California Department of Food & Agriculture
Specialty Crop Block Grant Program

FINAL PERFORMANCE REPORT

USDA Project No.: 31	**Project Title:** Effectiveness Study of Multiple Off-Farm Treatment Practices for Specialty Crop Farmers	
Grant Recipient: San Jose State University Foundation	**Grant Agreement No.:** SCB14031	**Date Submitted:**
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Grant Award Amount (A)	Amount Invoiced to Date (B)	Remaining Grant Balance (A-B)	Program Income	Committed Match/In-Kind Funds	Match/In-Kind Funds Utilized to Date
$344,437	$ 344,437	$ 0	$0	$0	$0

Project Summary (Please respond to all bulleted items)

- *Provide a background for the initial purpose of the project, which includes the specific issue, problem, or need that was addressed by this project.*

Response: The Salinas Valley supports farming of specialty crops including multi-year perennials (strawberries and artichokes) and annuals (leafy greens and broccoli) in constant production, leaving little opportunity for field fallowing. These intensive agricultural operations have led to impaired water quality for which the Central Coast Regional Water Quality Control Board (RB3) has developed a regulatory Agricultural Order, known as the Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Ag Order). The Central Coast Wetlands Group (CCWG) and partners have demonstrated load reduction potential of off-farm treatment systems (bioreactors, treatment wetlands, etc.) based on the results of local pilot projects over the past decade. However, data from these pilot projects, along with studies in other parts of the U.S.A., are difficult to compare between system types because field variables including pollutant load, flow and retention time and temperature are inconsistent among studies. The purpose of this Treatment Effectiveness Project is to study the nutrient load reduction potential of several off-farm treatment systems for the management of water quality within the Salinas Valley.

Project Goals

- Construct a working laboratory of four treatment measures, replicated three times each, for statistical validation; (Complete, see Attachment A: Photo documentation of Construction and Operations of Multi-Chamber Bio Reactor)
- Establish decay rate/load reduction estimates for each of the three discrete management measures and a control; (Complete, See Attachment B: Project Design and Sampling Results for Multi-Chamber Bioreactor Research Project and Attachment E: Multi-Chamber Bioreactor Model-based Analysis)
- Dissemination of results to various users; (Complete: See Attachment C: List of presentations and partners who have received information on intended nutrient reduction rate estimates of the project during 2016-2017)
- Integration of load reduction estimates into a watershed-based alternative compliance strategy. (Complete: See Attachment D: Draft Lower Salinas Valley Water Quality Cooperative).

- *Describe the importance and timeliness of the project.*

  Response: This project is an important step toward the use of treatment systems within defined drainage basins to reduce nutrient loading that cannot be dealt with by employing on-farm practices alone. As a resource, it allows farmers to make informed decisions on how to best improve water quality and meet state regulatory objectives for their specific specialty crops and drainage conditions.

  Specifically, this project supports unique efforts to investigate the effectiveness of several commonly used treatment options under similar environmental conditions. Unfortunately, many funding sources do not support these research activities. Without research opportunities such as this effort, industry and regulatory agencies are at an impasse to develop alternative compliance options.

- *If the project built on a previously funded SCBGP project, describe how this project complemented and enhanced previously completed work.*

  Response: This was the first project funded by SCBGP. Our partners are building off the success of this project within a recently awarded Natural Resources Conservation Service (NRCS) grant to establish an industry-lead nutrient cooperative compliance program for the Ag Order's discharge requirements. California State University-Monterey Bay (CSUMB) and CCWG researchers have begun looking for additional funding to improve and expand nutrient decay rate curves and investigate additional treatment systems.

Project Approach (Please respond to all bulleted items)

- *Briefly summarize activities and tasks performed during the entire grant period. Whenever possible, describe the work accomplished in both quantitative and qualitative terms. Specifically, discuss the tasks provided in the* ***Work Plan*** *of the approved project proposal. Include the significant results, accomplishments, conclusions and recommendations. Include favorable or unusual developments.*

  Response: The project: 1.) Quantified nutrient load reduction of various treatment designs under the same field conditions; 2.) Improved load reduction models using local data; and 3.) Supported adoption of treatment systems for Ag Order compliance, reducing farmer costs.

  Key Actions taken to complete the project:

  Task 1-Project Construction:

  Task Description: CCWG created an "outdoor laboratory" to test the decay rate constants for nitrates within 12 treatment chambers using standard flow rates, retention times, and nutrient inputs.

Actions taken:

- Permitting (2015- Fall 2016): In 2015, a Coastal Development Permit was submitted but approval, and contingent construction of the bioreactor chambers, was severely delayed. The grading permit was approved by the County, and construction of the project began in September 2016.

- Creation of 12 total above-ground chambers for treatment systems (Fall 2016-Spring 2017): Construction of 12 above-ground chambers, each measuring 80'x2.5'x5', was completed in spring 2017. The 12 linear chambers are contained in a large earth basin and each chamber is separated by chain-link fencing and posts, and lined with impermeable pond liner. Perforated drainage is installed beneath the pond liner to prevent water from pooling under the chambers. Sump pumps have been installed to regulate ground water interactions with the chambers. Winter flooding restricted access to the site (needed to install wood chips and plant materials) and caused considerable delays into late spring 2017. Initial flow studies were completed while site access was limited, and initial nutrient load reduction experiments began June 5, 2017.

- Pipe and pump installation and retention system for water (Fall 2016-Spring 2017): Individual chamber inlet and outlet piping and pumps were installed and appropriately modified based on initial flow experiments (Attachment A). Dedicated power lines and a PG&E transformer were installed to ensure that continuous power was available to regulate flows and maintain sampling equipment. A fore bay to the treatment chambers was constructed to retain water, reduce sediment, and maintain consistent flow to all the treatment chambers through a distribution trough. The fore bay contains an overflow mechanism that is connected to the adjacent agricultural ditch, and two bypass lines that are connected to the treatment wetland, located just beyond the bioreactor. The trough runs across the beginning of the chambers and allows for adjustable flowrates and hydraulic residence time (HRT) in each chamber using adjustable v-notch distribution points. A CSUMB student created a model to calculate v-notch height adjustments in order to achieve specific flow rates into the chambers. A different model was used to calculate flowrates for specific HRT within each treatment. The standpipe at the end of each chamber is perforated to collect treated water from the entire water column. Removable screens were needed to cover each standpipe and prevent larger debris (e.g. woodchips, algae) from clogging the perforations. The outlet of each chamber discharges into the adjacent treatment wetland. The height of the pipe outlet acts as the hydraulic control for the height of the water within the chamber, allowing easy access for water sampling.

- Filling the chambers with materials to create three replicates of 4 treatment systems (Spring 2017): Initial treatment systems to be tested include 1) wood chip bioreactor 2) heated wood chip bioreactor 3) wetland emergent plant growth chambers and an agriculture ditch/control treatment. The treatments were successfully filled on May 31, 2017. JetMulch Inc. was hired to install the 320 cubic feet of wood chips quickly without use of heavy equipment to ensure no damage was done to the chambers. To fill the vegetated wetland channels, *Hydrocotyle* (known as pennywort) was transplanted from the adjacent agricultural ditch and was suspended in the channels by using several sections of wide mesh for support.

Tracer tests to determine to standardize rate of water flow (Fall 2016, Winter 2017): The Watson Lab at CSUMB completed a set of three flow model runs to estimate retention time, water flow rate, and depth for each treatment. These models aided the design and construction of the various treatment chambers and development of load reduction models for each treatment type.

Task 2-Project Monitoring, Model Development and Partner Outreach:

Task Description: CCWG and partners used resulting data from each of the treatments to develop load reduction models and evaluate the functional constraints of each technology. These data will enable growers to reduce nitrate levels in farm runoff through application of treatment techniques best suited for the specific specialty crops and drainage conditions.

Actions taken: During construction permitting delays, the scientific team worked to improve the data collection capacity of the system and further integrate the resulting data into industry-led discussions with RB3. CCWG and CSUMB researchers continued collaborations to identify additional projects that could be implemented collaboratively to further nutrient reduction research and program development goals. A pilot bioreactor was constructed in March 2016 and provided the project team with a single-chamber working laboratory while construction delays at the multi-chamber were addressed. This allowed for research into retention times, nutrient reduction rates, and pesticide removal potential. Lessons learned from construction of and research at the pilot bioreactor provided invaluable insight and improvements to the design and construction of the 12-chamber bioreactor.

- Sample and monitor input and output parameters (temp, DO, salinity, conductivity) (Spring 2017): Funds provided by Anthropocene enabled the CCWG team to purchase a multi-parameter water quality monitoring probe that includes a nitrate sensor. The probe is incorporated into the Hydra-Nutrient Analyzer, an automated sampling system, which collects and analyzes source drainage water and water from each of the nutrient reduction chambers every four hours. This consistent, continuous sampling significantly increases the resolution of our nutrient reduction models and can account for daily fluctuations in nutrient loading. The Hydra-Nutrient Analyzer has been tested in a lab setting and was deployed May 19, 2017 to collect load reduction data necessary to build nutrient reduction curves. After deployment in the field, a number of hardware issues were discovered and resolved, including: installation of valve filters to prevent snails from clogging the collection/analysis system, replacement of the nitrate probe, and reworking inadequate pumping of source water samples from the fore bay. All issues were resolved as of July 18, 2017. During June 2017, 16 sets of grab samples were collected from the distribution trough (source water), each of the 12 chambers, and the end of the treatment wetland, to inform nutrient reduction curves and capture initial reduction processes after the bioreactor was turned on. A YSI sonde was used to collect temperature, dissolved oxygen (DO), salinity and specific conductivity data, and a turbidimeter was used to test turbidity. Nutrient sampling was conducted by collecting 30ml of water, using a 50ml syringe with filter, at each sample location.

- Collect field records of ambient temperature and recent rainfall events (Spring 2017). The Moss Landing Marine Labs Weather Station is online and collecting continuous data.

- Lab analysis of water samples for nitrates (Fall 2016-Summer 2017): At the pilot bioreactor, nutrient concentration grab samples were collected at the input and output locations. Nutrient concentrations in source water for the multi-chamber system were collected daily in September 2016. Fluctuations in daily nutrient concentrations in these samples documented the benefits of sampling nutrients within all treatments multiple times a day.

  After completion of contraction of the multi-chamber bioreactor, the Hydra-Nutrient Analyzer was deployed and recalibrated using grab samples taken from the same locations from which the system draws its samples.

  All grab samples were processed in the Null Lab at Moss Landing Marine Labs.

- Tracer tests to determine mechanisms and rate of water quality improvement (Spring 2017): After construction was completed, the Watson Lab at CSUMB completed a set of flow model runs to estimate retention time, water flow rate, and depth for each treatment. Additional tracer tests were performed to confirm the HRT, especially in the wood chip treatment channels.

- Data synthesis and analysis (Spring 2017): See Attachment B for a complete description. Reductions were calculated from grab samples collected in June 2017, assuming a one-day HRT. Nutrient reduction rates were averaged by treatment and for all dates. Initial results document a significant reduction in nutrient concentrations in the heated and unheated woodchip treatments, but not in the vegetated and control treatments. Initial results indicate that the unheated woodchip treatment is outperforming the heated woodchip treatment. This may change as the bioreactor is better established, and during the colder months of the year which usually arrest performance of nitrate-consuming bacteria.

- Develop and refine models (Summer 2017): See Attachment E for a complete description. The model results indicated that all three channels with a given treatment behaved similarly to each other, and differently to channels with a different treatment. All channels experience nutrient reduction to varying degrees. The woodchip channels experienced much greater reduction than the control and surface-vegetated channels. The cool woodchip channels experienced slightly more reduction than the warmed channels, probably due to the shorter residence times apparent in the warmed woodchip channels. There was no apparent difference in the instantaneous rate of reduction between the cool and warmed woodchip channels. These results were obtained in mid-summer; we would expect a different result in winter, when the temperature difference between the cool and warmed channels is expected to be much greater. Warmer temperatures were indicated to have a positive effect on reduction in all channels.

While the nature of the results is consistent with a denitrification process (the intended outcome), we cannot yet rule out that the reduction is due to other processes, such as adsorption or conversion to other nitrogen species. All that we have observed is reduction in the concentration of certain aqueous inorganic nitrogen species. This is typical of many bioreactor studies.

Initial model-based estimates of reduction rates for each treatment are shown in Table 1, notwithstanding the shortness of the data set, and the lack of winter data. Based on the data collected to date, and assuming a near-optimal (i.e. summer) temperature of 20°C, the nutrient reductions in woodchip reactors of the kind we installed could be expected to be around 6-7% per hour, or 75-80% per day.

- Outreach to growers based on results: Tours of the multi-chamber bioreactor have been orchestrated with CSUMB researchers and new questions and experiments are in development. Several CSUMB graduate students are now working on the project, documenting flow characteristics and nutrient load reductions. Partnerships have been established with California Dept. of Pesticide Regulation and new pesticide reduction studies and toxicity experiments are being developed and are scheduled for funding at this and the adjacent pilot bioreactor. CCWG is are working with the Monterey County Resource Conservation District (MCRCD) and the Monterey Grower-Shipper Association to help cooperative groups of specialty crop growers adopt these treatment systems within defined drainages and gain credit for their construction with state regulatory agencies. The MCRCD recently received a grant from the Federal Government (USDA-NRCS) to help farmers construct treatment systems, and will use the data from this project to complete a site evaluation and cost-benefit analysis needed for industry to select the most effective treatment system. See Attachment C for a full list of outreach activities.

- *If the overall scope of the project benefitted commodities other than specialty crops, indicate how project staff ensured that funds were used to solely enhance the competitiveness of specialty crops.*

Response: Data results focused on nutrient reduction potential of various treatments within the highly productive Salinas Valley specialty crop farming areas. This research specifically focuses on aiding farmers to meet regional environmental laws and centers on agriculture practices unique to this region and these crops (drip tape, tile drains, etc.).

- *Present the significant contributions and role of project partners in the project.*

Response: Each team member excelled in completion of their tasks and meeting their responsibilities. The project team was able to work around permit delays and construction challenges. The Watson Lab at CSUMB used their hydraulic modeling capabilities to guide chamber design and flow regulation infrastructure to obtain equal flow and residence times for each chamber as needed to establish accurate load reduction estimates. They also aided in design and construction of thermal insulation needed to raise temperatures within the heated chambers. The Null Lab at MLML provided field support and rapid return of nutrient analyses to generate reduction data enabling the team to produce fine scale changes in chamber design and sample collection strategies necessary to optimize nutrient reduction estimations. MLML staff invested significant time in building the Hydra-Nutrient Analyzer auto sampler. CCWG staff and interns effectively coordinated chamber construction, hydraulic design, and data collection. Staff continually integrated project design refinements into the system to achieve optimal performance. CCWG managed reporting, budget oversight, and project completion. Each member performed above expectations and was driven by the importance and innovative nature of the project goals. The entire technical team aims to identify additional funding to continue the study of nutrient reduction techniques now that the multi-chamber bioreactor research facility is operational.

Goals and Outcomes Achieved (Please respond to all bulleted items)

- *Describe the activities that were completed in order to achieve the performance goals and measurable outcomes identified in the approved project proposal or subsequent amendments.*

  Response: Because of permit and weather related construction delays, nutrient load reduction sampling of the various treatments was completed in the spring and summer of 2017. Additional student field assistants were hired to assist with sample collection to complete the extensive data collection, analysis and modeling required to achieve the key goals and outcomes of this project. This includes documenting load reductions and developing load reduction curves for several different treatment options. The CCWG team coordinated data collection and analysis efforts among the partners to ensure that the goals and outcomes of this project were achieved. The Null lab prioritized the analysis of more than 210 nutrient samples during this period and completed all Quality Assurance measures needed to verify results. MLML staff invested significant time to ensure that the Hydra-Nutrient Analyzer auto sampler functioned properly and data generated by the Hydra and Null lab were consistent. CCWG partnered with CSUMB to obtain a summer intern to focus additional field and office time to collect, analyze and process nutrient load reduction data for load reduction estimations. The Watson lab at CSUMB focused their efforts during the spring and summer on improving hydraulic residence time for each treatment chamber and logging fluctuations in temperature to establish precise measurements needed to establish the nutrient reduction curves. The combined focus of the technical team allowed us to meet our outcomes and goals and develop scientifically defensible nutrient reduction estimates for the tested treatment options.

- *If outcome measures were long term, summarize the progress that has been made towards achievement.*

  Response: Key outcomes of this project were to create the nutrient reduction curves for the tested treatment systems. A long-term outcome is for the specialty crop industry to use this information to identify appropriate nutrient treatment systems for construction on their farms. We are working with the Monterey County RCD and the Grower-Shipper Association of Central California to help cooperative groups of specialty crop growers adopt these treatment systems within defined drainages and gain credit for their construction with state regulatory agencies. The MCRCD recently received a Conservation Innovation Grant from the Federal Government (USDA-NRCS) to help farmers construct treatment systems and will use the data from this project to complete a site evaluation and cost benefit analysis needed for industry to select the most effective treatment system.

- *Provide a comparison of actual accomplishments with the goals established for the reporting period.* *Goals for this reporting period and resulting accomplishments were:*

    1) Filling of the chambers will begin in April: Completed in May- a total of 320 yards of wood chips were placed into the 6 test chambers

    2) Sampling of water quality will begin in May: 210 nutrient and basic water chemistry samples were collected in June - equating to 15 individual load reduction calculations for each treatment chamber, or 45 load reductions for each treatment type.

    3) Data synthesis and analysis is ongoing as data are collected: Synthesis is complete and load reduction data are attached to this final report.

    4) Models will be further refined as data are generated. Staff at CSUMB will continue to input data to refine nutrient reduction curves weekly through June: All data have been submitted to CSUMB researchers who have used those data to generate load reduction curves for each treatment type.

    5) Initial outreach has begun and will continue through the end of the project: CCWG has successfully integrated the use of this project's load reduction information into the MCRCD's USDA-NRCS grant effort in coordination with the Grower-Shipper Association. The results of this project will help farmers select appropriate treatment systems.

- *Clearly convey completion of achieving outcomes by illustrating baseline data that has been gathered to date and showing the progress toward achieving set targets.*

Response: Our set target was to establish decay rate/load reduction estimates for each of the four discrete treatment systems. Daily concentration estimates were collected from 16 sampling events (Fig. 1), and were used to calculate reduction rates in two ways. The first method uses a modelling approach to account for variability in flow rate/retention time, initial source water concentration, and average water temperature (Table 1). The second method calculated reduction assuming a one-day residence time for average concentration by treatment over the sampling period (Table 2).

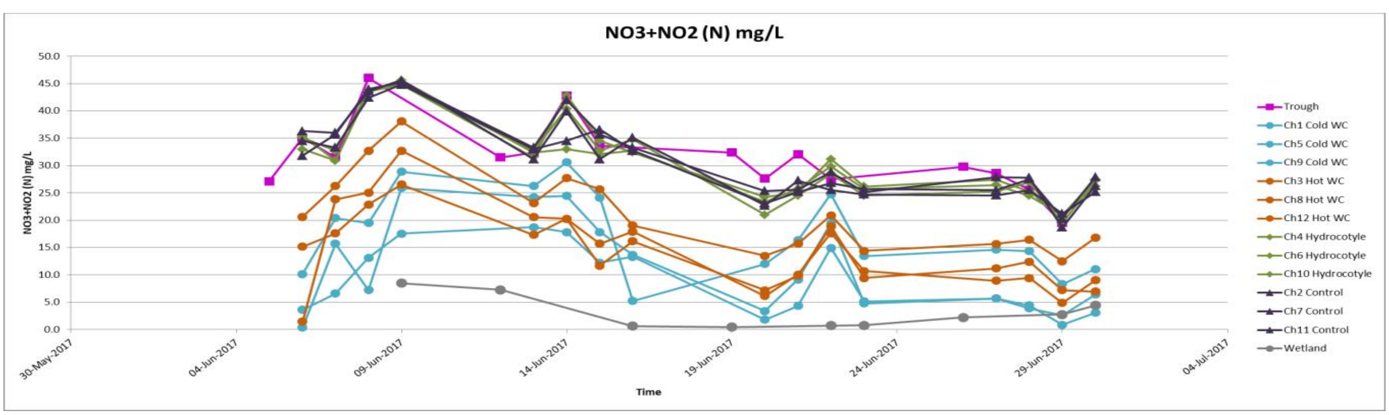

Figure 1. Daily concentration of water discharged from each of the 12 treatment chambers and source water (trough), as well as the adjacent treatment wetland.

Table 1. Reduction rates estimated from fitted model for each treatment.

Treatment	Channel number	First-order reduction coefficient (at 20C) by channel	First-order reduction coefficient (at 20C) mean	Reduction per hour (at 20 C) by channel	Reduction per hour (at 20 C) mean	Reduction per day (at 20 C) by channel	Reduction per day (at 20 C) mean
Control	2	0.154	0.15	0.6%	0.6%	14%	14%
Control	7	0.113		0.5%		11%	
Control	11	0.183		0.8%		17%	
Cool woodchips	1	1.763	1.45	7.1%	5.9%	83%	75%
Cool woodchips	5	1.687		6.8%		82%	
Cool woodchips	9	0.914		3.7%		60%	
Warm woodchips	3	1.953	1.70	7.8%	6.8%	86%	80%
Warm woodchips	8	1.166		4.7%		69%	
Warm woodchips	12	1.973		7.9%		86%	
Floating vegetation	4	0.185	0.18	0.8%	0.7%	17%	16%
Floating vegetation	6	0.201		0.8%		18%	
Floating vegetation	10	0.139		0.6%		13%	

Table 2. Average nutrient reduction estimates for each treatment.

Treatment	Average dischage concentration	Flow Rate (g/m)	HRT	area (sq ft)	Volume (cubic feet)
Ag Ditch	32.47	4.64	21.96	400	1000
Hydrocotyle	32.85	4.39	21.16	400	1000
Cool woodchips	13.51	2.78	20.65	400	500
Heated woodchips	18.23	2.64	22.12	400	500
Treatment wetland	3.27	43.35	84.00	465,000	558000
Treatment	**Percent Reduction**	**mg/L Reduction**	**Load Reduction g/day**	**Load Reduction (grams/day) per 1000 sq ft of treatment**	**Concentration (mg/l) Reduction per 1000 sq ft**
Ag Ditch	3%	0.90	22.68	56.70	2.24
Hydrocotyle	2%	0.46	11.08	27.69	1.16
Cool woodchips	45%	14.87	225.44	563.61	37.19
Heated woodchips	28%	9.21	132.72	331.79	23.03
Treatment wetland	89%	20.99	6,176.63	13.28	0.05

- *Highlight the major successful outcomes of the project in quantifiable terms.*

Response: Quantified results of key project outcomes:

1.) Construction of a working laboratory of four treatment measures replicated three times each for statistical validation: The project team constructed a 8000 sq. foot research facility that includes dedicated power, an automated nutrient sampling system, and flow regulation infrastructure that can be modified for a range of flow rates. The infrastructure supports water quality research within 12 treatment chambers within a working agricultural landscape.

2.) Establish decay rate/load reduction estimates for each of the four discrete treatment systems: Load reductions were established for each of the treatments (Tables 1 and 2) and decay rates were calculated by integrating information on initial concentration, flow rates and water temperature. See Attachment E.

3.) Dissemination of results to various users: Initial results have been presented at 3 regional workshops and industry meetings, discussed with RCD and Grower-Shipper staff on three occasions, and presented at the California Headwaters to Oceans Conference in May. Results of decay rates will be presented at an upcoming Agriculture Water Quality Alliance meeting and used by partners to aid project selection and design for the USDA-NRCS grant project. Please see Attachment C for a full list of outreach events.

4.) Integration of load reduction estimates into a watershed-based alternative compliance strategy: Load reduction estimates have been provided to the agriculture cooperative development team (results presented at the most recent meeting). The USDA-NRCS grant directly references the use of this project's results by specialty crop farmers to design and prioritize treatment projects and aid negotiations with the state regulators (by providing defensible and quantifiable load reduction estimates of proposed actions).

Beneficiaries (Please respond to all bulleted items)

- *Provide a description of the groups and other operations that benefited from the completion of this project's accomplishments*.

Response: The beneficiaries of this project will be any specialty crop growers in the region that are looking for effective ways to improve water quality before it leaves the farm. Growers are actively seeking innovative ways to improve water quality and are open to novel beneficial management practices, such as edge-of-farm or off-farm woodchip denitrifying bioreactors and constructed treatment wetlands. The data generated by this project will help farmers meet agriculture waiver requirements.

- *Clearly state the number of beneficiaries affected by the project's accomplishments and/or the potential economic impact of the project*.

Response: The load reduction estimates will be used in development of the Agriculture cooperative for two watersheds in the lower Salinas Valley (Attachment D). Between 20 and 30 different specialty crop farmers are anticipated to participate in these Phase I cooperatives when established, representing more than **xx acres** of specialty crop agriculture lands. If successful, the Cooperative approach to Ag Order compliance is expected to be reproduced throughout specialty crop areas of the Salinas Valley and Central Coast.

Lessons Learned (Please respond to all bulleted items)

- *Offer insights into the lessons learned by the project staff as a result of completing this project. This section is meant to illustrate the positive and negative results and conclusions for the project. Lessons learned should draw on positive experiences (i.e., good ideas that improve project efficiency or save money) and negative experiences (i.e., lessons learned about what did not go well and what needs to be changed).*

Response:
General Design Considerations When Building a Bioreactor

1. Choose dimensions
   The width and length of a bioreactor will depend on the desired amount of water to be treated. There is little consensus regarding optimal dimensions, but it is our goal to use our denitrification rate data to build a model that will estimate required bioreactor size based on the desired number of acres to be treated and the peak flow from that land.
2. To line or not to line
   Using a polyethelene pond liner ensures all water entering the chamber is treated and leaves via the outlet, as opposed to some unknown amount of water contributing to groundwater recharge. While this makes quantifying the total amount of water treated easier, there are drawbacks to using a liner when it comes to maintenance and construction. In our experience, making the lining leak free at the outlet is difficult, and any liner above the water-line makes great habitat for rats to nest in. Though there are ways to mitigate these problems, an alternative option in predominantly clay soil, as is present in the Lower Salinas Valley region, is to have an unlined chamber.
3. Choose source material for woodchips
   While there is little evidence to suggest a significant difference between source material for woodchips, pressure treated wood and eucalyptus should be completely avoided because of their undesirable chemical composition. For our facility we are using woodchips sourced from Randazzo Salvage, which gets wood from local construction and landscaping projects.
4. Filling the bioreactor
   The bioreactor can be filled by using a tractor to dump woodchips in or near the site, and using pitchforks to manually spread the woodchips. However, if the chamber is inaccessible by tractor, contracting with a blown woodchip delivery service, like JetMulch Inc., is a great alternative.
      Note: If using pond liner, do a leak test by filling the chamber with only water before filling it with a treatment. All repairs become more difficult when navigating around woodchips or plants.
5. Maintenance
   Leaving a treatment-free space around both the inlet and outlet of the chamber allows for easy access for maintenance and repairs. Our woodchip chambers contain barriers that allow water to pass through but hold the woodchips in place. Nevertheless, routine maintenance will still be required to prevent clogging and biofouling.

- *Describe unexpected outcomes or results that were an effect of implementing this project.*

Response:

1. The unexpected growth of algae (*Ulva intestinalis*) in the control chambers provides the opportunity to partner with local organizations who are interested in using the biomass of this alga to develop agricultural fertilizers and biofuels for use on farms. Such a partnership can help increase nutrient cycling and efficiency in agricultural production and treatment of runoff.

2. Heated wood chips begin to produce similar reductions in nutrient concentration after a fortnight delay in denitrification. The delay and resulting denitrification processes are different between heated and cool wood chip chambers. It is uncertain if modifications to the chambers can be made to increase the efficiency of the heated chambers to offset added materials costs.

3. The aquatic plant *Hydrocotyle* showed limited nutrient reduction value, even as biomass increased significantly. Further studies are needed to determine if shallower water (i.e. more root contact) would increase nitrogen uptake rates. *Hydrocotyle* may also be a valuable secondary product of treatment chambers if nitrogen reductions can be improved.

4. The treatment wetland showed the most consistent nitrogen removal capacity (as expected) but was found to be less efficient in load reductions because of the significant acreage needed to construct the wetland. We anticipate that because nitrogen removal rates within wetlands are dependent on initial concentration (zero order reaction) a significantly smaller wetland may produce a disproportionately large removal capacity. Further sampling at 500 foot increments within the wetland will aid our understanding of load reduction within small wetlands relative to initial nutrient concentrations.

- *If goals or outcome measures were not achieved, identify and share the lessons learned to help others expedite problem-solving.*

Response: All goals and outcomes were achieved. However, data collection was compressed within one sample season (spring/summer) due to permit and construction delays. Future sampling during fall and winter seasons (funding dependent) will help document denitrification during sup-optimal seasonal conditions. Permit delays were not expected because the constructed infrastructure was placed on agriculture lands and was comprised of agricultural management measures. However, because of this project's link to the treatment wetland project directly downstream, this project was found to need to be covered within the larger site permit, leading to delays.

Remaining Grant Balance (Please respond to all bulleted items)

- *If there is a remaining balance, explain why the project did not utilize all awarded grant funds*

Response: No balance is remaining.

Additional Information (Please respond to all bulleted items)

- *Provide additional information available (i.e. publications, websites, photographs) that is not applicable to any of the prior sections.*

Response: Please see Attachments A-F for more information on this project. A publication is anticipated to be written in 2018 that reflects the success of this set of experiments. We are working with CSUMB to seek additional funding to continue research at this site and expand the number of treatment types and field conditions tested to increase the amount of available information for growers.

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

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Figure 1. Initial site condition – disked field

Figure 2. Initial Grading

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 3. Construction of Containment berm per county permit requirements

Figure 4. Construction of Containment berm per county permit requirements

Figure 5. Forebay source water containment area showing input pipe and overflow

Figure 6. Initial flooding of fore bay from distribution pipe.

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 7. Initial construction of sub-basin drainage and chamber boundaries

Figure 8. Layout of discharge drain pipes and fencing.

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 9. Layout of discharge drain pipes and fencing.

Figure 10. Completion of linear chamber fencing substructure

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

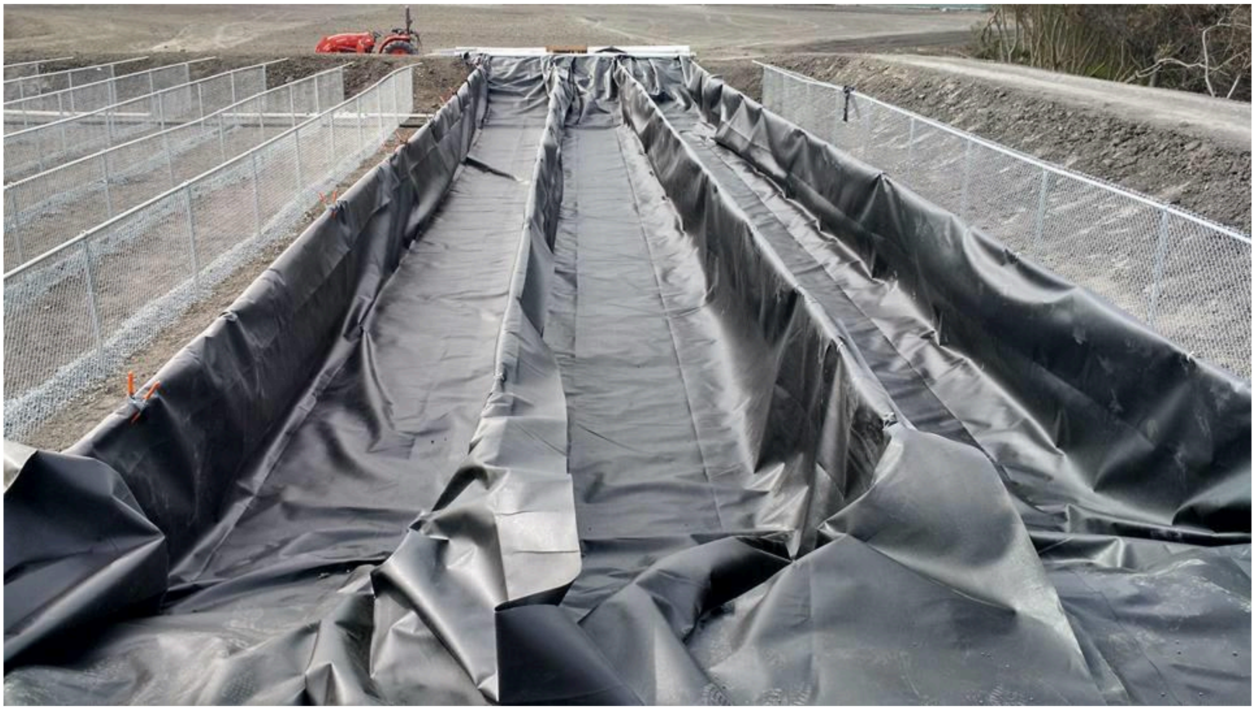


Figure 11. Initial lining of chambers with pond liner

Figure 12. Completion of Pond Liner

Figure 13 source water distribution pipes before V-notch flow devices are installed

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 14. Outflow pipe installation for each of the twelve treatment channels

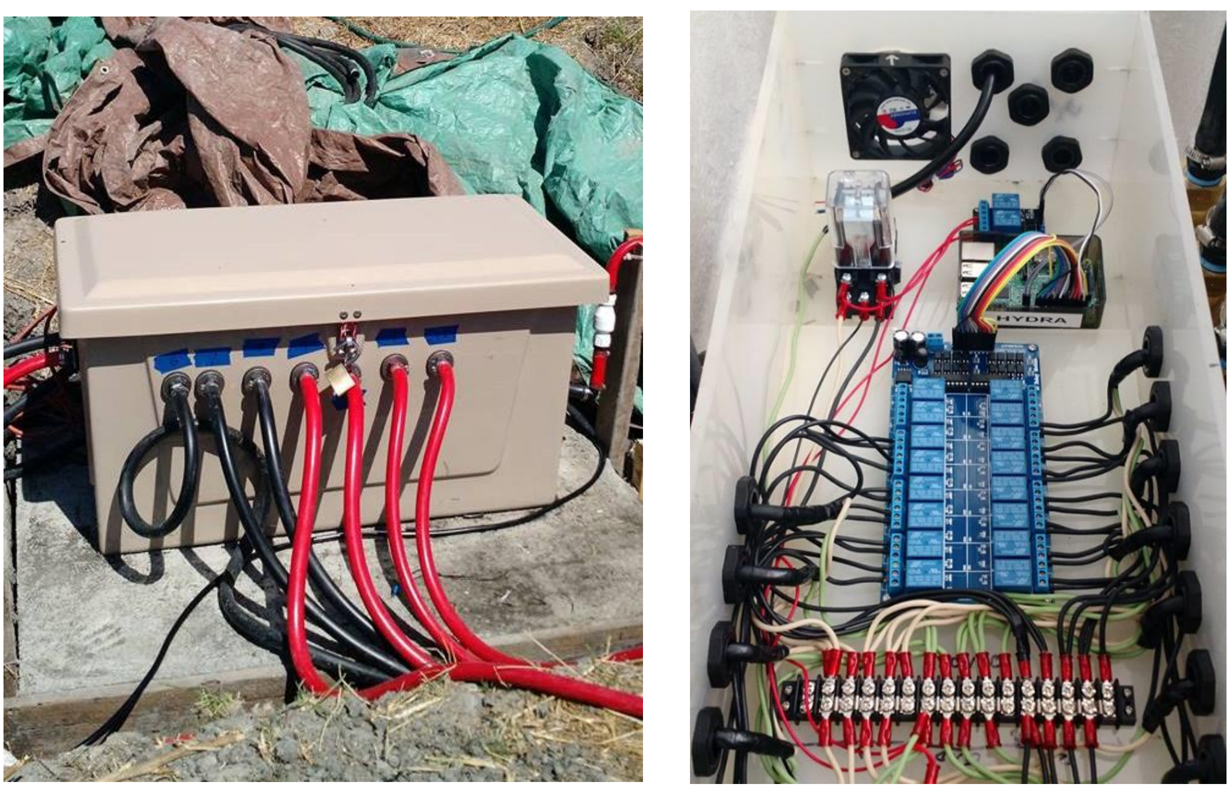


Figure 15. Installation of Hydra nutrient sampling system

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 16. Dye tracer flow test

Figure 17. Flow study using fluorescein dye.

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 18. Close up of discharge and screen of wood chip reactor

Figure 19. Initial flooding of treatment chambers (from left- control, heated wood chips, cool wood chips, hydrocotyle).

Attachment A: Photo Documentation of Construction and Operations of Multi-Chamber Bioreactor Research Project

Figure 20. Treatment wetland down stream of Multi-Chamber bioreactor

Attachment B: Project Design and Sampling Results for Multi-Chamber Bioreactor Research Project

Multi-Chamber Bioreactor Project Observations and Results

Introduction

Bioreactors provide an effective means of reducing nitrates and other non-point source pollutants from surface waters within tile drain systems. With their small footprint and relatively low costs, they provide commercial farmers with a viable method for reducing their environmental and human health impact.

The newly constructed bioreactor, located in Castroville, California under the PG&E powerline corridor, uses an experimental side-by-side comparison of three treatments, listed below, to fill data gaps regarding the performance of bioreactors on California's central coast. Our current research focus is determining the effect of initial nitrate concentration and hydraulic residence time on the rate of nitrate load reductions.

The goals of our project are: 1) to provide local growers with the best available data needed to determine what type of bioreactor is appropriate for their farm, and 2) to share design and construction findings with others interested in constructing bioreactors.

The current design includes 12 linear flow-through chambers comprised of three treatment systems (wood chip bioreactor, heated wood chip bioreactor, aquatic plant growth) replicated three times each. The remaining chambers are used as a control, replicating flow through a similarly sized agricultural ditch. The temperature in the heated wood chip chambers was increased passively using greenhouse tarp materials and varied slightly with daily climate conditions. Year-round data collection is required to fully assess the effectiveness of the greenhouse tarp materials for heating woodchips. In the future, multiple repeated heating experiments will be completed using different temperature ranges and heating methods to generate the data set needed to develop more complete nutrient reduction curves.

Enhanced Water Quality Sensor System

The original nutrient sampling design included collection of nutrient grab samples from the detention basin source water and from the discharge of each of the treatment chambers during 15 sampling events. Each sample reports nutrient level, temperature, dissolved oxygen, pH, and specific conductivity. A one-day lag between sampling of the source water and the discharge water was specified to account for the residence

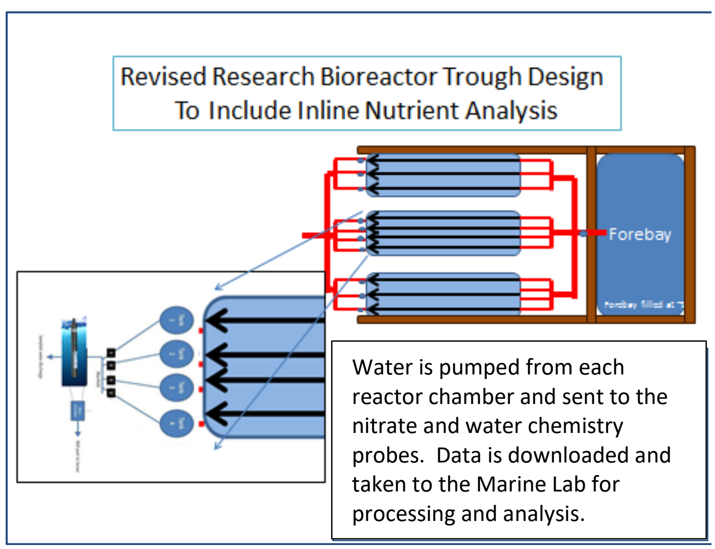


Figure 1. Bioreactor Design and Hydra-Nutrient Analyst sampling.

time of water within the treatment chambers. With separate funding from Anthropocene Institute, we were able to improve the monitoring capacity of the facility to include a multi-channel water sampling system that enables each of the 13 chambers (source water and 12 chamber discharges) to be automatically monitored in series. The revised design (Fig.1) will increase the data collection capacity of this system from 15 grab samples events to multiple samples collected daily for weeks at a time between calibration events. We collected grab samples to calibrate the water probes and provide quality assurance throughout the research project.

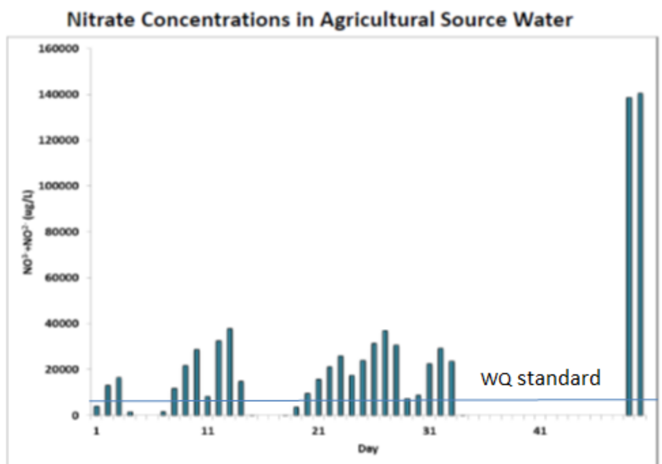


Figure 2. Nitrate Concentrations (NO2-NO3) are represented as daily average concentration over a month in summer 2015. Concentrations fluctuate from below detection limits to 140 mg/l.

Source Water Analysis

One of the benefits of constructing this research project within a working agriculture landscape is that nutrient concentrations within the source water represent ambient conditions and fluctuate in relation to adjacent farm practices (irrigation, crop rotation, etc.). The source water nutrient concentration study documented daily nutrient concentrations in the source water destined for the bioreactor system (Fig.2). Concentrations within the source water ranged from zero (detection limit 0.5 mg/l N) to 140 mg/l (140000 ug/l). The horizontal line in the figure denotes the 4 mg/l water quality objective set by the Central Coast Regional Water Board. These data demonstrate the range of concentrations that occur in this system and the temporal fluctuations in those concentrations. The multi-chamber bioreactor system will help document the efficacy of new designs within a field setting with highly variable nutrient concentrations.

Additional source water characterization was completed using nitrate concentration data of source water collected in June 2017. Daily concentrations of total dissolved inorganic nitrogen (DIN) collected during this summer growing season were within a smaller range of 24 to 48 mg/l. Two possible reasons for the lower (but still significant) range in nitrate concentrations may be due to seasonal differences in fertilizer and irrigation schedules, or due to a change in the reporting of nitrates from NO3-NO2 mg/l to total DIN mg/l.

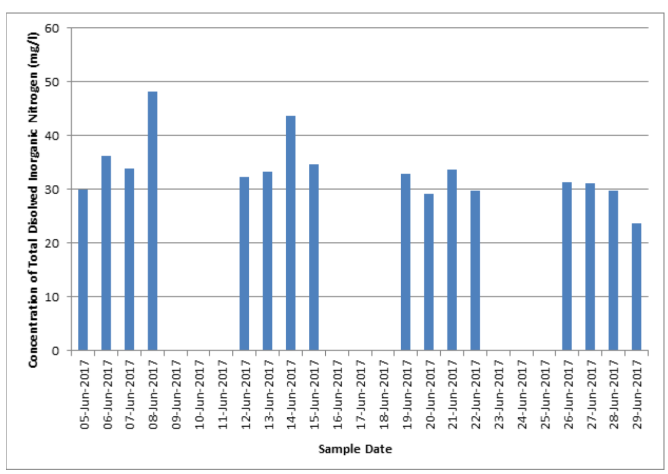


Figure 3. Source water nitrate concentrations (DIN) during field experiments.

Development of Load Reduction Curves for three Bioreactors and control (Ag ditch) systems

Nutrient reductions from each treatment chamber were estimated using data collected over a 25 day period in June 2017. Discrete water samples were collected from the source water and from discharges of each treatment chamber four times each week. Source water was collected one day before associated discharge water was sampled to account for the 24-hour residence time within each treatment chamber. Daily reductions in nutrient concentrations were then estimated for each chamber using a two-day average to account for any variation in residence time (Fig. 4). Each treatment was also calculated as an average of its three treatment chambers to mute individual variability.

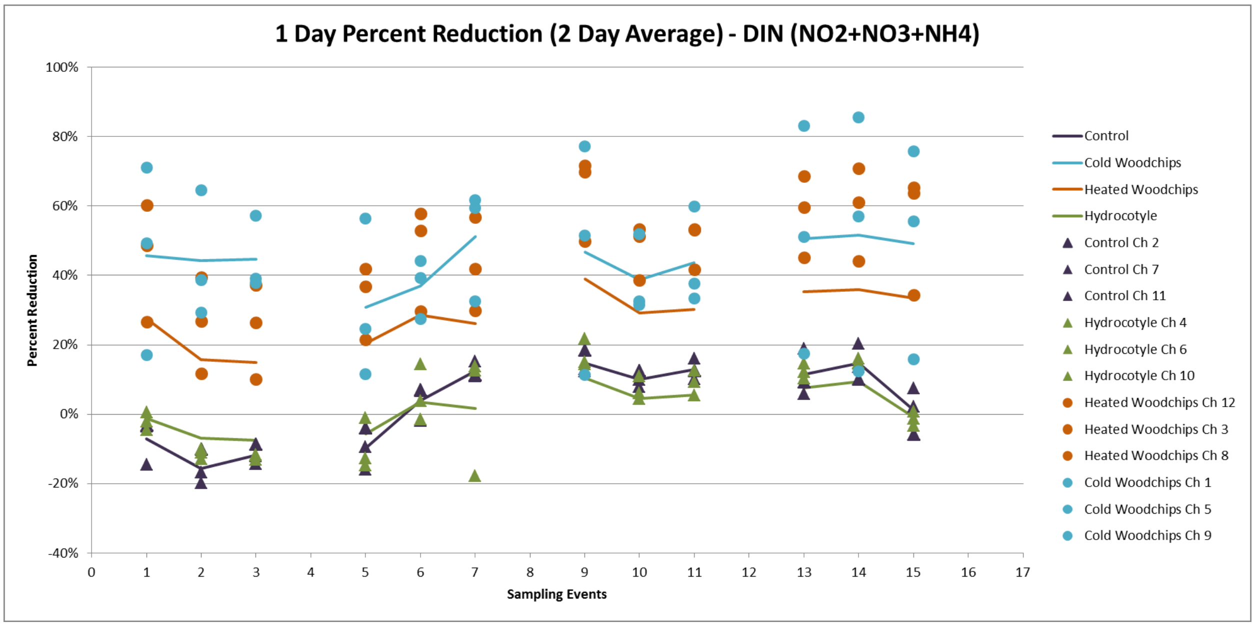


Figure 4. One-day total DIN percent reduction by treatment using a two-day average to account for water mixing within chambers. 16 samples were collected over a four-week period, and indicate that both the woodchip and heated woodchip treatments have the greatest reduction of treatments considered.

Woodchips and other treatment media cause some mixing of water and thus discharge water concentrations were assumed to be a mixture of treated water from within a small time window. We were able to estimate that water mixing occurs for approximately one day after water enters each treatment chamber using dye tracer tests and load calculations within control chambers. Water sampled at the discharge point was found to be a mix of water that entered the chamber between 48 and 24 hours earlier.

To account for this mixing, daily nutrient concentration reductions were estimated as two-average concentrations originating one day earlier from the fore bay than the treatment chamber discharge: [input concentration (average T0&T1) – discharge concentration (average discharge T1&T2)].

Average flow and nitrate concentration data were used to estimate key data for each treatment and to establish load reduction curves. Data variables measured include flow rate (adjusted by chamber to achieve a 24 hour residence time), hydraulic residence time (HRT), surface area, and volume. These variables were used to estimate average nitrate reductions as percent reduction, concentration reduction (mg/l), and load reductions (total DIN g/day). Load reductions were standardized as grams of total DIN reduction per 1000 sq. feet per day (Table 1).

Table 1. Average reduction in nitrate concentration (mg/l DIN) and load reductions (g/day) within each treatment over 16 sampling events.

Treatment	Average dischage concentration	Flow Rate (g/m)	HRT	area (sq ft)	Volume (cubic feet)
Ag Ditch	32.47	4.64	21.96	400	1000
Hydrocotyle	32.85	4.39	21.16	400	1000
Cool woodchips	13.51	2.78	20.65	400	500
Heated woodchips	18.23	2.64	22.12	400	500
Treatment wetland	3.27	43.35	84.00	465,000	558000
Treatment	**Percent Reduction**	**mg/L Reduction**	**Load Reduction g/day**	**Load Reduction (grams/day) per 1000 sq ft of treatment**	**Concentration (mg/l) Reduction per 1000 sq ft**
Ag Ditch	3%	0.90	22.68	56.70	2.24
Hydrocotyle	2%	0.46	11.08	27.69	1.16
Cool woodchips	45%	14.87	225.44	563.61	37.19
Heated woodchips	28%	9.21	132.72	331.79	23.03
Treatment wetland	89%	20.99	6,176.63	13.28	0.05

Denitrification rates of bacterial reduction processes are dependent on numerous environmental factors. Because denitrification rates are based on initial concentration, denitrification rates change with residence time and source water concentrations. Specific factors accounted for when establishing nitrate reduction rates include, 1) initial nitrate concentrations in source water (if a zero order nitrogen reduction reaction is assumed appropriate), and 2) ambient water temperature within the treatments. Reduction duration was standardized by regulating the residence time to 24 hours within all treatments.

Lessons Learned and Design Considerations for Your Bioreactor

Heated Woodchip Bioreactor

The effectiveness of woodchip bioreactors decreases as temperature declines (Miller 2014). This is particularly problematic along the central coast where the need for nitrate reduction persists into the winter months, but the ambient water temperatures decrease below optimal levels. To address this, we covered our heated woodchip chambers with a polyethylene greenhouse fabric that is anti-condensate and lets both UV and IR radiation through.

The temperature within the heated bioreactors increased on sunny afternoons by as much as 11°C within the upper portion of the chambers, but the temperature in lower portions of the chamber was lower than source water. This suggests that thermal stratification is an important factor in the design and operations of a greenhouse heated bioreactor. This stratification may also limit mixing and reduce the volume of wood chips providing nutrient reduction value. This observation led CSUMB researchers to assume that water below the thermocline was isolated from flow and therefore residence time within heated wood chip chambers was lessened to a half-day. The research team has installed solar thermal panels and heat pumps to increase temperature within the lower portion of these chambers to reduce stratification and increase residence time. This infrastructure will be used once initial experiments are complete.

Pennywort Bioreactor

Pennywort (*Hydrocotyle ranunculoides*) is a native perennial aquatic plant that forms large dense vegetation mats and can grow either floating in-channel or rooted in sediment. This species of Pennywort is associated with reducing nitrates, phosphates and turbidity in sewage water (Basilico 2017). In the Salinas Valley it has also been shown to reduce more hydrophobic pesticides, organochlorine and pyrethroid, when used in conjunction with a sediment settling basin (Anderson 2011). In future research we will work with Department of Pesticide Regulation to determine if pesticide loads are reduced within these chambers.

General Design Considerations When Building a Bioreactor

1. Choose dimensions.
    - The width and length of a bioreactor will depend on the desired amount of water to be treated. There is little consensus regarding optimal dimensions, but it is our goal to use our denitrification rate data to build a model that will estimate required bioreactor size based on the desired number of acres to be treated and the peak flow from that land.
2. To line or not to line?
    - Using a polyethelene pond liner ensures all water entering the chamber is treated and leaves via the outlet, as opposed to some unknown amount of water contributing to groundwater recharge. While this makes quantifying the total amount of water treated easier, there are drawbacks to using a liner when it comes to maintenance and construction. In our experience, making the lining leak free at the outlet is difficult, and any liner above the water-line makes great habitat for rats to nest in. Though there are ways to mitigate these problems, an alternative option in predominantly clay soil, as is present in the Lower Salinas Valley region, is to have an unlined chamber.
3. Choose source material for woodchips (if applicable).
    - While there is little evidence to suggest a significant difference between source material for woodchips, pressure treated wood and eucalyptus should be completely avoided because of their undesirable chemical composition. For our facility we are using woodchips sourced from Randazzo Salvage which gets wood from local construction and landscaping projects.
4. Filling the bioreactor.
    - **Wood chips**. A woodchip bioreactor can be filled by using a tractor to dump woodchips in or near the site, and using pitchforks to manually spread the woodchips. However, if the chamber is very large in size or inaccessible by tractor, contracting with a blown woodchip delivery service, like JetMulch Inc., is a great alternative.
    - **Pennywort**. Pennywort is a very hearty plant that can easily be transplanted. For our project, we tore large sections of the plant from the Castroville Slough and transported it in containers to the chamber without much detriment to the plants.
    - **Note:** If using pond liner, do a leak test by filling the chamber with only water before filling it with a treatment media. All repairs become more difficult when navigating around woodchips or plants.

5. Maintenance
    - Leaving a treatment-free space around both the inlet and outlet of the chamber allows for easy access for maintenance and repairs. Our woodchip chambers contain barriers that allow water to pass through but hold the woodchips in place. Nevertheless routine maintenance will still be required to prevent clogging and biofouling.

Integration of Experimental results into water quality regulatory compliance.

Farmers are being asked to adopt practices that demonstrate progress towards achieving water quality objectives. Currently, most actions have been focused on reducing runoff of pollutants from farms. Moving forward, treatment will become a standard practice. Farmers will need guidance on how and where to construct treatment systems and understand the potential construction and operating costs. State regulators are interested in compiling data on the effectiveness of these measures to aid industry negotiations. Our data demonstrate the load reduction potential of wood chip bioreactors and compile construction and operating "lessons learned" that will help industry use of these techniques.

Moving forward, load reduction data from treatment systems will be used to document environmental success and help demonstrate regulatory compliance for farmers up stream of treatment systems. Figure 5 depicts farms within a defined watershed that have already participated in treatment systems and additional farms where treatment systems can be constructed. Demonstrating water quality improvements from pilot areas and from industry monitoring should benefit future regulatory compliance for specialty crop growers.

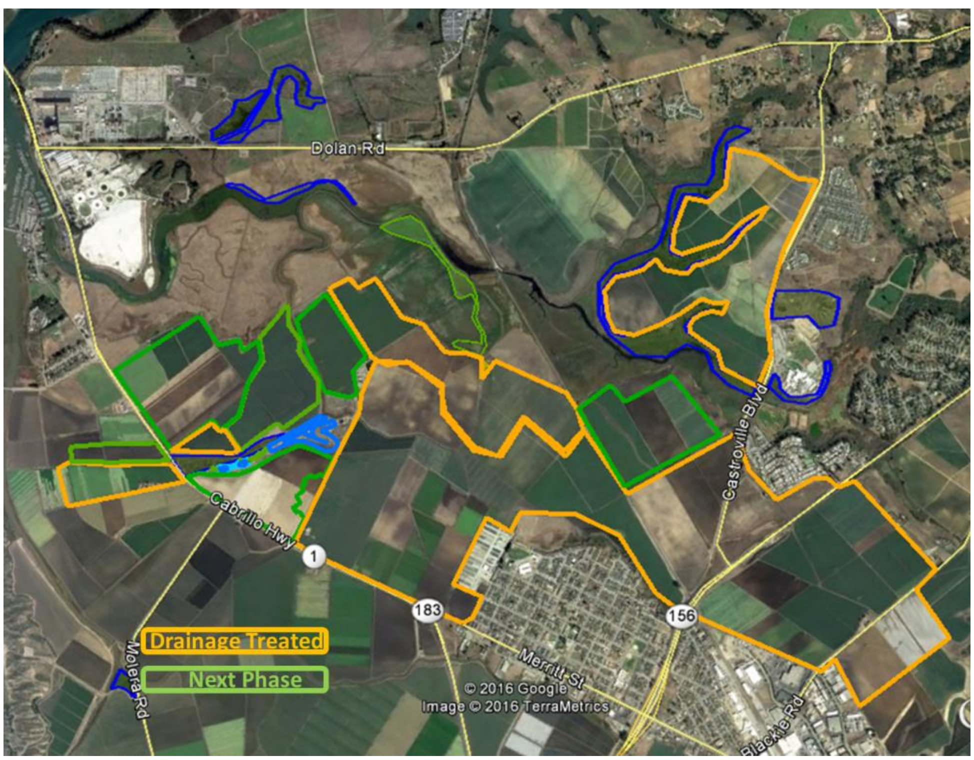


Figure 5. Example of watershed based water quality management. Yellow areas are farms currently being treated by off farm practices and green areas will be treated once newly designed practices are installed.

Attachment B: Project Design and Sampling Results for Multi-Chamber Bioreactor Research Project

References

Miller, G. "Limitations on Nitrogen Removal by Treatment Wetlands Under Maritime Climatic Conditions" (2014). *Capstone Projects and Theses*. 588. http://digitalcommons.csumb.edu/caps_thes/588

Basilico, G., A. Magdaleno, M. Paz, J. Moretton, A. Faggi, L. deCabo. "Sewage pollution: genotoxicity assessment and phytoremediation of nutrients excess with Hydrocotyle ranunculoides" (2017) Environ Monit Assess 189:182.

Anderson, B., B. Phillips, J. Hunt, B. Largay, R. Shihadeh, R. Tjeerdema. "Pesticide and toxicity reduction using an integrated vegetated treatment system" (2011). Environmental Toxicology and Chemistry 30:5.

Attachment C: List of presentations and partners who have received information on intended nutrient reduction rate estimates of the project during 2016-2017

2017 Meetings:

- Agriculture Water Quality Alliance (AQWA) Meeting: 6/14
- Meeting with Moon Glow Dairy: 6/2
- NRCS Conservation Innovation Grant (CIG)- Nutrient management team meeting: 6/2
- Salinas water quality monitoring/modeling TNC-MLML grant wrap up meeting: 5/25
- Headwaters 2 Oceans Conference, Irvine, CA: 5/23
- Big Sur Land Trust coordination meeting: 5/8
- Meeting with Professor Doug Smith (CSUMB faculty) and new intern for Bio-Reactor Project: May 2017
- Blanco Drain land owner meeting (Farm Nutrient Coop partners): Spring 2017.
- Multiple meetings with Emma Hiolski, Ph.D. Science Communication Program, University of California, Santa Cruz regarding new article and podcast on bioreactors: Spring 2017

    Podcast: https://soundcloud.com/scicom-slugs/deterring-pesky-geese
    video: https://vimeo.com/222961280

- Meeting with regulatory compliance manager Ocean Mist Farms: 4/18
- Professor John Silva's CSUMB class field trip -Molera Treatment Wetland and Multi-Chamber Bio-Reactor: 3/3
- Greater Monterey County IRWMP, Regional Water Management Group meeting: 2/15
- Ventana teen environmental group tour of Bio-Reactor: 2/14
- Meeting with Monterey County Supervisor, John Phillips: 2/13
- Sea Mist Farms sustainability meeting: 2/10
- SWRCB Irrigation Nutrient Management Grant, final presentation to Regional Water Quality Control Board: 2/6
- Sea Mist Farms initial info meeting: 2/8
- Elkhorn Slough National Estuarine Research Reserve Science Symposium: 1/24
- Nature Conservancy Donor tour of Multi-Chamber Bio-Reactor: 1/17
- NRCS CIG Nutrient management team meeting: 1/12
- State Coastal Conservancy Healthy Watersheds meeting: 1/4

2016 Meetings:

- Monterey Bay Farm Nutrient Coop Partners, Steering Committee meeting: 12/28
- Meeting with Sea Mist Farms compliance manager regarding watershed approach to water quality solutions: 10/28
- NRCS CIG, grower outreach meeting: 10/27
- Ag Order development presentation at AQWA meeting: 2/3

Lower Salinas Valley Water Quality Cooperative

Addressing Nutrients within Irrigated Lands

Initial Pilot Program

For the Moro Cojo Watershed

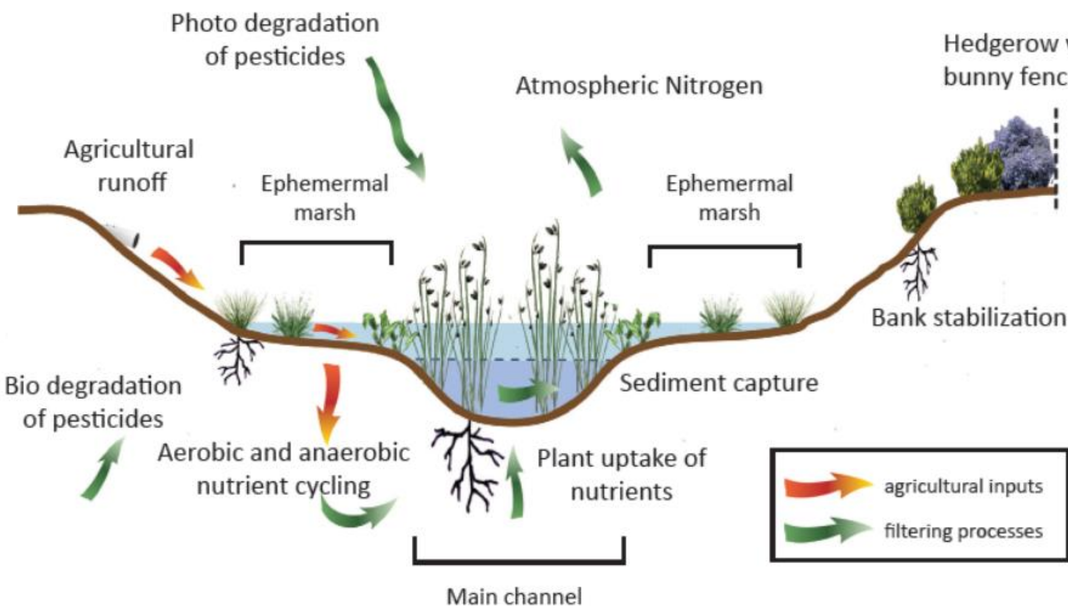
DRAFT PROPOSAL FOR DISCUSSION

January 2016

Ross Clark CCWG @ MLML

Jennifer Biringer, TNC

Paul Robins, RCDMC



The physical, chemical, and biolgical processes that occur in wetlands help filter out pollutants

Nutrient Management Practices

On-Farm practices consist of actions and technologies that lead to a reduction in the application and/or release of nutrients within a farm field. Many practices aim to increase the efficiency of current farming practices in order to reduce over watering and over application of fertilizers (i.e. PICA). Such efficiencies often require technical experts to provide sub farm soil and crop data so that farmers can apply nutrients more precisely. Such practices aim to reduce nutrient application and thus unintended loading to waterways.

Edge-of-Farm practices consist of infrastructure (detention basins, grassed drainages, bio-reactors) that collect, filter and treat farm drainage (surface or tile drain) prior to those waters being released to public drainages. Many practices aim to remove nitrates through biological activity, releasing nutrients as Nitrogen gas. Such practices help to reduce nutrient loading prior to discharge into public waters.

Off-Farm treatment systems are designed to collect, filter and treat water within common drainages, both agriculture ditches and local creeks. Such systems have been documented to effectively remove Nutrients, sediments, pesticides and pathogens from waterways, resulting in lower concentrations in downstream receiving waters. Such systems include natural restored wetlands, treatment wetlands (designed to facilitate load reductions), bio-reactors and vegetated detention systems and drainage channels.

Cellulose wood chip bioreactors are a relatively new technique to treat irrigated agriculture tail water specifically to reduce nitrate concentrations (Figure 2). Water is directed from fields or drainage channels to the input location for a bio-reactor. Water flows through the bioreactor and is then discharged back into the drainage channel or receiving water. Benefits of a bio-reactor include its compact size, relative quick time to full function (wetlands take several years to

mature to full function) and limited food safety concerns. Limitations include concerns with sediments leading to clogging, bacterial respiration reduced at lower temperatures, limited ability to decrease other pollutant concentrations, and no added environmental value to adjacent water bodies (i.e. habitat and buffer value).
The cumulative effect of bio-reactors strategically placed adjacent to farm drainages and treatment wetlands placed at the lower end of sub-drainages have been demonstrated to provide, in concert with on farm practices, superior nitrate load reduction potential (Watson 2007).

Other technologies are being developed to filter and treat agriculture discharge waters to remove nutrients. Resin polymers are being investigated that extract nitrate from water as are investigations to the effectiveness of culturing algae that uses the nutrients in discharge water and sell the algae as a secondary product. Such innovative approaches will need to be tested to evaluate their efficacy similar to recent work documenting the treatment capacity of wetlands and bioreactors.

Tracking and Monitoring Program

The effectiveness of the Lower Salinas Valley Cooperative at reducing surface water quality (nutrient concentrations and loading) will be quantified through several measured metrics. Specifically the Cooperative will collect necessary data as specified in an adopted *Surface Receiving Water Quality Sampling and Analysis Plan* to quantify and report the status of several variables;

1) Surface water quality trends of sub-drainage discharges before the confluence with receiving waters.
2) Treatment system effectiveness monitoring.
    a. Concentration changes achieved through system
    b. Instantaneous and seasonal load reductions achieved through system
3) Correlative analysis of cooperative nutrient reduction trends and ambient data collected by CCAMP and Preservation Inc.
4) On-farm management efforts of Cooperative members

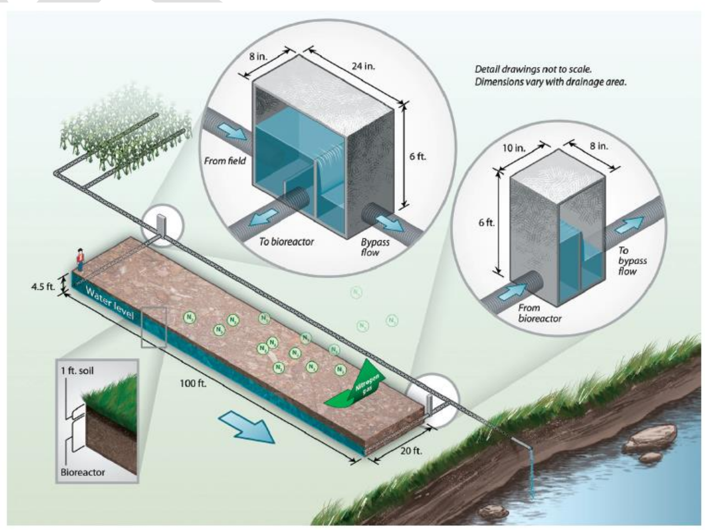


Figure 3: Descriptive illustration of a woodchip bioreactor (image by John Petersen, www.petersenart.com)

Monitoring strategy:

1) Monthly monitoring of total nitrogen at locations selected specifically to track sub-watershed nutrient reduction trends

2) Sampling to quantify load and concentration reductions of total nitrogen of all treatment systems
3) Source tracking and sub-watershed evaluation measures as needed based on monthly monitoring results

Estimated Costs of Monitoring within the Moro Cojo Watershed pilot area:

1) Monthly sampling of 7 drainage sites = $12,000 annually
2) Annual intensification monitoring at treatment systems = $18,000 annually
3) Source Tracking =$ 12,000 Annually

Reporting

The Cooperative will report the cumulative level of effort taken by members to reduce nutrient loading within the defined watersheds. In an effort to demonstrate continuous progress towards water quality improvement, the cooperative will report:

1) Agricultural lands participating in the cooperative; acres of land within each sub-watershed (total and participating members), percentage of various crops in production for those drainages, total nutrients applied and average per acre allocation within each drainage area, percent of lands within each drainage implementing some type of water and nutrient management strategy (necessary to determine nitrate loading risk factor).
2) Location, size, status and effectiveness of cooperative treatment systems
3) Cumulative load reductions achieved within sub-watershed due to the combine effect of treatment systems and on-farm practices.
4) Additional actions that will be employed to ensure "continuous improvement and sufficient progress towards water quality improvement"
5) Load and concentration trends of waters flowing from sub-watersheds to receiving waters.

Membership

Growers that own lands within a Nutrient Management Cooperative are invited to become members. If negotiations with Regional Board Staff are successful reporting and monitoring requirements will be assigned to the cooperative, and thus, greatly reduce Order administrative costs for individual growers.

The Cooperative will take responsibility for reporting to the State the combined efforts of members to comply with the Order.

Cost sharing of Cooperative Members

1) Costs for program implementation will be allocated annually among members as a membership fee and as a per acre charge.
2) Credits will be apportioned to landowners that support expansion of the cooperative by providing access to lands where additional cooperative treatment systems will be

installed or where private treatment systems are implemented that benefit the success of the cooperative.

3) Additional charges/costs may be allocated to members who fail to meet minimum implementation of on-farm practices and where site specific discharges place an undue burden on the cooperative.
4) An agreed upon annual budget share that will be allocated to support ongoing monitoring and expansion of treatment systems within the sub-watershed.

Nutrient Load Reduction Credit System

A credit trading system will be investigated as a mechanism to allow co-op members to contribute to compliance in proportion to their impact. Co-op members will ultimately determine how credits should be allocated, but potentially creditable actions include:

- Co-operative funding of a wetland restoration or construction project;
- Placement of on-farm interventions on own lands;
- Funding of on-farm interventions on another member's lands;
- Documented reduction in instantaneous N-loads;
- Contribution to research on innovative nutrient reduction strategies.

Co-op members may decide to make credits available for sale to co-op members who are unable or unwilling to take any creditable action. Cooperative Program members will also work with State grant programs to secure matching funding to support treatment system construction.

PG&E Bioreactor Model-based Analysis

F. Watson et al. 27 Jul 2017

Please DO NOT DISTRIBUTE YET beyond Watson, Clark, O'Connor, Adelaars, Leandro, Morris with checking first with Watson.

Model description

We assumed that underlying governing equation for nutrient reduction was a temperature-modulated first-order process:

$$\frac{\partial N}{\partial t} = \alpha_N \, N \, f(T)$$

where N is nutrient concentration (e.g. nitrate+nitrate as N in mg/L), *t* is time (days), α_N is an rate parameter, *T* is temperature (°C), and *f*(*T*) is a temperature modulation function.

Temperature is arguably the primary limiting factor for denitrifying wetland or bioreactor function along California's Central Coast (Miller et al., in prep). This region differs from most of the USA in having a maritime climate with temperatures that are sufficient for year-round crop growth, but too cool for rapid microbial function in the winter.

The temperature function represents the expectation that nutrient removal – like many processes in environmental biology – will be maximized at a temperature somewhere above 20°C, and minimized at temperatures near 0° and 40°C. The desired function should thus should be unimodal with a maximum value of 1 at the mode, and minima of 0 either side of the mode (or possibly -1 in some future analysis that recognizes the possibility of nutrient **increases** at sub-optimal temperatures).

For the temperature modulation function we used a standard beta distribution function (Yan & Hunt 1999). The beta distribution function typically has two shape parameters (*a* and *b*) that yield an upward modal function when both parameters have values greater than 1.

$$f(T) = Beta(T, a, b)$$

We re-expressed the function to have one parameter ($\alpha_{T,opt}$) representing the optimum temperature, leaving the other ($\alpha_{T,shape}$) to represent the shape. Values of $\alpha_{T,shape}$ near one lead to a broad mode, and large values lead to a narrow mode. Thus:

$$f(T) = \mathrm{Beta}(T, a, b) = \mathrm{Betamod}(T, \alpha_{T,shape}, \alpha_{T,opt})$$

$$a = \alpha_{T,shape}$$

$$b = (a - 1)/\alpha_{T,opt} + 2 - a$$

(the latter function is just a re-arrangement of the standard formula for the mode of a beta distribution)

Solving the governing equation yields:

$$N = N_0 \exp(\alpha_N \, f(T) \, t)$$

where N_0 is the initial nutrient concentration.

Translating this equation to a flow-through reactor context yields:

$$\mu_{N,out} = N_{in} \exp(\alpha_N \, f(T) \, t_{res})$$

where N_{in} is the inlet concentration, $\mu_{N,out}$ is the mean outlet concentration, and t_{res} is the mean residence time (days).

The above equation estimates a mean condition, about which random variation is expected to occur. An appropriate statistical model for the random variation is a Tobit-normal distribution, which is like a normal (Gaussian) probability distribution, but truncated below impossible (e.g. negative) values:

$$Y_{N,out} \sim \text{Tobit-normal}\left(\mu_{N,out}, \sigma, \lambda, \infty\right)$$

where $Y_{N,out}$ is a random variable representing observed outlet concentrations, σ is the standard deviation of the Tobit-normal distribution (mg/L), λ is a laboratory detection limit (e.g. 0.1 mg/L).

The final, complete statistical model was thus:

$$Y_{N,out} \sim \text{Tobit-normal}\left(\mu_{N,out}, \sigma, \lambda, \infty\right)$$

$$\mu_{N,out} = N_{in} \exp\left(\alpha_N \text{ Betamod}\left(T, \alpha_{T,shape}, \alpha_{T,opt}\right) t_{res}\right)$$

with fitted parameters σ, α_N, $\alpha_{T,shape}$, and $\alpha_{T,opt}$, and measured input variables N_{in}, T, and t_{res}.

Model fitting

We estimated inlet concentration from measurements taken at the inlet trough, linearly interpolated over time, and then lagged by the estimated mean residence time. This could be improved in future using a weighted average of lag times based on the full temporal distribution of residence times.

We estimated channel temperature as the average of outlet temperature and inlet temperature (interpolated and lagged).

We prescribed the flow rates of each channel in order to achieve a nominal 1-day mean residence time, based on measurements of channel geometry and initial assumptions about the porosity and hydraulic efficiency.

We then estimated the actual mean residence time using dye tracer tests (using Rhodamine WT dye). The tests met with various complications, resulting in substantial 'noise' in the data. Enough 'signal' was present in the data to suggest that thermal stratification in the woodchip channels led to multiple flow paths and non-nominal mean residence times. In particular, the warmed woodchip channels appeared to experience a faster-than-nominal mean residence time. Given this, for the initial modeling presented here, we assumed mean residence times of 16.1 hours for the three warmed woodchip channels, and 35.7 hrs for the remaining nine channels. These residence times were achieved at a mean flow rate of approximately 2.5 gpm per channel.

Early data were discarded (prior to 13 Jul 2017) because they were more indicative of a reactor start-up process (e.g. adsorption of nitrate to woodchip particles) than of longer-term intended reactor function (denitrification).

Formal statistical analysis remains incomplete until we formally compare the full model (described above) to various simplified models that exclude one or both effects (initial concentration & temperature).

We fitted the model separately to each channel. This provides a useful comparison of within-treatment variation versus between-treatment variation. In future, a single mixed-effects model could be fitted to all data, considering treatment as a fixed effect, and channel number as a random effect. This would yield a more quantitative comparison of with-treatment and between-treatment effects.

Model results

All results are preliminary until more data are obtained, especially during the cool season.

The model results indicated that all three channels with a given treatment behaved similarly to each other, and differently to channels with a different treatment. All channels experience nutrient reduction to varying degrees (Table 1 and Figs 1 to 6). The woodchip channels experienced much greater reduction than the control and surface-vegetated channels (Fig. 1). The cool woodchip channels experienced slightly more reduction than the warmed channels, probably due to the shorter residence times apparent in the warmed woodchip channels. There was no apparent difference in the instantaneous rate of reduction between the cool and warmed woodchip channels (Figs 4 and 5). These results were obtained in mid-summer; we would expect a different result in winter, when the temperature difference between the cool and warmed channels is expected to be much greater. Warmer temperatures were indicated to have a positive effect on reduction in all channels (Figs 4 to 6).

While the nature of the results is consistent with a denitrification process (the intended outcome), we cannot yet rule out that the reduction is due to other processes, such as adsorption or conversion to other nitrogen species. All that we have observed is reduction in the concentration of certain aqueous inorganic nitrogen species. This is typical of many bioreactor studies.

Model application

Initial model-based estimates of reduction rates for each treatment are shown in Table 2, notwithstanding the shortness of the data set, and the lack of winter data. Based on the data collected to date, and assuming a near-optimal (i.e. summer) temperature of 20°C, the nutrient reductions in woodchip reactors of the kind we installed could be expected to be around 4.0-5.3% per hour, or 62-71% per day. Assuming a typical 40 mg/L inlet concentration, this equates to a 25-29 mg/L reduction over one day.

A goal for growers may be to attain concentrations below the typical regulatory standard of 10 mg/L, this would require residence times of 1.13-1.52 days, given the existing geometry of the reactors. Achieving these residence times would require either 13% slower flow rates, or a 13% larger reactor.

The farm block area treatable in this way by one of the bioreactors is estimated to be 2.98 acres. This assumes 2 mm runoff per irrigation events, with irrigation events spaced 2-days apart (Watson et al. 2003; Harris et al. 2007). Larger farm blocks would require larger reactors, or improved reactor function, which may come to pass as the microbial communities develop further.

Table 1. Fitted model parameters.

Treatment	Channel number	Sample size	AIC	Model parameters σ	mean	α_N	mean	$\alpha_{T,opt}$	mean	$\alpha_{T,shape}$	mean
Control	2	12	73.151	3.654		-0.220		22.0		40.0	
Control	7	12	78.528	4.571	4.29	-0.161	-0.21	22.0	22.0	40.0	40.0
Control	11	12	78.945	4.651		-0.261		22.0		40.0	
Cool woodchips	1	12	68.809	3.049		-1.540		22.0		29.5	
Cool woodchips	5	12	73.192	3.660	4.18	-1.621	-1.29	22.0	21.7	39.1	36.2
Cool woodchips	9	12	84.350	5.826		-0.695		21.0		40.0	
Warm woodchips	3	12	69.439	3.130		-1.713		22.0		16.7	
Warm woodchips	8	12	60.112	2.122	2.73	-1.070	-1.50	22.0	22.0	20.0	17.7
Warm woodchips	12	12	67.924	2.939		-1.728		22.0		16.2	
Floating vegetation	4	12	74.612	3.883		-0.264		22.0		40.0	
Floating vegetation	6	12	80.431	4.948	4.48	-0.287	-0.25	22.0	22.0	40.0	40.0
Floating vegetation	10	12	78.774	4.618		-0.198		22.0		40.0	

Table 2. Reduction rates estimated from fitted model.

Treatment	Channel number	First-order reduction coefficient (at 20C) by channel	mean	Relative reduction (%) per hour (at 20 C) by channel	mean	Relative reduction (%) per day (at 20 C) by channel	mean	Absolute one-day reduction (mg/L), assuming 40 mg/L initial (at 20C) by channel	mean	Days to reach 10 mg/L from 40 mg/L initial (at 20 C) by channel	mean
Control	2	0.154		0.6%		14%		5.7		8.98	
Control	7	0.113	0.15	0.5%	0.6%	11%	14%	4.3	5.6	12.26	9.61
Control	11	0.183		0.8%		17%		6.7		7.59	
Cool woodchips	1	1.188		4.8%		70%		27.8		1.17	
Cool woodchips	5	1.146	0.99	4.7%	4.0%	68%	62%	27.3	24.6	1.21	1.52
Cool woodchips	9	0.633		2.6%		47%		18.8		2.19	
Warm woodchips	3	1.484		6.0%		77%		30.9		0.93	
Warm woodchips	8	0.900	1.30	3.7%	5.3%	59%	71%	23.7	28.6	1.54	1.13
Warm woodchips	12	1.504		6.1%		78%		31.1		0.92	
Floating vegetation	4	0.185		0.8%		17%		6.8		7.49	
Floating vegetation	6	0.201	0.18	0.8%	0.7%	18%	16%	7.3	6.4	6.89	8.12
Floating vegetation	10	0.139		0.6%		13%		5.2		9.99	

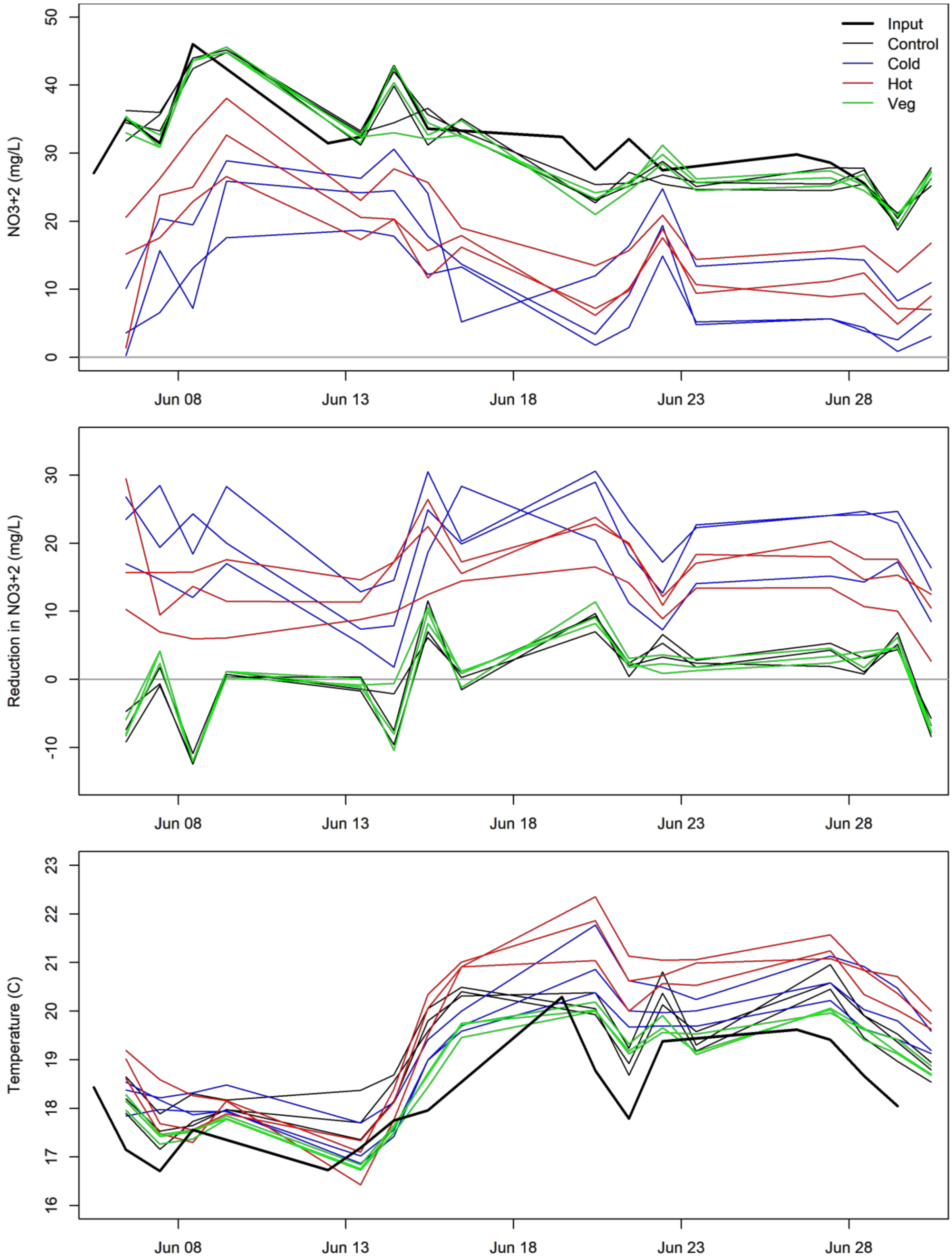


Figure 1. Raw time series of nitrate+nitrite and temperature in 12 bioreactors and the inlet trough.

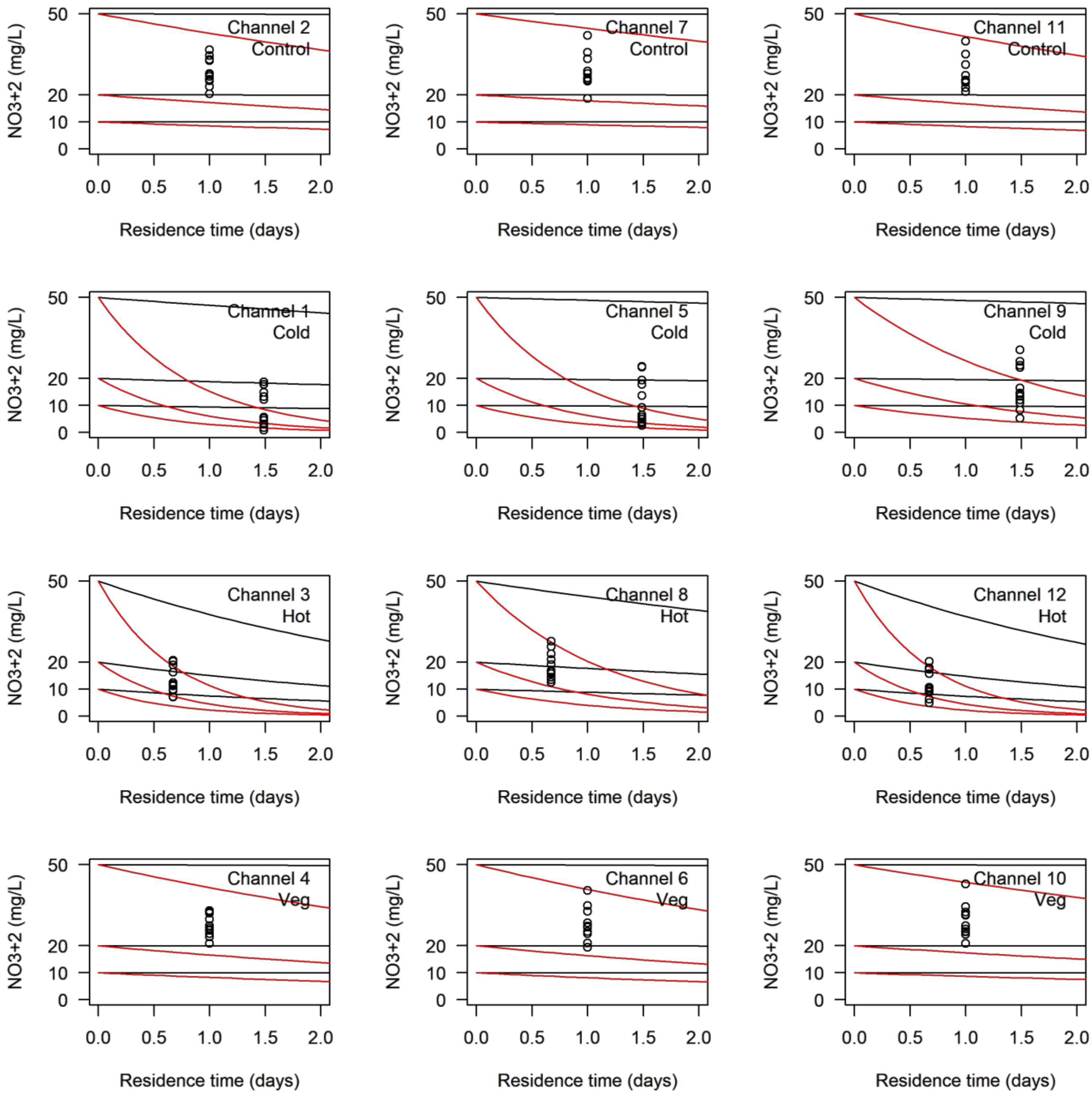


Figure 2. Fitted nutrient reduction models, plotted with respect to ***residence time****. Black and red lines are for cooler and warmer conditions (15℃ and 20℃) respectively. Circles are raw data,* ***not*** *differentiated by controlling variables (input concentration and temperature).*

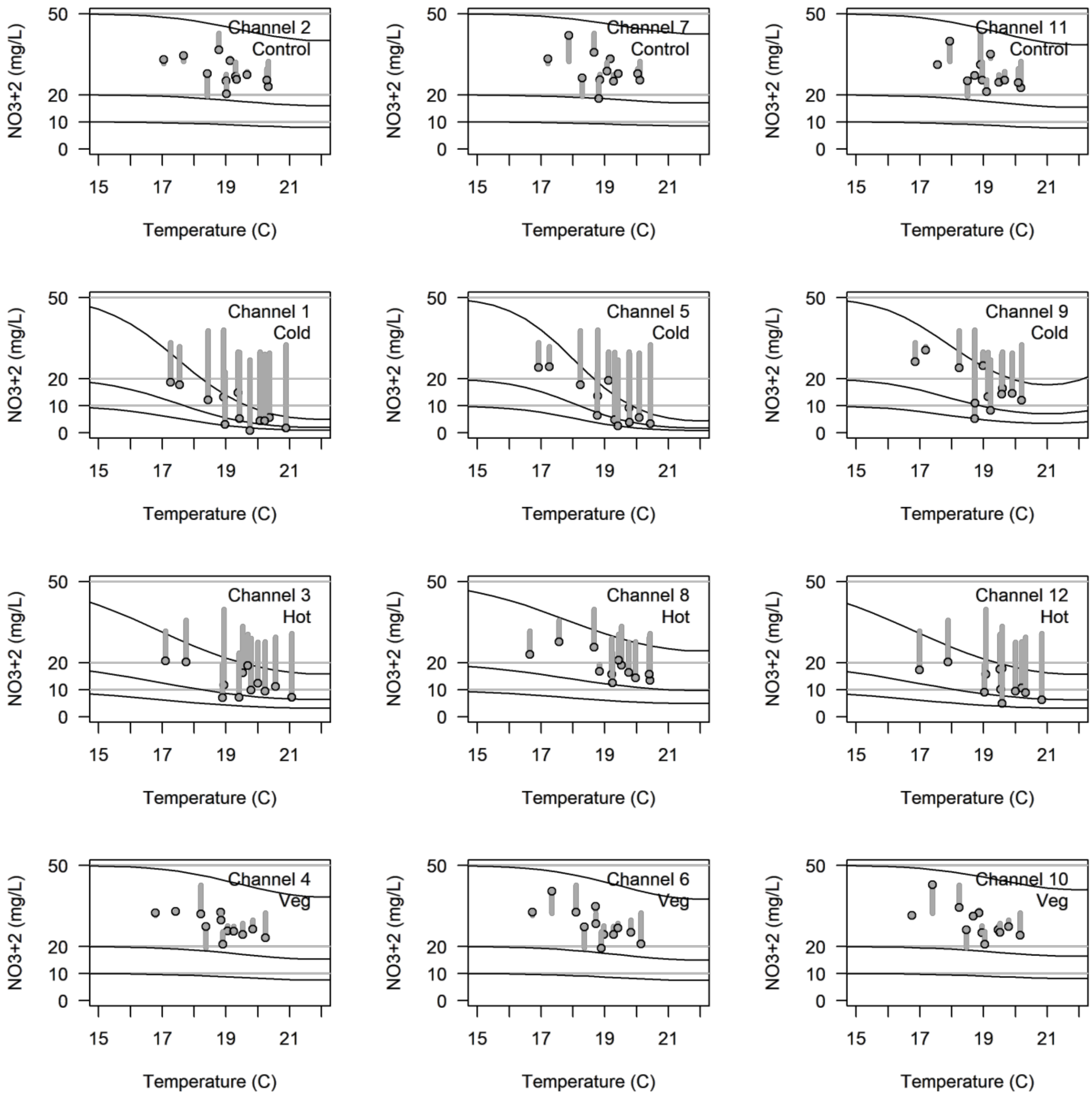


*Figure 3. Fitted nutrient reduction models (black lines), plotted with respect to **temperature**. Circles indicate raw data (final concentration), with gray tails pointing to initial concentration.*

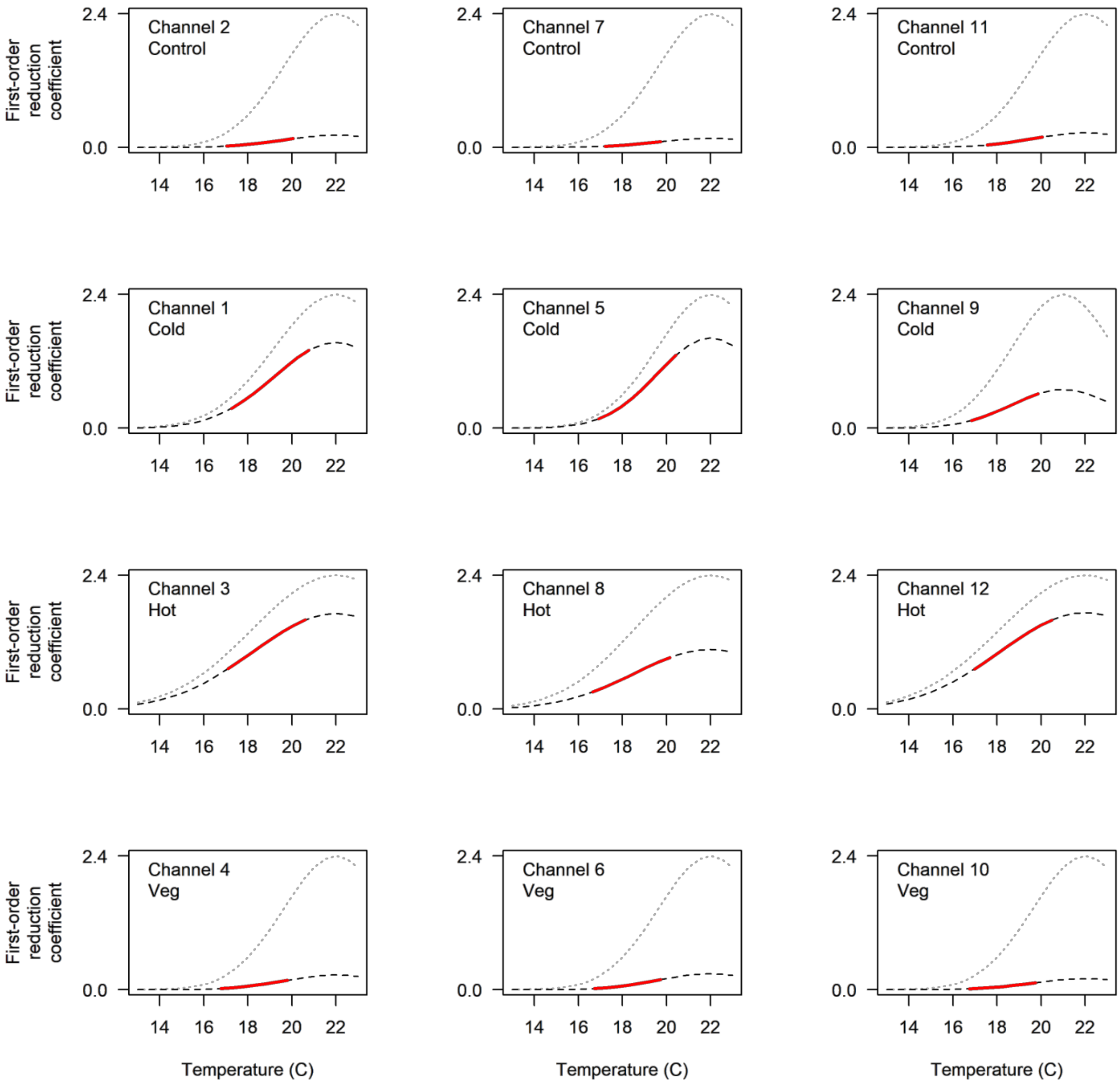


Figure 4. Modeled first-order reduction rate coefficients, over the range of temperatures observed to date (red).

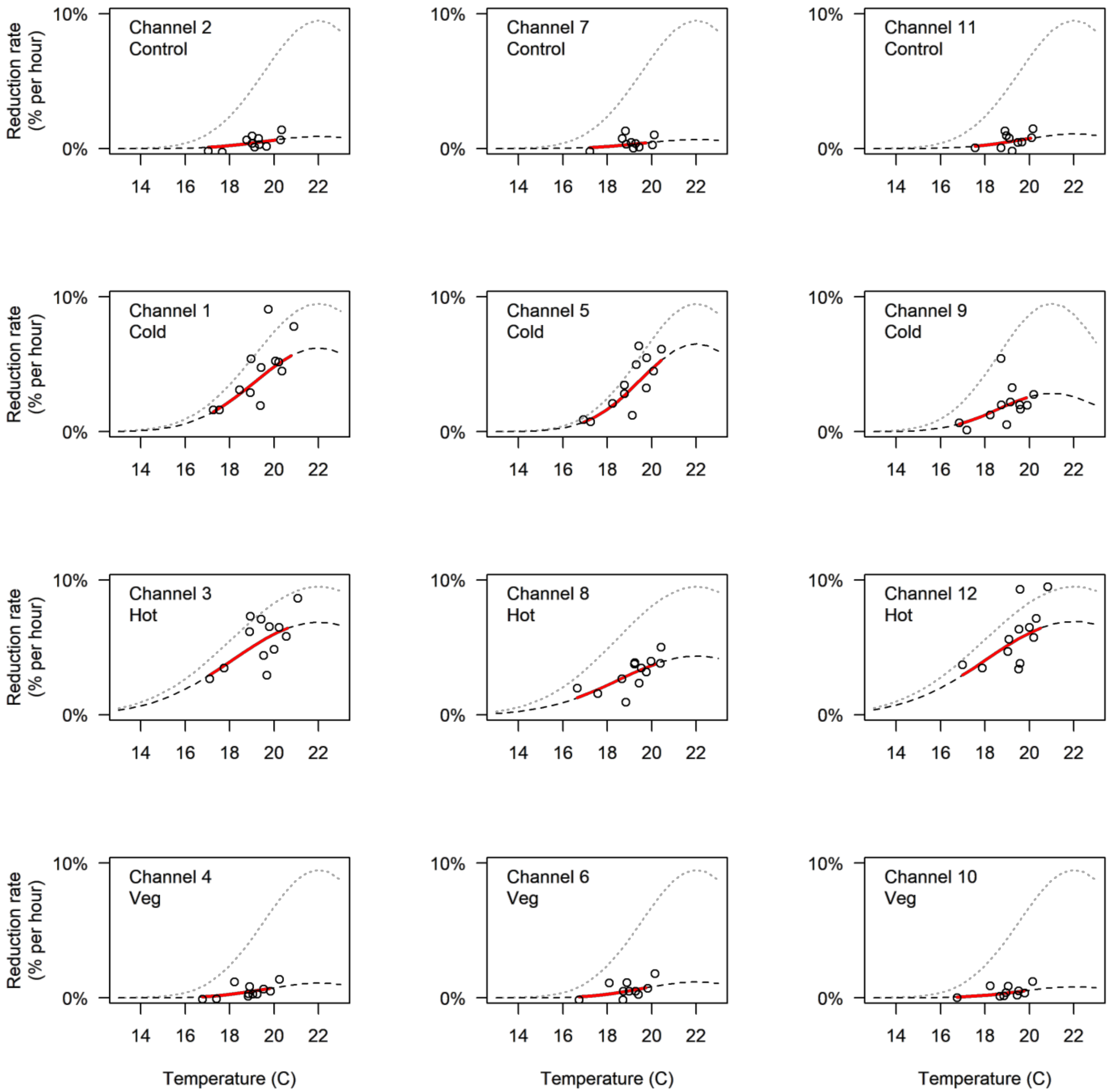


*Figure 5. Modeled nutrient reduction rates (nitrate+nitrite), per hour. Circles indicate reduction rate computed directly from raw observations, **not** differentiated by variation in inlet concentration.*

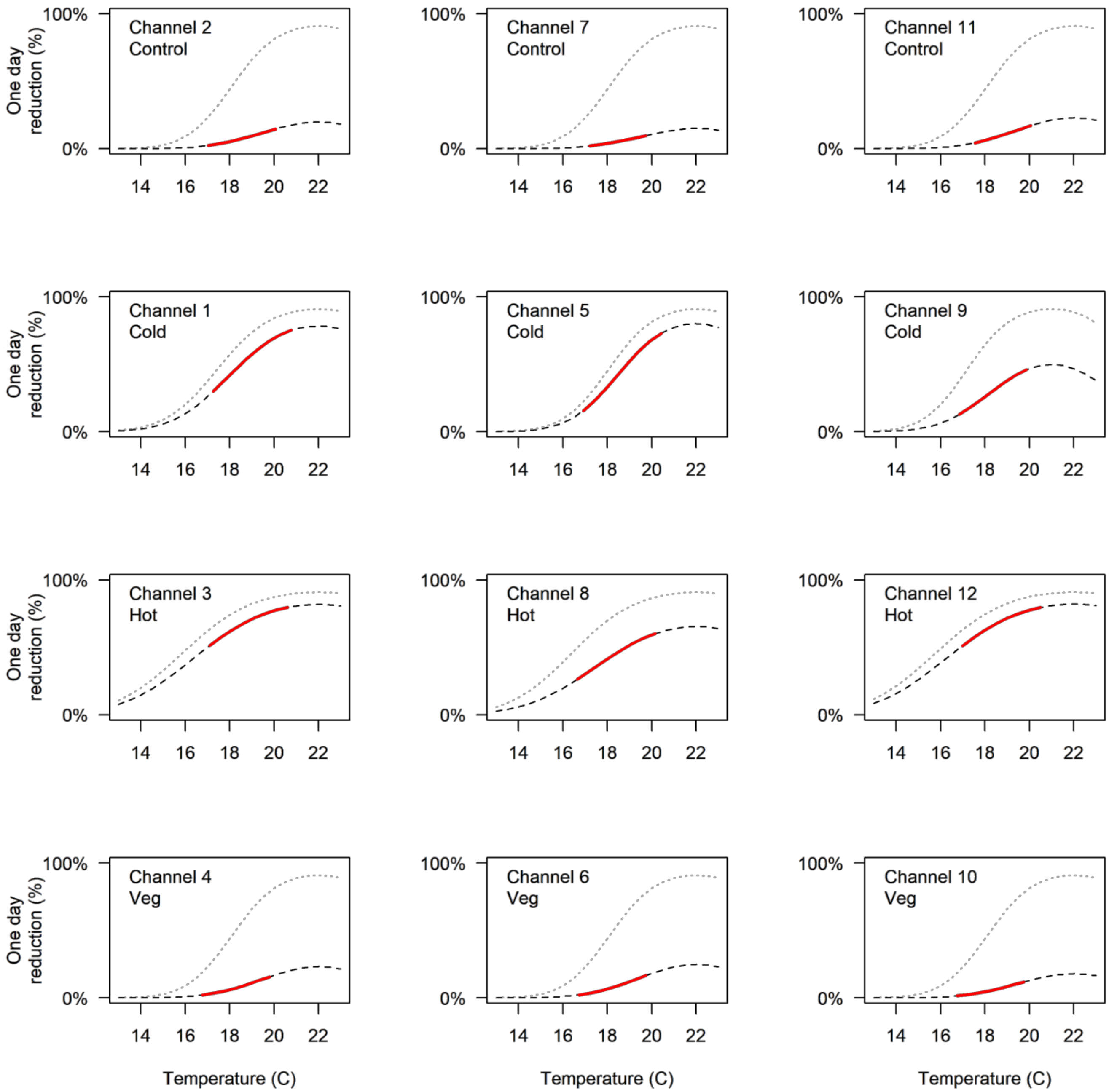


Figure 6. Modeled nutrient reduction rates (nitrate+nitrite), as a percentage over a one-day interval.

Bioreactor Design and Performance

Based on Results of Experimental PG&E Bioreactor

Introduction

Bioreactors provide an effective means of reducing nitrates and other non-point source pollutants from surface waters within tile drain systems. With their small footprint and low costs, they provide commercial farmers with a viable method for reducing their environmental and human health impacts.

Our Project

The newly constructed PG&E bioreactor located in Castroville, CA uses an experimental side by side comparison of three treatments, listed below, to fill data gaps regarding the performance of bioreactors on California's central coast.Our current research focus is determining the effect of initial nitrate concentration and hydraulic residence time on the rate of nitrate load reductions. With the ultimate goal of: 1) providing local growers with the best available data needed to determine what type of bioreactor is appropriate for their farm, and 2) sharing our lessons learned regarding their design and construction.

Treatments

Non-heated Woodchips

Due to their low costs and favorable hydraulic properties, woodchips are the most common media for bioreactors. Woodchips act as a substrate and carbon source for denitrifying bacteria which convert environmentally harmful nitrate into an inert gaseous form.

Our preliminary results show this treatment to be the most effective. However, this data is from spring/summer. Heated woodchips may prove more effective in winter months.

Estimated cost*
Materials—$2,200
Maintenance—$500/year

Heated Woodchips

The effectiveness of woodchip bioreactors decreases as temperature declines (1). This is particularly problematic along the central coast where the need for nitrate reduction persists into the winter months, but ambient water temperatures decrease below optimal levels. To address this, we covered our heated woodchip chambers with a polyethylene greenhouse fabric.

Estimated cost*
Materials—$1,900
Maintenance—$500/year

Pennywort

Pennywort (*Hydrocotyle ranunculoides*) is a native perennial aquatic plant that forms large dense vegetation mats and can grow either floating or rooted in sediment. This species of Pennywort is associated with reducing nitrates, phosphates and turbidity in sewage water (2). Locally, it has been shown to reduce hydrophobic pesticides, when used in conjunction with a sediment settling basin (3).

Estimated cost*
Materials—$600 **
Maintenance— $0.00

* Cost estimates based off of 1000 ft^2 of treatment , ** Cost of pondliner, Pennywort locally sourced from ag ditch for free

Treatment	Avg. Discharge Conc.	Flow Rate (g/m)	Hydraulic Residence Time	% Reduction	Load Reduction (g/day)	Load Reduction (g/day) per 1000 ft^2 of treatment
Ag. Ditch	32.47	4.64	21.96	3%	22.68	56.70
Pennywort	32.85	4.39	21.16	2%	11.08	27.69
Non-heated Woodchips	13.51	2.78	20.65	45%	225.44	563.61
Heated Woodchips	18.23	2.64	22.12	28%	132.72	331.79

General Design Considerations When Building a Bioreactor

Choose dimensions

The width and length of a bioreactor will depend on the desired amount of water to be treated. There is little consensus regarding optimal dimensions, but it is our goal to use our denitrification rate data to build a model that will estimate required bioreactor size based on the desired number of acres to be treated and the peak flow from that land.

To line or not to line?

Using a polyethelene pond liner ensures all water entering the chamber is treated and leaves via the outlet, as opposed to some unknown amount of water contributing to groundwater recharge. While this makes quantifying the total amount of water treated easier, there are drawbacks to using a liner when it comes to maintenance and construction. In our experience, making the lining leak free at the outlet is difficult, and any liner above the water-line makes great habitat for rats to nest in. Though there are ways to mitigate these problems. An alternative option in very clayey soil, such as we have in the Monterey Bay region, is to have an unlined chamber.

Choose source material for woodchips (if applicable).

While there is little evidence to suggest a significant difference between source material for woodchips, pressure treated wood and eucalyptus should be completely avoided. For our facility we are using woodchips sourced from Randazzo Salvage which gets wood from local construction and landscaping projects.

Filling the bioreactor.

Woodchips. The bioreactor can be filled using a tractor to dump the woodchips, then spreading them manually with pitchforks. However, if the chamber is very large in size or unaccessible for a tractor, contracting with a blown woodchip delivery service, like JetMulch Inc., is a great alternative.

Pennywort. Pennywort is a very hearty plant and can easily be transplanted. For our project, we tore large sections of the plant from the Castroville Slough and transported it in containers to the chamber.

Note: If using pond liner, do a leak test by filling the chamber with only water before filling it with a treatment. All repairs become more difficult when navigating around woodchips or plants.

Maintenance

Leaving a treatment-free space around both the inlet and outlet of the chamber allows for easy access for maintenance and repairs. Our woodchip chambers contain barriers that allow water to pass through but hold the woodchips in place. Nevertheless routine maintenance will still be required to prevent clogging and biofouling.

FOR MORE INFORMATION

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