Amphibians and Water Quality:

Assessing Water Quality Impacts on Aquatic Amphibians in the Santa Monica Mountains National Recreational Area

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1 Introduction

1.1 Background

The freshwater ecosystems in the Santa Monica Mountains have been subject to fragmentation and upstream development since the early 20th century. Riley *et al.* (2005) observed a correlation between urbanization and reduced diversity, distribution, and abundance of native amphibians. Because amphibians breed in water and have permeable skin, they are vulnerable to chemical and hydrological changes caused by urbanization. Understanding how water quality affects native amphibians is crucial to conservation efforts, as amphibians are considered indicators of ecosystem health.

1.2 Client

The National Park Service has been documenting changes in water quality and amphibian populations of the aquatic ecosystems in the Santa Monica Mountains. The National Park Service (NPS) is a federal agency that manages all national parks and monuments. Within the NPS, the Mediterranean Coast Network (MEDN) oversees three protected areas: Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SMM NRA). MEDN operates an Inventory and Monitoring (I&M) Program, which studies the status and trends of protected ecosystems under stewardship of the NPS. The information gathered provides support for planning, decision-making, and management of the protected areas.

1.3 Study Site

The SMM NRA is located about 30 miles to the northwest of Los Angeles and includes 154,095 acres fragmented by urbanization (Figure 1-1). The SMM NRA is bordered to the south by the coastline and encompasses mountain slopes covered with coastal sage scrub and chaparral. Riparian woodlands border streams in canyons, and oak woodland, oak savannah and open grassland cover valley floors.

The SMM NRA has a Mediterranean climate that is characterized by mild, wet winters and hot, dry summers (NPS 2013). In the Santa Monica Mountains, the coolest and wettest months are typically January and February and the mean annual precipitation can be as high as 30 inches near the crest of the mountains. Precipitation is highly variably from year to year, however, and it is not uncommon for extended droughts to last several years (NPS 2013).

There are dozens of streams throughout the mountains, most of which flow seasonally. Most run north-south, but there are also many east-west tributaries. Steep stream channels and heavy rainfall can create strong debris flows. In these flows, sediment mixes with water, forming a dense flow with the ability to cause great destruction. Winds can reach high intensities within and adjacent to the Santa Monica Mountains. During late fall, winter, and spring, Santa Ana winds are generated by the buildup of high pressure conditions over the high desert, creating disastrous fires and aggravating the debris flows via vegetation removal and top soil erosion. The Santa Monica Mountains experience landslides, due to the steep slopes and the poorly-cemented sedimentary rock, as well as earthquakes, which can also increase sedimentation (NPS 2013).

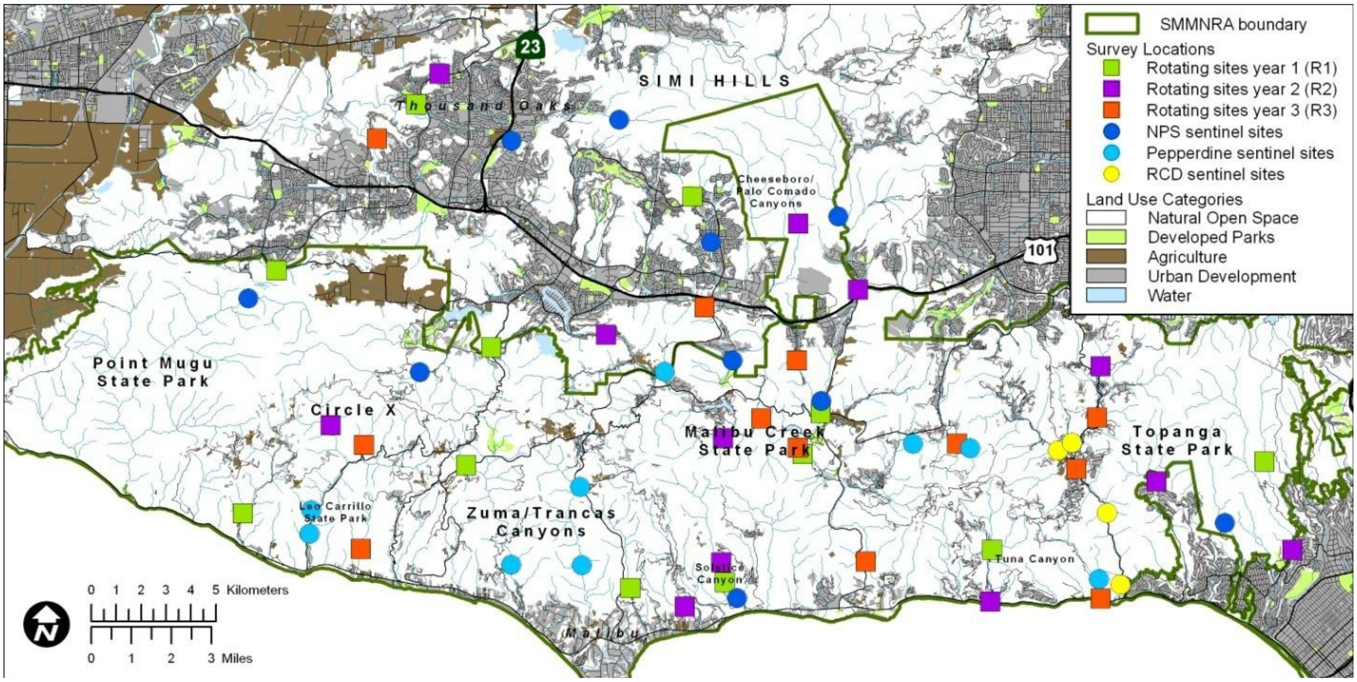


Figure 1-1 - Map of the Santa Monica Mountains National Recreation Area and marked study sites

1.4 NPS Monitoring Program

1.4.1 Amphibians

1.4.1.1 Species

The National Park Service monitors four native amphibian species under its Inventory and Monitoring Program (Table 1-1), as well as invasive fauna including crayfish, invasive fish, and the New Zealand Mudsnail. For some species and life stages they record an actual count of individuals, while other species-life stage combinations are recorded with an abundance estimate (Table 1-2). The method of recording depends on the nature of the life stage in question. Egg masses, for example, must be estimated, while individual adults can be counted more easily. There are five abundance estimate categories: less than 5, 5-20, 21-100, 101-500, and greater than 500.

Table 1-1 - Four native amphibian species monitored by the NPS

Common Name	Scientific Name	Four-Letter Abbreviation
Pacific Treefrog	*Pseudacris regilla*	HYRE
California Treefrog	*Pseudacris cadaverina*	HYCA
Western Toad	*Bufo boreas*	BUBO
California Newt	*Taricha torosa*	TATO

Table 1-2 - Method of recording abundance for each species and life stage

Species	Egg Masses	Larvae	Juveniles	Adults
HYRE	Abundance est.	Abundance est.	Abundance est.	Actual counts
HYCA	Abundance est.	Abundance est.	Abundance est.	Actual counts
BUBO	Abundance est.	Abundance est.	Abundance est.	Actual counts
TATO	Actual counts	Abundance est.	Abundance est.	Actual counts

1.4.1.2 Monitoring Sites

The NPS regularly monitors amphibians at ten sentinel sites comprised of “larger, mostly perennial streams, within the Santa Monica Mountains and Simi Hills.” In addition to the sentinel sites, there are 36 random sites, which were selected through a combination of generalized random tessellated stratified (GRTS) methods, percent protected lands within the surrounding area, and accessibility to the stream itself. All ten sentinel sites and twelve random sites are visited every year, such that the sentinel sites are visited annually and the random sites are visited once every three years (Hibbs et al 2006).

Each monitoring site is 250 meters long. Monitoring is conducted at multiple stops along this length, at each change of habitat. Stream habitat is classified as one of the following four types: riffle, pool, run, and dry (Table 1-3).

Table 1-3 - Four different habitat types identified in a reach, including their definitions.

Habitat Type	Definition
Run	Deeper slow-moving water
Riffle	Quick shallow-moving water
Pool	Slow to non-moving bodies of water
Dry	No standing or flowing water

1.4.1.3 Site Visits

Sites are visited twice within their designated year, once as an “intensive survey” and once as an “occupancy survey.” The dates of the intensive survey are determined by species-specific breeding patterns and are dependent on yearly climate variations. They typically occur between March and June, and the National Park Service collects detailed demographic data concerning abundance of the target amphibian species and non-native fauna. The occupancy survey follows within two weeks to three months and is used to note presence/absence of the target amphibian and non-native fauna species along the same 250-meter length of stream.

1.4.2 Water Quality

1.4.2.1 Parameters

The NPS monitored sixteen water quality parameters (Hibbs et al. 2006) through its MEDN Fresh Water Quality Monitoring Program (Table 1-4). These measurements were taken by a contracted scientist, not by NPS staff.

Table 1-4 - Water Quality Parameters Monitored by the MEDN Fresh Water Quality Monitoring Program

Water Quality Parameters
Specific Conductance
Dissolved Oxygen
pH
Temperature
Total Suspended Solids (TSS)
Turbidity
Chloride
Nitrate-Nitrogen
Ammonia-Nitrogen
Total Nitrogen
Phosphate-Phosphorus
Phosphorus
Fluoride
Bromide
Sulfate-Sulfur
Discharge

1.4.2.2 Monitoring Sites

The site locations, although listed under different vernacular names, are the same for water quality monitoring as for amphibian monitoring. The National Park Service included a stream code for each reach to avoid confusion. Water quality monitoring does not follow the stops method of amphibian monitoring, but it includes three measurements for each parameter for a given sampling event and monitoring site.

Water quality monitoring sites are coincident with the amphibian monitoring sites, resulting in ten sentinel sites and 36 random sites, which were supposed to be sampled on the same schedule as the amphibian random sites, according to the monitoring protocol. Water quality monitoring also included nine judgment sites, which do not correspond with amphibian monitoring sites.

1.4.2.3 Monitoring Dates

According to the protocol, water quality monitoring should be conducted three times a year: at first flush, during mid-flow (early spring), and during summer low-flow (late summer). [Note that actual dates often did not correspond with the amphibian monitoring dates.]

1.5 Research Question and Project Objective

This report analyzes six years of amphibian and water quality data (2006-2011) collected by the I&M Program for the SMM NRA to answer the following research question: are there relationships between native amphibian distribution and abundance and the tested water quality parameters? We have temporally and spatially summarized the range and variation of each water quality parameter as well as the variation in abundance of each species. We examined the relationship between the tested parameters and each species individually as well as relationships between the tested parameters and different amphibian life stages.   For both summary statistics and correlation analyses, the report discusses percent urbanization of monitored streams and presents findings in the context of urbanization.

Ultimately, the findings from this project will help to further characterize the relationship between urbanization and amphibian occupancy and formulate recommendations for a revised water quality monitoring protocol.

2 Methods

2.1 Literature Review

We focused our literature review on the relationship between the four native amphibian species monitored by the National Park Service (Table 1-1) and the 15 monitored water quality parameters. To narrow our search we began with studies concerning the water quality parameters and eliminated research based on species and location. Our first priority was to find studies involving the four native amphibian species, and if such studies were unavailable we expanded to other amphibian species. We focused location on the Santa Monica Mountains and California as much as possible, but where information was lacking we expanded globally. We also examined the context of the study to be sure it applied to the Santa Monica Mountains. For example, studies concerning extremely cold weather, high altitudes, or mining activities were not included because of their irrelevance to our study site.

2.2 Literature Index

To summarize our literature review, we created an index of all of our sources (Appendix I).This index lists each study by author's last name and year and identifies whether the study involved one of the four monitored amphibian species or 15 monitored water quality parameters. We indicated whether the study site was located in the Santa Monica Mountains or California, and whether it was a lab study, field study, or a review. The index also indicates if the study involved additional amphibian species, other animal taxa, or additional parameters of interest.

2.3 Data Management

2.3.1 Data Organization

We organized the original water quality dataset by three filters: year, monitoring location, and parameter, and applied each filter separately. We organized amphibian data similarly, by species, monitoring site, and year. We used site codes rather than site names to ensure monitoring locations were the same for both the amphibians and the water quality parameters.

2.3.2 Analysis Focus

Due to the extensiveness of the data and the limits on our time, we narrowed our focus for both the water quality parameters and the amphibian data.

2.3.2.1 Water Quality Parameters

This report focuses only on data from the NPS and its Inventory and Monitoring Program. Although amphibian monitoring is also conducted by Pepperdine and the Resource Conservation District, there was no corresponding water quality monitoring data.

Due to time constraints, our goal was to focus the scope of our study on the most important water quality parameters. We narrowed our scope based on four qualifications: quality of data, literature review, local context, and water quality criteria. Parameters without complete data sets would provide too little data for analysis and were therefore eliminated from any statistical analysis. The literature review indicated which parameters were likely to have the largest effect on amphibians, as well as which of two similar parameters (such as turbidity and total suspended solids) would provide more quantitative statistical results. Local context refers to the geography, climate, and anthropogenic influence in the SMM NRA: parameters whose sources did not apply to the local context were eliminated. Finally, if our summary statistics indicated that a parameter did not exceed regulatory or recommended values, we did not proceed with further analyses.

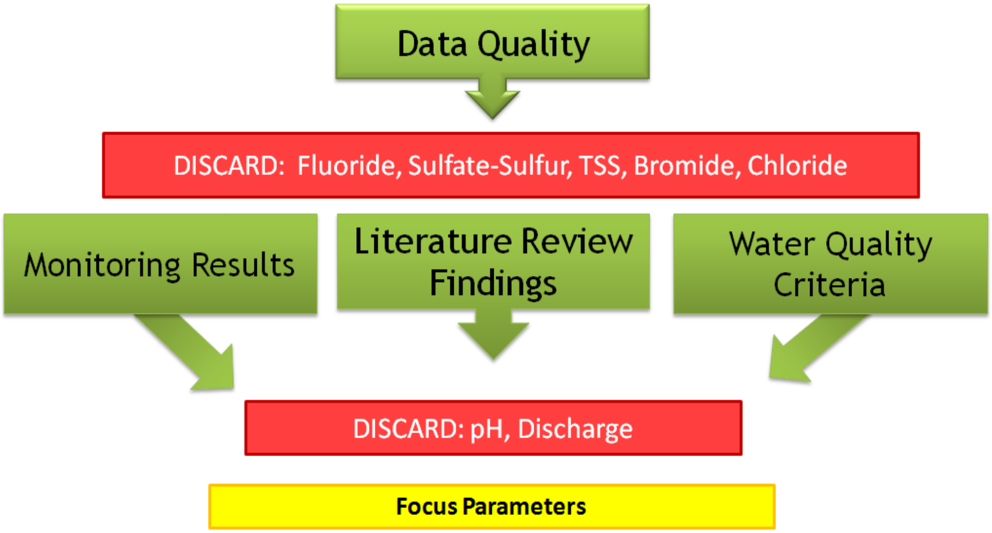


Figure 2-1 - Method for narrowing our analysis focus

2.3.2.2 Amphibian Data

From a discussion with our client contact, Dr. Katy Delaney, we decided to focus on the larvae abundance estimates for all species and the adult counts for the California Newt (Federico 2013). This decision stems from the fact that the Western Toad, Pacific Treefrog, and California Treefrog are active primarily at night; counts during the day do not give an accurate representation of abundance. Furthermore, we worked with abundance data only and did not analyze the second monitoring of presence/absence.

2.3.2.3 Water Quality Criteria

The Los Angeles Regional Water Quality Control Board (LARWQCB) Basin Plan (1994) specifies water quality objectives for many parameters, including some of the 15 parameters monitored by the NPS (Table 2-1). A water quality objective defines maximum or minimum levels of a parameter, consistent with the beneficial uses for a water body or region. A beneficial use "defines the resources, services, and qualities of these aquatic systems that are the ultimate goals of protecting and achieving high water quality" (LARWQCB), and can range from recreational uses to fishing services to aquatic habitat. Water quality objectives set by the LARWQCB are consistent with or more stringent than the criteria set by the EPA, and we therefore used the Water Basin Plan as a guideline for criteria. Parameters whose levels in the SMM NRA violated the water quality criteria or objectives were considered priority parameters for our statistical analysis. Some parameters did not have an established criterion or objective, and we found values in the literature to guide our analyses and recommendations.

We based our temperature water quality objective on the upper limit for warm waters, despite the mix of warm and cold waters in the Santa Monica Mountains, because warm waters have a single temperature objective, whereas cold water temperature objectives vary according to the normal temperature of the stream. The warm water upper limit is 26.7 degrees Celsius, and we determined that any waters exceeding this standard would also exceed any stricter standards. Water quality objectives for Ammonia-Nitrate exist are dependent on pH and temperature as well (LARWQCB), and we assumed a pH of 7 and temperature of 25 degrees Celsius to calculate the 30-day benchmark value (Basin Plan 1994).

Table 2-1 - Water Quality Objectives and guidelines as defined by the LARWQCB, US EPA, and other sources. A * indicates recommended guidelines based on studies, observations, or literature.

Water Quality Parameter	Units	State Water Resources Control Board Water Quality Control Basin Plan	United States Environmental Protection Agency	Other Sources
Ammonia	mg/L	30-day Average Concentration: 3.0		
Dissolved Oxygen	mg/L	Minimum for all waters: 7.0 Min. for cold waters: 6.0 Min. for warm waters: 5.0		
Nitrate-Nitrogen	mg/L	Maximum: 10.0		
Nitrate	mg/L	Maximum: 45.0		
Phosphate as Phosphorus	mg/L		Minimum: 0.1*	
Phosphate as Phosphate	mg/L		Minimum: 0.1*	
Specific Conductance	µS/cm		Maximum: 500*	

Temperature	ºC	Maximum: 27.6*		
Turbidity	NTU	0-50 NTU areas: exceed no more than 20%; >50 NTU areas: exceed no more than 10%		
pH	pH	Between: 6.5 and 8.5		
Discharge	cfs	No set standards.		
Fluoride	mg/L			Maximum: 1.5, with 1.0 as recommended level for drinking water (US Public Health)
Sulfate	mg/L	No set standards.		
TSS	mg/L	No set standards.		
Bromide	mg/L			Maximum: 1.0* (Flury & Papritz, 1993)
Chloride	mg/L		Acute: 860 mg/L; Chronic: 230 mg/L	

Table 2-2 - Beneficial Uses of waters in the Santa Monica Mountains (Hibbs et al. 2006)

Acronym	Definition
AGR	Agricultural Supply
COLD	Cold Freshwater Habitat
FRESH	Freshwater Replenishment
GWR	Groundwater Recharge
MIGR	Fish Migration
MUN	Municipal Supply
RARE	Preservation of Rare and Endangered Species
REC1	Contact Water Recreation
REC2	Non-contact Water Recreation
SPWN	Fish Spawning
WARM	Warm Freshwater Habitat
WET	Wetland Habitat
WILD	Wildlife Habitat

2.3.3 Pairing Data

As mentioned earlier, the dates of amphibian monitoring often did not correspond with the dates of water quality monitoring. We therefore needed to select the most appropriate water quality monitoring date to pair with each amphibian monitoring date, to conduct our analyses.

We paired data from 2006 to 2011 for the Sentinel and Random 1 sites. The Random 2 and Random 3 sites did not have enough data to create pairs, and the water quality judgment sites did not have corresponding amphibian monitoring sites. Our approach was to pair dates within the same wet season, the first rainfall in the fall through August 30th of the following year (Table 2-3); however, to make better decisions on a year-by-year basis, we also researched the date of the first rainfall event for each year in the study period (Table 8).

Table 2-3 - Dates of first rainfall at Malibu Canyon RAWS Station (Climate Analyzer).

Water Year	First Rainfall
2006-2007	October 13, 2006
2007-2008	September 21, 2007
2008-2009	November 4, 2008
2009-2010	October 13, 2009
2010-2011	October 6, 2010

If there were two water quality monitoring dates equidistant from the amphibian monitoring date within the same water year, we chose the water quality date that occurred earlier in the year, with the assumption that that date would be more representative of actual water quality conditions. The resulting paired dates are shown in the following tables:

Water Quality		2006		2007		2008		2009		
Location	**Type**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 3**
Sentinel										
Big Sycamore	S	**09/19/06**		**08/22/07**		**04/23/08**				
Carlisle Canyon	S	**09/19/06**				**04/06/08**				
Lang Ranch South (Erbes)	S					**03/25/08**	**11/25/08**	**05/11/09**	**08/25/09**	**12/23/09**
Lang Ranch North	S	**08/31/06**		**05/28/07**		**03/26/08**				
Las Virgenes (N)	S	**08/08/06**		**04/19/07**		**02/19/08**	**10/30/08**	**05/06/09**	**08/17/09**	**12/29/09**
Las Virgenes (S)	S	**09/14/06**		**05/25/07**		**02/02/08**	**11/04/08**	**06/08/09**	**08/20/09**	**12/21/09**
Medea Creek (N)	S	**08/29/06**		**04/24/07**		**01/13/08**	**11/06/08**	**05/31/09**	**08/24/09**	**12/23/09**
Medea Creek (S)	S	**09/05/06**		**05/11/07**		**03/25/08**	**11/18/08**	**06/08/09**	**08/24/09**	**12/30/09**
Lower Solstice Canyon Creek	S	**08/10/06**		**05/31/07**		**07/22/08**	**12/11/08**	**06/16/09**	**09/28/09**	
Temescal Canyon	S	**10/19/06**		**07/16/07**		**04/20/08**		**01/04/09**	**06/23/09**	**09/18/09**
Random 1										
Arroyo Conejo	R1									
Conejo Creek	R1			**06/01/07**		**04/06/08**	**12/30/08**	**06/22/09**		
Carlisle Creek (Eleanor)	R1					**04/01/08**	**12/21/08**			
Las Flores	R1									
Liberty Canyon (at confluence)	R1			**05/25/07**		**02/02/08**	**10/30/08**	**05/11/09**		
Little Sycamore (Jewish camp)	R1									
Malibu Creek (Mott adobe)	R1			**06/07/07**		**06/05/08**	**11/20/08**	**07/07/09**		
Medea Creek (at park)	R1			**05/28/07**		**01/08/08**		**05/06/09**		
Ramirez Canyon	R1			**08/22/07**		**04/23/08**		**01/13/09**	**07/01/09**	
Solstice Creek (at bridge)	R1			**05/31/07**		**07/22/08**	**12/11/08**	**06/16/09**		
Sullivan Canyon	R1					**06/17/08**		**03/26/09**	**07/01/09**	
West Fork Trancas	R1			**07/01/07**		**04/01/08**	**12/18/08**	**06/23/09**		
Random 3										
Arroyo Sequit (Year 3)	R3							**10/12/09**		

Cold Creek (off Stunt Road)	R3					**10/16/09**		
Conejo Creek (Year 3)	R3					**10/26/09**		
Ladyface	R3					**10/07/09**	**12/30/09**	
Liberty Canyon (above pitfalls)	R3					**10/07/09**		
Malibu Creek (Crags Road)	R3					**10/23/09**		
Malibu Creek (at Cross Creek)	R3							
Malibu Creek SP (rock pool)	R3							
Malibu Nature Preserve	R3					**11/05/09**		
Topanga Creek (at Summit Road)	R3					**10/07/09**		
Topanga Creek (at Topanga Blvd)	R3					**10/16/09**		
Tuna Canyon (from PCH)	R3					**10/12/09**		
Judgment								
Arroyo Sequit	J	**08/10/13**	**05/31/07**	**04/20/08**	**12/18/08**	**06/11/09**	**08/25/09**	**10/12/09**
Cheeseboro Creek (1st well)	J			**04/08/08**				
East Fork Las Virgenes	J	**08/10/06**	**05/11/07**	**03/26/08**		**03/25/09**	**06/25/09**	**10/12/09**
La Jolla	J	**09/11/06**	**07/18/07**	**06/18/08**				
Lower Cold Creek	J	**08/08/06**	**04/19/07**	**02/02/08**		**05/13/09**	**12/21/09**	
Lower Topanga Creek	J	**08/14/06**	**06/07/07**	**05/21/08**	**12/04/08**	**06/18/09**	**09/18/09**	
Malibu Creek Lower	J	**10/05/06**	**07/18/07**			**01/04/09**	**06/11/09**	**09/21/09**
Malibu Creek Upper	J	**10/05/06**	**06/07/07**	**06/05/08**	**11/20/08**	**07/07/09**	**09/21/09**	
Upper Cold Creek	J	**08/08/06**	**04/24/07**	**02/19/08**	**11/04/08**	**05/13/09**	**08/20/09**	**12/29/09**
Upper Topanga Creek	J	**08/14/06**	**06/07/07**	**05/21/08**		**06/18/09**		

Water Quality		2010				2011
Location	**Type**	**Visit 1**	**Visit 2**	**Visit 3**	**Visit 4**	**Visit 1**
Sentinel						
Big Sycamore	S	**03/09/10**	**06/25/10**			**03/03/11**
Carlisle Canyon	S	**02/22/10**	**05/24/10**			**01/25/11**
Lang Ranch South (Erbes)	S	**05/12/10**	**08/26/10**	**12/10/10**		
Lang Ranch North	S	**01/11/10**	**06/23/10**			**02/08/11**
Las Virgenes (N)	S	**05/19/10**	**09/09/10**			**01/04/11**
Las Virgenes (S)	S	**04/29/10**	**08/30/10**	**12/30/10**		
Medea Creek (N)	S	**05/19/10**	**08/26/10**	**12/10/10**		
Medea Creek (S)	S	**06/18/10**	**09/01/10**	**12/28/10**		
Lower Solstice Canyon Creek	S	**02/17/10**	**05/20/10**	**09/13/10**		**02/15/11**
Temescal Canyon	S	**01/13/10**	**06/10/10**	**09/27/10**		**02/18/11**
Random 1						
Arroyo Conejo	R1					**03/18/11**
Conejo Creek	R1	**05/24/10**	**09/25/10**			**02/22/11**
Carlisle Creek (Eleanor)	R1	**04/21/10**				**01/25/11**
Las Flores	R1					
Liberty Canyon (at confluence)	R1	**04/29/10**	**08/30/10**	**12/30/10**		
Little Sycamore (Jewish camp)	R1					**03/31/11**
Malibu Creek (Mott adobe)	R1	**06/11/10**	**10/13/10**			**03/16/11**
Medea Creek (at park)	R1	**04/21/10**	**12/28/10**			
Ramirez Canyon	R1	**07/02/10**	**11/08/10**			**03/31/11**
Solstice Creek (at bridge)	R1	**05/20/10**	**09/13/10**			**02/15/11**
Sullivan Canyon	R1	**06/25/10**	**08/31/10**			**03/28/11**
West Fork Trancas	R1	**06/04/10**	**09/07/10**			**01/28/11**
Random 3						
Arroyo Sequit (Year 3)	R3	**03/10/10**				
Cold Creek (off Stunt Road)	R3	**03/03/10**				
Conejo Creek (Year 3)	R3	**03/08/10**				
Ladyface	R3					
Liberty Canyon (above pitfalls)	R3	**01/11/10**				
Malibu Creek (Crags Road)	R3	**01/06/10**				
Malibu Creek (at Cross Creek)	R3	**03/03/10**				

Malibu Creek SP (rock pool)	R3					
Malibu Nature Preserve	R3	**03/11/10**				
Topanga Creek (at Summit Road)	R3	**01/25/10**				
Topanga Creek (at Topanga Blvd)	R3	**01/27/10**				
Tuna Canyon (from PCH)	R3	**01/13/10**				
Judgment						
Arroyo Sequit	J	**01/17/10**		**06/04/10**	**09/20/10**	**01/28/11**
Cheeseboro Creek (1st well)	J					
East Fork Las Virgenes	J	**02/22/10**	**06/05/10**	**10/03/10**	**12/27/10**	
La Jolla	J	**02/17/10**	**07/02/10**			**02/18/11**
Lower Cold Creek	J	**05/04/10**	**09/02/10**	**12/08/10**		
Lower Topanga Creek	J	**01/27/10**	**06/17/10**	**09/15/10**		**02/11/11**
Malibu Creek Lower	J	**01/17/10**	**06/10/10**	**09/20/10**		**03/18/11**
Malibu Creek Upper	J	**01/06/10**	**06/11/10**	**10/13/10**		**03/16/11**
Upper Cold Creek	J	**05/04/10**	**09/08/10**	**12/08/10**		
Upper Topanga Creek	J	**01/25/10**	**06/17/10**			**02/11/11**

Species Data		2006		2007		2008		2009	
Location	**Type**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**
Sentinel									
Big Sycamore Canyon	S	**07/25/06**						**05/13/09**	
Carlisle Canyon	S	**05/25/06**				**06/11/08**		**06/25/09**	
Erbes (Lower)	S	**06/06/06**		**05/16/07**		**06/10/08**		**05/21/09**	
Lang Ranch (N)	S	07/26/06				**07/02/08**		**05/22/09**	
Las Virgenes (N)	S	**05/09/06**		**04/11/07**		**06/06/08**		**05/28/09**	
Las Virgenes (S)	S	**05/11/06**		**05/29/07**		07/11/08		06/30/09	
Medea Creek (N)	S	06/07/06		**05/18/07**		**06/10/08**		**06/26/09**	
Medea Creek (S)	S	**05/10/06**		**05/25/07**	06/26/07			**06/04/09**	
Solstice Canyon	S	**07/12/06**		**07/24/07**		**06/17/08**		**06/17/09**	
Temescal Canyon	S	**07/06/06**				**06/10/08**	**06/19/08**	**06/16/09**	
Random 1									
Arroyo Conejo	R1								
Conejo Creek	R1			**04/26/07**					
Eleanor	R1			**04/03/07**					
Las Flores	R1								
Liberty	R1			**04/19/07**					
Little Sycamore	R1								
Malibu Creek	R1			**04/27/07**					
Medea Creek	R1			05/10/07					
Ramirez	R1			**08/09/07**					
Solstice Canyon (upper)	R1			**07/24/07**					
Sullivan Canyon	R1			08/03/07					
West Fork Trancas	R1								
Random 3									
Arroyo Sequit (year 3)	R3							**05/20/09**	
Cold Creek (Stunt Rd)	R3							**07/01/09**	
Conejo Creek (year 3)	R3							07/22/09	
Ladyface	R3							**06/09/09**	
Liberty Canyon (above pitfalls)	R3							**06/03/09**	
Malibu Creek (Crags Rd)	R3							07/10/09	

Malibu Creek (at Cross Creek)	R3	07/23/09
Malibu Creek SP (rock pool)	R3	07/16/09
Malibu Nature Preserve	R3	
Topanga Creek at (Summit Rd)	R3	07/21/09
Topanga Creek (at Topanga Rd)	R3	
Tuna Canyon (from PCH)	R3	07/06/09

Species Data		2010		2011		2012	
Location	**Type**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**	**Visit 1**	**Visit 2**
Sentinel							
Big Sycamore Canyon	S	**06/14/10**		**06/21/11**		05/30/12	
Carlisle Canyon	S	06/09/10		04/19/11		06/12/12	
Erbes (Lower)	S	**06/21/10**		**06/22/11**		06/11/12	
Lang Ranch (N)	S	**06/17/10**		**06/30/11**		**05/31/12**	
Las Virgenes (N)	S	**06/10/10**		04/12/11		05/16/12	
Las Virgenes (S)	S	**06/30/10**		**07/06/11**		**06/15/12**	
Medea Creek (N)	S	**07/07/10**		**06/20/11**		**06/20/12**	
Medea Creek (S)	S	**06/29/10**		05/04/11		**06/14/12**	
Solstice Canyon	S	**06/02/10**		**06/22/11**		**07/16/12**	
Temescal Canyon	S	**06/22/10**		**07/07/11**		06/07/12	
Random 1							
Arroyo Conejo	R1						
Conejo Creek	R1	**07/06/10**					
Eleanor	R1	**06/14/10**					
Las Flores	R1	**06/24/10**					
Liberty	R1	**06/28/10**					
Little Sycamore	R1	**06/22/10**					
Malibu Creek	R1						
Medea Creek	R1	**06/16/10**					
Ramirez	R1	**06/15/10**					
Solstice Canyon (upper)	R1	**06/29/10**					
Sullivan Canyon	R1	**06/23/10**					
West Fork Trancas	R1	**07/02/10**					
Random 3							
Arroyo Sequit (year 3)	R3					05/29/12	
Cold Creek (Stunt Rd)	R3					**07/12/12**	
Conejo Creek (year 3)	R3					**07/30/12**	
Ladyface	R3					07/30/12	
Liberty Canyon (above pitfalls)	R3					**06/13/12**	
Malibu Creek (Crags Rd)	R3					08/07/12	

Malibu Creek (at Cross Creek)	R3	07/12/10	08/01/12
Malibu Creek SP (rock pool)	R3		**06/26/12**
Malibu Nature Preserve	R3		
Topanga Creek at (Summit Rd)	R3		**06/18/12**
Topanga Creek (at Topanga Rd)	R3		**07/11/12**
Tuna Canyon (from PCH)	R3		06/07/12

Master Paired Data		2006		2007		2008		2009	
Location	**Type**	**WQ**	**Species**	**WQ**	**Species**	**WQ**	**Species**	**WQ**	**Species**
Sentinel									
Big Sycamore	S	09/19/06	07/25/06						
Carlisle Canyon	S	09/19/06	05/25/06						
Lang Ranch South (Erbes)	S					03/25/08	06/10/08	05/11/09	06/21/09
Lang Ranch North	S	08/31/06	07/26/06			03/26/08	07/02/08		
Las Virgenes (N)	S	08/08/06	05/09/06	04/19/07	04/10/07	02/19/08	06/06/08	06/06/09	05/22/09
Las Virgenes (S)	S	09/14/06	05/11/06	05/25/07	05/28/07	02/02/08	07/11/08	06/08/09	06/30/09
Medea Creek (N)	S	08/29/06	06/07/06	04/24/07	05/17/07	01/13/08	06/10/08	05/31/09	06/30/09
Medea Creek (S)	S	09/05/06	05/10/06	05/11/07	05/24/07			06/08/09	06/04/09
Lower Solstice Canyon Creek	S	08/10/06	07/12/06	05/31/07	07/23/07	07/22/08	06/17/08	06/16/09	06/17/09
Temescal Canyon	S	10/19/06	07/06/06			04/20/08	06/10 & 19	06/23/09	06/16/09
Random 1									
Arroyo Conejo	R1								
Conejo Creek	R1			06/01/07	04/26/07				
Carlisle Creek (Eleanor)	R1								
Las Flores	R1								
Liberty Canyon (at confluence)	R1								
Little Sycamore (Jewish camp)	R1								
Malibu Creek (Mott adobe)	R1			06/07/07	04/27/07				
Medea Creek (at park)	R1			05/28/07	05/10/07				
Ramirez Canyon	R1			08/22/07	08/09/07				
Solstice Creek (at bridge)	R1			05/31/07	07/24/07				
Sullivan Canyon	R1								
West Fork Trancas	R1								

Master Paired Data		2010		2011	
Location	**Type**	**WQ**	**Species**	**WQ**	**Species**
Sentinel					
Big Sycamore	S	**06/25/10**	**06/14/10**	**03/03/11**	**06/21/11**
Carlisle Canyon	S	**05/24/10**	**06/09/10**	**01/25/11**	**04/19/11**
Lang Ranch South (Erbes)	S	**05/12/10**	**06/21/10**		
Lang Ranch North	S	**06/23/10**	**06/17/10**	**02/08/11**	**06/30/11**
Las Virgenes (N)	S	**05/19/10**	**06/10/10**	**01/04/11**	**04/12/11**
Las Virgenes (S)	S	**04/29/10**	**06/30/10**		
Medea Creek (N)	S	**05/19/10**	**07/07/10**		
Medea Creek (S)	S	**06/18/10**	**06/29/10**		
Lower Solstice Canyon Creek	S	**05/20/10**	**06/02/10**	**02/15/11**	**06/22/11**
Temescal Canyon	S	**06/10/10**	**06/22/10**	**02/18/11**	**07/07/11**
Random 1					
Arroyo Conejo	R1				
Conejo Creek	R1	**05/24/10**	**07/06/10**		
Carlisle Creek (Eleanor)	R1				
Las Flores	R1				
Liberty Canyon (at confluence)	R1	**04/29/10**	**06/28/10**		
Little Sycamore (Jewish camp)	R1				
Malibu Creek (Mott adobe)	R1				
Medea Creek (at park)	R1	**04/21/10**	**06/16/10**		
Ramirez Canyon	R1	**07/02/10**	**06/15/10**		
Solstice Creek (at bridge)	R1	**05/20/10**	**06/29/10**		
Sullivan Canyon	R1	**06/25/10**	**06/23/10**		
West Fork Trancas	R1	**06/04/10**	**07/02/10**		

2.3.4 Assumptions

2.3.4.1 Zero Data

The data we received only included abundance values for species found in the field; no data was provided for when amphibians were absent. Based on a discussion with Dr. Katy Delaney (Delaney 2013), we assumed that NPS staff searched for all species when conducting amphibian monitoring. If a species was not listed on a given date and location, we assumed that none were found. For monitoring sites where no native species amphibian data was recorded, we assumed zero amphibian abundance for the entire site on that date. For sites where native species were found at certain stops but not listed at others, we assumed the highest stop number to be the total number of stops and assumed zero amphibian abundance for each missing stop number.

2.3.4.2 Non-Detect Measurements

For data labeled as "ND", we assumed a value equal to half the minimum detection limit for that parameter (NPS 2012):

Table 2-4 - Assumptions for non-detect measurements

Chemical Parameter	Minimum Detection Levels	Assumption
Ammonia - Nitrogen	0.015 mg/L NH3-N	0.0075mg/L NH3-N
Nitrate-Nitrogen	0.1 mg/L NO3-N	0.05 mg/L NO3-N
Nitrate	0.1 mg/L NO3-N	0.05 mg/L NO3-N
Phosphorus	0.02 mg/L HPO4	0.01 mg/L HPO4
Phosphate-Phosphorus	0.02 mg/L HPO4	0.01 mg/L HPO4
Specific Conductance	1 uS/cm	0.5 uS/cm
Bromide	0.014 mg/L	0.007 mg/L

2.4 Summary Statistics

2.4.1 Quality Control

Water quality parameters were measured at three points across the stream for each location and date; the average of the three measurements was meant to be used as the final value for that site. As a quality control check, we plotted these values using a box-and-whisker plot, where each box-and-whisker plot represented one date's measurement at one monitoring site (Appendix E)(Figure 2-2). We visually assessed the consistency between each of the three measurements, with input from UCLA Professor Jenny Jay. We determined there were no anomalies, and therefore did not eliminate any measurements based on this review. These three values were averaged for every date and site and treated as one value for the remainder of the project.

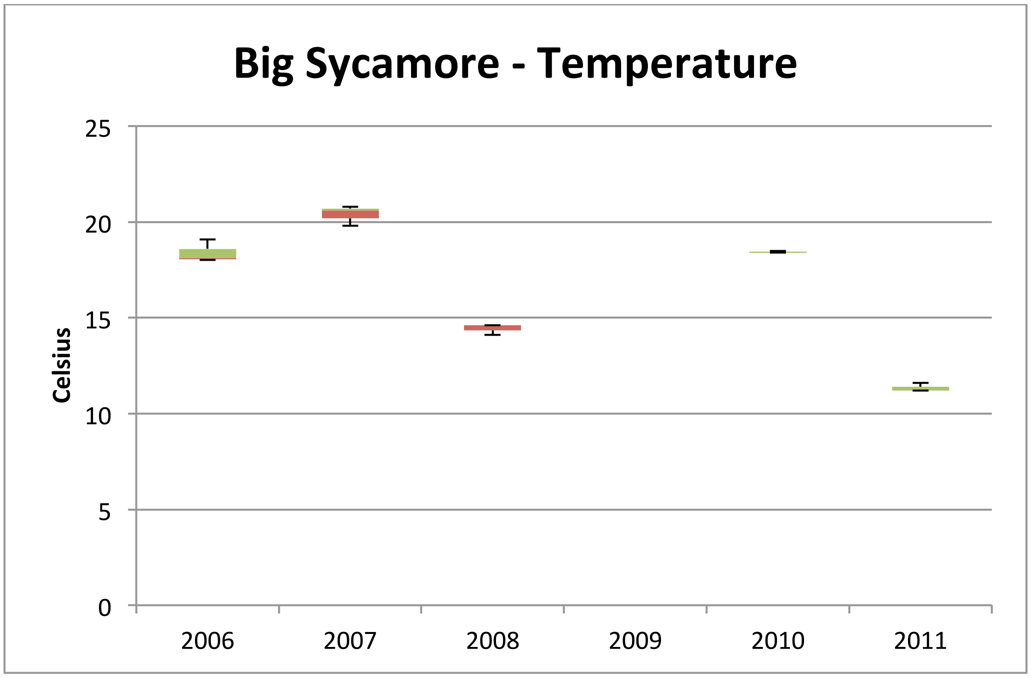


Figure 2-2 - Example of a Quality Control box-and-whisker plot series for Temperature at Big Sycamore. Each box-and-whisker plot shows the three measurements taken on the monitoring date for that year.

2.4.2 Water Quality

We summarized each water quality parameter with three graphs. The first is a box-and-whisker plot with data from all years to compare locations (Figure 2-3). The second graph is a bar chart examining each location over the study period (Figure 2-5), and the third is a bar chart comparing all locations within one year (Figure 2-6). All of these graphs were created in Microsoft Excel.

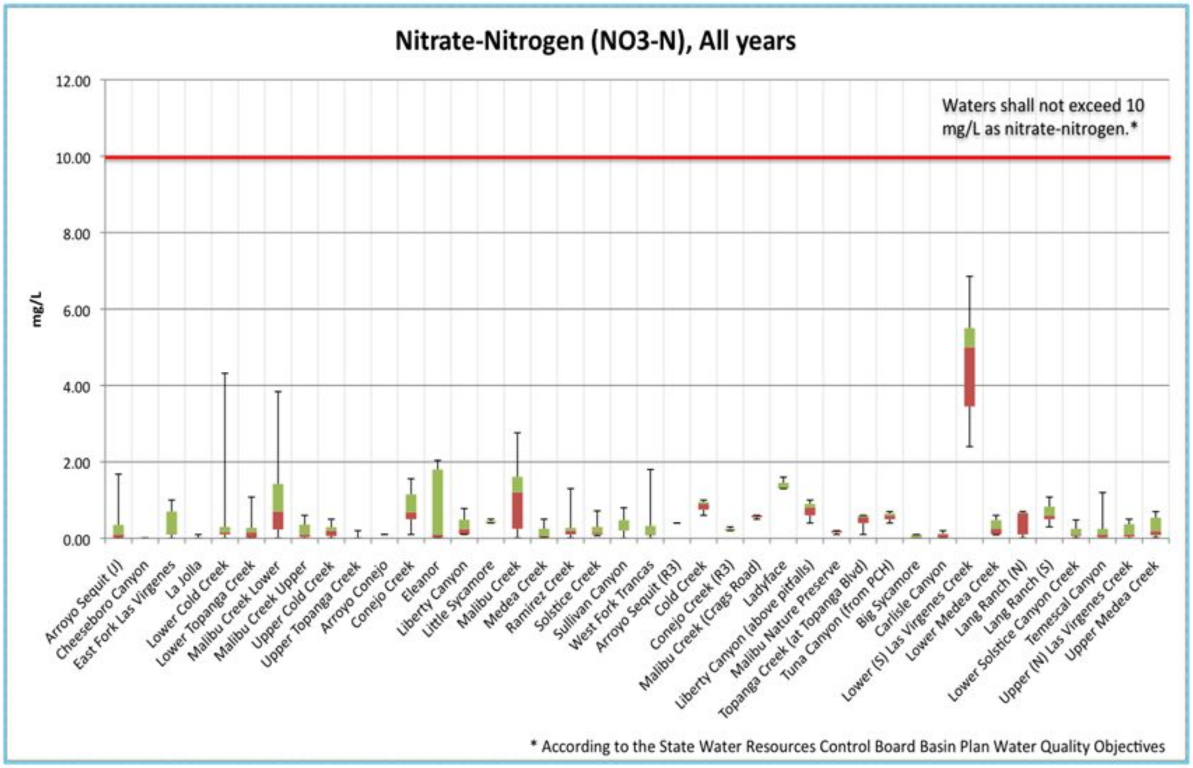


Figure 2-3 - Example of a box-and-whisker plot comparing Nitrate-Nitrogen data between monitoring sites. Each box-and-whisker plot contains all of the data available for that site. The red line indicates a water quality objective as defined by the LA Regional Water Quality Control Board Basin Plan.

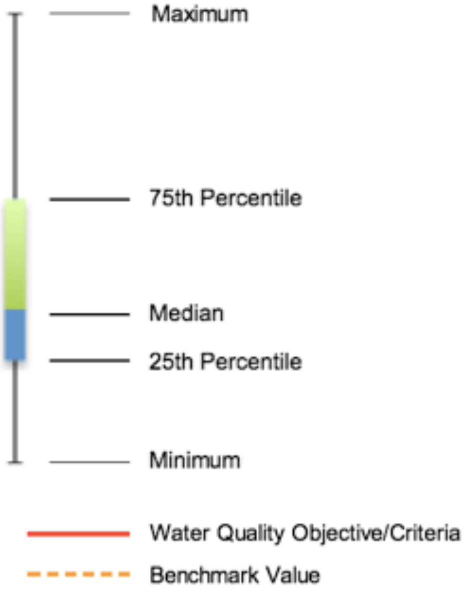


Figure 2-4- Legend explaining the box plot summary statistic graphs

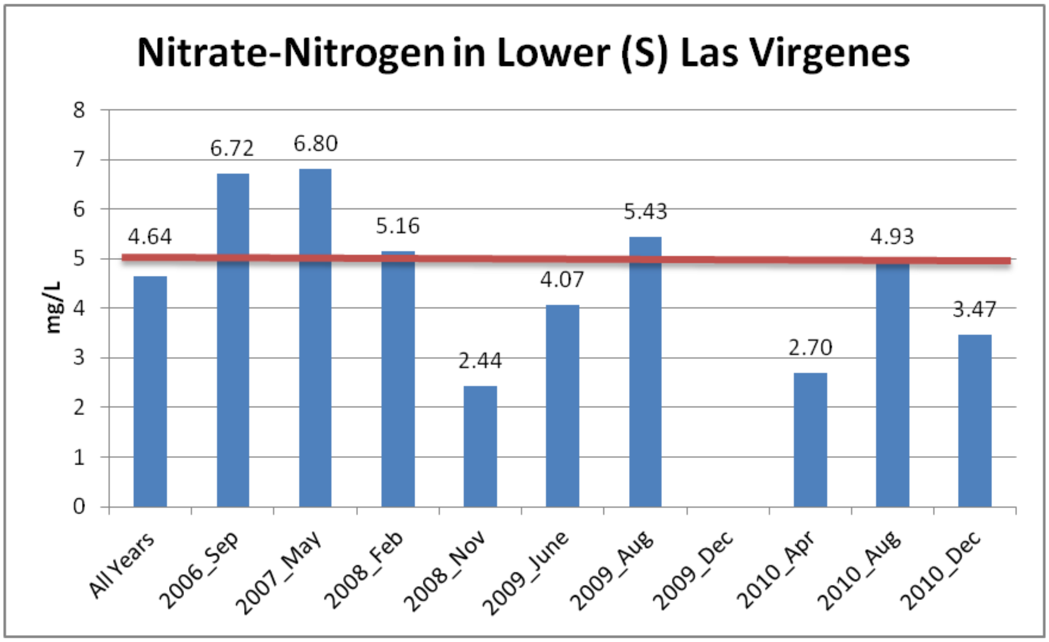


Figure 2-5 - Example of a bar chart showing a parameter at one site over time. This graph shows the change in Nitrate-Nitrogen at Lower (S) Las Virgenes from year to year. The red line indicates a water quality objective of 10.0 mg/L from the Basin Plan (1994). There were no nitrate-nitrogen measurements from December of 2009.

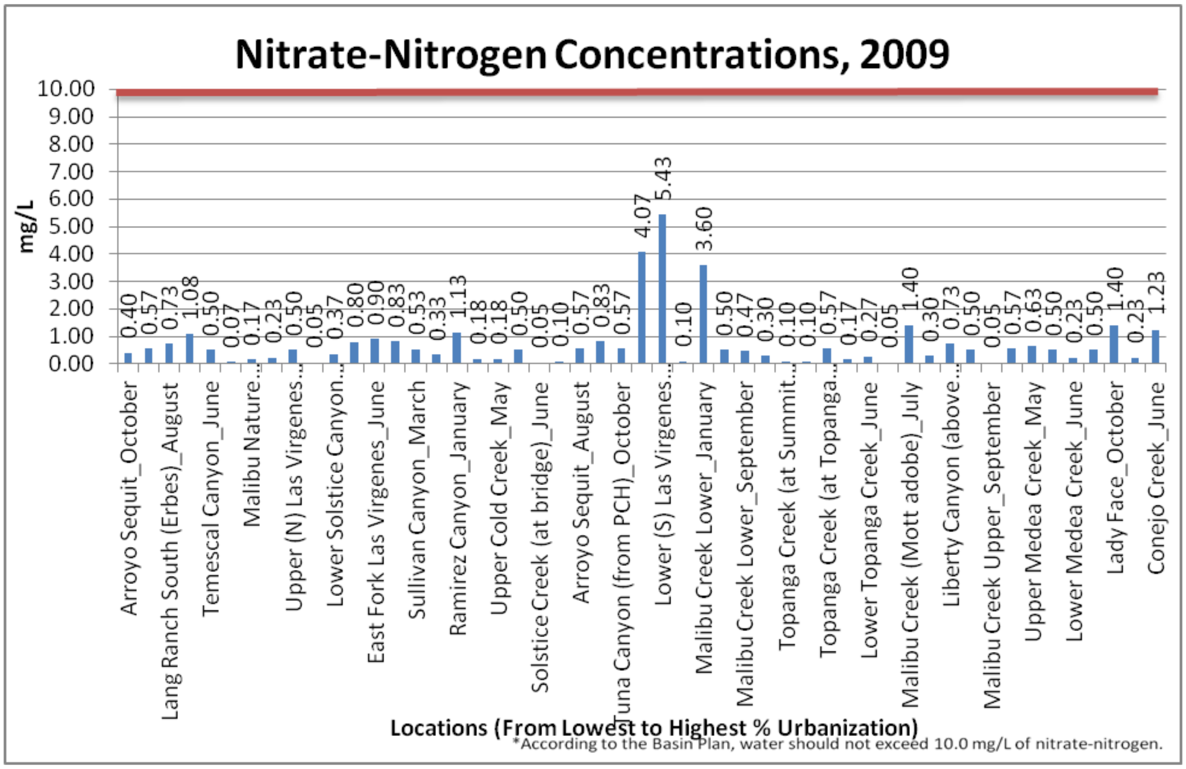
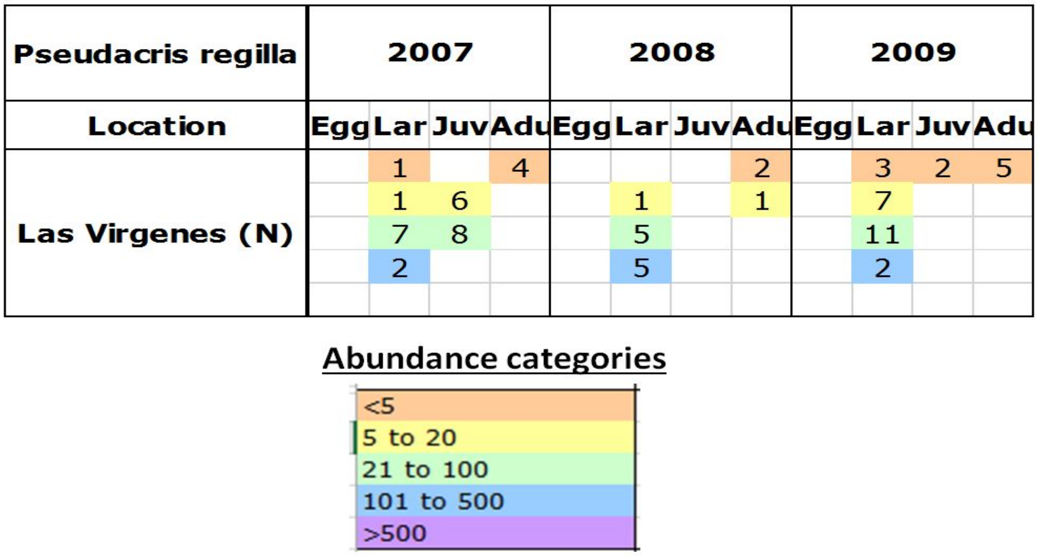


Figure 2-6 - Example of a bar chart showing the variation of one parameter in a given year among locations. Nitrate-Nitrogen is examined across locations for 2009. The red line indicates a water quality objective of 10.0 mg/L from the Basin Plan (1994).

2.4.3 Amphibians

To summarize the amphibian data, we first divided the data according to species: each species has its own chart. On the chart, each location occupies five rows and 24 columns: rows indicate abundance categories and columns indicate the year, which is further divided by life stage. One box on the chart indicates the life stage, year, location, and abundance category for a given species. The value in that box indicates the number of times an abundance category for a given life stage was recorded. Note that the number of stops in a reach varies by location and year. The chart was then further color-coded to allow for easy visual reference (Figure 2-7).



Pseudacris regilla	**2007**				**2008**				**2009**			
Location	**Egg**	**Lar**	**Juv**	**Adu**	**Egg**	**Lar**	**Juv**	**Adu**	**Egg**	**Lar**	**Juv**	**Adu**
Las Virgenes (N)		1		4				2		3	2	5
		1	6			1		1		7		
		7	8			5				11		
		2				5				2		

Abundance categories

🟧 <5
🟨 5 to 20
🟩 21 to 100
🟦 101 to 500
🟪 >500

Figure 2-7 - Excerpt of Amphibian Summary Chart. Refer to Appendix B for full chart.

2.5 Statistical Analysis

2.5.1 Relationship Graphs

We conducted a pre-test using a visual assessment of possible correlations between water quality parameters and amphibian abundance. For each larval stage of each species and for the adult stage of the California Newt we graphed abundance versus water quality. Note that these graphs plot abundance values measured at every stop within a single monitoring site, although there is only one corresponding water quality value. Subsequent statistical analyses discussed below involve creating a total abundance value for each site.

Abundance categories were converted into numbers for easy plotting:

Abundance Category	Number Value
0	0
<5	1
5-20	2
21-100	3
101-500, >100	4
>500	5

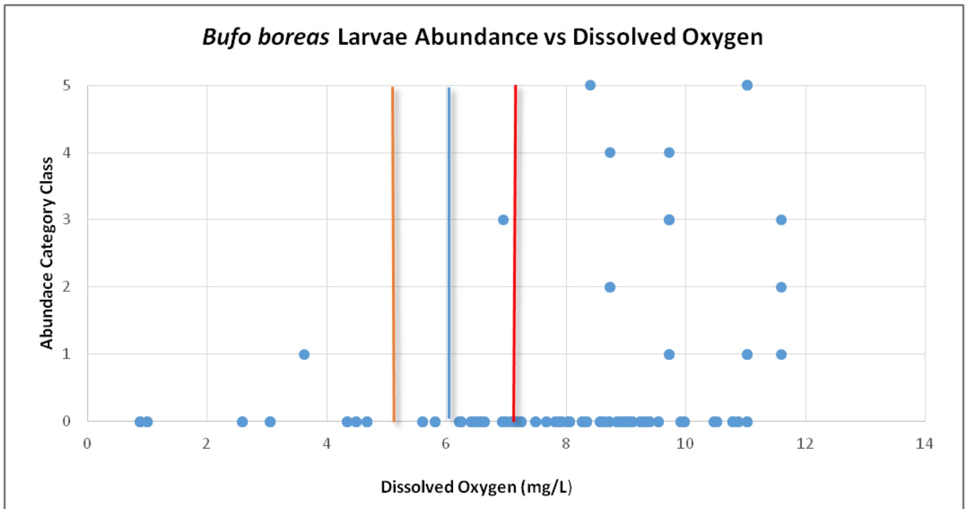


Figure 2-8 - Pre-test relationship graph comparing larval Western toad against dissolved oxygen concentrations. The three lines indicate (from left to right) a warm water objective of 5.0 mg/L, a cold water objective of 6.0 mg/L, and an annual average objective of 7.0 mg/L from the Basin Plan (1994).

2.5.2 Regression

Regressions were performed with R Commander. To run a regression analysis, we created one minimum amphibian abundance value for the entire reach by summing the lowest value of each recorded abundance estimate. (For example, three abundance estimates of 5-20 would be summed as 5+5+5 to have a minimum abundance value of 15 for the entire reach.) We then used the natural log of this number and paired it with the water quality value for that reach to run a regression test. Water quality is the independent variable and amphibian abundance category is the dependent variable in these regression analyses.

2.5.2.1 Interpreting Regression Results

The regression test yielded an R-squared value between 0 and 1 and a p-value between 0 and 1. To obtain a correlation coefficient from the R-squared value we took the square root and visually compared the value with the regression line to determine if it was a positive or negative correlation. Values closer to +1 indicate a stronger positive correlation, whereas values closer to -1 indicate a stronger negative correlation. The p-value indicates the statistical significance of the correlation, and for this project we defined a correlation to be statistically significant if the p value was less than 0.05.

3 Results

3.1 Introduction

We identified nine water quality "focus" parameters (Table 3-1) for which we conducted a full statistical analysis. Non-focus parameters included those for which there was insufficient or poor quality data, as well as those whose values were all within critical levels established by water quality criteria and literature review findings (Table 3-2). The following section presents the result of our research, organized by parameter; for each parameter we provide background information including literature review findings and water quality criteria or recommended levels, summary statistics of the monitoring data, graphs and statistical analyses exploring the relationship between the parameter and native amphibian abundance (for the priority parameters), and recommendations for continued monitoring as applicable. We included graphs and charts in the body of the report where they support parameter-specific conclusions or recommendations, and regression graphs are only included if the results were statistically significant. All other charts, such as summary statistics, relationship graphs, and logistic regression results, can be found in the appendices. Some parameters mention sentinel sites separately, because these sites had the most consistent data and provide the best foundation for an analysis of summary statistics.

After discussing each parameter, we provide a discussion of the East Fork Las Virgenes water quality monitoring site, based on the specific request by NPS, followed by a section on other water quality parameters for which NPS should consider monitoring in the future.

Table 3-1 –Focus parameters for statistical analysis

Focus Parameters
Dissolved Oxygen
Nitrate-Nitrogen
Ammonia- Nitrogen
Nitrate
Specific Conductance
Phosphorus
Phosphate-Phosphorus
Water Temperature
Turbidity

Table 3-2 – Non-focus parameters and reason for classification

Non-Focus Parameter	Reason for Omission
Total Suspended Solids (TSS)	Quality of data: qualitative rather than quantitative; turbidity is a quantitative measurement of suspended solids.
Discharge	Quality of data and local context: continuous discharge measurements are necessary for accurate statistical analysis
Chloride	Quality of data: chloride is missing from most sites in the 2008-2009 and 2009-2010 water years

Bromide	Quality of data: bromide is missing from most sites in the 2008-2009 and 2009-2010 water years.
Sulfur	Quality of data: data is only complete through 2008.
Fluoride	Quality of data: data is only complete through 2008.
pH	Literature review and local context: our summary statistics indicated that pH rarely dropped below 6.5, a common threshold indicated by our literature review.

3.2 Dissolved Oxygen

3.2.1 Background

Sustainable concentrations of dissolved oxygen (DO) are crucial for the survival of aquatic amphibians. The amount of dissolved oxygen in a stream is dependent on water temperature, stream flow, altitude, time of day, and season (USEPA, 2012). Dissolved oxygen concentrations are negatively correlated with water temperature and positively correlated with turbidity, thus warm waters typically hold lower levels of DO than do cool turbid waters (Woods et al. 2010). Waters at high altitudes tend to have lower dissolved oxygen levels. Mornings also typically have lower dissolved oxygen levels due to plant respiration at night (USEPA, 2012). Urban and agricultural runoff can lower DO concentrations in natural habitats since it often carries oxygen-demanding components, including fertilizers and pesticides (Woods et al. 2010). The Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties (2004) has set a 7 mg/L mean annual minimum water quality objective for dissolved oxygen concentration of all waters; it also requires warm surface waters to not have dissolved oxygen levels below 5 mg/L and cold surface waters to not have dissolved oxygen levels below 6 mg/L.

Reduced levels of DO can negatively affect aquatic amphibians by limiting the amount of oxygen in their blood, a condition known as hypoxia. Studies have shown hypoxia to halt or slow embryonic and juvenile amphibian development (Mills & Barnhart, 1999; Werner & Glennemeier 1999). In their study, Wassersug and Feder (1983) observed aquatic hypoxia conditions reduced the stamina (time to fatigue) in the Rio Grande leopard frog (*Rana berlandieri*), African clawed frog (*Xenopus laevis*), and the American toad (*Bufo americanus*) larvae. Other experimental studies suggest aquatic amphibians respond to levels of DO below 3.4 mg/L either by migrating to areas of higher DO concentrations or by bobbing: swimming to water surfaces and exposing their skin and gills to allow for increased gas exchange (Woods et al. 2010). Wassersug and Seibert (1975) examined the bobbing rates of tadpoles at various DO concentrations for the northern leopard frog (*Rana pipiens)*, western chorus frog *(Pseudacris triseriata)*, woodhouse toad *(Bufo woodhousii),* plains spadefoot toad *(Scaphiopus bombifrons*) and the tiger salamander (*Ambystoma tigrinum)* species. Bobbing is used as an indicator in DO experiments because it indicates that DO levels are too low for amphibians to respire through their skin. Wassersug and Seibert found that bobbing rates increase in all five species only when DO concentrations declined to critical levels of 2-4 mg/L. The species differed, however, in bobbing pattern and frequency. Wassersug and Seibert suggest this could be due to differing stages of lung development and DO tolerances among the species. Wassersug and Seibert also suggest certain species may adjust gas exchange activity in their oral and pulmonary surfaces under stressed conditions. In one case low DO levels of 2 mg/L resulted in the death of a woodhouse toad (Wassersug & Seibert 1975). These studies indicate critical concentrations of DO vary by species.

3.2.2 Statistical Analysis

3.2.2.1 Summary statistics

Average dissolved oxygen levels in the SMM NRA range from 0.36 mg/L at Liberty Canyon to 10.83 mg/L at Malibu Creek (Lower). The box and whisker plots for dissolved oxygen show the variation of DO levels over the years at each location (Figure 3-1). Liberty Canyon (above pitfalls) had DO levels consistently below the water quality objective and it had the lowest average for dissolved oxygen at a highly critical concentration of 0.36 mg/L. Malibu Creek (Lower) had the highest average for dissolved oxygen at 10.8 mg/L. Other locations with critically low DO average levels are listed in Table 3-3.

Table 3-3 - Monitoring Sites with DO levels below the WQ objective of 7.0 mg/L

Monitoring Site	DO Level (mg/L
East Fork Las Virgenes	4.1
Malibu Creek (Crags Road)	5.0
Sullivan Canyon	6.3
Tuna Canyon	6.5
Temescal Canyon	4.0
Lang Ranch (North)	6.8
Upper (N) Las Virgenes	6.4
Upper (N) Medea	6.5

The bar charts comparing dissolved oxygen concentrations between locations for each year revealed seasonal variations of DO levels in fresh water (Appendix E). The summer months, particularly August, had lower DO levels (Figure 3-3), while winter months such as January and February had higher DO concentrations (Figure 3-2). The bar charts for each sentinel site displaying the change in dissolved oxygen levels over time revealed no apparent trend over the years (Appendix E). Big Sycamore was the only site with a distinguishable increase of dissolved oxygen values that increased from 4.7 mg/L to an annual average of 10.8 mg/L (Figure 3-4).

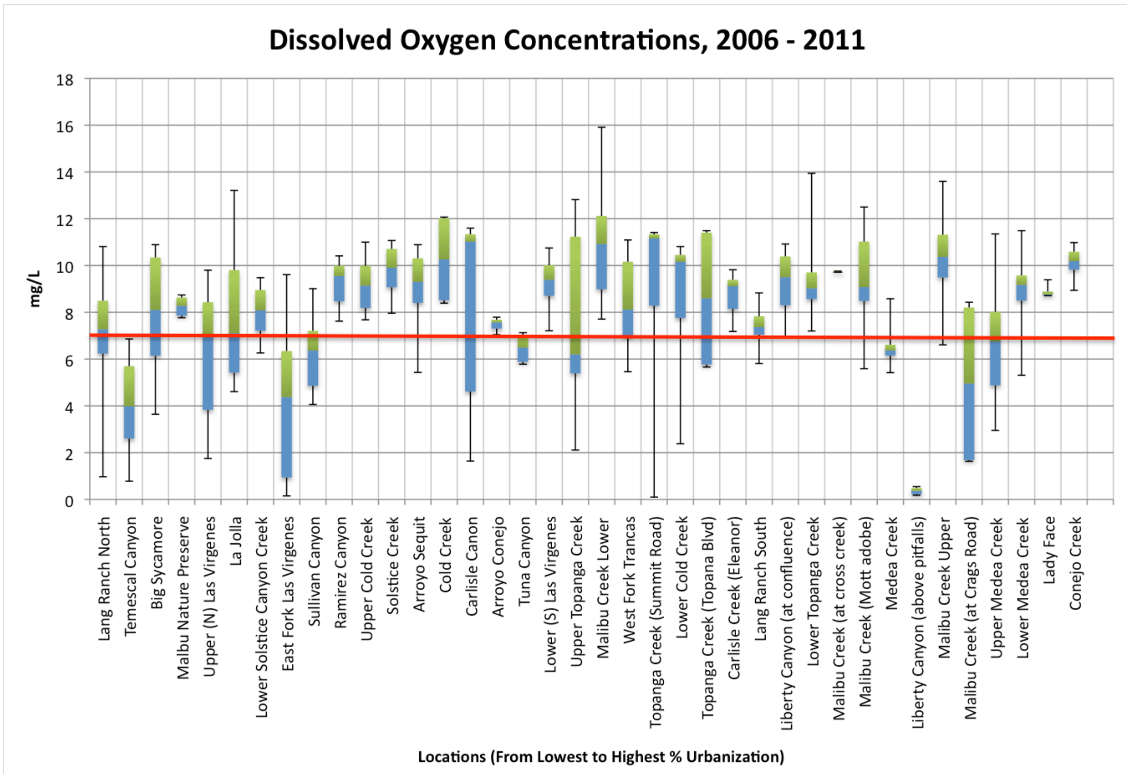


Figure 3-1 - Dissolved Oxygen compared among locations with data from all yea,rs. The red line indicates a water quality objective of 7.0 mg/L from the Basin Plan (1994).

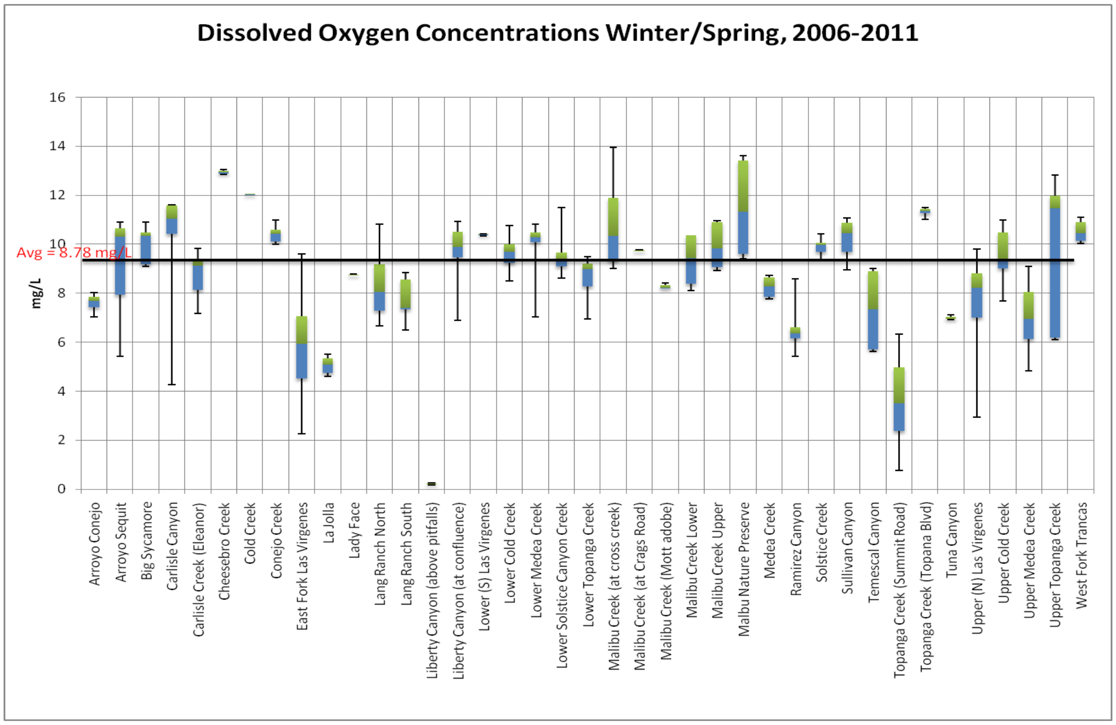


Figure 3-2 Average dissolved oxygen concentrations during the winter and spring, ranging from first rainfall (Table 2-3) through June 20th. The black line indicates average levels of 8.78 mg/L

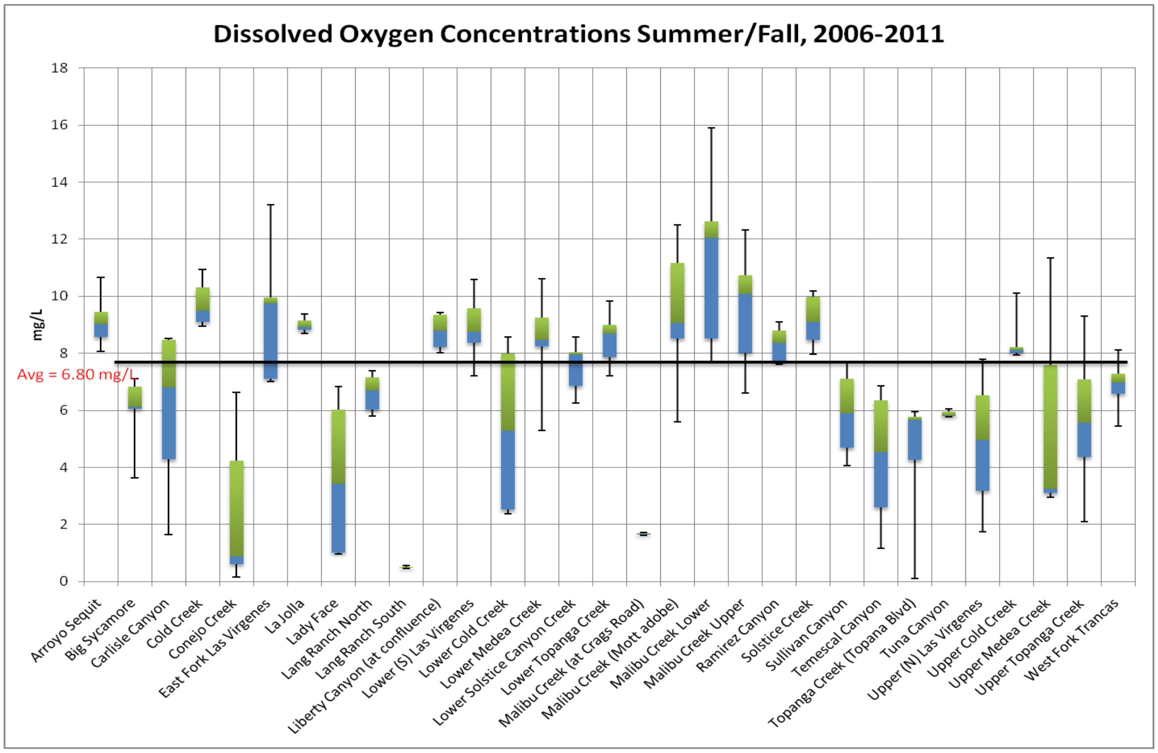


Figure 3-3 Dissolved oxygen concentrations during the summer and fall, including June 21st through first rainfall (Table 2 3). The black line indicates average levels of 6.8 mg/L

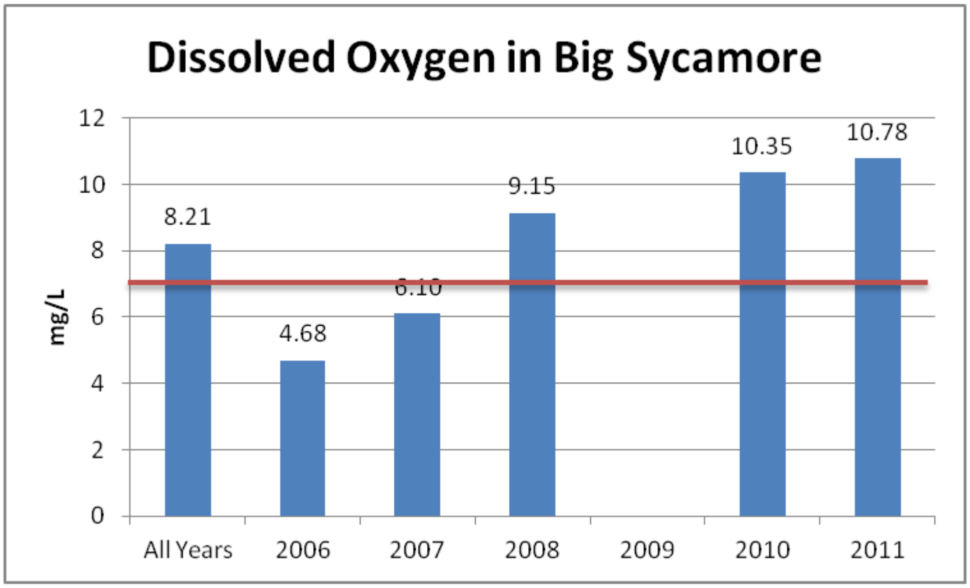


Figure 3-4 - Bar Chart showing the increase of dissolved oxygen concentrations at Big Sycamore from 2006 to 2011. Big Sycamore was not visited in 2009. The red line indicates a water quality objective of 7.0 mg/L from the Basin Plan (1994).

3.2.2.2 Relationship graphs

Relationship graphs between the dissolved oxygen water quality data and amphibian abundance showed increased observation of high abundance categories for western toad and Pacific treefrog populations at DO levels above 7 mg/L. The Pacific treefrog demonstrated high population abundances at values of dissolved oxygen ranging from ~0-12.5 mg/L but showed significantly greater abundance values (>500 larvae) at DO levels greater above 6.5 mg/L. The western toad was present at a limited range of DO levels between 7.8-11.75 mg/L (Figure 3-5).

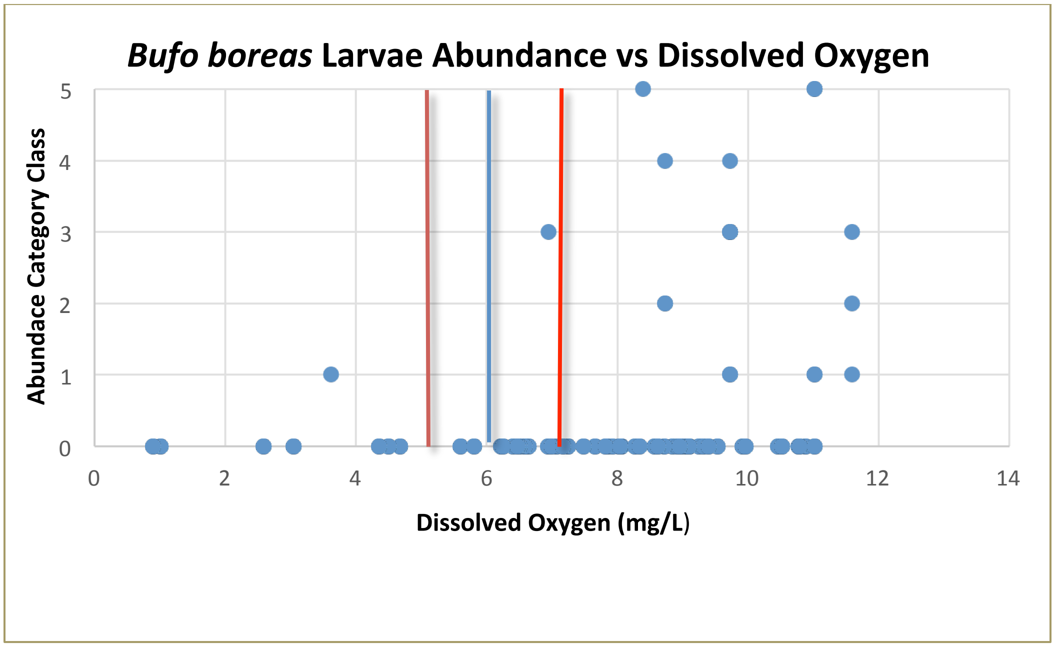


Figure 3-5 Larval western toad abundance against dissolved oxygen concentrations. The three lines indicate (from left to right) a warm water objective of 5.0 mg/L, a cold water objective of 6.0 mg/L, and an annual average objective of 7.0 mg/L from the Basin Plan (1994).

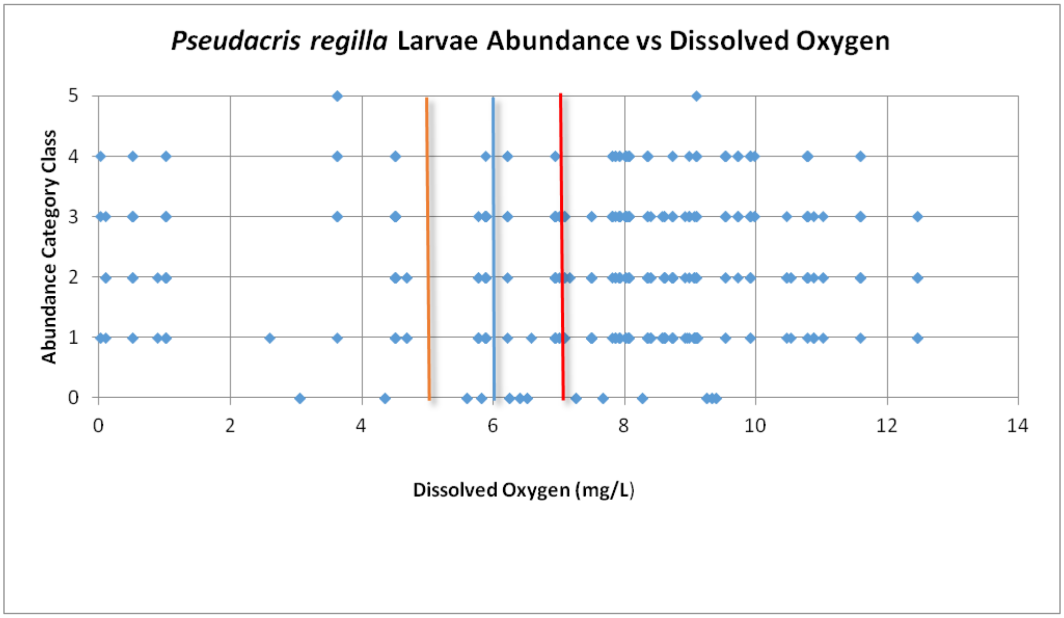


Figure 3-6 Larval Pacific treefrog abundance against dissolved oxygen concentrations. The three lines indicate (from left to right) a warm water objective of 5.0 mg/L, a cold water objective of 6.0 mg/L, and an annual average objective of 7.0 mg/L from the Basin Plan (1994).

3.2.2.3 Regression analysis

The western toad showed a significant positive correlation with dissolved oxygen levels (Figure 3-8), and the California treefrog showed a significant negative correlation with dissolved oxygen levels (Figure 3-7). This is contrary to scientific research found in the literature, and we suspect it might be due to the large time gap between amphibian monitoring dates and water quality monitoring dates. The Pacific treefrog and California newt may not have shown significant relationships because of this same time gap.

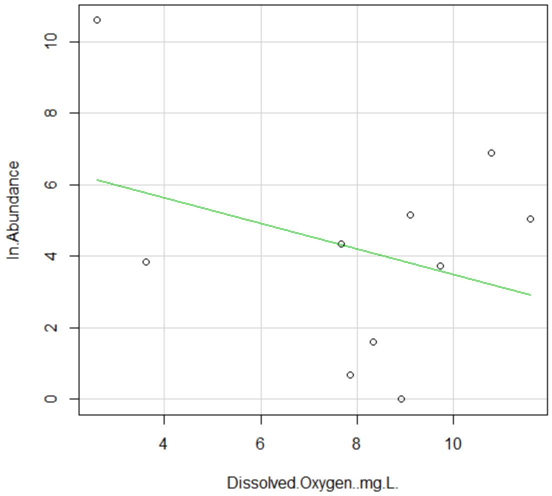


Figure 3-7 Regression results for the California treefrog and dissolved oxygen.
R-value = -0.299 and p-value = 0.004

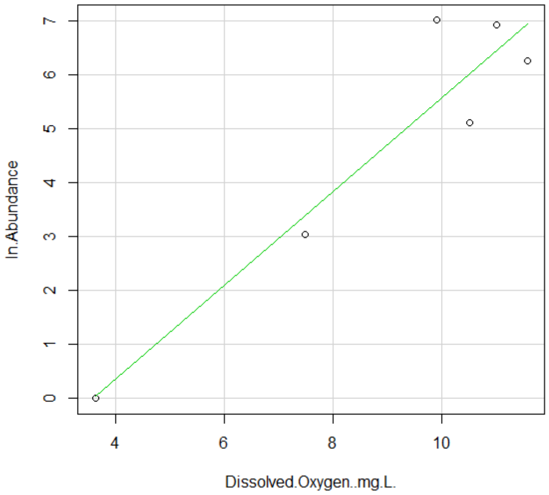


Figure 3-8 - Regression Results for the Western toad and dissolved oxygen.
R-value = 0.946 and p-value = 0.004

3.2.3 Discussion

Many sites have low dissolved oxygen levels that do not comply with the basin plan water quality objective of 7 mg/L (Figure 3-1). Low levels of dissolved oxygen may affect the abundance of the four native species larvae at these sites since the species showed low population frequencies at DO levels below 7 mg/L.

3.2.4 Recommendations

Summary statistics of dissolved oxygen measurements compared to Basin Plan objectives and literature review findings indicate that dissolved oxygen is a parameter of concern. Liberty Canyon (above pitfalls), East Fork Las Virgenes, Topanga Canyon, and Temescal Canyon are sites with critically low DO levels. The sentinel sites of Medea Creek (North), Las Virgenes (North), and Lang Ranch (North) are sites with moderately low DO levels. The NPS should focus their monitoring efforts on these sites with low DO. Monitoring for low dissolved oxygen levels can also aid the NPS in identifying sites with oxygen-demanding nutrients and chemical contaminants such as heavy metals, and DO should therefore remain a general parameter for monitoring. NPS staff should also consider equipment for continuous measurements since DO values vary daily and seasonally and in response to other variables.

3.3 Ammonia-Nitrogen

3.3.1 Background

Ammonia is the most toxic of nitrogen compounds (Rouse et al. 1999), but it occurs in low concentrations, resulting in few research studies on its effects. There are natural ammonia concentration fluctuations, such as reduced water volume in the summer leading to higher ammonia concentrations (Boyer & Grue 2005). Furthermore, Boyer and Grue (2005) found that the toxicity of ammonia increases as temperature increases and pH decreases, meaning ammonia is most harmful to amphibians during summer months. The EPA's water quality standards for ammonia in fresh water are 5.0 mg/L NH3 at an acute level and 2.9 mg/L NH3 at a chronic level (US EPA 2002).

3.3.2 Statistical Analysis

3.3.2.1 Summary Statistics

Generally the ammonia-nitrogen levels in the study site were very low, and well below the EPA threshold. One violation is the 3.37 mg/L value in Lower Las Virgenes in December of 2009 (Figure 3-10). This is particularly high compared to concentrations in the same location in other years which range from 0.01 to 0.04 mg/L.

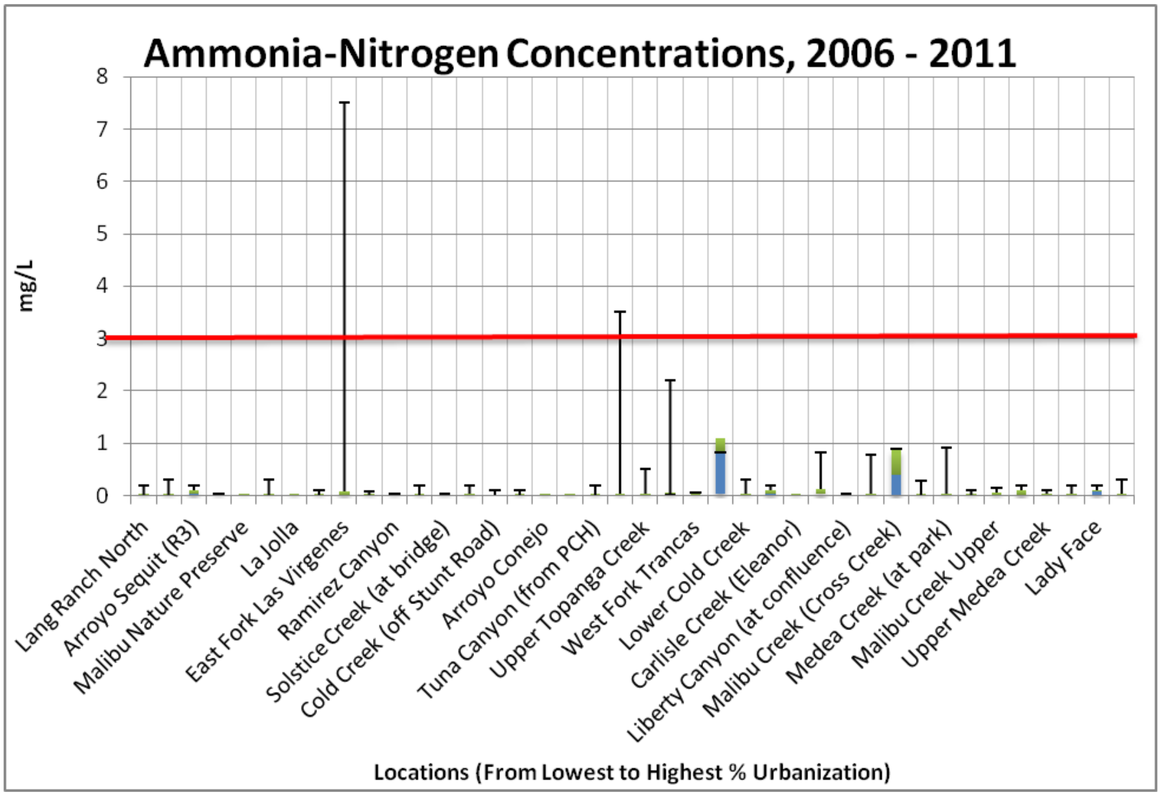


Figure 3-9 - Ammonia-Nitrogen using data from all years to compare locations comparing locations. The red line indicates a benchmark Ammonia value of 3.0 mg/L.

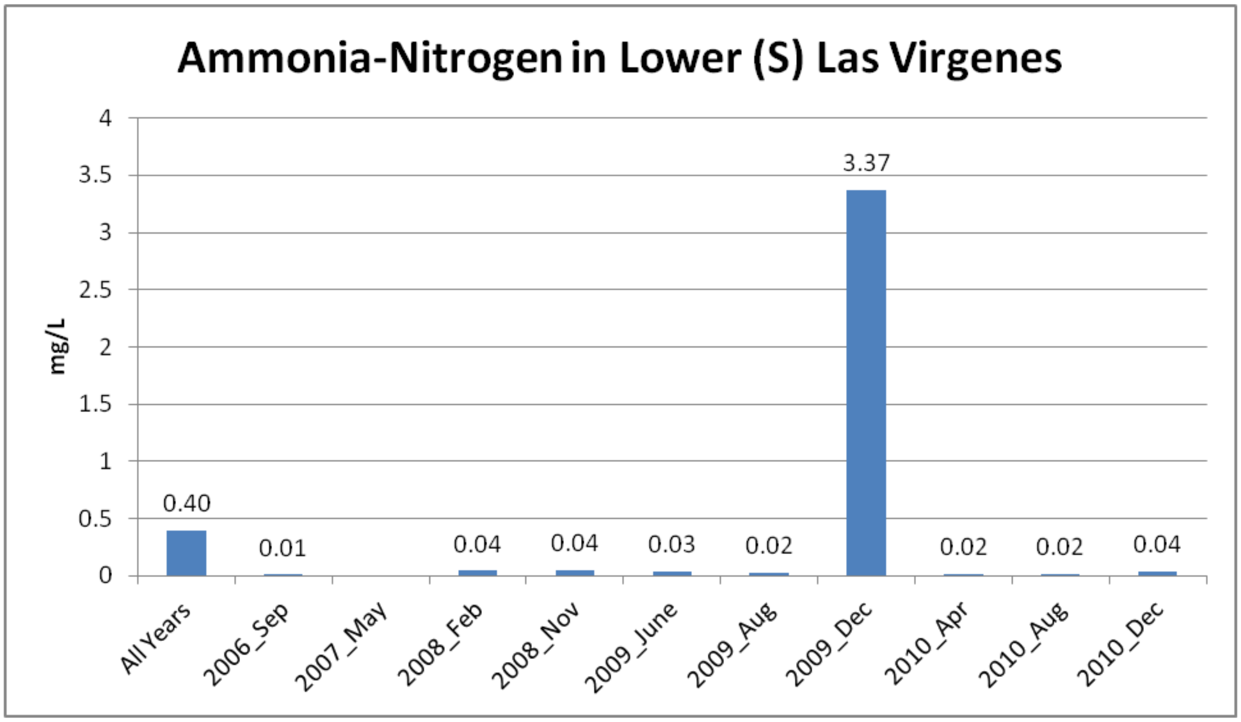
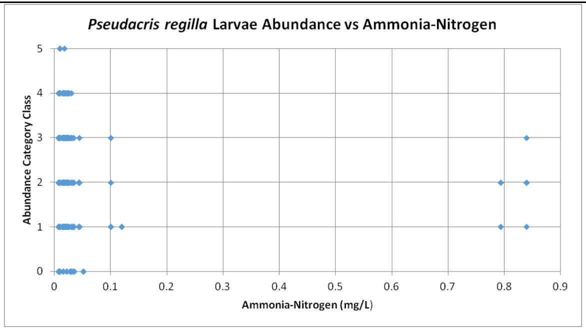
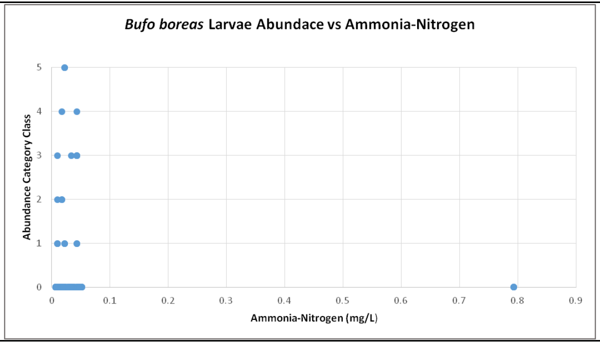


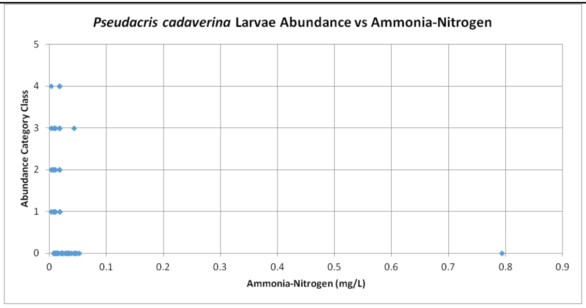
Figure 3-10 - Ammonia-Nitrogen levels in Lower (S) Las Virgenes

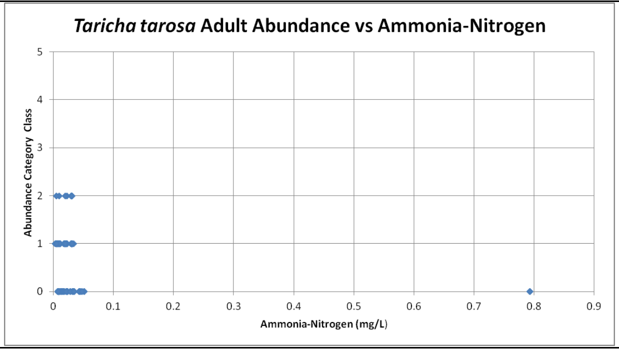
3.3.2.2 Relationship Graphs

BUBO larvae are present at ammonia-nitrogen concentrations ranging from 0.01 to 0.04 mg/L, while HYCA larvae are only present at concentrations below 0.02 mg/L. TATO larvae are present in concentrations below 0.05 mg/L, but TATO adults are only present where concentrations do not exceed 0.033 mg/L. HYRE larvae have larger populations below 0.2 mg/L but are still present at concentrations as high as 0.8 mg/L (Figure 3-11).









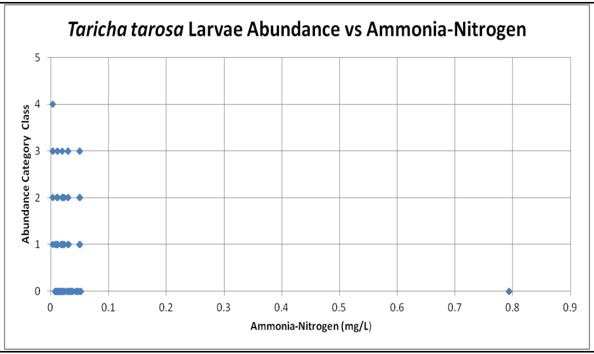


Figure 3-11 Abundance for all four native species against ammonia-nitrogen concentrations.

3.3.2.3 Regression Analysis

The regression test did not yield statistically significant results for any of the species and ammonia-nitrogen. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

3.3.3 Discussion

The Santa Monica Mountains appear to have a safe range of ammonia-nitrogen concentrations for amphibian livelihood. With the exception of Lower Las Vigenes in 2009, the concentrations do not exceed the EPA criteria for ammonia levels, and the regression tests reveal that the amphibian population is not currently influenced by ammonia-nitrogen concentrations.

3.3.4 Recommendations

Ammonia-nitrogen is not a priority for continued monitoring because almost all monitoring sites had ammonia-nitrogen levels that complied with the EPA water quality criteria for ammonia-nitrogen, with the exception of Topanga Creek (at Summit Road) and Malibu Creek (Cross Creek). While ammonia-nitrogen is a parameter of interest because of the negative effects listed in scientific literature, it appears that ammonia-nitrogen has little influence on the amphibian population in the Santa Monica Mountains. Therefore, strict and detailed monitoring of this parameter is not necessary, but continued measuring of ammonia will allow the NPS to notice any dangerous increases such as the anomaly in 2009.

3.4 Nitrate-Nitrogen

3.4.1 Background

Nitrate is the least toxic of the nitrogen compounds (Rouse et al. 1999), but it typically occurs in the highest concentrations, and toxicity effects vary between and within species. Nitrogen compound concentrations vary with season, typically reaching their lowest levels in the summer due to increased biological uptake (Rouse et al. 1999). Baker and Waights (1994) found that the common toad (*Bufo bufo*) and White's tree frog (*Litoria caerulea*) exhibited diminished growth rates and behavioral changes at extreme low and high nitrate concentrations. Similarly, Hecnar (1995) determined that nitrate concentrations as low as 3 mg/L could cause physical and behavioral abnormalities in the larvae of the American toad (*Bufo americanus*), the chorus frog (*Pseudacris triseriata*), the green frog (*Rana* *clamitans*), and the leopard frog (*Rana pipiens*). Low concentrations of nitrate typically affect amphibians over long exposure times. For example, adult common frogs (*Rana temperoraria*) exhibited reduced ventilation rates at high nitrate levels of 24.8 g/m^2 ground area after only fifteen minutes, but tolerated 360 minutes at the same concentration before suffering physical and behavioral deterioration (Oldham et al. 1997).

Impeded swimming ability is a side-effect of physical deformations, but nitrate and nitrite can directly alter amphibians' behavior through methemoglobinemia, a condition that reduces amphibians' ability to transport oxygen via blood circulation (Marco & Blaustein 1999). Marco and Blaustein (1999) synthesized the effects of nitrogen-based fertilizers on amphibians and found a concentration of 3.5 mg/L caused tadpoles to spend more time in shallow water and expose their heads to air. This is a direct result of reduced oxygen circulation to the amphibian's central nervous system, an issue that can also lead to paralysis, disequilibrium, uncoordinated movements, and obstructed motor skills (Marco & Blaustein 1999; Xu & Oldham 1997). Methemoglobinemia also reduces digestive activity in amphibian larvae by preventing gut bacteria from reducing nitrates to nitrites (Hecnar 1995). Poor physical performance reduces an individual's fitness and its ability to survive to reproduction, leading to an overall decline in amphibian populations.

A concern surrounding nitrate and nitrite contamination is amphibians' inability to recognize its presence. Hatch *et al.* (2001) explored how western toads (*Bufo boreas*) and cascade frogs (*Rana cascadae*) respond to urea, a forest fertilizer common to the Sierra Nevada foothills, and recorded significantly increased mortality rates in both species among individuals exposed to urea for five days. Frogs tended to avoid paper towels impregnated with urea, but were unable to recognize the fertilizer in complex substrates such as soil (Hatch et al. 2001). Hatch's findings indicate that frogs in the wild might be more vulnerable to urea because they lack the instinct to detect and avoid it. While Hatch *et al.*'s study was in the Central Valley, fertilizer contamination is a potential issue in Southern California, so their results could suggest a closer examination of nitrogen contamination would be beneficial.

There are studies that indicate potential benefits from nitrate exposure. Xu and Oldham (1997) found common toad (*Bufo bufo*) larvae increased in size after 30 days of exposure to 50 mg/L NO3, which could be a result of eutrophication and more food for the larvae to feed on. Higher larvae body mass is an indicator of higher survival rates post metamorphosis, but, according to Boyer and Grue (1995), Xu and Oldham's results could be misleading because long term eutrophication conditions reduce dissolved oxygen levels and are ultimately harmful to amphibian communities. In a study with contrasting results, Baker and Waights examined the common toad and found an 84.6% mortality rate for larvae exposed to 29 mg/L NO3 for 13 days (Baker & Waights 1993). Xu and Oldham's and Baker and Waights' contradictory results indicate that amphibians could have different tolerance levels to nitrate.

The Basin Plan (1994) objective for nitrate-nitrogen is 10 mg/L (2004). Nitrate concentrations above the natural concentration of 3 mg/L signify anthropogenic influences (Madison & Brunett 1985), and studies show that lethal nitrate concentrations for many amphibians occur between 13 and 40 mg/L (Rouse et al. 1999).

3.4.2 Statistical Analysis

3.4.2.1 Summary statistics

About 85% of the monitoring sites remained at or below 2.00 mg/L nitrate-nitrogen from 2006 to 2011, and average nitrate-nitrogen values ranged from 0.01 mg/L to 0.44 mg/L. These sites meet the water quality objective established by the Basin Plan, but consistently higher concentrations were found at Lower Las Virgenes and Malibu Creek Lower (Figure 3-12). Malibu Creek Lower concentrations do not exceed Lower Las Virgenes concentrations.

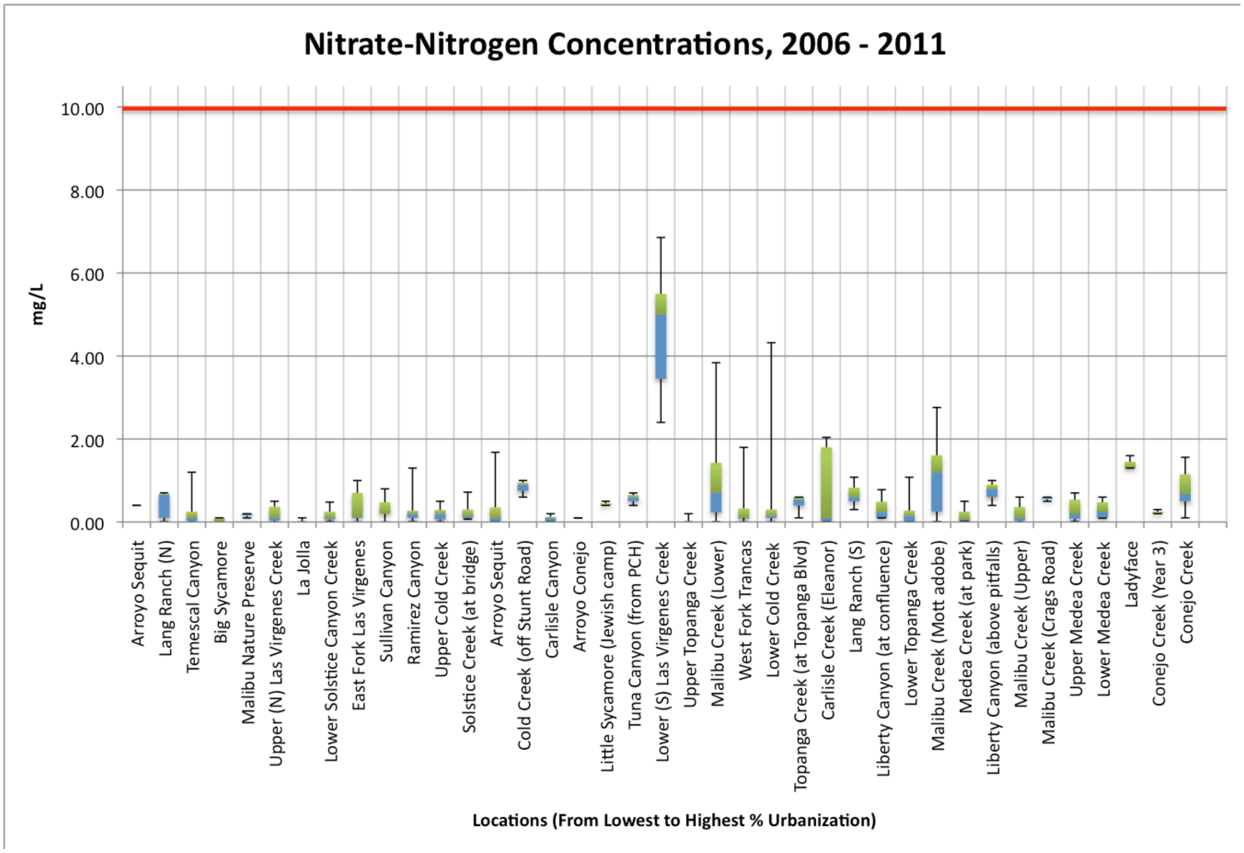


Figure 3-12 - Nitrate-Nitrogen using data from all years to compare locations: higher values are present at Lower Las Virgenes. The red line indicates a water quality objective of 10.0 mg/L as defined by the Basin Plan (1994).

3.4.2.2 Relationship graphs

The larval population of HYCA is larger at concentrations under 0.2 mg/L of nitrate-nitrogen, and the upper limit for larval presence is approximately 0.7 mg/L nitrate-nitrogen (Figure 3-14). Results show more observations of higher abundance categories of TATO larvae as nitrate-nitrogen concentrations decreased. However, TATO larvae were still sparsely present at nitrate concentrations above 2.1 mg/L (Figure 3-13).

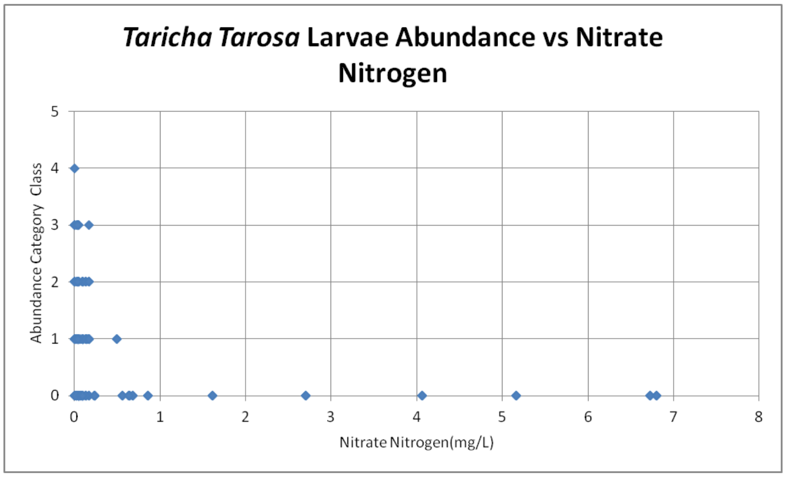


Figure 3-13 California newt abundance against nitrate-nitrogen concentrations

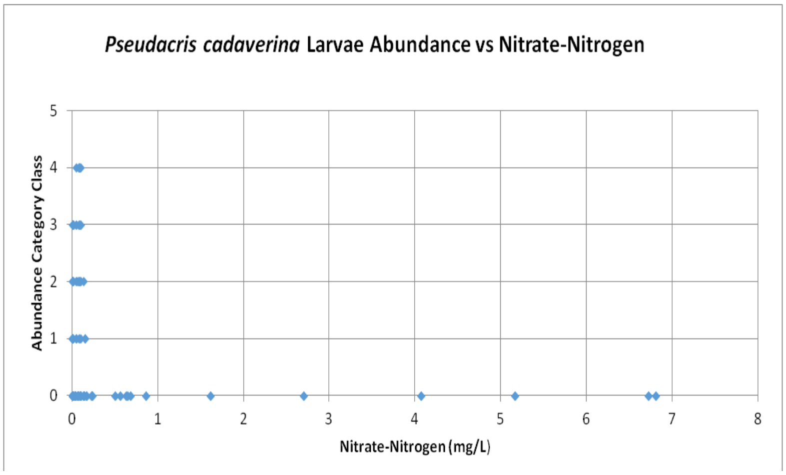


Figure 3-14 Pacific treefrog abundance against nitrate-nitrogen concentrations

3.4.2.3 Regression Analysis

The regression test did not yield statistically significant results for any of the species and nitrate-nitrogen. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

3.4.3 Discussion

Lower Las Virgenes has an anomalously higher range of nitrate concentrations (Figure 3-12) than the other locations and as such is a location of interest for analysis. Most locations do not exceed concentrations of 0.6 mg/L.

3.4.4 Recommendations

Due to the high concentrations of nitrate-nitrogen in Lower Las Virgenes, the NPS should continue to prioritize monitoring efforts at this site. The missing data from this site in 2011 is concerning given the high nitrate concentration there from 2006 to 2010. Malibu Creek Lower is a location of emerging concern due to the sudden increase in nitrate from 2007 to 2008, and the subsequently high nitrate concentrations in 2009, 2010 and 2011. Investigation as to the cause of this change could support efforts to control nitrate levels in this location in the future. Exposure to the Monterey/Modelo Formation, a marine Tertiary-age sedimentary geologic formation and important petroleum source rock known to be associated with high background levels of biostimulatory substances such as nitrate, could be a natural source responsible for these high nitrate concentrations (LVMWD Report, 2011).

3.5 Specific Conductance

3.5.1 Background

Specific conductance, also referred to as conductivity, is a measure of the ability of water to conduct electricity. Conductivity affects amphibians because it interferes with osmoregulation, the transport of ions across membranes (Chambers 2011). Pure water has low conductivity, whereas water with a significant amount of dissolved salts has high conductivity; the amount of salt in the water is referred to as total dissolved solids (TDS) (Said et al. 2004). Ions such as chloride and sulfate are constituents that, when dissolved in water, increase the salinity and conductivity of water. Stream bottom components such as clay soils, limestone bedrocks, and sulfur springs are natural sources that may increase water conductivity (Pellet & Perrin., 2004; USEPA 2010). Lenat and Crawford (1994) observed that urban streams have relatively higher specific conductance and TDS than natural streams. Correspondingly, Conway (2007) studied watershed quality in an urbanizing coastal region in New Jersey, and found that impervious surfaces (an indicator of urban development) had a strong positive correlation with increased specific conductance. Urban and agricultural runoff from impervious surfaces carrying environment containments such as ions, heavy metals, and nutrients are highly accountable for the elevated conductivity levels in urban streams (Paul & Meyer, 2001). The USEPA suggests adequate specific conductance stream conditions that support fresh water aquatic life should range from 150 and 500 µS/cm (USEPA 2010).

Studies have shown that high conductivity can adversely affect amphibian health and diversity (Chambers, 2011). In their study, Karraker *et al*. (2008) observed that wood frog (*Rana sylvatica*) larvae survival declined to 54%-60% at moderate conductivity levels of 500 µS/cm and then rapidly declined to a 20% survival rate at high conductivity levels of 3000 µS/cm. Sanzo and Hecnar (2006) observed similar declines in wood frog larvae survival when they increased larvae exposure to salinity (in the form of sodium chloride (NaCl)) from 200 µS/cm to 2000 µS/cm; they found survival reduced from 60% to 17%. Hamer and Parris (2011) observed negative effects of high water conductivity on amphibian species diversity within ponds along an urban-rural gradient in Greater Melbourne, Australia. In their study, they observed that ponds with high water conductivity accounted for 15.8% of the variability in species-environment relationships and 7.4% of the variability in species data. They found the common froglet (*Crinia signifera*), Haswell's froglet (*Paracrinia haswelli*) , and the eastern and southern banjo frog (*Lymnodynastes dumerilli*) species to be strongly associated with ponds characterized by low conductivity and found only a slight association between the southern brown tree frog (*Litoria ewingii*) and the whistling tree frog (*Litoria verreauxii)* and ponds with high conductivity. In their study, Smith et al. (2006) measured wetland conductivity in the Wimmera region of western Victoria, Australia in efforts to examine the effects varying conductivity levels may have on the abundance of several Australian species. They found the species to be negatively correlated with wetland conductivity and observed species presence predominately at conductivity levels below 3000 μS/cm and nonexistent at levels above 6000 μS/cm.

In 2005, Riley *et al.* measured the water quality of 35 natural and urban streams in the highly urbanized Southern California region. They found average conductivity in urban streams at 1643.3 μS/cm, which was significantly higher than the 903.8 μS/cm average for natural streams. High conductivity levels may be a threat to the native amphibian species abundance and distribution.

3.5.2 Statistical Analysis

3.5.2.1 Summary statistics

Average specific conductance ranged from 505.69 µS/cm at Carlisle Creek to 4081.7 µS/cm at East Fork Las Virgenes (Figure 3-15), and the majority of the NPS's sites exceeded the EPA's acute concentration limit for specific conductance of 800 μS/cm. East Fork Las Virgenes had the maximum value for specific conductance at 5110 μS/cm and an average specific conductance of 4082 μS/cm (Figure 3-15). Carlisle Canyon, which is one of the ten sentinel monitoring sites, had the minimum value for specific conductance at 349 μS/cm and an average specific conductance of 506 μS/cm. Liberty Canyon had the second highest specific conductance average value of 3803 μS/cm. From the sentinel sites, Upper Medea Creek had the highest specific conductance average at 3535 μS/cm followed by Lower Las Virgenes, which had an average specific conductance of 3378 μS/cm.

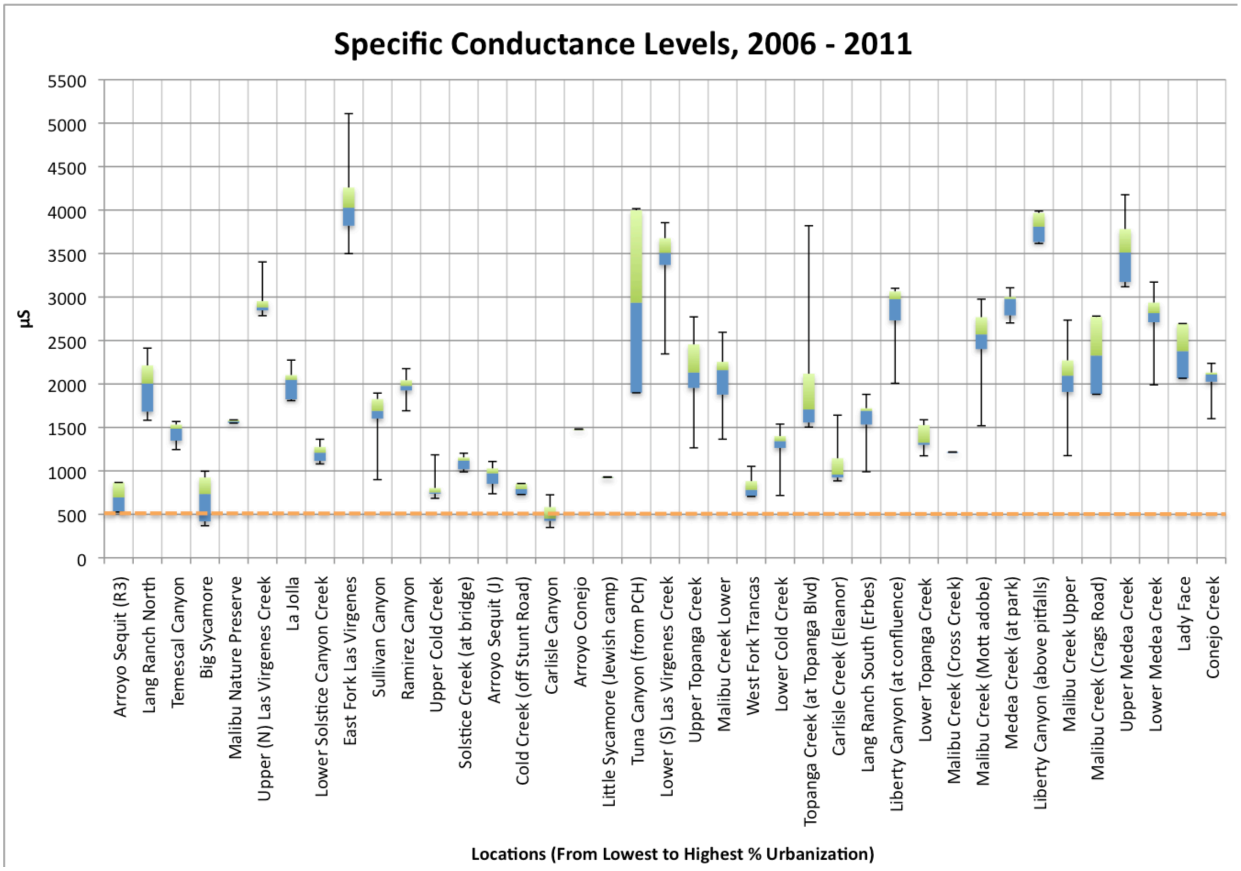


Figure 3-15 - Specific Conductance compared among locations with data from all the years. The orange dotted line indicates typical background levels for freshwater of 500 µS/cm, defined by the EPA (2010).

The bar charts for each sentinel site displaying the change in specific conductance levels over time suggest that higher specific conductance levels occurred in 2009 and 2010 in most of the sites (Appendix E). Big Sycamore was the only site to show a distinguishable decrease of specific conductance values from 993 to 371 *µ*S/cm (Figure 3-16).

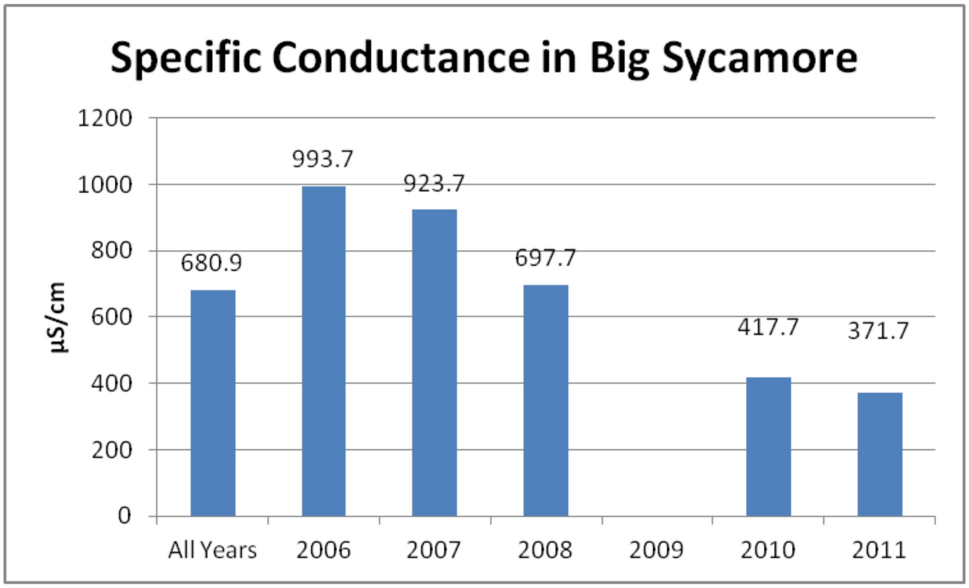
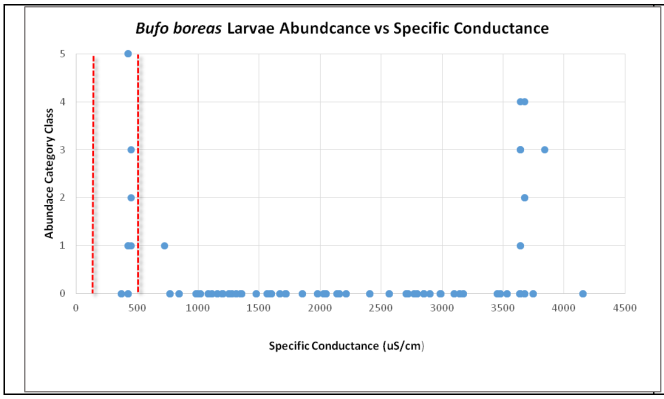


Figure 3-16 - Bar Chart showing the overall decline in specific conductance levels at Big Sycamore from 2006 to 2011

3.5.2.2 Relationship graphs

The graph showing adult California newts compared to specific conductance show TATO individuals were only present in streams with specific conductance values below 2500 μS/cm and had higher population abundances at specific conductance values below 1600 (Figure 3-17). Relationship graphs for California newt larvae showed they were only present in streams with specific conductance values below 2500 μS/cm, with the highest single abundance value observed at levels below 500 μS/cm (Figure 3-17). The California treefrog larvae was present at specific conductance levels up to 2575 μS/cm which is a similar range as the one found for the California newt larvae. The Pacific treefrog demonstrated high population abundances at values of specific conductance that widely ranged from 400 to 3800 μS/cm (Figure 3-24). Similarly, the western toad was present at conductance levels between 500-3800 but was absent in ranges between 1000-3000 μS/cm which is most likely a result of insufficient western toad amphibian monitoring data (Figure 3-24).



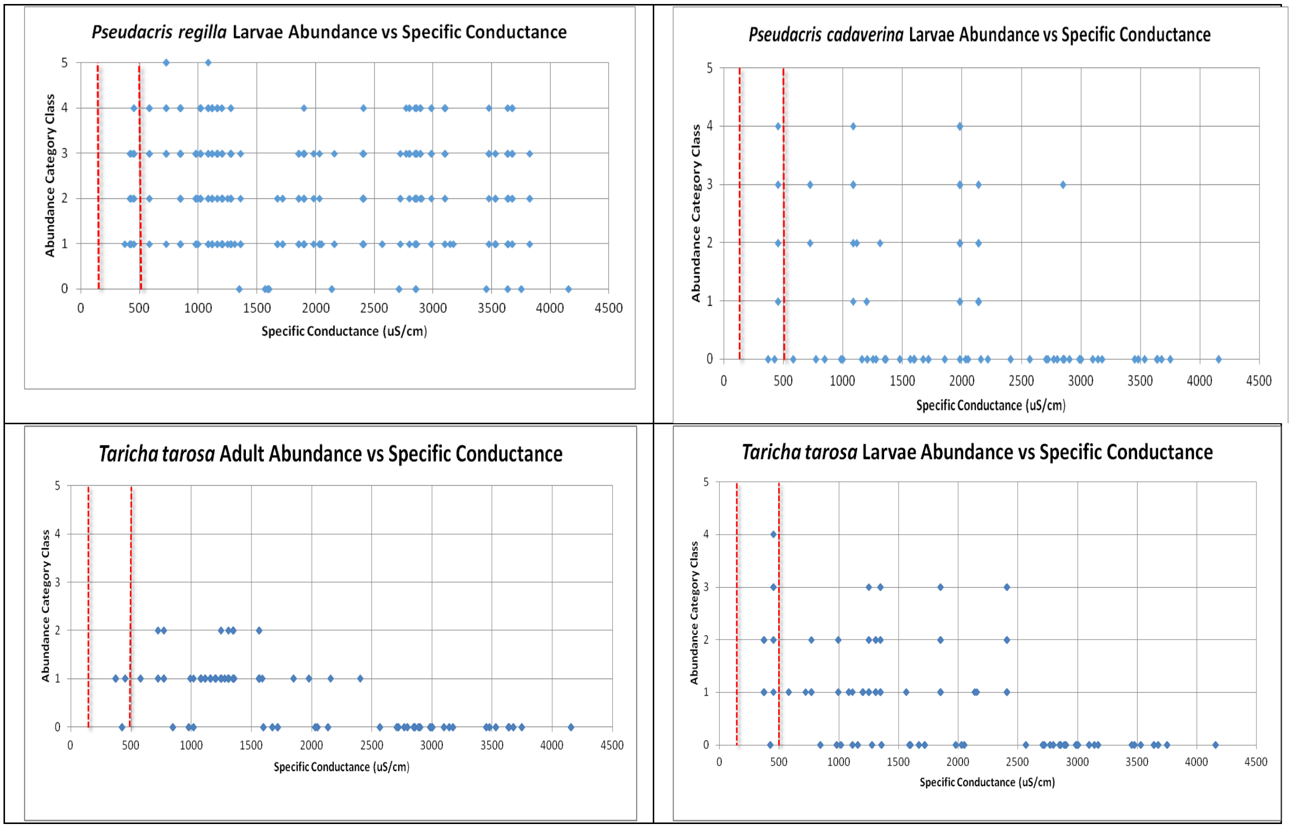


Figure 3-17 Abundance for all species against specific conductance levels. The red dotted lines indicate typical freshwater levels as defined by the EPA: 120-500 µS/cm.

3.5.2.3 Regression analysis

The regression test did not yield statistically significant results for any of the species and specific conductance. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

3.5.3 Discussion

The levels of specific conductance in the sentinel sites are high when compared with specific conductance levels recommended for freshwater streams by the US EPA. Amphibians were present in ranges that agreed with findings in the studies previously reviewed: amphibians were rarely present in specific conductance levels above 3000 μS/cm.

3.5.4 Recommendations

East Fork Las Virgenes and the sentinel sites of Upper Medea and Lower Las Virgenes are creeks that have shown critical levels of specific conductance and thus we recommend that the NPS improve their monitoring efforts on these sites. Sulfur springs along Las Virgenes creeks may be responsible for the high conductivity at these sites and so it would be beneficial to further research the anthropogenic and natural sources that influence increased conductivity levels at this specific site and that may affect amphibian abundance (Sikich et al. 2013). Monitoring specific conductance will furthermore help NPS identify areas with high concentrations of heavy metals, nutrients (e.g. nitrate and phosphate), and organic pollution with components of herbicides and pesticides since these are usually chemicals found in waters with high levels of conductivity (Hamer & Parris 2011, Pellet & Perrin 2004).

3.6 Phosphorus

3.6.1 Background

Phosphorus is the second nutrient that can be limiting to primary production. Phosphorus is necessary and beneficial, but increased additions through anthropogenic activity can disrupt an ecosystem's balance (Carpenter et al. 1998). The Mediterranean Coast Network measures phosphorus in two forms, Phosphorus and Phosphorus-Phosphate.

Phosphorus enters aquatic environments naturally through rock weathering, but its inputs have recently increased due to nonpoint source pollution such as mining, industry, and agriculture (Carpenter 2008, Carpenter et al*.* 1998). Agriculture is of greater concern in Southern California, which can increase phosphorus levels in aquatic environments through fertilization. Phosphorus accumulates in the soil before erosion carries the soil and associated phosphorus downstream.

General urban runoff can increase phosphorus loading when rainwater carries runoff from lawn fertilizers, construction sites, and inputs from un-sewered developments (Carpenter et al. 1998). Streams in the Santa Monica Mountains range from almost completely natural (less than 1% upstream urbanization) to more than 70% urbanized (NPS 2013), indicating that the influence of urbanization on Phosphorus levels is important. According to the Southern California Coastal Water Research Project's (SCCWRP) Natural Loadings Report (Stein & Yoon 2007), background phosphorus levels in dry weather range from 0.01 to 0.1 mg/L in un-developed streams, but range from 0.1 to 1 mg/L in developed streams. Wet weather reveals a similar dichotomy, with un-developed streams ranging from 0.07 to 0.21 mg/L phosphorus concentrations and developed streams ranging from 0.01 to 10 mg/L.

Elevated phosphorus levels can directly affect amphibian abundance, as found in a field survey by Houlahan and Findley (2003). Houlahan and Findley surveyed ponds in Ontario, Canada with Total Phosphorus (TP) concentrations ranging from 0.01 to 1.7 mg/L and found that "amphibian species richness" was strongly negatively correlated with water nutrient levels. Within this total phosphorus range, mean levels of TP ranged from 0.02 to 0.68 mg/L and showed a statistically significant negative correlation with amphibian abundance. Hamer *et al.* (2004) tested the relationship between phosphorus and amphibian survival in the lab and found that extremely high levels of calcium phosphate (15 mg/L) reduced survivorship in the striped marsh frog (*Limnodynastes peronii*) and the golden bell frog (*Litoria aurea*) by almost 20%.

Phosphorus can indirectly affect amphibian abundance through anthropogenically-induced eutrophication and the alteration of ecosystem balances. Carpenter *et al.* (1998) explained that eutrophication leads to "increased growth of algae and aquatic weeds", oxygen shortages, loss of habitat, and overall loss of aquatic biodiversity. Of these, amphibian species suffer from oxygen shortages the most, because the larval stage of the amphibian life cycle relies on dissolved oxygen for respiration. Johnson and Chase (2004) observed a shift in predator-prey interactions as a result of eutrophication: the influx of nutrients and increased biomass at lower trophic levels allowed larger species of snails from the *Planorbella* genus to thrive. These snails are the “exclusive first intermediate hosts” of *Riberoia ondotrae* (Johnson and Chase 2004), and decreased mortality of *Planorbella spp.* snails lead to increased growth time for this common amphibian parasite. *Riberoia* infections limit limb development in amphibians, leading to severe malformations (Johnson *et al.* 2007), and Johnson and Chase concluded that the combined factors of nutrient influx, eutrophication, and community shifts toward *Planorbella spp.* “increase amphibian infection intensity and overall infection prevalence.” Phosphorus reversal processes are difficult due to both internal cycling in ponds and lakes and accumulation in upland soils (Carpenter et al. 1998). Unlike some nutrients, such as iron, which can be deposited through atmospheric deposition, phosphorus sorbs to sediment particles and is retained by organisms (Carpenter 2008). This results in slow erosion and delayed response times, indicating that phosphorus monitoring should continue into the future, because the effects of fertilization in Southern California might not yet be apparent in surface water quality.

3.6.2 Statistics

3.6.2.1 Summary Statistics

Of the ten sentinel sites, Lower (S) Las Virgenes had the highest overall phosphate-phosphorus concentrations, with a six-year average of 0.70 mg/L (Figure 3-18,Figure 3-19). Solstice Creek, meanwhile, had the lowest phosphate-phosphorus concentrations with a six-year average of 0.10 mg/L (Figure 3-18,Figure 3-20). With the given data it is not possible to determine either a seasonal pattern or a long-term trend in phosphate-phosphorus concentrations.

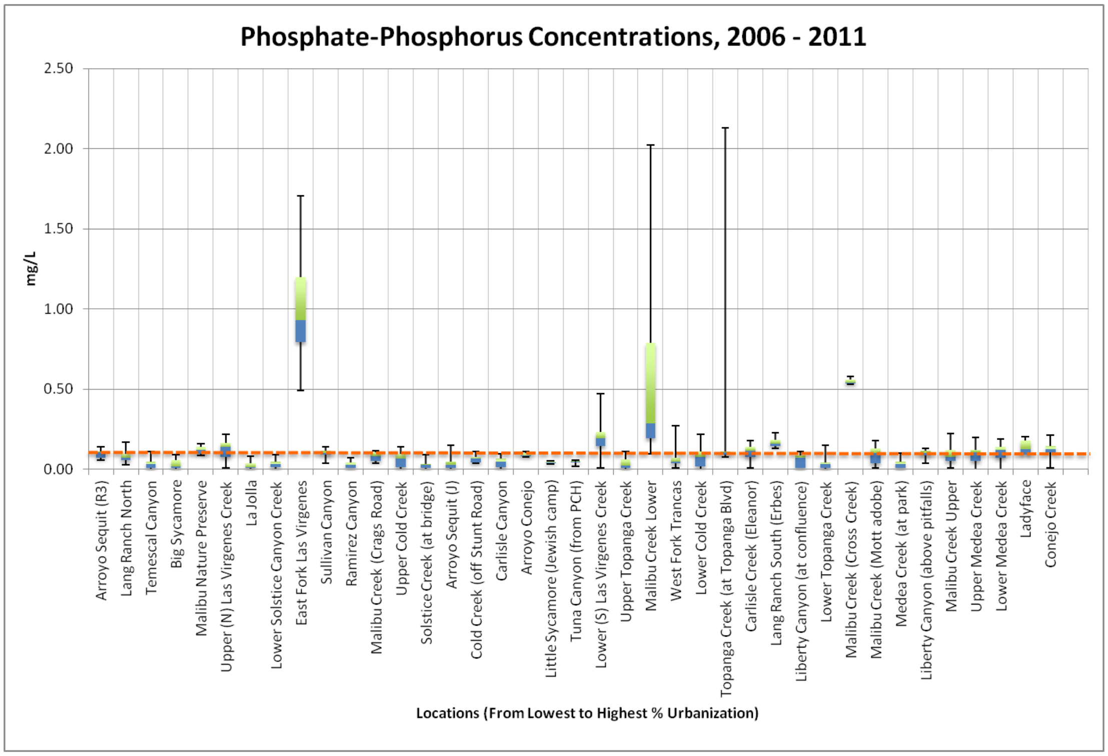


Figure 3-18 - Phosphorus concentrations compared among locations with data fro all years. The orange dotted line indicates an EPA guideline that phosphate-phosphorus levels should not exceed 0.5 mg/L (2010).

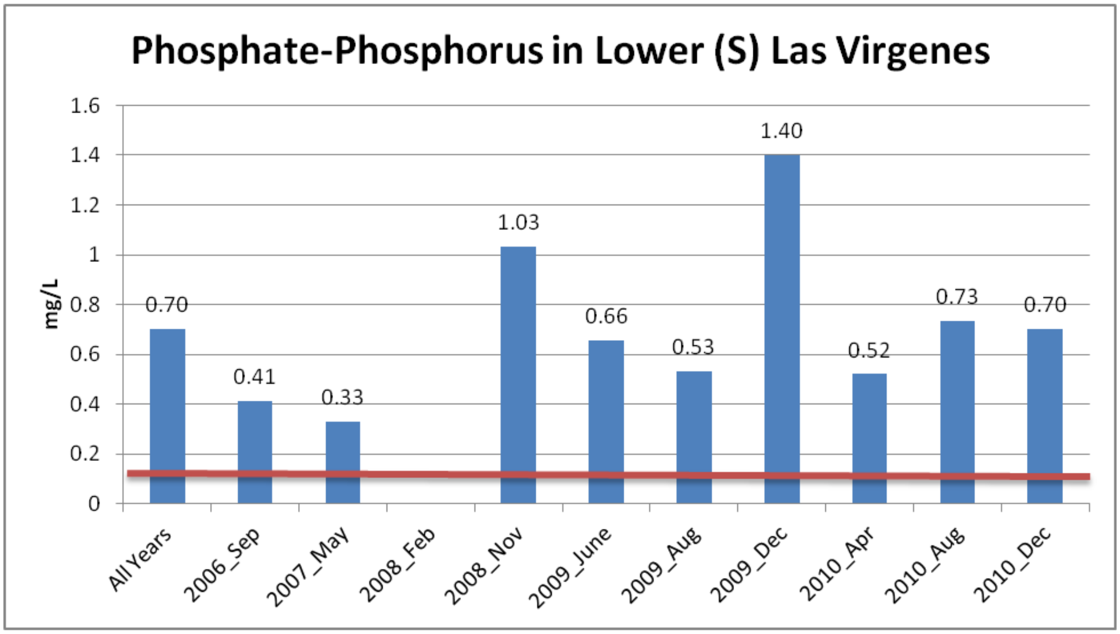


Figure 3-19 - Phosphate-Phosphorus concentrations at the most contaminated site, Lower Las Virgenes

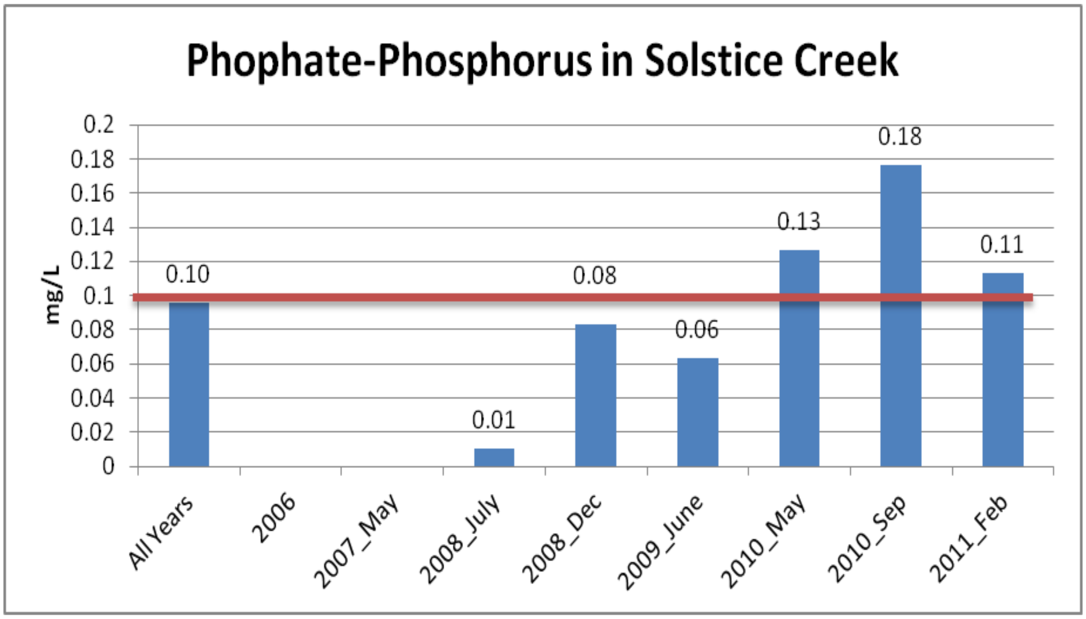


Figure 3-20 - Phosphate-Phosphorus concentrations at the least contaminated site, Solstice Creek

3.6.2.2 Relationship Graphs

The chart comparing the Pacific Treefrog and phosphate-phosphorus shows a strong congregation of HYRE abundance at lower concentrations of phosphate-phosphorus, with an apparent boundary at about 0.5 mg/L (Figure 3-22). California Newt larvae are found at the abundance category <5 with phosphate-phosphorus concentrations up to 0.3 mg/L whereas they are only found at the abundance category >100 at very low levels of phosphate-phosphorus (Figure 3-21).

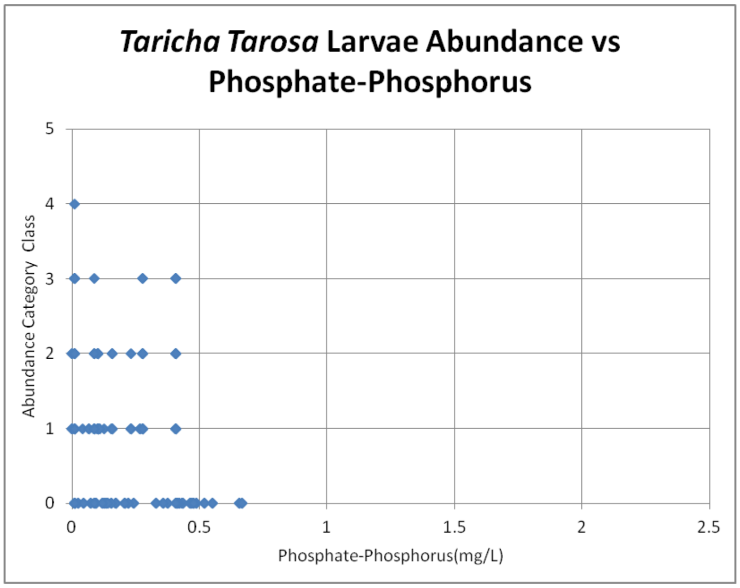


Figure 3-21 California newt abundance against phosphate-phosphorus concentrations

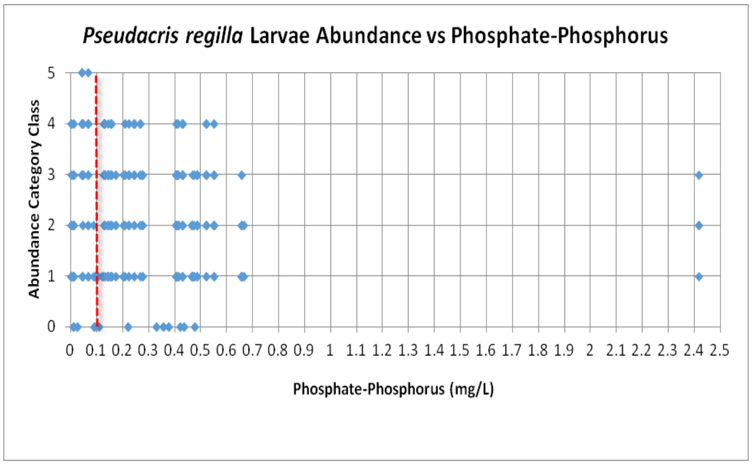


Figure 3-22 Pacific treefrog abundance against phosphate-phosphorus concentrations

3.6.2.3 Regression Analysis

The regression test did not yield statistically significant results for any of the species and phosphate-phosphorus. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

3.6.3 Discussion

The literature indicates that phosphorus is potentially harmful to amphibians, and the summary statistics reveal potential negative correlations between phosphate-phosphorus and both HYRE and California newts. It is therefore important to continue monitoring phosphate-phosphorus as a water quality parameter.

3.6.4 Recommendations

Future studies should focus on those sites where phosphate-phosphorus levels are above the overall average for the SMM NRA (Figure 3-18). The NPS could benefit from research into the natural sources of phosphorus and phosphate-phosphorus, particularly in Malibu Creek where concentrations were consistently above the Basin Plan objectives. A natural source relevant to Malibu Creek is the Monterey/ Modelo Formation, a petroleum source rock abundant in Malibu Creek that contains phosphatic nodules and has been known to increase phosphorus levels in the area (LVMWD Report 2011). East Fork Las Virgenes is also of particular concern because of its consistently high phosphate-phosphorus levels. Although the literature concerning this water quality parameter is limited, the NPS should continue monitoring it because of local conditions.

The Pacific treefrog and the California newt in particular should be monitored in conjunction with phosphate-phosphorus because its influence on the abundance of these two species is stronger than for the California treefrog or the bullfrog.

3.7 Water Temperature

3.7.1 Background

Amphibians are ectotherms, meaning they are dependent on external sources of heat and therefore highly affected by their surrounding temperature (Wells 2007). Amphibian body temperature is regulated by heat exchange with air, water, and, in some cases, soil (DuShane & Hutchinson 1941). Body temperature is a major determinant in biochemical and physiological processes, such as circulation, digestion, respiration, and reproduction (Rome et al. 1992 as cited by Carey & Alexander 2003). While species vary in temperature tolerance, all amphibians have a lethal temperature limit at which they lose coherence, locomotive abilities, and the ability to escape deadly conditions (Cowles & Bogert 1944 as cited in Carey & Alexander 2003). In a study by Lillywhite, Licht, and Chelgren (1973), young toads preferred body temperatures of 26 to 27˚C in both the laboratory and natural habitats. The authors observed maximum appetite, linear growth, weight increase, and energy conversion efficiency at water temperatures of 27˚C. Young toads exhibited an increase in metabolism at temperatures between 10 and 33˚C, but stopped feeding at temperatures over 33˚C. Brattstrom (1963) reviewed the thermal conditions of various amphibian species and found their mean body temperature to be 21.7°C. For several species he observed intolerance to temperatures below 15°C (Brattstrom 1963).

Newman (1998) studied the development of amphibians in high water temperatures (up to 37˚C in the afternoon and down to 19˚C at night) and in low temperatures (up to 28˚C in the afternoon and down to 19˚C at night). He found that larvae reared in high water temperatures tend to metamorphose earlier and develop faster, which leads to smaller adult sizes (Newman 1998). This is problematic because large surface-area-to-volume ratios of smaller amphibians are positively correlated with susceptibility to desiccation (Donnelly & Crump 1998). In addition, higher water temperatures drive evaporation, resulting in shallower ponds, and therefore heightened exposure of amphibian eggs to harmful UV-B radiation.

Low water temperatures generally decrease locomotive performance, reduce frog immunity, and hinder behavior development in embryos, which can result in immobilization (Berger et al. 2004; Wells 2007; DuShane & Hutchinson 1941). High water temperatures cause dehydration in amphibians due to amphibians' permeable skin and the tendency for warm water to evaporate (Brattstrom 1979).

Low water temperatures are not predominant in Southern California due to its Mediterranean climate, but increased urbanization induces warmer temperatures in regional aquatic habitats (Krause 2004). The pavement of watersheds and the removal of riparian vegetation prevent water from infiltrating soil before entering water bodies. Because infiltration through soil cools water, the temperature of streams fed by urban surface runoff over impervious surfaces is higher than natural stream temperatures (Krause 2004). Additionally, water temperatures affect the concentration of many of the parameters in our study such as dissolved oxygen, as the amount of a dissolved parameter that water can hold varies with water temperature.

3.7.2 Statistical Analysis

3.7.2.1 Summary Statistics

The SMM NRA has 27 existing warm water sites, 17 intermittent warm water sites, 19 existing cold water sites, and 6 potential cold water sites. The data exhibits a large range over all the years due to the diversity of ecological regions in the Santa Monica Mountains and the variation of temperature with season. Over all the years and among all the locations the range in temperature was 8.0°C to 33.2°C (Figure 3-23). The maximum water temperature was documented in June of 2008 at La Jolla, an existing cold water and intermittent warm water location. The EPA standard for warm waters is a maximum of 26.7°C (2009) and cold water standards are dependent upon natural temperatures, so this high value of 33.2°C at La Jolla was well above the permitted range; however, this was the only instance of a violation for water temperature. The average temperature for all the locations in each year ranged from 13.2°C (2011) to 21.1°C (2007).

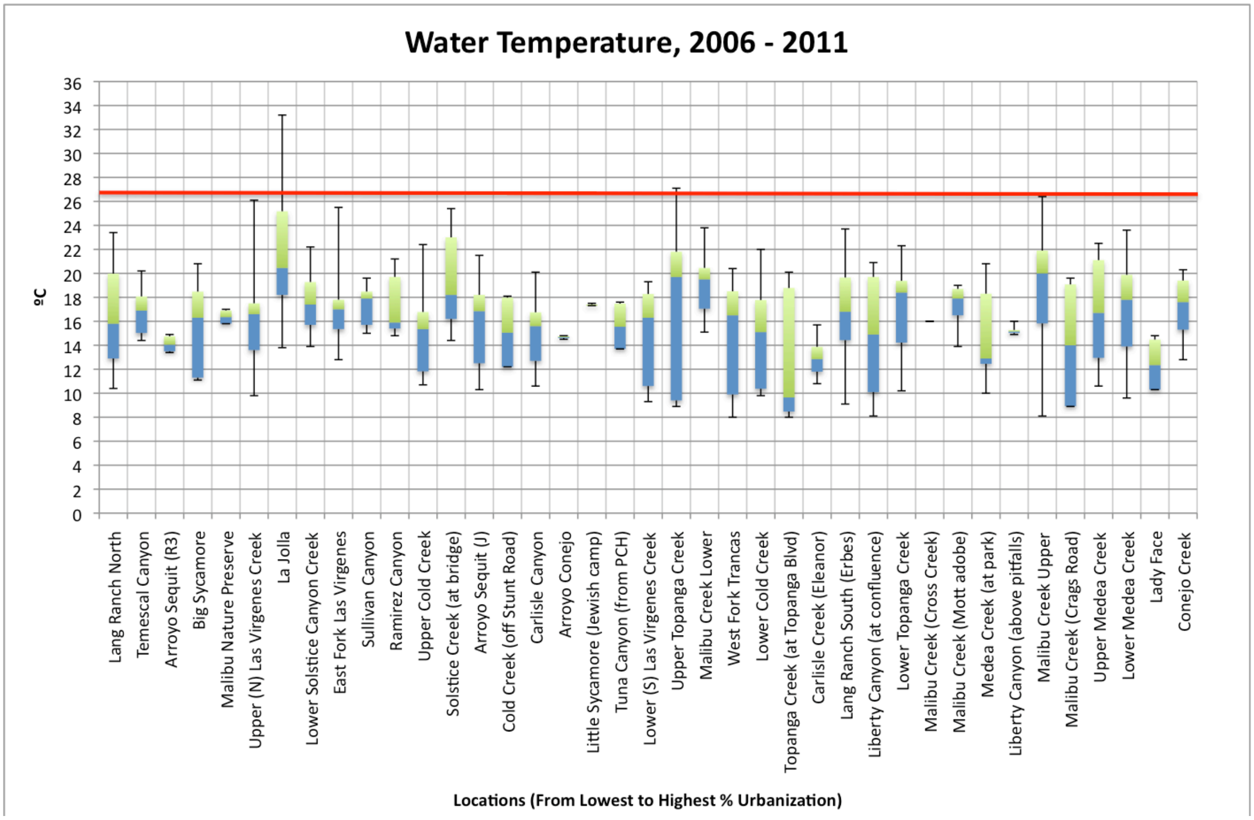
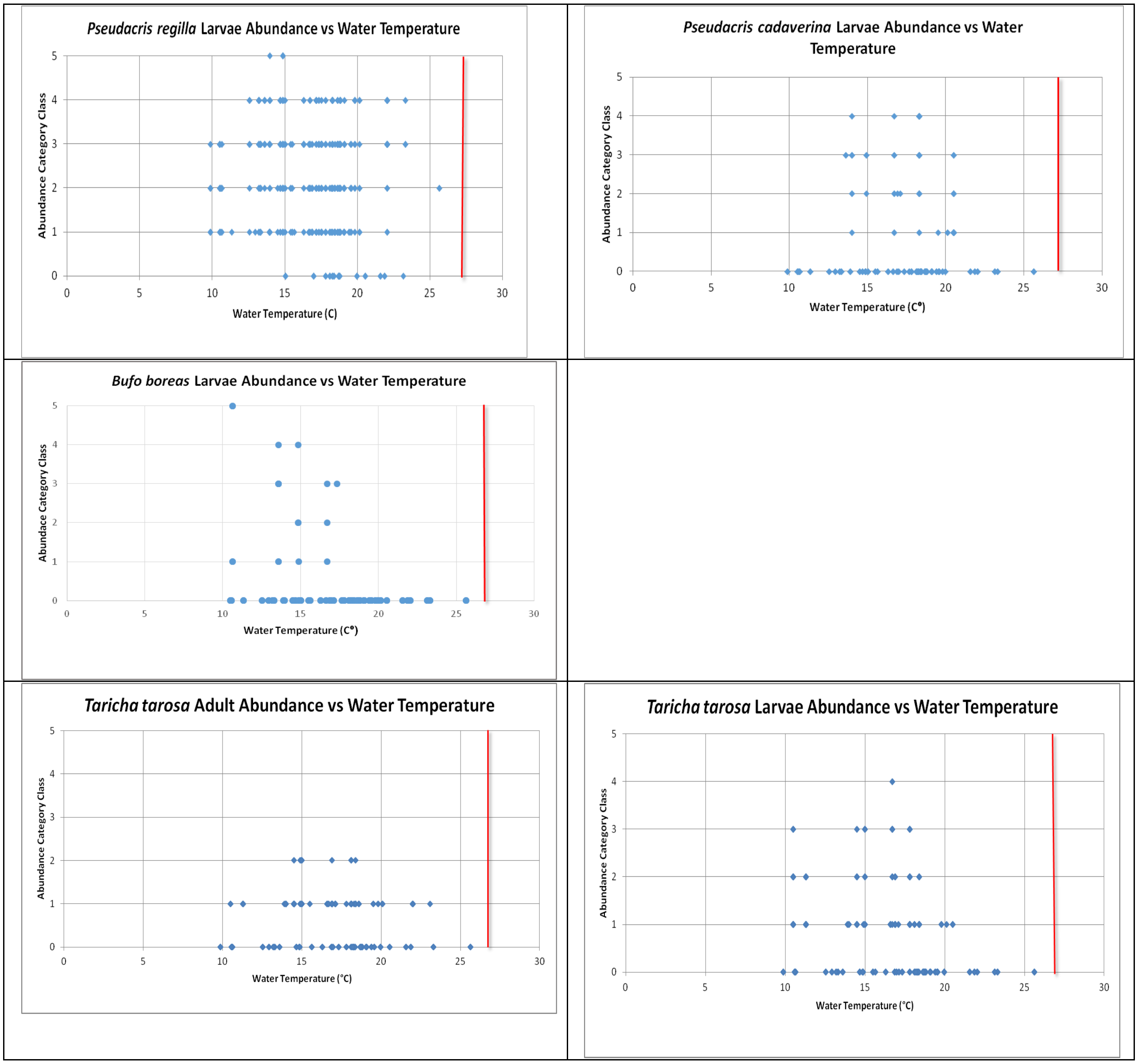


Figure 3-23 - Water Temperature compared among locations with data from all years. The red line indicates a warm water temperature objective of 26.7 degrees Celsius from the Basin Plan (1994).

3.7.2.2 Relationship Graphs

The focus species showed a clear preference for certain temperatures. BUBO larvae were present in water temperature of 10 °C to 18°C (Figure 3-24). HYCA larvae were observed in water temperatures from 14°C to 21 °C (Figure 3-24). HYRE displayed a wide range of 9°C to 26°C (Figure 3-24). TATO larvae were present in water temperature ranging 10°C to 21°C. Finally, TATO adult were present when water temperatures were 10°C to 23 °C, and most abundant between 15°C and 20°C.TATO larvae 10°C to 21°C (Figure 3-24).



Pseudacris regilla Larvae Abundance vs Water Temperature

Pseudacris cadaverina Larvae Abundance vs Water Temperature

Bufo boreas Larvae Abundance vs Water Temperature

Taricha tarosa Adult Abundance vs Water Temperature

Taricha tarosa Larvae Abundance vs Water Temperature

Figure 3-24 Abundance for all species against water temperature. The red line represents a water quality objective of 26.7 degrees Celsius from the Basin Plan (1994).

3.7.2.3 Regression Analysis

The regression test did not yield statistically significant results for any of the species and water temperature. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

3.7.3 Recommendations

There are not any unusual patterns in the annual temperature cycle in the Santa Monica Mountains. While there were locations that exceeded the water quality objective of 26.7 °C (Figure 3-23), the regression results did not show a significant correlation between amphibian abundance and water temperature levels (Figure 3-24). The NPS should continue monitoring this parameter, however, because it influences the concentrations of other parameters. Warmer waters, for example, can hold less dissolved oxygen than cold waters and are more likely to be acidic.

When monitoring dissolved oxygen, the NPS should be aware of which streams are cold water and which streams are warm water, as these waters have different water quality objectives as defined by the basin plan. The majority of the sentinel streams in the Santa Monica Mountains are warm water, but a few are defined as either intermittent cold water or potential cold water, and many random sites provide cold water beneficial uses.

3.8 Turbidity

3.8.1 Background

Turbidity measures the clarity of a body of water and the decrease in light penetration within the water column due to total suspended solids (TSS). Turbidity background levels generally vary with the type of soil present. Loam soils, for example, cause higher turbidity because they have a loose soil structure and are suspended more readily than clay soils (Stumm & Morgan 1981). High concentrations of TSS and therefore high levels of turbidity increase water temperatures because added suspended particles absorb more heat. Consequently, the warmer water temperatures then reduce concentrations of dissolved oxygen in the water. Furthermore, the lack of light penetration reduces photosynthetic activity which in itself also reduces the presence of dissolved oxygen (USEPA, 2012). Due to these effects, waters with high levels of turbidity can have adverse effects on aquatic life. The Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties has water quality objectives that determine that turbidity in waters should not exceed 20% where natural turbidity is between 0 and 50 NTU and where turbidity is greater than 50 NTU, turbidity in waters should not exceed 10% (1994).

Elevated levels of turbidity in waters can be due to soil erosion, waste discharge, and agricultural and urban runoff. Hecnar and M'Closkey (1997) discovered that grazed ponds and ponds adjacent to grazed and row crop agriculture had higher turbidity due to high phosphorus and nitrogen concentrations than non-grazed and natural ponds. High nutrient concentrations were attributed to runoff from agriculture fertilizers. Wildfires can also increase turbidity by destroying vegetation and leading to top soil runoff. Most recent wildfires have been caused by humans, such as a 1996 wildfire in Coldwater Canyon in the Santa Monica Mountains (Gamradt & Kats 1997). By initiating sedimentation removal, decreased soil stability, and consequent sedimentation and landslides, fires alter the geomorphology of the stream, reduce the number of pools and runs, and reduce the number of available oviposition sites for the California newt (*Taricha torosa*) (Gamradt & Kats 1997).

In their study of amphibian health following a wildfire, Gamradt and Kats (1997) found that total California newt egg mass in streams in the Coldwater Canyon decreased following a wildfire, but prevalence of adult newts went unchanged. The authors concluded that this dichotomy indicates that wildfires and the subsequent increase in sedimentation and turbidity affect oviposition rather than adult habitat. According to Gamradt and Kats, California newts prefer deep, calm waters to lay their eggs, and fewer pools leads to fewer oviposition sites. Reduced egg masses persisted for two years after the fire before returning to normal.

Knutson *et al*. (2004) found that high turbidity lowered the reproductive successes of ten various species of amphibians: tiger salamander (*Ambystoma californiense*), American toad (*Anaxyrus americanus*), western chorus frog (*Pseudacris triseriata*), wood frog (*Rana sylvatica*), gray tree frog (*Chiromantis xerampelina*), spring peeper (*Pseudacris crucifer*), northern leopard frog (*Rana pipiens*), pickerel frog (*Rana palustris*), blue-spotted salamanders (*Ambystoma laterale*), and green frog (*Rana clamitans*). Factors that contributed to poor water quality and subsequent low reproductive success were disturbance from the agriculture near the breeding ponds, which uprooted aquatic vegetation and increased nitrogen levels (Knutson *et al*., 2004). In contrast, Sparling *et al*. (1995) found that increased turbidity, which was partly due to suspended organic matter, increased the southern leopard frog and green frog populations because soil particles adsorb nutrients and organic matter, making more nutrients available to tadpoles. Thus, the effects of turbidity need to be examined separately for each species.

3.8.2 Statistical Analysis

3.8.2.1 Summary statistics

The average turbidity in the SMM NRA ranges from 0.26 NTU at Lower Solstice Canyon Creek to 13.00 NTU at Sullivan Canyon (Figure 3-25). East Fork Las Virgenes had the maximum value for turbidity at 105 NTU and an average turbidity of 7.0 NTU. Sullivan had the second highest maximum value of 76 NTU. Liberty Canyon (above pitfalls) had the second highest average turbidity at 5.7 NTU (Figure 3-25). For the purposes of this report, there is no standard water quality objective, because the water quality objective for turbidity are designed for point discharge and are set relative to background levels.

The bar charts at each location that compare data among the years showed constant turbidity levels throughout each year (Appendix E). The histograms for each sentinel site displaying the change in turbidity levels over time showed no distinguishable trend for change in turbidity over the years (Appendix E).

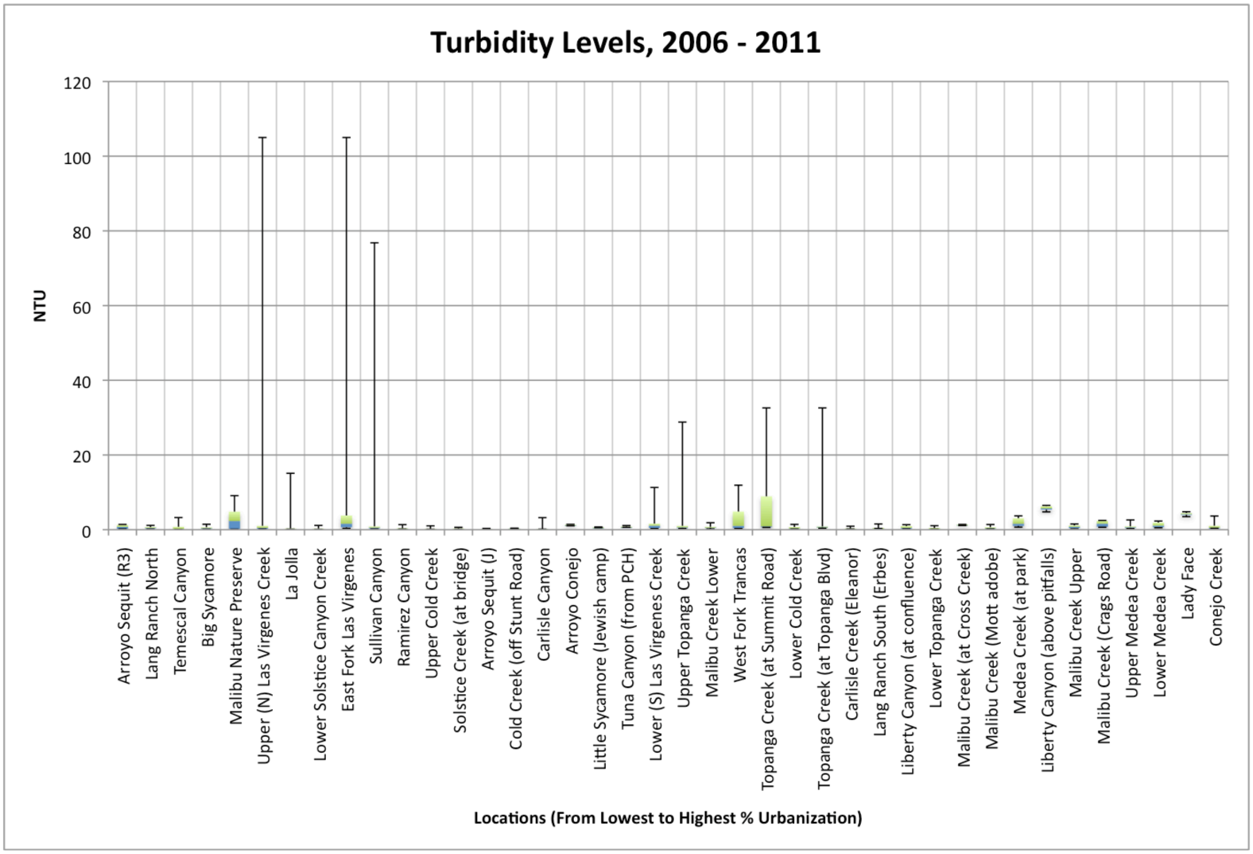
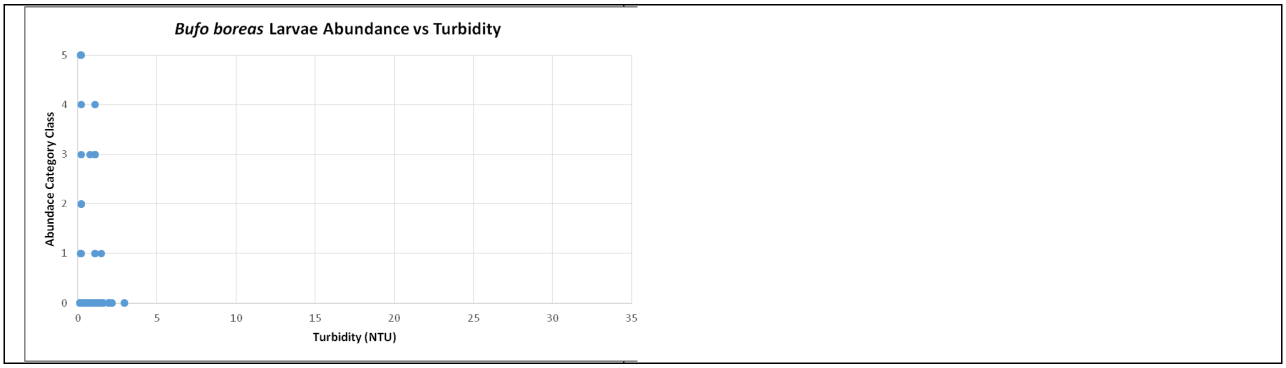


Figure 3-25 - Turbidity compared among all locations with data from all years

3.8.2.2 *Relationship graphs*

None of the species were found at turbidity levels beyond 4 NTU (Figure 3-26).



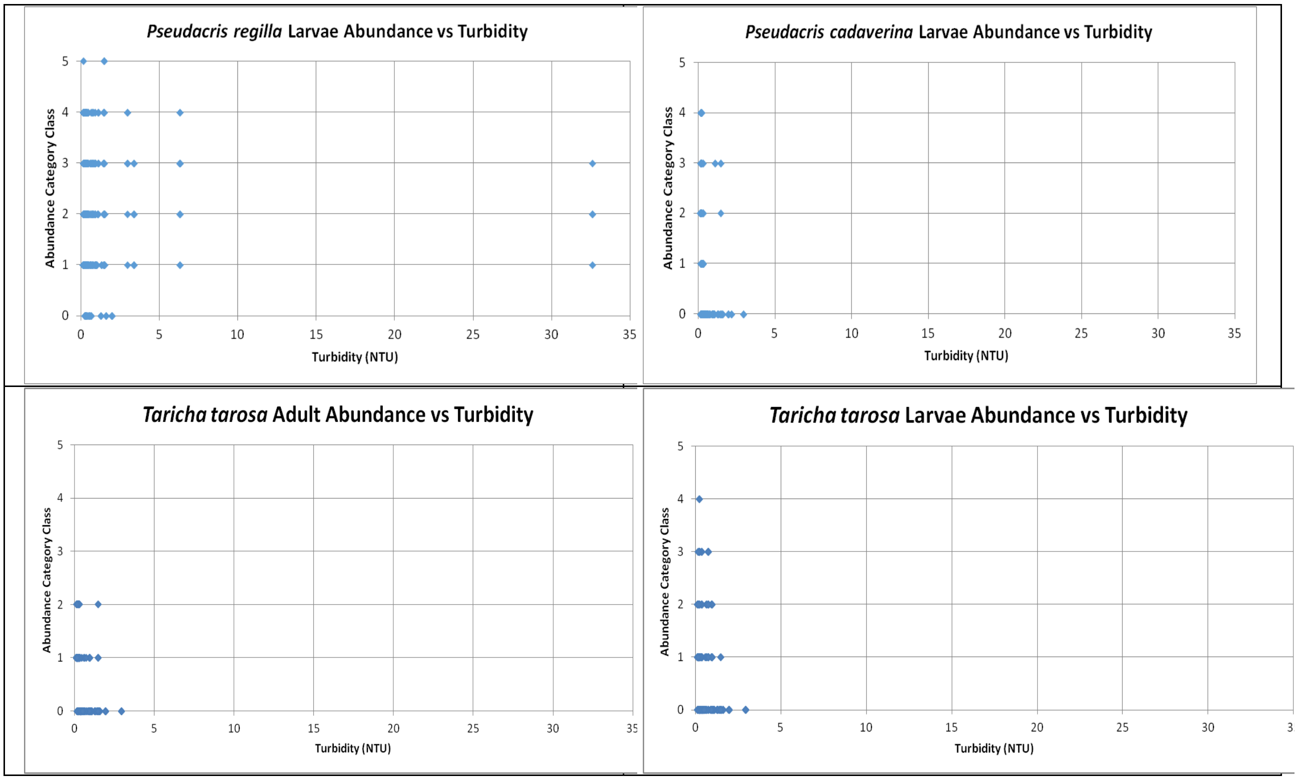


Figure 3-26 – Abundance for all species against turbidity levels.

3.8.2.3 Regression analysis

The western toad showed a statistically significant negative correlation with turbidity (Figure 3-27). The regression test did not yield statistically significant results for any of the other three species and specific conductance. This does not necessarily imply a lack of relationship, however, and we hypothesize that the time gap between amphibian monitoring dates and water quality monitoring dates may have affected statistical accuracy. Refer to Appendix G for all regression plots, correlation coefficients, and p-values.

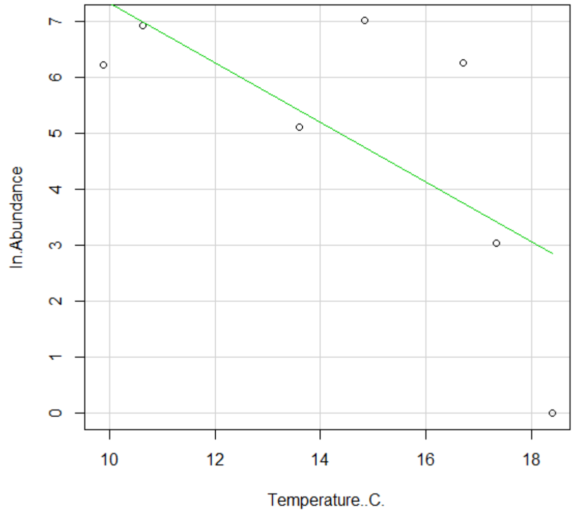


Figure 3-27 - Regression results for BUBO and turbidity. R-value = -0.889 and p-value = 0.007

3.8.3 Discussion

Turbidity levels at the sentinel sites are not at critical levels. While none of the species were found at turbidity levels beyond 4 NTU, the Pacific treefrog seems to be adaptable to a wider range of turbidity levels.

3.8.4 Recommendations

East Fork Las Virgenes and Sullivan canyon have critical turbidity levels and may be sites for future monitoring. West Fork Trancas also had unusually high turbidity levels during July 2007 and June 2010; as these are not typical storm months, this is a potential location-related concern. All the sentinel sites had low levels of turbidity and so the NPS need not prioritize monitoring efforts of turbidity levels, but turbidity levels can aid in determining areas of low dissolved oxygen levels and should be monitored as time permits.

4 Other Parameters

The following parameters were not included in the statistical analysis because of either poor quality of data, lack of scientific literature, or no indication of problems with the measured values (Refer to "Methods" for full explanation). All summary statistics and graphs for these parameters can be found in Appendices A, E, and F.

4.1 Discharge

4.1.1 Literature Review Background

The breeding and growth periods of aquatic amphibians in Southern California are synchronized and adapted to the region's seasonal cycles of wet winters and dry summers (Yarnell et al. 2012). California amphibians breed during spring and larvae undergo steady growth and metamorphosis in the lower flows of summer and fall (Yarnell et al. 2012). Stream flow (hereafter referred to as discharge) alterations during these sensitive breeding and growth development times can negatively affect aquatic amphibians.

Upstream urban development may contribute to discharge and habitat alterations that together affect amphibians through phenomena such as increased flow and loss of rocky habitats (Barrett et al., 2010). Barrett *et al*. (2010) researched the effects of urbanization on the two-lined salamander (*Eurycea cirrigera)* and found that increased magnitude and frequency of discharge (from low levels of 2–4 cm/s to critical levels of 43–200 cm/s) washed out embedded salamander egg masses and reduced the potential salamander abundance. These negative effects occurred more frequently for a sand substrate habitat than for a pebble substrate habitat.

Aquatic amphibians that breed in flowing waters such as streams may be more susceptible to the negative effects of increased discharge than those breeding in standing waters such as lakes and ponds (Kupferberg et al., 2011). Kupferberg *et al*. (2011) performed several experiments with differing discharge conditions on the foothill yellow-legged frog (*Rana boylii),* which normally breeds in flowing waters. They found found that tadpoles displaced from the shore in low velocity environments (5-10 cms) did not return. Critical water velocity levels of 13-23 cm/s caused tadpoles to attempt to swim against the current and eventually sink or swim downward, sometimes using their mouthparts to anchor themselves. In another experiment Kupferberg *et al.* exposed the tadpoles to similar velocity increases twice, once with flow refugia and once without flow refugia. The maximum duration of the amphibians' swimming stamina decreased from 85 minutes to 25 without refugia. Kupferberg *et al.*'s experiments reveal that amphibian survivorship is likely to be lower in streams with high discharge.

4.1.2 Recommendations

Discharge is a complex parameter to analyze because of inconsistent measurements ranging from 1 to 3 times a year per location (most locations had 1 entry/year). These data points were insufficient for statistical analysis regarding the relationship between discharge and the abundance /distribution of amphibians in the SMMNRA. Furthermore, because these measurements are instantaneous data points, it is difficult to determine what measurements are "abnormal" without knowing the physical and natural conditions of the tributary watersheds and the normal flows at that point.

4.2 pH

4.2.1 Literature Review Background

Aquatic amphibians favor naturally slightly acidic water during their breeding season and early life stages; these natural conditions occur as a result of waters having low buffering abilities and containing elevated levels of natural organic acids (Barth & Wilson 2009). Increased water temperatures and acidic precipitation inputs, however, can lead to unnaturally acidic waters (Pierce et al. 1984). Water pH levels not within the 6.5-8.5 pH water quality objective (Basin Plan 1994) may affect the abundance and distribution of aquatic amphibians with low tolerance to acidity. An amphibian's tolerance to pH alteration varies with life stage, as follows:

4.2.1.1 Embryonic Stages

4.2.1.1.1 Sperm

Acidic waters affect amphibian sperm by lowering its motility, which results in fewer fertilized eggs. Schlichter (1981) experimented with the fertilization and development of leopard frog (*Rana pipiens*) eggs. He tested the sperm motility at multiple pH levels and found that sperm motility began to decrease when the pH levels reached 6.5.

4.2.1.1.2 Eggs

Amphibian eggs are affected outside of the shell by positively charged hydrogen ions. Hydrogen ions inhibit the release of the embryo's hatching enzyme and reduce the water permeability of the egg membrane (Freda 1991). PH also affects egg deposition. Most amphibian breeding periods occur during the spring when pH is lower due to an increase in temperature (Pierce et al. 1984). Gascon and Planas (1986) observed fifteen different ponds with pH values that ranged from 3.4 to 6.7 and found that egg mass densities were lower in areas with pH levels ranging from 3.4 to 5.5.

4.2.1.1.3 Embryo

The most acid-sensitive life stage for amphibians is the embryonic stage (Dale et al. 1985; Freda 1991), which is also the most important stage in an amphibian's life cycle. An amphibian develops rapidly in the embryonic stage before it can hatch from its egg and live in its aquatic environment. In low pH environments, embryonic development often ceases entirely (Freda 1991). If an amphibian is harmed while it is an embryo, it will have a difficult time surviving to adulthood. Amphibian embryos are also very sensitive to habitats with low pH because of the sensitivity of their perivitelline space. The perivitelline space that surrounds an embryo inside an amphibian's egg is susceptible to shrinking in acidic environments (Dunson & Connel 1982). If the egg is then transported into a slightly less acidic environment, the embryo will continue to grow but the perivitelline space will still not expand, resulting in curled embryos deformed from the constriction of the perivitelline membrane (Freda 1991). Dunson and Connel studied the hatching rate of the African clawed frog (*Xenopus laevis*) in low pH environments. Their results indicate that *Xenopus laevis* have a lower success rate in bog water with a pH of 5.0 or less.

4.2.1.2 Larval Stage

Larval amphibians have a slightly higher tolerance to low pH than embryonic amphibians (Freda & Dunson 1986; Pierce et al. 1984), but acidic environments can still result in damage to larvae. Acidic environments cause tadpoles to lose sodium through their permeable skin, and the tadpole reaches fatal conditions once it has lost 50% of its normal sodium levels (Freda & Dunson 1984). Freda and Dunson studied the salamander larvae (*Ambystoma opacum*) in three different acidic solutions (3.0, 3.5, and 4.0) and discovered that lower pH was associated with increased sodium efflux and reduced survival times.

4.2.1.3 Adulthood

Amphibians are most tolerant to low pH as adults, but Wyman (1990) noted that there is a relationship between distribution of adult amphibians and pH. Wyman (1988) suggested that amphibians aggregate in areas with higher pH as opposed to areas with low pH. In his study, Wyman (1988) traced the locations of amphibians in five different plots in New York and found adult amphibians were typically absent in plots with a soil pH lower than 4.7.

4.2.2 Recommendations

The pH levels recorded in the SMM NRA were almost all within the 6.5-8.5 water quality objective (Basin Plan 1994), with the exception of a few maximum measurements up to 8.68 (Arroyo Sequit in 2008). No measurements were less than 6.5. Furthermore, pH values were much higher than the critical acidic pH levels that studies suggested were harmful to abundance and distribution of aquatic amphibians. Nevertheless, pH is an important parameter to continue monitoring because it can have a significant effect on amphibian health and abundance. (Appendix G)

4.3 Bromide

4.3.1 Literature Review Background

According to Flury and Papritz (1993), the main anthropogenic sources of bromide include potassium mining, fertilizer and pesticides, and 1,2-dibromoethane, a synthetic compound used as an additive in leaded fuels. Freshwater ecosystems have natural aqueous bromide concentrations of <0.004 to 1.0 mg Br-/L (Flury & Papritz, 1993). Li et al. (2009) studied the toxic effects of 1-methyl-3-octylimidazolium bromide ([C8mim]Br), an ionic liquid, on the embryonic development of the dark-spotted frog (Rana nigromaculata). Li *et al.* found that embryonic mortality was especially high in embryos exposed to [C8mim]Br during the neural plate stage, the beginning of the formation of the central nervous system. Lethal concentrations for embryos were 42.4, 43.4, and 85.1 mg/L for 96 hours of exposure during the early cleavage, early gastrula, and neural plate stages, respectively. This indicates that frogs in the early developmental stages are more sensitive to toxicity of this ionic liquid. Exposure to [C8mim]Br also delayed the development of frog embryos and caused morphological malformations (Li et al. 2009). Malformations included white spots in the belly, flexural body shape, abnormally short tails, a pronounced spinal area and tail, and fluid accumulation near the brain.

Canton *et al.* (1983) studied the toxicity of bromide on freshwater algae, crustaceans, and fish, and found significantly impaired reproduction in crustaceans and fish. Although this study did not involve amphibians directly, it could imply a similar effect in amphibians.

4.3.2 Recommendations

Due to insufficient data and missing measurement entries, accurate statistical tests for bromide were not possible. In addition, literature on bromide's effects on aquatic amphibians does not indicate that the bromide concentrations found in the SMM NRA, ranging from 0.19 to 8.05 mg/L per-site average, are harmful to the amphibians of that region. Furthermore, the average measurement values for bromide were relatively consistent among the years and locations, indicating that the surrounding urbanization and continued development likely does not play a role in bromide concentrations. Therefore, we do not consider bromide to be an important parameter for NPS to monitor, and the NPS would do well to discontinue it to make time for other parameters.

4.4 Chloride

4.4.1 Literature Review Background

Chloride is a common ion found in freshwater that is essential for biological processes in aquatic amphibians. Chloride in aquatic amphibians allows for a balanced exchange of ions in their cell membranes, but increased concentrations of chloride in the water can disrupt this balance and result in osmotic stress than can be physically harmful (Shoemaker & Nagy 1977). Chloride contamination in aquatic habitats can be due to anthropogenic sources such as industrial and agricultural runoff, water-disinfecting agents, soaps, and de-icing salts. The US EPA requires acute concentrations of chloride in freshwater to be less than 860 mg/L and chronic concentrations to be less than 230 mg/L (USEPA, 2010).

Many studies have examined the toxic effects of high concentrations of chloride on fresh water aquatic life, but relatively studies are specific to aquatic amphibians (Elphick et al, 2010). In addition, those studies that do test for the effects of chloride on amphibians test for chloride in the form of sodium chloride (NaCl) originating from de-icing salts. In their study, Sanzo and Hecnar (2006) examined the effects of road de-icing salt (NaCl) on larval wood frogs (Rana sylvatica) and found survivorship rates, time to metamorphosis, weight, and activity decreased in the larvae as salt exposures increased from 0.39 mg/L concentrations to median 77.50 mg/L concentrations to high 1030.00 mg/L concentrations.

4.4.2 Recommendations

A lack of road de-icing activity near the Santa Monica Mountains implies that harmful concentrations of chloride from this source will not be a problem in the SMM NRA. The summary statistics indicate sites with relatively high chloride concentrations (Figure 4-1). These sites with chloride concentrations higher than the US EPA recommended chronic concentration of 230 mg/L include Medea (Entire Creek), La Jolla, Conejo Creek, Upper Topanga creek, and Upper Malibu Creek. Chloride data is missing from many sites in the 2008-2009 and 2009-2010 water years, however, and we were unable to conduct a thorough statistical analysis. The NPS should continue monitoring and may want to research the sources that have caused elevated chloride concentrations at these sites.

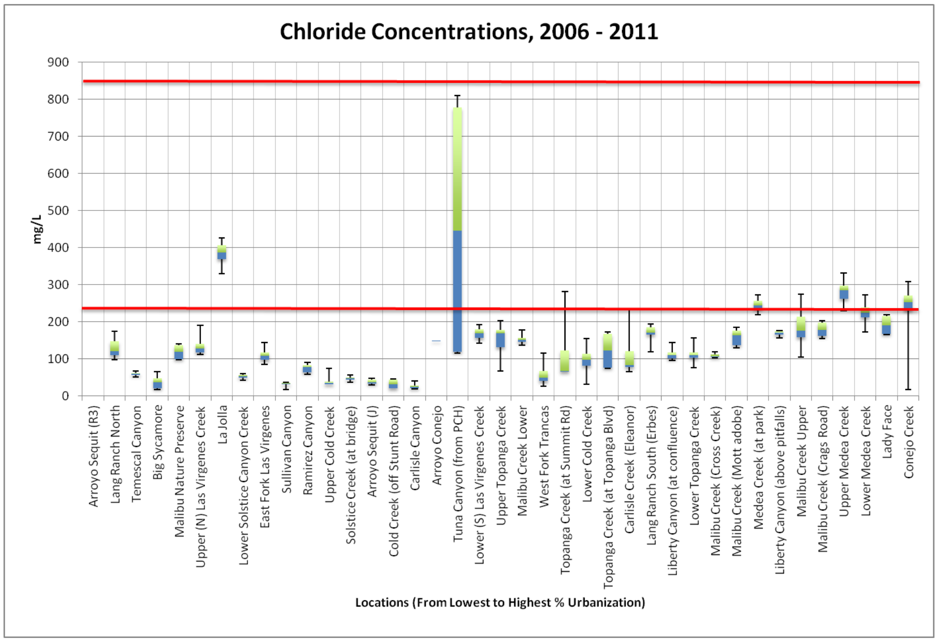


Figure 4-1 Chloride compared among locations with data from all years. The red lines indicate a chronic water quality criterion of 230 micro Siemens per centimeter and an acute criterion of 850 micro Siemens per centimeter.

4.5 Sulfate-Sulfur

4.5.1 Literature Review Background

Sulfates enter water bodies through leaching from soil, fertilizers, insecticides, the combustion of fossil fuels, and the decay of plant and animal material (Saskatchewan 2007). While there is research regarding various sulfate compounds, the majority of the research focuses on the effects of the other elements in the compounds. The other elements in sulfate compounds are typically metals or nitrogen compounds. In a study of embryos and tadpoles of the leopard frog (Rana pipiens), green frog (Rana clamitans), and bullfrog (Rana catesbeiana), heightened levels (from 0.2 to 5.5 mg/L) of sulfate from the insecticide fenitrothion, resulted in sublethal impacts such as abnormal swimming behavior, paralysis, reduced growth, and delayed development in the amphibians (Berrill et al. 1994). Limited literature, however, makes it difficult to characterize a relationship between sulfate and amphibian health.

4.5.2 Recommendations

Sulfate-sulfur was only monitored between the years 2006 and 2008, which does not provide sufficient data to run statistical analyses of this parameter. We did not conduct further statistical analysis due to the lack of supportive literature and a sulfate criterion for aquatic life. NPS would benefit, however, from researching anthropogenic and natural sources of sulfur-sulfate such as sulfur springs along Las Virgenes creeks that may be responsible for the high conductivity levels at these sites (Sikich et al. 2013).

4.6 Fluoride

4.6.1 Literature Review Background

High concentrations of fluoride may potentially harm amphibians because fluoride can accumulate in their tissues and interfere with their biological processes (WHO 1984). Industrial processes such as aluminum smelting can cause elevated concentrations of fluoride in freshwaters (WHO 1984). Research on the effects of fluoride on amphibian distribution is limited, and studies have yielded conflicting results because species differ in their response to the presence of fluoride. Clark and LaZerte (1985) found that the presence of fluoride was not a statistically significant determinant of the presence of amphibians. In contrast, Glooschenko *et al.* (1992) found a positive correlation between the presence of American toads (*Bufo americanus*) and green frogs (*Rana clamitans*) and fluoride concentrations ranging from 22 µg/L to 250 µg/L (Glooschenko et al. 1992). Mishra and Mohaptra (1997) studied the physiological effects of fluoride on the Asian common toad (*Bufo melanostictus*) and found fluoride concentrations were approximately 11 times greater in the bones of toads from the contaminated fluoride areas. They found these toads also had decreased body weight, lowered hemoglobin levels, and inhibited synthesis of essential proteins (Mishra & Mohaptra 1997).

4.6.2 Recommendations

Studies concerning effects of fluoride on amphibian physiology are sparse and do not indicate whether the fluoride concentrations measured by the NPS are critical to the amphibian abundance and distribution of amphibians in the SMM NRA. The NPS also only monitored fluoride between 2006 and 2008, which prevented an accurate statistical analysis. Summary stats for fluoride show concentrations up to 1.0 mg/L (Figure 4-2). There is insufficient information to support a recommendation for continued monitoring, and the NPS may want to discontinue monitoring this parameter to allow time and money for other parameters.

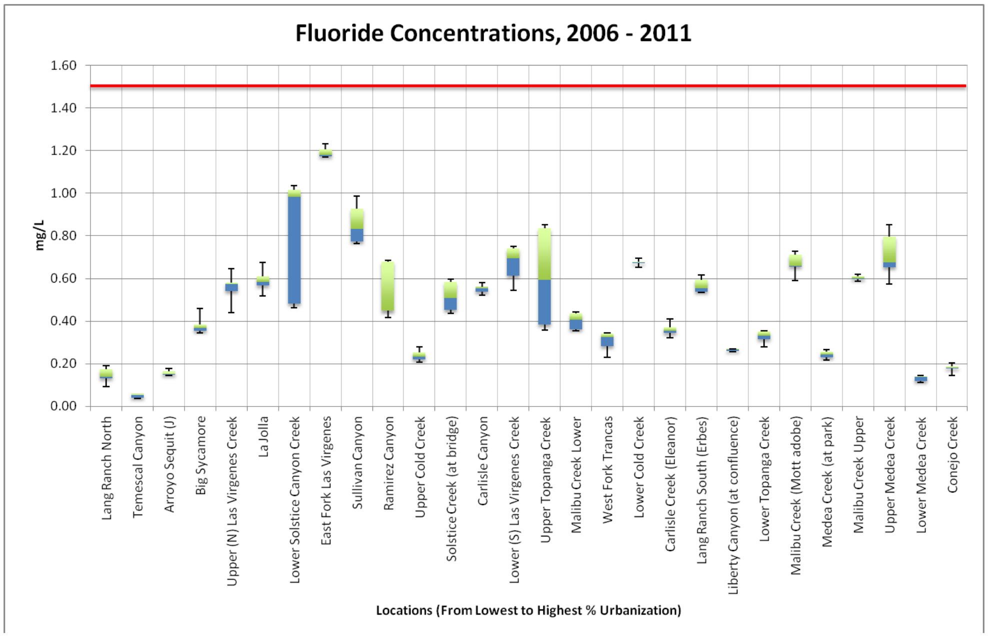


Figure 4-2 - Fluoride compared among locations with data from all years. The red line indicates a water quality objective for drinking water of 1.5 mg/L, defined by US Public Health.

5 East Fork Las Virgenes

5.1 Background

East Fork Las Virgenes is a branch of Upper (N) Las Virgenes, located North of Calabasas and the 101 Freeway (Figure 5-1). This site is of interest because it is the only known location in Southern California that is home to a population of the threatened California red-legged frog (*Rana draytonii*) (FWS 2013). It is currently classified as a judgment water quality site and is not monitored for amphibian abundance, therefore, we were not able to run regression tests, but summary statistics provided the basis for our recommendations

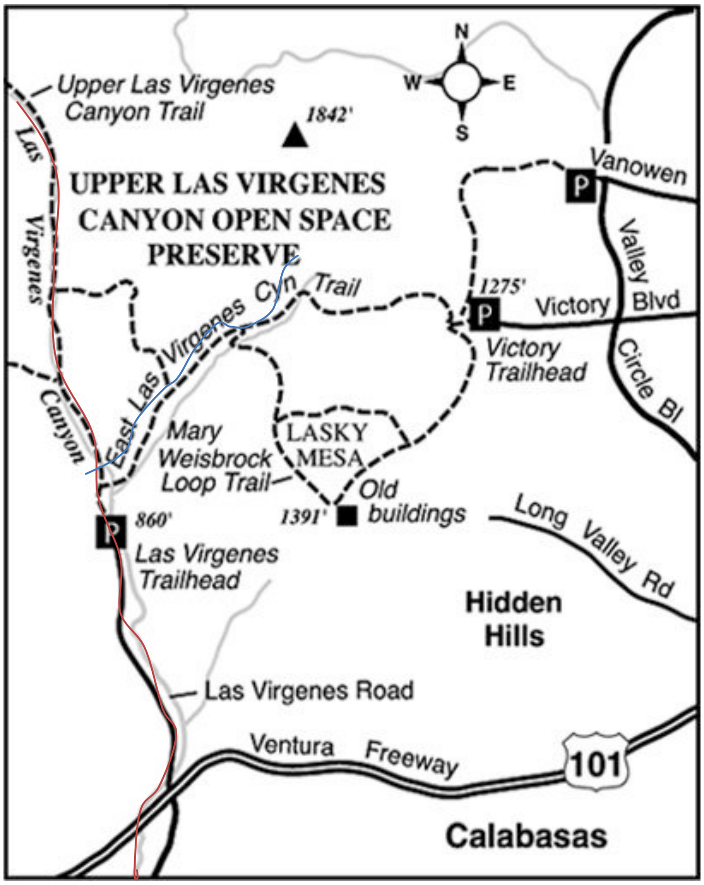


Figure 5-1 Map of East Fork Las Virgenes. Upper (N) Las Virgenes is in blue and East Fork Las Virgenes is in red.

5.2 Summary Statistics

East Fork Las Virgenes has water quality that is relatively poor when compared with other monitoring locations. Its specific conductance values are the highest overall with an average of 4081.7 µS/cm (Figure 5-3), it has very hypoxic conditions with an average dissolved oxygen level of 4.13 mg/L and a minimum of 0.15 mg/L (Figure 5-2), and its phosphate-phosphorus average is among the highest at 1.00 mg/L (Figure 5-4).

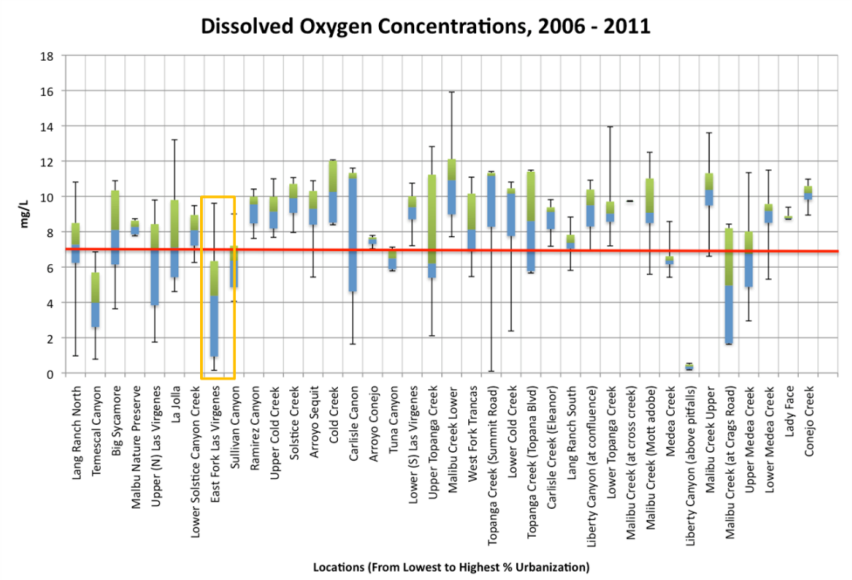


Figure 5-2 DO concentrations highlighting East Fork Las Virgenes. The red line indicates the Basin Plan's water quality objective of 7.0 mg/L.

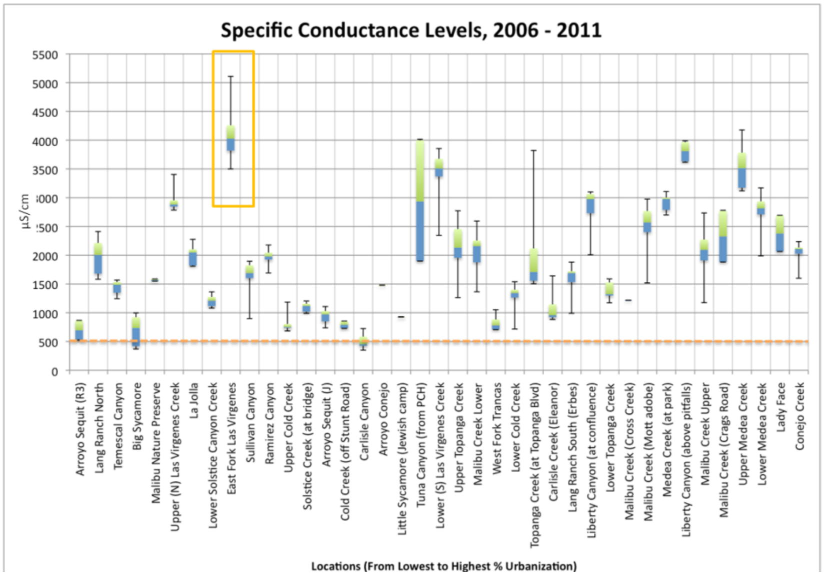


Figure 5-3 Specific conductance values highlighting East Fork Las Virgenes. The orange dotted line signifies typical freshwater levels as defined by the EPA (500 µS/cm).

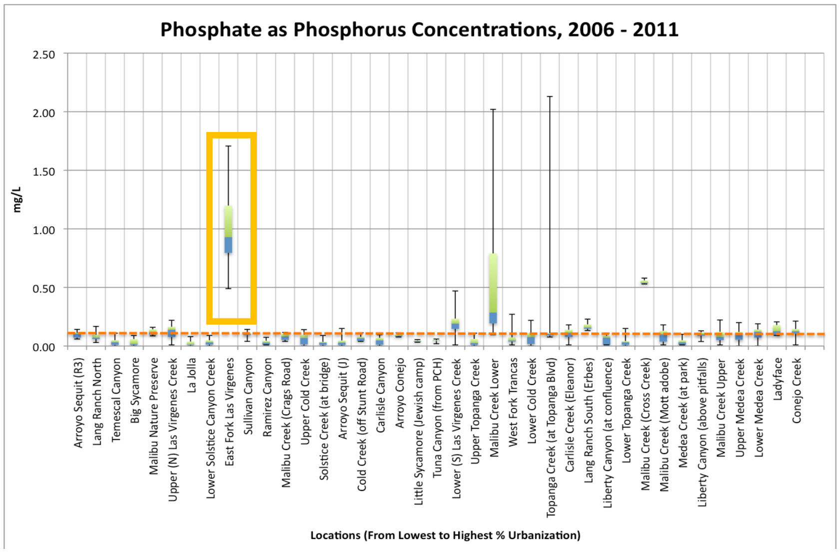


Figure 5-4 Phosphate-phosphorus concentrations highlighting East Fork Las Virgenes. The orange dotted line signifies recommended levels of 0.5 mg/L as defined by the EPA.

5.3 Discussion

Literature findings, as well as an analysis of SAMO data, show that some native amphibian species have clear preferences for high DO and low nitrate-nitrogen. The Western toad and the Pacific treefrog both seem to prefer higher levels of DO (Figure 3-5 Figure 3-6). The California newt and Pacific treefrog also showed a preference for lower levels of phosphate-phosphorus (Figure 3-21 Figure 3-22). The amphibian population at East Fork Las Virgenes therefore seems to be anomalous, but it is possible that other factors affect the presence of California red-legged frog populations. We suggest that this site be added to the amphibian monitoring.

5.4 Recommendations

The water quality measurements at East Fork Las Virgenes and its importance as a habitat to a threatened species lead us to recommend that NPS add this site to its amphibian and water quality monitoring protocols. Also, to fully understand the California red-legged frog's choice of habitat, NPS should consider other factors, such as noise, predation, human interaction, and light pollution.

6 Parameters of Interest

The chemical parameters currently monitored by MEDN's Inventory and Monitoring Program are only a subset of the urban stream parameters with the potential to affect aquatic amphibian abundance and distribution. Because of their applicability to the SMM NRA amphibian species and region, we will further focus on parameters not currently monitored such as heavy metals, pesticides, and contaminants of emerging concern (CECs). Our findings on these subjects will provide insight on possible recommendations for additional parameter monitoring.

6.1 Heavy Metals

According to Blaustein *et al.* (2003), heavy metals enter water bodies through mining, industrial pollution, and coal combustion. The category "heavy metals" is a long one and includes aluminum, lead, zinc, cadmium, mercury, silver, copper, arsenic, manganese, molybdenum, and antimony (Blaustein et al. 2003). When dissolved in water, these metals may be severely toxic to aquatic amphibians. Lefcort *et al*. (1998) suggested that heavy metals have a negative effect on amphibian larval development, behavior, and survival by delaying growth, lowering body mass, and reducing anti-predatory behavior (Lefcort et al. 1998). Lefcort *et al.* also found that combinations of metals may pose even greater harm to amphibians. For example, in their study, LC50 values (lethal concentrations that cause 50% mortality in the sample populations over a period of time) for combined concentrations of zinc and cadmium were significantly lower than LC50's calculated for individual zinc and cadmium concentrations for the spotted frog (*Rana luteiventris*) larvae.

6.1.1 Aluminum

A common metal found in amphibian ponds is aluminum, which is abundant in soils and enters amphibian habitats through either acidified surface runoff or sediment leaching. Aluminum toxicity and solubility increase as pH levels decrease (Freda & McDonald 1990). Therefore, even though aluminum naturally occurs in soil, it has become an issue now because anthropogenically-induced acid rain accelerates the dissolution of aluminum in soil (Bradford et al. 1994).

To better understand aluminum toxicity to amphibians, Freda and McDonald (1990) examined aluminum toxicity in the leopard frog *(Rana pipiens)* over a range of pH at several developmental life stages. Embryos were more sensitive to low pH (pH 4.2- 4.4), than to aluminum (0-1 mg/L Al) and died instantly when exposed to only low pH. When exposed to both low pH and aluminum, the embryos developed abnormal growths, such as a curling defect on their bodies that hindered their swimming abilities, but did not die. Aluminum prevented early mortality by maintaining a membrane balance of electrolyte loss and hydronium ion intake, a process which low pH disrupts, inhibiting proper larvae growth. This study suggests that aluminum mitigates some effects of low pH, although toxic itself. In contrast to embryos, tadpoles were less sensitive to low pH, but much more sensitive to aluminum. At concentrations of .25 mg/L Al, they were swollen, unable to swim, and often dead before maturation.

Bradford *et al.* (1994) observed similar life-stage differences of the effects of aluminum, but they also found differences between species. Aluminum in concentrations averaging .07 mg/L Al caused shortened body length in the Yosemite toad (*Bufo canorus*) larvae at pH 5.3 and 5.8 and only at pH 5.3 in the long-toed salamander *(Ambystoma macrodactylum) larvae*. The aluminum concentrations also caused a reduction in hatching time for the Yosemite toad embryos but not in the long-toed salamander embryos. While both studies show the significance of aluminum on amphibian embryos and larvae, Bradford *et al.*'s study demonstrates the importance of testing multiple species.

6.1.2 Arsenic

Arsenic compounds in water bodies can originate from natural sources such as weathering and volcanic activity but they mainly arise from anthropogenic sources such as urban runoff, combustion, and mining (Chen et al. 2009). The inorganic species of Arsenic, including aresenate (As[V]) and arsenite (As[III]), predominate in aquatic systems (Chen et al. 2009). Arsenate is less toxic and most prevalent in freshwater systems (ATSDR 2007). The U.S. Environmental Protection Agency has set a water criterion maximum concentration of .34 mg/L (acute) and .15 mg/L (chronic) for arsenic in protection of aquatic species (US EPA, 2010).

Chen *et al*. (2009) examined the effects of varying doses of arsenic (.01, .02, .15, .5, and 1.0 mg/L As[V]) on larval leopard frogs *(Rana pipiens).* They observed that the larvae absorbed and accumulated arsenic in their tissue, but this had no major effects other than reducing their swimming velocity. Bryszewska *et al*. (2011) exposed larval Iberian green frogs *(Rana perezi)* to arsenic concentrations of 50 and 100 ng/g and similarly found no significant effects on the larvae. These studies suggest that amphibians can be resistant to arsenic pollution, but further research on arsenic's effects on aquatic amphibians is needed to determine the relationship between amphibians and arsenic at multiple life stages and concentration levels.

6.1.3 Copper

Copper is a necessary trace element essential for catalytic and structural functions in proteins (Hercovits & Perez-Coll 2007). However, excessive concentrations of copper in aquatic freshwater can result highly toxic and pose adverse effects to the health of aquatic species (Hercovits and Perez-Coll, 2007). Furthermore aquatic amphibians and amphibian larvae have been shown to have lower tolerance levels to copper toxicity than other aquatic species such as fish (Bridges et al. 2002). Runoff with weathered soil rich in copper is the main natural source of copper introduction to freshwater bodies (ATSDR 2004). Anthropogenic sources such as industrial and agricultural runoff, mining practices, and petroleum refining can elevate natural copper water concentrations (Chen et al. 2006). A freshwater chronic criterion for copper was set at 9 g/L by the U.S. Environmental Protection Agency in protection of aquatic species (US EPA 2002).

Chen et al. (2007) exposed samples of Northern leopard (Rana pipiens) larvae to environmentally relevant concentration levels of copper (0, 5, 25, and 100 g/L as $CuSO4$) and found the US EPA copper freshwater-quality chronic criterion to be effective in the larval protection of this species. They observed long-term exposure of the higher concentrations of copper to have a negative effect on the survival, development, growth, swimming performance, and metamorphosis of the larval. They found a significant increase in deformities for high copper treatments such as a 64.7% increase in deformed gills and 11.8% increase in deformed mouth parts when compared to control copper treatments. They also found larval survival rates to be dependent on the concentration treatment and found the 100 g/L concentration exposure to result in a less than 10% survival rate. The 100 g/L copper treatment also resulted in delayed metamorphosis and decreased swimming capabilities in the larvae. Other studies examining the sensitivity to sub-lethal copper exposures of the Northern leopard larval found similar sensitivity levels. Redick and La Point (2004) found concentration levels above 71 g/L to lead to significantly smaller larval. Lande and Guttman (1973) found copper concentration exposures of 310 g/L to result in a 100% mortality rate and found growth inhibition to prevail for exposures between 60 to 160 g/L.

Redick and La Point (2004) suggest that, while their study resulted in decreased body length and heightened lethargy in the larvae, the exposed larvae exhibited no significant difference in body length after a certain period of days. This suggests that short-term exposure to high concentrations of copper may not result in long-term effects.

6.1.4 Lead

Lead is a non-essential metal that enters water bodies via natural sources such as erosion as well as anthropogenic sources such as sewage treatment plant discharge, mining, and urban and highway runoff (Pattee & Pain 2002). The toxicity of lead to fish, birds, and mammals has been extensively studied, but the potential negative effects of lead on aquatic amphibians remain under-researched (Gross et al. 2006).

Gross *et al*. (2006) exposed northern leopard frog *(Rana pipiens*) tadpoles to environmentally relevant low lead concentrations of 3 µgPb/L and to high concentrations of 100 µg Pb/L to observe lead's effects on the tadpoles' growth, behavior, and survival. When exposed to high concentrations tadpoles experienced slower growth, reduced swimming speeds, and significant spinal deformities. Concentrations of 3 µgPb/L did not have any noticeable effect on the tadpoles.

Herkovits and Pérez-Coll (1990) suggest lead toxicity to be amplified at early amphibian life stages. They exposed Argentine toad (*Bufo arenarum*) embryos in the neuromuscular activity and gill circulation embryonic stages to concentrations of 1 ppm Pb 2+. They observed a 50% decrease in survival rates for embryos at the neuromuscular activity stage. Conversely, they found the gill circulation stage to be most resistant to the lead exposure. Embryos at this stage had reduced cases of malformations such as decreased body size and spinal curvatures.

6.1.5 Zinc

Zinc is a trace element important to biochemical cell functions such as those that allow for tissue growth in aquatic amphibians (Herkovits & Pérez-Coll 1991). Studies have suggested zinc induces beneficial synergistic effects in amphibians exposed to highly toxic metals such as lead and nickel by mitigating the other metals' harmful effects (Herkovits & Pérez-Coll 1991; Herkovits et al. 2000). Herkovits and Pérez-Coll (1991) tested the combined effects of lead and zinc on Argentine toad (*Bufo arenarum*) larvae. When lead doses were less than 8 mg/L, zinc inhibited deleterious effects of lead such as spontaneous malformations in the larvae. Zinc has similar beneficial effects when combined with copper or with nickel (Herkovits & Helguero 1998; Herkovits et al. 2000). Herkovits *et al*. observed complex zinc-nickel interactions where high concentration of zinc (between 2-20 mg Zn^2+/L) enhanced nickel toxicity but even higher concentrations of zinc (60-100 mg Zn^2+/ L) had beneficial effects in Argentine toad larvae by protecting them against nickel uptake (2000). Zinc alone can be deleterious to amphibian abundance, however. In examining the amphibian distribution with respect to pond water chemistry near Sudbury, Ontario, Glooschenko et al. (1992) found that the absence of northern leopard frog *(Rana pipiens)* was associated with high zinc levels in the ponds that had a range of 3-139 µg/L. The U.S. Environmental Protection Agency has set a water criterion maximum concentration of 120 µg/L (both chronic and acute) for zinc in protection of aquatic species (US EPA 2010).

6.1.6 Discussion

Heavy metals brought in via urban runoff may deteriorate the water quality conditions of the SMM NRA. We recommend that the NPS measure the concentration of the heavy metals previously discussed and identify those that are found at critical concentrations. It would be beneficial to monitor metals at critical levels and research their effects on the distribution and abundance of the native amphibians.

6.2 Pesticides

Pesticides are chemical agents that, although agriculturally beneficial, can be environmentally harmful. Ecologists suggest pesticides might be toxic to amphibian populations and some scientist even hold pesticides to be responsible for the major amphibian decline in the California Sierra Mountains downwind from the highly agricultural San Joaquin Valley (Bradford et al., 2011). Though recent research examining the effects of agricultural pesticides on amphibian health has been extensive, findings have been inconclusive in determining how pesticides are specifically involved with amphibian population declines (Avery et al., 2005). And while laboratory studies have found low doses of pesticides to result in high mortality rates in amphibians, these tests do not explain amphibian declines in a natural environment where pesticide exposures are long term, may pose a lag effect, and are usually composed of multiple pesticide combinations (Taylor et al. 1999; Sparling & Fellers 2007; Rohr 2006). Several spatial test studies have however found a strong positive correlation between amphibian population declines and upwind agricultural land-use, indicating that atmospherically-deposited pesticides can indeed be a factor affecting amphibian abundance (Davidson et al. 2001; Davidson et al. 2002; Davidson 2004).

6.2.1 Field Observations

In 2001, Davidson *et al.* examined the spatial distribution of California red-legged frog (Rana *aurora draytonii*) sites and observed that habitats with absent amphibian populations had a percentage of upwind agricultural land-use 6.5 times greater than that for habitats with preserved populations. The same study revealed that the decrease in number of amphibian communities is a phenomenon linked specifically to pesticides, not general land-use change. Davidson (2004) further examined the spatial decline patterns in the California red-legged frog, foothill yellow-legged frog (*Rana boylii*), Cascades frog (*Rana cascadae*), and the mountain yellow-legged frog (*Rana muscosa*) and found strong associations between atmospheric depositions of organophosphates and carbamates pesticides and population declines. Atmospheric deposition is a potential concern in those areas of the SMM where fertilizer contamination could result from aerial deposition.

Bradford *et al.* (2011) found a positive correlation between yellow-legged frog (*Rana muscosa and Rana sierra*) presence and habitat distance from the Central Valley (Bradford et al. 2011), but unfortunately these results were inconclusive, because there was no confirmed correlation between the pesticide levels in soil samples and yellow-legged frog presence.

6.2.2 Laboratory Experiments

Sparling and Fellers (2007) conducted laboratory experiments on yellow-legged frogs' response to the three most common pesticides used in the San Joaquin Valley: chlorpyrifos, malathion and diazinon. All three pesticides initiated a significant dose-response relationship in yellow-legged frogs, but mortality varied with time of exposure, dose, and the chemical (Sparling & Fellers 2007). During their 96-hour exposure study, they found concentrations that produced mortality in 50% of subjects to be 3.00 mg/L for chlorpyrifos, 2.14 mg/L for malathion, and 7.49 mg/L for diazinon.

Later research explored the effects of chlorpyrifos and endosulfan on yellow-legged frogs (*Rana boylii*) and Pacific tree frogs (*Pseudacris regilla*) and found that consistent exposure to chlorpyrifos reduced the growth of both species' tadpoles (Sparling & Fellers 2009). For both species, a 34-day exposure to chlorpyrifos reduced snout-vent length (a measure used to indicate individual size), and 54 days of exposure to chlorpyrifos reduced the mass in individuals that were exposed to 200 µg/L (Sparling & Fellers 2009). Endosulfan also reduced growth in both frogs, reducing snout-vent length and mass after just 10 days of exposure (Sparling & Fellers 2009).

Sparling and Fellers (2009) also found that endosulfan caused 100% of individuals of both yellow-legged frogs and treefrogs to develop right-angled bends in their bodies when exposed to 3µg/L over a few days. This effect increased in frequency as concentration and length of exposure increased.

Sparling and Fellers (2009) found that yellow-legged frogs experienced higher mortality than Pacific tree frogs at the most lethal concentration of chlorpyrifos, 200 µg/L. In both species, an endosulfan concentration of 50 µg/L induced death in 100% of individuals, and yellow-legged frogs died en masse with only 0.8 µg/L. Overall, yellow-legged frogs experienced more detrimental effects than Pacific treefrogs, but pesticides caused reduced growth, abnormalities, and eventual death in both species.

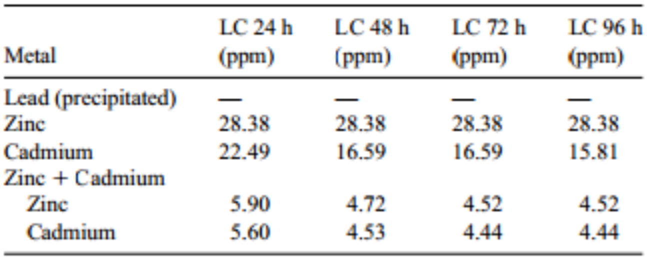
The oxidized forms of chlorpyrifos, malathion, and diazinon induce a more rapid decline of cholinesterase activity than their parent chemicals and are commonly found in yellow-legged frog habitats (Sparling & Fellers 2007). This is a concern because inhibition of cholinesterase leads to neurological dysfunction and ultimate lack of fitness (Sparling & Fellers 2007). Sparling and Fellers hypothesize that the combined effects of these pesticides and their oxons could generate even larger declines in amphibian populations in the Sierra Nevada foothills, where yellow-legged frogs are frequently exposed to all three chemicals simultaneously. However, a subsequent study found that reduced growth occurs only when uninterrupted exposure continues for at least 10 days, and mortality requires at least 34 days of exposure, but the oxons of chlorpyrifos, malathion, and diazinon all have a half-life that is shorter than 34 days (Sparling & Fellers 2009). Therefore, frequent repeated application of pesticides could be problematic, whereas short periods of application spaced sufficiently apart might reduce impacts.

6.2.3 Discussion

Although laboratory studies such as the ones previously discussed demonstrate a direct lethal effect of pesticides on amphibian health, recent studies suggest amphibian population declines are more likely due to sub-lethal and indirect effects (Davidson 2004, Relyea & Diecks 2008). In 1997, Bridges observed that exposure to sub-lethal concentrations of carbaryl of 3.5, 5.0, and 7.2 mg/L reduced the swimming performance and activity leopard frog tadpoles (*Rana blairi*) therefore decreasing their chances of survival. Relyea and Diecks (2008) observed that low consistent doses of malathion (10-250 µg/L) triggered a trophic cascade in their outdoor mesocosms that ultimately altered the community dynamic and reduced leopard frogs (Rana pipiens) populations. The added doses of malathion caused a decline in zooplankton due to their direct toxicity and thereafter initiated a phytoplankton bloom that outcompeted the periphyton which was the main food source for the tadpoles. They did not observe similar effects on the wood frog (Rana sylvatica) which they hypothesized was due to their shorter metamorphosis span. Biotic factors such as the amphibian's sensitivity levels, duration of metamorphosis, and community dynamics play a role in the potential harm pesticides pose to amphibian populations.

In addition to agricultural influences, urbanization could play a role in pesticide contamination of the SMM NRA. Up to 20% of pesticide use in California can be attributed to urban sources (Kiely et al. 2004), and a lack of homeowner-based reporting could result in higher actual values. Ensminger *et al.* (2012) sampled for pesticides in Orange County, Sacramento County, and the San Francisco Bay area and found that 90% of the sampled sites were positive for at least one pesticide, and three-quarters were positive for at least two pesticides. Ensminger *et al.* also found that, from the entire study, 72% of water samples had at least one pesticide exceed its benchmark concentration. All bifenthrin, fipronil, and malathion detections exceeded the EPA benchmark, a finding that is concerning because of the toxicity these pesticides pose to aquatic invertebrates and fish. The surrounding urban and agricultural landscapes near the SMM NRA make all of these pesticides a concern in regards to amphibian abundance.

Table 6-1 - LC50 values of metals as calculated by Lefcort et al. (1998) in their study of the spotted frog larvae.



Metal	LC 24 h (ppm)	LC 48 h (ppm)	LC 72 h (ppm)	LC 96 h (ppm)
Lead (precipitated)	—	—	—	—
Zinc	28.38	28.38	28.38	28.38
Cadmium	22.49	16.59	16.59	15.81
Zinc + Cadmium				
Zinc	5.90	4.72	4.52	4.52
Cadmium	5.60	4.53	4.44	4.44

6.3 Contaminants of Emerging Concern

A growing number of chemicals have been categorized by the Environmental Protection Agency as contaminants of emerging concern. These compounds have recently been detected in aquatic environments, and the extent of their environmental effects needs to be researched. Contaminants of emerging concern are compounds found in personal care products, pharmaceuticals, veterinary medicines, cleaning supplies, fire retardants, plastics, and rubber. These common products are often disposed of improperly and the harmful chemicals are not completely removed in wastewater treatment (Caliman & Gavrilescu 2009; Ellis 2006). The presence of these contaminants is strongly tied with environments near urban areas (Ellis 2006). In a study regarding pharmaceuticals and personal care products in urban receiving water, Ellis collected water samples at an effluent discharge point of a sewage treatment plant as well as upstream and downstream from the point. The conclusion of this study was that the effluent discharge increased concentrations of personal care products at the discharge point, but that concentrations upstream and downstream from the point were very similar. This identifies non-point sources as the primary contributor to these contaminants (Ellis 2006). Therefore, monitoring urbanized areas, such as the Santa Monica Mountains, is justifiable.

A majority of research regarding contaminants of emerging concern addresses the identification, sources, and removal of these chemicals. The toxicity level for many of the contaminants is not yet determined, but a concern surrounding these chemicals is bioaccumulation (Daughton 2003; Ellis 2006).

Another concern is the endocrine-disrupting chemicals found in many of these contaminants that could potentially affect reproduction (Khan 2005). Associated effects include decreased hatching, low hatching rates, and inhibition of metamorphosis (Vos 2000). Due to the recent detection of these contaminants, long-term effects are not widely documented.

7 Recommendations

7.1 Monitoring

Water quality monitoring should be conducted according to protocol and on the same day as amphibian monitoring. Large time gaps between amphibian and water quality monitoring dates can lead to erroneous analyses and misleading conclusions. For example, our relationship graphs showed larval amphibians correlated with near anoxic conditions. This is likely due to large gaps between monitoring dates; the dissolved oxygen levels do not accurately represent environmental conditions at the time of amphibian monitoring. It is also important to record zeroes when monitoring for amphibian abundance; an accurate statistical analysis requires knowing when a species is absent, and this knowledge results from carefully recording "zero" abundance.

Nomenclature should be consistent between the protocol and the measurements. Phosphorus and Nitrogen in particular can be measured in multiple ways and naming standards should be clarified and followed carefully. Many parameters could also benefit from more frequent sampling, such as discharge and dissolved oxygen. Instantaneous data mean little for a parameter that describes the flow of a stream or a parameter that varies diurnally.

7.2 Parameter Recommendations

The parameters can be divided into three recommendation categories: priority for monitoring, non-priority but continue monitoring, and discontinue monitoring (Table 7-1). These decisions are based upon the literature, summary statistics, relationship graphs, and regression tests, which can also be divided into two categories: local context of the Santa Monica Mountains or significance in literature. Local context means there are sites of interest, while significance in literature means research has indicated that the parameter affects amphibian abundance.

Table 7-1 Parameters and recommendations for monitoring. "Priority" parameters are an issue in local context and literature, "non-priority" parameters are an issue in either local context or literature, and "discontinue monitoring" parameters are neither an issue in local context nor literature.

Parameter	Recommendation	Local Context	Significance in Literature
Dissolved Oxygen	Priority	X	X
Specific Conductance	Priority	X	X
Nitrate	Non-priority	X	X
Nitrate-Nitrogen	Non-priority	X	X
Ammonia-Nitrogen	Non-priority		X

Chloride	Non-priority	X	
pH	Non-priority		X
Phosphate-Phosphorus	Non-priority	X	
Sulfate-Sulfur	Non-priority	X	
Water Temperature	Non-priority		X
Discharge	Non-priority		
Bromide	Discontinue monitoring		
Fluoride	Discontinue monitoring		

7.2.1 Priority Parameters

Dissolved oxygen is a priority because of the hypoxic locations East Fork Las Virgenes, Topanga Creek (at Summit Road) and Liberty Canyon (above pitfalls) (Figure 3-1) and because of the importance of dissolved oxygen to the larval stage in particular. Dissolved oxygen is also one of only two parameters that yielded statistically significant regression results with amphibian abundance (Figure 3-7 Figure 3-8). Specific conductance was also classified as a priority because it can alter osmoregulation in amphibians. The Santa Monica Mountains appear to have unusually high levels of specific conductance (Figure 3-15), but the relationship graphs do not show any apparent relation between specific conductance levels and amphibian abundance (Figure 3-17). The literature indicated that sulfur may be a natural contributing factor to high specific conductance levels, and there are natural sources of sulfur in the SMM NRA (Sikich et al. 2013), meaning this could be an interesting topic of study.

7.2.2 "Non-priority" Parameters

Nitrate-nitrogen and nitrate do not violate water quality criteria, but there are locations of relatively high concentrations, such as Lower Las Virgenes and Lower Cold Creek (Figure 3-12). Nitrate is also known to cause deformations, reduced motility, delayed hatching time, and methemoglobinemia in amphibians, as well as eutrophication in ecosystems.

Our literature review did not describe direct effects of chloride, phosphate-phosphorus, or sulfate-sulfur on amphibians. Studies on phosphorus have shown it to have indirect effects on amphibian health through parasites and eutrophication, and sulfate-sulfur may be a contributing factor to high specific conductance values (Sikich et al. 2013). These parameters are classified as "continue monitoring" because the local context is interesting, while the literature information is lacking. Natural sources of sulfur in the Santa Monica Mountains make sulfate-sulfur an interesting research topic, and average phosphate-phosphorus levels are high in East Fork Las Virgenes and Malibu Creek Lower. Chloride is a parameter of interest at Medea Creek and La Jolla, because values are near 300 mg/L, while other sites range from 25 to 75 mg/L (Appendix A). High levels of chloride can alter osmoregulation in amphibians, making Medea Creek and La Jolla sites of interest.

Ammonia-nitrogen, pH, and water temperature are all classified as "continue monitoring" parameters because of scientific research, rather than local context in the Santa Monica Mountains. None of the sites regularly violate the water quality criteria (Figure 3-9, Appendix A, Figure 3-23), but the literature indicates that each could be potentially harmful to amphibians. Ammonia-nitrogen is the most toxic of nitrogen compounds, high water temperatures are lethal to amphibians, and low pH can cause deformations and delayed hatching time. Each of these parameters should therefore remain in the monitoring protocol.

7.2.3 "Discontinue Monitoring" Parameters

There are few studies concerning bromide and fluoride and little data to draw conclusions about the state of these parameters in the Santa Monica Mountains. We therefore recommend that NPS discontinue monitoring these parameters to focus on new parameters of interest.

7.3 Parameters of Interest

New parameters of interest include aluminum, arsenic, lead, zinc, and copper, because of the concerns outlined above. We also recommend that NPS research contaminants of emerging concern and pesticides, especially pyrethroids,bifenthrin, fipronil, diazinon, chlorpyrifos, malathion, and endosulfan. Certain CECs have been shown to harm other aquatic taxa, and studies in the Central Valley of California have revealed negative correlations between pesticides and amphibian abundance.

7.4 Locations of Interest

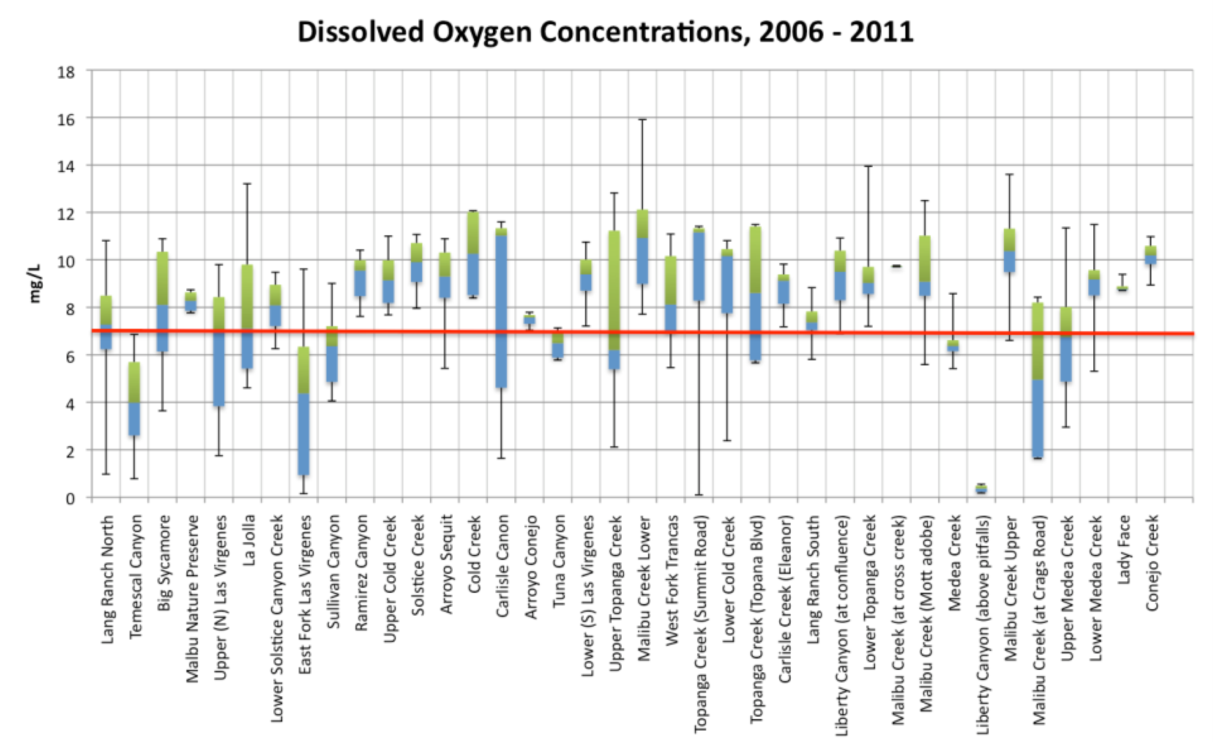
Locations of interest include those that violate water quality criteria on a regular basis (i.e., at least every other year). Refer to the executive summary for locations of interest organized by parameter. East Fork Las Virgenes is also of particular interest because of its connection to the California red-legged frog.

8 Executive Summary

Dissolved Oxygen

Typical Natural Background Levels: 2.7 – 9.5 mg/L

Ranges of Values in SMM: **0.10 – 15.9 mg/L**	Water Quality Objectives: Mean Annual Min: 7.0 Warm Waters Min: 5.0 Cold Waters Min: 6.0



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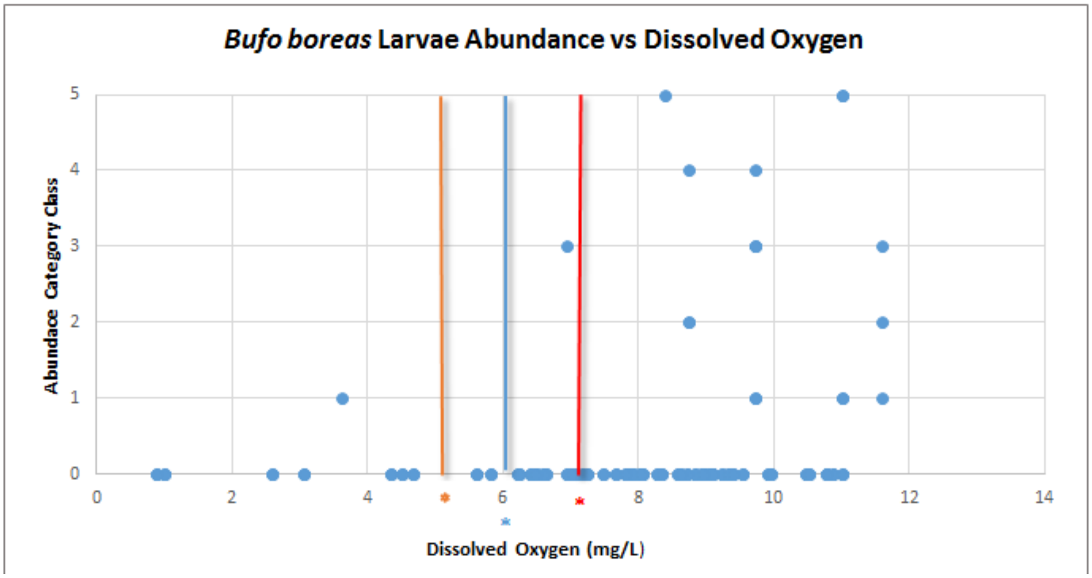


Locations of special concern: Liberty Canyon (Above Pitfall), East Fork Las Virgenes, Topanga Canyon, Temescal Canyon

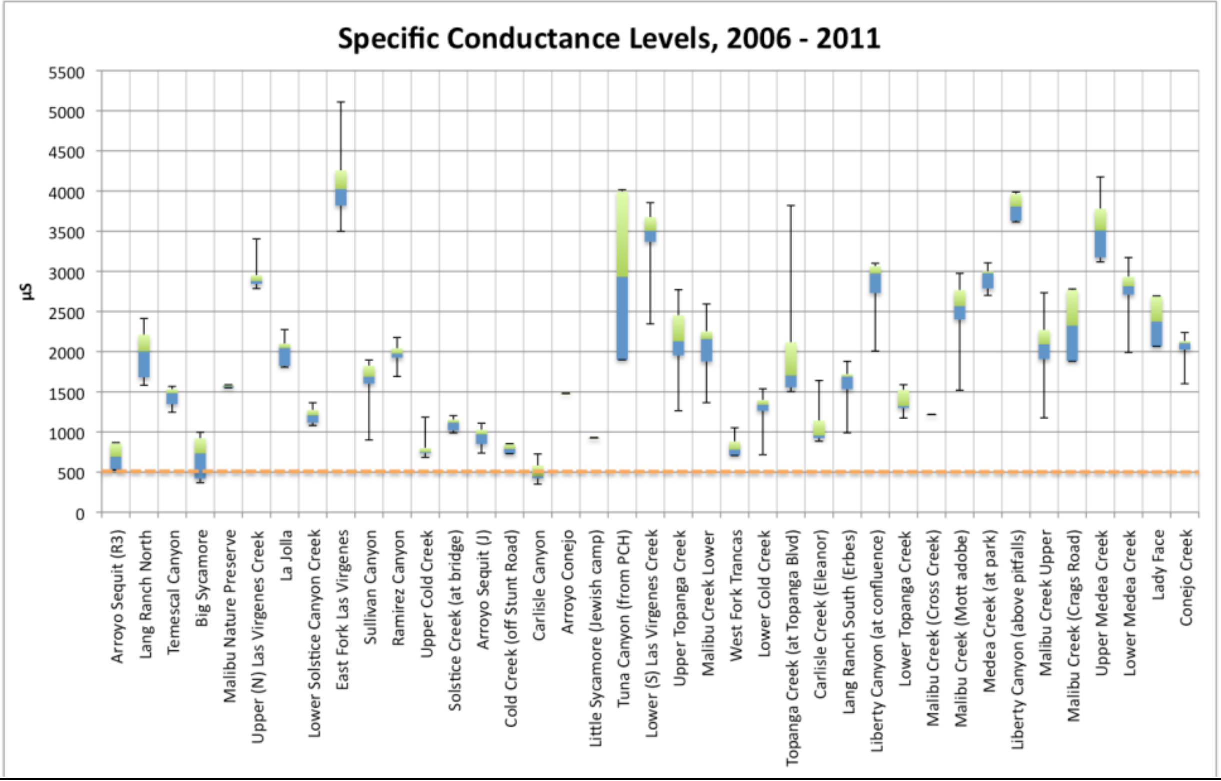
Recommendation: **Priority parameter – continue monitoring**

Specific Conductance

Typical Natural Background Level: 150-500 µS/cm

Ranges of Values in SMM: 349 – 5110 µS/cm

Water Quality Objective: 500 µS/cm



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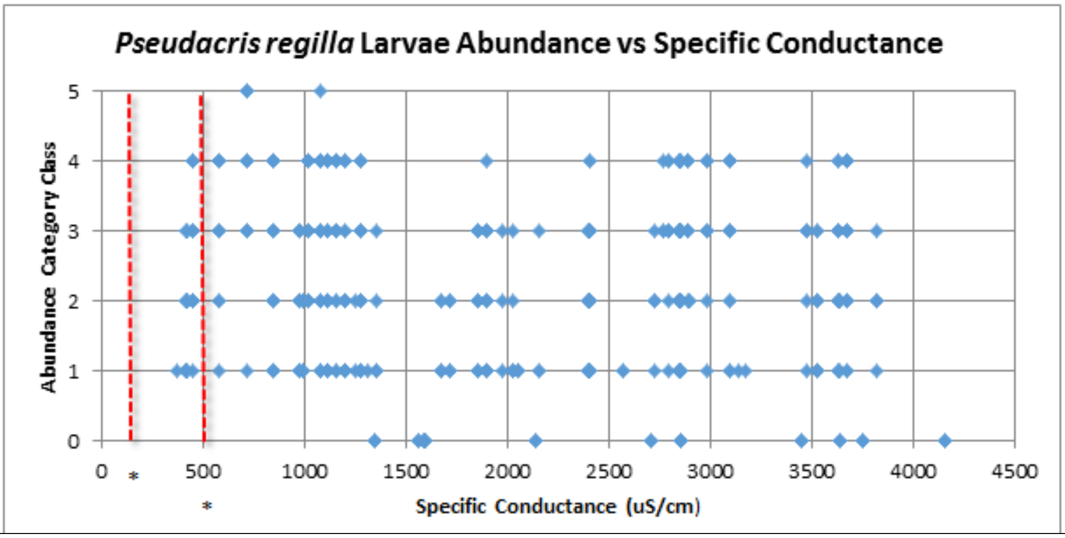


Locations of special concern: East Fork Las Virgenes, Upper Medea Creek, Lower Las Virgenes

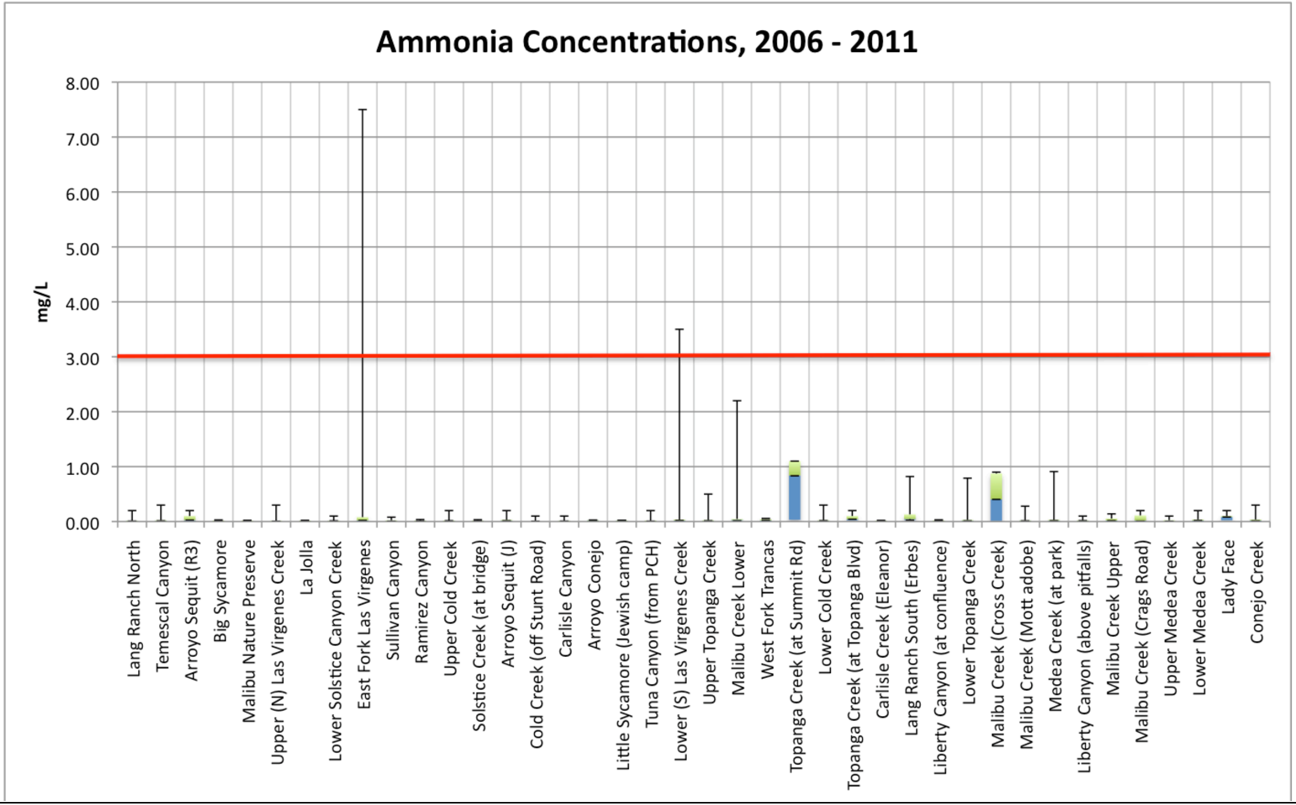
Recommendation: **Priority parameter – continue monitoring**

Ammonia-Nitrogen

Typical Natural Background Level: 0.01-0.04 mg/L

Range of values in SMM: ND – 7.5 mg/L

(Typical) Water Quality Objective: 3 mg/L



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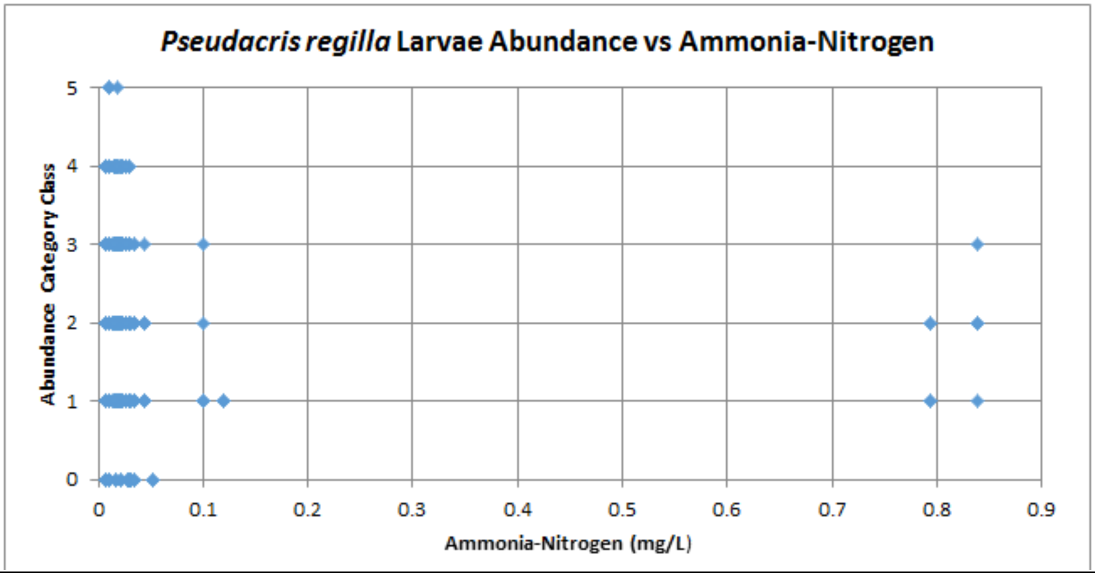


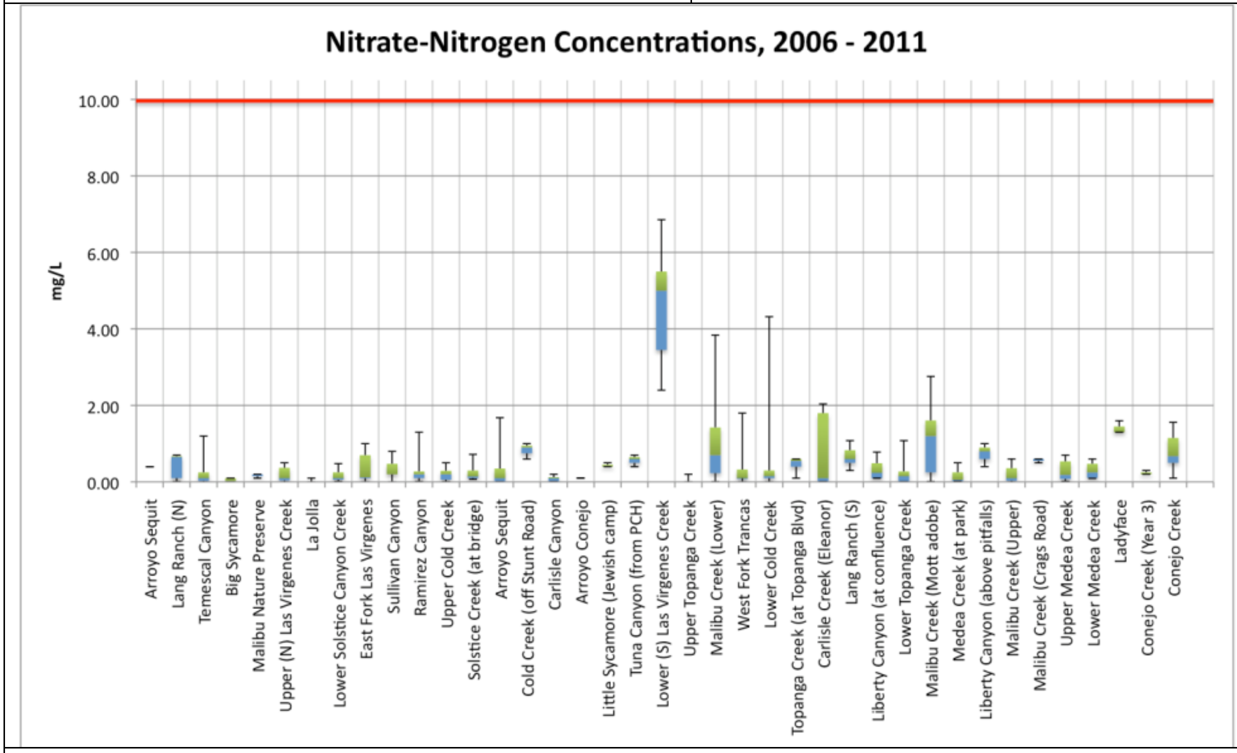
Locations of special concern: East Fork Las Virgenes

Recommendation: **Some concerns - continue monitoring**

Nitrate-Nitrogen

Typical Natural Background Level: 0.05-0.34 mg/L (Nitrate + Nitrite)

Ranges of Values in SMM: ND – 6.9 mg/L	Water Quality Objective: 10.0 mg/L max



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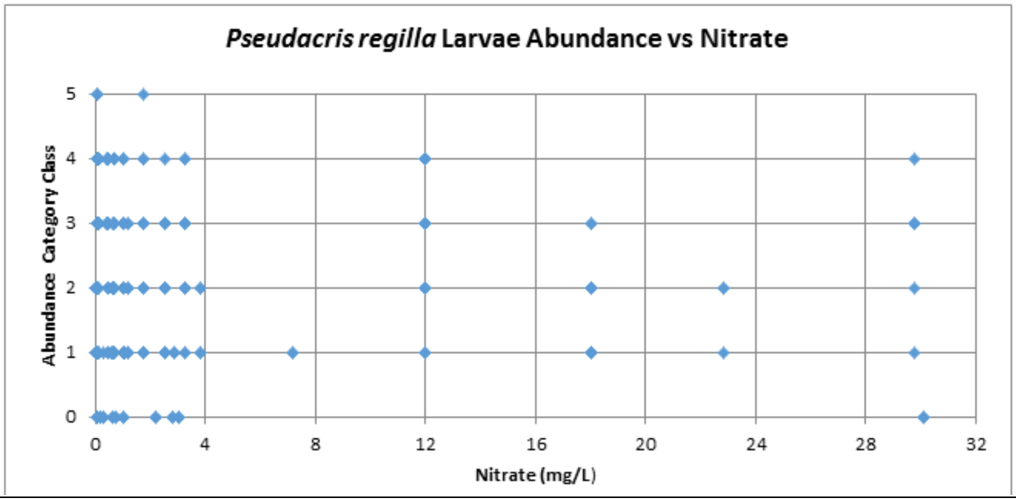


Locations of special concern: Lower Las Virgenes, Malibu Creek

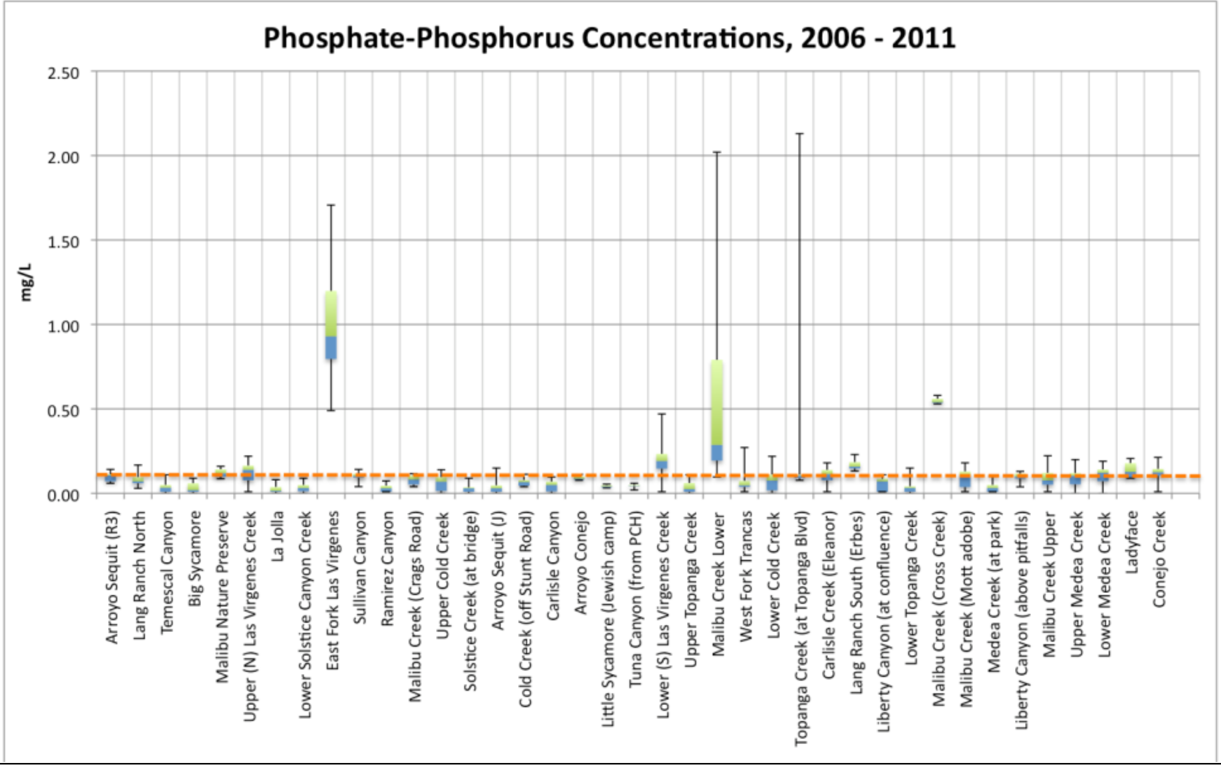
Recommendations: **Some concerns – continue monitoring**

Phosphate-Phosphorus

Typical Natural Background Level: 0.02-0.04mg/L (phosphate)

Ranges of Values in SMM: ND – 2.1 mg/L

Water Quality Objective: 0.1 mg/L



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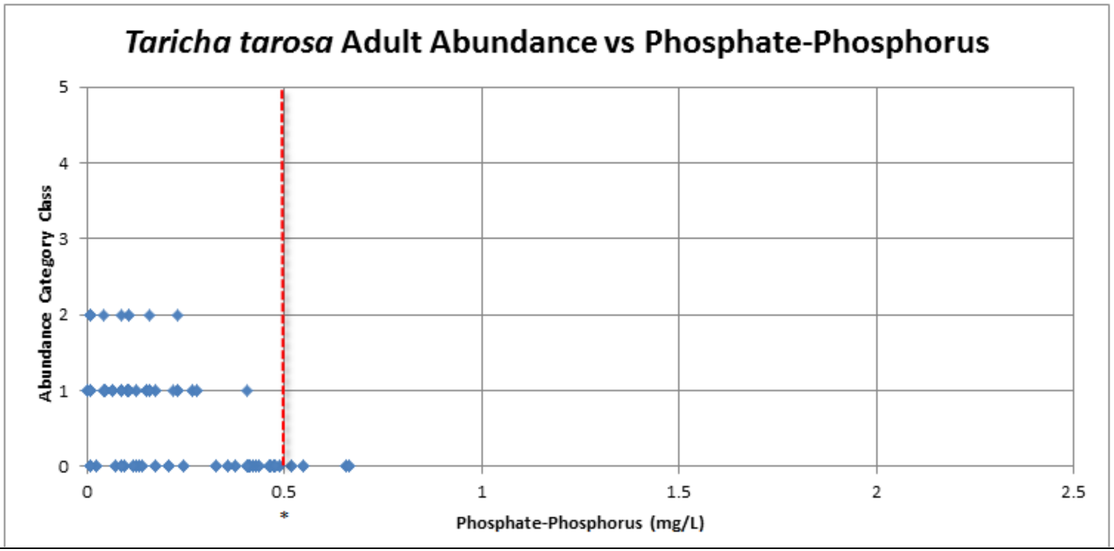


Locations of special concern: East Fork Las Virgenes, Malibu Creek

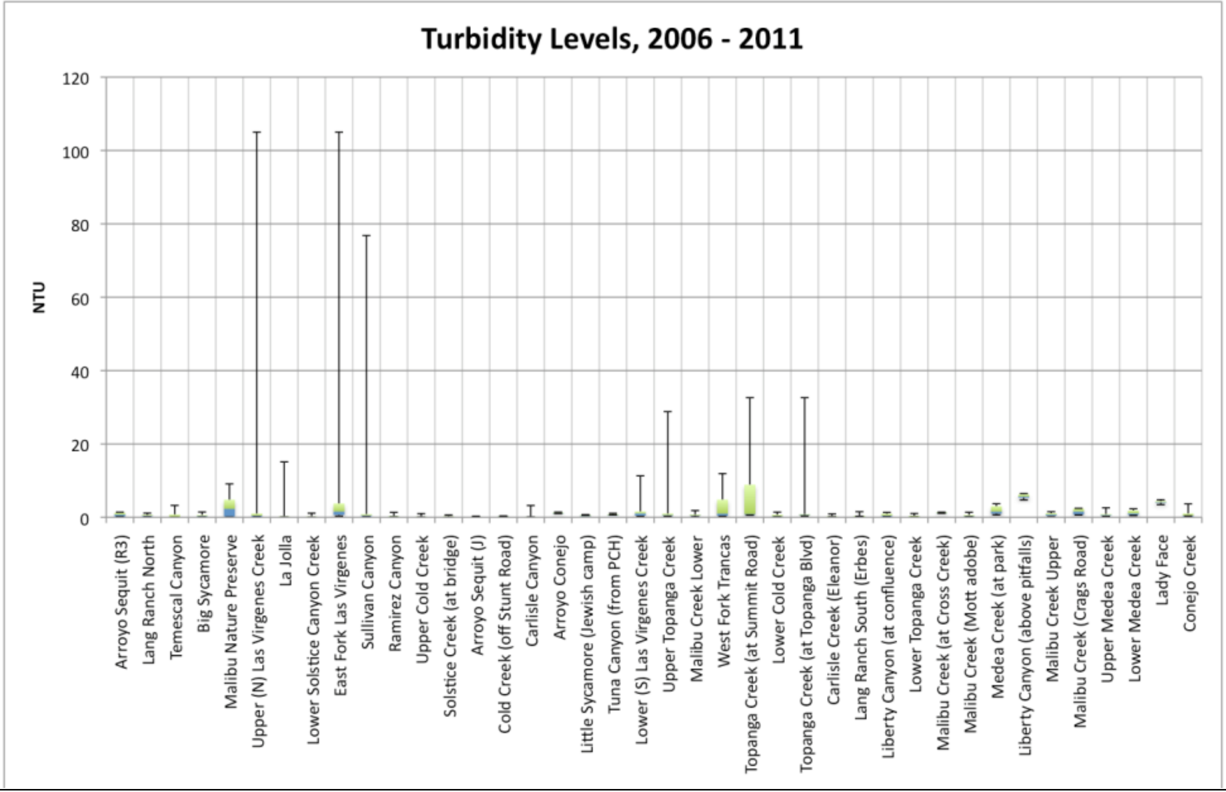
Recommendation: **Some concerns – continue monitoring**

Turbidity

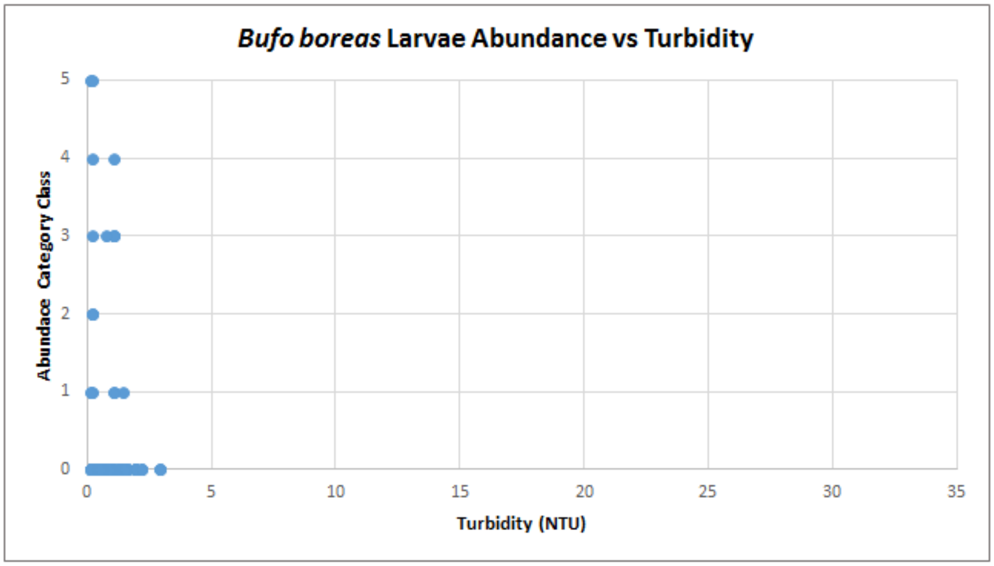
<u>Typical Natural Background Levels</u>: Varies

Ranges of Values in SMM: 0.07 – 105.0 NTU

<u>Water Quality Objective</u>: N/A



<u>Example Relationship Graph:</u>



<u>Locations of special concern:</u> East Fork Las Virgenes, Sullivan Canyon, West Fork Trancas

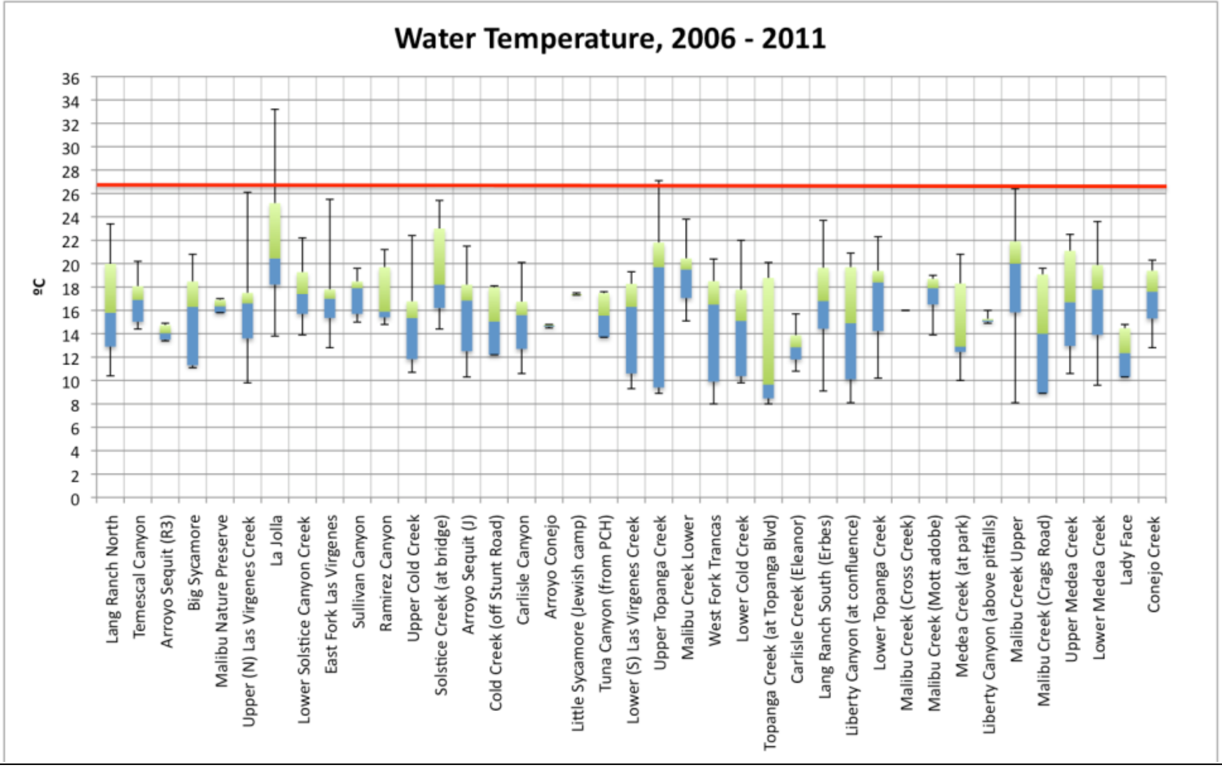
<u>Recommendations:</u> **Continue Monitoring**

Water Temperature

Typical Natural Background Levels: 13.8–19.8°C

Ranges of Values in SMM: 8°C – 33.2°C

Water Quality Objective: 27.6°C (maximum)



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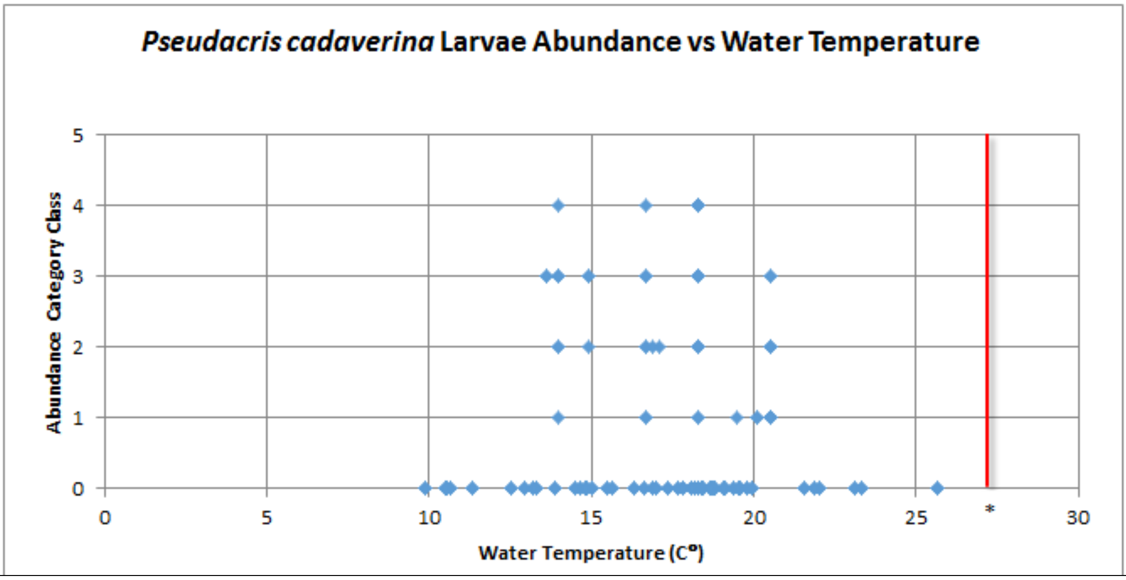

Locations of special concern: None

Recommendations: **Some concerns – continue monitoring**

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10 Appendices

10.1 A - Omitted Parameters

10.2 B - Amphibian Summary Chart

10.3 C - Water Quality Criteria Chart

10.4 D - Summary Statistics Table

10.5 E - Summary Statistics Graphs

10.6 F - Relationship Graphs

10.7 G - Regression Results

10.8 H - Paired Date Chart

10.9 I - Literature Index