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Research Brief #8

Land Use and Phosphorus Levels in the Elkhorn Slough and Pajaro River Watersheds

The Pajaro River and Elkhorn Slough watersheds on California's Central Coast include some of the state's most productive and highly valued agricultural lands. The watersheds' streams and rivers serve as key municipal and agricultural water sources, recreational areas, and wildlife habitat. Both watersheds drain into Monterey Bay, a nationally protected marine sanctuary, and water from the Elkhorn Slough watershed passes through Elkhorn Slough, the largest tidal salt marsh along the Central Coast and a critical resource for resident and migratory birds, fisheries, and other wildlife.

Agricultural and urban land uses in the Pajaro River and Elkhorn Slough watersheds have compromised the quality of their waterways. Two nutrients, nitrogen (nitrate-N) and phosphorus (in the form of soluble reactive phosphorus, or SRP), are of particular concern. High levels of nitrate-N in drinking water pose a threat to human health, and both nitrogen and phosphorus are linked to excessive growth or "blooms" of algae and other plants that can decrease the amount of dissolved oxygen in waterways below the levels that aquatic organisms need to survive.

As part of state and federal efforts to protect and restore water quality, regulatory agencies have been charged with establishing target concentrations for pollutants in waterways that will protect beneficial uses[1] (see details, page 8). The Central Coast Regional Water Quality Control Board (RWQCB) has set a preliminary target of 0.12mg/L for soluble reactive phosphorus concentrations, based on the lowest concentrations they have observed in waterways of the Pajaro watershed with excessive plant or algae growth. This pollution is thought to come primarily from "non-point" sources, which are unregulated discharges from urban and agricultural land uses.

Most growers along California's Central Coast use phosphorus fertilizer to maintain high crop production. Increasing evidence suggests that crops cannot take up all of the phosphorus fertilizer being applied (Hartz et al. 2003); as a result, excess phosphorus accumulates in the soil. High levels of soil phosphorus in turn lead to higher phosphorus levels in water draining from agricultural fields (Sharpley et al. 2000).

In the Pajaro River and Elkhorn Slough watersheds, high concentrations of phosphorus have been identified in several waterways. The RWQCB Watershed Management Initiative implicates agriculture as the primary source of this and other nutrient pollution (Jones 2002). However, little empirical data exists to demonstrate that agriculture is responsible for nutrient loading into these waterways.

In this research brief we present data from water quality monitoring conducted between October 2000 and September 2004, to demonstrate the way that agricultural land use influences phosphorus concentrations in streams and rivers. We discuss the nature of phosphorus pollution from agriculture along the Central Coast, examine the implications of these data for agricultural regulations, and offer suggestions for reducing phosphorus losses from farmlands.

STUDY SYSTEM

The Pajaro River watershed drains approximately 1,300 square miles of land, with 7.5% (60,815 acres) of the watershed in agriculture. Agricultural activities are concentrated in three productive areas: on the flood plain of the Pajaro River near the towns of Watsonville (Santa Cruz County) and Aromas (Monterey County); in South Santa Clara Valley near Gilroy and San Martin (Santa Clara County); and in the San Juan Valley near San Juan Bautista and Hollister (San Benito County).

Production near the coast is dominated by cool-weather vegetables, berries, flowers, and apples. In the warmer inland areas—east of the Santa Cruz and Gabilan ranges—growers rotate crops of cool- and warm-weather vegetables, along with grapes, flowers, and stone fruits.

Approximately 70 square miles in size, the Elkhorn Slough watershed drains northern Monterey County and a small portion of San Benito County. Approximately 24% of the watershed is in agriculture (10,318 acres), with strawberries and cool-weather vegetables making up the majority of cultivated acreage (Silberstein et al. 2002).

WATER SAMPLING AND ANALYSIS

To assess the role of agricultural land use on phosphorus levels in waterways, we began sampling two creeks in October 2000 in the Elkhorn Slough watershed (Carneros and Corn Cob Canyon Creeks), and several waterways in the Pajaro River watershed, including Corralitos Creek, Watsonville Slough, the Pajaro River, and publicly accessible agricultural drainage ditches. In October 2002 we expanded the project to include all tributaries of the Pajaro River (Llagas Creek, Uvas Creek, San Benito Creek, Miller's Canal) to determine the proportion of nutrients each water basin contributes to the river.

We collected water samples every 2 weeks at approximately 60 sites throughout the watershed. Sites were selected to bracket agricultural activity and other land uses in order to compare concentrations upstream and downstream of potential nutrient sources. In addition, several locations were sampled more frequently to capture storm event variability and to measure water discharge for calculations of nutrient loads (the total mass of nutrient transported past a gauging station over a period of time, or the average nutrient concentration times the volume of water discharged). For brevity we report here on several key sites that demonstrate spatial and temporal patterns we found to be characteristic of the entire watershed.

GEOGRAPHICAL PATTERNS OF SOLUBLE REACTIVE PHOSPHORUS (SRP)

Geographical patterns of dissolved phosphorus concentrations (reported as soluble reactive phosphorus, or SRP) suggest that levels are influenced by land features as well as land use practices. Soil characteristics such as a shallow water table are associated with elevated stream SRP levels, particularly in agricultural areas. In the south Santa Clara Valley, SRP concentrations were low in all waterways with the exception of San Juan Creek. The San Juan drainage has a shallow, perched water table, and receives discharge from artificial tile drain systems, used

Phosphorus Movement from Land to Water

Naturally occurring phosphorus (P) is derived from apatite, a common mineral consisting of calcium fluoride phosphate or calcium chloride phosphate. The availability of P to plants in any soil is limited by the rate at which apatite dissolves. Relative to other plant macronutrients, inorganic P is fairly insoluble and binds to soil particles. This means it is typically retained in the soil profile and doesn't leach into groundwater. Phosphorus availability to plants is greatest when the soil's pH is around 6.55–7.5. In acid soils, dissolved phosphate can precipitate with iron and aluminum oxides, making it unavailable to growing plants, whereas in alkaline soils, dissolved phosphorus can precipitate with calcium.

Both inorganic and organic forms of P are found in soils. Since soils tend to "hold" P, it is most commonly lost from soils via erosion. However, if sufficient amounts of P are added to soils over time in the form of fertilizers or other inputs, all the attachment sites on soil particles can become filled, at which point the soluble form of P will be lost through runoff or by leaching.

The amount of phosphorus lost from agricultural fields varies greatly, and is specific to both local environmental conditions and land management practices. Conditions that increase erosion, runoff, and subsurface water flow also increase soil P losses. Therefore, climate, soil type, and slope can all influence P losses. In addition, a number of nutrient and soil management practices impact soil P movement, including the amount of P applied in fertilizer, the solubility of applied P, the timing of fertilizer applications in relation to plant use and irrigation or rain events, the presence of artificial (tile) drainage systems, and cover cropping and tillage practices that affect erosion and water infiltration.

In general, most soil P is lost via surface runoff and erosion, but the amounts lost and the timing of such losses are unique to the conditions and management practices used at each ranch or farm. For example, the use of tile drainage systems, which are common in parts of the Pajaro River and Elkhorn Slough watersheds, can greatly increase subsurface P losses. (Tile drains are perforated pipes installed under fields to remove water from the rooting zone.)

Drains can affect P movement and loss in different ways. As water moves through the soil profile toward the drain, the soil can bind dissolved P, thus removing it from the water; however, tile drains also reduce the amount of time P fertilizer is in contact with soil particles, so overall a smaller fraction of applied P may be retained in the soil profile (Heathwaite 1997). Tile drains have also been shown to transport significant amounts of particulate P from topsoil to surface waters during storm events (Dils and Heathwaite 1999). Conversely, in soils with poor drainage, installation of tile drains can reduce total P losses during storms by improving infiltration and reducing P lost via surface runoff (Simard et al. 2000). Therefore, determining the role of tile drains in P transport under local soil and climate conditions is important for managing P levels in the Central Coast region.

In addition to agriculture, natural processes and urban runoff may also contribute P to waterways. Small amounts of P are deposited from the atmosphere in rainfall and in dry airborne particulates. Urban sources of P include residential fertilizer use, automotive products, and septic tanks and leach fields. In the past, detergents were a significant source of urban P pollution, but most detergents are now phosphate-free.

In aquatic environments, particulate P can convert to dissolved forms and increase the pool of reactive, dissolved P (Correll 1998). These reactive forms, called orthophosphate (ortho-P) or soluble reactive phosphorus (SRP), are readily taken up by algae, and in excess levels may lead to algae "blooms" and eutrophication (see sidebar, page 4).

Perforated pipes or "tiles" drain water from the root zone of crops into adjacent ditches and other waterways.

in agricultural fields to remove water from the rooting zone of crop plants. In contrast, Llagas and Uvas Creeks, which do not receive tile drainage, had low SRP concentrations at all sites. Median SRP concentrations increased slightly at sites downstream of agriculture (Bloomfield Avenue), but exceeded the target level on fewer than 20% of visits (Table 1). San Benito Creek and Miller's Canal, which were both sampled near agricultural fields, also had low median SRP concentrations.

The use of tile drainage systems may account for higher SRP levels in waterways with shallow water tables and agricultural land use, including Watsonville Slough and Corn Cob Canyon Creek. Tile drainage systems can increase phosphorus losses by increasing soil infiltration rate and reducing the amount of phosphorus that adheres to soil particles (see sidebar at left). During winter storms, tile drains may also act as conduits for particulate phosphorus, carrying eroded topsoil to waterways (Laubel et al. 1999).

Non-agricultural land uses, and occurrence of mineral types naturally high in SRP, may also contribute to elevated SRP concentrations in some areas. While nutrients were generally higher at locations downstream of agriculture, Corralitos Creek had elevated nutrients both upstream and downstream of agriculture. At the most upstream site (Las Colinas Road), SRP concentrations often exceeded the target level of 0.12 mg/L while two other nutrients, nitrate and ammonium were very low. The elevated SRP levels are not likely from fertilizer or septic sources, which also tend to be high in nitrogen compounds, but may be due to the mineral composition of soils in this drainage and/or soil erosion.

AGRICULTURAL LAND USE AND SRP

Comparisons of sites upstream and downstream of agriculture revealed higher downstream SRP concentrations in many waterways, providing evidence that agricultural land is a source of phosphorus in surface waters. In the Elkhorn Slough watershed, SRP progressively increased with the amount of cultivated acreage located upstream (Table 1). The phosphorus content of the soils in the watershed may play a role in how phosphorus moves through this system, but this has not been looked at systematically.

In Carneros Creek at Dunbarton Road, which is at the upstream edge of cultivated acreage, the median SRP concentration was 0.10 mg/L, and at San Miguel Canyon Road, downstream of several miles of farmland, the median concentration was 0.53 mg/L. However, in addition to row crops, land use along Carneros Creek is mixed with ranches and rural homes, and more intensive monitoring is necessary to partition nutrient inputs from these potential sources. In Corn Cob Canyon Creek, the median SRP concentration was 0.11 mg/L at Lewis Road, where the stream emerges from an underground

Table 1. Median concentrations and percent of samples that exceeded the RWQCB target of 0.12mg/L SRP for biweekly samples collected between Oct 2002 and September 2004. Sites are listed from most upstream to most downstream for each waterway.

Location	Median concentration (mg/L)	% samples over 0.12 mg/L target
Llagas Creek		
Below Chesbro Reservoir	0.045	9.8
Monterey Rd.	0.034	10.5
Bloomfield Ave	0.054	15.7
Uvas Creek		
Below Uvas Reservoir	0.028	8
Highway 152	0.027	9.84
Bloomfield Ave.	0.033	15.7
Miller's Canal		
Frazer Lake Rd	0.047	26.7
San Benito Creek		
Y Road	0.023	3.4
San Juan Creek		
Anzar Road	0.29	96.8
Pajaro River		
Chittenden	0.137	53.6
Murphy's Crossing	0.097	22
Main Street	0.11	35.8
Corralitos Creek		
Las Colinas Rd.	0.113	40.4
Green Valley Rd.	0.081	25.7
Salsipuedes Creek		
Riverside Drive	0.149	62.3
Watsonville Slough		
Ohlone Rd.	0.309	80.4
Shell Rd.	0.252	96.1
Corn Cob Canyon Creek		
Lewis Rd.	0.113	48.7
Hudson Landing Rd.	2.163	100
Carneros Creek		
Dunbarton Rd.	0.093	40.9
San Miguel Canyon Rd.	0.526	100

Ecosystem and Community Reponses to Elevated Nutrient Levels

Algal growth is generally limited by available nutrients. In freshwater systems, an increase in either phosphorus and/or nitrogen can stimulate production (biostimulation). Agronomically small losses from the farm are sufficient to stimulate algae growth in lakes and streams. For example, 0.03–0.05 mg PO_4-P L^{-1}, which are very low concentrations, stimulate high growth rates in algae. The excess growth of algae or aquatic plants, a process termed eutrophication, can threaten drinking water supplies by creating toxic conditions, fouling water intakes, and changing the availability of oxygen in the water.

In addition to compromising drinking water quality, elevated nutrient levels may increase or decrease the abundance of specific species in a freshwater system. The change in species abundance can affect the taste and odor of water, making it unpalatable or even toxic to some organisms. These potential ecosystem changes have not been investigated in Central Coast surface waters. With the increase in algae, levels of dissolved oxygen in the water column during the day can become very high (super saturated, in excess of atmospheric equilibrium). At night the activity of microbes that break down decaying organic matter in the sediments can reduce oxygen concentrations to the point that some aquatic species have difficulty surviving. Thus, very high, low, or fluctuating concentrations of dissolved oxygen can indicate eutrophic conditions.

Although nutrient levels influence the growth of algae, the overriding factors that control algae growth in streams are disturbance (e.g., scouring from flooding), light availability (open or closed canopy), and consumption by animals. Thus, even if nutrient levels are elevated, excess algae growth may not occur. This fact severely complicates the development of an enforceable numeric standard for phosphorus along the Central Coast, as it is difficult to find a direct relationship between nutrient levels and algal growth.

The growth of floating algae mats in Llagas Creek may be influenced by a combination of factors, including nutrient levels, light availability, and composition of the creek's substrate.

culvert, and 2.2 mg/L at Hudson Landing, downstream of row crops. At the downstream locations in both Carneros and Corn Cob Canyon Creeks, SRP concentrations exceeded the 0.12 mg/L target level in 100% of biweekly samples.

In Uvas and Llagas Creeks in the south Santa Clara Valley, SRP concentrations were generally below the target SRP concentration of 0.12 mg/L at all locations. However, water quality problems occurred more frequently downstream of agricultural land use (Bloomfield Avenue), where a greater percentage of collected samples were over the target concentration (Table 1).

In the Pajaro River, elevated SRP concentrations occurred in the river's upstream reaches at Chittenden Gap, due in large part to flow from San Juan Creek and associated ditches that drain irrigated fields in the San Juan Valley. In contrast to tributaries draining the south Santa Clara Valley, San Juan Creek had elevated SRP levels (median of 0.29 mg/L), and was a particularly significant source of nutrients to the Pajaro River during summer months, when flow from other creeks declined. In addition to San Juan Creek, several agricultural ditches in the south Santa Clara and San Juan Valley regions that flow intermittently may also contribute nutrients to the Pajaro River. We hope to address these issues in future research.

URBAN AND SUBURBAN LAND USE

In addition to agriculture, natural processes and urban runoff may also contribute phosphorus to waterways. Although no increase in phosphorus levels was detected at urban sampling locations on Llagas and Uvas Creeks (data not shown), urban runoff from the city of Watsonville may contribute to elevated SRP levels in Watsonville Slough and the lower Pajaro River, particularly during the winter storm season. At Ohlone Road, our most upstream site in the slough, surface runoff from the city of Watsonville may also contribute to elevated SRP levels during winter storms. It is also worth noting that Watsonville Slough at Ohlone Road had a period of very high SRP concentrations in the late summer through fall of 2003; these may be associated with erosion from a development project that occurred adjacent to the sampling site.

SEASONAL AND LONG-TERM PATTERNS OF SRP CONCENTRATIONS

We detected seasonal changes in SRP concentrations in many waterways. One prominent seasonal pattern was an increase in SRP concentrations during the late summer in waterways that receive discharge from cultivated lands. This late summer increase occurred in San Juan Creek, in the Pajaro River at Chittenden Gap, and in Corn Cob Canyon Creek (Figure 1a), and may be due to the combined effects of irrigation discharges and decreasing stream flows, which limit the capacity of waterways to dilute nutrient inputs.

In contrast, Watsonville Slough had its highest SRP concentrations from fall through spring, with concentrations declining to an annual low point in mid summer (Figure 1b). High SRP concentrations in the winter rainy season may be associated with increased surface runoff from agricultural fields located along the slough. Tile drains may also facilitate subsurface loses of phosphorus (see sidebar, page 2).

In Carneros Creek, which is dry from approximately May until December each year, a third seasonal pattern emerged (Figure 1c). SRP concentrations were moderately elevated at both upstream and downstream sites following the first winter rains, which suggests that soil phosphorus accumulates over the summer months and is flushed into the creek with the first rains. At Dunbarton Road where there is little cultivation upstream, sources may include natural decomposition in grasslands, cattle grazing, and rural residential land use; at downstream sites sources also include agricultural land use. At San Miguel Canyon Road, the downstream location, SRP concentrations increased again in the late winter and spring of 2002 and 2003, reaching very high levels that

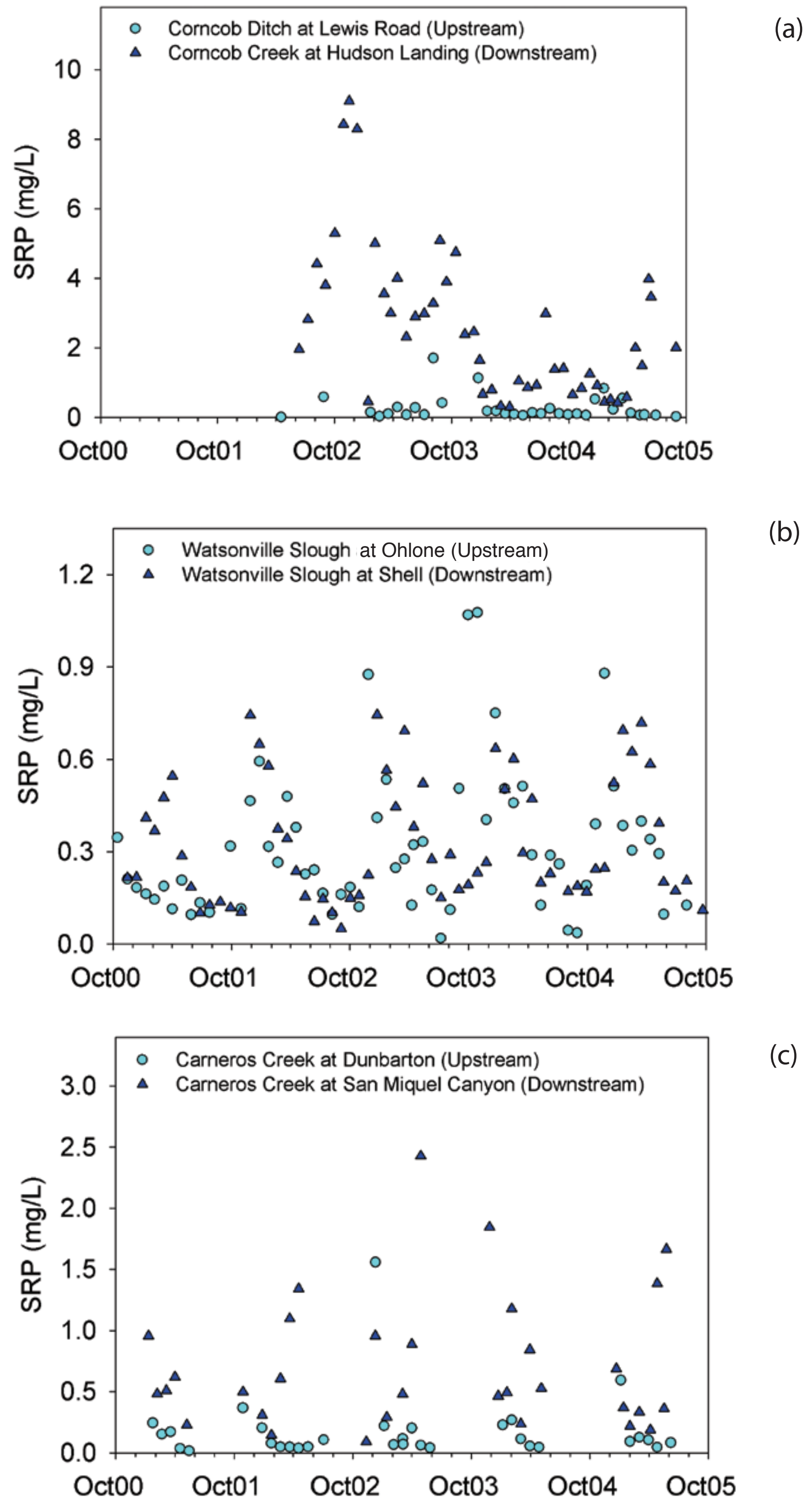

Figure 1. Median monthly SRP concentrations in a) Corn Cob Canyon Creek, b) Watsonville Slough, and c) Carneros Creek. Carneros Creek had no flow from May–December and Corn Cob Canyon Creek at Lewis Road had no flow from October to the season's first rains.

frequently exceeded 1 mg/L. Nutrient concentrations were highly erratic in 2002 and 2003, and subsequently declined in 2004, suggesting that nutrients originated from a point-source that has ceased to discharge.

No seasonal concentration trends were observed in the upstream tributaries of the Pajaro River (Llagas Creek, Uvas Creek, San Benito Creek, and Miller's Canal). At these locations SRP concentrations remained low throughout the year. We calculated the SRP load discharged by each tributary (2002–2003), and found loads varied seasonally corresponding with discharge (Figure 2). The SRP load was greatest at Chittenden during January and February, when discharge was also greatest. San Juan Creek was not sampled during this period, but likely accounts for a significant portion of the unaccounted load because it has elevated SRP concentrations and year-round flow.

In the Pajaro River, there is a strong seasonal trend in SRP concentrations (Figure 3a). Concentrations decline after the rainy season ends. Because SRP concentrations remain relatively high in the winter, rainfall probably transports SRP to surface waters. Furthermore, the loss of SRP from Santa Clara/San Benito Counties is highest during these rainfall periods (Figure 3b). Because concentrations and export of SRP in the Pajaro River are rainfall dependent, it is difficult to determine long-term trends independent of recent rainfall patterns.

BIOSTIMULATION

Elevated phosphorus concentrations can cause excessive algal growth in waterways, and preventing excessive growth is the primary reason phosphorus concentrations are regulated. Algal biomass in the water column can be determined from the concentration of chlorophyll *a*, which indicates the degree of excessive algal growth.

We monitored chlorophyll *a* concentrations at several sites in the Pajaro River watershed on a biweekly basis and compared these concentrations to phosphorus. We found no direct

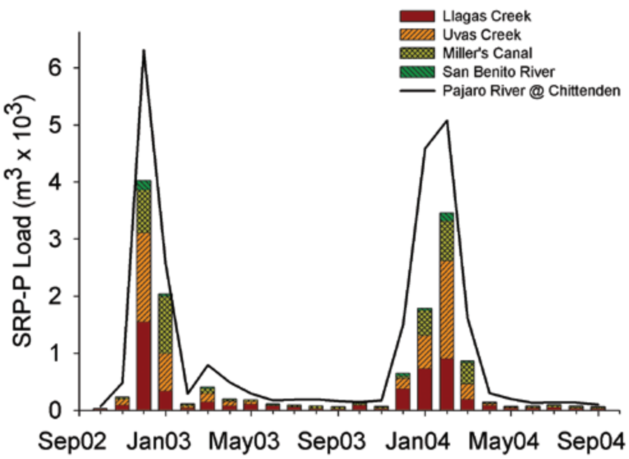

Figure 2. SRP loading to the Pajaro River at Chittenden Gap by location and month.

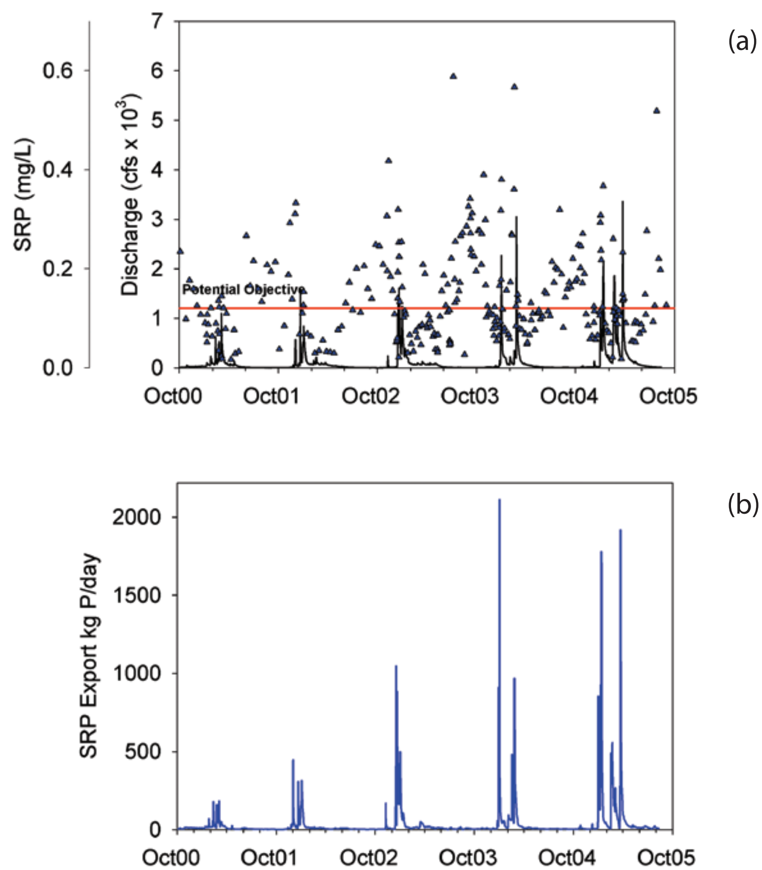

Figure 3. (a) Seasonal trends in SRP concentrations in the Pajaro River. (b) Seasonal trends in SRP export from Santa Clara/San Benito Counties, reflecting rainfall pulses.

relationship between chlorophyll *a* and phosphorus levels (total phosphorus or SRP) at any of the locations (Figure 4).

The lack of a direct correlation between chlorophyll *a* and phosphorus levels indicates that P availability is only one of the factors controlling algal growth. Canopy cover and turbidity (which influence light availability), algae-eating organisms (e.g., snails and clams), substrates that allow different types of algae to attach, and algae sources (e.g., reservoirs) also play a role in algal growth and chlorophyll *a* concentrations. Furthermore, additions of nitrogen can stimulate algal growth in streams and rivers, which challenges the commonly held belief that phosphorus is the nutrient that controls the growth of algae in freshwater ecosystems. Our research group from the Center for Agroecology and Sustainable Food Systems has begun efforts to assess the growth patterns of algae in order to determine how elevated phosphorus and nitrogen levels influence these patterns.

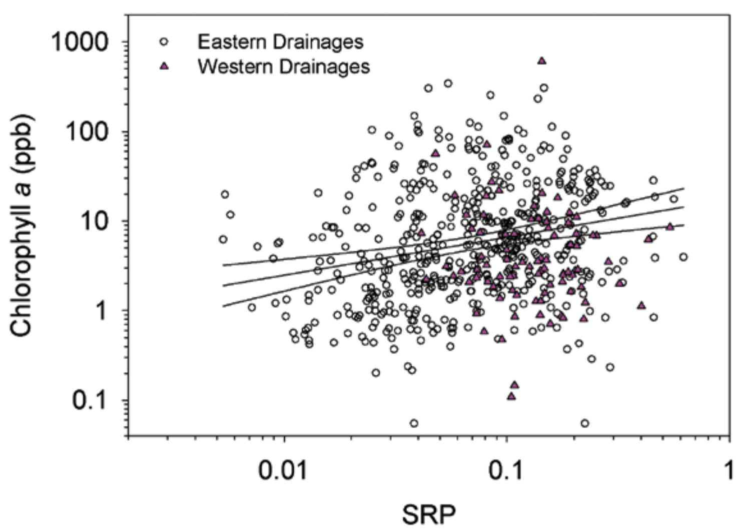

Figure 4. Chlorophyl *a* content and SRP concentrations in the eastern and western drainages of the Pajaro River watershed.

REGULATORY ENVIRONMENT AND FARMING PRACTICES

Under state legislation known as the Agricultural Discharge Waiver that took effect in January 2005, farmers are required to develop farm water quality plans to protect surface waters along the Central Coast. One goal of our research is to inform growers of current water quality conditions in waterways adjacent to their land so that they can take steps to reduce their impacts on waterways while continuing to farm profitably.

Because phosphorus is transported to waterways in storm and irrigation runoff, reducing soil erosion and surface runoff is an important step in reducing phosphorus losses from the farm (Gillingham and Thorrold 2000). Subsurface flow is also an important mechanism of phosphorus losses from the farm (Simard et al. 2000). Growers can address these losses by matching P demand in plants with fertility management, keeping P concentrations in soils at agronomically responsive levels (approximately 40 ppm Olsen-P in this region), and managing irrigation to minimize or eliminate runoff. It is important to note that many growers on the Central Coast and throughout the state have already initiated practices to reduce the loss of phosphorus from their farms. The University of California has several research projects in progress to document the impacts of changes in farm management, and a number of government agencies and NGOs are working with growers to improve water quality (Table 2).

Table 2. Contact information for Central Coast region resource groups involved in water quality improvement.

Resource Group	Monterey County	San Benito County	San Mateo County	Santa Clara County	Santa Cruz County
UC Cooperative Extension	831.759-7350	831.637-5346	650.726-9059	408.282-3110	831.763-8040
Natural Resources Conservation Service (NRCS)	831.637-4360 x108	831.637-4360	650.726-4660	831.637-4360	831.475-1967
Resource Conservation Districts	831.424-1036	831.772-4398	650.712-7765	408.847-4171	831.464-2950
Agricultural Land-Based Training Association (ALBA) (Se habla español)	831.786-8760 or 831.758-1469 (all counties)				
Agricultural Water Quality Alliance (AWQA)	www.awqa.org (all counties)				

Despite growers' efforts, the target level of 0.12mg/L or lower for ortho-P set by the RWQCB may be difficult to attain in the lower Pajaro River and Elkhorn Slough watersheds, where natural sources of phosphorus may be high, and tile drainage systems facilitate losses of phosphorus to surface waters. Even with changes in agricultural practices, the ambient water quality improvements may not be detected for several years, which makes enforcing the water quality regulations difficult on the short-term. Thus, long-term monitoring programs are important to determine the success of changing management practices.

SUMMARY

In the Pajaro River and Elkhorn Slough watersheds, a history of phosphorus fertilizer application has led to phosphorus losses from agricultural areas and elevated SRP levels in waterways. The combination of a moderate climate suitable for year-round farming combined with high property values dictates production of high-value, phosphorus-demanding crops such as vegetables, berries, and cut flowers. In the Pajaro Valley, phosphorus fertilizer applications often exceed an expected crop response (Hartz et al. 2003). Several regions within the watersheds with elevated water tables also require artificial tile drainage systems to allow cultivation, which may facilitate export of phosphorus from soils. While implementing better nutrient management plans is likely to reduce phosphorus accumulation, in many locations soil phosphorus levels are elevated from years of applications and remediation may be a long-term process.

– Marc Los Huertos, Claire Phillips, Carol Shennan

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[1]The State Water Resources Control Board (SWRCB) must develop and enforce water quality objectives aimed to protect water quality in terms of beneficial uses as part of the state Porter-Cologne Act and the federal Clean Water Act. The SWRCB has delegated that state mandate to the nine Regional Water Quality Control Boards. Along the Central Coast this agency is Region 3, the Central Coast Region Water Quality Control Board (RWQCB). The regional board has developed a Basin Plan, which is the legal basis for water quality protection for surface waters in the region. Using a combination of numeric and narrative objectives (e.g., taste, odor, and clarity), the regional board has determined which waters currently meet and do not their beneficial uses. When waters do not meet their beneficial uses, the RWQCB must develop enforceable actions to improve water quality.

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