PINTO LAKE TOTAL MAXIMUM DAILY LOAD (TMDL) PLANNING AND ASSESSMENT

Prepared for:

STATE WATER RESOURCES CONTROL BOARD
CALIFORNIA'S NONPOINT SOURCE POLLUTION CONTROL PROGRAM
FEDERAL CLEAN WATER ACT SECTION

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Executive Summary

Pinto Lake is a 126 acre, natural lake located just outside of Watsonville, California. The lake typically develops heavy cyanobacteria blooms from May through December. These blooms frequently produce toxins with concentrations above the state health limit of 0.8 ppb. Pinto's cyanobacteria blooms have been implicated in fish kills, bird deaths and the death of several southern sea otters in Monterey Bay. The purpose of this project was to determine what environmental factors are causing these blooms and identify what management measures and practices could be taken to eliminate or substantially reduce the blooms and their toxins.

Water quality sampling in the lake and its tributaries was conducted by the California State University Monterey Bay (CSUMB). This sampling covered basic water quality parameters, such as dissolved oxygen, pH and nutrients as well as identifying cyanobacteria species. Sampling of cyanotoxins was conducted by the University of California at Santa Cruz (UCSC). Water quality and bloom toxicity data were analyzed by UCSC using a statistical predictive model. Based on this analysis, it was determined that phosphorus, and to a lesser degree nitrogen, were the principal drivers of Pinto's toxic cyanobacteria blooms.

Based on the findings of the water quality study, CSUMB and the Resource Conservation District of Santa Cruz County (RCD) identified a number of management measures and practices that would help reduce nutrient loadings (phosphorus and nitrogen). These management measures include:

- In- lake treatments to limit release of phosphorus from lake sediments.
- Erosion control/sediment capture practices to reduce nutrient loadings from agricultural and/or urban properties in the watershed.
- Irrigation and nutrient management programs for agricultural, commercial and residential properties in the watershed.
- Public education regarding management of on-site wastewater systems, gray water disposal and landscaping practices.
- Investigating options for sewer system extensions .

Three public workshops were organized by the RCD to inform and engage key stakeholders and residents in the Pinto Lake watershed. The workshops were well attended and helped facilitate critical dialogue with community members.

While the project was successful in its purpose of identifying the principal drivers of the lake's cyanobacteria blooms and selecting management measures to address those drivers, more work is needed to determine the efficacy of specific management measures. For example, in- lake treatments range from simple water mixing systems (such as aeration) to the addition of chemicals (such as alum) which effectively lock phosphorus in lake sediments. The effectiveness of these management measures should be determined through pilot scale studies before commitment to full-scale implementation. In addition, more water quality sampling needs to occur within the watershed, to determine if there are nutrient contributing hotspots where focused management measures could be most effective.

Grant Summary

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http://www.waterboards.ca.gov/water_issues/programs/grants_loans/grant_info/index.shtml

Date filled out: 04/08/13

Grant Information: Please use complete phrases/sentences. Fields will expand as you type.
1. **Grant Agreement Number:** 10-443-553-02
2. **Project Title:** Pinto Lake Total Maximum Daily Load (TMDL) Planning and Assessment
3.**Project Purpose – Problem Being Addressed**: The purpose of this project was to identify the causes of cyanobacteria harmful algal blooms (CHABs) and recommend an implementation strategy and sequence to eradicate/reduce CHABs in Pinto Lake.
4. **Project Goals** **a. Short-term Goals:** 1. Develop educational and outreach materials to provide information about the Pinto Lake and CHABs to the public through workshops as well as other public relations avenues 2. Determine which physical/chemical/biological conditions are driving the toxic CHABs. 3. Determine the sources (Pinto Creek and its tributaries, shallow groundwater, or the lake's sediments) of pollutants that cause or contribute to the cyanobacteria blooms so as to determine the focus for future implementation efforts. 4. Develop implementation strategies to eliminate or modify the identified cyanobacteria supporting conditions and pollutant sources. **b. Long-term Goals**: Eliminate toxic bacterial blooms and restore Pinto lake water quality as set forth in the implementation strategy detailing recommended MM/MPs and an implementation sequence. The implementation strategy and sequence were developed based on the results of water quality monitoring and modeling. Ultimately the main long term goal is to restore the beneficial uses of the Pinto Lake by providing information critical to current TMDL implementation efforts as well as the development of future TMDLs.

5. **Project Location**: (lat/longs, watershed, etc.) Lat: 36.94716 ; Long: -121.76597, Pinto Lake	
a. **Physical Size of Project**: (miles, acres, sq. ft., etc.) 1485 acres - Pinto Lake Watershed	
b. **Counties Included in the Project:** Santa Cruz	
c. **Legislative Districts:** (Assembly and Senate) Assembly: 28, Senate District: 15, U.S. Congressional District: 17	
6. **Which SWRCB program is funding this grant?** Please "X" box that applies. ☐ Prop 13 ☐ Prop 40 ☐ Prop 50 x EPA 319(h) ☐ Other	
Grant Contact: Refers to Grant Project Director. **Name:** Carlos Palacios	 **Job Title:** City Manager
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Grant Time Frame: Refers to the implementation period of the grant. **From:** 12/1/10	 **To:** 6/30/13
Project Partner Information: Name all agencies/groups involved with project. The completed project was a partnership between the City of Watsonville (COW), California State University Monterey Bay (CSUMB), Santa Cruz County Resource Conservation District (RCDSCC), University of California Santa Cruz (UCSC), United Stated Department of Agriculture Natural Resource Conservation District (USDA NRCS), and Santa Cruz County.	
Nutrient and Sediment Load Reduction Projection: (If applicable) N/A	

Please provide an electronic copy to your Grant Manager and Program Analyst for the State Water Board web site posting. All fields must be completed. Incomplete forms will be returned.

Glossary

- **Aerosolization:** The process of converting a physical substance into the form of particles small and light enough to be carried on the air
- **Ammonium:** A positively charged form of nitrogen with the formula NH_4^+. A byproduct of animal and microbial metabolism, ammonium can enter a water system through surface runoff or be released from lake sediments.
- **Cyanobacteria:** Aquatic bacteria that obtain energy through sunlight via photosynthesis. Some cyanobacteria form dense accumulations on the surface of water bodies.
- **Cyanotoxin:** Naturally-occurring chemicals produced by cyanobacteria that have health or ecosystem impacts.
- **Epilimnion:** The top-most and warmer layer of water in a temperature-stratified lake. Due to the physics of water, warmer water is less dense than cooler water. As a result of the surface layer being warmer and less dense than deeper, cooler water, the epilimnion floats above deeper layer and is resistant to mixing with deeper layer.
- **Eutrophic:** A water body with high biological productivity as demonstrated via high dissolved nutrients and dense water column accumulations of algae and cyanobacteria.
- **Hepatotoxin:** A toxic substance that damages the liver
- **Hypereutrophic:** A water body with high nutrient levels (greater than 0.1 ppm phosphorus) and a corresponding density of phytoplankton (less than 3 foot visibility).
- **Hypolimnion**: The dense, bottom layer of water in a thermally-stratified lake.
- Limnological: relating to the study and biological, chemical, physiological and geological properties of lakes.
- **Microcystis:** A genus of freshwater cyanobacteria.
- **Microcystin:** A hepatotoxic cyanotoxin produced by several cyanobacteria
- **Nitrate:** A negatively charged form of nitrogen with the formula NO_3^-. Highly soluble and biologically active form of nitrogen, nitrate is widely applied in fertilizers.
- **Total phosphorus:** A measure of the combined dissolved phosphate plus insoluble phosphorous in the form of precipitates or within microbes
- **Watershed:** An area of land where surface water from rain flow converges to a single outlet, usually at the junction with another water body such as a lake, reservoir, estuary, wetland or ocean.

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Project Summary

Project Background:

Pinto Lake is a shallow, 126 acre hyper-eutrophic lake (Photo 1) located within the Pajaro River watershed in Santa Cruz County. The lake is bordered by two public parks and private lands. Land use in the lake's 1,480 acre watershed (Photo 2) outside of the park is primarily agricultural and ranch land, with some suburban and rural residential areas and businesses including stables, kennels and a composting facility (Table 1).

Currently, the lake poses a significant health risk to humans and other mammals from frequent cyanobacteria algal blooms (CHABs), which dominate the lake's aquatic ecosystem. Freshwater CHABs create an array of potent cyanotoxins, that can cause serious health impacts through direct ingestion and bioaccumulation. Acute microcystin exposure through direct ingestion can lead to liver failure and death within 24-48 hours. Lower level exposure through recreational contact or accidental ingestion can result in less severe symptoms such as nausea, vomiting, and diarrhea. Chronic low-level exposure to microcystin has also been associated with the long-term development of liver and gastrointestinal cancers in mammals (Ueno et al. 1996). Pinto Lake demonstrates seasonal CHABs with microcystin toxin levels measuring an average of 183 ppb, during blooms(2007 - 2011). In many years, toxin levels measured at the City launch ramp have exceeded 10,000 ppb. These toxin levels exceed the safe recreational exposure limit of 0.8 ppb established by the State of California (Cal EPA 2012). In addition to human health effects, freshwater CHABs have been linked to the deaths of 31 southern sea otters (a Federally listed endangered species) in Monterey Bay. Pinto lake discharges to the Monterey Bay via the Pajaro River and as such potentially linked to these deaths. Health risks to park visitors and the community as well as southern sea otters would be significantly reduced through eradication of the cyanobacteria and associated toxins.

In 2006, the Pajaro Nitrate TMDL implementation plan recommended 1) additional monitoring to address biostimulatory substances, algal growth, and low DO, and 2) revisiting and revising or developing subsequent Pajaro Nutrient TMDLs (TN, Nitrate, or TP) as needed to correct the impairments. In addition, Pinto Lake was placed on the California Impaired Water Bodies 303(d) list in 2009.

In 2010, the City of Watsonville was awarded funding through an EPA Clean Water Act Section 319(h) grant to identify the environmental drivers of the cyanobacteria blooms and develop an implementation strategy to mitigate and restore Pinto Lake water quality. The strategy was required to include a summary of management measures and management practices (MMs/MPs), an implementation sequence for MM/MPs to minimize and/or eliminate the cyanobacteria blooms. Actions included minimizing nutrient loadings into the lake and recommended treatments for managing nutrients in the lake. The Pinto Lake Total Maximum Daily Load Planning and Assessment Project (Project) provided the first analysis of the potential sources (Pinto Creek and its tributaries, shallow groundwater, or the lake's sediments) of pollutants and conditions that initiate and support toxic cyanobacteria blooms in Pinto Lake. It provides recommendations for an implementation strategy that can be used in current TMDL implementation efforts as well as in the development of future TMDLs.

Project Purpose:

The purpose of this project was to identify the causes of cyanobacteria harmful algal blooms (CHABs), determine the sources of pollutants that cause or contribute to the cyanobacteria blooms, and to develop strategies to eliminate or modify the identified cyanobacteria supporting conditions and pollutant sources.

Project Goals:

The goals and objectives of the project were the following:

1. Develop educational and outreach materials to provide information about Pinto Lake and CHABs to the public through workshops as well as other public relations avenues
2. Determine which physical/chemical/biological conditions are driving the toxic CHABs.
3. Determine the sources (Pinto Creek, shallow groundwater, or the lake's sediments) of pollutants that cause or contribute to the cyanobacteria blooms to determine the focus of future implementation efforts.
4. Develop a summary of strategies, proposed MM/MPs as well as a proposed MM/MPs implementation sequence.
5. Help restore the beneficial uses of the Pinto Lake while providing information critical to current TMDL implementation efforts and the development of future TMDLs.

Activities and Techniques:

The following Plans and compliance documents were completed as part of this agreement:

- Project Assessment and Evaluation Plan
- Monitoring Plan/Quality Assurance Project Plan
- CEQA Negative Declaration

In addition, the City of Watsonville (COW) used funds from this grant to complete the following activities and techniques:

1. Development of educational and outreach materials used in Project workshops and other related public outreach events.
2. Two (2) general public, one (1) agricultural workshop, and one (1) septic-owner workshop were conducted to inform stakeholders and the public about the Project
3. Water Quality Monitoring

The Project collected and analyzed two groups of data:

First Data Group

- To understand the timing, duration and severity of the toxic cyanobacterial blooms in Pinto Lake, samples were collected for cyanobacteria taxa identification and enumeration, dissolved and intercellular microcystins and chlorophyll a concentrations.

Second Data Group

- To understand the environmental factors driving the toxic cyanobacterial blooms, samples were collected and analyzed for dissolved and total nutrients, sediment nutrient flux and physical limnological and environmental parameters ("in situ" temperature, pH, and dissolved oxygen). Sample sites were located in tributary streams, in groundwater (via two sampling wells), and in the lake itself from the shallow upper lake, over the deep mid lake areas and down to the city boat dock.
- Because wind has a significant effect on cyanobacteria distribution, mid-water and surface samples were collected at GPS mapped locations along the prevailing wind direction (Northwest). These locations were marked by buoys at 250 meter (820 feet) intervals. In the profundal (deepest area) of the lake, samples were also collected from below the surface including both sides of the thermocline (if present) and 10 cm (4 inches) above the lake bottom. Shoreline samples were also collected from the city launch ramp and adjacent beaches, which represent the downwind end of the lake.
- Sediment flux chambers were installed in the lake to estimate the amount of phosphorus being released from lake sediments (a source of nutrients documented in many other lakes with cyanobacterial blooms). A total of twenty sediment flux experiments were conducted. Phosphorus flux is the measurement of the change in phosphorus concentration over time in the water column overlaying the sediments. The final phosphorus flux is measured in mass of phosphorus per unit area per unit time.
- Since cyanobacteria do not normally bloom year-round, regular sampling of microcystin concentrations was only started when there were signs of bloom initiation. Extended sampling continued throughout each bloom cycle, on a weekly basis, for a total of thirty (30) individual sampling events.
- Predictive statistical models used environmental, cyanobacterial abundance and toxicity data to determine which factors drive bloom toxicity.

Identification of Nutrient Loading Sources

Three sources were evaluated for nutrient loading:

1. Internal sediment loading (through flux chamber experiments)
2. Shallow groundwater (through monitoring wells)
3. Surface water runoff (through sampling in the lake's main tributary)

Sediment flux data consistently showed that lake sediments were the most significant source of nutrient loading in Pinto Lake. This data was corroborated by the high levels of nutrients found in the water column below the thermocline.

Surface water flows were identified as a significant nutrient source.

Due to problems with the monitoring wells, we are unable to make declarative statements regarding the role of groundwater in nutrient loading at Pinto Lake at this time.

Management Measures

An audit was conducted to identify existing management measures in the watershed. This provided a better understanding of the types of management measures currently in use in the watershed and should help avoid any future duplication of efforts.

Potential future Management Measures (MMs) were identified as well as any existing MMs that have the ability to control pollutant loading.

An implementation strategy and implementation sequence for management measures was developed based on the water quality monitoring and statistical modeling results. The strategy includes management measure recommendations for in lake treatments and watershed loading reductions.

Project Partners:

The completed project was a partnership between the City of Watsonville (COW), California State University Monterey Bay (CSUMB), Santa Cruz County Resource Conservation District (RCDSCC), University of California Santa Cruz (UCSC), United Stated Department of Agriculture Natural Resource Conservation District (USDA NRCS), and Santa Cruz County.

Project Locations / Management Measures Implemented

Research was conducted on management measures currently and historically implemented in the Pinto Lake Watershed (Table 2). This data was collected by speaking with landowners and with the various agencies that work in the watershed. All implemented management practices that provide reduction of the pollutants that drive CHABs are listed. Existing programs that provide outreach, education, technical and financial assistance for the implementation of management practices are also included.

Implemented In-Lake Management Measures

Following identification of nutrient release from lake sediments as a primary driver of CHAB's, the City of Watsonville implemented a carp eradication program. Carp are known to disturb lake sediments (bioturbation) as part of normal feeding behaviors. This has been identified as a significant factor in phosphorus release in other lakes.

Parks

The County of Santa Cruz Parks Department has an active Integrated Pest and Nutrient Management Program that includes only necessary removal of poison oak and other invasive plants to minimize bare soil and erosion. Management of the sports field is done using slow-release fertilizer and is timed to reduce any potential runoff, thus reducing nutrients to the lake. The park maintenance personnel have also attended erosion control workshops and the park has an active stormwater management plan to assist in reducing erosion and sediment transport to the lake.

Residential

The County of Santa Cruz currently has ordinances in place to reduce nutrient loading from erosion, vegetation clearing, and septic systems, although many of the residences in the Pinto Lake watershed predate current septic system requirements. Homeowners are required to comply with current requirements when new additions or substantial changes are made to their properties. The County provides a uniform level of septic system oversight throughout the County. Currently, there are no additional septic system requirements for properties in the Pinto Lake watershed. A database is maintained of all septic system permits, complaints, inspections, and septic tank pumping activities. Occasionally, samples are collected from roadside ditches during late winter/early spring to check for septic system overflows. Records of septic tank pumping have been maintained since 1989. A review conducted in late 2012 showed that 13% of the septic systems in the Pinto Lake Watershed did not report records of pumping to the County. This is important, because depending on how a septic system is managed, a lack of pumping could result in movement of solids into the leachfield and subsequent failure of the system.

This project did not address the amount of nutrients coming from each land-use type, so the actual level of nutrient loading from septic systems to Pinto Lake is currently unknown.

Agricultural

<u>Local Farm Bill Programs</u>

Over the last 38 years the Natural Resources Conservation Service (NRCS) has worked on numerous properties in the Pinto Lake watershed. In the last 5-7 years the NRCS has had at least 5 EQIP (Environmental Quality Incentive Program) contracts on farms in the watershed. These farms have (or are currently in the process of installing) a number of conservation practices that will benefit both surface and/or groundwater quality. Practices include cover crops, hedgerows, sediment basins, irrigation reservoirs (tanked), runoff control, road seeding, irrigation systems, irrigation pipelines, flow meters, roof runoff structures and irrigation water management. In addition, both the RCD and NRCS have provided onsite technical assistance on a variety of conservation practices to properties that do not have EQIP contracts. The benefits and intent of all of these practices is to protect and improve the quality of soil and water resources.

<u>RCD Programs</u>

In 2011, the RCD launched the Irrigation and Nutrient Management (INM) Program, focused initially on the Pajaro River Watershed, which includes Pinto Lake. The INM program is funded by the California State Water Resources Control Board (SWRCB) and the Natural Resources Conservation Service (NRCS), and is designed to address concerns regarding declining water quality and water supply in the region. Building on a long history of conservation efforts in the Pajaro Watershed, the INM program is conducting on-site irrigation evaluations and collecting data to monitor fertilizer inputs and make recommendations on how systems can be improved to conserve resources and mitigate impacts of agricultural run-off.

In 2010 the RCD was awarded funding from the US Department of Agriculture’s Outreach and Assistance for Socially Disadvantaged Farmers and Ranchers Program. For the past three years, this program, called Manejo Agricola con Nuevos Amigos (MANA) has been supporting the Resource Conservation District of Santa Cruz County (RCD) initiative to provide better conservation and education assistance to Spanish speaking growers.The MANA program has developed tools and resources specifically targeted to Spanish speaking farmers in Santa Cruz County, including: erosion control assistance, farm water quality and compliance assistance, and irrigation and nutrient management assistance.

Although RCD INM and MANA services have been provided across Santa Cruz County, Pinto Lake Watershed has not been specifically targeted. By focusing future services in this watershed, these services will assist in the implementation of projects associated with any TMDL efforts for Pinto Lake.

Project Performance

Goals and Targets

All project goals and corresponding targets identified in the PAEP (Performance Assessment and Evaluation Plan) were achieved:

Goal 1: Develop educational and outreach materials

- <u>Target 1.</u> Conduct a minimum of two (2) public and one (1) septic workshops
- <u>Target 2.</u> One (1) formal press release

Targets outlined for Goal 1 were met through the execution of three workshops, and the drafting of a formal press release. In addition, two newspaper articles were published about the project on July 16, 2012 and included information about the planned public meetings. The project team kept partners, such as the NRCS, up to date on the test results to help in decision making with recommended agricultural management practices with the Pinto Lake watershed.

Goal 2: Determine which physical/chemical/biological conditions are driving the toxic CHABs.
Target 1. Summary of sample analyses
Target 2. Commencement of intensive bloom sampling
Target 3. Quarterly report of nutrient sampling data and in situ conditions
Target 4. Predictive model relating environmental conditions to toxic CHABs
Target 5. Database with toxin information

The targets outlined in Goal 2 were met through the completion of the project sampling as designed, and by the successful creation of statistical predictive models capable of identifying the environmental factors contributing to cyanobacteria blooms. Data collection was completed and the results were reported and entered into the CEDAN database.

Goal 3: Determine the sources of pollutants that cause or contribute to the cyanobacteria blooms.
Target 1. Quarterly summary of Pinto Creek nutrient analyses, final report with relative contribution of Pinto Creek to the lake's nutrient budget
Target 2. Summary report of lake sediment nutrient flux
Target 3. Post-construction photos of groundwater monitoring wells

Results from the water quality monitoring and modeling were collected to meet Goal 3 targets and were also used to develop the implementation strategy and sequence. Phosphorous was identified as the environmental constituent most associated with the toxic cyanobacterial blooms.

Goal 4: Develop strategies to eliminate or modify the identified cyanobacteria supporting conditions and pollutant sources.

- Target 1. A summary of proposed management measures and practices strategy and proposed MM/MPs implementation sequence

The data from Goal 3 helped identify and prioritize the proposed in-lake and watershed-scale MM/MPs to target and reduce the phosphorus.

In addition, one major outcome of this project was the establishment of a consistent dataset of cyanobacteria bloom development and toxicity in relation to lake nutrient and temperature dynamics. Using this dataset, models were developed describing the associations between the environmental variables and the presence and abundance of seasonal CHABs and microcystins. This information can be used to adapt outreach activities to target sources of nutrients that might stimulate CHABs as well as shape interim and long-term strategies for controlling Pinto Lake cyanobacteria.

Water Quality Monitoring Results

Cyanobacteria blooms

The Pinto Lake Project succeeded in confirming that the combination of high nutrient (P and N) levels and seasonal warm water in Pinto Lake were driving toxic cyanobacterial blooms. Because the lake becomes thermally stratified, the processes that influence cyanobacteria blooms are seasonally distinct. Lake sediments are the dominant source of nutrients for cyanobacterial growth and therefore should be a management priority. However, management of in-lake sediments alone will not be enough to rectify the problem, so watershed inputs must also be managed.

Cyanobacteria Monitoring

Cyanobacteria cell counts increased from undetectable levels in January through March to above 100,000 cells/ml in mid-May (Figure 2). The mass accumulation of cyanobacterial cells continued through late autumn and included several cyanobacteria (the dominant taxa included *Anabaena*, *Aphanizomenon and Microcystis*) capable of producing cyanotoxins. Cyanobacterial cell densities decreased in December and remained undetectable until the following March.

Cyanotoxins - Microcystins

The cyanotoxin (toxins produced by the cyanobacteria blooms) microcystin was detected throughout the year above the safe recreational exposure limit established by the State of California at 0.8 ug/L. There was a small 30 ug/L peak in July and a more sustained toxic period from October through December 2011 with a maximum of 607 ug/L (Figure 1). Besides posing immediate health risks for any members of the public engaging in recreational water contact, the documented high levels of microcystin may also pose health risks to nearby communities through aerosolization of the toxins at high concentrations (Cheng et al. 2007).

Cyanotoxin Release

The environmental factor(s) that trigger actual toxin production and release in cyanobacteria are currently unknown. As such, control of cyanotoxins can only be achieved through the elimination of cyanobacteria blooms at this time.

Nutrients

Nutrient concentrations varied with water column depth based on the season. Elevated dissolved inorganic nitrogen (both nitrate and ammonium) and phosphate was observed in surface waters in the winter and spring months. This was associated with seasonal tributary stream flows resulting from rainfall and associated runoff in the watershed (Figures 3 and 4). In the summer, when the lake became stratified, the deeper water (below 13ft) showed increased levels of phosphate (Figure 5) and ammonium (Figure 6). This was due to nutrient flux from the sediments. The summertime thermocline stratifies lake waters into two distinct layers and restricts mixing of the deeper waters. This significantly reduces the ability of cyanobacteria (which primarily inhabit the upper water column) to access the deeper nutrient- rich waters. However, as summer progresses to autumn, the entire water column eventually warms and the thermocline disappears. Without the constraints of stratification, nutrients from the deeper waters readily mix through the water column. As a result of this mixing, higher nutrient levels are registered at the surface (Figures 5 & 6).

The increase in surface water nutrient levels in the autumn occurs prior to the increase in runoff and nutrients associated with runoff from the watershed in early winter. This suggests that nutrient (phosphate and ammonium) loading in the lake during the peak bloom season (typically Sept- Nov) is dominated by internal loading. Nutrients are released from the lake sediments and are distributed throughout the water column through the seasonal mixing associated with the disappearance of the thermocline (Figures 7 & 8). The results from the nutrient flux experiments (Table 3) support the importance of internal loading of nutrients and explain the high concentrations of nitrogen and phosphorus in the water below the thermocline prior to the autumn mixing (Figure 7 & 8).

Throughout the sampling period, Pinto Lake phosphorus (0.15 – 0.8 mg/L) , chlorophyll *a* levels (71 ppb average) and water clarity (Secchi depth of 0.5 – 1 foot in summer) were within the range described for hypereutrophic waterbodies (56-155 ppb chlorophyll a, 0.096-0.385 mg/L phosphate and Secchi depth of 0.75 -1.5 feet) . In comparison, a clear water lake with dominant submerged vegetation is considered mesotrophic with 0.02 – 0.05 ppb chlorophyll a, 0.012 - 0.024 mg/L phosphate and a Secchi depth of 6-12 feet.

Internal Lake Loading

Low dissolved oxygen conditions found during the summer significantly increase the release of sediment-bound phosphorus into the water column. This process is called internal loading and in many lakes is a significant source of nutrients. To evaluate internal loading at Pinto Lake, sediment cores were collected from lake sediments and incubated to estimate nutrient flux. (Figure 9). Based on the flux tests, it is estimated that 1,100 – 2,645 pounds of phosphorus (total) is released to the water column by lake sediments on an annual basis. This release of phosphorus from sediments is most likely exacerbated by the sediment mixing activities of benthivorous fishes (such as carp) and invertebrates.

Watershed Inputs/External Lake Loading (Watershed and Groundwater Wells)

The streams that flow into Pinto Lake were monitored at various locations and times for in-situ water quality parameters and nutrient concentrations. The sampling sites included several locations on the main lake tributary, Pinto Creek (leading to the upper left lake finger) and also on the tributary leading to the middle lake finger and the smaller tributary flowing to the upper right lake finger (Table 4). The resulting nutrient concentrations (Figure 10) were used to evaluate the nutrient loadings from the watershed.

Because the Pinto Lake watershed area is relatively small compared to other neighboring watersheds and rainfall was only 74% of normal (average precipitation 23 inches), discharge and load estimates have high levels of uncertainty. Nevertheless, it was estimated that runoff from the watershed contributes an annual load of between 250 – 600 pounds of phosphorus (total)

Ground Water Well Nutrient Concentrations

Two ground water monitoring wells were constructed in early autumn 2011. The wells are located just north of the Santa Cruz County Pinto Lake Park and immediately to the west of the lake in the Villas del Paraiso residential development. Groundwater well water quality monitoring began in November 2011 and continued through December 2012. Depth to water ranged from 1.5 feet to 6 feet with an elevation of 4.5 – 24 feet above the average lake level. Ground water samples were taken after wells were purged of their volumes three times and collected monthly to determine nutrient contributions from groundwater sources. Between November 2011 and December 2012 nutrient concentrations ranged from 0.057 to 3.95 mg/L of phosphorus and between 0.12 to 1.47 mg/L of nitrogen, which suggests somewhat high concentrations (Figure 11). However, high sediment concentrations in the well samples may have biased these values. It is impossible to distinguish the mobile fraction of nutrients versus that which is bound to sediments. In addition, without nested wells and some estimate of ground water flow, it is difficult to gauge the potential load to the lake. However, these data suggest that ground water inputs into the lake should be further evaluated because the observed levels are above natural conditions and because of the potential for ground water to be an important source, if properly measured and documented.

Temperature, Dissolved Oxygen, pH

In general, cyanobacterial blooms tend to form in summer when there is increased sunlight, higher water temperatures, water column stability and nutrients emerging from lake sediments. Winter months with their lower solar radiation, reduced water temperatures and increased water mixing generally reduce cyanobacterial blooms.

In the winter months, Pinto Lake's surface water was cool with an average temperature of less than 14˚C and an average pH of 7, well within the range for regional water bodies. There was low dissolved oxygen saturation (between 40-60%) and the lake was well-mixed (Figure 7).As air temperature and solar radiation increased in the spring and summer, the temperature of the surface water (epilimnion) increased substantially with a summer average of 22˚C (Figure 12). In contrast the bottom waters (hypolimnion) increased only moderately to an average of 13˚C and at a slower rate. With the differences in water temperatures (and therefore water density), Pinto Lake became stratified—with a distinct thermocline demarcating a warm, oxygen-rich upper layer and a cooler, oxygen-depleted lower layer (Figure 8). Dissolved oxygen concentrations and pH increased in the surface waters as a product of the photosynthetic activity of cyanobacteria growth. Below the thermocline dissolved oxygen was consumed by respiratory activity in the lake bottom. As summer progressed into autumn, the entire water column warmed and mixed, with continuation of high dissolved oxygen at the surface and low-dissolved oxygen in much of the underlying water column. By early winter the water column cooled and there was a decline of the cyanobacterial bloom.

Summary of Water Quality Factors Promoting Toxic Cyanobacteria in Pinto Lake
**Statistical analysis was conducted by the University of California at Santa Cruz.*

Statistical analyses of the water quality data show strong positive relationships between phosphorus and both cyanobacterial cell density and microcystin concentrations. The data shows a weaker association with ammonium-nitrogen and both cyanobacterial cell density and microcystin. The data also shows a negative relationship between nitrate-nitrogen and both cyanobacterial density and microcystins. The strong relationship between phosphorus and toxic cyanobacteria suggests that management efforts should focus on reducing water column phosphorus availability as a primary goal. Internal loading from the lake sediments and seasonal runoff from the watershed were both found to contribute nutrients to Pinto Lake. However it was evident from the 2011 data, the nutrients derived from the lake sediments accounted for a much higher load of the lake's nutrients (Table 5).

Lessons Learned and Challenges

Project Management

The project was complex and challenging in ways that were not readily apparent at the outset. The most significant issue proved to be the different expectations of the project team and grant manager. These differences surfaced when the implementation strategy and final report were being drafted. Ultimately, the issues were resolved, but it is clear that a more in-depth discussion during the development of the grant agreement regarding project outcomes and the limitations of data and legal obligations would have been very beneficial. It also became clear that email correspondence is not an effective communication tool for resolving disputes, problems, and/or reaching consensus. Another challenge was the difficulty in rectifying, translating, and/or verifying the accuracy of technical reports prior to their submission. To improve administrative efficiency it is recommended that the Grantee and Grant Manager agree on report templates in advance of their submittal. In the end, the Project team learned from these challenges.

Watershed Hydrology Study

Prior to the execution of this Project, it was assumed that Pinto Creek was the most significant tributary to Pinto Lake. This was based on observations of the lake's morphology and preliminary investigations which reported the absence of significant flows from any other lake tributaries. While sampling the lake and tributaries, the project team observed significant surface flow from other tributaries draining to the lake during periods of high precipitation. A more comprehensive watershed study, including measurements of surface flow and sediment load during all seasons, from all tributaries, and in various regions of the watershed, would have provided a better understanding of the overall contribution of the various sub-watersheds and tributaries on sediment and nutrient loadings to the lake. This was a significant outcome and as a result a recommendation for a watershed study has been included in the Implementation Strategy and Sequence as a priority for future work.

Flexibility and Science

Cyanobacteria research is a rapidly evolving field. This Project was developed based on the best available knowledge in 2010. However, in the last three years some elements, such as information on toxins and treatment technologies, have undergone considerable advances. This highlights the importance of flexibility so that both the Project can evolve as needed.

This Project demonstrated that the species composition and toxin profile for Pinto Lake is dynamic, making it difficult to assign toxin trends to specific environmental conditions or land-use variables. As such, there is a need to conduct more monitoring and temporal analysis of lake water quality to adequately capture and understand the variability in monitoring results. This is important if we are to identify the most effective management practices/measures or mitigation solutions to solve the problem. Furthermore, more detailed monitoring of the fate and transport of nutrients in the Pinto Lake watershed and subwatersheds is needed to understand the timing, duration, location and nutrient loads emanating from the various areas of the watershed.

The diversity of toxin types was also surprising, and suggests that focusing solely or primarily on microcystin-LR underestimates the variability and potential impacts. Because the known cyanotoxin producers can generate several types of microcystin with varying toxicity and reactivity, understanding the range of toxin types is needed to identify the full impacts of the cyanotoxins in Pinto Lake.

Timeline and Outreach

Towards the end project, the team recognized that there was insufficient time allotted between the analysis of water quality monitoring results and the planned stakeholder outreach events. Adequate time needs to be provided for the project team to analyze data and reach conclusions that can be effectively conveyed to stakeholders. Furthermore, it is important to allow enough time for stakeholders to be able to plan ahead to attend outreach and educational events.

Outreach

A summary of education and outreach activities completed are as follows:

- The Project Team drafted a formal press release with the local press to inform the public about the Project.
- Newspaper articles were published on July 16, 2012 including information about the planned public meetings. News coverage on the water quality issues facing Pinto Lake were published on October 8, 2012. These articles appeared in two local papers: the Santa Cruz Sentinel and the Register Pajaronian.
- The Project Team planned and conducted a series of public meetings on July 17, 2012 to inform Pinto Lake residents and the public about water quality issues in Pinto Lake, the sampling protocols, the project goals and potential outcomes. The meetings were well attended with 28 attendees for each meeting. The first meeting was a general public session at which an overview of the water quality testing goals and purpose along with preliminary results was presented. The second meeting was focused on septic systems. Residents were educated about system malfunctions, proper maintenance and were provided with take-home materials. The third meeting was focused on informing agricultural operators about the Project. The attendees suggested the creation of a "Friends of Pinto Lake" group, formed by concerned residents to help build a community information network and brainstorm about ways to restore the lake water quality.
- The Project Team conducted a final public meeting on April 30, 2013 to discuss the final project results and recommendations for the implementation strategy. During this meeting, it was confirmed that residents were in fact interested in the formation of the "Friends of Pinto Lake" group and as a result this group is now holding meetings.

Project Funding

The total budget for the project was $125,000.00, with $0 required in matching funds. To date 93.47% of the budget has been billed, spending $116,837.60 to date, with $8,162.40 remaining.

Future Activity

As previously mentioned, one of the main goals of this Project was to identify solutions to eradicate/reduce CHABs in Pinto Lake. The following list details recommended actions in the lake and watershed in order of priority.

Reduction of Nutrient Loads in the Lake
Internal loading (movement of nutrients from sediments into water column) has been identified as the largest source of nutrients in Pinto Lake. Reduction of internal loadings can be achieved through three measures:

1. Removal of Carp
   Carp disturb lake sediments during feeding, which results in a significant transfer of nutrients from the sediments into the water column. Up to 30% of the phosphorus load in some lakes is attributable to carp.

   Recommend continuation of existing program and additional measures (such as gill netting) if necessary.

2. Alum Treatment
   Alum treatment has been demonstrated to successfully reduce internal loadings by as much as 50 to 80% in many other lakes across the globe.

   Recommend initial pilot scale testing of alum treatment, and if successful, application to entire lake

3. Floating Wetland Treatment Technology
   The use of floating treatment wetlands to control nutrients in lakes and ponds has been successfully demonstrated in the US and abroad. Water column nutrient reductions of 60 to 80% have been demonstrated.

   Recommend initial pilot scale testing of wetland treatment technologies and if successful full-scale implementation.

Reduction of Nutrient Loadings from Watershed
While internal loading has been identified as the most significant source of nutrients in Pinto Lake, inputs from the watershed are still significant and need to be addressed. Substantial reductions in watershed nutrient loadings can be achieved through the following measures:

1. Stakeholder Engagement

   The success of any watershed-based management program relies, in large part, on the engagement of the affected community. Friends of Pinto Lake is a recently established stakeholder group representing the community,

   Recommend assisting Friends of Pinto Lake in gaining membership and participation from agricultural and commercial sectors

2. Septic Tank Study

Poorly draining soils in the Pinto watershed have proven challenging for the operation of conventional septic tank systems. Saturated soils (often found during winter months) can lead to overflow of septic systems.

Recommend study of functioning of septic systems in the Pinto Lake watershed during winter months with recommendations for appropriate action to address failing/undersized systems.

3. Agricultural Erosion Control, Sediment Capture, Irrigation and Nutrient Management

   Improvements in erosion control and nutrient management would reduce agricultural runoff containing sediments and nutrients. Practices could include non-structural elements such as irrigation and nutrient management and structural measures such as detention basins, vegetative treatment systems and vegetated waterways

   Recommend SCCRCD and NRCS provide additional program resources to promote and help implement these practices with growers and ranchers in Pinto Lake watershed.

4. Street Cleaning

   Runoff from streets can contain significant levels of sediments and nutrients. Street sweeping is a proven method of reducing such loadings.

   Recommend Santa Cruz County street sweeping program frequency be increased in the Pinto Lake watershed.

5. Extending Sanitary Sewer On Amesti Road

   Replacing septic systems with a sanitary sewer on Amesti road would eliminate nutrient loadings from failing/ hydraulically undersized tanks and leachfields.

   Recommend study to determine cost and funding options for extending sanitary sewer line on Amesti road

6. Natural Wetland and Riparian Corridor Restoration

   Restoration of degraded wetlands and riparian areas has been show to be beneficial for nutrient uptake and sediment capture

   Recommend inventory and study of condition of existing Pinto Lake watershed wetland and riparian resources and measures needed to restore them.

7. Constructed Wetlands and Sediment Basins

   Constructed wetlands and sediment basins have been shown to effectively capture sediments and nutrients.

   Recommend study to determine appropriate locations for installation of created wetlands and sediment basins in the Pinto Lake watershed.

Appendix:

Items for Review

The following are the grant deliverables for review:

- 10-443-553 Task A.2 PAEP
- 10-443-553 Task A.3 Pinto Monitoring Plan
- 10-443-553 Task A.4 QAPP
- 10-443-553 Task A.6 CEQA Filing
- 10-443-553 Task B.1.4 LosHuertosPintoLake_presentation.pdf Jul-Sep 2012
- 10-443-553 Task B.1.4 Pinto Lake Workshop July 2012 (2) Jul-Sep 2012
- 10-443-553 Task B.1.4 Pinto_Lake_Press_Release_Final.pdf Jul-Sep 2012
- 10-443-553 Task B.1.4 R Ketley Pinto Lake Workshop Presentation July 2012
- 10-443-553 Task B.1.4 Rketley_Pinto Lake Worlkshop Management Measures April 30 2013
- 10-443-553 Task B.1.4 Septic System Handouts Jul-Sep 2012
- 10-443-553 Task B.1.4 Stanfield_cyano_presentation_Public Jul-Sep 2012
- 10-443-553 Task B.1.4 Stanfield_cyano_presentation_Public_April30_2013_2
- 10-443-553 Task B.1.4 Workshop_Signin_2012-04-30
- 10-443-553 Task B.1.4 Workshop_Signin_2012-07-17 Jul-Sep 2012
- 10-443-553 Task B.2 Data Analysis Appendix_FINAL_disputed_revised
- 10-443-553 Task B.2.1.1 Pinto Monitoring Plan_FINAL
- 10-443-553 Task B.2.1.3 Data Analysis Appendix A_B_C rev1
- 10-443-553 Task B.2.1.3_Analysis_Pinto_CEDAN Data Comp
- 10-443-553 Task B.2.2.3 Data Analysis Appendix

10-443-553 Task B.2.2.3 Data Analysis Appendix (2)

10-443-553 Task B.2.2.3 Data Analysis Appendix A_B

10-443-553 Task B.2.2.3 ProgresReport8_AppendixA-1ES

10-443-553 Task B.2.2.6 Data Analysis Appendix A B Jul-Sep 2012

10-443-553 Task B.2.2.7 Post Const Photo Documentation of Two Wells

10-443-553 Task B.2.3.2 Stat Packet Oct-Dec 2012

10-443-553 Task B.2.3.2 Stats Oct-Dec 2012

10-443-553 Task B.2.3.2 Summary of MM MP

10-443-553 Task B.A. Invoice01

10-443-553 Task B.A. Invoice02 rev1

10-443-553 Task B.A. Invoice03 rev1

10-443-553 Task B.A. Invoice04

10-443-553 Task B.A. Invoice05

10-443-553 Task B.A. Invoice06

10-443-553 Task B.A. Invoice07

10-443-553 Task B.A. Invoice08

10-443-553 Task B.A. Invoice09

10-443-553 Task B.E.1. Progress Report01

10-443-553 Task B.E.1. Progress Report02 rev1

10-443-553 Task B.E.1. Progress Report03
10-443-553 Task B.E.1. Progress Report04
10-443-553 Task B.E.1. Progress Report05_disputed_revised w comments
10-443-553 Task B.E.1. Progress Report06
10-443-553 Task B.E.1. Progress Report07
10-443-553 Task B.E.1. Progress Report08
10-443-553 Task B.E.1. Progress Report09
10-443-553 Task D.2. MBE WBE 5700-52a #1 Pinto Lake Jan-Mar 2011
10-443-553 Task D.2. MBE WBE 5700-52a #2 Pinto Lake Apr-Jun 2011
10-443-553 Task D.2. MBE WBE 5700-52a #3 Pinto Lake Jul-Sep 2011
10-443-553 Task D.2. MBE WBE 5700-52a #4 Pinto Lake Oct-Dec2011
10-443-553 Task D.2. MBE WBE 5700-52a #5 Pinto Lake Jan-Mar2012
10-443-553 Task D.2. MBE WBE 5700-52a #6 Pinto Lake Apr-Jun 2012
10-443-553 Task D.2. MBE WBE 5700-52a #7 Pinto Lake Jul-Sep 2012
10-443-553 Task D.2. MBE WBE 5700-52a #8 Pinto Lake Oct-Dec 2012
10-443-553 Task D.2. MBE WBE 5700-52a #9 Pinto Lake Jan-Mar 2013

List of Subcontractors

The following agencies, organizations, consultants, or companies were employed in the execution of this grant:

- Marc Los Huertos, California State University Monterey Bay
- Resource Conservation District of Santa Cruz County
- University of California, Santa Cruz

3) Tables, Graphics and Photos

Photo 1. Cyanobacteria bloom a Pinto Lake, September 2009

Photo 2. Ariel View of Pinto Lake Watershed

Table 1. Pinto Lake Watershed Land Use Summary

Land Use Categories	Area –Acres	% Total watershed area
Agriculture	422	35
Row Crop	374	25
Orchard	148	10
Commercia/ Residential	281	19
Grazing	267	18
Scrub/Shrub/ Forest	252	17
Open Water	89	6
Wetland	74	5
Total	**1485**	**100**

Table 2. Summary of Management Measures and Locations

Management Practice	Practice Size	Pollutant Addressed	Benefit	Creek	Land Use
Cover Crop	< 1 acre	Sediment and sedi-ment bound nutrients	Erosion control, Fertility Management (Legumes can add substantial amounts of available nitrogen to the soil. Non-legumes can be used to take up excess nitrogen from previous crops and recycle the nitrogen as well as available phosphorus and potassium to the following crop), rand educes leaching of nutrients	Pinto Creek	Agriculture
Critical Area Planting	1 acre	Sediments and some nutrients in runoff	Erosion control	Pinto Creek	Agriculture
Sediment basin	1 basin	Sediment and sedi-ment bound nutrients	Retains soil on property and some sediment that may con-tain pesticides and nutrients, potential for lowering peak tributary discharge rates and protect stream banks and drainage perimeters from erosion.	Pinto Creek	Agriculture
Grassed Water-way	< 1 acre	Dissolved nutrients in runoff and sediments	Reduces gully erosion. Vegeta-tion within the waterway may also trap sediment washed from cropland, absorb some chemicals and nutrients in the runoff water and provide cover for small birds and animals.	Pinto Creek	Agriculture
Irrigation Reservoir (water catchment and resuse)	10,000 gallon tank stor-age	Sediments and some nutrients in runoff	Reduces runoff from pervious surface thus reducing erosion. Conserves water requiring less groundwater use.	Pinto Creek	Agriculture
Irrigation and Nutrient Manage-ment	> 1 acre	Sediment and sedi-ment bound nutrients, dissolved nutrients		Pinto Lake	Park

Figure 1. Microcystins

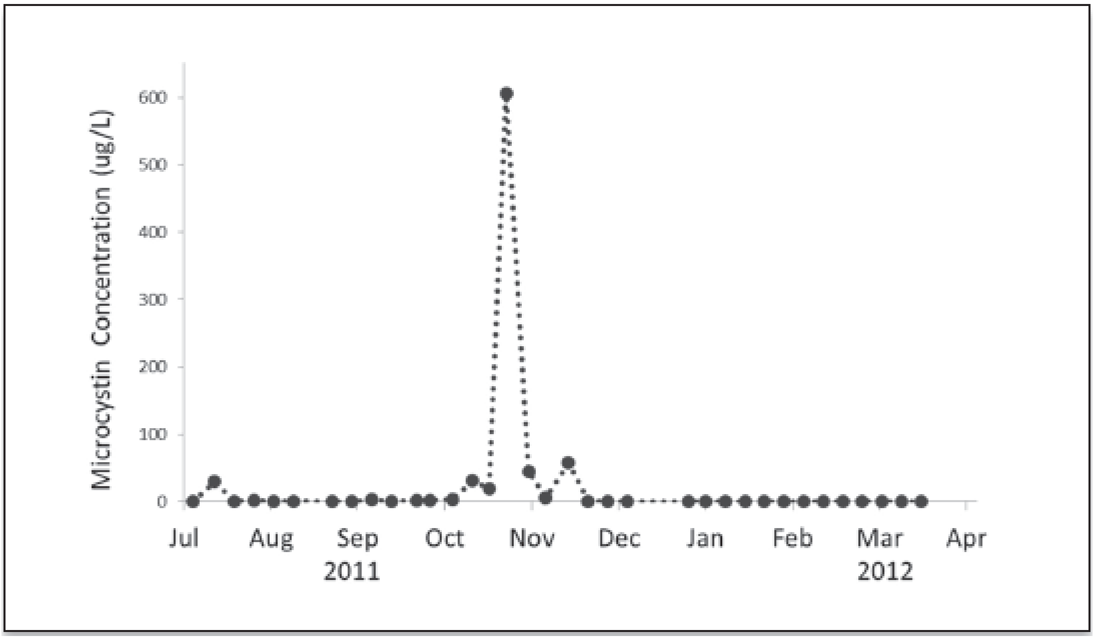

Figure 2. Cyanobacteria Cell Counts

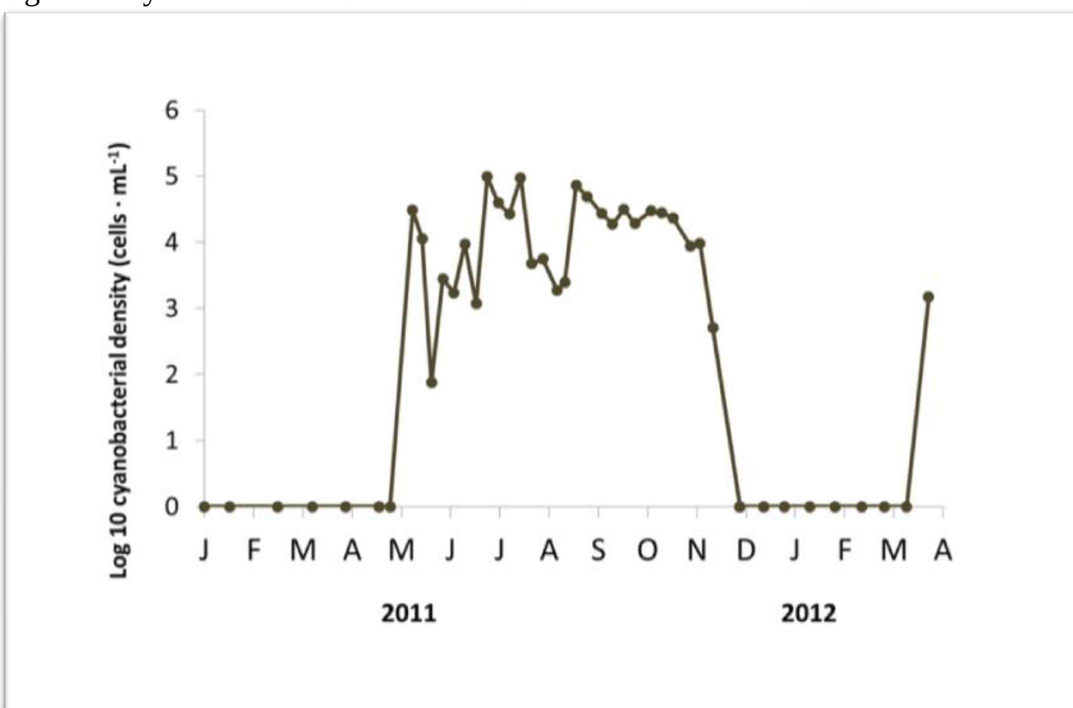

Figure 3: Average surface concentrations of Pinto Lake dissolved inorganic nitrogen

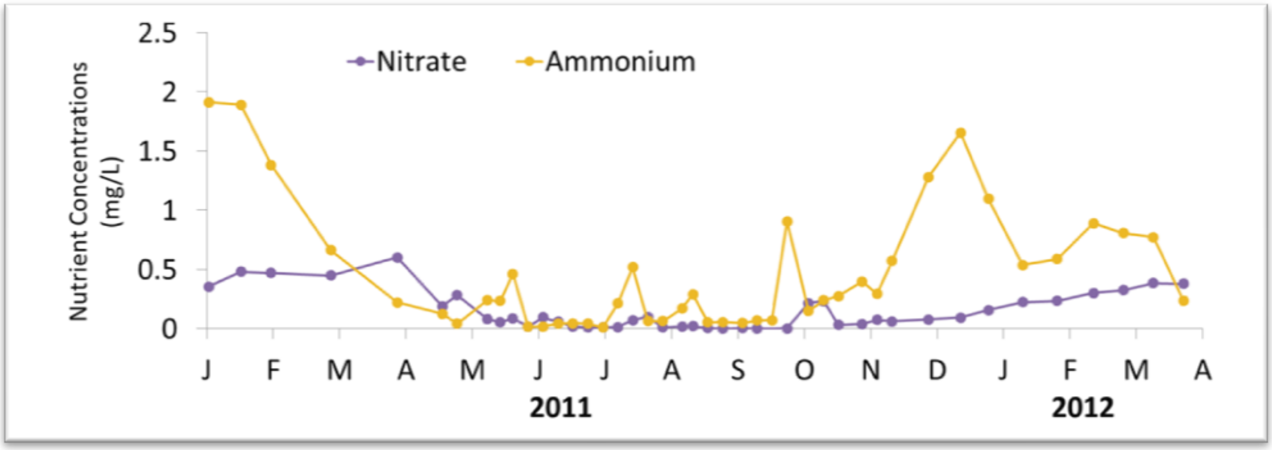

Figure 4: Average surface concentrations of Pinto Lake phosphorus

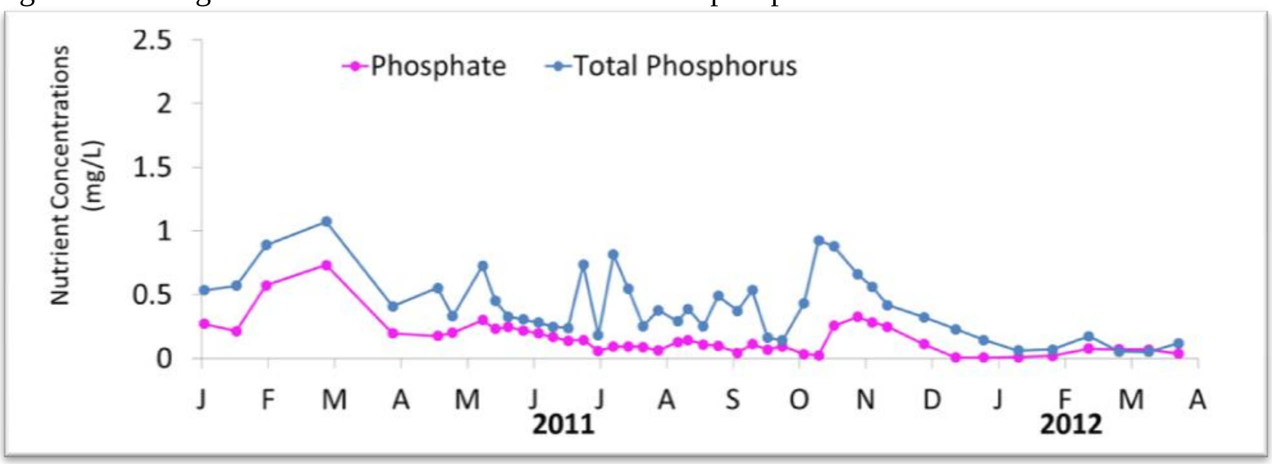

Figure 5: Phosphorus concentrations through the water column throughout the year with elevated phosphate in the summer at the deepest lake levels

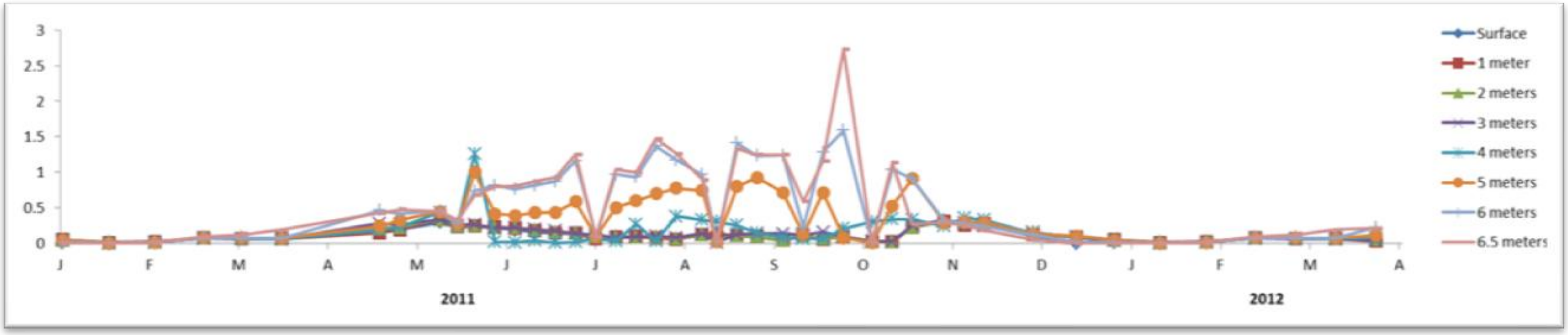

Figure 6. Ammonium concentrations through the water column throughout the year with elevated phosphate in the summer at the deepest lake levels

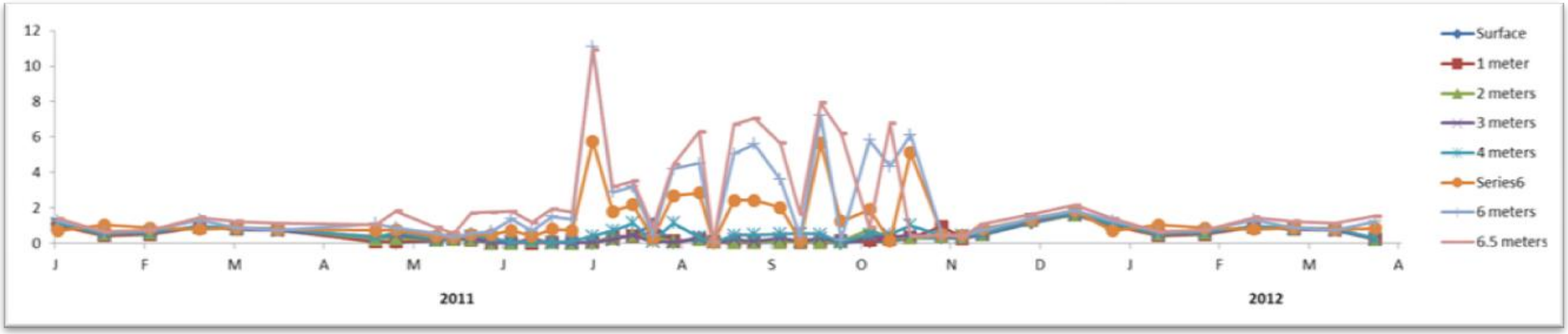

Figure 7. Winter Nutrients, Temperature, and Dissolved Oxygen

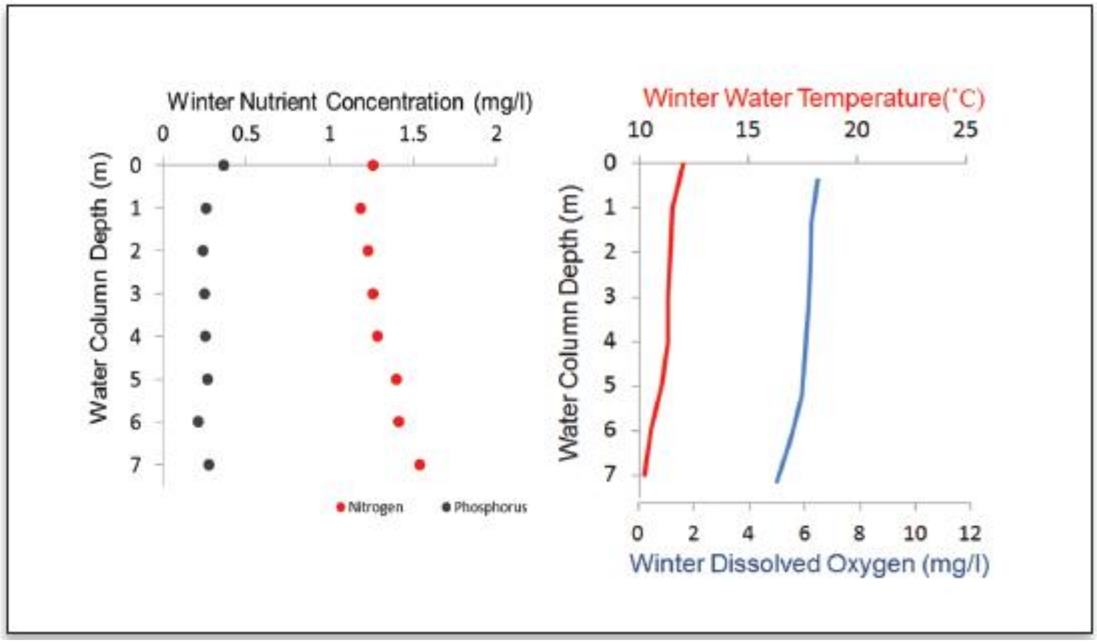

Figure 8. Summer Nutrients, Temperature, and Dissolved Oxygen

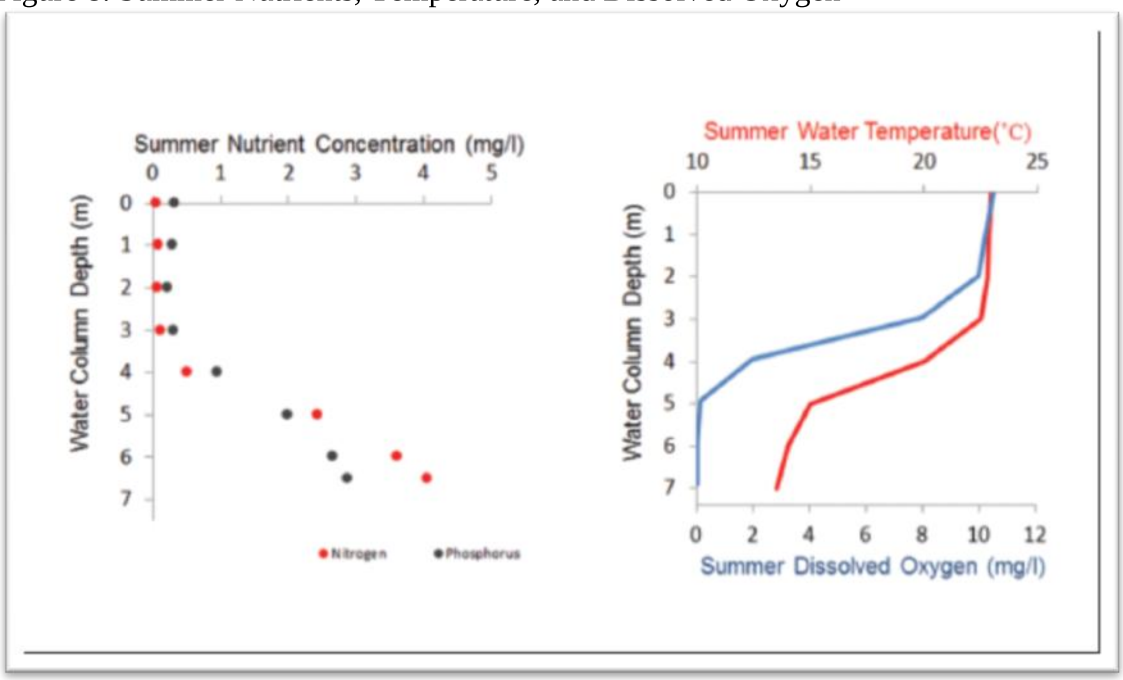

Table 3. Pinto Lake Nutrient Flux

	Phosphorus as phosphate	Nitrogen as ammonium
Nutrient flux range	0-0.172 mg/ft²/sec	0 – 1.29 mg/ ft²/sec
Average nutrient flux	0.067 mg/ ft²/sec	0.570 mg/ ft²/sec
Estimated average monthly flux	200 kg (440 pounds)	1700 kg (3740 pounds)

Figure 9: Nutrient concentrations documented in the water column overlaying the sediments and bound by the thermocline

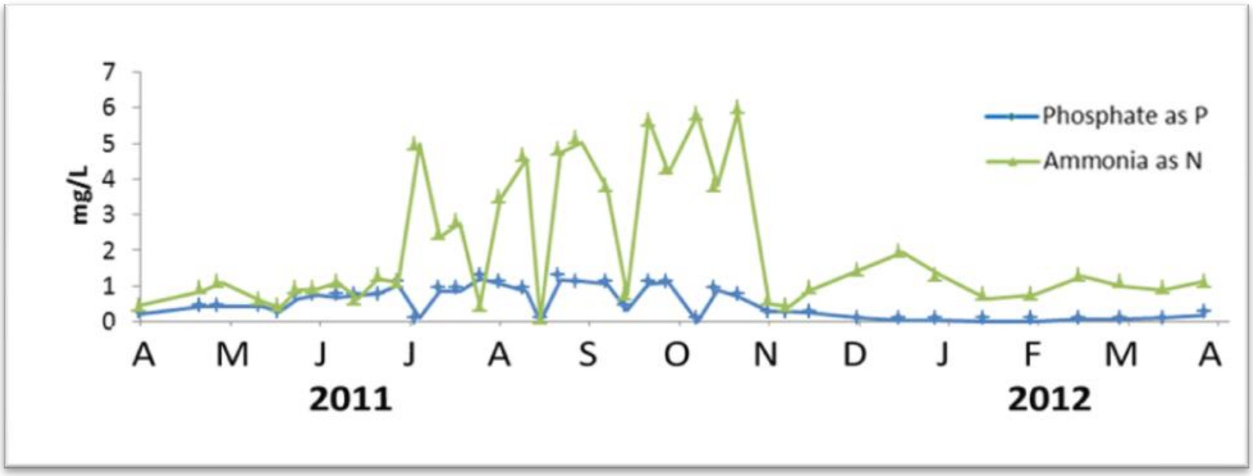

Table 4. Pinto Lake tributary water quality. Results are given in the range of observations and average values

Parameter	Range	Average
Temperature (°C)	12.51–13.64	(13.25)
pH	6.93–7.15	(7.01)
Dissolved oxygen (mg/L)	8.61–9.79	(9.31)
Dissolved oxygen (% Saturation)	73.3–88.7	(84.0)
Nitrogen (mg/L)	0.2–1.4	(0.59)
Phosphorus (mg/L)	0.15–0.8	(0.45)

Figure 10: Average nutrient concentrations of tributaries entering Pinto Lake

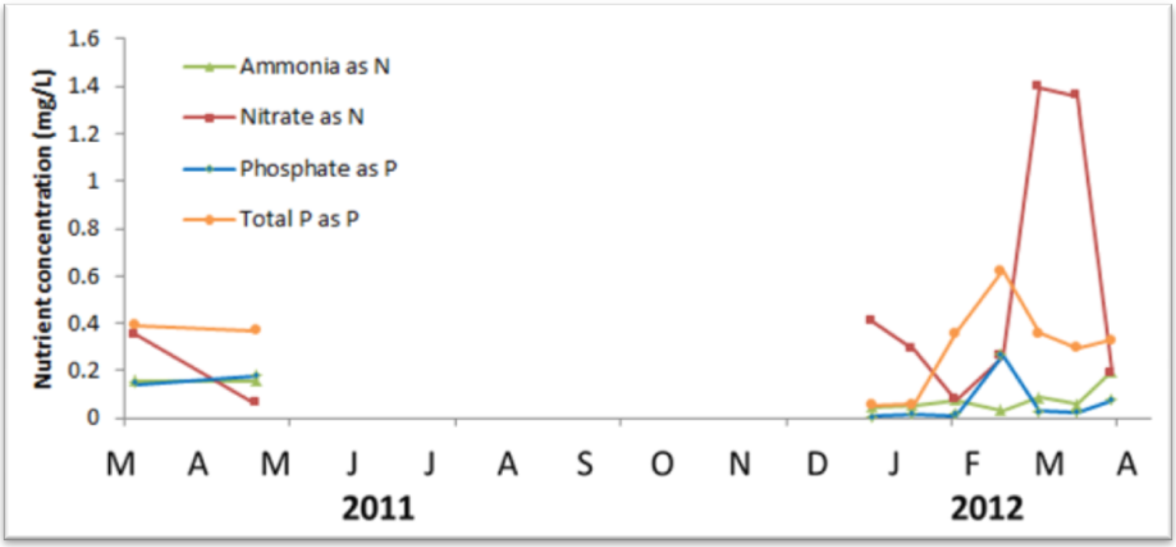

Figure 11: Average nutrient concentrations documented it the groundwater wells

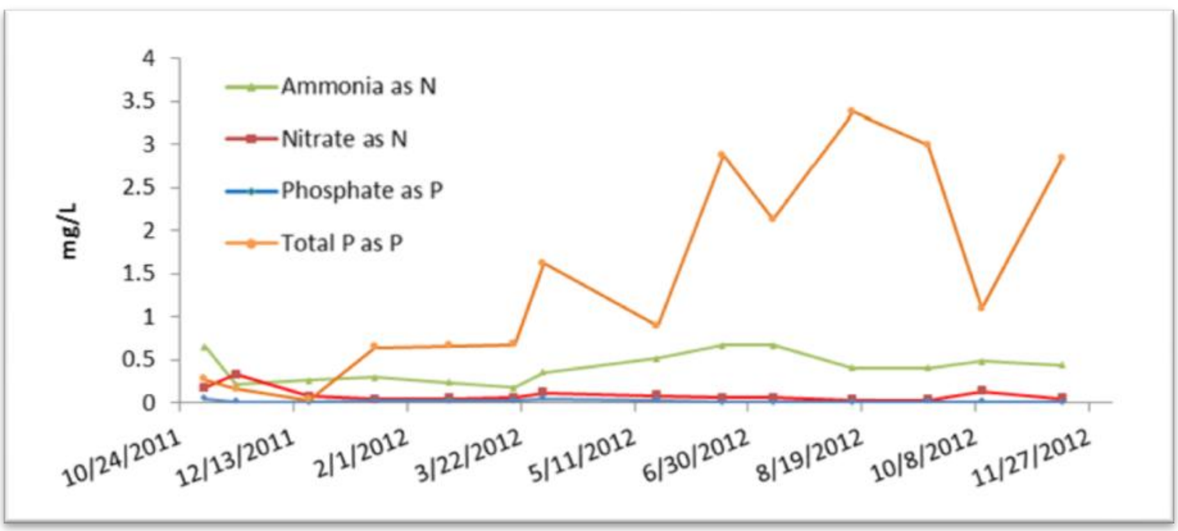

Figure 12. Surface Water Temperatures

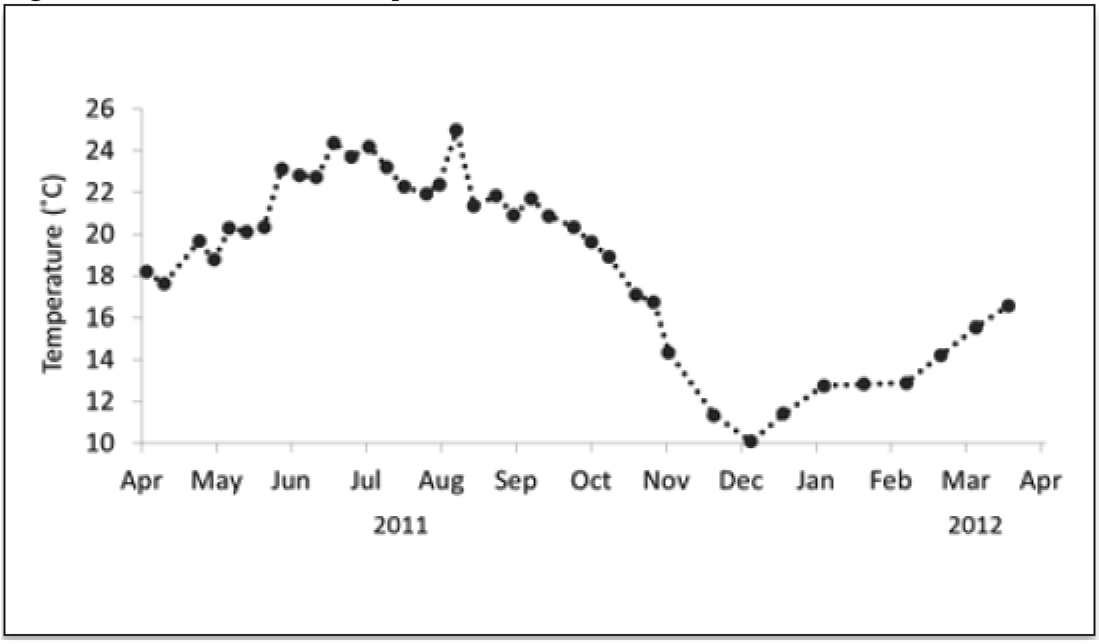

Table 5. Comparing nutrient loads to Pinto Lake

Source	Estimated 2011 load lbs
Lake sediments	1100 – 2645 pounds (mean 1650 pounds)
Watershed	220-660 pounds (mean 286 pounds)
Ground Water	Unknown without further research