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Water Quality Monitoring in Elkhorn Slough: a summary of results 1988-1996

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The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

Summary

Elkhorn Slough National Estuarine Research Reserve (ESNERR) and the Elkhorn Slough Foundation (ESF) have been supporting a volunteer water monitoring program since 1988.

Twenty four stations are sampled monthly for temperature, salinity, dissolved oxygen, pH, turbidity, nitrate, ammonium, and dissolved inorganic phosphate. This program represents a partnership among ESNERR, ESF, Monterey County Water Resources Agency, and highly dedicated volunteers.

Some trends we have observed from this data include:

- a significant increase in nitrate concentrations since the 1970s
- extraordinarily high nitrate concentrations in the lower Salinas River which may be the highest recorded in scientific literature for a river or estuary
- concentrations of ammonium that are an order of magnitude lower (or more) than nitrate
- low concentrations of dissolved oxygen in some areas which have restricted circulation
- opening of the Salinas River lagoon leads to rapid increases in salinity in the lower river even during the rainy season when river discharge is high.

Introduction

The Elkhorn Slough Foundation and Elkhorn Slough National Estuarine Research Reserve began water quality monitoring in September 1988. Initially, 6 stations were sampled. Eleven stations were added in 1989, three in 1991, three in 1992 and one in 1994. Currently, 24 stations are sampled monthly (Figure 1). These sites were chosen to monitor critical management areas within the slough watershed. For example, the three ponds on the Azevedo Ranch (upper, mid and lower) will allow us to track how implementation of best management practices on the property affect water quality. The Bennett Slough and Struve Pond sites are of particular interest because of the historic populations of the Santa Cruz long toed salamander in Struve Pond. As management plans for Moro Cojo are implemented, the monitoring data will provide an important record to track changes in the watershed. In addition, sites from the lower Salinas River, Carneros Creek, Bennett Slough, and Moro Cojo represent areas that are tributaries to the slough. How important are these areas in providing freshwater and nutrients to the main channel of Elkhorn Slough? What are the links between surface water and groundwater? A long term monitoring program is essential to address these questions.

Methods

Between 1988 and 1994, salinity and temperature were measured with a YSI model 33 SCT meter. Dissolved oxygen was measured using a YSI model 57 Dissolved oxygen meter. An Orion model 211 pH meter was used to measure pH. Turbidity was measured using a Monitek model 21 PE nephelometer. All instruments were calibrated before sampling according to the manufacturers' recommendations. Starting in 1994, a Solomat water quality meter with temperature, conductivity, dissolved oxygen, pH and turbidity sensors was used to measure these parameters. Sensors were calibrated with appropriate standards and according to manufacturer's recommendations before monthly sampling.

Nutrient analyses (nitrate, ammonium and inorganic phosphate) were performed by the Monterey Bay Aquarium between 1988 and 1991. Samples were centrifuged to remove sediment and then run on a flow injection analyzer. Standard wet chemistry techniques were used: cadmium reduction for nitrate, phenol-hypochlorite for ammonium and ascorbic acid-molybdate for phosphate. The Monterey County Consolidated Chemistry Laboratory began analyzing samples in December 1991. Samples are filtered when received and either analyzed or frozen until analysis. Nitrate and dissolved inorganic phosphate are analyzed using a spectrophotometer using wet chemistry techniques very similar to the Monterey Bay Aquarium (APHA 1989 and EPA 1979). Ammonium is determined using an ion selective electrode (APHA 1989).

Results

The seasonal pattern and magnitude of nutrient concentrations are fairly consistent throughout most of Elkhorn Slough, Bennett Slough and Moro Cojo (Figure 2a,b,c). The highest nitrate concentrations occur during the rainy season, particularly between January and March. Lowest concentrations normally occur during the summer and early fall. In Carneros Creek that discharges into Elkhorn Slough, nitrate concentrations can exceed 14 mg/l during the winter rainy season, although average concentrations are usually about 3 mg/l (Figure 2a). At 11 of the 24 stations, nitrate concentrations are less than 1 mg/l for at least 50% of the sampling period (Table 1). Nitrate concentrations are lowest at the three sites on the National Estuarine Research Reserve and have a small increase in concentration during the winter rainy season (Figure 2c). Concentrations at these three sites never exceed 14 mg/l (Table 1). Ammonium and dissolved inorganic phosphate concentrations throughout the Slough are much lower and average 0.01 and 0.1 mg/l, respectively (data not shown). Despite potential inputs from dairy farms in watershed, ammonium concentrations do not seem to be a problem.

In contrast, the lower Salinas River, which drains into the lower reaches of the slough, has excessive nitrate concentrations all year round. Concentrations usually exceed 30 mg/l during the summer months (Figure 2d). The highest concentrations occur in Tembladero Slough and at the old Salinas River channel at Monterey Dunes Way. In the lower Salinas River, nitrate concentrations exceed 14 mg/l about 70% of the time and concentrations are rarely, if ever, less than 1 mg/l (Table 1).

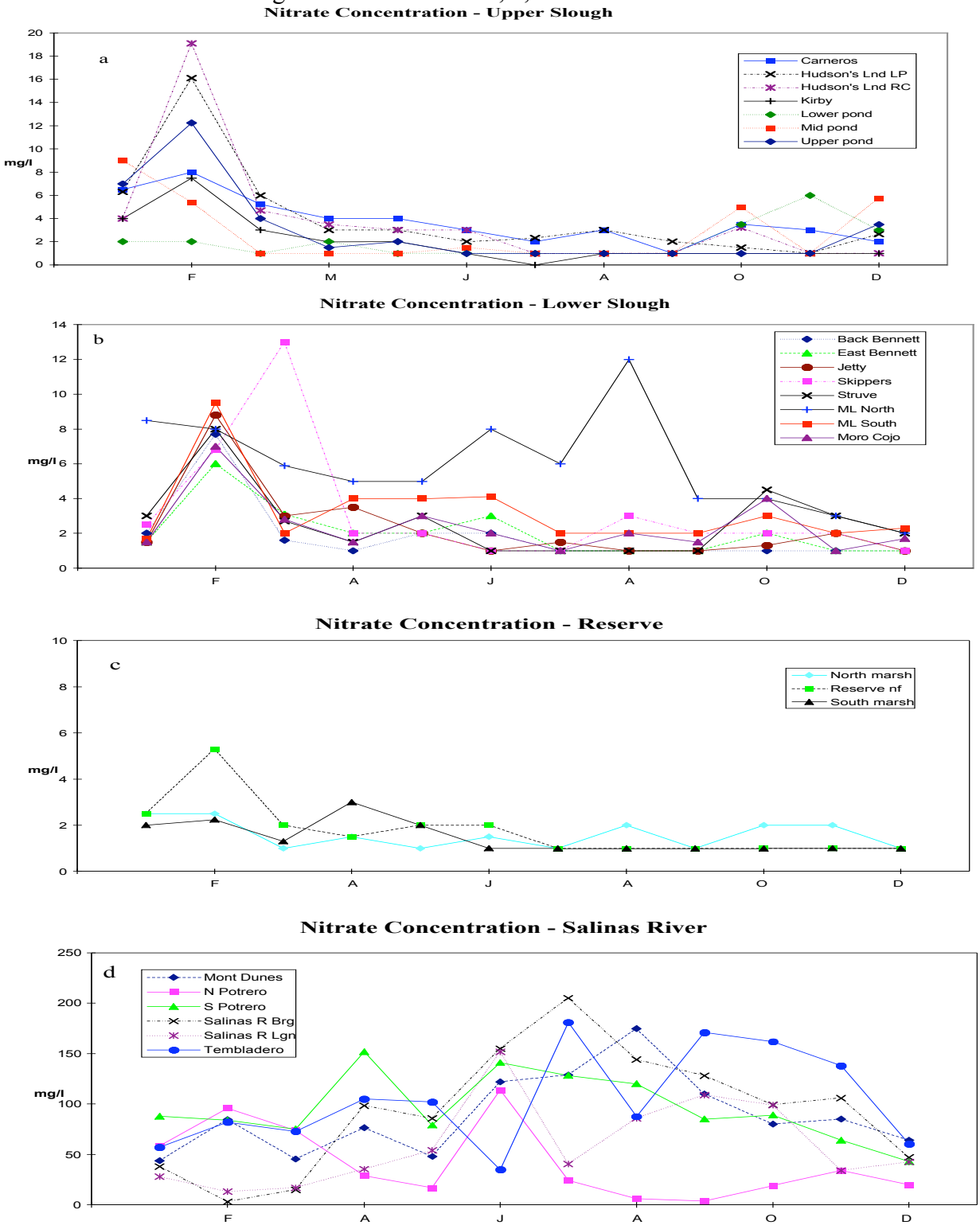
Dissolved oxygen concentrations are highly variable within Elkhorn Slough as in normal in estuaries. Although monthly sampling is not the most appropriate time scale to measure oxygen, these data are useful for targeting areas which may have chronic problems with low oxygen conditions. Although hypoxia does not seem to be widespread throughout the slough, areas with restricted circulation have more low oxygen events than well flushed areas (Table 1). This is consistent with the results of our SWMP-I monitoring program that measures dissolved oxygen concentrations at 15 minute intervals at two locations (Upper Pond and South Marsh). The results of the SWMP-I monitoring program have shown that the Upper Pond becomes hypoxic or anoxic on a daily basis for several weeks in late summer or early fall, while the South Marsh does not.

Turbidity is highest throughout most of the slough during the winter and spring rainy season. Peaks in turbidity seem to occur following rainfall events (data not shown).

Table 1 - Percent occurrence of NO_3^- concentrations less than 1 mg/l or greater than 14 mg/l and dissolved oxygen concentrations less than 2 mg/l between 1991-1996 in Elkhorn Slough. Blanks indicate no (0%) occurrence of condition.

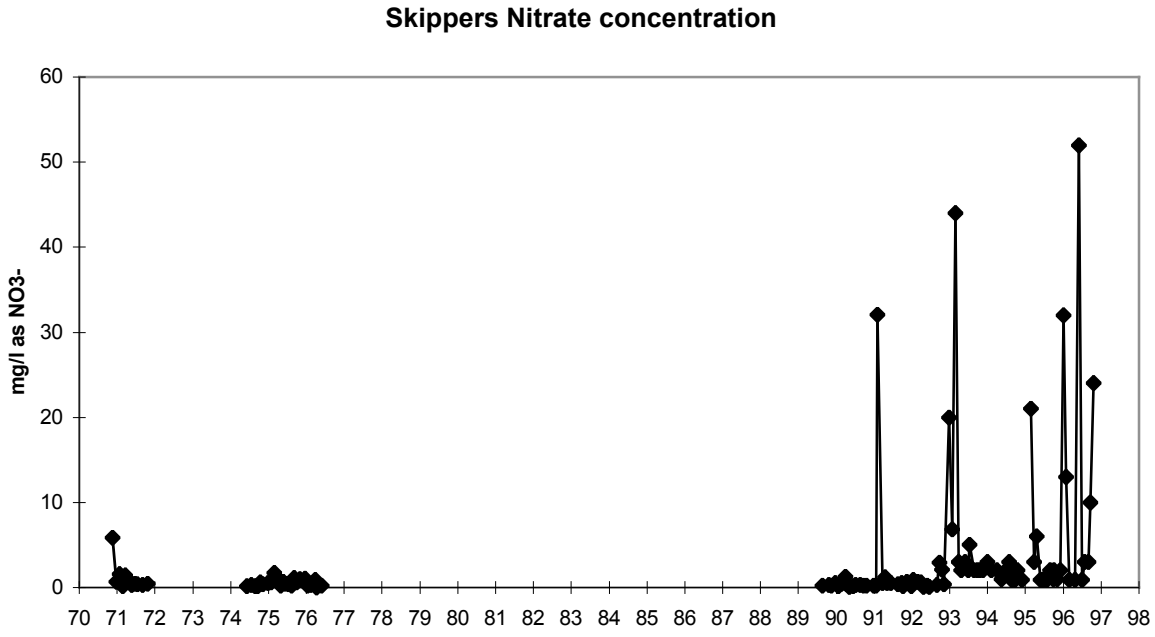
Sampling Location	Sampling site #	Nitrate		Dissolved Oxygen
		<1 mg/l	>14 mg/l	< 2 mg/l
Carneros Creek	15	49%	2%	
Hudsons Landing RC	13	48%	3%	
Hudsons Landing LP	14	55%	2%	
Lower Pond (Azevedo)	10	47%		
Mid Pond (Azevedo)	11	34%	3%	12%
Upper Pond (Azevedo)	12	36%	8%	
Kirby Park	9	65%		
South Marsh (Reserve)	6	59%		
Reserve Bridge (Reserve)	7	61%		
North Marsh (Reserve)	8	60%		6%
Skippers	1	59%	5%	
Moss Landing Rd. North	2	12%	19%	2%
Moss Landing Rd. South	3	24%	4%	2%
Moro Cojo Slough	20	52%		3%
Potrero Rd. North	4	13%	37%	
Potrero Rd. South	5		61%	
Monterey Dunes Way	21		98%	
Tembladero Slough	24		69%	11%
Salinas River Lagoon	22	8%	59%	2%
Salinas River Bridge	23	1%	61%	2%
Jetty Rd.	16	63%	1%	
East Bennett Slough	18	65%		
Struve Pond	19	58%	2%	8%
Back Bennett Slough	17	65%		

Figure 2 - Median nitrate concentration (mg/l) from water quality monitoring stations between 1988-1996. Note the change of scales between a, b, c and d.



There is strong evidence that nutrient concentrations in the slough have increased dramatically since the 1970s. During this period, nitrate concentrations at the mouth of the slough (Skippers) exceeded 1 mg/l on only one occasion and the average nitrate concentration was 0.2 mg/l (Smith 1972, Nybakken et al. 1977). The monitoring data collected from 1989 on shows that there are high spikes of nutrients during the winter months at levels not observed in the 1970s (Figure 3). The median nitrate value at this station is < 1 mg/l for the data collected since 1989. However, because the detection limits reported by the Monterey County Water Resources agency are 1 mg/l, it is not possible to determine what the lowest concentrations are or an accurate estimate of the mean nitrate value. For this reason, median values represent a more robust estimate of average nitrate value than an arithmetic mean. This pattern is not confined to the station at the mouth of the slough. Between the 1970s and 1990s, nitrate concentrations have increased at all stations where we have overlapping data.

Figure 3 - Nitrate concentrations from the mouth of Elkhorn Slough (Skipper) between 1970 and 1996.



The Salinas River lagoon is opened periodically when runoff is high to prevent flooding of agricultural fields. Salinity in the lagoon and even in the lower River at the Highway 1 bridge rapidly increases following the opening of the lagoon (Figure 4). This occurs despite high flow of the Salinas River measured at a USGS gauging station near Spreckels (Figure 5).

Figure 4 - Rainfall from the Salinas airport (in inches), salinity at the Salinas River Lagoon and Highway 1 Bridge (in practical salinity units), and opening of lagoon mouth between 1989 and 1995.

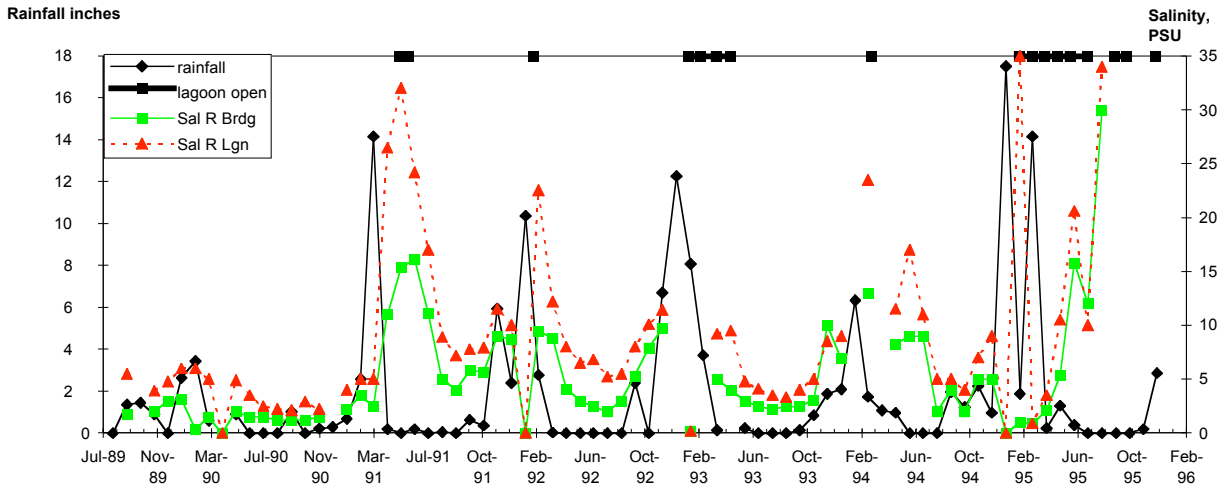
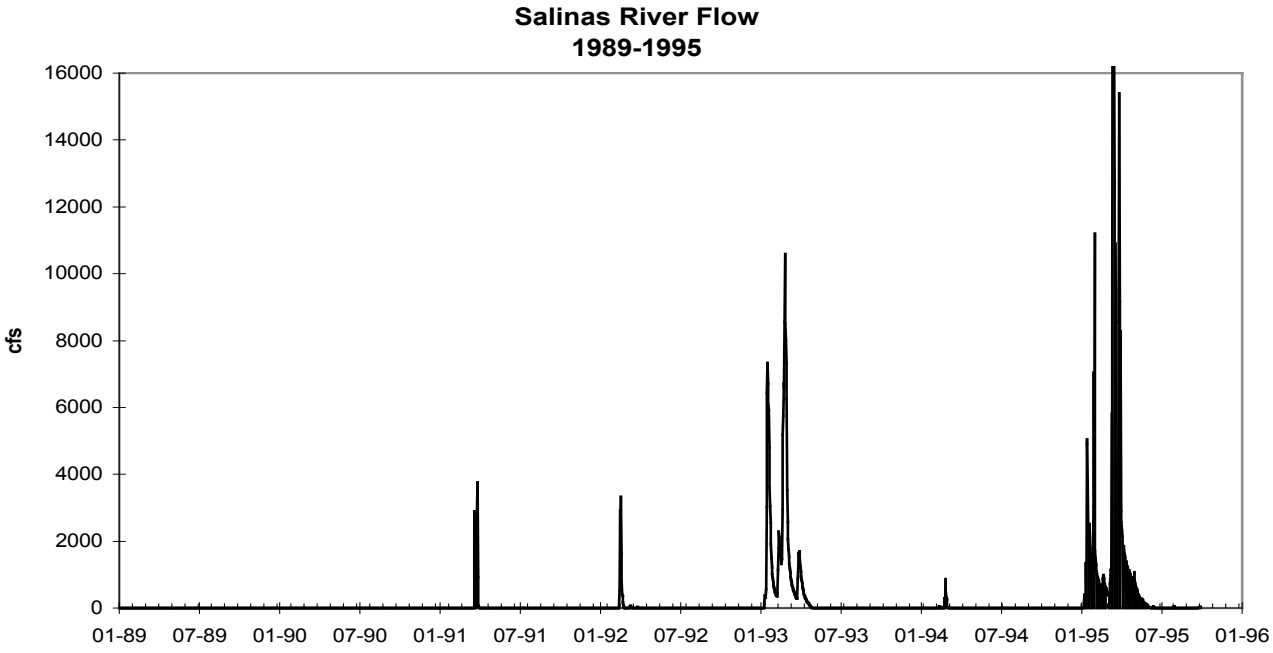


Figure 5 - Discharge (cfs) of Salinas River at Spreckels



Discussion

In general, nitrate concentrations in Elkhorn Slough are high compared to many estuarine systems, while concentrations in the lower Salinas River are unmatched for any estuarine system

reported in the literature (Table 2). Concentrations in the lower Salinas River can be higher than the highest values reported in Table 2 which are nitrate concentrations from sewage treatment plant effluent. Phosphate concentrations can also be high in the Slough and Salinas River, although concentrations are generally similar to other estuarine systems.

Table 2 - Comparison of nutrient concentrations in Elkhorn Slough and Lower Salinas River with other riverine, estuarine and coastal environments

Location	Nitrate mg/l as NO_3^-	Phosphate mg/l	Reference
Elkhorn Slough	<1-130	<0.03-0.6	this study
Salinas River	<1-360	<0.03-0.7	this study
69 Danish lakes	2-40		1
Norsminde Fjord, Dk	0.4-60		2,3
Morlaix River, FR	3-50	0.6-0.3	4
Morlaix Estuary, FR	1.3	0.06	4
Scheldt estuary	9-30		5
Peel Inlet, Australia	150		6
Harvey Estuary, Australia	2.2	0.01-0.15	6
Shenzhen Bay, China	0.4-4	0.05-1.2	7
Changjiang Estuary, China	4.4	0.02	8
Chesapeake Bay			
- riverine	4.4	0.01	9
- shelf	0.1	0.02	9
Delaware Bay			
- riverine	9	0.08	9
- shelf	0.9	0.04	9
Hudson River			
- riverine	2	0.04	9
- shelf	0.4	0.04	9
North San Francisco Bay	1.3-9		10
South San Francisco Bay	0.6-6	0-0.2	10
Fourleague Bay, LA	13.3		11
Septic Tank effluent	20-70		12
Secondary STP	22-220	25	12

1 - Jensen et al. 1990; 2 Jørgensen and Sørensen 1988; 3 - Nielsen et al. 1995; 4 - Wafar et al. 1989; 5 - Billen et al. 1985; 6 - McComb and Lukatelich 1995; 7 - Yu-Zao and Jia-Ping; 8 - Tian et al. 1993; 9 - Fisher et al. 1988; 10 - Hagar 1993; 11 - Caffrey and Day 1986; 12 - Clark 1974;

Significance

Why is a long term monitoring program needed? Long term monitoring programs, like the one in Elkhorn Slough are one of the few ways that we can track change in the system. The changes encountered can be natural, such as the 1989 Loma Prieta earthquake, or human induced, such as the development of best management practices. This is the only long term dataset on water quality for this region and will be essential for tracking long term trends in non-point source pollution. We will be able to document how changes in land-use practices affect aquatic resources in the area using this data. Two examples illustrate how these data have been and can be used.

The monitoring data have been used during the development of the Moro Cojo management plan. These baseline data will be critical to evaluate the success of management practices such as restoration of riparian corridors. In addition, the impact of changing freshwater inputs on *Tryonia imitator*, a brackish water snail that is a canditate for listing as a threatened species, can be determined because we have a long term record of salinity for this area. These data will allow Monterey County to ensure that water quality within this region remains good as recommended by the Moro Cojo Slough management and enhancement plan.

The success of best management practices can also be evaluated because we have a record of conditions before implementation. At the Azevedo Ranch, buffer strips have been planted to trap runoff of sediment and nutrients. The comparison of parameters such as turbidity and nutrient concentrations before and after the buffer strips will allow us to determine if they have a direct effect on water quality.

Two areas of great concern in the North Monterey County are saltwater intrusion and nitrate contamination of the groundwater. The linkage between surface water and groundwater has been appreciated for many years, so the ESF-ESNERR water monitoring data can provide a critical connection with the studies of saltwater intrusion and nitrate contamination of groundwater.

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