainage ditches. This water then flows passively through the bioreactor to the outlet where it gravity feeds into the Seamist wetland. From there water flows into the Moro Cojo Slough, before joining the Old Salinas River. The Old Salinas River flows out to the Pacific Ocean at Moss Landing Harbor, where it also meets and mixes with water entering Elkhorn Slough during incoming tides.

The Moro Cojo Slough is home to the endangered tidewater goby and is 303(d) listed for ammonia, sediment, and low dissolved oxygen. Old Salinas River water contributes to the hypoxic conditions found in Elkhorn Slough.

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Nutrient Treatment

Load and concentration removal are estimates based on 2 months of monitoring. Estimates will be updated through time as the bioreactor microbial population matures and removal rates increase.

Area contributing runoff: 100 acres
Bioreactor land Area: 0.5 acres
Wetted treatment Area: 7500 ft^2
Water Volume: 76,000 gallons
Capacity: 30,000-144,000 gal/day
HRT: 0.5—1.5 days
Nitrate Removal: 42%
Nitrate-N Load Reduction: 42%
Orthophosphate Removal: 29%
Orthophosphate Load Reduction: 29%

Ammonia Removal: Ammonia increased in the bioreactor, although outlet concentrations are well below EPA criteria limits. Steps are being taken to correct this issue.

The Department of Pesticide Regulations is planning field trials in 2017 to test pesticide reduction.

Partnerships

CCWG provided the conceptual design, coordination with the owners and contractors, obtained permits and oversaw the construction. The RCD of Monterey County provided the technical design. Oceanmist Farm provided the land, the inlet pump, and helped with the excavation of the basin. The project was funded by SWRCB grant # 12-414-553.

Prop 84 Grant Funding

State Water Resources Control Board's Proposition 84 Agricultural Water Quality grant paid for excavation, woodchips, pond liner, piping, project coordination and engineering. Oceanmist Farm provided the land and inlet pump. Monterey County Mosquito Abatement provided earth moving.

Construction: $88,000
Land: $5000
TOTAL: $93,000

AZEVEDO BIOREACTOR

DESCRIPTION

The Azevedo bioreactor treats runoff from 10 acres of strawberry fields on the Azevedo Ranch adjacent to Elkhorn Slough (Fig. 14). Irrigation and storm water runoff from the strawberry fields travels down furrows and farm roads into a sediment basin where heavier sand particles settle out prior to water being pumped into the bioreactor. When the water level in the sediment basin reaches a certain height, a floating pump powered by a solar panel and battery pack transports it to the bioreactor inlet through a pipe buried under the farm road. The bioreactor is a pond-lined basin filled with wood chips purchased at the local waste disposal facility, with care to insure a low percentage of eucalyptus and redwood. Water level in the bioreactor is controlled by a level control box at the outlet. Cleaned water exiting the outlet is gravity fed into a ditch that carries it to a tidally influenced pond on Elkhorn Slough Foundation property. From the pond it is conveyed by a culvert under railroad tracks and into Elkhorn Slough.

The bioreactor treats agricultural runoff through the action of denitrifying microbes that convert nitrate to nitrogen gas. Microbes live on the woodchip and pond liner surfaces and their growth is stimulated by the carbon contained in the wood chips and nitrate in the runoff. The wood chips last for 10-15 years, before requiring replacement. The bioreactor dimensions are 50 ft (L) by 8 ft (W) by 4 ft (D) the woodchip porosity is 55%. The bioreactor is designed to treat approximately 4300 gallons per day with a hydraulic retention time of 25 hours.

The Azevedo Ranch is owned by the Ag Land Trust, whose mission is to assist in the preservation and protection of productive agricultural lands, open space and historic land. The Ag Land Trust is concerned with water quality entering the environmentally sensitive Elkhorn Slough that is adjacent to these fields. Based on this desire to protect sensitive habitat in the Slough from nutrients and other NPS pollutants, the Ag Land Trust decided to install the bioreactor at their own cost. The Ag Land Trust paid for the materials, construction costs, and provided the land for this project, while the Prop 84 grant paid for professional time of the RCD to design and manage the project.

The Azevedo Bioreactor will be a site where research and educational outreach is welcomed. The landowner is interested in allowing others to learn from this project and in encouraging adoption of this bioreactor system for nutrient removal. Researchers, technical service providers and interested professionals are encouraged to enquire either through the Ag Land Trust or through the Monterey Bay National Marine Sanctuary's agricultural water quality coordinator.

Figure 22. Cleaned water exiting the outlet flows through a ditch to a tidally influenced pond and is then conveyed by a culvert under railroad tracks and into Elkhorn Slough.

Trench for Azevedo Bioreactor	Construction showing the pond liner and wood chips being added.	Final Project Completed
	 Photos 1 & 2 Ben Burgoa 5/14/16	 Photo 3 Pam Krone 2/16/17

Figure 22. Cleaned water exiting the outlet flows through a ditch to a tidally influenced pond and is then conveyed by a culvert under railroad tracks and into Elkhorn Slough.

Azevedo Bioreactor

Description

The Azevedo bioreactor treats runoff from 10 acres of strawberry fields on the Azevedo Ranch adjacent to Elkhorn Slough. Irrigation and storm water runoff from the strawberry fields travels down farm roads and into a sediment basin where heavier sand particles settle out. Water is actively pumped into the bioreactor inlet from a floating pump powered by a solar panel and battery pack. The pump turns off when the water level falls below a threshold depth. The bioreactor is a pond-lined basin filled with woodchips purchased at the local waste disposal facility, with care to insure a low percentage of eucalyptus. Water levels are controlled by a level control box at the outlet of the bioreactor. Cleaned outlet water is gravity fed into a ditch that carries it to a tidally influenced pond on Elkhorn Slough Foundation property. From the pond it is conveyed by a culvert under railroad tracks and into Elkhorn Slough.

PROJECT CONSTRUCTION

The bioreactor treats agricultural runoff through the action of denitrifying microbes that convert nitrate to nitrogen gas. Microbes live on the woodchip and pond liner surfaces and their growth is stimulated by the carbon contained in the woodchips. The woodchips are anticipated to last for 10-15 years, before requiring replacement.

The bioreactor is designed to treat up to 4300 gallons per day with a hydraulic retention time of 25 hours. The dimensions are 50 ft (L) by 8 ft (W) by 4 ft (D).

PROJECT LOCATION

Nutrient Treatment

Inlet nitrate as N concentration measures varied between 1 to 11 mg/L. Nitrate removal in the new bioreactor has not yet been assessed, but is expected to be 90%.

Demonstration Site

The Azevedo bioreactor is a demonstration site for researchers, agricultural professionals and growers interested in nutrient and pesticide removal by bioreactors.

Partnerships & Funding

The Ag Land Trust of Monterey County owns the Azevedo Ranch. They provided the land and paid for materials and construction. The RCD of Monterey County provided the technical design. Stockman's Energy designed the inlet pumping system. The technical design of the project was funded by SWRCB Proposition 84 grant # 12-414-553. Matching funds were provided from NRCS and UCCE.

Project Cost: $32,000

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STATUS AND PERFORMANCE

The Azevedo bioreactor was fully installed in January 2017. This included digging the pit, adding the woodchips, installing the bioreactor liner, the outlet water level control box, the floating pump, piping, solar panels and back up batteries. Water is pumped from the sediment pond into the bioreactor and then flows out a ditch to a pond in Elkhorn Slough. Sediment was removed from the sediment pond in July and again in December of 2016; however heavy winter storms have since caused the pond to refill with sediment. The water height is currently insufficient to allow for pumping from the sediment basin into the bioreactor. Once the rains stop, the pond will be dredged of excess sediment and the bioreactor will be activated.

Operation and maintenance of the Azevedo bioreactor will be the responsibility of the property owner, the AgLand Trust. The AgLand Trust has agreed to maintain the sediment pond, to replace the woodchips when needed and to monitor the system to insure that it remains operable.

MONITORING PLAN & QAPP COMPARED WITH ACTUAL MONITORING

The timing of monitoring from the Monitoring Plan is compared to actual sampling accomplished in Table 14. Due to project delays, limited time was available for the monitoring of projects. In order to obtain performance results, sampling was intensified when possible.

Table 14. Monitoring plan, actual monitoring and reasons for differences

	Monitoring Plan or QAPP	Actual Monitoring	Reason for Difference
Spence VTS	Conventional water quality parameters, including flow, total suspended solids, nitrate, total nitrogen, orthophosphate, and total phosphate will be sampled quarterly (three summer irrigation runoff events with one following fertilizer application on a contributing field and one winter storm event.)	1) Irrigation runoff occurred 4 times and was monitored 2 times in 2015 and 2 times in 2017. 2) Nitrate was not analyzed in 3 out of the 4 summer runotf events. OrthoPhosphate was not analyzed on 2 out of 4, 3) Four winter storm events were monitored: 3 in 2015 and 1 in 2016	1) Could not sample irrigation runoff one quarter as planned due to lack of irrigation runoff. 2)Technician did not communicate with the lab correctly. 3) Project leaders felt the extra storm sampling would be informative.
Soledad CIMIS station	Data from the CIMIS station will be automatically uploaded to the Calif. Department of Water Resources Website hourly. Cropmanage will provide quarterly reports summarizing how many ranches are using the new CIMIS station and the number of irrigation decisions that relied on the new CIMIS station.	The Soledad CIMIS station began operating on 2/20/17 and is providing hourly data to the DWR website.	There has not been sufficient time to transition CropManage users in the Soledad area to this station or to develop quarterly reports.
Azevedo bioreactor	Conventional water quality parameters including flow, conductivity, total suspended solids, nitrate, pH, transparency, ammonia, orthophosphate and temperature will be sampled monthly.	The Azevedo bioreactor has not been monitored.	Monitoring has not been initiated due to start-up issues caused by sediment in the inlet pond.

Table 14 (cont'd). Monitoring plan, actual monitoring and reasons for differences

Site	Monitoring Plan or QAPP	Actual Monitoring	Reason for Difference
Oceanmist bioreactor	*E coli* will be sampled at the inlet and outlet twice during the project period.	*E coli* was not sampled during the project period.	*E coli* sampling was planned for winter 2017 but the bioreactor was not operating due to flooding.
PG&E Treatment Wetland	*E coli* will be sampled at the inlet and outlet twice during the project period.	*E coli* was sampled at the inlet and outlet twice during the project period.	Monitored according to plan
PG&E Treatment Wetland	Conventional water quality parameters including flow, conductivity, total suspended solids, nitrate, pH, turbidity and temperature will be sampled monthly. Ammonia and orthophosphate will be sampled every other month.	Specified water quality paramters were sampled intensively following startup.	Project leaders sampled intensively to gain as much data as possible in the short time frame remaining in the grant.
PG&E Treatment Wetland & Oceanmist bioreactor	Pre-construction monitoring of the source water for the PG&E and Oceanmist sites will be completed 5 times to establish a baseline.	Pre-construction monitoring provided the baseline as planned.	Monitored according to plan

PROJECT ASSESSMENT AND EVALUATION PLAN VS ACCOMPLISHMENTS

Project performance was evaluated compared with the goals and targets set forth in the Project Assessment and Evaluation Plan (PAEP; Table 15).

Application Efficiency Projects

Our first goal was to provide growers with technical expertise to assess on farm irrigation and nutrient management practices, with a target of doing 5 assessments each. We conducted more INM assessments than targeted accomplishing 18 irrigation system distribution uniformity evaluations, 28 irrigation scheduling assessments and 25 nutrient management assessments.

Our second goal was to provide growers technical assistance in implementing on-site projects to conserve water and reduce nutrient loads to water bodies or groundwater, based on recommendations made during assessments. Our target was that 50% - 75% percent of growers receiving assessments would independently implement at least one BMP recommended. All growers (100%) interviewed had implemented at least 1 BMP. The water and nutrient reduction growers accomplished was measured or estimated in terms of numeric and percent savings. Water savings ranged between 3- 12 inches per crop with an average water reduction was 5 in/acre per crop. This represented a savings of 10%-40% compared with the targeted water reduction of 5-20%. Reduced fertilizer N application ranged from 0-73 lbN/acre per crop with an average fertilizer N savings of 38 lbsN/acre/year. This represented a reduction in fertilizer N use of 0–30%, slightly less than the targeted reduction of 10-40%.

The CIMIS station went online 2/20/17 on the Department of Water Resources CIMIS website and is now available for use by growers farming 60,000 acres of irrigated land in making irrigation scheduling decisions; however due to the short timeframe it has been available, we could not compare it to the project targets set forth in the PAEP.

Table 15A. PAEP goals 1 & 2 and targets established before implementing projects compared with accomplishments.

Project Goals	Targets	Accomplishments
1) Provide growers with technical expertise to assess on-farm irrigation and nutrient management practices.	1.1. *Conduct a minimum of 5 with a goal of 10 irrigation practice assessments.*	*1.1 Conducted 18 irrigation system distribution uniformity evaluations and 28 irrigation scheduling assessments.*
	1.2. Conduct a minimum of 5 with a goal of 10 nutrient management assessments.	*1.2. Conducted 25 nutrient management assessments.*
	1.3. For each assessment record the following information: crop type, irrigation type, acres impacted and hours consulted.	*1.3. Recorded this information for all assessments and included it in quarterly reports.*
	1.4.50% - 75% percent of growers receiving assessments independently implement at least one BMP included in the assessment recommendation form.	*1.4. Worked with 12 growers and had follow up contact with 10 growers. Of the 10 growers contacted, 100% had implemented at least one BMP, all were self funded.*
2) Provide growers technical and financial assistance in implementing on-site projects, water conservation insfrastructure,and/or sub-watershed nutrient treatment structures that can conserve water and reduce nutrient loads to water bodies or groundwater.	*2.1. On-farm BMP implementation: Achieve a reduction of 5-20% in water use on farms implementing irrigation BMPs, reduce nitrogen addition by 10-40%.*	*2.1. Contacted 5 out of 8 growers who received irrigation scheduling assessments, many on multiple fields. Water reduction varied between 3 - 12 inches for a crop, a 10-40% reduction. Average water reduction was 5 in/acre. Fertilizer N reduction varied between 0 and 73 lbsN/acre/yr, with an reduction average of 38 lbsN/acre/yr. This represents 0-30% reduction in nitrogen addition.*
	2.2. WM Infrastructure - CIMIS Station: A) Compare CIMIS data to closest alternative to evaluate increased accuracy of ET data, and B) Survey growers to evaluate the importance of increased confidence in using data	*2.2. The CIMIS Station went online 2/20/17 and ET data is available to growers farming 60,000 acres of land near Soledad. The short operational timeframe was insuffficent for a comparison to other stations or a survey of grower confidence.*

Growers who received assessments were interviewed, and they provided information on estimated or measured water and fertilizer savings compared with previous usage across their entire operation. Grower water use was reduced by approximately 10-40% and nitrogen application by 0-30%, depending on the grower. Growers reported that learnings from assessments were generally applied across their entire operation, not just on the fields evaluated. Based on grower feedback, an estimated total of 2704 ac-ft/yr less water is being used for irrigation and a total of 211 tons/year less fertilizer N is used in the Lower Salinas watershed.

Nutrient Removal Projects

Table 15B (cont'd). PAEP goals 3 & 4 and targets established before implementing nutrient removal projects compared with accomplishments.

Project Goals	Targets	Accomplishments
3) Make progress toward the achievement of the Lower Salinas Nutrient TMDL water quality targets for nitrate and unionized ammonia.	*3.1 CMP, Assess whether the on-farm effort impacted downstream WQ and why or why not.*	*3.1. There was an insufficient time frame to collect data from monitoring to ascertain whether an improvement was made.*
4) Reduce nitrate load contributions to surface water.	*4.1. Achieve 75% of the load and concentration reduction projections by the end of year 1 after installation. Projections are site specific based on wetland size, inlet load, and the median decay rate found in the literature.*	*4.1. For projects with less than one year of data, we based the percent on the available data: CIMIS ND*; Azevedo ND*; Spence 100%; Oceanmist 71%; PG&E 52%*
	4.2. In aggregate show a collective reduction of 5% in applied water and 15% nitrogen fertilizer by growers in the subwatershed .	*4.2. For the Lower Salinas watershed, a total of 2704 ac-ft/yr less water is being used for irrigation. Average water reduction for growers involved per acre was 0.32 acre-ft/year. Total fertilizer N reduction was 211 tons/year. Average N reduction was 38 lbs/acre. We did not compute the percent reduced collectively.*
		ND = no data

Project goal 3 related to both water and nutrient application efficiency projects and nutrient removal projects. This goal was to make progress toward the achievement of the Lower Salinas TMDL water quality targets for nitrate and unionized ammonia. There was insufficient time to collect enough data to ascertain whether progress was made or not toward this goal. In the future, a change point analysis using Cooperative Monitoring and CCAMP data could be undertaken to find out whether there was a before and after difference based on the 6 projects implemented through this grant project.

Nutrient Removal Projects

Goal 4 for nutrient removal projects was to reduce nitrate load contributions to surface water. The target for nutrient removal projects was to achieve a load reduction of 75% of the projected mature load reduction by the end of their first year of operation. Wetlands and bioreactors generally improve performance for a time period after their initiation as the plants and microbial populations become established. For this reason we did not expect 100% performance the first year, but targeted accomplishing 75% of estimated mature performance. Monitoring data could not be collected for the Azevedo bioreactor and performance could not be evaluated.

We estimated mature removal rates for the PG&E treatment wetland and Oceanmist bioreactor based on removal rates found in scientific literature and used these to compute the PAEP target, which was 75% of the load reduction of the mature rate. The load reduction at maturity for the PG&E treatment wetland was calculated using Kadlec's (2009) median aerial nitrate removal rate among 205 wetlands of 26.5 m/yr. We used the tanks in series model to estimate outlet concentration and compute load reduction, basing inlet concentration on the average concentration of nitrate entering the wetland over the course of our monitoring (24 mg/L). We used the Arhennius equation to estimate the performance based on temperature differences in the winter and summer, assuming 6 months of each. We calculated load removal for summer pumping into the wetland at a rate of 141,000 gallons per day and winter as 300,000 gallons per day. Based on these assumptions and calculations, the mature wetland is estimated to remove 84% of the nitrate as N at an average rate of 16.3 kg/day. During its first three months of operation, the PG&E treatment wetland achieved a load reduction of 44% based on monitoring data. Thus it achieved 52% (44/84) of the load reduction predicted at maturity compared with a target of 75%. A similar analysis was done for the Oceanmist bioreactor using the volumetric removal rate of 1.4 day^{-1} found by Leverenz et al. (2010) in the study of 5 woodchip bioreactors. The Oceanmist bioreactor achieved a load reduction of 42% with an estimated future mature load reduction of 59%. Thus it achieved 71% (42/59) of the load reduction predicted at maturity compared with a target of 75%. Although both projects underperformed according to target, neither was operational for a full year and much of the monitoring was in winter months when performance is worst due to lower microbial activity in cold temperatures. Both projects would have performed better had they been operational for a full year.

LESSONS LEARNED & FOLLOW-UP ACTIVITIES

Permitting

Permitting through Monterey County was costly and time consuming, due to the County review process: archaeological assessment, biological assessment, biological studies, biological and amphibian reports, and biological monitoring for PG&E and Oceanmist projects. There was a tendency on the part of the County to loose perspective of the purpose of the project as the creation of habitat and to treat it similarly to a commercial development. Having a permit streamlining process for conservation projects may have speeded up and simplified the process. Also, perhaps involving County upper level staff in the vision and benefits to Monterey County of having scenic coastal habitat, either through site visits or artist renditions, might help reduce permitting burden or speed the process.

There were a number of requirements the County considered, which took time to argue and avoid. At one point they considered requiring a three year amphibian study. At another time they considered requiring a conservation easement.

Some permits were avoided through scaling projects to avoid the need for permitting. For example earth removal, when possible, was kept under the total 100 cu yards that would trigger the need for a grading permit. The solar panel at Azevedo did not require a permit because the voltage was under 25V.

Having a previously approved Moro Cojo Slough Management Plan that included a filed CEQA negative declaration from May 2, 1996 and the programmatic CEQA exemption completed by the State Water Resources Control Board set precedent and enabled county staff to concur with the previous negative declaration for the PG&E treatment wetland and the Oceanmist bioreactor. CCR and CCWG have a well-documented history of permits and reports for this area, which is very helpful when seeking further approvals (Appendix A: Moro Cojo Permit History).

Having a streamlined permitting process in Monterey County, similar to those in place for Santa Cruz and San Luis Obispo Counties, could help reduce the burden of permitting for conservation oriented projects.

Technical and financial issues and resolution

At the Spence VTS during stormwater runoff, sometimes the VTS over-topped the edges and flowed onto the adjacent road. This is being resolved by adding sediment collected in the sediment basin to augment the berm between the VTS and the road.

The weirs installed to collect flow information caused flow to back up during high stormwater runoff events, thereby reducing the accuracy of the flow information and also resulting in overflow of the VTS at the low berm areas along its sides.

The grower was very efficient at irrigating during the summer, generated very little runoff, and re-circulation of water to irrigate the grass on the ditch sides was not plausible.

The Oceanmist Bioreactor outlet was originally sized too small for the needed throughput, and this resulted in flow issues. Our recommendation is to oversize outlet piping to avoid similar issues.

Soil emitted gas was a problem beneath the Oceanmist bioreactor liner, which caused elevation of the liner bed. A narrower design would allow for gas to escape around the sides, but the wide Oceanmist design resulted in the gas causing the liner to rise and resulting in flow issues. This could be resolved through not having a lined basin at the bottom or through use of large gravel or a French drain under the bioreactor.

Wood chips were a free commodity when the Oceanmist bioreactor project was originally budgeted. Subsequently a use was found for wood chips as a boiler fuel, and they acquired an economic value. This resulted in the unanticipated cost to acquire wood chips.

The CIMIS station experienced a grass failure due to the growth of weeds, which outcompeted the grass, when the irrigation system was turned on. This has resulted in the need to use an herbicide to kill the weeds, reseed the grass and check the irrigation system prior to replanting.

Labor costs due to the need to pay Prevailing Wages were much higher than if this were not a requirement. Getting labor therefore has a high relative value compared with material and land costs. Awareness of prevailing wage actual costs earlier in the project could have helped improve our estimates.

Wood chips settle through time and occasionally checking that they are covering the entire water column is important.

Organizational

Working across organizational boundaries where several players had different objectives and timing requirements proved to be challenging. Coordinating contractors, property owners, growers leasing the property, and engineers proved difficult at most implementation sites and caused project delays.

FOLLOW UP ACTIVITIES

The combination of on-farm work to more efficiently apply water and nutrients to meet crop demands along with treatment of runoff water to remove nutrients has proven to be a worthwhile strategy. Project partners have received a CDFA Conservation Innovation Grant for $1.3 million to continue working on this approach. The overall goal of the CIG project is to establish a cooperative model for pooling resources to comply with water quality regulations, making conservation practices more widely applicable in high-value, irrigated agricultural lands. The cooperative approach acts as a framework for strategic and spatially explicit modeling, siting, and monitoring of on- and off-farm treatment areas. The approach will provide a governance structure that links implementation of voluntary conservation practices with streamlined regulatory compliance, increasing the efficiency and affordability of program implementation.

In addition to the CIG grant, partners will continue working at the locations where implementation projects were established in order to evaluate ongoing performance and to provide tours and demonstrations to interested groups. We will also encourage research of the removal of other NPS pollutants including pesticides. CA Department of Pesticide regulation is planning to research pesticide removal at the Oceanmist bioreactor and UC Davis at Granite Canyon has already conducted pesticide removal research at the Spence VTS.

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Table A1. Monitoring results from irrigation event sampling at the Spence VTS in the summer of 2015 and 2016.

Sampling Location	Date	Kjehldahl Nitrogen mg/l	Nitrate as N mg/l	Nitrite as N mg/l	Total Nitrogen mg/l	o-phosphate as P mg/l	Phosphorus, Total mg/l	Specific Conductance (E.C.) umhos/c	Total Susp. Solids mg/l	Event Runoff volume cubic meters
309SVT-SedTrapOutflow	8/10/2015	3.4	nt	nt	nt	nt	2.7	644	1595	0.833
309SVT-InletA	8/10/2015	5	nt	nt	nt	nt	3.4	609	1250	0.833
309SVT-Outlet	8/10/2015	ns	ns	ns	ns	ns	ns	ns	ns	0.000
309SVT-SedTrapOutflow	8/12/2015	5.2	nt	nt	nt	nt	3.4	650	1248	0.844
309SVT-InletA	8/12/2015	3.6	nt	nt	nt	nt	2.7	620	580	0.844
309SVT-Outlet	8/12/2015	ns	ns	ns	ns	ns	ns	ns	ns	0.000
309SVT-InletB	7/26/2016	2.2	3.3	nd	5.5	0.2	1.1	5.5	304	31.779
309SVT-InletA	7/26/2016	1.7	0.9	nd	2.6	0.7	1	2.6	94	0.057
309SVT-Outlet	7/26/2016	ns	ns	ns	ns	ns	ns	ns	ns	0.000
309SVT-InletB	8/2/2016	1.8	nt	nt	nt	nd	0.42	nt	75	40.4995
309SVT-InletA	8/2/2016	1.2	nt	nt	nt	0.5	0.68	nt	11	0.29523
309SVT-Outlet	8/2/2016	ns	ns	ns	nt	ns	ns	ns	ns	0.000

ns= no sample taken. nt = not tested. nd = not detected by laboratory analysis.
Event runoff volume is the total runoff for the entire duration of the event.

Table A2. Monitoring results from stormwater event sampling at the Spence VTS.

Sampling Location	Date	Kjehldahl Nitrogen mg/l	Nitrate as N mg/l	Nitrite as N mg/l	Total Nitrogen mg/l	o-phosphate as P mg/l	Phosphorus, Total mg/l	Specific Conductance (E.C.) uS/cm	Total Susp. Solids mg/l	Event Runoff volume cubic meters
309SVT-SedTrapOutflow	11/9/2015	5.6	0.4	nd	6	1.6	5.5	303	900	142.69
309SVT-InletA	11/9/2015	11.6	0.7	nd	12.3	1	10	184	4580	142.69
309SVT-Outlet	11/9/2015	14.6	1	nd	15.6	1.3	9	154	4940	129.45
309SVT-SedTrapOutflow	11/10/2015	4.8	0.4	nd	1.8	4.5	283	283	676	405.20
309SVT-InletA	11/10/2015	6	0.5	nd	0.8	4.4	182	182	1160	405.20
309SVT-Outlet	11/10/2015	4.9	nd	nd	1	4.3	186	186	740	405.20
309SVT-InletB	11/16/2015	4.8	0.3	0.2	1.1	5	260	260	4860	861.47
309SVT-InletA	11/16/2015	5.9	0.4	0.2	0.4	6	169	169	5200	861.47
309SVT-Outlet	11/16/2015	7.7	0.4	0.2	0.6	7	168	168	5120	861.47
309SVT-InletB	12/11/2015	ns	ns	ns	ns	ns	ns	ns	ns	818.30
309SVT-InletA	12/11/2015	7	1.4	0.2	0.7	6	115	115	3640	818.30
309SVT-Outlet	12/11/2015	7.9	1.2	0.2	0.6	6	120	120	2810	818.30
309SVT-SedTrapOutflow	12/22/2015	5.6	1.9	0.2	0.6	4.6	103	103	1000	2175.99
309SVT-InletA	12/22/2015	8.9	1.2	0.3	0.7	7.5	92	92	3180	2175.99
309SVT-Outlet	12/22/2015	4.2	1.7	0.2	0.4	3.9	132	132	880	2175.99
309SVT-SedTrapOutflow	1/5/2016	7.9	1.2	nd	9.05	0.5	nt	106	5877	557.97
309SVT-InletA	1/5/2016	4.6	1.1	nd	5.7	0.5	nt	95.5	1062	557.97
309SVT-Outlet	1/5/2016	4.15	1.2	nd	5.4	0.6	nt	86.5	821	425.30

ns= no sample taken. nt = not tested. nd = not detected by laboratory analysis
Event runoff volume is the total runoff for the entire duration of the event.

Table A3: Field measurements for Oceanmist bioreactor at the inlet and the outlet.

StationCode	SampleDate	Temperature (Deg C)	Specific Conductivity (uS/cm)	Salinity	Oxygen, Dissolved (mg/L)	pH	Turbidity (NTU)
306OMB-In	8/29/2016	18.55	3328	1.75	9.32	6.76	5.95
306OMB-Out	8/29/2016	17.7	3420	1.8	2.45	7	3.45
306OMB-In	8/30/2016	17.33	2904	1.8	6.91	7.15	1.43
306OMB-Out	8/30/2016	17.45	2913	1.8	1.51	7.02	1.81
306OMB-In	8/31/2016	20.12	3101	1.52	17.68	7.04	1.45
306OMB-Out	8/31/2016	18.53	3073	1.87	5.21	7.14	1.67
306OMB-In	9/1/2016	21.96	3627	2.04	19.46	7.46	1.54
306OMB-Out	9/1/2016	18.5	3073	1.85	0.65	6.98	1.71
306OMB-In	9/2/2016	18.5	2919	1.75	10.92	6.95	1.94
306OMB-Out	9/2/2016	18.59	3470	1.83	4.07	7.14	1.77
306OMB-In	9/6/2016	16.99	2881	1.79	9.4	6.71	7.45
306OMB-Out	9/6/2016	17.09	2943	1.83	3.01	6.71	6.8

Table A4: Lab measurements for Oceanmist bioreactor at the inlet and the outlet.

SampleDate	StationCode	Ammonia as N (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	OrthoPhosphate as P (mg/L)
10/8/2015	306OMB-Source	0.03	3.83	0.29	0.15
4/16/2015	306OMB-Source	0.20	57.80	0.18	0.19
4/23/2015	306OMB-Source	0.13	73.40	0.06	0.22
5/15/2015	306OMB-Source	12.18	16.05	1.28	2.88
5/5/2015	306OMB-Source	0.13	73.40	0.06	0.22
7/9/2015	306OMB-Source	0.15	55.60	0.11	0.25
8/29/2016	306OMB-Discharge	1.28	40.40	nd	0.05
8/29/2016	306OMB-Source	0.33	68.80	0.50	0.13
8/30/2016	306OMB-Discharge	1.24	38.28	0.42	0.10
8/30/2016	306OMB-Source	0.24	73.20	0.96	0.17
8/31/2015	306OMB-Source	0.05	2.80	0.35	0.23
8/31/2016	306OMB-Discharge	1.33	36.16	0.36	0.13
8/31/2016	306OMB-Source	0.25	67.60	0.43	0.10
9/1/2016	306OMB-Discharge	1.23	36.60	0.54	0.07
9/1/2016	306OMB-Source	0.17	60.80	1.06	0.06
9/2/2016	306OMB-Discharge	1.24	38.12	0.50	0.10
9/2/2016	306OMB-Source	0.13	63.60	0.30	0.03
9/6/2016	306OMB-Discharge	1.24	41.60	0.36	0.06
9/6/2016	306OMB-Source	0.36	62.00	0.18	0.23

Table A5: Lab measurements for PG&E Treatment Wetland.

SampleDate	StationCode	Ammonia as N (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	OrthoPhosphate as P (mg/L)
4/16/2015	306PGE-Source1	4.40	14.20	1.33	0.77
4/23/2015	306PGE-Source1	1.34	17.58	1.32	1.07
5/5/2015	306PGE-Source1	1.34	17.58	1.32	1.07
5/15/2015	306PGE-Source1	0.10	67.50	0.09	0.25
7/9/2015	306PGE-Source1	4.08	10.72	1.15	1.75
8/31/2015	306PGE-Source1	3.10	2.76	1.17	0.39
10/8/2015	306PGE-Source1	3.29	2.71	1.03	0.40
11/29/2016	306PGE-Source1	0.16	22.10	0.23	0.39
11/29/2016	306PGE-Source3	0.18	20.43	0.25	0.37
12/1/2016	306PGE-MidPoint	0.13	13.83	0.32	0.17
12/1/2016	306PGE-Source1	0.53	16.59	0.17	1.01
12/1/2016	306PGE-Source3	0.31	22.98	0.21	0.90
12/5/2016	306PGE-Discharge	0.02	9.00	0.32	0.12
12/5/2016	306PGE-MidPoint	0.03	16.14	0.38	0.09
12/5/2016	306PGE-Source1	0.66	12.93	0.12	0.76
12/5/2016	306PGE-Source2	0.12	8.88	0.32	0.01
12/5/2016	306PGE-Source3	0.19	23.36	0.17	0.81
12/8/2016	306PGE-Discharge	0.02	9.06	0.33	0.11
12/8/2016	306PGE-MidPoint	0.01	12.42	0.70	0.02
12/8/2016	306PGE-Source1	0.58	7.59	0.28	0.71
12/8/2016	306PGE-Source2	0.17	8.94	0.34	0.01
12/8/2016	306PGE-Source3	0.43	11.40	0.13	0.86
12/12/2016	306PGE-Discharge	3.20	8.62	1.14	0.01
12/12/2016	306PGE-Source1	1.00	27.20	0.35	0.84
12/12/2016	306PGE-Source2	0.83	9.64	0.62	0.33
12/12/2016	306PGE-Source3	4.20	15.18	1.32	0.28
12/15/2016	306PGE-Discharge	0.13	11.90	1.21	0.02
12/15/2016	306PGE-MidPoint	0.17	19.80	0.87	0.26
12/15/2016	306PGE-Source2	0.10	12.00	1.21	0.02
12/19/2016	306PGE-Discharge	0.10	12.40	0.63	0.22
12/19/2016	306PGE-Source2	0.18	12.40	0.66	0.23
1/17/2017	306PGE-Source 1	0.59	40.08	0.14	0.91
1/17/2017	306PGE-Source 3	0.53	36.90	0.14	0.80
1/19/2017	306PGE-Mid Point	0.23	27.75	0.35	0.59
1/19/2017	306PGE-Source 1	0.37	10.56	0.17	0.81
1/19/2017	306PGE-Source 3	0.29	9.74	0.16	0.70
1/23/2017	306PGE-Discharge	0.31	2.12	0.12	0.52
1/23/2017	306PGE-Mid Point	0.26	2.35	0.12	0.62
1/23/2017	306PGE-Source 1	0.39	5.00	0.14	1.00
1/23/2017	306PGE-Source 2	0.24	2.10	0.12	0.50
1/23/2017	306PGE-Source 3	0.19	4.68	0.14	0.98
1/26/2017	306PGE-Discharge	0.35	2.05	0.15	0.79
1/26/2017	306PGE-Mid Point	0.21	4.17	0.15	0.77
1/26/2017	306PGE-Source 1	0.40	32.40	0.11	0.95
1/26/2017	306PGE-Source 2	0.18	2.05	0.15	0.77
1/26/2017	306PGE-Source 3	0.52	26.64	0.12	0.99
1/30/2017	306PGE-Discharge	0.17	19.17	0.23	0.40

Table A5 (cont'd): Lab measurements for PG&E Treatment Wetland.

SampleDate	StationCode	Ammonia as N (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	OrthoPhosphate as P (mg/L)
1/30/2017	306PGE-Mid Point	0.21	32.10	0.38	0.44
1/30/2017	306PGE-Source 1	0.38	50.00	0.12	0.71
1/30/2017	306PGE-Source 2	0.28	19.44	0.23	0.37
1/30/2017	306PGE-Source 3	0.36	48.63	0.13	0.68
2/2/2017	306PGE-Discharge	0.15	30.60	0.67	0.19
2/2/2017	306PGE-Mid Point	0.16	40.00	1.28	0.33
2/2/2017	306PGE-Source 2	0.17	29.97	0.65	0.17
2/6/2017	306PGE-Discharge	0.30	18.72	1.55	0.16
2/6/2017	306PGE-Source 2	0.14	18.63	1.57	0.13

Table A6: Field measurements for PG&E Treatment Wetland.

SampleDate	StationCode	Electrical Conductivity (uS/cm)	Oxygen, Dissolved (mg/L)	pH	Salinity (ppt)	Temperature (deg C)	Turbidity (NTU)
4/16/2015	306PGE-Source1	2840	13.63	NA	1.67	19.41	63.00
4/23/2015	306PGE-Source1	4053	16.59	8.98	2.7	15.1	60.00
5/15/2015	306PGE-Source1	2053	19.9	8.48	1.25	17.25	49.00
7/9/2015	306PGE-Source1	2583	11.29	8.26	1.44	21.19	37.00
8/31/2015	306PGE-Source1	2908	4.63	7.62	1.71	19.39	78.00
10/8/2015	306PGE-Source1	1579	1.79	7.55	0.98	15.84	13.00
11/29/2016	306PGE-Source1	1687	9.6	6.88	1.17	11.66	47.73
11/29/2016	306PGE-Source3	1639	11.57	7.34	1.04	14.55	29.60
12/1/2016	306PGE-MidPoint	1532	14.27	8.9	0.94	15.9	14.80
12/1/2016	306PGE-Source1	2016	8.66	7.76	1.29	15.08	66.23
12/1/2016	306PGE-Source3	2480	12.08	8.38	1	14.61	18.83
12/5/2016	306PGE-Discharge	1512	NA	9.8	0.92	16.71	21.40
12/5/2016	306PGE-MidPoint	2425	15.9	9.2	1.54	15.86	7.29
12/5/2016	306PGE-Source1	3010	9.1	8.15	1.94	15.87	94.80
12/5/2016	306PGE-Source2	1500	16.35	9.7	1.1	16.51	20.47
12/5/2016	306PGE-Source3	3269	17.22	8.83	2.1	15.98	9.86
12/8/2016	306PGE-Discharge	1533	14.97	9.59	1.04	12.44	23.67
12/8/2016	306PGE-MidPoint	2170	14.26	9.03	1.48	12.85	25.53
12/8/2016	306PGE-Source1	767	7.44	7.5	0.51	11.53	534.67
12/8/2016	306PGE-Source2	1534	13.94	9.57	1.03	12.6	54.70
12/8/2016	306PGE-Source3	1514	10.65	7.53	1.04	11.72	128.33
12/12/2016	306PGE-Discharge	1438	17.93	9.52	0.91	15.02	19.30
12/12/2016	306PGE-MidPoint	1298	16.51	9.17	0.82	14.53	16.03
12/12/2016	306PGE-Source1	2173	9.89	7.77	1.4	14.92	45.87
12/12/2016	306PGE-Source2	1586	14.11	8.74	1.03	14.08	33.03
12/12/2016	306PGE-Source3	1915	11.77	8.33	1.28	13.36	18.50
12/15/2016	306PGE-Discharge	2001	9.67	7.7	1.42	14.31	34.63
12/15/2016	306PGE-MidPoint	2071	10.06	8.62	1.37	14.02	140.67
12/15/2016	306PGE-Source2	2113	10.69	9.1	1.01	16.73	40.33
12/19/2016	306PGE-Discharge	2010	9.1	9.1	1.21	13.1	19.17
12/19/2016	306PGE-Source2	2100	8.72	8.6	1.01	13.01	20.17