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Agricultural Non-Point Source Pollution:
Best Management Practice Impacts on Water Quality & Recommendations to Improve Monitoring Programs in Ventura County, California

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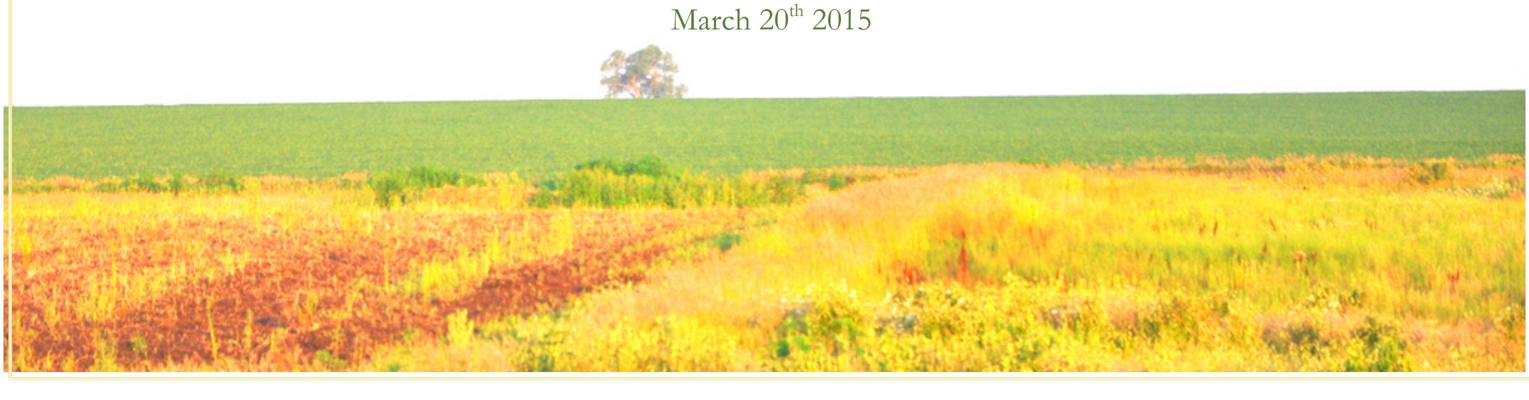

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As members of the AgVentura Group Project team, we hereby authenticate that we are the sole and original authors of this work. We are proud to archive this Final Report on the Bren School website and hereby agree to make our research and findings publically available. Our signatures on the document signify our joint responsibility in fulfilling the archiving standards set by the Bren School of Environmental Science & Management.

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The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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Dr. Andrew J. Plantinga

Acknowledgements

Completion of this project represents the most significant academic milestone the three of us have ever reached. And, though it goes without saying that this accomplishment would not have been possible without the brilliant and patient people in our lives, we would like to say it anyway— loud and clear.

We would like to extend our deepest thanks to our faculty advisor, Dr. Andrew Plantinga for his mentorship, assistance, guidance and support. His thoughtful comments have continually challenged us and have pushed us to put our best foot forward every step of he way. We would also like to extend our utmost gratitude to Matthew Fienup, who's particular brand of econometric genius and presentation advice has made this project both exciting and fun through even the most difficult stretches. We would like to make special mention of Dr. Arturo Keller, who's coursework and perspective helped guide the project from its foundations, and of Dr. Allison Horst, who has helped to debug both code and frustration throughout the year.

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We are all very lucky to have people like you in our lives.

List of Acronyms

BMP— Best Management Practice
Cal EPA— California Environmental Protection Agency
CalPIRG— California Public Interest Research Group
CWA— Clean Water Act, referring to 1972 amendments to the Federal Water Pollution Control Act
EPA— United States Environmental Protection Agency
Farm Bureau— refers specifically to the Farm Bureau of Ventura County
FWPCA— Federal Water Pollution Control Act 1948
GAO— United States Government Accountability Office
LARWQCB— Los Angeles Regional Water Quality Control Board
LOESS/LOWESS— Locally Weighted Scatterplot Smoothing
LWA— Larry Walker Associates, referring to the consultants hired by the Farm Bureau and VCAILG
NMP— Nutrient Management Planning
NPDES— National Pollutant Discharge Elimination System
NPS— Non-Point Source
PS— Point Source
RWQCB— Regional Water Quality Control Board
SWRCB— California State Water Resources Control Board
TMDL— Total Maximum Daily Load
UCCE— University of California Cooperative Extension, Ventura County
VADD— Vegetated Agricultural Drainage Ditch
VCAILG— Ventura County Agricultural Irrigated Lands Group
WQS— Water Quality Standards

Abstract

California's Conditional Waiver Program (CWP) requires all farmers to adopt best management practices (BMPs) in order to reduce pollutant loading into receiving waterways. Enforcement of CWP regulations varies throughout the state; this approach is intended to allow implementation of the most efficient and cost-effective BMPs for each region. However, this has led to wide variation between programs and regions, and few measurable water quality improvements. This report aims to provide a thorough summary of relevant agricultural BMP literature and pair research findings with a statistical analysis examining BMP efficacy in improving water quality throughout Ventura County. Results are then examined through the lens of relevant research literature to assess the overall effectiveness of the CWP, identify critical data limitations to the current monitoring program, and propose a series of final recommendations reflecting research findings and statistical results. It is ultimately recommended that the Farm Bureau and the Ventura County Agricultural Irrigated Lands Group act to: (1) augment and enhance the current water quality monitoring program, (2) increase the frequency and scope of BMP surveys, (3) encourage development of farm-to-gate nutrient management plans, and (4) apply for federal grant funding to supplement current and future monitoring program costs.

Executive Summary

California's Conditional Waiver is an iterative regulatory process with a five-year renewal cycle requiring all farmers to adopt best management practices (BMPs) in order to reduce pollutant loading into receiving waterways. Under Ventura County's Conditional Waiver Program (CWP), the Los Angeles Regional Water Quality Control Board (LARWQCB) acknowledges that agricultural non-point sources of pollution from irrigated lands are not in complete compliance with total maximum daily load (TMDL) benchmarks, but waives fines and pollution discharge permit requirements on the condition that frequent monitoring and best management practices (BMPs) are implemented.

California's enforcement of CWP regulations varies throughout the state; this approach is intended to allow implementation of the most efficient and cost-effective BMPs for each region. However, this has led to wide variation between programs and regions, and few measurable water quality improvements. As program implementation costs increase and water quality issues become more pressing throughout California, the need to quantify the effectiveness of BMPs is becoming urgent (B. Dowd, Press, & Huertos, 2008; Zhang & Zhang, 2011a).

In 2005 the Farm Bureau of Ventura County retained the services of Larry Walker Associates (LWA) to collect and manage water quality data and prepare and file mandated Annual Monitoring Reports and Water Quality Management Plans. Pollutant levels have been regularly monitored and recorded since 2007, and two BMP surveys have been completed over the past five years. Under the Ventura County CWP, irrigated lands growers are required to perform frequent monitoring, implement and track BMPs, and provide eight hours of education and training biannually. However, monitoring and program administration requirements are costly, and to divide program expenses, the Farm Bureau of Ventura County organized the Ventura County Agricultural Irrigated Lands Group (VCAILG) to serve as a singe "discharger group" under the CWP (Krist, 2005; VCAILG, 2009; Ventura County Farm Bureau, 2015a).

Monitoring results conducted in the years since the adoption of the CWP show that nutrients and pesticides are frequently detected at concentrations that exceed their respective TMDL benchmarks. Meeting TMDL benchmarks for these pollutants remains a complex issue in the region; climatic and spatial complexities, variation between individual farm application rates, and uncertainties surrounding the efficacy of management practices occlude the sources, pathways, and receptors associated with water quality impairment and improvement (Takele, 2012; Watts, 1998).

Additionally, various farmers and growers voiced discontentment with the regulations associated with the CWP, viewing them as rigid, demanding and numerous, adding that such stringent regulations could risk driving many farmers out of business. Hence, it is crucial to characterize the true relationships between agricultural activities, BMP implementation and water quality to implement policies, regulations and guidelines capable of generating true water quality improvements. If agricultural pollution control measures are feasible and capable of improving water quality to federal and state standards, it is important to provide Ventura County growers with the most economically viable options to encourage continued environmental quality improvement efforts (Mercer, 2005).

This report analyzes the 7+ years of publically available water quality data and the 5+ years of VCAILG BMP survey data to determine which practices have been most effective in reducing pollutant runoff. Additionally, this report aims to provide a thorough summary of relevant agricultural best management practice literature, and pair research findings with a quantitative analysis examining BMP efficacy in Ventura County. The resulting research and analysis is then synthesized to examine the overall effectiveness of the program to date, and create series of recommendations enhancing VCAILG's water quality monitoring program.

Results of the statistical analysis discussed in this report are inconclusive. Analysis of Ventura County water quality data acquired under the CWP is limited by inconsistent and infrequent data collection, inadequate BMP adoption data, and unknown values for irrigation quantity, nutrient and pesticide application rate, and continuous in-stream flow rate. Each of these data restrictions limits the ability of both regulators and VCAILG to accurately evaluate CWP success, determine BMP effectiveness, or analyze changes in water quality.

This report ultimately determines that the CWP in Ventura County has effectively fostered an organized, engaged response from irrigated lands farmers. The current nature of the Farm Bureau/VCAILG voluntary program enables adherence to the law and encourages improved land management throughout the county while diffusing and reducing program administration costs across VCAILG's nearly 3,000 members, saving greater than $95 million over the past eight years (VCAILG, 2009; Ventura County Farm Bureau, 2015b). VCAILG has successfully complied with CWP requirements throughout all changes and developments, and the educational components of the Conditional Waiver have cultivated an understanding of water quality and ecological health amongst Ventura County farmers (Merhaut et al., 2013). Over the past ten years, the CWP has mobilized a countywide voluntary grower response to reducing diffuse agricultural non-point source pollution. The VCAILG program enrolls an average 85% of Ventura County's total irrigated acres, and has measured BMP adoption in all sub-watershed monitoring areas (UCCE Agriculture & Natural Resources, 2009a, 2009b; VCAILG, 2009; Ventura County Farm Bureau, 2015b); in this sense, the program constitutes a significant success.

However, it must be noted that current monitoring requirements issued by the current Conditional Waiver do not provide data adequately demonstrating either reductions or increases in total pollutant loading over time. This problem is not unique to the Ventura County Conditional Waiver, and is consistently seen throughout State Water Resources Control Board regions (B. M. Dowd, Press, & Huertos, 2008a). Water quality and BMP implementation data collected and organized by VCAILG is currently insufficient in quantity to associate any potential reduction in total pollutant loading with grower action. Additionally, several key factors are missing from CWP requirements, and, subsequently, from VCAILG's data collection and water quality monitoring program. In this respect, current monitoring requirements under the CWP are less successful, and constitute a heavy expense for little return. However, designing an effective set of non-point source monitoring requirements is difficult, takes time, and requires refinement and calibration to best represent regional needs (Copeland, 2012). Though monitoring requirements do not generate all necessary data, this should by no means suggest that the program is holistically unsuccessful or unwarranted; these findings should instead suggest that monitoring requirements under the Ventura County CWP must be realigned to provide the most useful data possible under an economically feasible program budget.

Findings of this project should be used to identify the most effective ways to move VCAILG actions forward under the CWP during and beyond the 2015-2020 waiver. Ultimately, the final recommendations made in this report— if incorporated into future VCAILG actions— are designed to provide tools, resources, and a framework to improve water quality in the long term and statistically evaluate the overall effectiveness of the CWP's BMP and TMDL components.

In order to move forward and improve regional water quality in the face of data limitations, it is recommended that the Farm Bureau and VCAILG act to: (1) Augment and enhance the current water quality monitoring program, (2) Increase the frequency and scope BMP surveys, (3) Encourage development of farm-to-gate nutrient management plans, and (4) Apply for federal grant funding through Clean Water Act Section 319 and the Environmental Quality Improvement Program to supplement current and future monitoring program costs.

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Problem Statement

Agriculture plays a large role in the California's economy, reporting revenue greater than $40 billion annually across the state's approximately 80,500 farms and ranches (California Department of Food and Agriculture, 2009; National Agricultural Statistics Service, 2013). The state's widespread and intensive agricultural industry allows California to lead the nation in fruit and vegetable production (California Department of Food and Agriculture, 2009). However, agriculture releases pollutants to waterways and soils in quantities significant enough to impair environmental quality (Copeland, 2006). Agricultural intensification in combination with reduced discharges from point sources (PS) of pollution leaves agriculture increasingly responsible for the impairment of United States waterways (Copeland, 2012). The state's Conditional Waiver Program (CWP) serves to regulate and abate agricultural pollutant discharges that lead to waterway impairment; this program was adopted by the County of Ventura in 2010 and is set for renewal in 2015 (Farm Bureau of Ventura County, 2005).

The 2010-2015 CWP requires farmers and growers within Venura County to: (i) monitor the discharges from their farms annually, (ii) implement agricultural best management practices (BMPs) to minimize pollutant discharges, and (iii) participate in educational and instructional programs to facilitate the adoption of progressive farming practices (Farm Bureau of Ventura County, 2005). Farmland owners have invested heavily in CWP requirements in recent years, however not much is currently known about the true efficiencies of individual BMPs or their relative impacts on pollutant loadings.

Determining the overall effectiveness of the CWP is a two-part task requiring a thorough investigation and evaluation of: (1) efficacy of implemented BMPs individually and/or as a whole, and (2) the effectiveness of CWP water quality monitoring program. Having an understanding about these two components is essential to provide growers and farmland owners with the information necessary to manage runoff and soil erosion.

The Farm Bureau of Ventura County ("Farm Bureau") approached the Donald Bren School of Environmental Science and Management to conduct a graduate student research project with the goal of assessing the overall effectiveness of the CWP. This project analyzes Ventura County water quality and BMP implementation data to determine BMP efficacy and evaluate the overall success of the CWP in improving regional water quality.

Project Objectives

This project analyzes the 7+ years of publically available water quality data and the 5+ years of Ventura County Agricultural Irrigated Lands Group survey data to determine which BMPs have been most effective in reducing pollutant runoff. This report provides a thorough summary of relevant agricultural best management practice literature and pairs research findings with a quantitative analysis examining BMP efficacy in Ventura County. The resulting research and analysis is then synthesized to examine the overall effectiveness of the program to date and create a series of recommendations enhancing the Ventura County Agricultural Irrigated Lands Group (VCAILG) water quality monitoring program.

Findings of this project should be used to provide VCAILG and the Los Angeles Regional Water Quality Control Board (LARWQCB) with tools, resources, and a framework to improve water quality in the long term and evaluate the overall effectiveness of the CWP's BMP and total maximum daily load (TMDL) components. The report aims to identify necessary modifications to the CWP and generate recommendations augmenting VCAILG's water quality improvement efforts during and beyond the 2015-2020 Waiver cycle.

Although a comprehensive quantitative assessment of the CWP is outside the scope of this project, long term program effectiveness should be gauged by: (1) development of institutional capacity to manage large-scale water quality improvement efforts, (2) cost-effectiveness of implemented BMPs, (3) pollution reductions achieved since 2005 measured against the baseline readings, (4) pollutant reductions relative to the specific TMDL requirements issued by the California Environmental Protection Agency and the Los Angeles Regional Water Quality Control Board, and (5) the ability of the program to continue improving water quality in the future while simultaneously meeting the needs of society.

Significance of the Project

California's CWP requires all farmers to adopt best management practices (BMPs) in order to reduce pollutant loading into receiving waterways. Implementation and enforcement of CWP regulations varies by State Water Resources Control Board region (B. M. Dowd et al., 2008a; Ventura County Farm Bureau, 2015a); this approach is intended to allow implementation of the most efficient and cost-effective BMPs for each region (B. M. Dowd et al., 2008a). However, this has led to wide variation between programs and regions, and few measurable water quality improvements. As program implementation costs increase and water quality issues become more pressing throughout California, the need to quantify the effectiveness of BMPs is becoming urgent (B. M. Dowd et al., 2008a; Zhang & Zhang, 2011b). Though BMPs have been proven to effectively reduce pollutant concentrations in individual situations and case studies, there is little quantitatively defensible data demonstrating their effectiveness at a larger regional or watershed scale (D. Anderson & Flaig, 1995). It is therefore especially difficult to prove BMP implementation program efficacy at a countywide level (D. Anderson & Flaig, 1995; Clausen & Meals, 1989; Easton, 2008; GAO, 2000, 2002; Rao & Easton, 2009).

Most studies evaluating BMP efficacy are model based (B. M. Dowd et al., 2008a); to date, there is little empirical, non-experimental data collected at larger scales. Data collection performed by the Ventura County Agricultural Irrigated Lands Group (VCAILG) under the CWP therefore presents a unique opportunity to use empirically derived water quality data to assess BMPs' impacts on agricultural non-point source pollution loading. Additionally, this project signifies a novel attempt to evaluate and determine the usefulness of the products gathered under the Ventura County CWP's monitoring requirements; evaluation of these products simultaneously represents a critique of Conditional Waiver requirements, and provides a constructive space to recommend further actions to both VCAILG and its regulating body, the Los Angeles Regional Water Quality Control Board.

Research conducted throughout this project represents an original attempt to use the water quality and BMP implementation data collected under California's CWP to provide a quantitative assessment BMP efficacy in Ventura County irrigated lands. The project additionally strives to provide a framework to augment VCAILG's future data collection efforts, and recommends several additional low-cost BMPs to better understand pollutant transport and augment limited data resources while minimizing additional program costs.

Background

Importance of Federal Clean Water Act (CWA) and Amendments

The Federal Water Pollution Control Act (FWPCA) of 1948 represented the first US federal law to address the nation's widespread water contamination issues (US EPA, 2014). This statute eventually came to be known as the Clean Water Act (CWA) after a series of amendments was passed in 1972. Extensive amendments responded to the growing awareness among citizens and various stakeholders of the inadequacies of existing water pollution regulations. Additional amendments and state laws have since further altered and shaped several parts of the CWA, giving the law its unique variety of titles and codifications, and programs (US EPA, 2011).

303(d) Listings and Total Maximum Daily Load (TMDLs)

Many of the nation's waterways fail to meet state established water quality standards despite applying pollution prevention technologies, BMPs, and other based pollution control measures. States are required to compile a list of all impaired waterways within their territory and assign TMDL benchmarks for each pollutant of concern for each of the impaired waterways. This requirement is given under Section 303(d) of the CWA (US EPA, 2015)

A TMDL is a quantified pollutant discharge limit that is evaluated separately for each pollutant of concern and the waterway it affects. It is calculated as the sum total mass of a pollutant that a water body can receive while still meeting designated water quality standards (Metcalf & Eddy, 2003). The exact value of a TMDL is arrived at by summing (i) individual waste load allocations from point sources, (ii) load allocations for non-point sources, (iii) ambient or background pollutant levels, and (iv) an appropriate margin of safety (Metcalf & Eddy, 2003). TMDLs are set in such a way that it allows a given impaired water body to recover over time until it is fully restored to its designated beneficial use. All TMDLs assigned by the state are subject to review by the EPA (Gaba, 2007), in case the EPA rejects a state submitted TMDL, the former is required to develop and establish an appropriate TMDL within 30 days of rejection data (California Regional Water Quality Control Board, 2012).

The CWA itself does not give the EPA authority to regulate non-point sources; Section 303(d) of the statue makes no mention of whether or not TMDL requirements should be applied to non-point sources (NPS) as they are for point sources (PS). In cases where agricultural discharges are responsible for the impairment of water, then the respective farmlands are statutorily subject to the state water quality standards and TMDL benchmarks (Laitos & Ruckriegle, 2014).

NPDES Permit Regulations for Point Sources

The discharge of pollutants from point sources into navigable waters is legal provided the discharger acquires the appropriate National Pollutant Discharge Elimination System (NPDES) permit. As prescribed by Section 301(a) (US EPA Office Of Compliance, 2014) and governed under Section 402 of the CWA, the NPDES permit program was established to prevent uncontrolled discharge of contaminated water into rivers, reservoirs, wetlands and marine habitats (US EPA Office Of Compliance, 2014). The NPDES permit program was one of the most significant innovations of the 1972 CWA amendments. The structure of the program was favorable for the identification and enforcement of water quality standards (Gaba, 2007).

While point sources are required to purchase permits to discharge into the nations' navigable waterways the program exempts "return flows from irrigated agriculture" making the application of the NPDES program to nonpoint source agricultural discharges challenging in light of regional hydrological, geological, climatic, and ecological sensitivities. Hence, the authority and responsibility to regulate NPSs, such as agricultural discharges, falls largely upon individual states (Laitos & Ruckriegle, 2014).

Exclusion of agricultural non-point sources from federal regulation

The main goal of the CWA is "[to] restore and maintain the chemical, biological and physical integrity of the nation's waters" (33 USC § 1251), but as of the 1980s the statute mainly regulated point sources of pollution. CWA efforts to curtail pollution therefore saw reductions in PS discharges only, hence there were growing concerns regarding its limited scope in regulating overall pollant emissions, particularly since discharges from NPSs persisted largely unabated (R. A. Smith et al., 2009). As a result of this problematic trend of unregulated NPS discharges, Congress passed the 1987 Water Quality Act, to include NPS pollution within its purview (James, 2003). Though NPS pollution received increased attention following the 1987 amendments, identification, remediation, effective control of waters impaired by NPS pollution have remained significant challenges.

The 1987 amendments established the *Nonpoint Source Management Program* under Section 319 of the CWA (33 USC § 1329). This program requires states to establish *State Management Programs* and prepare *State Assessment Reports* to manage, remediate, and evaluate NPS discharges. The CWA additionally mandates every state to identify potential regions of water quality impairment within their respective jurisdictions. States are then required to estimate a cap for PS and NPS loadings through the development of TMDLs (Office of Water US EPA, 1999). After identification of an impairment, states are required to establish water quality standards for individual lakes, reservoirs, rivers, streams, and other waterbodies. The water quality standards for each waterbody includes two elements (i) the designated use(s) of the waterbody, and (ii) the "water quality criteria for such waters based upon such uses" (US EPA, 1999b). Although it is not a requirement, states are also recommended to consider implementing BMPs to control emissions from nonpoint source discharges.

The CWA gives individual states the primary authority to regulate respective agricultural non-point sources of water pollution. As a result, each state is largely responsible for controlling and abating pollutant discharges arising from irrigated lands. Under Sections 208 and 319 of the CWA, states are instructed to impose the implementation of agricultural BMPs in order to curtail runoff and pollutant loadings. Congress allocates federal funding to assist state development of NPS control methods but ultimately leaves enforcement and implementation responsibilities to state agencies under CWA Sections 208 and 319 (Copeland, 2012; GAO, 2000, 2002).

Agricultural activities currently contribute to 48% of waterway impairment in the United States (US EPA, 2002). Though the EPA has looked into various options to make Section 319 more effective, its reliance upon states to identify impairments, develop appropriate TMDLs, implement water quality improvement programs, and enforce requirements limits its ability to create more substantial change (Laitos & Ruckriegle, 2014).

CALPIRG and the impetus for legal action

The agricultural pollutant discharging groups in the state of California are subject to the California Water Code, which allows Regional Water Boards to waive waste discharge requirements if it is perceived as keeping with the best interests of the public. Prior to 2005, the state's agricultural dischargers did not have to comply with the federal NPDES program nor were they subject to any stringent water quality regulations (B. M. Dowd et al., 2008a). The lack of regulation was justified at the time by an assumption that the discharge of pollutant runoff from agriculture was low due to reduced application of fertilizers/pesticides in the region and the influence of California's Mediterranean climate, which was believed to keep irrigation water from running off the field (B. M. Dowd et al., 2008a). Observations began to show that the aforementioned assumptions were not harmonious with observations and stakeholders began to call for stricter laws protecting the integrity and beneficial uses of the state's waterways (B. M. Dowd et al., 2008a).

In 2002, the California Public Interest Research Group (CalPIRG) and the Waterkeepers of Northern California sued the state government for providing permit exemptions to agricultural sources, forcing reevaluation of agricultural NPDES permit exemptions (B. M. Dowd et al., 2008a). In response to the lawsuit, the California Water Code was amended such that all agricultural NPS dischargers are mandated to meet regionally established all TMDL benchmarks designed to improve water quality and enhance recovery of California waterbodies (B. M. Dowd et al., 2008a).

The lawsuit referenced various studies showing correlations between fertilizers and pesticide applications and degradation of water quality in agricultural watersheds; the court decision resulted in the subsequent creation of nine Regional Quality Control Boards ("Regional Boards") through the Porter-Cologne Act (B. M. Dowd et al., 2008a). This new law required the State Water Resources Control Board (SWRCB) and the nine Regional Boards to devise a program encouraging the implementation of proactive water quality improvement measures (B. M. Dowd et al., 2008a). To do this, the SWRCB and its advisory committee, consisting of farm bureaus and environmental organizations, aimed to develop and recommend a new voluntary program; the Conditional Waiver Program was therefore developed in 2004 as a consequence of this ongoing political process, and currently serves as a regulatory management tool facilitating the gradual reduction in TMDL exceedances (B. M. Dowd et al., 2008a).

Conditional Waiver Program

The CWP is an inclusive, negotiated, and regionally-focused voluntary program designed to identify the needs of regional water bodies and ecosystems, develop necessary water quality standards (WQS), foster countywide grower adoption and application of BMPs, and create a stakeholder-driven culture of progressive farm-scale water resource management practices. The CWP is an iterative regulatory process, with a five-year renewal cycle; all decisions are made on a regional basis to address the specific needs of each waterbody within a Regional Board's jurisdiction. Ventura County's CWP acknowledges that agricultural non-point sources of pollution from agricultural irrigated lands are not in complete compliance with TMDLs, but waives fines and pollution discharge permit requirements on the condition that frequent monitoring and BMPs are implemented and biannual education requirements are satisfied (Ventura County Farm Bureau, 2015a). Additionally, growers are allowed to form "discharger groups" to share monitoring program costs, consolidate data, and file a single state-mandated Annual Monitoring Report and Water Quality Management Plan (Larry Walker Associates, 2013; Ventura County Farm Bureau, 2015a). In 2005 the Farm Bureau of Ventura County retained the services of Larry Walker and Associates to collect and manage runoff data and file all state and local reports. Pollutant levels have been recorded for the past 7-10 years, and two BMP surveys have been completed over the past five years.

The CWP requires farm owners to routinely measure discharges from agricultural irrigated lands, irrigated return flows, and storm water runoff over irrigated acres through the operation of a water quality monitoring program sampling from receiving waterways. In addition, the program requires farmers to attend educational classes that are in place to allow for communication of important information and techniques that will help growers to adopt progressive farming practices. While the CWP specifically describes planning and implementation actions, it makes no mention of enforcement measure or actions to be taken against farmers whose land discharges high pollutant loading despite being in complete compliance with the program. As an alternative, the Regional Board may mandate those farmers to implement additional BMPs and conduct additional monitoring to display their effectiveness (Farm Bureau of Ventura County, 2005).

Specifically, the 2010-2015 CWP requires farmers and growers within Ventura County to: (i) monitor the discharges from their farms annually, (ii) implement agricultural best management practices (BMPs) to minimize pollutant discharges, and (iii) participate in biannual educational and instructional programs to facilitate the adoption of progressive farming practices (Farm Bureau of Ventura County, 2005).

Monitoring Program

In Ventura County, CWP monitoring program requirements are negotiated in stakeholder meetings and issued by regulators. The resulting monitoring program is designed to detect, measure, and report the concentrations of agricultural pollutants in streams and waterways receiving irrigated lands discharges. To design an effective monitoring program, consistent and field-tested design strategies must be employed. Such a monitoring program will allow an accurate measurement of pollutant loading despite variances in climate, river, and watershed system.

If the monitoring program design is faulty, complying farmers can potentially be penalized for exceedances that do not accurately reflect pollutant loading to a waterway. Additionally, a less-effective program may increase the likelihood of false detections and exceedances; similarly, true exceedances may go undetected. Both possibilities are of great concern to growers, farmland owners, regulators, and interest groups (Strobl & Robillard, 2008). Developing a monitoring plan based on empirical data, field-tested models, and stakeholder input will serve to increase data quality and voluntary compliance, thereby providing information necessary to effectively manage irrigated lands and improve environmental quality (Potoski & Prakash, 2004; Strobl & Robillard, 2008).

The current program requires that monitoring data is collected from twenty VCAILG member drainage sites, each of which encompasses multiple farms and landowners within a large area (Larry Walker Associates, 2013). Measurements are made for each of twenty sampling sites generating agricultural runoff during wet and dry events. Monitoring occurs four times per year at each site with samples taken during two unique wet events and two unique dry events. Water quality samples are collected mid-stream and analyzed for pollutants of agricultural origin specifically identified in the 2010 – 2015 Conditional Waiver (Larry Walker Associates, 2010, 2013).

Best Management Practice & Education Requirements

As per the CWP, growers are required to implement BMPs in addition to conducting routine water quality monitoring (Larry Walker Associates, 2010). BMP selection may be from a suite of practices recommended by the Regional Board, interests groups, or institutions such as the University of California Cooperative Extension (UCCE) or otherwise self-chosen to meet the individual cost needs of farmers (Desai, Minton, & Coyne, 2009; Farm Bureau of Ventura County, 2005). The adoption and implementation of BMPs is significantly influenced by the activity of local policy networks such as the Farm Bureau and VCAILG. VCAILG thereby collectively monitors and reports for all participating member, which provides significant cost reductions (Krist, 2005; VCAILG, 2009). VCAILG also provides farmers and growers with opportunities to participate in CWP-required educational programs (Mark Lubell & Fulton, 2008; Merhaut et al., 2013; Ventura County Farm Bureau, 2015a). These educational programs are in place to provide growers with instructions and information regarding effective BMP adoption. Pilot studies of the CWP's education requirements suggest that this component of the program both provides valuable, state-of-the-art information to Ventura County farmers and fosters increased BMP adoption in both irrigated lands and nurseries (Merhaut et al., 2013; UCCE Agriculture & Natural Resources, 2009a, 2009b). Merhaut et al. (2013) and UCCE (2009) studies indicate that growers left events and training sessions with plans to implement the BMPs.

Relative Expense of Conditional Waiver Program

While VCAILG's organization as a single discharger group provides farmers the opportunity to significantly reduce their individual monitoring costs, yet past budgets and accounting sheets show that implementation of CWP monitoring requirements has cost on the order of millions of dollars(VCAILG, 2009; Ventura County Farm Bureau, 2015b). To date, VCAILG has spent approximately $11.5 million on program administrations, but despite these heavy investments a thorough investigation of BMP effectiveness in improving overall surface water quality has yet to be conducted (Ventura County Farm Bureau, 2015b)

Regulators and Stakeholders

LA Regional Water Quality Control Board

The Los Angeles Regional Water Quality Control Board (LARWQCB) is the Regional Board in charge of protecting ground and surface water quality in the Los Angeles Region, including Ventura County watersheds. The LARWQCB adopted the CWP after an update of the CWA Section 303(d) list of Los Angeles Region impaired waterbodies showed that agricultural discharges were likely a potential cause of regional beneficial use degradation and waterway impairment (Farm Bureau of Ventura County, 2005).

NGO Reactions

Since the adoption of CWP in California, several NGOs have voiced that the program is insufficient to effectively regulate agricultural runoff to prevent the impairment or restore the beneficial uses of the region's waters. Organizations such as the San-Luis Obispo Coastkeeper, Monterey Coastkeeper, Santa Barbara Channelkeeper, and the Environmental Justice Coalition of Water are some organizations that have come to oppose the requirements of the CWP. Furthermore, these organizations, with the help of the Environmental Defense Center have even filed lawsuits challenging the legality of current CWP programs (The Otter Project, 2013).

Farm Bureau of Ventura County

The Farm Bureau of Ventura County is a nonprofit that provides political, administrative, and organizational services to its member Ventura County farmers. As a response to the high monitoring and penalty costs potentially required under the CWP, the Farm Bureau of Ventura County established VCAILG. The Regional Board approved VCAILG to function as a unit discharger in 2006 (Farm Bureau of Ventura County, 2014); today, the Farm Bureau continues to administer the VCAILG program under the guidance of an Executive Committee — consisting of Steve Bachman (United Water Conservation District), Jerry Conrow (Ojai Basin Groundwater Management Agency), John Krist (Farm Bureau), John Matthews (Arnold, Bleuel, LaRochelle, et al), Dave Souza (Pleasant Valley County Water District), Kelle Pistone (Association of Water Agencies of Ventura County) and Rob Roy (Ventura County Agricultural Association) — and a Steering Committee, consisting primarily of farmland owners and growers (Ventura County Farm Bureau, 2015a).

Watersheds of Ventura County

Ventura River Watershed

The Ventura River watershed is a coastal watershed drained by the Ventura River and its tributaries. Located in the Transverse Ranges, it is the smallest watershed of Ventura County, spanning an area of 235 square miles within the western part of the County (Ventura River Watershed Council, 2015).

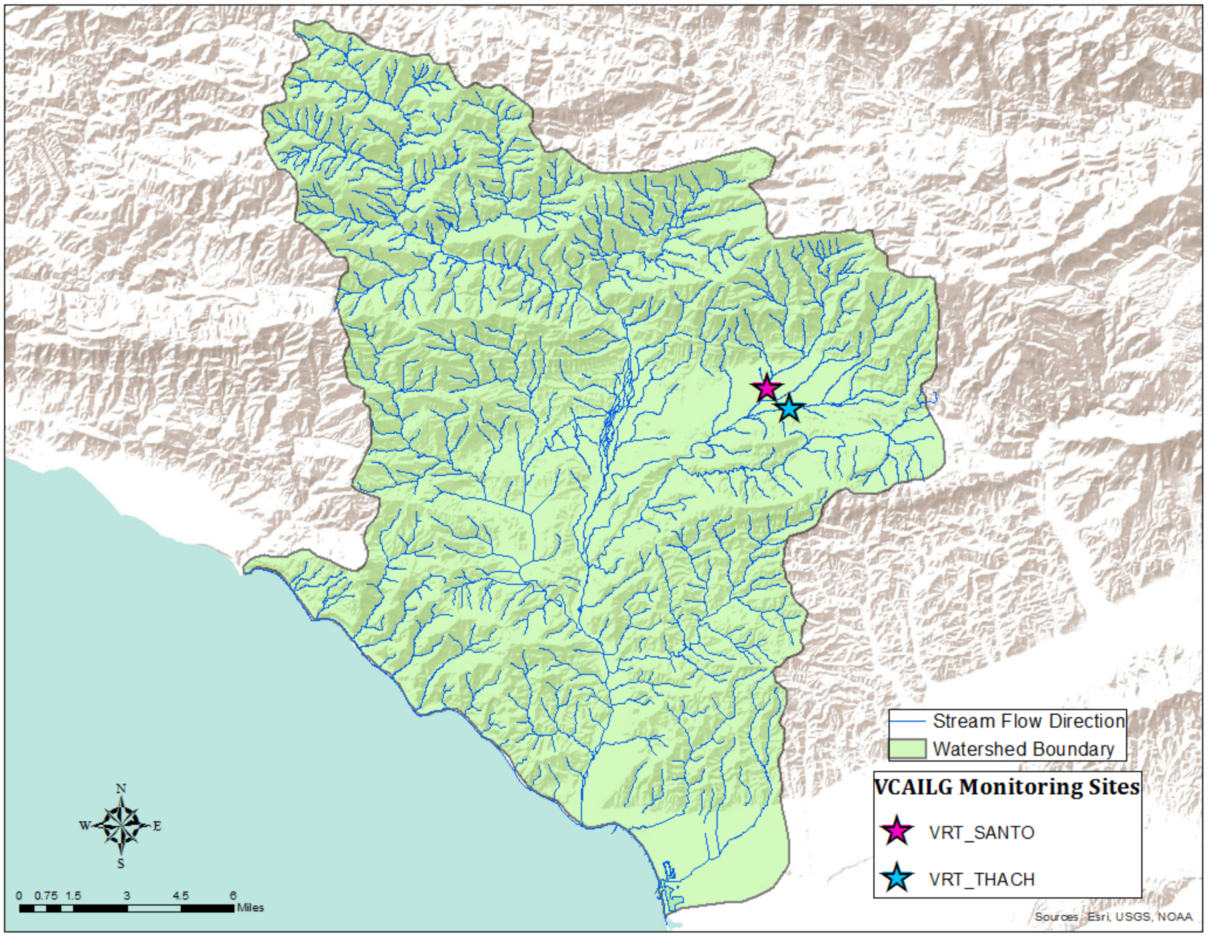

Figure 1. A map depicting the boundaries of the Ventura River Watershed along with the direction of Stream Flow and the locations of VCAILG Monitoring Sites present within the watershed.

- *Land Use:* The watershed is predominantly undeveloped open space, with a combination residential, agricultural and industrial sites found lining the main stem of the river. The northern half the watershed lies within the Los Padres National Forest, with much of the Matilija Creek sub-watershed (the actual beginnings of Ventura River) protected in a legislatively-designated wilderness area; most of the southern half of the watershed lies within unincorporated Ventura County, which has policies that favor agricultural and open space land uses.

- *Hydrology:* Lake Casitas, fed by diverted Ventura River water and Coyote Creek, is the primary supplier of water from the watershed. The city of Ventura also diverts surface and subsurface water from the Ventura River in the Foster Park area. Groundwater, provided by individual wells or small water companies, is another important water source in the watershed, especially for farmers. Aquifers in the watershed tend to drain relatively quickly, but also recharge quickly with sufficient rain. Many farmers and small water districts rely on groundwater until quantity decreases and Lake Casitas water provides reserve supplies.

- *Current Level of Compliance*: This watershed has only two monitoring sites, both immediately beside the river (Figure 1). Both of these sites remained dry during 2012 monitoring events hence no recent data on pollutant exceedances have been collected (Larry Walker Associates, 2010). The majority of water quality problems involve eutrophication (excessive nutrients and effects), especially in the estuary/lagoon. Sediment in the estuary, however, appears relatively uncontaminated. In some sub-watersheds, high TDS concentrations impair the use of water for agriculture. Most of the watershed's water quality problems occur due to NPS discharges. There have also been incidents of releases of toxic materials into storm drains entering the lower river. There is only one major PS discharger- a small POTW discharging to the lower river, the facility's effluent can make up two-thirds of the total river flow in that stretch for much of the year (California Regional Water Quality Control Board, 2012).

Santa Clara River Watershed

The Santa Clara River Watershed encompasses approximately 1,030 square miles. The Upper Santa Clara River Watershed is comprised of approximately 786 square miles contained within Los Angeles County and approximately 243 square miles within Ventura County; one square mile is found in Kern County. The Santa Clara River is one of the few unaltered, natural river systems remaining in Southern California (Department of Public Works LA County, 2014).

- *Land Use:* Predominantly open space with residential, agriculture and industrial uses seen along the mainstream of the Santa Clara River.

- *Hydrology:* Major water supply reservoirs are located in the Santa Clara River watershed, including Castaic Lake, Piru Reservoir, Bouquet Reservoir, and Pyramid Lake. The District has a number of basins designed to capture debris before it enters the Santa Clara River, including Warring Canyon, Jepson, Fagan, Adams Barranca, Cavin Road, Real Wash, and Franklin Barranca debris basins.

- *Current Level of Compliance:* The Santa Clara Watershed monitoring report suggests that the main exceedances shown at most of their monitoring stations is of Total Dissolved Solids (TDS), Chloride and Sulfate, although one station did show Nitrate exceedances and wet weather hits of DDT, DDE and DDD.

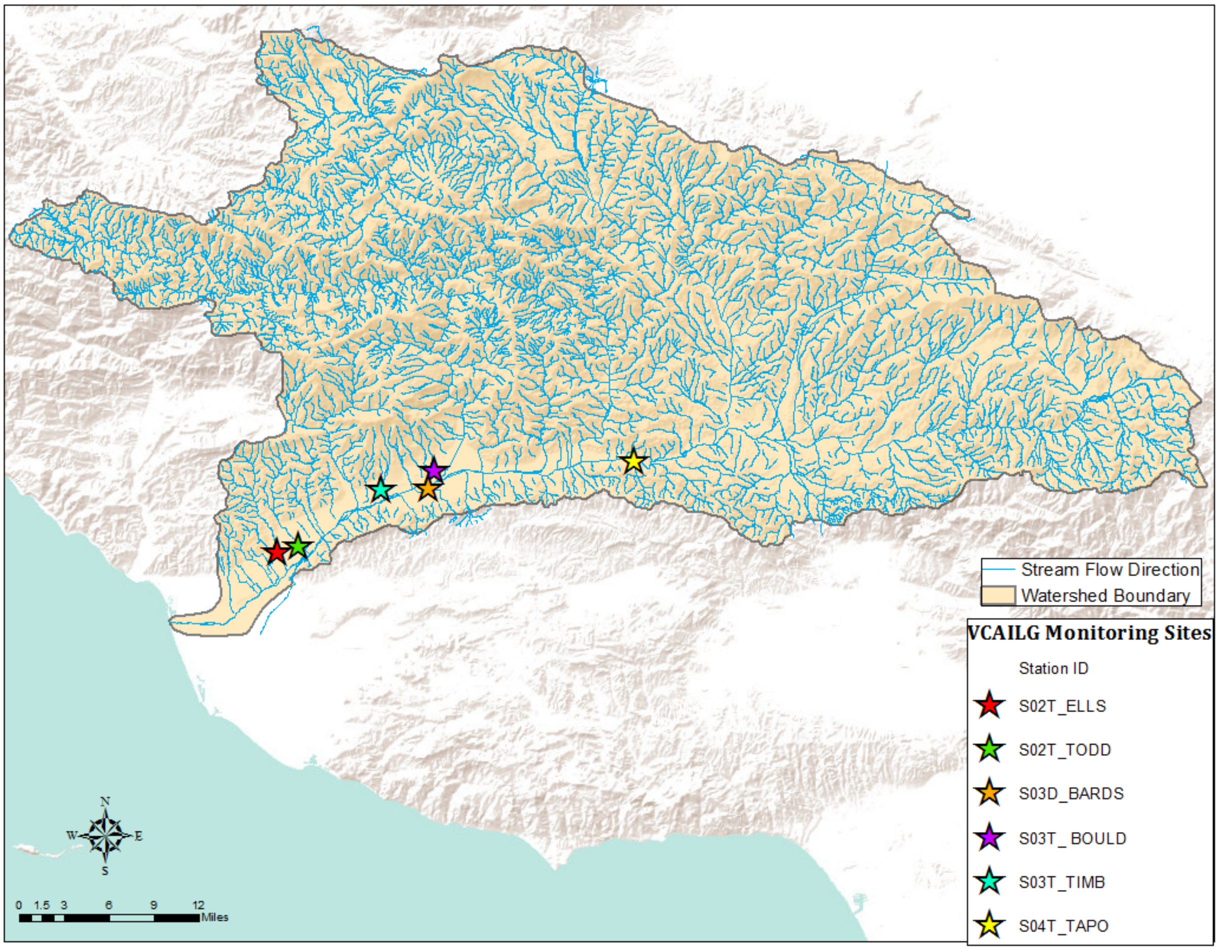

Figure 2. A map depicting the boundaries of the Santa Clara River Watershed along with the direction of Stream Flow and the locations of VCAILG Monitoring Sites present within the watershed.

Calleguas Creek Watershed

The Calleguas Creek watershed is located in south central California, in the southeastern region of Ventura County. The Calleguas Creek watershed runs 30 miles (southwest to northeast) and 14 miles across (north to south), covering an approximate 343 square miles. The watershed's northeastern border extends into Los Angeles County and is bordered by the Santa Susana Mountains.

- *Land Use:* Approximately 50% of the available area in the Calleguas Creek watershed is undeveloped; the remaining percentage is roughly divided as 25% urban, and 25-29% agricultural. The majority of the urban profile exists in the upper sub-watersheds, and the majority of agricultural land use is found in the mid-lower sub-watersheds.

- *Hydrology:* Water primarily collects in the upper Santa Susana Mountains to the north, and the Santa Monica Mountains to the south, where it flows southwest, passes through the Oxnard Plain, and ultimately discharges into the Pacific Ocean via Mugu Lagoon. Conejo Creek is the primary tributary to Calleguas Creek; these channels direct perennial flows that are primarily supplied and maintained by treated wastewater effluent and irrigation runoff. Both Calleguas and Conejo are ecologically important to the upkeep of Mugu Lagoon, a salt-marsh ecosystem that provides valuable habitat to endangered and threatened species. Numerous groundwater basins also exist throughout the Calleguas Creek watersheds. The Fox Canyon Aquifer System provides a connected series of deep aquifers that contribute to the groundwater basins in the lower watershed. These groundwater basins provide a significant portion of agricultural waters in the lower watershed, and therefore suffer from overdraft and decreases in water quality.

- *Current Level of Compliance:* The latest monitoring report shows that the primary TMDL exceedances occurring in this watershed is with nutrients like Ammonia-N and nitrate while also showing hits of legacy pesticides such as DDT, DDE and DDD, during both wet and dry events (Larry Walker Associates, 2013).

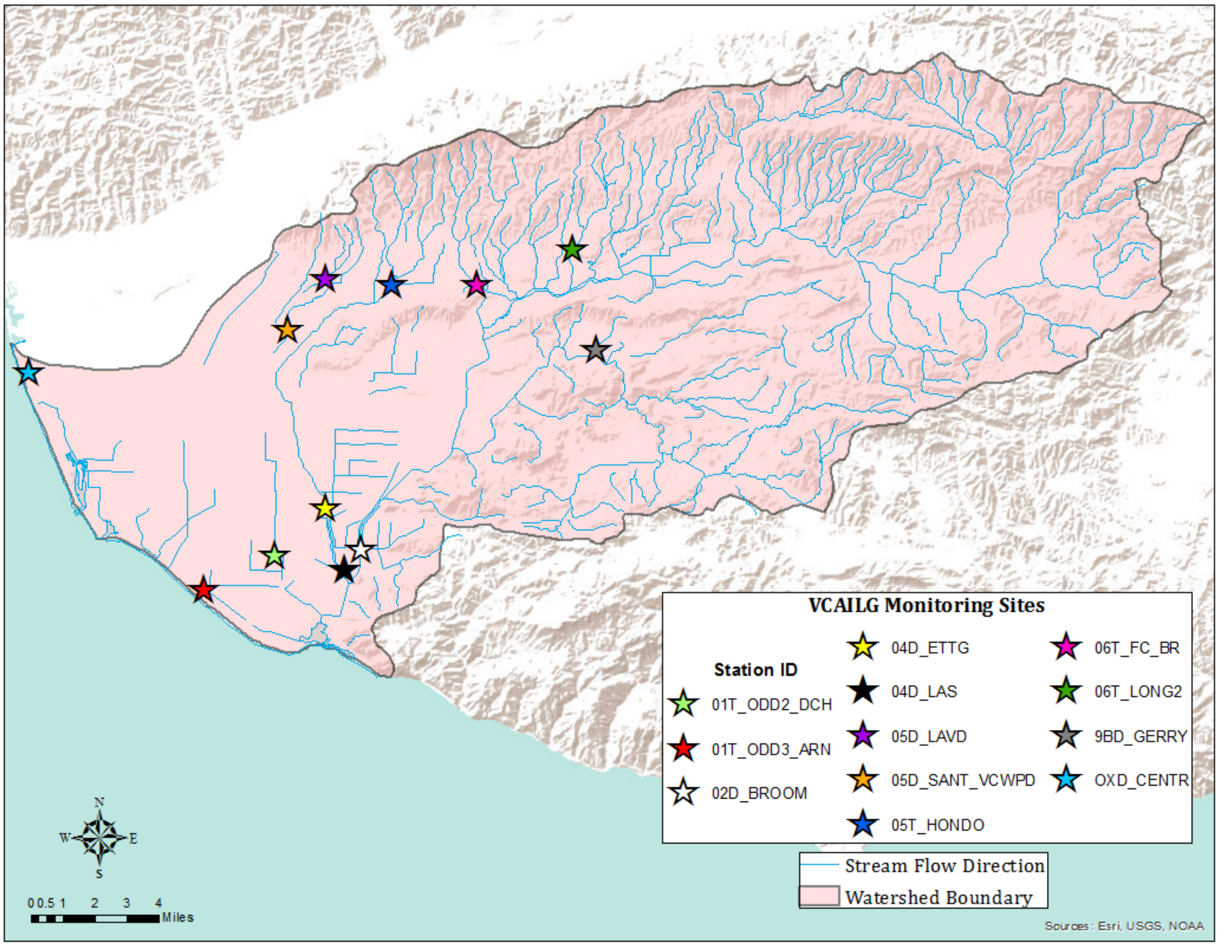

Figure 3. A map depicting the boundaries of the Calleguas Creek Watershed along with the direction of Stream Flow and the locations of VCAILG Monitoring Sites present within the watershed.

Literature Review

Introduction to the Literature Review

The literature referenced in this report provides a thorough and comprehensive qualitative framework for the technical analysis and final recommendations. Results of the technical analysis are examined through the lens of this research, and the final recommendations generated in this report reflect the combined findings of qualitative research and statistical analysis.

Critique of the Clean Water Act TMDL Program

The Clean Water Act has seen relative success eliminating point source pollution through establishing TMDLs and issuing NPDES permits (Copeland, 2012; B. M. Dowd et al., 2008a). However, as point sources have significantly reduced pollutant loading over time, unregulated non-point sources make up a larger relative proportion of total pollutant load contributions to impaired waterways (Copeland, 2012; US EPA, 2002). State 303(d) lists submitted to the United States EPA in in 2008 and 2010 identified approximately 41,000 waterbodies as significantly jeopardized by approximately 72,000 different causes (Copeland, 2012); this represents the impairment of more than 300,000 miles of U.S. rivers and shorelines, and 5 million acres of lakes (Copeland, 2012).

Despite the 40+ years since the implementation of the TMDL program, approximately 44% of United States waterways remain significantly impaired and subsequently unfit to serve their respective designated and beneficial uses (US EPA, 2009). non-point source agricultural pollution remains a significant contributor to water quality impairments, primarily discharging nutrients, pesticides, and sediments into receiving waterways. Agricultural non-point sources are estimated to contribute up to 48% of all waterway impairments throughout the United States (Laitos & Ruckriegle, 2014).

TMDL implementation for non-point sources of pollution have, overall, been far less successful than federal and state attempts to regulate point sources (Copeland, 2012; GAO, 2000, 2002). Successful TMDL program implementation and state sponsored non-point source pollution reduction programs frequently struggle with insufficient water quality data, inconsistent data collection methods, and a severe lack of funding for large-scale water quality monitoring programs (GAO, 2000). The Government Accountability Office of the United States acknowledges that many current waterway restoration plans and TMDL decisions are based on unreliable or incomplete datasets, and that the EPA's current 303(d) listing procedures likely fail to capture the actual scope of waterway impairment problems (GAO, 2000, 2002).

Despite criticisms, there are many cases that demonstrate water quality improvements through adherence to a TMDL process (B. Anderson, Phillips, & Hunt, 2010; D. Anderson & Flaig, 1995; Bennett et al., 2005; Clausen & Meals, 1989; M Lubell & Fulton, 2007). non-point source pollution is a complex problem; proper abatement program development and implementation requires intricate science, significant financial investment, heavy stakeholder involvement, and time (Copeland, 2012; B. M. Dowd et al., 2008a; Mark Lubell & Fulton, 2008). The U.S. GAO recognizes the difficulty in collecting the necessary state, federal, and local information, and it is only in recent years that non-point sources have begun to gain the same level of attention that point sources have received since the implementation of the CWA (Copeland, 2012).

Identifying and acknowledging data limitations provides significant insight into the federal TMDL program and California's CWP. These programs both aim to reduce non-point source water pollution and restore water quality to fit each waterway's designated and beneficial use; it is therefore important to redesign and recalibrate current monitoring and management methods in order to understand the true scope of regional water quality problems, and to develop an effective response.

Nitrogen and its importance to Ventura County

Nitrogen is arguably the most important agricultural chemical in the world. Although nitrogen makes up 78% of the atmosphere, it is not in a form readily available for most plants' use. Atmospheric nitrogen has an exceptionally strong triple bond that can only be broken (or "fixed") by specific microbes that live in the roots of a small subset of plants (the legumes, such as peanuts or lentils). Nitrogen availability is thus often a limiting factor to plant growth and fertilization is crucial to any commercial cropping system. Because of these facts, farmers have relied heavily on nitrogen application to soils to increase yields and provide the food demanded on a global scale. Nitrogen production and consumption has grown so massive that it is estimated that humans have doubled the natural rate of nitrogen input to terrestrial ecosystems from the atmosphere (Vitousek, 1997).

Unfortunately, if more "fixed" nitrogen is applied to the land than can be used by crops, it can either become oxidized to nitrous oxide (a potent and long-lived greenhouse gas) or nitrate and nitrite. Highly soluble and negatively charged nitrate will then simply wash away in the next irrigation event or storm, stripping the soil of positively charged nutrients such as calcium or magnesium in the process (Vitousek, 1997). This becomes a destructive cycle in which more fertilizers must be applied each season to maintain yields while irrigation runoff contaminates surface waters. Increased levels of nitrogen in streams cause eutrophication via explosions in algal growth; these algae "blooms" consume the dissolved oxygen in a water body as the algae die and are decomposed (Paerl, 2006). The resulting "dead zone" prevents the growth of plants and animals in these environments. The Gulf of Mexico is known for its unusually large eutrophication at the outlet of the Mississippi river, which drains runoff from the major agricultural area of the American Midwest.

Pesticide use and importance

Controlling weeds, insects, and diseases through the use of pesticides is the other major chemical input on large farms. Because pesticides are often deployed on a massive scale before their environmental impact is determined or even studied, they are notorious for producing unintended environmental harm. DDT was hailed as a miracle solution to pests before it was discovered that birds' eggshells were dangerously thinned by the chemical (Carson, 2002). Had this effect gone unnoticed, a generation of birds could have been killed with little potential for repopulation. More recently, the herbicide atrazine has been found to mimic estrogen in frogs, causing feminization and a repeat of Carson's concern in amphibians (Hayes et al., 2002).

While the detrimental environmental effects are often highlighted, these chemicals have also saved millions of lives through the destruction of disease carrying pests (Watts, 1998). Yield increases due to loss reduction on the farm is another benefit of pesticides, allowing for cheaper, more abundant food. More than 900 different pesticides are currently used on farms in the United States (Watts, 1998); VCAILG's monitoring program currently focuses on eight pesticides of concern, identified in Table 1 (Barry, 2013).

Table 1. Pesticides of Concern in Ventura County Watersheds

Pesticide	Chemical Family	Regulatory Status
Aldrin	Organochlorine	Suspended
Chlordane	Organochlorine	Suspended
Chlorpyrifos	Organophosphate	In Use
DDT	Organochlorine	Suspended
Diazinon	Organophosphate	In Use
Dieldrin	Organochlorine	Suspended
Endosulfan	Organochlorine	Suspended
Toxaphene	Organochlorine	Suspended

National Institute of Health (Watts, 1998)

Most pesticides fall into the organochlorine or organophosphate families. These chemicals consist of multiple hydrocarbon rings with attached chlorine or phosphate groups (Watts, 1998). Insects contacting these pesticides are usually killed through the disruption of their neurological functioning (Watts, 1998). Organochlorine pesticide ring structures contribute to high chemical stability while their organic composition leads to high hydrophobicity, causing sorption to organic carbon in soils. These properties combine to make these pesticides very long-lived in the environment, adding to their effectiveness but also making them difficult to remediate. For instance, DDT has been banned for use in this country for decades, but it still is occasionally registered in VCAILG monitoring due to its tight hold to soil particles and slow biochemical degradation (Larry Walker Associates, 2013). Recalcitrance in the environment and hydrophobicity also allows the organochlorines to bioconcentrate in the fatty tissue of organisms, becoming toxic at higher trophic levels in the food chain. Organophosphates are a newer generation of pesticides and are shorter-lived, lasting only days to weeks in the environment. However, organophosphate pesticides are often more toxic to humans (Watts, 1998).

In order to prevent pesticides form entering surface waters, the general policy is to ensure the chemicals remain on the farm. Erosion control is especially important. The soil particles that have pesticides sorbed to them must be prevented from depositing in streams to limit their environmental effects. Hydrology has relatively little impact on pesticide levels; irrigation events are not usually correlated with pesticide exceedances (Pedersen, Yeager, & Suffet, 2006). Management options such as constructed wetlands, ponds, buffer zones, or other vegetated treatment systems that prevent runoff have been shown to reduce pollutant concentrations as water flows through them (B. Anderson et al., 2010).

Voluntary programs

Kolstad (2010) provides a general framework explaining the reason why firms voluntarily organize to reduce emissions, despite increased costs (Kolstad, 2010). Economic theory assumes that the regulator is welfare-maximizing, and therefore prioritizes greater net social benefit above costs to a firm; the regulator then encourages the adoption of a voluntary program in which a firm maintains the ability to comply at the lowest cost (Kolstad, 2010). Assuming a firm acts to minimize total cost, a voluntary program will be adopted provided the cost of a voluntary action is less than the cost inflicted as a mandate (Kolstad, 2010).

Potoski and Prakash (2004) identify a similar framework, but provide a more detailed accounting of stakeholder motivations. While regulators may be theoretically idealistic, governmental agencies are frequently inhibited by insufficient staffing and relatively small operational budgets; these limitations make it difficult to adequately monitor firms and apply appropriate penalties (Potoski & Prakash, 2004; Prakash & Potoski, 2007). Fearing complete inability to enforce environmental regulations, an agency is encouraged to build relationships with firms by exchanging strict command and control policies for more lax, self-policing voluntary agreements (Potoski & Prakash, 2004). Under such an agreement, regulators forgive minor infractions and decrease the penalties for major exceedances while providing technical assistance; firms self-report and self-police to maintain a level of trust, and encourage regulators to lessen strict penalties if violations occur, are reported, and are remediated rapidly (Potoski & Prakash, 2004; Prakash & Potoski, 2007; Videras & Alberini, 2000).

This approach creates two primary scenarios: the win-win, and the lose-lose. The win-win scenario occurs when a cooperative voluntary agreement is reached, and firms choose to self-police and self-report (Potoski & Prakash, 2004); the outcome appeases regulators seeking superior environmental enforcement at a low internal cost, and lessens the burdens on firms, which cooperate with regulations in exchange for technical assistance and flexibility with penalties (Potoski & Prakash, 2004). The lose-lose scenario is instead characterized by distrust and inefficiency. A voluntary environmental agreement provides many opportunities for both firms and governments to act with self-interest (Kolstad, 2010; Potoski & Prakash, 2004); the problem of "freeriding" is often associated with voluntary programs, and is a primary concern of regulators and interest groups in environmental quality improvement programs (Delmas & Keller, 2005). In such a situation, agencies may doubt the honesty of firms and punish violations severely, thereby disincentivizing cooperation and self-reporting (Potoski & Prakash, 2004; Videras & Alberini, 2000); similarly, firms may seek to falsify self-reporting in order to evade penalties or avoid being seen as out of compliance. The basic premise of a voluntary program parallels the prisoner's dilemma, where each party acts to minimize personal losses and maximize personal gains.

Potoski and Prakash (2004) also investigate the role of environmental interest groups in voluntary program construction. Environmental groups frequently view voluntary programs with suspicion; such interests fear that governments have been captured by private interests, and therefore seek to implement command and control policies in favor of voluntary agreements (Carmin, Darnall, & Mil-Homens, 2003; Potoski & Prakash, 2004; Videras & Alberini, 2000). Regulators subsequently fear the social influence environmental organizations have upon public perspective, and seek to avoid situations in which an aggressive environmental interest interferes with proper operation of the voluntary agreement, or otherwise the agency's larger ability to function effectively (Carmin et al., 2003; Potoski & Prakash, 2004; Prakash & Potoski, 2007). Ideally, firms similarly react to avoid confrontation with an influential organization that possesses an ability to harm its relationship with a regulator and, in many cases, its consumer base (Potoski & Prakash, 2004).

The Conditional Waiver Program in Ventura County

Under the CWP, regulators maintain the authority to fine, alter existing or create new TMDL benchmarks, nullify an existing waiver exempting farmers from purchasing NPDES permits, or otherwise threaten to cease renewal of the waiver in the next cycle (Farm Bureau of Ventura County, 2005); these regulator capacities represent the majority of the CWP's "stick" provisions. The LARWQCB therefore carries a substantial amount of enforcement power. However, enforcement of NPS regulations is difficult, costly to the state, and necessitates challenging economically, politically, and socially powerful agricultural stakeholders (B. M. Dowd et al., 2008a). It is therefore in the interest of the LARWQCB to enter into a voluntary agreement with agricultural stakeholders in the region to dilute operational and enforcement costs, provide technical assistance, and maximize environmental benefits by allowing VCAILG to self-audit and select the most appropriate best management practices for each member's irrigated lands (Copeland, 2006, 2012; Potoski & Prakash, 2004).

It is likely that Farm Bureau and VCAILG have sought to avoid the regulator's use of enforcement mechanisms by creating a voluntary program designed to encourage county-wide landowner program enrollment, decrease the total number of TMDL benchmark exceedances, and foster adoption of all secondary CWP requirements. The benefits to Ventura County farmers include: (i) the repeated renewal of the agricultural conditional waiver exempting irrigated lands from NPS pollution discharge permit requirements under the California Water Code; (ii) decreased compliance costs compared to potential regulator-mandated command and control costs; and (iii) the freedom to design and adopt the most cost-effective BMPs for the region and specific crop types (Baumgart-Getz, Prokopy, & Floress, 2012; Krist, 2005; VCAILG, 2009). These benefits constitute the majority of CWP "carrot" provisions. Stakeholder consideration of costly regulator-mandated compliance measures and the potential benefits of voluntary actions are consistent with economic and political frameworks (B. M. Dowd et al., 2008a; Kolstad, 2010).

Additionally, organizations like Santa Barbara Channelkeeper serve the policing role of interest groups. Channelkeeper has worked to review, revise and update triennial 303(d) lists, and mobilizes citizen scientist volunteers to monitor water quality in the Ventura River (Santa Barbara Channelkeeper, 2015). Coalitions of environmental organizations like Channelkeeper represent significant stakeholder groups. Including and involving NGO stakeholders in voluntary program development and negotiations will theoretically serve to invest environmental groups in the program design and management process; this may additionally serve to manage expectations prior to program implementation, and provide the additional oversight, technical assistance, and cooperation necessary to achieve environmental quality improvements (Copeland, 2012; B. M. Dowd et al., 2008a; Potoski & Prakash, 2004).

The CWP is effectively characterized by the Potoski and Prakash model for a voluntary environmental program. All stakeholders appear to be invested in the win-win situation: the levels of voluntary compliance with regulations, monitoring, and self-auditing on behalf of VCAILG, and the provision of technical assistance and repeated renewal of the CWP and subsequent penalties for exceedances demonstrate mutual trust between the LARWQCB and VCAILG.

The role of policy networks and irrigated lands groups in BMP adoption

Though BMP adoption is largely based upon region, crop type, and regional culture, literature shows several key factors positively affecting adoption rates. While research is unable to identify a uniform set of these factors, several primary features are discussed in most relevant literature— education levels, income, farm acreage, investment capital, diversity, labor, access to information through educational programs, and access to social/policy networks are all considered to be important influences upon BMP adoption rates (Baumgart-Getz et al., 2012; Copeland, 2012; B. M. Dowd et al., 2008a; Mark Lubell & Fulton, 2008; Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008).

Many of the above listed factors are either arbitrary or dependent upon the growing region. However, the Farm Bureau and VCAILG have worked with the LARWQCB and the University of California Cooperative Extension (UCCE) to provide technical assistance with BMP implementation and create sophisticated educational programs, thereby fulfilling the CWP's grower education requirements (Merhaut et al., 2013; Ventura County Farm Bureau, 2015a). The result is a robust policy network that organizes growers representing approximately 80% of all irrigated lands within Ventura County as of 2014 (Ventura County Farm Bureau, 2015b).

Lubell and Fulton (2007) sufficiently correlate strong policy network presence with significant adoption of agricultural BMPs by Sacramento River orchard farmers (M Lubell & Fulton, 2007). The authors also identify significant differences in BMP adoption by management category. Policy network influence is correlated most strongly with changes in conventional pest management strategies, less strongly with nutrient runoff practices, and very weakly with conversion to alternative pest management strategies (M Lubell & Fulton, 2007). Therefore the relative influence of a policy network is largely determined by its presence and community engagement, but is also affected by the feasibility of conversion strategies and widely held external values, such as a common belief that traditional pest management practices may pose risks to human health (M Lubell & Fulton, 2007).

BMP adoption is largely driven by the activity and visibility of local policy networks seeking to foster educational opportunities, raise awareness, and augment the importance of environmental valuation (M Lubell & Fulton, 2007). The actions of strong policy networks like Farm Bureau and VCAILG are of vital importance to stakeholders—including regulators— seeking compliance. Lubell and Fulton's (2007) research suggests that the adoption of pollution reduction BMPs in Ventura County has been—and will continue to be— largely successful due to the Farm Bureau's strategic use of social capital and promotion of values balancing environmental and economic considerations (M Lubell & Fulton, 2007). It is therefore of the highest importance that regulators work with and through local policy networks to promote visibility and environmental valuation without damaging the social capital that drives voluntary compliance at such high rates in Ventura County (M Lubell & Fulton, 2007).

In 2006 the Farm Bureau organized VCAILG to collectively organize and manage Ventura County farmers, and reduce the cost of requirements placed on growers under the CWP (Krist, 2005; Ventura County Farm Bureau, 2015a). VCAILG's formation was largely driven as a way to reduce individual monitoring costs and compliance to farmers by empowering them through an organized advocacy group (Ventura County Farm Bureau, 2015a). Organizational advocacy and management by Farm Bureau and VCAILG has led to a strong working relationship with the LARWQCB, accumulation of social and political capital, and dramatic cost savings (VCAILG, 2009; Ventura County Farm Bureau, 2015a, 2015b). By consolidating resources and acting as one Discharger Group, VCAILG reduced monitoring and reporting costs in 2007-2008 from an estimated average of nearly $64,000 to an average just under $840 per land owner (VCAILG, 2009); considering the 2,989 growers enrolled at that time, VCAILG created a total savings estimated to be just under $94.7 million (VCAILG, 2009).

Review of agricultural BMP effectiveness

Sediment and Pesticide Control BMPs

Adoption of BMPs is considered to be among the most effective ways of combating agricultural non-point source pollution (Merhaut et al., 2013); with the application of various BMPs in combination, Zhang and Zhang (2011) observed a greater than 94% decrease in diazinon (a commonly useds pesticide) and an minimum 50% decline in sediment runoff in a major tributary of the San Joaquin River; both decreases effectively prevent pesticide and sediment runoff leaching into aquifers or surface waters.

Using BMPs to approach the complicated issue of non-point source pollution is recognized internationally as well. In 1991, the European Union (EU) adopted the Nitrates Directive (ND)— an important policy designed to curtail agricultural nitrogen emissions across Europe. The NDs' requirements resemble California's CWP in that they require farmers to routinely monitor nitrate emissions and adopt "Codes of Good Agricultural Practice." A 2012 study shows after adopting the ND, nitrate leaching in most regions of EU have decreased by at least 16% since 2004 (Velthof et al., 2014).

Proper BMP identification and implementation would theoretically allow farm optimization, resulting in improved economic and ecological productivity through reduced crop losses, erosion prevention, and lower irrigation and fertilizer application costs (Lopus, Santibáñez, Beede, Duncan, Edstrom, Niederholzer, Trexler, & Brown, 2010; Merhaut et al., 2013). Several BMPs provide environmental benefits at relatively low costs- vegetated agricultural drainage ditches (VADD) have been found to be far more effective than a non-vegetated ditch, while being environmentally and economically appealing. Farmers in Yolo County, CA saw diazinon's half distance (distance required to reduce its concentration by 50%) drop nearly 3 times lower than typical levels through the installation of VADDs, thereby serving their designated purpose of reducing sediment transport and pollutants sorbed to sediment organic fractions (Cooper et al., 2004; Denton et al., 2008). Numerous other studies report similar success after VADD, retention basin, and other sediment control practices were implemented (Bennett et al., 2005; Denton et al., 2008; M.T. Moore et al., 2008; Matthew T Moore et al., 2009; Osbourne & Kovacic, 1993).

Nutrient Management BMPs

Agricultural intensification and conversion to higher value crops places additional stress on surrounding environments (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). Tilman et al. (2002) report a 700% increase in global agricultural nitrogen use and a 350% increase in global agricultural phosphorous use between 1960 and 1995. This massive increase in developed nations' agricultural activity is largely due to declining nutrient uptake efficiency; trends suggest that without dramatic increases in fertilizer uptake efficiency, an additional tripling of both major nutrients will occur by 2050 (Tilman et al., 2002). The same authors estimate that only 30-50% of applied nitrogen and approximately 45% of phosphorous fertilizers are actually utilized by crops. These rates of over fertilization have led to doublings of terrestrial nutrient mobilization for both nitrogen and phosphorous, much of which is lost from fields and impacts surface and groundwater systems (Howarth, 2008; Paerl, 2006; Tilman et al., 2002).

BMPs strive to limit the surplus nitrogen applied to fields and exported to watersheds. The UC Agriculture and Natural Resource program has developed guidelines for crop-specific application rates; however these recommended rates are exceeded in approximately 32% of crops (Rosenstock, Liptzin, Six, & Tomich, 2013). Planting cover crops on fallow land has been shown to limit nutrient runoff (Smukler, O'Geen, & Jackson, 2012). In arid locations like California, fertilization timing can have a powerful impact on reducing total nitrogen transported to rivers; irrigation timing and climatic factors like precipitation events can also greatly affect nitrogen transport (Sobota, Harrison, & Dahlgren, 2009).

A variety of fertilization BMPs demonstrate significant success. Practices incorporating nutrient application timing, exchanging high mass nutrient applications with smaller, more frequent doses, and applying dissolved nutrients through drip line irrigation (fertigation) have been associated with increased nutrient uptake

(Bottoms, Hartz, Cahn, & Farrara, 2013; Lopus, Santibáñez, Beede, Duncan, Edstrom, Niederholzer, Trexler, Brown, et al., 2010; Roberts, 2007; UCCE Agriculture & Natural Resources, 2009b). These fertilization BMPs— fertigation in particular — provide effective alternative methods to deliver nutrients to a crop's root zone while simultaneously decreasing over application (UCCE Agriculture & Natural Resources, 2009b; Wamser, Morales, Álvaro, & Urrestarazu, 2015). Literature provides evidence that crop rotation patterns and application rates have the most significant impacts on nutrient leaching, regardless of crop type (Amon-Armah et al., 2013; Öborn et al., 2003). Effective crop rotation and nutrient management can therefore provide significant decreases in nutrient leaching responsible for waterway impairment (Amon-Armah et al., 2013).

Nutrient Management Planning

Similarly, effective nutrient management planning (NMP) and element (mass) balances provide useful mechanisms to anticipate an integrated total potential nutrient loss within a system (Öborn et al., 2003). NMP serves as a farm plan and nutrient accounting tool used to anticipate nutrient distribution, decrease over-application, create an internal reporting and management system, and identify polluting "hot spots" while simultaneously reducing unnecessary grower expenditures on costly fertilizers (Amon-Armah et al., 2013; Beegle, Carton, & Bailey, 2000; Öborn et al., 2003). These plans often take one of three forms: (1) a *farm-to-gate* budget, (2) a *soil surface* budget, or (3) a *soil system* budget (Beegle et al., 2000; Oenema, Kros, & De Vries, 2003).

Of the three NMP approaches, the farm-to-gate approach provides the most integrated method to assess environmental impacts, and is therefore the most well-suited for regional standardization and subsequent use an environmental performance indicator; a soil surface approach estimates the total nutrient loading to a defined soil system; the soil system approach is designed to generate the most detailed nutrient budget, and ultimately aims to account for all major sources, sinks, and nutrient recycling processes within a large-scale soil system (Oenema et al., 2003).

The farm-to-gate approach requires documentation of nutrient quantity and type in all applicable products entering the farm system. This approach identifies and records a farm's nutrient surplus or deficit by measuring the inputs against the outputs and adjusting for changes in soils storage potential (Oenema et al., 2003). The result is a balance identifying accumulation and a conservative estimation of total potential nutrient losses. Inputs can be derived through grower surveys or through cost records, providing multiple methods to obtain data and cross-reference for quality control (Beegle et al., 2000; Oenema et al., 2003). The farm-to-gate approach is easily standardized and applied on an individual farm basis, allowing for an organized group to generate a detailed aggregation of all nutrient management for all participants within a larger region (Oenema et al., 2003).

The soil surface approach is similar, accounting for inputs, outputs, and adjusting for soil storage. However, the soil surface budget also accounts for generation occurring from livestock and subsequent losses occurring from N-ammonia volatilization from fertilizers and manure (Oenema et al., 2003). The process is also easily standardized, but requires a more detailed accounting of nutrients distributed through livestock feed, and estimates of waste generated (i.e. feed provided to cattle and released as manure).

The soil system budget builds upon the soil surface and farm-to-gate approaches, representing the most comprehensive of the NMP approaches. In addition to tracking inputs, outputs and adjusting for changes in soil storage, a soil system budget identifies further nutrient partitioning at the soil surface, including volatilization as ammonia and nitrification of ammonium from manure, urine, and biochemical losses from fertilizers and manure stored for future use (Oenema et al., 2003). This approach is the most useful in anticipating potential environmental impacts from nutrient surpluses and the relative distribution thereof (Beegle et al., 2000; Oenema et al., 2003). However, monitoring and maintaining a soil systems budget is time, energy, and cost intensive, and frequently must be conducted on a larger scale to maximize efficiency. Additionally, the soil system approach requires precise data to generate accurate results. As many pieces of this process are often averages, projections, or estimates, a complete soil system budget is frequently subject to much greater uncertainty (Beegle et al., 2000; Oenema et al., 2003).

Summary of BMP Review

Although the benefits of adopting BMPs appear clear from a regulatory or management perspective, California farmers do not always have access to specific information on the best management designs or BMPs most suitable to a particular region, nor are the benefits of implementation necessarily clear, straightforward, or economically and statistically justifiable (Clausen & Meals, 1989; Copeland, 2012; B. M. Dowd et al., 2008a; Merhaut et al., 2013). High costs lead to infrequent monitoring, severe data limitations, and inconsistent water quality evaluation and impairment listing procedures between state regulatory agencies (Copeland, 2012; GAO, 2000). These inhibitors deter frequent, detailed data collection, thereby making it difficult to statistically demonstrate the impact of BMPs on improving water quality outside of experimental settings.

By carefully controlling an experimental setting and tracking water quality, it is possible to demonstrate specific BMP efficacy in individual situations, though it is difficult to predict the performance of the same practice in a different setting (Easton, 2008). In many cases, an effective BMP may fail to generate the expected water quality improvements. Easton, Walter, and Steenhuis (2008) correctly identify that many BMPs are simply "re-packaged soil conservation practices" that are not well suited to managing the suite of nutrients and pesticides that do not sorb as strongly to soils as phosphates or legacy pesticides.

BMP effectiveness must be studied at the watershed level to identify the practices most significantly improving water quality throughout Ventura County. The Farm Bureau and VCAILG have led arguably the most extensive data collection efforts under the CWP to track agricultural non-point source impacts on state waterways. However, this effort has led to large expenditures, totaling approximately $11.5 million since the program's initiation in 2005 (Ventura County Farm Bureau, 2015b). It is therefore important that future data collection is robust and able to statistically support proper assessment of Discharger Group action impacts on water quality.

Accurate monitoring to ensure effective program development

Many of the 41,000 miles of stream reach and coastline placed on the 303(d) list of impaired waterways are not even monitored (GAO, 2000). Implementing an effective monitoring program is both difficult and expensive, and as new agricultural pollution reduction policies are adopted, TMDLs established, and BMP requirements expanded in scope and reach, growers express significant concern over the economic realities of compliance (Brauer et al., 2009; GAO, 2000; Strobl & Robillard, 2008).

Many studies claim that opportunities to simultaneously reduce costs and significantly decrease pesticide and nutrient loading exist (Brauer et al., 2009; B. M. Dowd et al., 2008a; Gowda, Dalzell, & Mulla, 2007; Rejesus & Hornbaker, 1999). However, maintaining water quality necessitates statistically defensible validation currently absent in literature, leading to establishment of loose correlations and sometimes arbitrarily selected policies, TMDLs, and BMPs (Brauer et al., 2009; Strobl & Robillard, 2008). Holistic design methodologies are therefore required to ensure maximum pollution reduction at the lowest possible cost (Cryer, Fouch, Peacock, & Havens, 2001; Strobl & Robillard, 2008; Telci, Nam, Guan, & Aral, 2009). Well-designed monitoring methodologies include, but are not limited to, practices that determine the proper establishment and placement of monitoring sites, tracking of river system flow and ambient pollution levels, and monitoring at an appropriate frequency (Strobl & Robillard, 2008). It is important to note that the relevance of each variable is largely determined by the watershed and region; for example, frequency of monitoring is relatively less important in less climatically variable watersheds (Brauer et al., 2009).

When designed properly, river and watershed system monitoring networks are effectively able to measure pollutant loading despite variations caused by seasonal temperature, precipitation, and dispersion changes in complex watersheds (Brauer et al., 2009; Strobl & Robillard, 2008; Telci et al., 2009); effective monitoring systems simultaneously reduce the likelihood of "false exceedances," and enable prompt and cost effective pollution elimination, reduction, or remediation actions required by any "true" exceedances (Brauer et al., 2009; Strobl & Robillard, 2008). Effective monitoring networks are therefore essential to minimize the occurrence of false positives and false negatives, provide accurate and usable water quality data to assess BMP efficacy, and ultimately evaluate the overall effectiveness of the CWP.

Effective monitoring requirements are increasingly important as more TMDLs and BMPs are designed and implemented, and viable risk assessment tools are developed to identify environmental and human health hazards caused by agricultural NPS discharges to river systems, groundwater, and estuarine environments (Cryer et al., 2001; Fulton et al., 1999; Luo, Zhang, Liu, Ficklin, & Zhang, 2008; Telci et al., 2009). It is equally important both to regulators and to Ventura County farmers that accurate and economically responsible monitoring programs are developed. Reevaluation of current monitoring programs may suggest that the majority of costs and efforts be shifted away from less variable orchard crops and toward high value row crops with higher nutrient and pesticide demands, such as strawberries, lettuce, melons, and celery (B. M. Dowd, Press, & Huertos, 2008a; Rosenstock et al., 2013).

Technical Approach

Data Catalog

As mandated by the Conditional Waiver, non-point sources of water pollution must produce reports documenting water quality in their watersheds. VCAILG operates as a single Discharger Group representing 1,196 landowners and 77,019 acres in Ventura— roughly 85% of the irrigated land in the county (Larry Walker Associates, 2013). VCAILG has therefore been required to produce Annual Monitoring Reports since 2007; all Annual Monitoring Reports have been filed in compliance with the law by Larry Walker Associates (LWA), the consultants retained by the Farm Bureau.

LWA consolidates and maintains annual monitoring data for all required water quality indicators on a sub-watershed scale. Monitoring data is collected from twenty VCAILG member drainage sites (Figure 4); additional TMDL monitoring data is collected for another twelve sites operated by other parties (Larry Walker Associates, 2013). Monitoring occurs four times per year: twice during wet events and twice during dry events. Each of these drainages encompasses multiple farms and landowners within a large area. The monitoring approach provides a degree of anonymity, and prevents the targeting and identification of specific VCAILG members as more or less environmentally harmful. Anonymity was required by the Farm Bureau, VCAILG and LWA in order to allow students at the Bren School of Environmental Science & Management to obtain data and conduct this analysis. Ensuring anonymity is important in protecting grower privacy. However, it is important to note that preserving anonymity makes determining BMP effectiveness more difficult to quantify, as data must be aggregated to prevent identifying single farms.

Additionally, the CWP requires that VCAILG track BMP adoption rates and record progress throughout its membership. VCAILG has since conducted two surveys of its members in order to determine BMP adoption rates throughout the county. LWA has supported VCAILG's BMP survey development, distribution, collection, and preparation of results. These data, along with supplementary sources for climate, geographic, and agricultural data, forms the bulk of the material used in this analysis.

Water Quality and Flow Data

LWA provided extensive water quality data for analysis in the form of a Microsoft Excel file. Water quality samples were collected mid-stream and analyzed for chemicals of concern identified in the 2010 – 2015 Conditional Waiver. Measurements were made for each of twenty sampling sites generating agricultural runoff during wet and dry events. The measurements include nitrate (in mg/L), the select pesticides of concern (in mg/L), and flow rate at the time of sampling (in cubic ft/second) from 2007 - 2014.

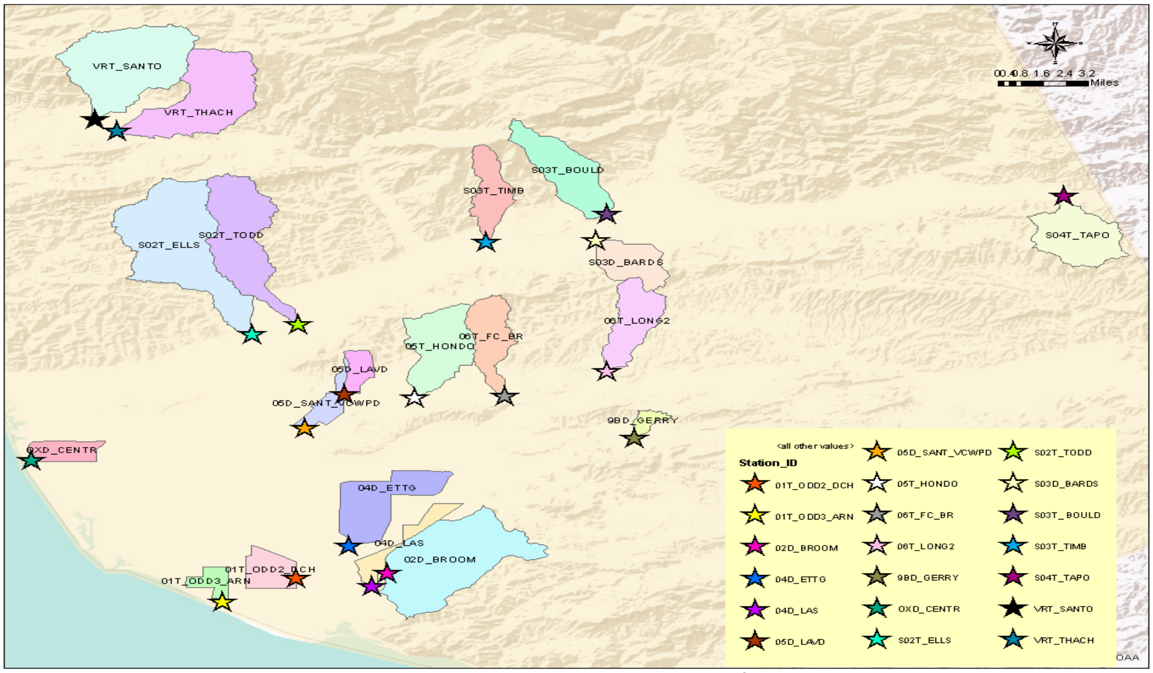

Figure 4. Map of sub-watersheds studied (polygons) and LWA sampling sites (stars) in Ventura County. Each sampling site is located at the point to which each sub-watershed drains.

The nitrogen concentration data were converted to kilograms per cubic foot water (kg-NO_3^-/ft^3); flow rate was converted to cubic feet per day (ft^3/day). When these converted values are multiplied, the result is the mass loading rate of nitrate, measured in kilograms of nitrate input to receiving waters per day (kg-NO_3^-/day). Analyzing nitrate loading rates accounts for both concentration and flow rate variation between samples. For example, it is possible that no actual difference exists in the total nitrate mass carried into streams if the flow rate is a extremely low and the concentration is high versus a flood scenario characterized by a low concentration and extremely high flow rates. In this hypothetical situation, the lower concentration in the high flow scenario is due to the dilution of the stream rather than decreased nitrate transport from fields. Both measures of nitrate (concentration and loading) were included in order to ensure the completeness of the analysis.

Survey Data

BMPs strive to limit surplus chemical input to fields and subsequent exports to waterways. The UC Agriculture and Natural Resource program has developed guidelines for crop-specific application rates; however these recommended rates are exceeded in approximately 32% of crops (Rosenstock et al., 2013). BMPs are therefore necessary in areas characterized by over-application of nutrients; BMPs may also act to reduce chemical runoff from lands characterized by improper chemical application rates. There are many different on-farm actions considered to be BMPs. Planting cover crops on fallow land has been shown to limit nutrient runoff (Smukler et al., 2012). In arid regions like California, the timing of fertilizer application can have a powerful impact on how much is transported to rivers; irrigation timing and climatic factors like precipitation events can also greatly affect nitrogen transport (Sobota et al., 2009).

LWA, in conjunction with the Farm Bureau of Ventura County, recently developed and issued a BMP adoption rate survey to all VCAILG members in October 2013 (Figure 5). The survey inquired about the total number of acres under a farmer's control, the number of acres adopting each BMP *prior to* October 2010, and the number of acres adopting each BMP *after* October 2010. The data were pooled across both time intervals to maximize the number of observations available in each model. A total of 36 different BMPs were surveyed, divided into the categories of "Irrigation and Salinity Management," "Nutrient Management," "Sediment Management," "Pesticide Management," and "Trash Management." Each of these categories was analyzed for contribution to nitrate and pesticide runoff except for "Trash Management," which was deemed irrelevant to the water quality analysis conducted in this study. LWA aggregated the survey results by sub-watershed. The data used in the final analysis consisted of the percent of applicable acres within each sub-watershed subject to each BMP. Some BMPs are not applicable to some crops or land types; these acres were therefore removed.

Grower Survey of Best Management Practices (BMPs)

VENTURA COUNTY
Agricultural Irrigated Lands Group

Irrigation and Salinity Management

#	BMP	Yes, new since October 2010	Yes, prior to October 2010	Planned for future	No, not currently used	Not applicable
1	Sprinkler irrigation runoff is captured or kept on the property.					
2	At least every 5 years, the irrigation system is tested for distribution uniformity by monitoring water delivery or pressure differences within a block.					
3	Regular maintenance is performed on the irrigation system to maintain distribution uniformity and prevent runoff caused by leaks or clogged lines.					
4	Pressure regulators or pressure compensating emitters are used.					
5	Sprinkler heads and drip emitters of the same flow rate are used within each block and replaced with the same heads or emitters, when necessary.					

Figure 5. Sample of the BMP survey issued by VCAILG. Questions were asked for each parcel or crop type.

GIS Layers

The Agricultural Commissioner's Office maintains geographic information system (GIS) files consisting of polygons demarcating each crop type grown in Ventura County. LWA provided these files for 2008, 2010, and 2012. LWA also made available a GIS file with polygons for each of the twenty drainages and their corresponding sample sites. Using geoprocessing tools in ArcGIS 10, all of the data were clipped to the drainages monitored by VCAILG, polygons of the same crop type were merged, and the area of each crop type within each drainage was calculated. Finally, Microsoft Excel was used to calculate the percentage of the irrigated area within each drainage under tree or row crop agriculture. The distinction between these two agricultural regimes is significant, as tree crops such as tangerines or avocados often require far fewer inputs year-to-year compared to row crops such as celery or strawberries, which must be replanted each year. The results of these calculations were used to control for the different demands of the two major crop types in multiple regression models.

Climate Data

The California Irrigation Management Information System (CIMIS) website was used to download daily climate data from 2007 to the present. Data was downloaded from three monitoring stations, located in Santa Paula, Oxnard, and Camarillo. Sampling sites were then paired with whichever weather station was closest in order to reflect as best as possible the conditions experienced at each site. Climate data included measurements of daily precipitation, evapotranspiration rate, and average relative humidity; precipitation data was collected for the day of, the day before, and two days before sampling events. Data for each of these variables was included to control for any climatic differences between sampling sites.

Methodology

Determining the relationships between BMPs and water quality will be useful to the Farm Bureau and farmers represented by VCAILG, as the most effective BMPs can be promoted while the least effective are discouraged. The ideal set of BMPs would lead to statistically significant water quality improvements and would include the most efficient or cost-effective options. Time and expense will be saved from eliminating those practices that do not serve to improve water quality.

The technical analysis relies on observational data, rather than data generated from the use of classic experimental techniques. Varying levels of water quality and BMP adoption data are analyzed in combination with supplementary environmental data. The relationship between water quality and BMP adoption is appropriately explored by multiple regression analysis.

The study will be performed on a sub-watershed level, as each sampling site drains many farms of diverse size and crop type. Survey data has been collected to determine which BMPs have been implemented throughout each drainage area. LWA has collated and processed the survey results, providing a percentage of applicable irrigated acres adopting each BMP in each sub-watershed (Figure 6). These percentages represent the main independent (or predictor) variables. The supplementary climate and crop type data will also be used as independent variables in order to control for variation other than in BMP adoption that may affect water quality. Additionally, each watershed will be used as a categorical (dummy) variable to control for any variation in location that may affect water quality. A confidence level of 0.05 will be used to determine significance. The regression models used are listed in Table 2. In addition to the regression analysis, exploratory data visualization will be performed to enhance the conceptual understanding of the problem. All analysis will be implemented using R statistical software, version 3.1.2.

Acreage Draining to VRT_THACH Monitoring Site	Irrigation & Salinity Management	Irrigation & Salinity Management	Irrigation & Salinity Management	Irrigation & Salinity Management
	Sprinkler irrigation runoff is captured or kept on the property.	At least every 5 years, the irrigation system is tested for distribution uniformity by monitoring water delivery or pressure differences within a block.	Regular maintenance is performed on the irrigation system to maintain distribution uniformity and prevent runoff caused by leaks or clogged lines.	Pressure regulators or pressure compensating emitters are used.
	Cropped Area Action	Testing	Cropped Area Action	Cropped Area Action
	Q1	Q2	Q3	Q4
Percent of Applicable Acres on which BMP was in use at time of survey regardless of whether the use started before or after October 2010	91%	18%	100%	35%
Percent of Applicable Acres on which BMP became in use **after October 2010**	1%	3%	1%	0%
Percent of Applicable Acres on which BMP became in use **prior to October 2010**	90%	15%	99%	35%

Figure 6. Sample BMP data of BMPs 1 to 4 for the THACH sub-watershed.

BMPs are split into five categories: Irrigation and Salinity Management, Nutrient Management, Sediment Management, Pesticide Management, and Trash Management. For the nitrate regressions, only BMPs in the irrigation/salinity and nutrient management categories were considered because nitrate is a highly soluble nutrient application and thus strongly affected by irrigation. Organochlorine pesticides are no longer legally applied in the United States. However, they can still be detected in surface water because they are strongly sorbed to organic matter in soils and sediments suspended in the water column. Therefore, only BMPs under the sediment management category are considered for the organochlorine regression. Some organophosphate pesticides are still applied; both the sediment and pesticide management categories were therefore considered in the organophosphate regression.

Nitrate is a recurring problem with frequent concentration-based TMDL exceedances observed. As nitrate is frequently detected with a wide range of concentrations, nitrate pollution is best represented as a normal, continuous dependent variable. Pesticide levels, however, only sporadically exceed the benchmarks; the majority of the pesticides in question are no longer applied, but remain in the environment as legacy pollutants. Infrequent detections combined with a the "spiking" nature of pesticides concentrations suggests that pesticide pollution should be analyzed as a binary dependent variable, with a one indicating a 'hit' at any detectable concentration and a zero indicating no detection. Coefficients in the pesticide models will therefore predict the relative probability of a hit.

Table 2. Linear models used to estimate the relationship between relevant BMPs and the water quality measurement of interest. See Table 3 for variable descriptions.

Dependent Variable	**Model**
Nitrate Concentration	$Nitrate\ (\frac{mg}{L}) \sim Flow + Eto + Precip + Precip1 + Precip2 + PrecipInt + AvgRelHum + (BMP1\ to\ BMP19) + Crop\ Type + subwatershed$
Nitrate Loading	$Loading\ (\frac{kg}{day}) \sim Eto + Precip + Precip1 + Precip2 + PrecipInt + AvgRelHum + (BMP1\ to\ BMP19) + Crop\ Type + subwatershed$
Organochlorine Pesticides	$Hit \sim Flow + Eto + Precip + Precip1 + Precip2 + PrecipInt + AvgRelHum + (BMP20\ to\ BMP28) + Crop\ Type + subwatershed$
Organophosphate Pesticides	$Hit \sim Flow + Eto + Precip + Precip1 + Precip2 + PrecipInt + AvgRe\square Hum + (BM20\ to\ BMP34) + Crop\ Type + subwatershed$

Results

Preliminary Data Visualization

It is not apparent that nitrate pollution has declined over time with the adoption of BMPs. A smoothed curve for average nitrate concentration by sample date for the entire county does not display any trends besides what appears to be a slight rise from 2011 onward (Figure 7). Average nitrate loading, however, appears to show a decrease in its smoothed curve with time since 2010, although this pattern may be driven primarily by two extremely high outliers. Eliminating these two outliers reveals a potential slight negative trend over time. Based on these preliminary graphs, nitrate loading may show more of a trend than nitrate concentration over time, due to environmental factors, BMP adoption rates, or unobserved variables.

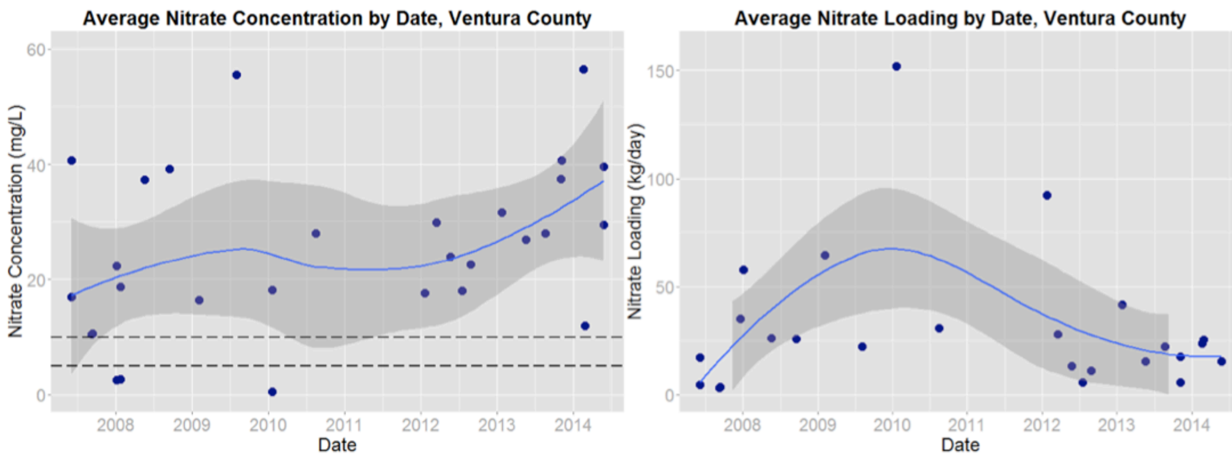

Figure 7. Average nitrate concentration and loading by date for all sampling sites in Ventura County, with a LOESS-smoothed curve and 95% confidence interval. The TMDLs are shown in dashed lines. For Oxnard, the Calleguas Creek watershed, and the Santa Clara River reaches 1 and 2 the TMDL is 10 mg/L; for the Santa Clara River reaches 3 and 4 and the Ventura River the TMDL is 5 mg/L.

Nitrate pollution is highly variable across different sampling sites within the county. Certain sub-watersheds, such as BARDS, ELLS, FCBR, and TIMB seem to have very minimal nitrate concentration and loading rates (Figures 8 and 9). Others, such as ETTG, LAS, ODD2DCH, and SANTO, seem to have excessive nitrate concentrations or loadings. A common explanation for the differences is varying farmland use, with row crops generally assumed to be more chemically intensive than tree crops. The statistical analysis may answer whether this is the source of the observed heterogeneity.

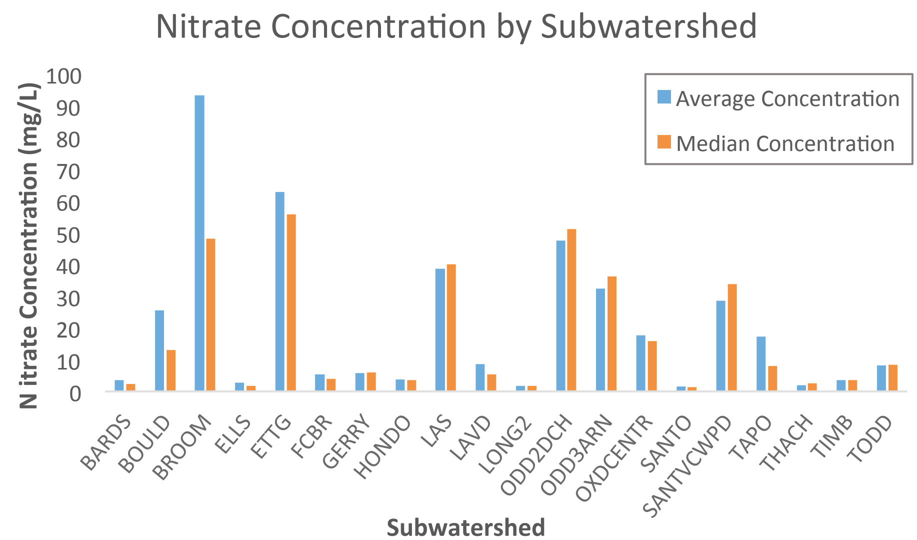

Figure 8. Average and median nitrate concentration by sub-watershed in Ventura County, 2007-2014.

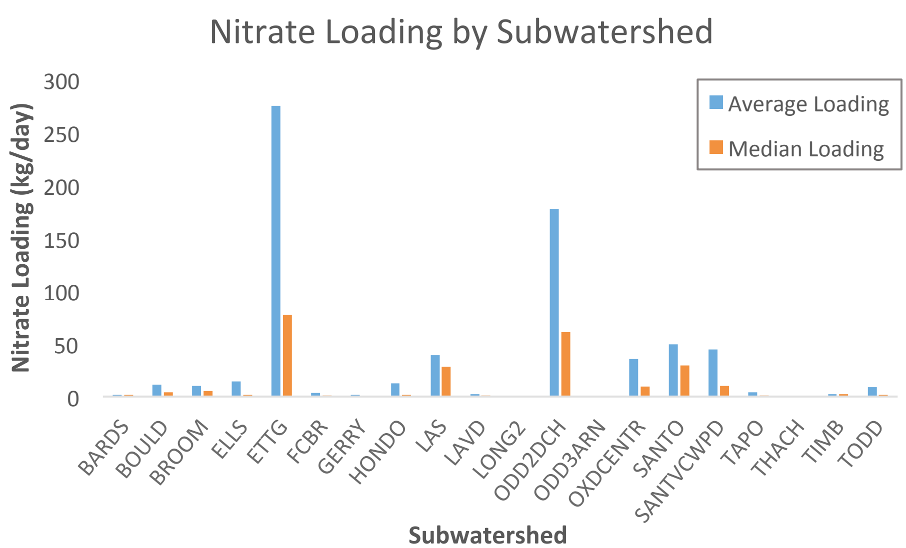

Figure 9. Average and median nitrate loading by sub-watershed in Ventura County, 2007-2014. Loading could not be calculated for sub-watersheds THACH and ODD3ARN because no flows were recorded during the period for which data was available.

The pesticide data is similarly difficult to interpret. The raw data in terms of number of total hits across all sampling sites on each sampling day does not appear to show a trend over time (Figure 10). A smoothed trend curve seems to show peaks in both pesticide categories around 2010 with a subsequent decline and return to levels similar to pre-2010 measurements. In the BMP data, adoption was only recorded as having occurred “before” or “after” October 2010, so there may be a correlation between the apparent decrease in number of hits and changes in BMP adoption. The absolute number of hits is not directly comparable between organochlorine and organophosphate models, as six organochlorine pesticides were analyzed while only two organophosphate pesticides were considered. After normalizing for the difference in number of pesticides, the maximum hits on a given day for organochlorine is reduced to twenty while the maximum number for organophosphate is twelve. Therefore, organochlorine pesticides had higher maximum number of hits in the time period studied.

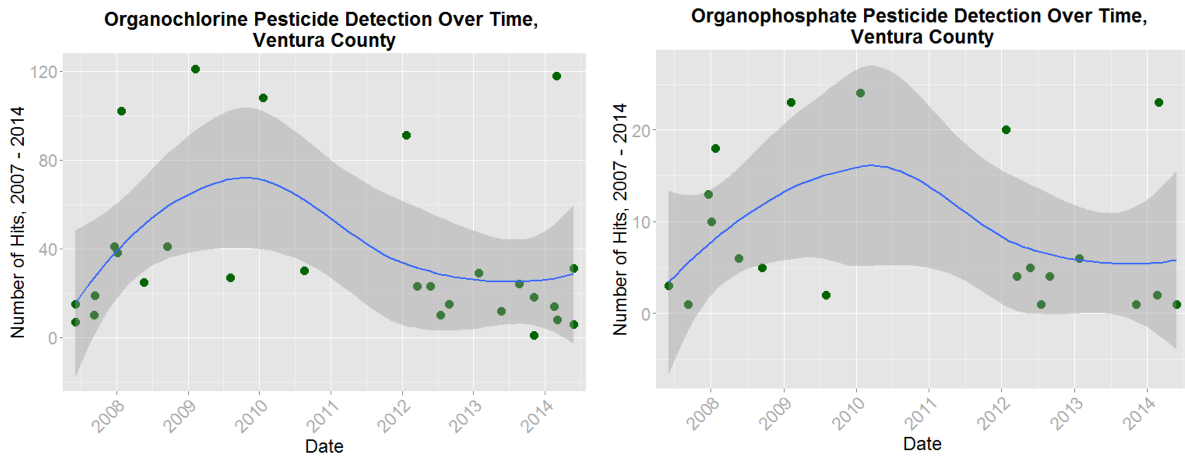

Figure 10. Number of pesticide hits summed across all sampling sites on each sampling date in Ventura County, with a LOESS-smoothed curve and 95% confidence interval.

Pesticide hit counts by sub-watershed also differ spatially, but within a smaller range than the nitrate parameters. Except for the BROOM sub-watershed, there seems to be a correlation between sites with high nitrate loading or concentration and high pesticide counts. ETTG, LAS, ODD2DCH, ODD3ARN, and SANTVCWPD all have high average nitrate concentrations and a high number of pesticide hits in both categories. Again, crop type may be responsible for the differences across sub-watersheds, as certain row crops such as strawberries require higher pesticide use.

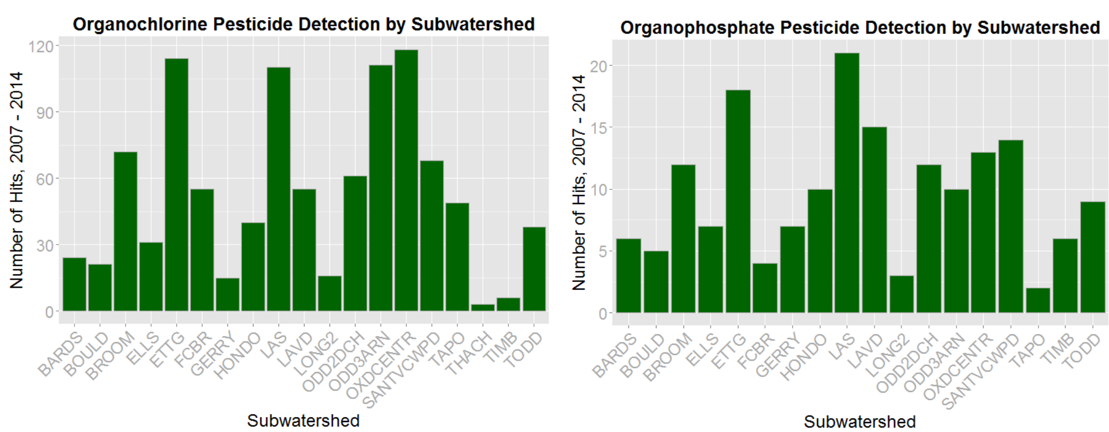

Figure 11. Total number of pesticide hits by sub-watershed for Ventura County.

Nitrate Models Results

The results indicate that while no BMPs had a statistically significant effect on nitrate loading, 12 BMPs had a significant effect on nitrate concentration. In addition, unobserved basin-specific characteristics (captured in the sub-watershed categorical variables) were shown to significantly affect nitrate concentration. No climatic variables were significant in either the nitrate concentration or loading models.

Most models did not show BMPs to have a significant effect on the water quality outcome variables (Table 3). The nitrate concentration model outcome was significantly affected by many of the relevant BMPs, although the standard error values are generally large. It is important to remember that the BMP variables were input as percent adoption while the coefficients are scaled to integers. The coefficient values were scaled down by a factor of 100 so that they represent the increase or decrease in nitrate concentration expected from a 1% increase in adoption.

Because the results are inconclusive, these statistical models should not be used to interpret BMP efficacy or predict the likely outcome of a future scenario. Instead, the models can help to reveal the direction and relative magnitudes of the relationships. BMP 10 (Irrigation decisions are made by trained personnel) appears to have had the largest negative effect on nitrate concentration. Surprisingly, several BMPs have positive and significant coefficients, meaning they are associated with an increase in nitrate concentration. All BMPs in theory should reduce nitrate concentration or have no effect. BMP 18 (Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills) has the largest positive effect.

The sub-watershed categorical variables also exhibit positive and negative effects, meaning that some watersheds would be expected to have higher nitrate concentrations while others would be lower simply because they are in different locations, even after controlling for climatic variables, crop type, and BMP adoption rates. The climatic variables and crop type had no significant effect on nitrate concentration. The nitrate loading model had no significant predictor variables. Precipitation on the day of monitoring was the closest, demonstrating a positive effect with $p = 0.0791$; this suggests that nitrate leaching from soils outweighs the dilution of the stream water. No other variables were close to significance in predicting nitrate loading.

Pesticide Models Results

The significant variables in the pesticide model are mostly in a different category than those of the nitrate concentration model. While no BMPs were significant predictors of organochlorine detection, two BMPs in the sediment management category were significant and positive for organophosphate detection. Climatic variables were also significant in both pesticide models. In the organochlorine model, the sub-watershed ETTG also showed significance. Evapotranspiration had the biggest negative effect on hit probability. The interaction between precipitation one and two days before sampling had the largest positive effect, although this was an order of magnitude smaller than that of evapotranspiration. The precipitation interaction term, representing the cumulative effect of precipitation one and two days prior to sampling, is significant. The interaction term is thus interpreted to mean that the full effect of precipitation the day before sampling is different if it also rained two days before sampling. The effect of yesterday's rain is decreased if it also rained two days ago because the interaction term is positive, while yesterday's precipitation term is negative. So, if precipitation two days before sampling is high enough, the cumulative effect on detection could be positive. Flow rate and humidity had very small positive effects. As for the organophosphate model, evapotranspiration had a large effect while precipitation the day before sampling had a small effect. These results are very similar to the organochlorine model, except the evapotranspiration effect is of twice the magnitude.

Table 3. Multiple regression linear models predicting nitrate concentration, nitrate loading, and the probability of organochlorine and organophosphate hits. Variables significant at the 0.05 level in each model are shown.

Dependent Variable	Significant Independent Variables	Description	Coefficients (scaled to 1%)	Standard Error	P value
Nitrate Concentration (mg/L)	BMP2	Irrigation distribution uniformity tested at least every 5 years	-12.73	6.173	0.0409
	BMP3	Regular maintenance of irrigation system is performed	-31.71	12.73	0.0138
	BMP6	Soil moisture is measured using any of the following: sensors, tensiometers, probes, irrigation monitoring service	-17.66	8.423	0.0376
	BMP9	Water use for plant establishment has been reduced by adopting more efficient irrigation methods	51.55	21.30	0.0167
	BMP10	Irrigation decisions are made by trained personnel	-75.57	33.06	0.0236
	BMP11	Salt leaching is performed only when necessary, as determined by measuring soil solution electrical conductivity	-4.952	2.498	0.0493
	BMP12	Soil or leaf/petiole tests are conducted to determine fertilization needs and the minimum amount necessary is applied based on the results	-13.20	5.30	0.0138
	BMP13	Fertilizer applications are split into multiple smaller applications to maximize plant uptake	30.20	12.29	0.0151
	BMP16	Fertilizer applications are adjusted to account for other nutrient sources, such as: irrigation water, cover crops, and residuals from previous fertilizations	34.98	15.93	0.0296
	BMP17	Fertilizer decisions are made by trained personnel who understand nutrient management	-33.46	14.19	0.0197
	BMP18	Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills	69.79	30.00	0.02132
	BMP19	Backflow prevention devices are installed and maintained	-22.55	9.567	0.0197
	BOULD	Subwatershed code	-11.63	5.005	0.0215
	BROOM	Subwatershed code	14.95	6.287	0.0187
	ELLS	Subwatershed code	2.665	1.163	0.0233
	ETTG	Subwatershed code	12.71	4.938	0.0110
Nitrate Loading (kg/day)	Precip	Precipitation, day of sampling, (in)	4.230	2.393	0.0791*
Organochlorine Pesticides (Probability of detection)	Flow	Flow during sampling (cu. ft/s)	0.00001355	0.000004119	0.00101
	Eto	Evapotranspiration, (in)	-0.01565	0.002095	<<0.001
	Precip1	Precipitation, day before sampling (in)	-0.001084	0.0002162	<<0.001
	PrecipInt	Precipitation, interaction between day before and two days before (in²)	0.001020	0.0004425	0.02125
	AvgRelHum	Average relative humidity (%)	-0.00003026	0.000009912	0.00229
	ETTG	Subwatershed code	-0.02133	0.0001074	0.04711
Organophosphate Pesticides (Probability of detection)	Eto	Evapotranspiration, (in)	-0.03032	0.005039	<<0.001
	Precip1	Precipitation, day before sampling (in)	-0.001066	0.0005305	0.0451
	BMP24	Berms, culverts, or flow channels are in place to divert water away from roads. These devices or structures are maintained to preserve their functionality.	0.1684	0.08157	0.0396
	BMP26	Non-cropped areas with bare soil are protected from erosion with any of the following: vegetation, mulch, gravel, water diversion	0.2389	0.1210	0.0490

*This was the closest variable to significance for the nitrate loading model.

Discussion

Effectiveness of BMPs

Based on the results, one cannot conclude that BMPs as a whole have an effect on nitrate concentration or loading of surface waters. The nitrate loading model showed no significant independent variables; it is therefore necessary to reject the null hypothesis that the considered factors have a detectable effect on nitrate loading. The nitrate concentration model is more difficult to interpret. The sub-watershed effects on nitrate concentration can be interpreted to mean that some sampling sites will have higher or lower nitrate concentration than others, controlling for all of the other independent variables in the model. This conclusion is straightforward, but not useful to recommend specific BMP actions to farmers because the site of a given field is fixed.

While eight of the significant BMPs showed the predicted result of a negative effect on nitrate concentration, four had a positive effect. Any potential mechanisms for these positive effects remain elusive, casting doubt on the validity of all the model results. For example, BMP 18 (Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills) would be expected to have either a small negative effect or no effect on nitrate concentrations, but it exhibits a strong positive effect. Conversely, BMP 19 (Backflow prevention devices are installed and maintained) could be expected to have a very small or no effect on nitrate concentration, but it displays a strong negative effect. It could be possible that a given BMP is adopted more frequently in areas where farmers know there are higher nitrate concentrations, resulting in the observed positive correlations. Controlling for each sub-watershed, however, should help to eliminate this counterintuitive result.

It is worth noting that three out of the six nutrient management BMPs had positive effects on nitrate concentration while only one out of six irrigation and salinity management (12 – 19) BMPs showed a positive relationship. This observation may hint that water use and management is more important than fertilizer management. In terms of water quality, it may be more important to manage runoff from irrigation than fertilizer use. Alternatively, the extra focus on fertilizer use from adopting BMPs could correlate with more usage and subsequently more runoff. The lack of a consistent theoretical framework to explain contradictory results prohibits the endorsement of any specific BMP adoption recommendations to reach surface water nitrate concentration reduction benchmarks.

Of the pesticide models, only organophosphate displayed a significant effect of BMPs on detection. The lack of significant BMPs in the organochlorine model can be explained by the fact that these pesticides are no longer legal for application in the U.S. Therefore, any effect of the BMPs is likely to be hidden by the random detection of chemicals which are no longer used. The sediment management BMPs could theoretically be effective in reducing detection of legacy pollutants, but no evidence supporting this hypothesis was seen. In the organophosphate model, two BMPs were identified as statistically significant; both significant BMPs were positive and of large magnitude. This result is not consistent with theory and is therefore difficult to interpret. In light of data gaps within the study, there is a strong possibility that a lack of data produced confounding results. Based on results, it is necessary to reject the hypothesis that BMPs affect the detection of both legacy pollutants and the organophosphate pesticides still actively applied.

Effect of Environmental Variables

Evapotranspiration was strongly negative and significant in both pesticide models, albeit twice as large in the organophosphate model. This suggests that there is an underlying mechanism between evapotranspiration and pesticide detection extending beyond the effects of the other variables controlled in the model. It is possible that increased evapotranspiration requires more irrigation to compensate for the water loss, leading to more dilute streamwater and a lower probability of pesticide detection.

Likewise, precipitation on the day before the sampling has a negative effect on pesticide detection in both models, supporting the dilution hypothesis. Alternatively, precipitation the day before may create an initial disturbance that "pre-washes" away sediments with sorbed contaminants. By the time monitoring occurs on the subsequent day, there may be less to detect.

Flow shows a weakly positive coefficient in the organochlorine model. A higher flow rate can often signify greater disruption and mixing of sediments. Turbulence increases mixing potential and likely re-suspends remaining or recently mobilized sediments during events with more turbulent flow. This might make detection more likely.

Spatial Interpretation

Nitrate concentration was shown in the regression models to be significantly correlated with specific locations. Nitrate loading was not correlated with any locations, but spatial heterogeneity did exist. Some of this spatial variation was conventionally attributed to the type of crop grown in one area versus another. Row crops like strawberries or tomatoes are annual plants, typically requiring new planting and intensive chemical inputs every year. Tree crops like avocados and oranges are planted once and produce for many years, requiring less intensive chemical input. The analysis, however, does not support this conclusion. ETTG was over 85 percent tree crops while ODD2DCH was over ninety nine percent row crops during the years studied. However, they both demonstrate high nitrate loading and concentration values (Figures 8 and 9). It appears that unobserved factors relating to characteristics of the land but extending beyond crop type are more important in predicting nitrate levels in surface water.

The pesticide data in Figure 10 is also spatially complex. The coefficient for ETTG was negative yet it showed one of the highest hit counts. The total hits are likely to have been lower than the expected total given the influence of other variables. Furthermore, the pesticide categories appear highly correlated by location. This could be evidence that some watersheds are simply more intensively farmed and use more chemical inputs, or, in the case of organochlorine legacy pollutants, were farmed more intensely in the past. However, without more detailed farming practices data, it is impossible to confirm whether or not farming intensity is driving these trends.

Data Deficiencies

Despite access to a solid record of VCAILG monitoring program water quality data, data quality and quantity problems still hampered the analysis. As only two BMP adoption farmer surveys were available, BMP adoption data was limited to only two time periods: pre- and post-October 2010. Sampling for water quality was more frequent in the earlier time period, with an average of 6.7 samples per site, versus the later period, with a 4.95 average. Two sites recorded zero samples in the later period, while only one recorded zero samples in the earlier period.

Samples are only required four times per year under the 2010-2015 Conditional Waiver, with two samples during dry weather and two during wet weather. Equal data collection in wet and dry conditions is inherently unreflective of the actual environment at any given time in a dry, less variable ecosystem like Ventura County. For example, while dry events samples are expected to demonstrate significantly less variability than those taken during wet events, the lack of precipitation throughout the recent drought has often prevented the collection of wet event samples; this limits the quantity of data available during highly variable inclement weather. LWA and VCAILG satisfy the compliance conditions for twenty sites, but at this point there is simply not enough data to estimate a robust linear regression model, given the significant spatial, weather, and other variability across the county. Less plentiful data in the most recent years makes it more difficult to observe a significant change in any of the water quality variables that may be attributed to an increase in BMP adoption. Some sites were severely data-limited, likely due to the absence of wet events that could be sampled in some years; seven of the twenty sampling sites had less than seven observations spread across the seven years in question.

BMP data limitations also contributed to the mixed results. The survey data reveal the heterogeneous adoption of BMPs across each sub-watershed. Sampling stations are capturing all of the upland variation between watersheds also in addition to the uneven adoption of BMPs. A great majority of BMPs had strongly skewed or bimodal adoption distributions. Figure 12 shows histograms for the significant BMPs in the nitrate concentration regression across the early and later periods. BMPs 3, 9, 10, and 12 - 19 are highly skewed toward full adoption, while BMPs 2, 6, and 11 are bimodal with high frequencies at the very low and very high adoption rates. The general lack of low to mid-range adoption rates makes evaluating relationships difficult. If the majority of adoption rates are high, these variables will not be able to explain variation in water quality observations. Essentially, the results are unable to provide confidence in the regression's predictive capability because of the lack of observations across the full spectrum of possibilities.

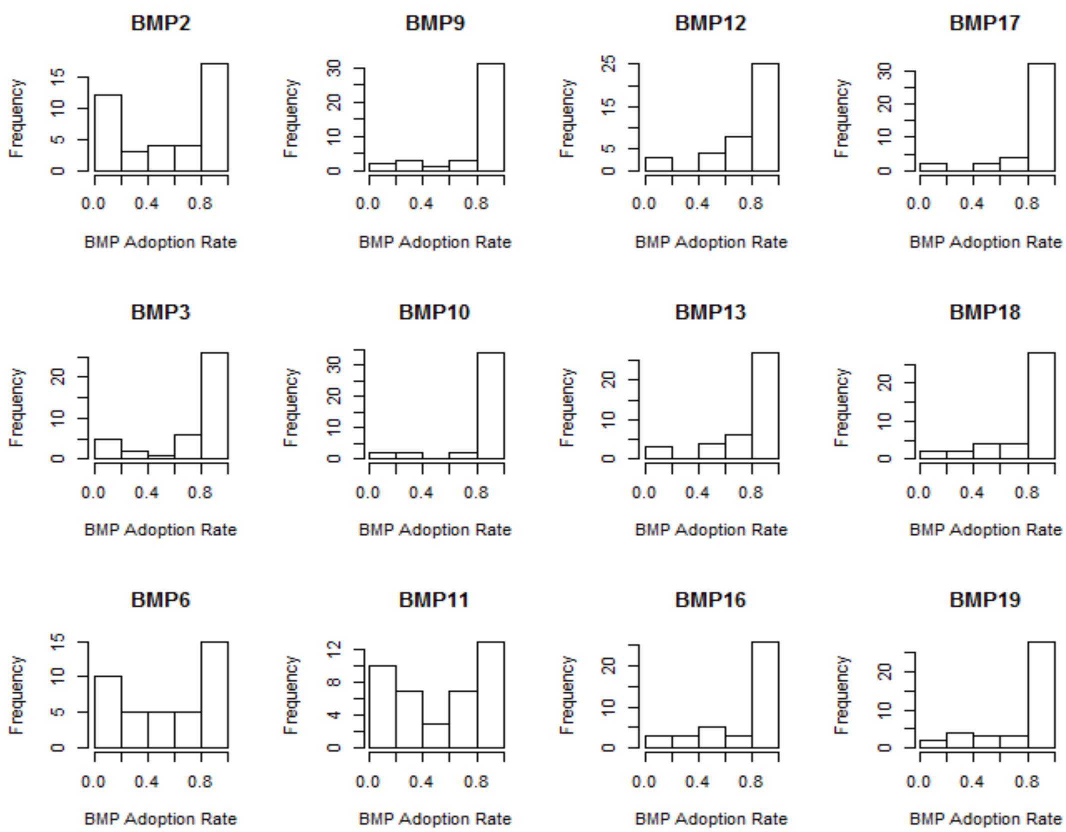

Figure 12. Adoption rate and frequency for significant BMPs in the nitrate concentration regression.

Along with a lack of low adoption BMP observations, the format of the BMP data was restrictive to conducting analyses useful to the Farm Bureau and VCAILG. As previously mentioned, data from two farmer surveys was available. This creates only two points in BMP adoption rates before and after a single point in time: October 2010. The selection of this point in time was arbitrary and had more to do with the timing of the Conditional Waiver's implementation stages rather than any specific point in history relevant to BMP adoption.

While the two surveys offer before and after adoption rates, they do not specify when exactly BMP adoption occurred. A change in BMP adoption may have happened at any point between November 2010 and November 2014, or incrementally across the whole time period. Likewise, in the before condition, it is not known whether the farmer was practicing a BMP since the land was first farmed or began to right before the survey question was asked. These complications add measurement error that cannot be accounted for in the regressions, decreasing data quality and reliability. The actual changes in adoption rates were also very minimal, as seen in Figure 13. Zero-percent changes in adoption rate are seen across the vast majority of BMPs. This suggests that farmers do not seem to be changing practices in response to the conditional waiver or in the pursuit of further water quality improvements; it is important to note, however, that the CWP requires adoption, and it is known that the CWP and Farm Bureau and UCCE grower education initiatives have, in fact, fostered greater rates of BMP adoption. Again, the predictive power is limited as there is little to no change in adoption rates; an increase or decrease along with a change in water quality would assist in correlating the two variables.

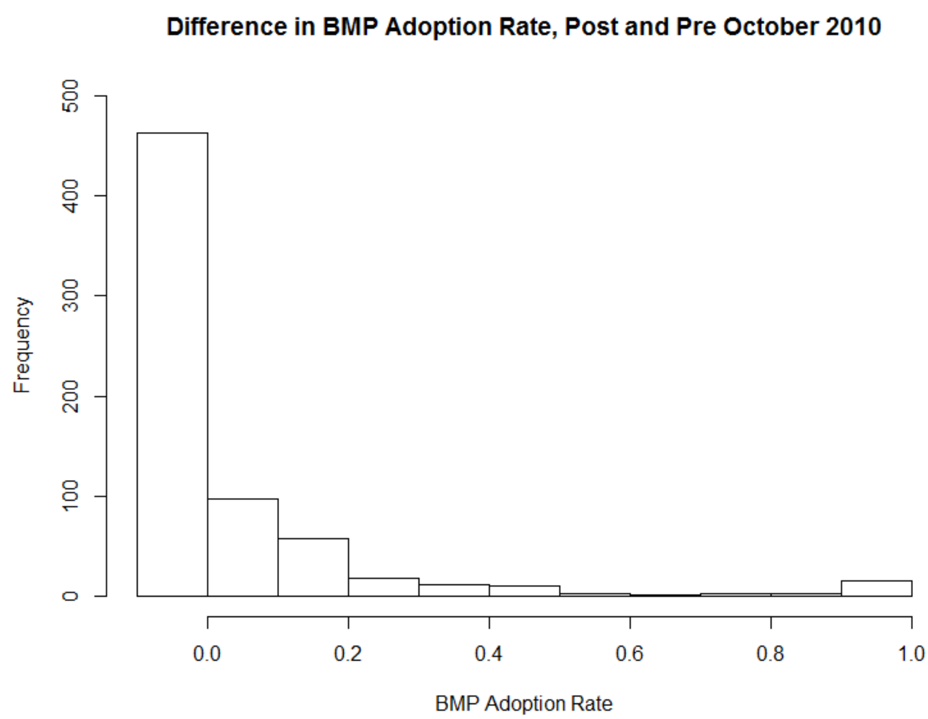

Figure 13. Difference between BMP adoption rate in the post-October 2010 and pre-October 2010 surveys for all BMPs and all sites.

Several sources of data highly relevant to this project were unavailable for use. Irrigation and nitrate application rates are clearly essential to any model attempting to predict nitrate runoff. While optimal irrigation rates for different weather conditions are available for some crops, actual water usage is not collected at a farm-level. Recommended nitrate usage for some crops has been documented, but not for the full diversity of crops grown in Ventura County. Moreover, each farmer may choose to use more or less nitrate fertilizer based on atmospheric conditions and his or her own understanding of the land. The same is true for pesticide application. This data would have greatly improved the predictive capacity of the models and helped to explain water quality variation. A higher volume of data for the underrepresented sample sites and a greater spread of data overall would have also improved the quality of the statistical analysis.

Final Recommendations

Inconclusive results of the technical analysis identify several critical data limitations:

- **Inconsistent and infrequent water quality monitoring data make it difficult to observe a significant change in any of the water quality parameters that may be attributed to an increase in BMP adoption.** Water quality sampling is only required four times per year under the 2010-2015 Conditional Waiver, with two samples required annually during dry weather events, and two during wet weather events. Equal data collection in wet and dry conditions does not reflect the actual environment, and substantially more variability is expected during wet weather storm events in a dry, Mediterranean ecosystem like Ventura County. While dry weather events are likely accurately represented in the two dry weather monitoring events, it is less clear that this is true during wet weather events. Additionally, some sites were severely data-limited, and unable to be appropriately assessed; seven of the twenty sampling sites had less than seven observations spread across the seven years of monitoring data; a higher volume of data for the underrepresented sample sites and a greater spread of data overall would have also improved the quality of statistical analysis. Though continued monitoring over time will provide a more robust dataset, current rates of data collection inhibit the predictive ability of the statistical models and prohibited the determination of individual BMP effectiveness.

- **BMP adoption data displays too little variability to allow accurate predictive ability.** Despite seven years of monitoring data, BMP adoption rates were only identifiable through one survey providing estimates of percentage BMP implementation by drainage area before and after a single point in time, October 2010. A great majority of BMPs had strongly skewed or bimodal adoption distributions; the general lack of low to mid-range adoption rates makes it difficult to explain variation in water quality. The absence of yearly BMP adoption rate data and its aggregated nature also reduced the predictive ability of statistical models.

- **Several sources of data that are highly relevant to the project were unavailable for use**. Irrigation and nitrate application rates are essential to any model attempting to predict nitrate runoff. While optimal irrigation rates for different weather conditions are available for several crops, actual water usage is not collected or reported at a farm-level. Recommended nitrate usage for some crops has been documented, but not for the full diversity of crops grown in Ventura County. Moreover, each farmer may choose to apply more or less fertilizer or pesticide based on his or her own understanding of the land. These data would have greatly improved the predictive capacity of the statistical models and helped to provide valuable explanations for water quality variation.

Each of the above listed components contributes to data limitations; any resulting products of quantitative research are therefore expected to be inconclusive, or otherwise confounded by data scarcity. This limits the ability of both regulators and voluntary program participants to accurately assess CWP effectiveness in improving regional water quality.

It is therefore recommended that the Ventura County Farm Bureau and VCAILG adhere to the following four point plan to augment data collection efforts, implement an additional nutrient management strategy, and mitigate private costs by applying for federal grant funding for non-point source water quality improvement programs.

The AgVentura Four Point Plan

The four-point plan provides a framework allowing the Farm Bureau and VCAILG to suggest modifications to the CWP in the upcoming waiver negotiation cycle. The purpose of these recommendations extends beyond assessing BMP efficacy or assessing program effectiveness; recommendations are instead designed to inform stakeholders of the information required to collect data necessary to monitor and manage water quality in Ventura County waterways impaired by irrigated land runoff.

(1) The Farm Bureau and VCAILG should augment and enhance the water quality monitoring program.

An effective monitoring program is essential when managing diffuse pollution from non-point sources (B. M. Dowd et al., 2008a; Easton, 2008; C. N. Smith et al., 1985; Strobl & Robillard, 2008). Although Ventura County growers have been proactive, progressive, and demonstrate high rates of compliance with CWP requirements, the provisions of the CWP itself do not fully require a holistic or comprehensive approach to water quality monitoring. It is critical when designing a monitoring framework that the program be designed with purpose, designed for efficiency, and redesigned in accordance with proper operation and maintenance to provide the most reliable water quality data, and therefore provide statistical power necessary when evaluating the efficacy of the CWP and grower compliance measures (B. M. Dowd et al., 2008a; Easton, 2008; C. N. Smith et al., 1985; Strobl & Robillard, 2008). The following suggestions are tailored to enhance VCAILG's current water quality monitoring program and inform the actions of the Farm Bureau and LARWQCB:

- **Monitoring should be designed to focus more heavily on times of high relative climate variability, such as storm or "wet" events.** Ventura County's dry, Mediterranean climate suggests that most dry season runoff tends to be due to inefficient agricultural irrigation (Brauer et al., 2009; Merhaut et al., 2013; UCCE Agriculture & Natural Resources, 2009b). In less climatically variable watersheds, steady nutrient and pesticide application rates tend to generate less variable mass loads into waterways (Brauer et al., 2009). Assuming relatively consistent dry season irrigation practices, concentrations detected during dry season events are expected to be fairly consistent within an individual sub-watershed or drainage area. Total pollutant loading during dry events is expected to be less do to a low flow rate, assuming proper irrigation management is designed to minimize runoff.

- **It is therefore important to establish a baseline average and range of pollutant concentrations for each sub-watershed during dry seasons.** Average concentration will provide a useful metric to evaluate pollutant loading without the need for continuous monitoring throughout the dry season; a dry season baseline will allow a reduction in monitoring frequency, and allow the focus of water chemistry monitoring to be placed upon the variable wet season. Identifying and understanding variability in pollutant concentration will assist both LARWQCB and VCAILG in quantifying uncertainty and adjusting TMDL benchmarks in future Conditional Waiver cycles.

- **Relatively more water chemistry monitoring should be conducted during variable wet seasons, and a baseline average and range of pollutant concentrations should be established for each sub-watershed during wet seasons.** During wet events with high runoff rates and/or high dilution, it is beneficial to monitor fluctuations and variability in both concentration and flow rate more frequently, thereby ensuring that the total load is accurately reflected, and loading is not over or underestimated (Brauer et al., 2009; Reinelt, Horner, & Mar, 1988; Telci et al., 2009).

- **More frequent flow rate monitoring is necessary to accurately track and estimate pollutant loading in both wet and dry seasons.** Currently, flow rate measurements are only recorded at the time of monitoring, and there is no record of flow rate variability over time. As flow varies with season, climate, and irrigation rates, total loading in receiving waterways is dependent on both flow rate and pollutant concentration. For this reason, concentrations may not be accurately reflecting total daily pollutant loading. Therefore, in order to better monitor total pollutant loading over time, more continuous measurements of flow rate should be taken throughout the day of a monitoring event. This is especially true for wet events, which are expected to see higher degrees of fluctuation for pollutant concentrations and flow rate. Additionally, it is necessary to provide estimates of flow rate during high-flow storm events; many high flow events in recent years have not been measured, because flow was too high and represented a danger to samplers. It is especially important to measure flow in high events, as loading is expected to be higher during high-flow events. Observations may then be used to generate an average flow rate and more accurate total daily load estimates. Additional flow rate monitoring throughout the course of a year will provide observations that will allow VCAILG to use previously obtained or average concentrations to project loading throughout the course of the year. This "spot check" approach provides useful information that can be used at any point to compare total daily load estimates against TMDL benchmarks; such estimates can be employed at any time to evaluate grower compliance outside of regulator-mandated water quality monitoring events. If functional pollutant concentration baselines and ranges are established, additional flow monitoring may provide much more accurate estimates of pollutant loading. Additionally, flow monitoring is substantially cheaper than water chemistry monitoring, and offers an opportunity to better understand true pollutant loading in less climatically variable watersheds.

- **Use hydrological data to determine likely pollutant lag times, and monitor at peaks and lows.** Understanding hydraulic transport and lag times associated with pollutant diffusion will help provide a more accurate picture of actual pollutant loading; maintaining an understanding of pollutant transport processes will also allow VCAILG to identify regional "hot spots," and adjust monitoring to focus on areas/pollutants of specific concern to a particular drainage area. Lag time data will also serve to provide a more in-depth picture of true pollutant loading over time, allow for monitoring during critical moments, and enable quantitative analyses to adjust for delays, thereby improving the predictive power of models.

- **Develop a combined monitoring and modeling approach for specific pollutants of concern using SWAT or another viable model.** Targeting hydrologically sensitive areas, such as those with high erosion potential or in close proximity to reaches has been shown to effectively reduce runoff and pollutant loading (Easton, 2008; Rao & Easton, 2009). Modeling tools will prove useful and allow more predictive power as more data is collected. Though model operation and calibration is typically expensive and requires a high level of expertise, there are opportunities to conduct this analysis for a low cost. For example, development and application of a water quality or risk management model may constitute a viable Bren School group project in the near future, and such a project could be completed with minimal investment from the Farm Bureau or VCAILG.

- **It is recommended that the VCAILG monitoring program restructure reporting mechanisms away from measured concentrations and toward total daily loading.** TMDL requirements expressed as concentrations are less effective for agricultural non-point sources, as they are likely not reflective of true pollutant loading rates from sources without a consistent or well-monitored flow. While switching to a total loading-based approach requires additional monitoring of flow rate throughout the course of monitoring events (and ideally before and after), addressing total daily loads will account for concentration and dilution effects and thereby prevent the likelihood of false negatives or false exceedances. Accurately measuring flow rate over time is essential in order to properly integrate total mass loading and is more essential during wet events with high variability.

(2) The Farm Bureau should increase BMP survey frequency and broaden survey scope.

While the surveys used in this report provide a broad view of BMP adoption rates before and after October 2010, they do not provide the information required to track incremental BMP adoption over time. Although incremental BMP adoption has likely occurred throughout the past seven years, the vast majority of adoption rates see a zero percent change. This is likely due to significant adoption prior to October 2010, or inaccuracies found within grower survey responses. The binary division of practices pre- and post-October 2010 therefore generates significant uncertainty, decreases data reliability, and subsequently limits VCAILG's ability to prove program effectiveness. The following recommendations will improve future survey data collection efforts:

- **Future VCAILG surveys should be standardized to provide useful comparisons between years.** The two surveys provided by the Ventura County Farm Bureau and VCAILG ask very different questions, and responses are not comparable. Standardizing the survey format will allow for easier data consolidation and comparison.

- **Issue BMP surveys annually through an automated online format.** Annual online surveys will return up-to-date information in a standardized and useful format, allowing for a better understanding of true BMP adoption rates and current practices. More frequent survey data will also serve to inform the educational components of the CWP; more frequent responses will allow the Farm Bureau and VCAILG to develop program materials best fitting the current needs of members. Additionally, developing an online format will provide growers with a convenient and consistent survey and reduce administrative burdens on the Farm Bureau

- **Inquire about total irrigation quantities by crop in annual BMP survey.** Currently, there is no consolidated local database identifying irrigation quantity. Many common pollutants—like nitrates—are readily dissolved in and mobilized by water; estimating total irrigation quantity will enhance quantitative assessments evaluating of the relative impact of irrigation on pollution control. Climate in Ventura County suggests that irrigation quantity and efficiency is likely to have a significant effect on pollution output, especially during dry seasons (Brauer et al., 2009; UCCE Agriculture & Natural Resources, 2009b).

- **Surveys should also be designed to inquire about fertilizer types and soil amendments applied, local nutrient application rates, and total costs of fertilization.** The most useful data would be obtained by inquiring what type and how much of each fertilized type is distributed to each acre of each specific crop. Supposing this level of detail is not manageable, more general information on these practices would still be highly beneficial. Responses would provide necessary material input data for each sub-watershed, and could potentially create a valuable data consolidation tool for growers throughout California's Central Coast. Studies suggest that individuals are influenced by the actions of their respective neighbors (Beckman, 2012); tracking grower conservation activities through surveys would allow VCAILG to set specific management goals for growers based upon the actions of their respective neighbors.

- **Identify the quantity of pesticides actually applied on a farm-by-farm basis, relevant pesticide application rates by crop, and the total costs associated with application.** Although many currently used pesticides are not regulated by a specific TMDL benchmark, gathering this data will allow the Farm Bureau and VCAILG to identify potential hot spots for contamination and anticipate necessary management practices prior to TMDL implementation.

- **Include questions inquiring about annual BMP implementation expenses.** This will provide a picture of local practices and relative expense. Ultimately, once individual BMP efficacy is identified, this information can be used to generate a BMP cost-benefit analysis.

- **Surveys should inquire about the degree of implementation for each BMP.** Current survey design presupposes that if a BMP is implemented, it is 100% efficient and functioning on 100% of applicable acres. Acquiring more detailed information will assist VCAILG in determining true BMP efficiency and implementation rates.

- **Survey design may be conducted as part of future Bren group projects.** This would provide valuable information from Ventura growers, and potentially gather and consolidate much-needed information on local fertilizer and pesticide application rates and BMP costs. Working with the Bren School also allows for thorough survey development at little or no cost to the Farm Bureau and VCAILG.

(3) Encourage development of nutrient management plans to decrease nitrogen pollution, estimate nutrient uptake efficiencies, and model pollutant fate.

VCAILG is required under the CWP to monitor and reduce agricultural impacts to surface waters. Nitrate contamination is widespread across the Calleguas Creek and Santa Clara watersheds, and statistical analysis of BMP effectiveness in controlling diffuse nitrate pollution is inconclusive. It is recommended that the Ventura County Farm Bureau and VCAILG employ nutrient management planning as a new BMP in priority sites. The farm-to-gate budget approach will likely provide the most reasonable nutrient management framework, given limited access to data and the overall purpose of reducing inputs to maximize yield while minimizing risks.

- **It is recommended that the farm-to-gate approach be used as VCAILG's nutrient management planning framework.** The farm-to-gate approach provides an easily standardized framework that eliminates soil surface and system processes largely irrelevant to surface water quality at points of discharge. The relatively smaller scope of the farm-to-gate approach allows VCAILG to acquire and cross reference data by way of grower self-reporting of application and expenditures.

- **The first year of farm-to-gate nutrient management plan implementation can be useful in establishing a baseline for future reductions.** This allows growers to vocalize specific concerns surrounding risk management through over application of nutrients. A progressive nutrient management plan should begin after baseline establishment, and subsequently set reduction targets in respect to appropriate risk management strategies employed to protect crop yields.

- **Effective nutrient management planning encourages efficient fertilizer application, decreasing grower expenditures on synthetic fertilizers and incorporating uncertainty and grower risk into the framework.** The point is not to deprive farmers of their nutrient safety nets, but rather to enhance crop nutrient uptake efficiency, increase yields while decreasing expenditures, and minimize environmental impacts. This approach is already underway in the Central Coast RWQCB, and is likely to be a common BMP in the next decade (Amon-Armah et al., 2013; Öborn et al., 2003).

- **There are two primary data challenges to building a farm-level nutrient management plan: (1) the wide variability between true and reported chemical composition of fertilizers, and (2) the accuracy of information supplied by growers** (Öborn et al., 2003)**.** Obtaining this information is critical to constructing a useful nutrient management plan. Data obtained through the annual VCAILG BMP survey and site visits will allow growers in each sub-watershed to compare their practices with those of their neighbors and make appropriate adjustments.

The farm-to-gate approach provides a nutrient management tool that characterizes and accommodates an "acceptable" level of risk management by determining the deficits between input, output, and soil storage (Beegle et al., 2000; Öborn et al., 2003). Soil surface nitrogen losses through ammonia volatilization are largely ignored in this approach in order to provide a conservative estimate of total potential nutrient loss from the system. Individual farm strategies can be compared, contrasted, and adjusted to accommodate the needs of farmers while minimizing environmental impacts.

(4) Further explore increasing institutional capacity at the Farm Bureau, and apply for federal funding through Clean Water Act Section 319 and Environmental Quality Improvement Program grants.

- **Multiple millions of dollars are allocated annually to non-point source water quality monitoring an improvement programs in California every year** (Copeland, 2006; B. M. Dowd et al., 2008a; GAO, 2000). In 2007 alone, $10.2 million was allocated to California projects through Clean Water Act Section 319; Environmental Quality Improvement Act funding reached $20 million that same year. Grant dollars could greatly alleviate monitoring costs and serve to greatly enhance VCAILG's current monitoring program at little or no additional cost; alternatively, funding could be used to mitigate current monitoring expenses. Adding a salaried employee to apply for and administer federal and state grants would lead to significant cost reductions to VCAILG members.

Conclusions

This project signifies a novel attempt to evaluate and determine the usefulness of data gathered under the Ventura County CWP's monitoring requirements; evaluation of these data simultaneously represents a critique of Conditional Waiver requirements, and provides constructive recommendations to VCAILG and its regulating body, the Los Angeles Regional Water Quality Control Board.

The CWP in Ventura County has effectively fostered an organized, engaged response from irrigated land farmers. The current nature of the Farm Bureau/VCAILG voluntary program enables adherence to the law and encourages improved land management throughout the county while diffusing and reducing program administration costs across VCAILG's nearly 3,000 members (VCAILG, 2009; Ventura County Farm Bureau, 2015b). VCAILG has successfully complied with CWP requirements throughout all changes and developments, and the educational components of the Conditional Waiver have cultivated an understanding of water quality and ecological health amongst Ventura County farmers (Merhaut et al., 2013). Over the past 10 years, the CWP has mobilized a countywide voluntary grower response to reducing diffuse non-point source pollution; in this sense, the program constitutes a huge success.

However, current monitoring does not identify any success in reducing total pollutant loading. This problem is consistently seen throughout State Water Resources Control Board regions, and is not unique to Ventura County or the LARWQCB's approach (B. M. Dowd et al., 2008a). Water quality and BMP implementation data collected and organized by VCAILG is currently insufficient in quantity to associate any potential reduction in total pollutant loading with grower action. Additionally, several key factors are missing from CWP requirements, and subsequently, from VCAILG's data collection and water quality monitoring program. In this respect, current monitoring requirements under the CWP are less successful and constitute a heavy expense for little return. However, designing an effective set of non-point source monitoring requirements is difficult, takes time, and requires refinement and calibration to best represent regional needs (Copeland, 2012). Though monitoring requirements do not generate all necessary data, this should by no means suggest that the program is unsuccessful or unwarranted; these findings should instead suggest that monitoring requirements under the Ventura County CWP must be realigned to provide the most useful data possible under an economically feasible program budget.

Results of the statistical analysis discussed in this report are inconclusive. Analysis of Ventura County water quality data acquired under the CWP is limited by inconsistent and infrequent data collection, inadequate BMP adoption data, and unknown values for irrigation quantity, nutrient and pesticide application rate, and continuous in-stream flow rate. Each of these data restrictions limits the ability of both regulators and VCAILG to accurately evaluate CWP success, determine BMP effectiveness, or analyze changes in water quality.

In order to move forward and improve regional water quality in the face of data limitations, it is recommended that the Farm Bureau and VCAILG act to: (1) Augment and enhance the current water quality monitoring program, (2) Increase the frequency and scope BMP surveys, (3) Encourage development of farm-to-gate nutrient management plans, and (4) Explore opportunities for federal grant funding through Clean Water Act Section 319 and Environmental Quality Improvement Program to supplement current and future monitoring program costs.

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Appendix A: Complete Regression Tables

Table A1. Full coefficient table for multiple regression linear model predicting nitrate concentration. Variables significant at P= 0.05.

Dependent Variable: Nitrate Concentration (mg/L)				
Significant Independent Variables	**Description**	**Coefficients (scaled to 1%)**	**Standard Error**	**P value**
(Intercept)		19.13	7.288	0.00956
Flow	Flow during sampling (cu. ft/s)	-0.0005595	.001824	0.7595
Eto	Evapotranspiration, (in)	-1.335	0.08633	0.1240
Precip	Precipitation, day of sampling (in)	-0.1975	0.01754	0.2620
Precip1	Precipitation, day before sampling (in)	-0.06694	0.01027	0.5157
Precip2	Precipitation, two days before sampling (in)	-0.07821	0.02930	0.7899
PrecipInt	Precipitation, interaction between day before and two days before (in^2)	0.02727	0.01859	0.8836
AvgRelHum	Average relative humidity (%)	0.0007559	0.002133	0.7235
BMP1	Sprinkler irrigation runoff is captured or kept on the property	-9.511	6.072	0.1193
BMP2	Irrigation distribution uniformity tested at least every 5 years	-12.73	6.173	0.0409
BMP3	Regular maintenance of irrigation system is performed	-31.71	12.73	0.0138
BMP4	Pressure regulators or pressure compensating emitters are used.	11.92	9.076	0.1909
BMP5	Sprinkler heads and drip emitters of the same flow rate are used within each block and replaced with the same heads or emitters, when necessary.	-6.190	10.92	0.5715
BMP6	Soil moisture is measured using any of the following: sensors, tensiometers, probes, irrigation monitoring service	-17.66	8.423	0.0376
BMP7	Flow meters are used to measure actual water use and are coupled with known crop use values or other measurements to match irrigation to plant needs.	5.429	3.234	0.09530
BMP8	Irrigation water quality is tested for parameters of interest: Nitrate, pH, electrical conductivity (EC), sodium, chloride, bicarbonate, boron	-1.465	3.140	0.6415
BMP9	Water use for plant establishment has been reduced by adopting more efficient irrigation methods such as: Early drip use, intermittent sprinklers, micro-sprinklers	51.55	21.30	0.0167
BMP10	Irrigation decisions are made by trained personnel	-75.57	33.06	0.0236
BMP11	Salt leaching is performed only when necessary, as determined by measuring soil solution electrical conductivity	-4.952	2.498	0.0493
BMP12	Soil or leaf/petiole tests are conducted to determine fertilization needs and the minimum amount necessary is applied based on the results	-13.20	5.30	0.0138
BMP13	Fertilizer applications are split into multiple smaller applications to maximize plant uptake	30.20	12.29	0.0151
BMP14	Fertilizer levels in fertigation water are tested to ensure that injectors are correctly calibrated.	3.644	3.612	0.3146
BMP15	Fertilizer applications are timed to consider irrigation and potential rain events.	-2.942	3.426	0.3918
BMP16	Fertilizer applications are adjusted to account for other nutrient sources, such as: irrigation water, cover crops, and residuals from previous fertilizations	34.98	15.93	0.0296
BMP17	Fertilizer decisions are made by trained personnel who understand the four Rs of nutrient management: Right fertilizer source, right rate, right time, right place	-33.46	14.19	0.0197
BMP18	Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills	69.79	30.00	0.02132
BMP19	Backflow prevention devices are installed and maintained	-22.55	9.567	0.0197
Tree	Sprinkler irrigation runoff is captured or kept on the property	0.5826	2.496	0.8158
BOULD	Irrigation distribution uniformity tested at least every 5 years	-11.63	5.005	0.0215
BROOM	Regular maintenance of irrigation system is performed	14.95	6.287	0.0187
ELLS	Pressure regulators or pressure compensating emitters are used.	2.665	1.163	0.0233
ETTG	Sprinkler heads and drip emitters of the same flow rate are used within each block and replaced with the same heads or emitters, when necessary.	12.71	4.938	0.0110
FCBR	Soil moisture is measured using any of the following: sensors, tensiometers, probes, irrigation monitoring service	0.9835	1.190	0.4099
GERRY	Flow meters are used to measure actual water use and are coupled with known crop use values or other measurements to match irrigation to plant needs.	-3.033	2.989	0.3118
HONDO	Irrigation water quality is tested for parameters of interest: Nitrate, pH, electrical conductivity (EC), sodium, chloride, bicarbonate, boron	-1.375	1.551	0.3768
LAS	Water use for plant establishment has been reduced by adopting more efficient irrigation methods such as: Early drip use, intermittent sprinklers, micro-sprinklers	1.927	1.425	0.1782
LAVD	Irrigation decisions are made by trained personnel	NA	NA	NA
LONG2	Salt leaching is performed only when necessary, as determined by measuring soil solution electrical conductivity	NA	NA	NA
ODD2DCH	Soil or leaf/petiole tests are conducted to determine fertilization needs and the minimum amount necessary is applied based on the results	NA	NA	NA
OXDCENTR	Fertilizer applications are split into multiple smaller applications to maximize plant uptake	NA	NA	NA
SANTO	Fertilizer levels in fertigation water are tested to ensure that injectors are correctly calibrated.	NA	NA	NA
SANTVCWPD	Fertilizer applications are timed to consider irrigation and potential rain events.	NA	NA	NA
TAPO	Fertilizer applications are adjusted to account for other nutrient sources, such as: irrigation water, cover crops, and residuals from previous fertilizations	NA	NA	NA

Note: "NA" indicates values that could not be calculated due to singularities within the model.

Table A2. Full coefficient table for multiple regression linear model predicting nitrate loading. Variables significant at P= 0.05.

Dependent Variable: Nitrate Loading (kg/day)				
Significant Independent Variables	**Description**	**Coefficients (scaled to 1%)**	**Standard Error**	**P value**
(Intercept)	Fertilizer decisions are made by trained personnel who understand the four Rs of nutrient management: Right fertilizer source, right rate, right time, right place	-64.42	234.57	0.7840
Eto	Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills	-8.630	12.32	0.4846
Precip	Backflow prevention devices are installed and maintained	4.230	2.393	0.0791*
Precip1	Sprinkler irrigation runoff is captured or kept on the property	0.07212	1.466	0.9608
Precip2	Irrigation distribution uniformity tested at least every 5 years	2.243	4.174	0.5918
PrecipInt	Regular maintenance of irrigation system is performed	-1.142	2.651	0.6672
AvgRelHum	Pressure regulators or pressure compensating emitters are used.	-0.01163	0.0340	0.7024
BMP1	Sprinkler heads and drip emitters of the same flow rate are used within each block and replaced with the same heads or emitters, when necessary.	-60.82	150.5	0.6868
BMP2	Soil moisture is measured using any of the following: sensors, tensiometers, probes, irrigation monitoring service	97.63	286.1	0.7334
BMP3	Flow meters are used to measure actual water use and are coupled with known crop use values or other measurements to match irrigation to plant needs.	-2.382	55.14	0.9656
BMP4	Irrigation water quality is tested for parameters of interest: Nitrate, pH, electrical conductivity (EC), sodium, chloride, bicarbonate, boron	40.74	164.5	0.8047
BMP5	Water use for plant establishment has been reduced by adopting more efficient irrigation methods such as: Early drip use, intermittent sprinklers, micro-sprinklers	-118.2	467.3	0.8006
BMP6	Irrigation decisions are made by trained personnel	42.89	88.94	0.6303
BMP7	Salt leaching is performed only when necessary, as determined by measuring soil solution electrical conductivity	17.56	76.06	0.8177
BMP8	Soil or leaf/petiole tests are conducted to determine fertilization needs and the minimum amount necessary is applied based on the results	10.60	55.20	0.8480
BMP9	Fertilizer applications are split into multiple smaller applications to maximize plant uptake	-140.0	372.2	0.7073
BMP10	Fertilizer levels in fertigation water are tested to ensure that injectors are correctly calibrated.	239.9	691.7	0.7292
BMP11	Fertilizer applications are timed to consider irrigation and potential rain events.	-9.268	65.68	0.8880
BMP12	Fertilizer applications are adjusted to account for other nutrient sources, such as: irrigation water, cover crops, and residuals from previous fertilizations	81.04	320.6	0.8007
BMP13	Fertilizer decisions are made by trained personnel who understand the four Rs of nutrient management: Right fertilizer source, right rate, right time, right place	-41.74	167.0	0.08030
BMP14	Fertilizers are stored where they are protected from rain and on an impermeable pad with a curb to contain spills	-34.80	105.63	0.7423
BMP15	Backflow prevention devices are installed and maintained	33.70	91.12	0.7120
BMP16	Sprinkler irrigation runoff is captured or kept on the property	-26.85	113.4	0.8131
BMP17	Irrigation distribution uniformity tested at least every 5 years	-24.07	68.32	0.7250
BMP18	Regular maintenance of irrigation system is performed	-143.3	331.5	0.6661
BMP19	Pressure regulators or pressure compensating emitters are used.	101.1	249.3	0.6856
Tree	Fraction of tree crops (%)	22.92	35.56	0.5202
BOULD	Subwatershed code	-11.63	5.005	0.0215
BROOM	Subwatershed code	14.95	6.287	0.0187
ELLS	Subwatershed code	2.665	1.163	0.0233
ETTG	Subwatershed code	12.71	4.938	0.0110
FCBR	Subwatershed code	-10.71	65.38	0.801
GERRY	Subwatershed code	27.12	115.0	0.8139
HONDO	Subwatershed code	-20.81	79.13	0.7929
LAS	Subwatershed code	-29.11	117.1	0.8039
LAVD	Subwatershed code	NA	NA	NA
LONG2	Subwatershed code	NA	NA	NA
ODD2DCH	Subwatershed code	NA	NA	NA
OXDCENTR	Subwatershed code	NA	NA	NA
SANTO	Subwatershed code	NA	NA	NA
SANTVCWPD	Subwatershed code	NA	NA	NA
TAPO	Subwatershed code	NA	NA	NA

* Designates the variable closest to statistical significance; this model did not predict any statistically significant variables within a 95% confidence interval.

Note: "NA" indicates values that could not be calculated due to singularities within the model.

Table A3. Full coefficient table for multiple regression linear model predicting the probability of organochlorine hits. Variables significant at P= 0.05.

Dependent Variable: Probability of Organochlorine Hit				
Significant Independent Variables	**Description**	**Coefficients (scaled to 1%)**	**Standard Error**	**P value**
(Intercept)		0.2332	0.1726	0.1767
Flow	Flow during sampling (cu. ft/s)	0.00001355	0.000004119	0.00101
Eto	Evapotranspiration, (in)	-0.01565	0.002095	<<0.001
Precip	Precipitation, day of sampling, (in)	0.0005791	0.0003441	0.09249
Precip1	Precipitation, day before sampling (in)	-0.001084	0.0002162	<<0.001
Precip2	Precipitation, two days before sampling (in)	-0.00008020	0.0006499	0.9018
PrecipInt	Precipitation, interaction between day before and two days before (in^2)	0.001020	0.0004425	0.02125
AvgRelHum	Average relative humidity (%)	0.00003026	0.000009912	0.00229
BMP20	Long runs of production area are broken up by access roads or buffer strips to reduce sediment movement	0.01206	0.03497	0.7302
BMP21	In sloped production areas, one or more of the following management practices is used to minimize erosion: Contour farming, contoured buffer strips, terracing	0.0004356	0.01450	0.9760
BMP22	Bare soil is minimized through use of cover crops, mulch, leaving plant debris, or planting subsequent crops, and the soil cover is replenished periodically to maintain effectiveness	0.01564	0.01810	0.3876
BMP23	Soil amendments, such as polyacrylamide (PAM), are used to reduce sediment movement and retain water	-0.001028	0.003322	0.7569
BMP24	Berms, culverts, or flow channels are in place to divert water away from roads. These devices or structures are maintained to preserve their functionality	0.05651	0.09584	0.5555
BMP25	Road erosion is minimized by use of any of the following: Grading, gravel, grass, mulch, water bars, drains	-0.003326	0.01021	0.7447
BMP26	Non-cropped areas with bare soil are protected from erosion with any of the following: Vegetation, mulch, gravel, water diversion	0.01043	0.03896	0.7889
BMP27	Ditch banks are protected from erosion with vegetation, rock placement or geotextiles	-0.3653	0.3159	0.2476
BMP28	One or more of the following is in place to treat runoff before it leaves the property: Grassed waterways, vegetated filter strips, sediment traps, tailwater recycling systems	-0.01432	0.02045	0.4836
Tree	Fraction of tree crops (%)	-0.005635	0.005573	0.3121
BARDS	Subwatershed code	-0.1725	0.1816	0.3423
BOULD	Subwatershed code	0.04293	0.04631	0.3540
BROOM	Subwatershed code	-0.1153	0.08556	0.1778
ELLS	Subwatershed code	0.03120	0.03631	0.3903
ETTG	Subwatershed code	-0.02133	0.01074	0.04711
FCBR	Subwatershed code	0.07276	0.07959	0.3601
GERRY	Subwatershed code	0.04871	0.05386	0.3658
HONDO	Subwatershed code	0.03264	0.03699	0.3776
LAS	Subwatershed code	-0.001108	0.08627	0.1990
LAVD	Subwatershed code	0.003565	0.01369	0.7946
SANTO	Subwatershed code	0.02385	0.02833	0.3999
SANTVCWPD	Subwatershed code	-0.01354	0.007467	0.06999
TAPO	Subwatershed code	-0.3039	0.2487	0.2219
THACH	Subwatershed code	-0.08253	0.06346	0.1936
TIMB	Subwatershed code	0.06605	0.06829	0.3336
TODD	Subwatershed code	0.002740	0.04178	0.5120

Note: "NA" indicates values that could not be calculated due to singularities within the model.

Table A4. Full coefficient table for multiple regression linear model predicting the probability of organophosphate hits. Variables significant at P= 0.05.

Dependent Variable: Probability of Organophosphate Hit				
Significant Independent Variables	**Description**	**Coefficients (scaled to 1%)**	**Standard Error**	**P value**
(Intercept)		0.08009	0.1197	0.5037
Flow	Flow during sampling (cu. ft/s)	0.000007214	0.00001018	0.4791
Eto	Evapotranspiration, (in)	-0.03032	0.005039	<<0.001
Precip	Precipitation, day of sampling, (in)	-0.0003329	0.0008694	0.7020
Precip1	Precipitation, day before sampling (in)	-0.001066	0.0005305	0.0451
Precip2	Precipitation, two days before sampling (in)	0.001888	0.001613	0.2424
PrecipInt	Precipitation, interaction between day before and two days before (in^2)	-0.0004746	0.001089	0.6633
AvgRelHum	Average relative humidity (%)	-0.0000339	0.00002040	0.0974
BMP20	Long runs of production area are broken up by access roads or buffer strips to reduce sediment movement.	0.07312	0.1294	0.5724
BMP21	In sloped production areas, one or more of the following management practices is used to minimize erosion: Contour farming, contoured buffer strips, terracing	-0.08717	0.1652	0.5980
BMP22	Bare soil is minimized through use of cover crops, mulch, leaving plant debris, or planting subsequent crops, and the soil cover is replenished periodically to maintain effectiveness.	-0.02380	0.07073	0.7367
BMP23	Soil amendments, such as polyacrylamide (PAM), are used to reduce sediment movement and retain water.	0.01853	0.03424	0.5886
BMP24	Berms, culverts, or flow channels are in place to divert water away from roads. These devices or structures are maintained to preserve their functionality.	0.1684	0.08157	0.0396
BMP25	Road erosion is minimized by use of any of the following: Grading, gravel, grass, mulch, water bars, drains	-0.001531	0.1199	0.2026
BMP26	Non-cropped areas with bare soil are protected from erosion with any of the following: vegetation, mulch, gravel, water diversion	0.2389	0.1210	0.0490
BMP27	Ditch banks are protected from erosion with vegetation, rock placement or geotextiles.	0.03748	0.06551	0.5676
BMP28	One or more of the following is in place to treat runoff before it leaves the property: grassed waterways, vegetated filter strips, sediment traps, tailwater recycling systems	0.003887	0.03680	0.9159
BMP29	Before application of pesticides, pest scouting is conducted using one or more of the following methods: Yellow sticky traps, pheromone traps, plant inspection, beating, net sweeping	-0.2694	0.2387	0.2598
BMP30	Natural enemy populations are considered when choosing pesticides, application rates, and timing.	0.1189	0.2797	0.6710
BMP31	Sprayers are routinely calibrated to ensure accurate application rates.	-0.03961	0.6942	0.9545
BMP32	Worn nozzles and screens are replaced to ensure the best coverage of pesticide applications.	-0.003729	0.07612	0.9610
BMP33	Pesticides are stored and mixed on an impermeable pad and at least 100 feet down slope from water sources (such as wells).	-0.06451	0.4203	0.8781
BMP34	Pesticides are not applied when rain or scheduled irrigation events are anticipated.	-0.03991	0.4802	0.9338
Tree	Fraction of tree crops (%)	-0.006779	0.01468	0.6445
BARDS	Subwatershed code	-0.01271	0.09809	0.8970
BOULD	Subwatershed code	-0.03486	0.03054	0.2544
BROOM	Subwatershed code	-0.01214	0.02079	0.5594
ELLS	Subwatershed code	-0.03872	0.04886	0. 4286
ETTG	Subwatershed code	0.03612	0.05482	0.5103
FCBR	Subwatershed code	-0.03537	0.06773	0. 6013
GERRY	Subwatershed code	-0.02678	0.07973	0. 7372
HONDO	Subwatershed code	-0.02744	0.03750	0.4647
LAS	Subwatershed code	-0.02568	0.01757	0.1446
LAVD	Subwatershed code	-0.06489	0.2397	0.0.7868
LONG2	Subwatershed code	-0.03918	0.05365	0. 4657
OXDCENTR	Subwatershed code	-0.1056	0.08507	0. 2151
SANTO	Subwatershed code	NA	NA	NA
SANTVCWPD	Subwatershed code	-0.06772	0.04105	0.8691
TAPO	Subwatershed code	NA	NA	NA
THACH	Subwatershed code	NA	NA	NA
TIMB	Subwatershed code	-0.04015	0.09858	0.6840
TODD	Subwatershed code	-0.02560	0.03572	0. 4741

Note: "NA" indicates values that could not be calculated due to singularities within the model.

Appendix B: Supplemental Maps & Figures

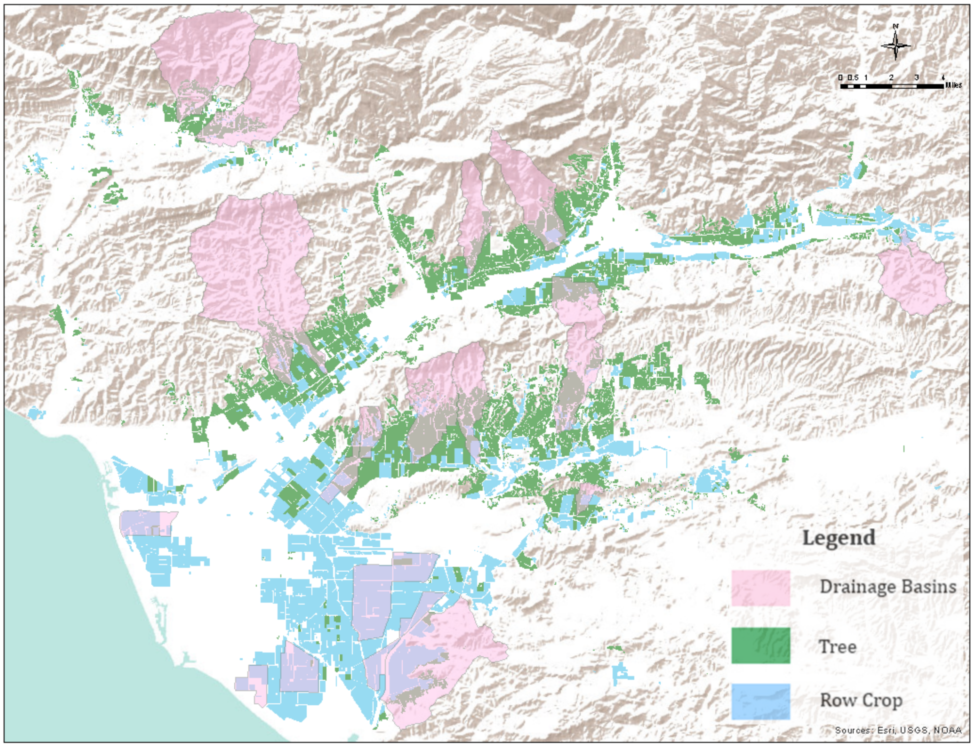

Figure B1. Tree & Row Crop for 2008.

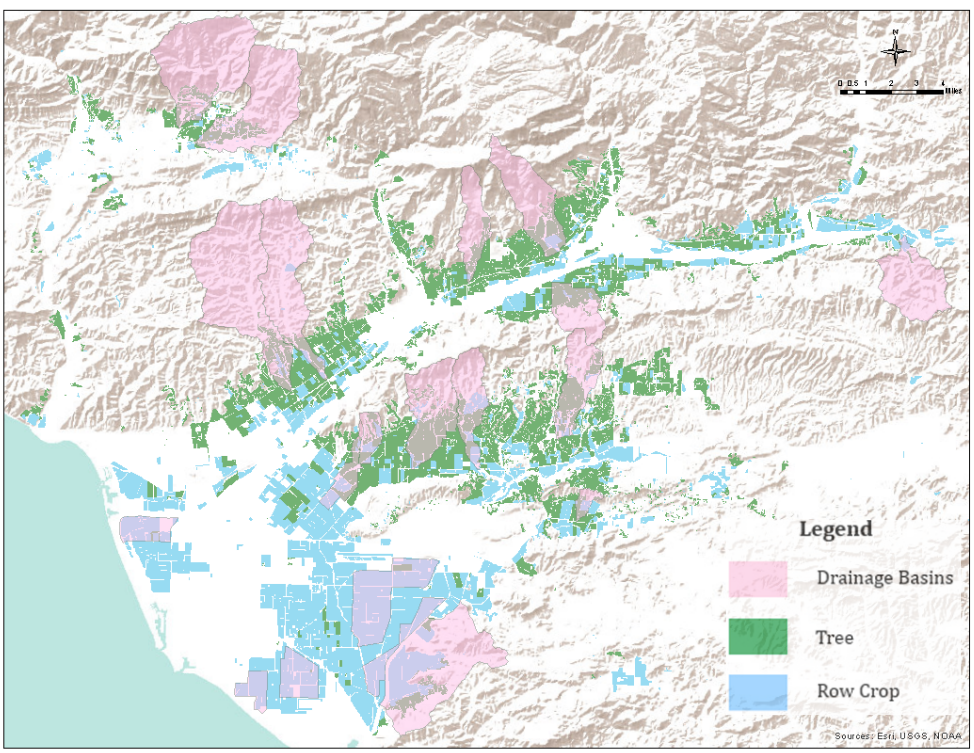

Figure B2. Tree & Row Crops for 2010.

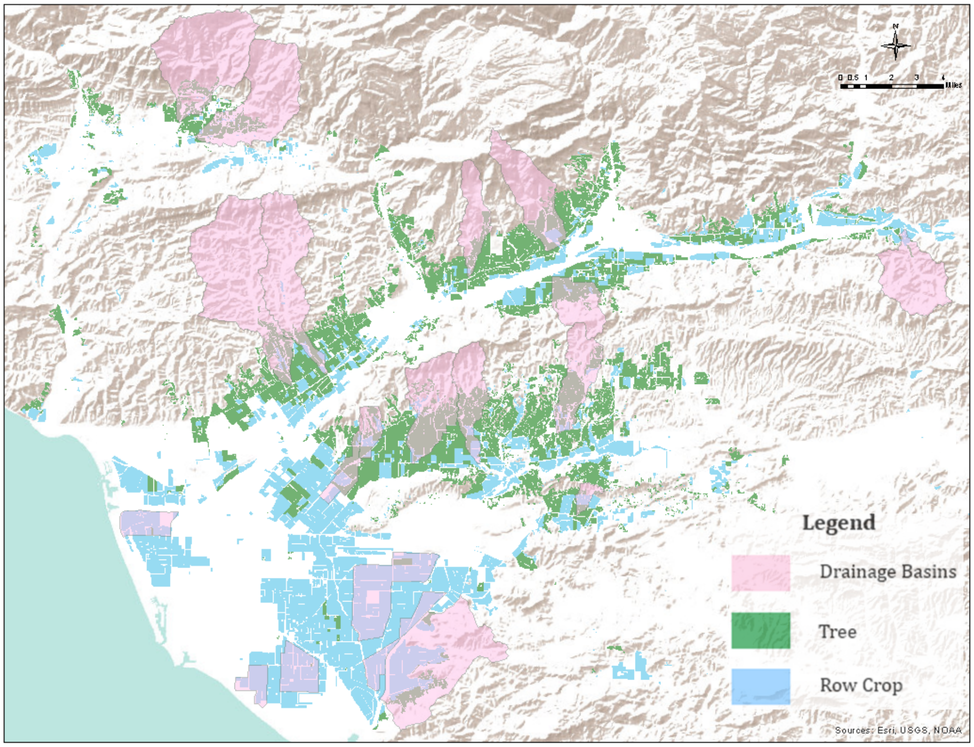

Figure B3. Tree & Row Crops for 2012.

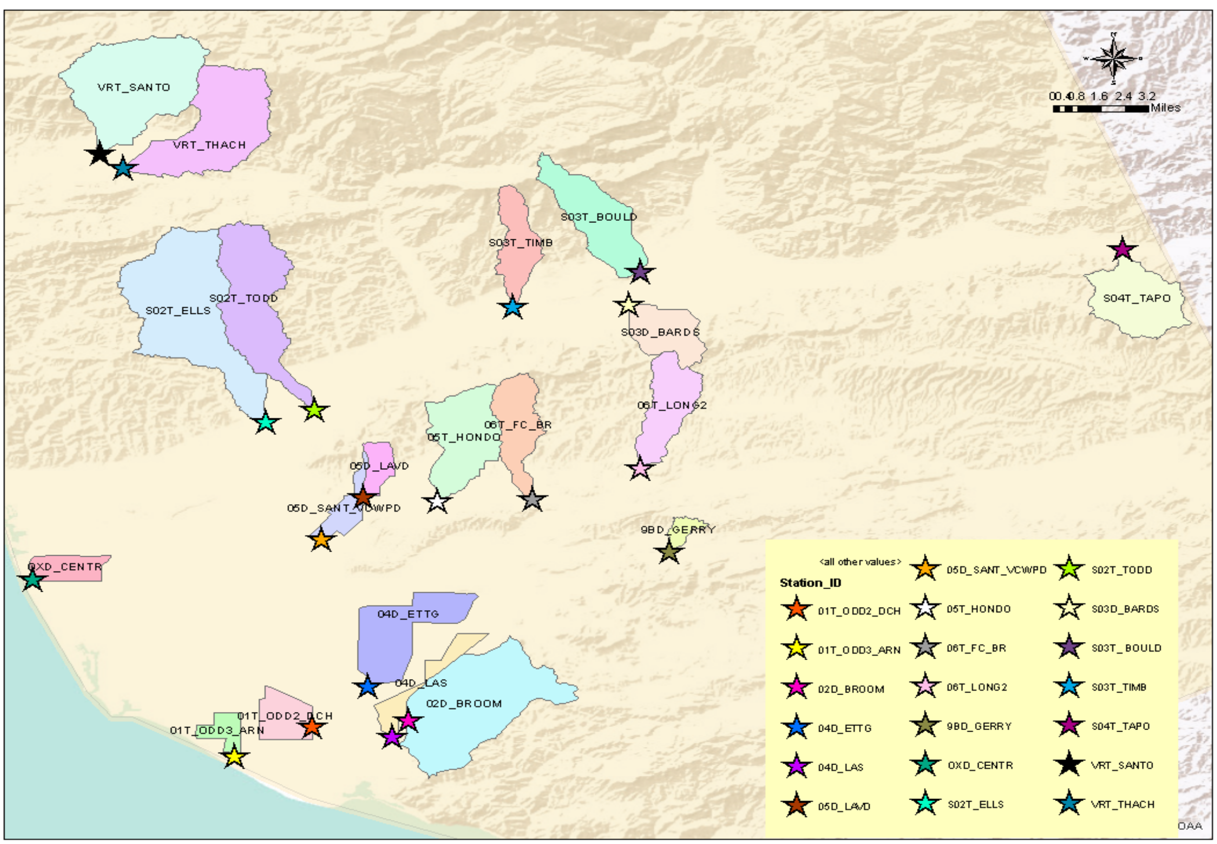

Figure B4. VCAILG drainages and monitoring sites.

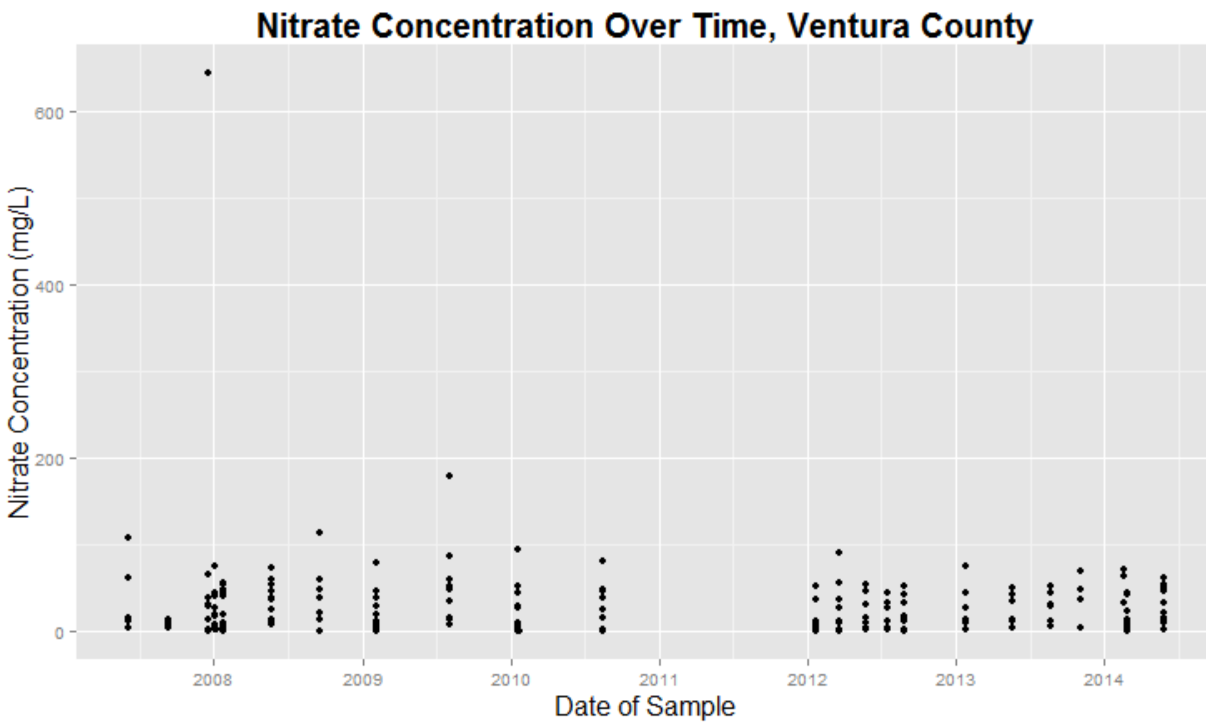

Figure B5. All data points for nitrate concentration over time, for all sites in Ventura County.

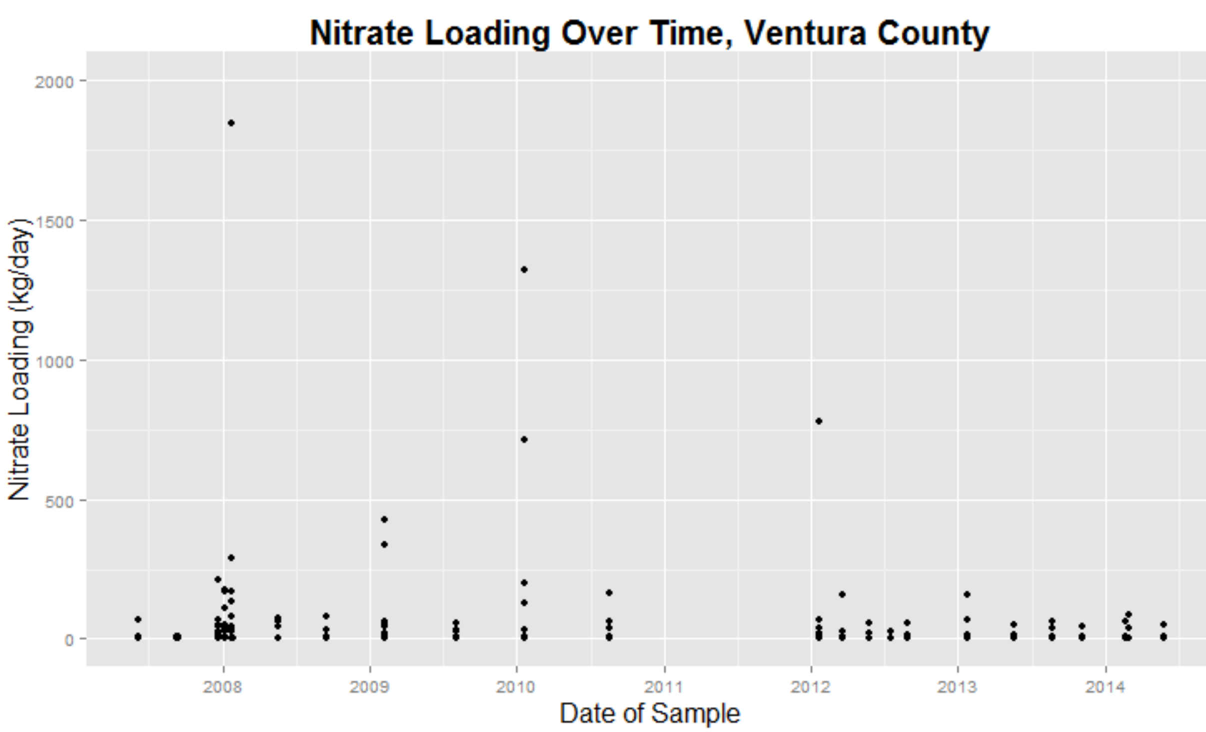

Figure B6. All data points for nitrate loading over time, for all sites in Ventura County.