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Aquatic Ecology of San Felipe Lake, San Benito County, California

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AQUATIC ECOLOGY OF SAN FELIPE LAKE,
SAN BENITO COUNTY, CALIFORNIA

A Thesis

Presented to

The Faculty of the Department of Biological Sciences

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Julie R. Casagrande

August 2010

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The Designated Thesis Committee Approves the Thesis Titled

AQUATIC ECOLOGY OF SAN FELIPE LAKE,
SAN BENITO COUNTY, CALIFORNIA

by

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APPROVED FOR THE DEPARTMENT OF BIOLOGICAL SCIENCES

SAN JOSÉ STATE UNIVERSITY

August 2010

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ABSTRACT

AQUATIC ECOLOGY OF SAN FELIPE LAKE, SAN BENITO COUNTY, CALIFORNIA

by Julie R. Casagrande

This two-year study examined San Felipe Lake environmental factors and food-web relationships. The lake is shallow, warm, productive, and generally well-mixed. High turbidity resulted from wind mixing of bottom sediments, carp feeding activity, and plankton blooms and excluded submerged aquatic plants. Emergent vegetation was restricted by cattle grazing. Summer temperatures reached 26-28°C throughout the water column, and dissolved oxygen was occasionally low on the bottom overnight and during windless daytime periods. Phytoplankton, fine organic matter, and detritus formed the base of the food web, supporting a zooplankton community dominated by copepods, the water column macroinvertebrate *Neomysis*, and several open water fish species. Fine organic matter and detritus supported benthic macroinvertebrates (chironomids and oligochaetes), which in turn supported benthic, omnivorous fish species. Carp, hitch, and Sacramento suckers were the most common fish captured by gill net. Predatory fish, including Sacramento pikeminnow, brown bullhead, and largemouth bass, formed the top of the aquatic food web, although observed abundance was low. Fish predation on juvenile steelhead was not a likely threat, and turbid water and greater relative spring depth likely limited avian predation. San Felipe Lake is too warm for steelhead summer rearing but is suitable for spring growth before and during steelhead smolt out-migration.

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Introduction

Few studies have been conducted on the ecology of natural, shallow, warm lakes in California. This is in part due to the rarity of this habitat throughout California since many of the historic, shallow, warm lakes, such as Tulare Lake, Kern Lake, and Buena Vista Lake, were drained for agriculture beginning in the mid-1800s (Dahl and Allord 1996; Moyle 2002). Although many studies have been conducted on California fish species, particularly those native to the Sacramento-San Joaquin drainage system, the research has been primarily focused on stream and estuarine habitats. With the exception of extensive fisheries and aquatic ecology research in Clear Lake, Lake County (Moyle 2002), there is limited information on the feeding ecology and community relationships of California native fish species in shallow, warm systems.

Previous studies have shown that food webs and trophic relationships within lake ecosystems can be very complex (Carpenter et al. 1985; McQueen et al. 1986; Ramcharan et al. 1995; Jeppesen et al. 1997; Tessier and Woodruff 2002). Carpenter et al. (1985) suggested that cascading trophic interactions led to differences in productivity among lakes with different trophic levels. For instance, an increase in the number of piscivores can lead to a decrease in planktivores, which can then result in an increase in zooplankton and decrease in phytoplankton. Jeppesen et al. (1997) and Tessier and Woodruff (2002) suggested that interactions between fish and zooplankton are stronger in shallow lakes than in deeper lakes, except for those with an abundance of macrophytes, because of increased planktivory with reduced vertical migration and lack of a deep-

water refuge for zooplankton. Researchers have also suggested that processes controlling food webs can be even more complex than simply top-down control and cascading interactions, and that instead omnivory can play an important role in food-web dynamics (Polis and Strong 1996).

Many factors such as dissolved oxygen levels, temperature, nutrient concentration, turbidity, substrate, freshwater inflow, water depth, lake area, degree of shoreline development, abundance and types of aquatic vegetation, and degree of mechanical mixing contribute to how aquatic ecosystems function and influence species composition (Cole 1994; Moyle and Cech 2000; Wetzel 2001). Therefore, in order to understand the community structure of an aquatic ecosystem, it is important to examine environmental factors as well as relationships within the food web.

San Felipe Lake is a shallow, natural, warm lake located in the upper Pajaro River watershed just east of Gilroy, California (Figure 1). The upper Pajaro River watershed is recognized as an important wetland complex and potential wildlife migration corridor linking the Diablo Mountain Range in the east to the Santa Cruz Mountain and Gabilan Mountain ranges in the west and southwest (The Nature Conservancy 2010). San Felipe Lake, which is currently in private ownership, is under consideration for land acquisition or easement by the Nature Conservancy as part of the Mount Hamilton Project. However, although the lake is heavily used by water birds, very little is known about the aquatic ecology and food webs of the lake. In an extensive study of the fishes of the Pajaro River system (Smith 1982), federally threatened steelhead, *Oncorhynchus mykiss*, were indicated as migrating through San Felipe Lake to spawning habitat upstream of the

lake, but no study had ever been done of the lake itself. The lake would probably be too warm for summer steelhead rearing but might be used for feeding by migrating steelhead smolts; fish in the lake could be predators on steelhead smolts.

My primary research objectives for this two-year study were to gain a better understanding of aquatic ecosystem function in San Felipe Lake, as a rarely studied shallow, warm lake system, and to determine the extent to which upper Pajaro River watershed steelhead and other wildlife may be affected by the lake. The specific aims of my research were 1) to examine environmental factors, including water quality and lake morphology, which may drive habitat conditions, 2) to determine fish species relative abundance, size composition, and general growth patterns, and 3) to investigate aquatic food-web relationships.

Study Area

San Felipe Lake is located east of the City of Gilroy in northern San Benito County near the border of Santa Clara County (Figure 1). San Felipe Lake is a sag pond dammed by the fault scarp of the Calaveras Fault, which runs along the western shoreline of the lake (Figure 2). The western shoreline of the lake is visibly 3-4 m higher in elevation than the eastern shoreline and forms a natural, shallow impoundment. San Felipe Lake is located in the upper Pajaro River watershed, which drains to Monterey Bay. The lake is the terminus for Pacheco Creek and for Tequisquita Slough, which receives runoff from Santa Ana Creek, Arroyo de las Viboras, and Arroyo Dos Picachos. Small, intermittent Ortega Creek drains the small watershed northeast of the lake. All drain the Diablo Range. North Fork Pacheco Reservoir alters summer and winter flow patterns in Pacheco Creek. San Felipe Lake is perennial in all but very severe drought years, such as 1977 when the lake dried (Smith 1982).

The outlet of San Felipe Lake once formed the beginning of the Pajaro River through a series of meandering sloughs and wetlands (Grossinger et al. 2008). Today, the lake drains through two man-made outlet channels cut in the fault scarp that join to form Miller Canal, which was completed in 1874 (Grossinger et al. 2008). Construction of Miller Canal significantly reduced the size of the lake. According to a review of historical accounts, San Felipe Lake is less than 50-60% of its original summer size (Grossinger et al. 2008). Based on National Agricultural Inventory Program (NAIP) aerial imagery from June 2005, the summer surface area of the lake today is

approximately 30 ha. The maximum length is 900 m, and the maximum width is 370 m. Remnants of the historic Pajaro River slough channel are still visible in the aerial imagery. Through the 1970s and 1980s agricultural groundwater pumping resulted in intermittent inflow to the lake from Pacheco Creek and Tequisquita Slough in mid- to late-summer (Smith 1982). As a consequence of lake level drop in summer, Miller Canal was also dry by mid- to late-summer. The availability of imported water for San Benito County in the last two decades has reduced or eliminated groundwater pumping in most years, and Pacheco Creek, Tequisquita Slough, and Miller Canal are now usually perennial.

San Felipe Lake is surrounded by freshwater wetland habitat and grazing lands dominated by ruderal grassland habitat (The Nature Conservancy 2010). The area has a Mediterranean climate, which is typical for the central coast region of California, with warm, dry summers and mild, wet winters. Typical Mediterranean vegetation communities including oak woodland, coastal scrub, and grassland habitat are present in the hills to the north and east of San Felipe Lake. The primary land uses in the area include agriculture, grazing, and rural residential.

San Felipe Lake is situated in the upper portion of a broad, low-lying area known as the Soap Lake floodplain. The western portion of Soap Lake extends from San Felipe Lake west to Highway 101. The low-lying areas upstream and downstream of the lake are seasonally flooded and, together with San Felipe Lake, provide a great deal of flood attenuation; they are extremely important for flood control in the Pajaro River watershed. The lake itself is a self-emptying flood detention basin that captures peak runoff and

releases it over several days, substantially reducing downstream flood peaks. Hydraulic modeling by RMC (2005) indicated that approximately 3,650 ha in the Soap Lake floodplain (more than 100 times the summer area of San Felipe Lake) would be flooded during a 100-year storm event, which would reduce the 100-year event peak flow of the Pajaro River by approximately 425 m³/s (15,000 ft³/s). Preservation of the Soap Lake floodplain was recommended by the Pajaro River Watershed Flood Prevention Authority as a preferred alternative for flood control in the Pajaro River watershed (RMC 2005). The proposed Soap Lake Floodplain Preservation Project would maintain the current floodplain limits and hydrologic conditions by purchasing land or establishing floodplain easements to restrict development and preserve agriculture and open space (RMC 2005).

Methods

Limnology

Limnological investigations were conducted at San Felipe Lake from March 2005 to November 2006. The investigation included sampling for basic hydrologic parameters (precipitation, stream flow, and water elevation), documenting morphological characteristics of the lake (bathymetry, shoreline development, and zonation), and water quality sampling (temperature, dissolved oxygen, turbidity, secchi depth [a measure of transparency], and nutrients). The sampling methods are summarized below.

Hydrology.—Permanent staff gauges were installed in March 2005 at two locations within the San Felipe Lake basin. The primary gauge was located offshore near the southern outflow canal. The second gauge was installed in the flood inundation portion of the basin near the southern access road in order to monitor lake water elevation during flood stage. The two gauges were cross calibrated to read to the same arbitrary elevation. The water elevation was recorded on each visit to the lake.

Periodic stream discharge measurements were made at the two primary inflows, Pacheco Creek and Tequisquita Slough, using one of two methods. The first method involved measuring velocity along a cross-sectional area of the channel. Average water velocity measurements were taken at regular intervals along a transect at 6/10 water depth using an impeller-type flow meter. A less precise alternate method that was sometimes used was based on surface velocity and measured width and depth. Surface velocity was determined by measuring the time for a wooden dowel to travel a set

distance. The average width and depth of the water were measured using a stadia rod. Discharge was then calculated using the channel dimensions and 85% of the surface velocity, which has previously been shown to approximate the mean channel velocity (Gordon et al. 1992).

To better understand the hydrology of the lake in relation to the watershed, supplemental data were obtained from a variety of resources. Historic flow data for Pacheco Creek were obtained for the United States Geological Survey (USGS) gauging station (#1153000) located approximately 14.5 km upstream at Walnut Avenue. Releases from the North Fork Pacheco Reservoir, located approximately 28 km upstream of the lake on North Fork Pacheco Creek were estimated based on changes in the reservoir level from storage data obtained from the Santa Clara Valley Water District (SCVWD).

Hourly, daily, and monthly precipitation and wind speed data for the study period were obtained from the California Irrigation Management Information System (CIMIS) for the San Benito station (CIMIS Station #126). Historic precipitation data were obtained from the San Benito County Water District (SBCWD), as well as for the San Benito CIMIS station.

Lake Morphology.—Bathymetry of the lake was determined by conducting sonar transects. Water depth measurements were taken along two transects at 30.5 m increments or at breaks in bottom topography using a portable depth sounder and a hip chain. Other morphological information such as area, shoreline length, volume, zonation, and shoreline vegetation types were determined using a combination of visual field observations and digital aerial photograph imagery (Figure 3).

Water Quality.—An array of continuous temperature loggers (*Onset StowAway*) provided by the SCVWD was installed on a mid-lake buoy located at Site 1 (Figure 2). Loggers were arranged at depths of 0.1, 0.25, 0.5, 1.0, and 1.5 m and programmed to record temperature every 30 min. Additional water temperature loggers were deployed in Pacheco Creek, 975 m upstream of the lake, and in Miller Canal, 500 m downstream of the lake. An air temperature logger was installed within the riparian canopy of Pacheco Creek, upstream of the confluence with the lake.

Environmental aspects of the lake, including temperature and dissolved oxygen profiles, secchi depth, turbidity, nitrate ($\text{NO}_3\text{-N}$), orthophosphate (PO_4), and conductivity were monitored approximately monthly beginning in late spring 2005. The monitoring plan was flexible and adaptive in order to allow for detection of important events or conditions such as dissolved oxygen stratification, phytoplankton blooms, lethal temperatures for aquatic organisms, and other stressors. Many of these conditions were driven by weather-related factors such as cloud cover, air temperature, and wind; these ultimately affect important biological processes such as photosynthesis, respiration, metabolism, and decomposition. Morning and afternoon sampling was conducted during each visit for at least one site.

Water quality profiles for dissolved oxygen and temperature were taken at seven sampling sites (Figure 2). The sites were selected to detect any spatial variation in water quality conditions that may have existed due to hydrologic influences from the three inflows (Tequisquita Slough, Pacheco Creek inflow, and Ortega Creek) and the two Miller Canal outflow channels, as well as variation related to wind fetch. Water quality

measurements were taken at 0.25-m intervals using a *YSI Model 85* handheld probe. Secchi depth readings were taken at each profile location using a 20-cm secchi disk.

Water quality samples were collected at three primary lake locations: south lake near the two primary inflows (Site 7), mid-lake (Site 5), north outflow canal (Site 3), and in the two primary tributaries, Pacheco Creek and Tequisquita Slough (Figure 2) and were analyzed for turbidity, nitrate, and orthophosphate. Conductivity readings were also taken at these locations using the *YSI* handheld probe. Turbidity was measured using either a *Hach* or *Helige* portable turbidimeter. Nitrate and orthophosphate were measured using *Hach* portable water quality test kits. Alkalinity and pH were less frequently measured. pH was measured using a portable handheld probe, and alkalinity was measured using a *Hach* portable water quality test kit. Chlorophyll *a* data were obtained from concurrent research conducted by Marc Los Huertos, California State University Monterey Bay.

Biological Communities

Zooplankton.—Water column zooplankton and other pelagic invertebrates were sampled using a plankton tow net (20.3 cm diameter) with 153 μm mesh and identified to determine a seasonal abundance index. Seasonal open water surface tows (approximately 100 m) were made along a transect from Site 1 to Site 7 as an index to lake zooplankton abundance (Figure 2). Less frequent exploratory tows were made along the transect within the bottom third of the water column.

Samples were preserved in ethanol in the field. In the laboratory, samples were filtered, and biomass was determined by wet weight. Samples were adjusted to a known

volume, thoroughly mixed, and then sub-sampled to a smaller known volume using a wide bore pipette. Zooplankton in sub-samples were enumerated and identified to the lowest practical taxonomic level to determine percent composition.

Aquatic Macroinvertebrates.—Sampling was conducted seasonally at four sampling sites that were representative of the primary lake habitats: tributary confluence, mid-lake benthic, near shoreline with no vegetation, and near shoreline with vegetation. Kick-samples were collected at the Pacheco Creek confluence using a D-frame net with 1 mm mesh. Composite samples were taken from the left bank side, mid-channel, and right bank side; the technique involved disturbing the substrate immediately upstream of the D-frame net for approximately 30 s. Benthic samples were collected at Site 1 using an Ekman grab sampler and sieved through a bucket with 500 μ m mesh. Two areas, with and without vegetation, were sampled along the western shoreline near the southern outflow canal (Site 2). Samples were collected by water column sweeps (six approximately six-m sweeps per sample) with a D-frame net. Less frequent exploratory sampling was conducted at several other locations, including the shoreline habitat in the flooded eastern field, shoreline habitat along the vegetated eastern cove, and benthic habitat near the tributary confluences and southwestern shoreline.

All samples were preserved in ethanol in the field. In the laboratory, samples were identified to the lowest practical taxonomic level and enumerated. To insure accuracy of invertebrate identification, an aquatic invertebrate expert, Michael Bogan (Oregon State University), reviewed a subset of the samples. A reference collection was also kept for use in examining fish stomachs.

Fish.—Fish sampling to determine species relative abundance was conducted, using a combination of gear, at times when steelhead smolts were not expected to be present. Sampling gear included a multifilament trammel net with 5.1 and 25.4 cm (2 and 10 inch) meshes, two monofilament gill nets with 1.3, 1.9, 2.5, 3.8, and 5.1 cm (0.5, 0.75, 1, 1.5, and 2 inch) meshes, two monofilament gill nets with 2.5, 3.8, 5.1, 6.4, 7.6, and 10.2 cm (1, 1.5, 2, 2.5, 3, and 4 inch) meshes, and one multifilament gill net with 2.5, 3.8, 5.1 cm (1, 1.5, and 2 inch) meshes. The number of nets set on a given sampling day was dependent on the number of assistants available to check the nets. Nets were set in the early morning and checked frequently during daily sampling periods, which were approximately 5 h. The nets were aligned from the western shoreline near Site 2 toward the mid-lake buoy at Site 1, with the smallest mesh size closest to shore. All captured fish were identified and standard length (SL) measurements were made in 5 mm increments. Sub-samples were retained for later stomach content analysis.

Limited seining and dip net sampling were conducted to collect smaller fish that could not be captured by gill net. Due to the fine clay and silt substrate, seining was possible only near the Pacheco Creek delta where the substrate was predominantly coarse sand. A 0.6 cm (0.25 inch) mesh beach seine was used in this area. Fish species captured were noted and a sub-sample was retained for later stomach content analysis.

In order to determine general growth rates and age classes of selected species, scale samples and length measurements were taken in the field. Age classes were initially determined using the Peterson length-frequency method (Devries and Frie 1996). Frequency of individuals was plotted against fish length. Different age classes (age 0

through 2) were identified as frequency clusters in the plot and confirmed by the scale analysis.

Scales were mounted between two microscope slides and analyzed using a microfiche reader for projection. Scale annuli, the outer border of closely spaced circuli and the area in which crossing over typically occurs, were identified and counted to determine the age class. Measurements from the scale focus to each annulus and the total scale radius were made for selected species. Sizes at annuli were back-calculated to determine sizes at the end of growing seasons, using the following Fraser-Lee equation shown below (Murphy and Willis 1996):

$$L_i = \left(\frac{S_a}{S_c} \right) \times [(L_c - I)] + I$$

Where:

L_i = length of fish at i^{th} increment, or annulus (mm)

L_c = length of fish (mm SL)

S_a = radius of scale at i^{th} increment, or annulus (mm)

S_c = radius of scale (mm)

I = intercept for scale formation (mm SL)

Stomach contents of selected fish were examined to determine general food habits. During the fish sampling, sub-samples were preserved in formalin for later stomach content analysis. Samples were collected in June, August, October, and November 2005, and in June and November 2006. In the laboratory, fish stomachs were rinsed to remove excess formalin, uncoiled, and measured. The contents from a selected

portion of the digestive tract were removed. The portion of the digestive tract analyzed was dependent on the fish species and stomach type to provide largely undigested samples. For species without a differentiated, pouched stomach (including most of the cyprinids, Sacramento sucker [*Catostomus occidentalis*], and inland silverside [*Menidia beryllina*]), the foregut (first 30% of the digestive tract) was analyzed. For common carp (*Cyprinus carpio*) (carp) and goldfish (*Carassius auratus*), the first 10% of the digestive tract was analyzed. For species with pouched stomachs (the centrarchids, striped bass [*Morone saxatilis*], brown bullhead [*Ameiurus nebulosus*], and prickly sculpin [*Cottus asper*]), the contents of only the stomach pouch were analyzed. For threadfin shad, the contents of the gizzard-like stomach and the first 30% of the intestine were analyzed. Contents were sorted and identified to lowest practical taxonomic level using a dissecting microscope. Food items were quantified using frequency of occurrence and a modification of the point-volume method (Hynes 1950). Point-volume assignments were aided by a reference invertebrate collection, and volume was standardized using a 2 mm by 2 mm grid approximately 1 mm thick.

Results

Limnology

Precipitation.—Based on over a hundred years of precipitation data from the SBCWD, the average annual precipitation for the area is 33.3 cm. Based on CIMIS data, the area received above-average rainfall (42.4 cm) during the 2005 water year and average rainfall (33.1 cm) during the 2006 water year. The study commenced on 31 March 2005 following two large storm events: one on 15 February 2005 and one on 22 March 2005 (Figure 4). During both events, rainfall exceeded 2.5 cm in less than a 24-h period. In the 2005 water year, monthly rainfall was above average in October, December, February, March, May, and June (Figure 6). Monthly rainfall during the 2006 water year, when the majority of sampling took place, was below average with the exception of December, March, and April (Figure 6), but March and early April were unusually wet.

Lake Water Elevation.—The lake water elevation was 2.5 m (equating to a mid-lake water depth of 2.1 m) on 31 March 2005 (Figure 7). The water elevation decreased 1.0 m from 31 March 2005 to 31 May 2005 and then gradually decreased an additional 0.16 m through the end of July. The water elevation increased 0.22 m from the beginning of August through the end of September and then remained relatively level until the beginning of December. The lake level fluctuated throughout the winter and spring of 2006 as a result of storm events and increased inflow from the tributaries. Lake water elevation peaked in early January 2006 following a large storm event in late December

2005/January 2006 and also in early April 2006 following several large storm events in March and early April 2006 (Figure 5). The water elevation receded to 1.5 m from early April 2006 to late May 2006, similar to the level observed at the end of May 2005. The water elevation gradually declined 0.37 m from the end of May 2006 to the beginning of August 2006. As in 2005, the water elevation increased in later summer. The water elevation increased 0.13 m in August 2006 and then continued to slowly increase through the end of the study period in early November 2006. The lowest water elevation, 1.14 m (equating to a mid-lake water depth of 0.79 m), was observed in early August 2006. This was 0.18 m less than the lowest level observed in 2005, which was not unexpected as total precipitation was above average in 2005 and near average in 2006. The highest water elevation, 4.22 m (equating to a mid-lake water depth of 3.87 m), was observed in early April 2006.

Stream Flow.—The lake drains through two outlets, the north outflow canal and the south outflow canal (Figure 2). The two canals join approximately 475 m downstream to form Miller Canal. The north canal is lower in elevation than the south canal. The lake spilled year-round through the north canal. The south canal stopped spilling at a lake level of approximately 1.4 m. The rate of spilling appeared to decrease in late summer as increased tule growth in the canals restricted flow.

The two primary tributaries to the lake, Pacheco Creek and Tequisquita Slough, were perennial, although summer flow in Tequisquita Slough was substantially lower (Table 1). Dry season flow in Tequisquita Slough immediately upstream of the confluence with the lake ranged from 0.02-0.05 m³/s (0.8-1.8 ft³/s). Dry season flow in

Pacheco Creek, approximately 975 m upstream of the confluence with the lake, ranged from 0.06-0.28 m³/s (2.0-9.9 ft³/s), with flows increasing after early August. In both years of the study, the lake level decreased from April to July and then increased in August as flows increased in Pacheco Creek.

Stream flow in Pacheco Creek was influenced by releases from the North Fork Pacheco Reservoir, which is operated by the Pacheco Pass Water District. Based on daily mean discharge data (1940 to 1982) from the USGS Pacheco Creek gauging station (#11153000), reservoir releases have typically begun in late spring or early summer (Figure 8). The USGS gauging station is located approximately 14.5 km upstream of San Felipe Lake and 13.5 km downstream of the reservoir. The station did not begin re-operating until the end of the study period; therefore, stream flow data for the study period were not available. However, based on reservoir capacity data from the SCVWD ALERT system (March 2005 through September 2006), the 2005 releases began in early July and continued through mid-November. The mean monthly release rate was 0.62 m³/s (22 ft³/s) from July through September, 0.52 m³/s (18 ft³/s) in October, and 0.13 m³/s (4.7 ft³/s) in November 2005 (Table 1). Flow releases ended on November 16, 2005. The average flow release for early November 2005 was 0.20 m³/s (7.1 ft³/s). Reservoir releases in 2006 also began in early July and continued until the start of the rainy season. The mean monthly release rate was 0.19 m³/s (6.8 ft³/s) in July, 0.34 m³/s (12 ft³/s) in August and September, and 0.14 m³/s (5.0 ft³/s) during October and November 2006 (Table 1). USGS discharge data from the Pacheco Creek gauging station for the summer of 2008 (Figure 9) represents a deviation from the typical long-term

summer release pattern. Based on the 2008 USGS discharge data, summer reservoir releases began in mid-July but ended by mid-August.

Lake Bathymetry.—From the western shoreline, the lake bottom dropped 1.8 m over a distance of 26 m (Figure 10). The remainder of the lake bottom was relatively uniform with a mean depth of 2.0 m over 335 m. The variation in depth across most of the lake was less than 0.4 m. From the eastern shoreline the lake dropped 1.1 m over a distance of 23 m. The fields along the western shoreline on the west side of the Calaveras Fault are substantially higher than the lake and fields along the eastern shoreline. Due to the lower elevation, the fields along the eastern and southeastern shoreline were often flooded during storm flows (Figure 2).

From the northern shoreline, the lake dropped 1.7 m over a distance of 21 m (Figure 11). The remainder of the lake bottom was uniform with a mean depth of 2.0 m over 701 m. The range in depth across most of the lake was 0.6 m. The transect ended at Site 7, a shallow depositional area near the Pacheco Creek and Tequisquita Slough confluences with the lake (Figure 2).

Shoreline Development & Zonation.— Based on the water level elevation from the June 2005 field visit, the lake depth was 1.0 m. Therefore, given the 30 ha surface area of the lake estimated from NAIP imagery, the early summer 2005 lake volume was approximately 300,000 m³ (240 ac-ft). The lake has a high surface area to volume ratio, and therefore has high heating and mixing ability. The lake was turbid and eutrophic with a limited littoral zone and broad limnetic (open water) zone.

The length of the summer shoreline was approximately 4,000 m, of which approximately 30% was barren or sparsely vegetated with ruderal plants, 55% was dominated by a mostly narrow band of emergent vegetation, and the remaining 15% consisted of scattered patches of willow (*Salix* spp.) (Figure 3). Tules (*Scirpus* spp.) and smartweed (*Polygonum* spp.) were the two primary emergent plants present along the shoreline of the lake. Tules were present near the Tequisquita Slough and Ortega Creek confluences with the lake, the Pacheco Creek delta, along the northern shoreline, and within the two outflow canals. A narrow strip of tules was present just off of the southwestern shoreline. Throughout the study period, cattle were observed grazing on the tules within the two outflow canals and on the narrow strip of tules near the southwestern shoreline. The western shoreline was barren or sparsely vegetated due to cattle activity, whereas the eastern shoreline, where cattle access was more limited, was dominated by smartweed and willow. No submerged or floating aquatic plants were observed in San Felipe Lake.

Light and Turbidity.—Throughout the study period, I measured turbidity in samples collected from the mid-lake sampling site and at the Pacheco Creek and Tequisquita Slough confluences with the lake. Turbidity in the lake ranged from 14-171 NTU (Nephelometric Turbidity Units) with a mean of 81 NTU (Table 3). Lake turbidity levels were highest from May through August (generally greater than 100 NTU). Turbidity levels decreased in August through November, and they were lowest from December through May.

The turbidity of the Tequisquita Slough inflow ranged from 39-261 NTU with a mean of 82 NTU (Table 3), and the seasonal pattern was similar to the lake turbidity. The Pacheco Creek inflow was much clearer. Turbidity ranged from 6-53 NTU with a mean of 25 NTU (Table 3). A plume of clear water was often observed at the Pacheco Creek confluence with the lake.

Secchi depth measurements were taken at the mid-lake sampling site. Mid-lake secchi depths ranged from 0.10-0.45 m with a mean of 0.20 m (Table 3). Consistent with turbidity values, secchi depth (depth of visibility into water column, or the inverse of turbidity) was lowest from May through August (generally less than 0.15 m). Secchi depth was highest from November through May (greater than 0.2 m). The maximum secchi depth was 0.45 m and was observed in January and March. Secchi depth measurements were also taken at the six other lake monitoring sites; however, no differences among sites were detected.

Phytoplankton blooms contributed to the turbidity of the lake. A shift from inorganic to organic turbidity in summer was observed as evident by the shift in coloration of the water from brown to green. Algal blooms as surface films were also commonly observed throughout the summer during both years of sampling. The toxic cyanobacteria, *Anabaena flos-aquae*, was detected in a water sample collected from the lake during the summer of 2006 (Marc Los Huertos, personal communication). Although lake sampling for chlorophyll *a*, a pigment found in algae and cyanobacteria, was not conducted, limited chlorophyll *a* data were obtained from concurrent research conducted by Marc Los Huertos. Data were obtained for monthly samples (August 2005 through

November 2006) collected from Miller Canal at Frazier Lake Road, located approximately 3,000 m downstream of the lake. Chlorophyll *a* levels were highest summer and lowest in winter (Figure 12). The relationship between phytoplankton, represented by the chlorophyll *a* concentration, and total organic and inorganic turbidity was weak ($R^2=0.19$) (Figure 13). However, there was a positive correlation between turbidity and zooplankton biomass ($R^2=0.80$) and between chlorophyll *a* and zooplankton biomass ($R^2=0.75$) (Figures 14-15).

Temperature.—The lake was coolest in December, with a minimum of 7°C recorded in 2005 (Figure 16c). It remained between 10-16°C from January through March (Figure 17a) and gradually warmed from April through June (Figure 17b). The temperature of the lake peaked in July of both years, with a maximum of 32°C in July 2006 (Figures 16b and 17c), and gradually cooled from August through November (Figures 16b, 16c, and 17c). The trend for water temperature followed that of air temperature, which gradually increased from April through June (Figures 18a and 19b), peaked in July (Figures 18b and 19c), and cooled from August through November (Figures 18b, 18c, and 19c).

The average daily maximum temperature in the water column during January through March ranged from 12-14.5°C. The average daily maximum temperature during April through June ranged from 17-25°C. The average daily maximum temperature during July through September ranged from 21-28°C, and the average daily maximum temperature during October through December ranged from 12-18°C (Table 2). The average daily temperature range between the surface and bottom waters, based on the

difference of the mean daily minimum and maximum temperatures for each month, was approximately 2°C during October through March, 3°C during April through June, and 4°C during July through September (Table 2).

Based on profiles taken at mid-lake (Site 1), temperature and dissolved oxygen patterns in 2005 (Figures 20-29) and 2006 (Figures 30-39) were similar. During late spring and summer, the temperature within the upper portion of the water column generally increased on sunny, calm mornings. In the afternoon as winds increased, the temperature was more uniform throughout the water column, as on 31 May 2005 (Figure 20), 30 June 2005 (Figure 22), and 23 July 2005 (Figure 23). On foggy or overcast mornings, temperature was more uniform throughout the water column. It then uniformly increased throughout the water column during the day due to wind, as on 17 June 2005 (Figure 21), 27 July 2005 (Figure 24), and 18 August 2005 (Figure 25). When calm or with only light afternoon winds, such as on 27 July 2005 (Figure 24) and 23 June 2006 (Figure 36), the lake was stratified for temperature in the afternoon.

Water temperatures in generally well-shaded Pacheco Creek upstream of the lake ranged from 10-15°C from January to March, 11-22°C from April to June, 15-25°C from July to September, and 9-18°C from October to December (Figures 18 and 19). The mean temperature was 12°C from January to March, 17°C from April to June, 19°C from July to September, and 13°C from October to December. Outflow water temperatures just downstream of the lake in un-shaded Miller Canal ranged from 9-17°C from January to March, 13-28°C from April to June, 17-33°C from July to September, and 7-19°C from October to December. Outflow mean temperature was 12°C from January to

March, 20°C from April to June, 22°C from July to September, and 11°C from October to December. Based on inflow and outflow temperature differences, there was negligible difference in the temperature of the water entering and exiting the lake from November to March (Figure 18c and 19a). However, from April to September, the mean change in temperature entering and exiting the lake was 3-5°C. In late spring and summer during the afternoon, the difference in inflow and outflow temperature was often greater than 5°C and as much as 8°C on multiple occasions. Additional afternoon heating likely occurred within Miller Canal due to the low flow, shallow water depth, and lack of canopy.

Dissolved Oxygen.—Dissolved oxygen levels were variable throughout both 2005 (Figures 20-29) and 2006 (Figures 30-39). During October through March, dissolved oxygen levels generally ranged from 5-12 mg/L and were usually relatively uniform from top to bottom (Figures 26-31). From April through September, dissolved oxygen levels were more variable, with levels often dropping below 5 mg/L in the bottom waters in the morning (Figures 20-25 and 32-38). On sunny, calm mornings the lake was stratified, with higher dissolved oxygen levels at the surface and lower dissolved oxygen levels near the bottom due to a lack of photosynthesis and wind throughout the night, as on 31 May 2005 (Figure 20), 30 June 2005 (Figure 22), and 23 July 2005 (Figure 23). Conversely, on foggy or overcast mornings, the dissolved oxygen levels were uniformly low throughout the water column, as on 17 June 2005 (Figure 21), 27 July 2005 (Figure 24), and 18 August 2005 (Figure 25). In the afternoon, photosynthesis, wind, and mixing often increased, leading to uniformly higher dissolved oxygen levels throughout the water

column, as on 31 May 2005 (Figure 20), 30 June 2005 (Figure 22), and 23 July 2005 (Figure 23), and 18 August 2005 (Figure 25). When calm or with only light afternoon winds, such as on 27 July 2005 (Figure 24) and 23 June 2006 (Figure 36), dissolved oxygen levels were higher at the surface due to photosynthesis. However, strong winds in the afternoon (and water column mixing) were typical during the spring and summer (Figures 40 and 41).

The lowest dissolved oxygen levels (less than 5 mg/L) were observed in bottom waters from late spring to late summer and generally in the morning hours. Throughout the year, winds at night were usually calm (Figure 41). However, higher dissolved oxygen levels (near 10 mg/L) were usually present at the surface. One notable exception was on 27 July 2005 when in the morning the dissolved oxygen level was approximately 3 mg/L from top to bottom. Dissolved oxygen levels increased at the surface in the afternoon to 7.4 mg/L (Figure 24). Several congregations of 10 to 15 large adult carp, were observed gulping air and surface water in the morning when dissolved oxygen levels were low.

Super-saturated dissolved oxygen levels, greater than 15 mg/L, were observed in late spring and early summer 2006, especially on calm afternoons, such as on 29 May 2006 (Figure 34), 14 June 2006 (Figure 35), 23 June 2006 (Figure 36), and 12 July 2006 (Figure 37).

Routine dissolved oxygen profiles were taken at six other sampling sites (Figure 2), and the same patterns were observed: relatively uniform profiles in fall and winter; stratified morning profiles when sunny and calm; more uniform morning profiles when

foggy or overcast; uniform afternoon profiles when windy; and more stratified afternoon profiles when calm.

Chemistry.—I periodically measured a variety of chemical parameters including pH, alkalinity, nitrate, orthophosphate, and conductivity in samples collected from the mid-lake site and at the lake confluences of the two primary inflows, Pacheco Creek and Tequisquita Slough. The average alkalinity was 428 mg/L CaCO₃ in the lake ($n=4$), 817 mg/L CaCO₃ in Tequisquita Slough ($n=4$), and 240 mg/L CaCO₃ in Pacheco Creek ($n=2$). In the lake, pH ranged from 8.3-8.9 with a mean of 8.6 ($n=6$). In Tequisquita Slough, pH ranged from 8.2-8.7 with a mean of 8.4 ($n=6$), and in Pacheco Creek, pH ranged from 7.8-8.2 with a mean of 8.0 ($n=6$). Conductivity in the lake ranged from 304-1,126 μ S with a mean of 825 μ S ($n=19$) (Table 4). Conductivity in Tequisquita Slough ranged from 445-2,298 μ S with a mean of 1,671 μ S ($n=19$) (Table 4). Conductivity in Pacheco Creek ranged from 274-748 μ S with a mean of 567 μ S ($n=20$) (Table 4). Conductivity was lower in winter and spring when diluted by storm runoff.

Nitrate was never detected in samples ($n=7$) collected from the mid-lake site. Nitrate was detected only in one sample from Tequisquita Slough at a concentration of 0.9 mg/L NO₃-N in June 2005. Nitrate was detected in 5 of 13 samples collected from Pacheco Creek. The detected levels ranged from 0.1-1.0 mg/L NO₃-N. Unlike nitrate, phosphate was detected in all samples collected from the two inflows and in all but two samples collected from the lake (Table 4). Orthophosphate concentrations in the lake ranged from 0.0-0.7 mg/L PO₄ with a mean of 0.3 mg/L PO₄ ($n=20$). Orthophosphate concentrations in Tequisquita Slough ranged from 0.4 mg/L PO₄ to greater than 3 mg/L

PO₄ with a mean of 1.3 mg/L PO₄ ($n=19$). Orthophosphate concentrations in Pacheco Creek ranged from 0.1-0.6 mg/L PO₄ with a mean of 0.3 mg/L PO₄ ($n=19$).

Zooplankton

A total of eight seasonal open water surface tows were made along a primary transect from Site 1 and Site 7 during the study period. The zooplankton biomass index was lowest (0.02 mg/L) in early May 2006 (Figure 42) following above-average rainfall in March and April and the highest observed lake water level during the study period in early April (Figure 7). The zooplankton biomass index was highest, 1.9 mg/L, less than two months later in late June 2006. In general, the zooplankton biomass index was highest from June through November (Figure 42).

The zooplankton community was composed primarily of copepod adults and nauplii (larvae). Cyclopoida and Calanoida were the two orders of copepods found in the lake, and Cyclopoida were usually the most abundant of the two. There were two observed peaks in the density of copepods, one in June and another in October (Figure 43).

Cladocerans were also present in the lake but at much lower densities than copepods. Cladocerans were most abundant in April 2006 (Figure 43), but still less than 10% of captured zooplankton. Rotifers and ostracods were also detected, but capture densities were very low. *Neomysis* was also regularly captured in open water plankton samples, as well as elsewhere. It is treated with macroinvertebrates (below).

Exploratory zooplankton tows were made on four occasions within the bottom third of the water column. During three of the four trials, the zooplankton biomass index

within the bottom third of the water column was somewhat greater than the zooplankton biomass index observed near the surface, but in April 2006, when the lake was relatively deep and clear, bottom abundance was three times greater (Figure 44).

Aquatic Macroinvertebrates

A total of 20 macroinvertebrate samples were collected from four sampling sites that were representative of the primary lake habitats: tributary confluence, mid-lake, shoreline with no vegetation, and shoreline with vegetation. Samples were collected during fall 2005 (early December), winter 2006 (February), spring 2006 (May), summer 2006 (late June), and fall 2006 (November). Eight taxa of macroinvertebrates were present in the benthic and shoreline habitats, and twenty-two taxa were present at the Pacheco Creek confluence (Table 5).

Oligochaetes (including Tubificidae *Branchiura*) and Diptera larvae (Chironomidae) were the only macroinvertebrates present in benthic samples collected at the mid-lake buoy location near Site 1 (Figure 45a). Oligochaetes were by far the most abundant of the two with a mean relative abundance of 95% (Figure 45a). Chironomid larvae were most abundant in early December 2005 and were absent in samples collected in late June and November 2006 (Figure 46a). Oligochaetes were most abundant in May 2006 and were present year-round (Figure 46b).

The shrimp, *Neomysis*, was the primary invertebrate present in samples collected in shoreline habitat that lacked vegetation. The mean relative abundance of *Neomysis* was 99.7% (Figure 45b). *Neomysis* was most abundant in shoreline samples collected in May 2006 and was absent from shoreline samples collected in November 2006 (Figure 47).

Neomysis in plankton samples was scarce in October through April but very abundant in May and June. Other taxa less commonly detected at the site included the Amphipoda (Gammaridae) and Chironomidae pupae (Table 5).

Neomysis (68% mean relative abundance) and Chironomidae larvae (19% mean relative abundance) were the most abundant invertebrates present in the vegetated shoreline habitat (Figure 45c). Samples were collected near the base of tules growing on the western shoreline. Amphipods, Gammaridae (mean relative abundance 4%) and *Corophium* (mean relative abundance 4%), and oligochaetes (mean relative abundance 2%) were also present (Figure 45c). Other invertebrates found in the vegetated shoreline habitat included Odonata (Aeshnidae) and Hemiptera (Corixidae and Notonectidae) (Table 5), although the mean relative abundance was less than 3% (Figure 45c). As for the unvegetated shoreline, *Neomysis* was most abundant in May 2006 and was absent in samples collected in November 2006 (Figures 47 and 48a). Chironomidae larvae were most abundant in February 2006 and were absent in samples collected in late June 2006 (Figure 48b).

Neomysis (mean relative abundance 20%) and amphipods (mean relative abundance 23%, primarily *Corophium*, were the most abundant invertebrates present in samples collected at the Pacheco Creek confluence (Figure 45d). Ephemeroptera (mean relative abundance 16%), oligochaetes (mean relative abundance 16%), and dipterans (mean relative abundance 15%), primarily Chironomidae larvae, were also relatively common (Figure 45d). Other orders of insects that were present included Trichoptera (mean relative abundance 2.5%), Hemiptera (mean relative abundance 2%), and

Coleoptera and Collembola (mean relative abundance less than 2%) (Figures 45d and Table 5). Other invertebrates that were present (mean relative abundance 4%) included Gastropoda (snails), Bivalvia (clams), Decapoda (crayfish), and Hirudinea (leeches) (Table 5). Chironomidae larvae and *Corophium* were most abundant in late June and November 2006, and Ephemeroptera were most abundant in late June 2006 (Figure 49a-c). Leptohiphidae was the primary Ephemeropteran. Trichoptera was most abundant in June and November 2006 (Figure 50c). Hydropsychidae was the primary Trichopteran. *Neomysis* was present and common in early December 2005 and May 2006 and was most abundant in early December (Figure 50a). Oligochaetes were most abundant in February 2006 and November 2006, but were also present year-round (Figure 50b).

Macroinvertebrates were also collected during the open water zooplankton tows. Taxa included *Neomysis*, Chironomidae, and oligochaetes. *Neomysis* was present year-round and were most abundant in tows made during early June 2006. Chironomidae larvae were present in November and April 2006, and oligochaetes were present in February and April 2006. Chironomidae larvae and oligochaetes were most abundant in tows made in the bottom of the water column in April 2006. Chironomidae exuvia were present in October 2005, November 2005 and 2006, February 2006, April 2006 and May 2006, but were not present in tows conducted in late June 2006. They were most abundant in late October and early November.

Fish

A total of 17 fish species, including 6 native species, were collected in the lake. Twelve species of fish were captured by gill net in 32 h of sets during seven sampling

periods (Figure 51). Native species collected by gill net were hitch (*Lavinia exilicauda*), Sacramento blackfish (*Orthodon microlepidotus*), Sacramento sucker, and Sacramento pikeminnow (*Ptychocheilus grandis*). Additionally, two adult Chinook salmon (*Oncorhynchus tshawytscha*) were captured in late June 2005. Non-native species captured by gill nets were carp, brown bullhead, threadfin shad (*Dorosoma petenense*), goldfish, bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and striped bass.

Based on total catch by gill nets (Figure 51), hitch and carp were the two dominant species observed in the lake. Sacramento sucker and Sacramento blackfish were the next most abundant species, followed by scarce Sacramento pikeminnow and brown bullhead.

Nine species of fish were captured by seining. Native species were threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin, and juvenile Sacramento sucker, hitch, and Sacramento pikeminnow. Non-native species were fathead minnow (*Pimephales promelas*), inland silverside, carp, and largemouth bass.

Non-native mosquitofish (*Gambusia affinis*) were observed along the shoreline in December 2005, but they were not captured during any of the fish sampling events. Mosquitofish were occasionally captured by D-frame net during invertebrate sampling along the shoreline in 2005 and 2006.

With the exception of carp and fathead minnow, no spawning fish were observed along the margins of the lake and tributary confluences during 33 site visits in 2005 and 2006. Carp were observed spawning in Miller Canal, a flooded ditch that flows to Miller

Canal, and in flooded fields between the lake and Pacheco Creek and Tequisquita Slough in March and April. Fathead minnow breeding occurred in August 2005 based on the dark coloration and presence of distinct tubercles on the snouts of males captured by seine near the shoreline by the confluence of Pacheco Creek.

A 975 m reach of Pacheco Creek immediately upstream of the lake was walked in March and April 2006 to search for spawning fish such as hitch, Sacramento sucker, and Sacramento pikeminnow, which typically spawn in stream habitat with coarse substrate. Although suitable habitat was present, no spawning fish were observed. Despite this, the condition of fish captured by gill net and seining provided information on the timing of reproduction for several species. Two ripe male blackfish and a gravid female blackfish were captured in late June 2005, and a ripe male blackfish was captured in mid-June 2006. Three gravid females (brown bullhead, bluegill, and largemouth bass) were captured from the lake in late June 2005.

I analyzed the stomach contents of 13 fish species. A total of 221 fish stomachs were analyzed, 33 of which were empty. Age, growth, and stomach content analysis results are detailed below by species.

Hitch.—Hitch were the most abundant fish species captured in San Felipe Lake ($n=183$), and they were captured during each sampling event. Sizes of captured fish ranged from 75-190 mm SL which, based on scale analysis and the length-frequency histogram, represented at least three age classes (Figure 52). On average, hitch grew to 80 mm SL by the end of their first growing season, based upon scale back-calculations.

Stomach contents of hitch ($n=34$; 75-190 mm SL) in San Felipe Lake consisted of zooplankton, algae, phytoplankton, detritus, and *Neomysis*. Copepods were the dominant food items by volume (58%) and were present in 96% of the sampled hitch (Figures 53 and 54). Algae and phytoplankton were 26% of the volume, and detritus was 5%. Algae and phytoplankton were present in 54% of the hitch, and detritus was present in 36%. The mean percent volume of *Neomysis* was 11%, and the frequency of *Neomysis* was 21%. Cladocerans and ostracods were present in 7% of the fish stomachs.

Sacramento Sucker.—Sacramento suckers were the third most abundant fish species captured in San Felipe Lake ($n=106$) (Figure 51), and they were captured during each sampling event. Sizes of captured fish ranged from 90-390 mm SL which, based on scale analysis and the length-frequency histogram, represented more than three age classes, with growth slowing after reaching about 270 mm (Figure 55). Juvenile Sacramento suckers were also captured by seine in August (35-75 mm SL) and October 2005. On average, Sacramento suckers grew to 115 mm SL by the end of their first growing season, based upon back-calculation from scales.

Stomach contents of Sacramento sucker ($n=16$; 120-315 mm SL) in San Felipe Lake consisted of algae, phytoplankton, detritus, zooplankton, Chironomidae larvae, and amphipods. Algae/phytoplankton and detritus were the overwhelmingly dominant food items by volume (90%) and were present in all of the sampled fish (Figures 53 and 56). By volume, 25% of the identifiable stomach contents of Sacramento suckers was detritus. The mean percent volume of zooplankton was 8%, with ostracods present in the guts of 94% of the fish, copepods present in 88% of the fish, and cladocerans present in 44% of

the sampled fish. The mean percent volume of *Corophium* was 3%, and Chironomidae larvae were less than 1%. The frequency of occurrence of *Corophium* was 25%, and Chironomidae larvae was 38%.

Sacramento Blackfish.—Sacramento blackfish were the fourth most abundant fish species captured in the lake ($n = 79$), and they were captured during each sampling event. Sizes of captured fish ranged from 80-420 mm SL which, based on scale analysis and the length-frequency histogram, represented four age classes (Figure 57). On average, Sacramento blackfish grew to 130 mm SL by the end of their first growing season, based upon scale back-calculations.

Stomach contents of Sacramento blackfish ($n=24$; 80-285 mm SL) in San Felipe Lake consisted of algae, phytoplankton, detritus, and zooplankton. Algae and phytoplankton were the dominant food items by volume (86%) and were present in all of the sampled fish (Figures 53 and 58). Detritus was the next most frequent food item, occurring in 71% of the sampled Sacramento blackfish, but accounting for only 8% of volume. The mean percent volume of zooplankton was 6%. Copepods were present in 46% of the stomachs, ostracods were present in 21% of the stomachs, and cladocerans were present in 13% of the stomachs.

Sacramento Pikeminnow.—Sacramento pikeminnow were the fifth most abundant fish species in the lake ($n = 34$), and they were captured during five of the seven sampling events. Sizes of captured fish ranged from 90-255 mm SL which, based on scale analysis and the length-frequency histogram, represented two age classes (Figure 59). On average, Sacramento pikeminnow grew to 85 mm SL by the end of their first

growing season, although whether they reared their first year in Pacheco Creek or in San Felipe Lake is not known.

Stomach contents of pikeminnow in San Felipe Lake ($n=33$; 90-245 mm SL) consisted of fish, corixids, algae, phytoplankton, and detritus. Many of the analyzed stomachs were empty (64%) and/or parasitized by tapeworms (76%). Fish were the dominant prey item by volume (58%) and were present in 58% of the pikeminnow with stomach contents ($n=12$) (Figures 53 and 60). The frequency of algae and phytoplankton was 33% and detritus was 17%, and together accounted for 33% of volume. The mean percent volume of corixids was 8%, and they were present in 8% of pikeminnows.

Prickly Sculpin.—Prickly sculpin were captured only by seine near the Pacheco Creek confluence in August and October 2005. Therefore, the relative abundance of prickly sculpin captured by seine in comparison to the abundance of species captured by gill netting is unknown. Sizes of captured fish ranged from 35-100 mm SL.

Stomach contents of prickly sculpins in San Felipe Lake ($n=15$; 40-100 mm SL) consisted of a wide variety of food items including fish, small crustaceans, insects, zooplankton, and detritus. Chironomidae larvae were the dominant food items by volume (60%) and were present in 87% of the sampled fish (Figures 53 and 61). The mean percent volume of fish was 8%, crayfish 13%, corixids 5%, and *Neomysis* 6%. Detritus represented 4% of the volume, and zooplankton were less than 1% of the total volume. The frequency of occurrence of detritus was 33%. Corixids were present in 27% of the prickly sculpin stomachs, and crayfish were present in 20%. The frequency of fish,

Neomysis, and Chironomidae pupae was 13%. Copepods were present in 13% of the fish stomachs, and cladocerans and ostracods were present in 7%.

Common Carp.—Carp were the second most abundant fish species captured in San Felipe Lake ($n = 181$), and they were captured during each sampling event. Sizes of captured fish ranged from 50-550 mm SL, which represented six age classes based upon scale analysis and the length-frequency histogram (Figure 62). On average, carp grew to 150 mm SL by the end of their growing season and an average of 70 mm each additional year. Since many of the carp were quite large (Figure 62), they appear to have dominated the fish biomass of the lake.

Stomach contents of carp in San Felipe Lake ($n=23$; 95-550 mm SL) consisted of algae, phytoplankton, detritus, *Neomysis*, Chironomidae larvae and pupae, and *Corophium*. Carp were often observed rooting around bases of tules and the shallows along the shoreline. Algae and phytoplankton were the dominant food items by volume (53%) and were in 91% of the sampled fish (Figures 53 and 63). Detritus was the next most frequent food item, occurring in 82% of the carp and accounting for 21% of volume. The mean percent volume of zooplankton was 16%, with 15% as copepods. The frequency of zooplankton was 73% for copepods, 18% for cladocerans, and 32% for ostracods. Chironomidae larvae were present in the gut of 73% of the fish, and the mean volume was 10%. *Neomysis* and *Corophium* were present in 5% of the fish stomachs but were less than 1% of volume.

Brown Bullhead.—Brown bullhead were the sixth most abundant fish species captured in San Felipe Lake ($n = 28$), and they were captured during four of the seven

sampling events. Sizes of captured fish ranged from 70-275 mm SL, which may have represented three to four age classes (Figure 64).

The stomach contents of brown bullhead in San Felipe Lake ($n=26$; 70-275 mm SL) contained a wide variety of food items, including fish, small crustaceans, insects, zooplankton, algae, phytoplankton and detritus. *Neomysis* was the dominant food item by volume (33%) and was present in 74% of the sampled fish (Figures 53 and 65). The mean percent volume of fish was 21%, *Corophium* was 9%, and corixids was 5%, and Chironomidae was 4%. Algae and phytoplankton represented 20% of the volume, and detritus was 8%. Crayfish and copepods were less 1% of the total volume. *Corophium* were present in 48% of the sampled brown bullhead. The frequency of Chironomidae larvae was 39% and pupae were 30%. Fish and corixidae were each present in 26% of the bullhead stomachs, and crayfish were present in 4%. Copepods were present in 9% of the fish stomachs. The frequency of occurrence of algae and phytoplankton was 61%, and detritus was 65%.

Threadfin Shad.—Threadfin shad ($n= 16$) were captured only during three of the seven sampling events. Sizes of captured fish ranged from 45-115 mm SL which, based on the length-frequency histogram and scale analysis, represented two age classes (Figure 66).

Stomach contents of threadfin shad in San Felipe Lake ($n=14$; 65-115 mm SL) consisted primarily of zooplankton and algae/phytoplankton with lesser amounts of *Neomysis*, Chironomidae larvae, and detritus. By volume, 80% of the identifiable stomach contents of threadfin shad was zooplankton (69% copepods, 11% cladocerans)

(Figures 53 and 67). Copepods and algae/phytoplankton were present in all of the sampled fish. The mean percent volume of algae/phytoplankton was 18%. Cladocerans were the next most frequent food item, occurring in 43% of the sampled threadfin shad. Detritus was present in the gut of 21% of the fish, and *Neomysis* and Chironomidae larvae were present in 7% of fish stomachs, but volume contribution was low. *Neomysis* represented approximately 2% of the total volume. Threadfin shad rarely fed on benthic invertebrates, with less than 1% of the volume being represented by Chironomidae larvae and detritus.

Goldfish.—Goldfish were apparently not abundant in San Felipe Lake ($n=9$), and they were captured only during four of the seven sampling events. Sizes of captured fish ranged from 95-250 mm SL which, based on scale analysis and the length-frequency histogram, represented two age classes (Figure 68).

Stomach contents of goldfish in San Felipe Lake ($n=7$; 120-250 mm SL) consisted primarily of algae, phytoplankton, and zooplankton. By volume, 75% of the identifiable stomach contents of goldfish was zooplankton (Figure 53). Algae and phytoplankton represented 23%. Algae, phytoplankton, and copepods were present in 86% of sampled fish, and cladocerans were present in 57% (Figure 69). Goldfish also occasionally fed on *Neomysis*, which were 1% of the volume and present in 14% of fish.

Bluegill.—Bluegill were apparently not abundant in San Felipe Lake ($n=4$), and they were captured only during two of the seven sampling events. Sizes of captured fish ranged from 110-160 mm SL (Figure 70).

Only three stomachs were analyzed. By volume, 67% of the identifiable stomach contents of bluegill was *Neomysis* (Figure 53). Detritus was 23% of the volume, and algae and phytoplankton were 2%. The mean percent volume of Chironomidae larvae was 5%, and pupae volume was 1%. Corixidae, amphipods, and zooplankton were also present (Figure 71), but were each less than 1% of the total volume.

Largemouth Bass.—Largemouth bass were apparently not abundant in San Felipe Lake ($n=5$). Three largemouth bass were captured during one of the seven gill net sampling events in late June 2005, and two largemouth bass were captured by seine in October 2005. Sizes of captured fish ranged from 125-395 mm SL (Figure 72).

Only five stomachs were collected for analysis, two of which were empty. Stomach contents of largemouth bass consisted of fish, hemipterans, Chironomidae, small crustaceans, and algae/phytoplankton (Figure 73), but by volume, 67% of the identifiable stomach contents of largemouth bass was threespine stickleback (Figure 53). *Neomysis* and hemipterans each comprised 16% of the volume. Chironomidae larvae, amphipods, algae and phytoplankton were also consumed, but were less than 1% of the total volume.

Inland Silverside.—Inland silversides were captured only by seine near the Pacheco Creek confluence in October 2005. Sizes of captured fish ranged from 55-60 mm SL.

Stomach contents of inland silversides in San Felipe Lake ($n=7$; 55-60 mm SL) consisted of zooplankton and *Neomysis*. Copepods were the dominant food item, accounting for 75% of volume and were present in 86% of sampled fish (Figures 53 and

74). Cladocerans were present in 57% of the inland silversides, and accounted for 16% of volume. Inland silversides also fed on *Neomysis*, which were 10% of the volume and in 14% of stomachs.

Fathead Minnow.—Fathead minnow were captured only by seine near the Pacheco Creek confluence in August and October 2005. Length measurements were not taken.

Stomach contents of fathead minnows in San Felipe Lake ($n=15$; 40-55 mm SL) consisted of algae, phytoplankton, detritus, Chironomidae larvae and pupae, and ostracods. Algae and phytoplankton were the dominant food items, composing 78% of the stomach volume (Figure 53), and were present in 93% of sampled fish (Figure 75). Detritus was present in 67% of the fathead minnow stomachs, but accounted for only 16% of volume. The frequency of observance of Chironomidae pupae was 13%, and for Chironomidae larvae and ostracods was 7%. Chironomidae pupae were 6% of the total volume. Chironomidae larvae and ostracods were 1% of the total volume.

Striped Bass.—Two striped bass were captured during the study period. One was captured in June 2006 and the other in November 2006. Sizes were 290 mm and 360 mm SL. The stomach contents of both striped bass were fish.

Chinook Salmon.—Two Chinook salmon were captured, measured, tagged with coded floy tags, and released in late June 2005. One was a male, 600 mm SL, and the other was a female, 650 mm SL. The fish were silvery indicating that they had recently immigrated from the ocean.

Threespine Stickleback.—Threespine stickleback were common, but captured only by seine near the Pacheco Creek confluence in August and October 2005. Length measurements and samples for dietary analysis were not taken.

Mosquitofish.—Mosquitofish were observed along the shoreline in December 2004, and they were occasionally captured by D-frame net along the shoreline in 2005 and 2006.

Discussion

Limnology

Hydrology.—The water level of San Felipe Lake was primarily controlled by the elevation of the two outflow canals, local groundwater elevation, and inflow from two tributaries, Pacheco Creek and Tequisquita Slough. The lake spilled year-round in 2005 and 2006, with flow observed from the north canal in July 2006 when the lake was at its lowest level. The majority of the dry season flow into the lake was from Pacheco Creek. Flow in Pacheco Creek was influenced by reservoir releases from the North Fork Pacheco Reservoir, which began in July and continued through November in both 2005 and 2006. Summer reservoir releases coupled with high groundwater levels and decreased percolation led to increased flow in the lower reach of Pacheco Creek immediately upstream of the lake. This resulted in an increase in the water level of San Felipe Lake of 0.22 m in August 2005 and 0.13 m in August 2006.

Water levels in San Felipe Lake and dry season flow in Pacheco Creek and Tequisquita Slough have varied considerably in the past due to hydromodification, land use change, and the pumping of groundwater. There are records of artesian water near the project area in the late 1800s and early 1900s (Grossinger et al. 2008; SBCWD 2003). Miller Canal was completed in 1874 and drained approximately 2,800 ha of wetland habitat, making it suitable for agriculture and cattle grazing (Grossinger et al. 2008). The acreage of irrigated agriculture in the region increased from 20,000 acres in 1929 to 45,000 acres in 1997 (SBCWD 2003). As agriculture increased in the area, so did the number of wells. The early 1900s were marked by decreased groundwater levels,

prompting an increased reliance on surface water and construction of the North Fork Pacheco Reservoir in 1939. Based on descriptions from 1854, Tequisquita Slough was perennial but appeared dry in photographs from 1949 (Grossinger et al. 2008).

During the 1970s and 1980s, there was often no inflow into the lake from Pacheco Creek and Tequisquita Slough, and in 1977, the second year of a severe drought, the lake dried (Smith 2007a). In 1987, the Central Valley Project, San Felipe Division, began delivering water to the basin from the San Luis Reservoir. Imported water from the Central Valley Project is currently used for agricultural, municipal, and industrial supplies. The decreased use of groundwater led to recovery from past pumping conditions. Groundwater elevations in most of the SBCWD sub-basins are close to the historical (1913) levels (SBCWD 2006). Since the late 1990s, flowing artesian wells have been present near Lover's Lane and Shore Road, which are located upstream of the lake (SBCWD 2005). Artesian flow in this area upstream of the lake is influenced by the Calaveras Fault, which forces groundwater toward the surface in Pacheco Creek and Tequisquita Slough. Pacheco Creek and Tequisquita Slough are located in the Pacheco groundwater sub-basin. Groundwater levels are lower on the western side of the fault in the Bolsa sub-basin, which does not receive imported water and is still heavily reliant on groundwater (SBCWD 2005).

Lake Morphology.—The western shoreline of the lake is higher than the eastern shoreline as a result of the Calaveras Fault. Due to the lower elevation, the fields along the eastern and southeastern shoreline were often flooded during high flows and thus provided a great deal of flood retention capacity and short duration winter habitat. The

summer surface area of San Felipe Lake during 2005, a slightly above-average water year, was approximately 30 ha, but during storms, surface area can exceed 200 ha.

Bathymetric transects conducted during this study revealed that the lake bottom was relatively uniform throughout. The northern, eastern, and western shorelines dropped 1-2 m over a distance of approximately 20 m to a relatively consistent summer depth of 0.8 – 1.0 m, whereas the slope of the southern shoreline of the lake was more gradual due to sediment deposition from Pacheco Creek and Tequisquita Slough.

Water Quality.—San Felipe Lake was turbid due to the shallow depth of the lake and mechanical mixing of fine sediments from the bottom. High turbidity levels may also have been due substantially to feeding activity by carp, which disturbed fine bottom sediments. On numerous occasions, plumes of sediment were observed in areas where carp were feeding. The lake was most productive in late spring and summer when the lake warmed and phytoplankton increased, as evident by the green coloration of the water. Turbidity both increased and shifted from the inorganic turbidity of storm runoff to phytoplankton in the lake and Miller Canal (Los Huertos unpublished data 2006). High lake turbidity levels, both inorganic and organic, throughout the year limited light penetration and thus prevented the growth of submerged aquatic plants.

The trend for water temperature in San Felipe Lake followed that of air temperature with cool, steady temperatures in December through March, gradually-increasing temperatures in April through June, maximum temperatures of 25-30°C in July, and gradually-decreasing temperatures in August through November. The difference in water temperature throughout the shallow water column was affected by

wind and turbidity. During late spring and summer, temperatures were generally uniform throughout the water column in the early morning. During the late morning and early afternoon when calm, the temperature of the surface waters generally increased due to solar radiation and heat absorption at the surface. On most afternoons, winds increased, mixing the entire water column due to the shallow depth. The mixing of heat throughout the water column resulted in uniformly warm water temperatures in the afternoon.

In late spring and summer, the difference in temperature entering and exiting the lake was often greater than 5°C and on occasion greater than 8°C. Pacheco Creek, just upstream of the lake, was well shaded with summer temperatures ranging from 15-25°C. Miller Canal, just downstream of the lake, was unshaded with summer temperatures ranging from 17-33°C.

In March through May, the period for potential steelhead rearing in the lake and smolt out-migration through the lake, the average daily maximum temperature in the water column increased from 13 to 23°C. Temperatures within this range may be suitable for steelhead, but at the higher temperatures would be suitable only if enough food is available to maintain metabolic demands (Smith and Li 1983; Myrick and Cech 2005). The average daily maximum temperature in the water column during June through September ranged from 22-28°C. The maximum water temperature measured in the lake was 32°C in July of 2005 and 2006. Prolonged temperatures from 24-27°C are often lethal to steelhead (Moyle 2002); therefore, as expected, San Felipe Lake was too warm for steelhead rearing in June through September.

During all seasons, the dissolved oxygen levels were lower in the morning due to bacterial respiration at night and were higher in the afternoon due to increased photosynthesis driven by sunlight and temperature. Larger diurnal swings in dissolved oxygen levels were often observed in summer, with levels below 5 mg/L on calm, overcast mornings and as high as 20 mg/L on calm, sunny afternoons. In general, dissolved oxygen profiles were uniform in fall and winter and were more variable in late spring and summer. In late spring and summer, dissolved oxygen levels were generally stratified throughout the water column during calm mornings due to increased photosynthesis at the surface and were more uniform on windy afternoons due to mixing.

Nitrate was never detected in samples collected from the lake, and nitrate levels in samples collected from Pacheco Creek and Tequisquita Slough were below detection or less than 1 mg/L NO₃-N. Orthophosphate was present in both inflows and in the lake, so nitrogen was the limiting nutrient, although high turbidity (low light) also limited phytoplankton production. Nitrogen limitation was also probably responsible for the presence of nitrogen-fixing cyanobacteria in the lake.

Biological Communities

Zooplankton.—The zooplankton community consisted primarily of copepods with far lower densities of cladocerans, and relatively few rotifers and ostracods. The low densities of rotifers may have been the result of reduced capture efficiency due to their small size. The zooplankton biomass index, determined from open water surface tows, was lowest in early May 2006 following above-average rainfall in March and April, and

it was highest in late June 2006. In general, the zooplankton biomass index was highest from June through November.

There were two observed peaks in the density of copepods, one in June and one in October. This corresponded with peaks in chlorophyll *a* concentration downstream in Miller Canal (Los Huertos unpublished data 2006).

The results of exploratory zooplankton tows indicated that zooplankton biomass index within the bottom third of the water column was somewhat greater than the zooplankton biomass index observed near the surface, but vertical movement of zooplankton is probably not an important factor in such a shallow and turbid lake. The effect was much stronger in April when the lake was deeper and clearer.

Aquatic Macroinvertebrates.—A total of 24 macroinvertebrate taxa were collected from the primary lake habitats, but many were restricted to the limited sand and gravel habitat at the Pacheco Creek delta. Only 8 taxa of macroinvertebrates were collected in mid-lake benthic and shoreline habitats, whereas 22 taxa of macroinvertebrates were collected at the confluence of Pacheco Creek. The diversity of macroinvertebrates inhabiting the mid-lake and shoreline habitats of the lake was limited by the fine substrate, the lack of emergent vegetation and submerged and floating aquatic plants, and possibly by occasional low dissolved oxygen concentration in bottom waters. Oligochaetes and Chironomidae larvae were the only macroinvertebrates collected from the mid-lake benthic habitat. Both taxa are tolerant of low dissolved oxygen concentration (Smith 2001; Thorp and Covich 2001).

Neomysis was collected in mid-lake plankton tows and was also the primary macroinvertebrate collected from shoreline habitat that lacked vegetation, which was approximately 30% of the total shoreline. More macroinvertebrate taxa (eight versus three) were collected from shoreline habitat with generally sparse emergent vegetation, which was approximately 55% of the total shoreline. *Neomysis* and Chironomidae larvae were the most commonly observed macroinvertebrates in the vegetated shoreline habitat.

Based on the limited seasonal sampling conducted for this study, *Neomysis* was most abundant during May and June 2006 and were not present in samples collected in November 2006. *Neomysis* is a common food item for steelhead smolts in estuaries (Martin 1995). They would be available as food in spring for migrating steelhead smolts in San Felipe Lake, but would probably be too scarce to support winter rearing by early emigrants. Chironomidae larvae and *Corophium* were present year-round and were most abundant in the Pacheco Creek confluence habitat in June and November 2006.

Fish.—A total of 17 fish species were collected in San Felipe Lake. Of these, six fish species, hitch, Sacramento blackfish, Sacramento sucker, Sacramento pikeminnow, prickly sculpin, and threespine stickleback, are native to the Pajaro River watershed and are common freshwater fish species of the Sacramento-San Joaquin Province (Snyder 1913; Smith 1982; Moyle 2002).

Gobalet (1995) investigated an archaeological site (SCL-119/SBN-24/H) near San Felipe Lake as part of a broader study to determine prehistoric Native American fisheries along the central California coast and detected hitch, Sacramento blackfish, and Sacramento sucker. Sacramento pikeminnow, threespine stickleback, and prickly sculpin

were not detected by Gobalet (1995) but were collected from the lake during this study. Fish species remains that were recovered by Gobalet (1995) but were not observed in the lake during this study included Sacramento perch (*Archoplites interruptus*), tule perch (*Hysterocarpus traskii*), and thicktail chub (*Gila crassicauda*). Thicktail chub are now extinct (Moyle 2002), and Sacramento perch (*Archoplites interruptus*) and tule perch (*Hysterocarpus traskii*), two species that were historically found in deep, slow sections of the Pajaro River with sandy substrate (Snyder 1913) were likely extirpated in the 1960s (Smith 1982).

An extensive study of the fishes of the Pajaro River watershed was conducted in the 1970s (Smith 1982). Native species that were documented in the Pajaro River system in the 1970s that were not captured in the lake during this study included Pacific lamprey (*Lampetra tridentata*), California roach (*Lavinia symmetricus*), speckled dace (*Rhinichthys osculus*), and riffle sculpin (*Cottus gulosus*) (Smith 1982). Given the stream habitat preferences of these species, they would not be expected to inhabit San Felipe Lake.

Non-native fish species that were captured in the lake included carp, brown bullhead, threadfin shad, goldfish, bluegill, largemouth bass, striped bass, fathead minnow, inland silverside, and mosquitofish. With the exception of striped bass and inland silverside, these non-native fish species were previously documented in the Pajaro River watershed in 1972-1975 (Smith 1982). Striped bass, inland silverside, and threadfin shad were likely introduced from the San Luis Reservoir via occasional discharges from San Felipe Pipeline, which is adjacent to the San Felipe Lake. *Neomysis*,

Corophium, and Gammaridae could also have been originally introduced to the lake via Sacramento River Delta water delivered through the San Felipe Pipeline.

Many of the species of fish observed in the lake are capable of spawning along the shoreline of San Felipe Lake or in the adjacent ditches and flooded fields. However, carp and fathead minnow were the only fish observed spawning along the margins of the lake and tributary confluences during 33 site visits in 2005 and 2006. Carp and goldfish generally spawn in spring and early summer. Spawning often takes place in shallow, vegetated, flooded areas where they can develop and hatch within one week (Moyle 2002). Accordingly, carp were observed spawning in a ditch that drains to Miller Canal, in Miller Canal, near the Tequisquita Slough confluence, and in a flooded field near San Felipe Lake in March and April. Fathead minnow nests are generally constructed in areas with rock and debris, such as sticks and root masses (Moyle 2002). In San Felipe Lake, breeding occurred in August 2005 based on the dark coloration and presence of tubercles observed on the snouts of captured males near the Pacheco Creek confluence.

Other fish that would be expected to spawn along the shoreline of the lake are Sacramento blackfish, largemouth bass, bluegill, brown bullhead, inland silverside, and goldfish. Sacramento blackfish spawning generally takes place over vegetation in shallow water in late spring (Murphy 1950; Wang 1986). Although spawning was not observed, a gravid female blackfish was captured in June 2005 and ripe males were captured in June of 2005 and 2006. Largemouth bass and bluegill spawning generally takes place in spring and summer with nests constructed in gravel, sand, or mud with debris and detritus (Moyle 2002). Although bluegill and largemouth bass were not

observed spawning in San Felipe Lake, a gravid female bluegill and a gravid female largemouth bass were captured in late June 2005. Similarly, brown bullhead also spawn during spring and summer in habitats such as sand and gravel depressions with structures such as bank burrows, hollow logs, or piles of rock nearby for cover (Moyle 2002). Although spawning was not observed, a gravid female brown bullhead was captured in late June 2005. The fine substrate and bottom feeding by large carp may reduce the spawning success of bottom nesters, and the lack of rooted aquatic vegetation may affect Sacramento blackfish. Threadfin shad and inland silverside spawning generally takes place in April through August or September around floating objects such as logs, aquatic vegetation, and debris (Moyle 2002).

Sacramento pikeminnow, hitch, Sacramento sucker, and prickly sculpin are generally stream spawners (Wang 1986, Moyle 2002), although spawning of hitch in lake habitats has been documented (Moyle 2002). Hitch usually spawn in gravel reaches of streams in spring; however, observations of lake spawning have been observed (Moyle 2002). Kimsey (1960) noted a population of hitch in Lake Merced with no access to a stream and observed spawning behavior of hitch on the shores of Clear Lake, Lake County. Kimsey also noted a reproducing population in a farm pond near Clear Lake. Nicola (1974) documented lake spawning for the hitch population in Beardsley Reservoir along the Middle Fork of the Stanislaus River. Prickly sculpin generally spawn in flowing water, but they are capable of completing their life cycle within lake environments. Nests are often constructed in habitats with rock substrate (Broadway and Moyle 1978; Wang 1986). The most ideal spawning locations for these fish species in

the project area would be in Pacheco Creek upstream of the lake where there is coarse sand and small gravel substrate. Despite numerous visits to the lake throughout 2005 and 2006 and upstream spawning checks in Pacheco Creek in March and April 2006, spawning Sacramento pikeminnow, hitch, Sacramento sucker, and prickly sculpin were not observed. These species are common in the upstream perennial reaches of Pacheco Creek and are also present downstream in the Pajaro River (Smith 1982; Smith 2007a). If reproducing lake populations are not present, resident populations in Pacheco Creek or the Pajaro River may provide a source of recruitment for the lake.

The assemblage of fish observed in San Felipe Lake is somewhat similar to that of Clear Lake. Clear Lake is a relatively shallow, warm, productive, well-mixed lake, but is much larger (surface area 17,670 ha versus 30 ha), deeper, and less turbid than San Felipe Lake. Clear Lake has similarly lost many of its native fish, but is presently dominated by non-native forage (inland silverside) and sport fish (largemouth bass, bluegill, crappie [*Pomoxis* spp.], and catfishes [*Ameiurus catus* and *Ictalurus punctatus*]) (Moyle 2002). These fish were scarce or absent in San Felipe Lake, but introduced carp dominated the lake ecosystem in biomass and by their rooting actions.

Food-Web Relationships

The growth of submerged aquatic plants in San Felipe Lake is restricted by high turbidity, the resulting low light levels, and by carp foraging activities. With the lack of submerged aquatic plants, the lake is dominated by a limnetic (open water) food web. Single celled phytoplankton, including cyanobacteria, form the base of the food chain in San Felipe Lake. Fine organic matter and detritus, such as leaves and twigs delivered by

the tributaries, also contribute to the base of the food chain. The abundance of phytoplankton supports a zooplankton community dominated by copepods with lower densities of cladocerans, rotifers, and ostracods. The phytoplankton also support *Neomysis*, one of the most abundant macroinvertebrates in the lake, and several open water phytoplankton and zooplankton feeding fish species. Fine organic matter and detritus on the bottom of the lake support Chironomidae larvae and oligochaetes, the two primary benthic macroinvertebrates present in the lake that are capable of withstanding the low dissolved oxygen levels and that can inhabit the fine sediments on the lake bottom. In the limited locations where emergent vegetation is present along the shoreline, the accumulation of fine organic matter and biofilms on the base of the plants provides a food source for *Corophium*, one of the other more abundant macroinvertebrates in San Felipe Lake. *Corophium*, along with a more diverse assemblage of macroinvertebrates, were present at the Pacheco Creek confluence with San Felipe Lake, where dissolved oxygen levels were higher and coarse substrate was more abundant.

Three primary fish feeding strategies were observed in the lake – water column feeders, benthic omnivores, and piscivores. Water column feeders included hitch, Sacramento blackfish, inland silverside, and threadfin shad. Zooplankton was the primary food source for hitch, inland silverside, and threadfin shad; whereas phytoplankton and algae were more important for Sacramento blackfish. Zooplankton was also an important food source for less abundant goldfish. Benthic omnivores included Sacramento sucker, carp, prickly sculpin, brown bullhead, and fathead

minnows. Algae, detritus, and Chironomidae larvae were important food items for these species. For Sacramento sucker and brown bullhead, *Corophium* was also a relatively common food item. Piscivores that were present in the lake included Sacramento pikeminnow, largemouth bass, and striped bass. However, abundance was low, which was likely due to reduced visibility for feeding due to high turbidity levels. Prickly sculpin and larger brown bullhead also preyed upon fish. Corixids were a relatively common part of the diet for the Sacramento pikeminnow, largemouth bass, prickly sculpin, and brown bullhead. *Neomysis* was a common food item for several of the fish species present in San Felipe Lake. Nine of the thirteen sampled fish species consumed *Neomysis*. Of the nine species, percent composition *Neomysis* was highest for hitch, prickly sculpin, inland silverside, bluegill, largemouth bass, and brown bullhead.

Conditions For Steelhead

Steelhead were not captured in San Felipe Lake although they are known to migrate through the lake to spawning and rearing habitat in upper Pacheco Creek and Arroyo Dos Picachos Creek (Smith 1982). Due to the fine substrate of the lake and the need to sample with gill nets (which could potentially harm steelhead), sampling was designed to take place at times when steelhead were not present in the lake.

Chinook salmon had not previously been reported in the Pajaro watershed. The two fish captured during this study, during relatively warm conditions in June 2005, were most likely strays from local salmon rearing operations as part of the Monterey Bay Salmon and Trout Project's Chinook Enhancement Program (Monterey Bay Salmon and Trout Project 2010).

San Felipe Lake is too warm for steelhead rearing during the summer months (June through September) when the average daily maximum temperature in the water column ranged from 22-28°C. However, the period from March through May, when the average daily maximum temperature in the water column ranged from 13-23°C, may be suitable for a short period of spring growth for steelhead before and during smolt out-migration. Turbidities were also lower during this period prior to an increase in late May and early June when levels increased largely due to increased phytoplankton abundance. Lower turbidity in early spring would allow for enhanced visibility and feeding conditions for steelhead. Steelhead are opportunistic water column feeders. The most likely food source in San Felipe Lake for steelhead is *Neomysis*, which peaked in late spring and early summer. Benthic Chironomidae larvae and *Corophium* are much less likely to serve as food for steelhead.

Potential predators on steelhead smolts, such as Sacramento pikeminnow, largemouth bass, striped bass, and brown bullhead, were present in San Felipe Lake. However, the limited sampling conducted as part of this study suggests that abundance of these species is low. Pikeminnows present in 2005 and 2006 were small. Therefore, they are most likely not a significant predatory threat to migrating steelhead smolts.

Potential avian predators that were observed during the study included American white pelican (*Pelecanus erythrorhynchos*), double crested cormorant (*Phalacrocorax auritus*), great egret (*Ardea alba*), snowy egret (*Egretta thula*), great blue heron (*Ardea herodias*), green heron (*Butorides virescens*) black-crowned night heron (*Nycticorax nycticorax*), western grebe (*Aechmophorus occidentalis*), common merganser (*Mergus*

merganser), terns (*Sterna* spp.), belted kingfisher (*Ceryle alcyon*), and gulls (*Larus* spp.). Their ability to prey on juvenile steelhead, potentially rearing in the lake during spring, was likely limited by the turbid water and greater relative depths observed during this period.

Streamflow for smolt out-migration has been identified as a limiting factor for steelhead in the Pacheco Creek and Tequisquita Slough watersheds (Smith 2007a; 2007b). Releases from the North Fork Pacheco Reservoir, owned and operated by the Pacheco Pass Water District, usually did not occur until water demand increased in summer. This in combination with high percolation rates often resulted in a dry stream channel in the reach of Pacheco Creek upstream of San Felipe Lake near the Walnut Avenue USGS gauging station during the typical steelhead smolt out-migration period in spring (Shapovalov and Taft 1954; Spencer et al. 2006; Smith 2007a; Smith 2007b). The channel dry back after winter flows subsided and reduced flow into San Felipe Lake also coincided with the timing of spawning of several native fish species such as hitch, Sacramento sucker, and Sacramento blackfish that inhabit the lake and either spawn in the flooded back waters of the lake or in Pacheco Creek upstream of the lake. With the delivery of imported water to the basin from the San Luis Reservoir beginning in 1987, groundwater levels have risen (SBCWD 2003). However, the past reservoir release strategy has continued with little or no water releases in late spring, when flows are needed for smolt out-migration, and with larger reservoir releases beginning in July when conditions for steelhead in the lake are no longer suitable. This was the case during the

data collection period for this study in 2005 and 2006. Releases were even more restricted in 2008 and 2009, when they were limited to about one month in mid-summer.

A new management strategy focusing on earlier reservoir releases in April and May would likely improve conditions for steelhead out-migration and increase spawning habitat for several native fish species that inhabit San Felipe Lake. Groundwater elevations in the area have increased resulting in decreased percolation and thus higher summer stream flow in the lower reach of Pacheco Creek. However, in the former rearing habitat downstream of the reservoir (Smith 1982; Smith 2007b), the recent lack of flow in late spring and fall has eliminated most of the potential steelhead rearing, so smolt migration is not the only problem for maintaining or improving steelhead in the watershed.

Study Limitations

The primary limitation of this study was that it was broad and exploratory, and therefore detailed information on aspects of the aquatic ecology of San Felipe Lake was not obtained.

Although the fish sampling conducted for this study provides insight into the fish species present in the lake and their relative abundance, there were limitations. First, the fine lake bottom sediment limited sampling to primarily gill nets. The gill net sampling site was fairly representative of the entire lake due to the uniform depth and substrate and lack of submerged and emergent vegetation. Second, sampling with gill nets is selective for both fish species (i.e., microhabitat utilization, seasonal and daily activity levels) and size. Nets were frequently checked to reduce injury and mortality, so sampling was

generally conducted from early morning to early afternoon. Species that are more active at night, such as brown bullhead and Sacramento sucker, may have been underrepresented. Smaller fish species such as prickly sculpin, threespine stickleback, fathead minnow, and inland silverside were not captured by gill net and were only captured by seine.

There were also limitations to the dietary analysis. Oligochaetes were present in lake but were not detected in fish stomachs during the dietary analysis. This may have been due to their unavailability in sediments or rapid digestion. If due to rapid digestion, the importance as a food source would be underrepresented. Similarly, the tiny heads of Chironomidae larvae were often the only identifiable portion remaining in the gut of sampled fish. Therefore, the importance of Chironomidae larvae, by volume, may also have been underrepresented. Alternatively, their persistence in the environment and possibly in fish guts may overestimate their importance.

Management Recommendations

Based on the results of this study, several management actions could be implemented to improve aquatic habitat conditions in San Felipe Lake and for steelhead populations in the Pacheco Creek watershed. Management recommendations include the following:

- 1) Spread releases from Pacheco Reservoir over the entire steelhead summer/fall rearing periods downstream of the reservoir, and also increase stream flow releases from North Fork Pacheco Reservoir in early spring to improve steelhead out-migration conditions.

2) Fence portions of the shoreline to restrict cattle access to promote growth of shoreline vegetation such as tules and willows and to reduce excess nutrient inputs. An increase in tules, overhanging willows, and smartweed would provide additional escape cover for fish, spawning habitat for lake spawning fish species, and a substrate for macroinvertebrate colonization, which may potentially increase macroinvertebrate diversity and abundance (especially of *Neomysis* and amphipods) along the shoreline.

3) Regulate blow-off flows from the San Felipe Pipeline to prevent future introductions of non-native fish species from the San Luis Reservoir, such as striped bass, threadfin shad and inland silverside. This might be accomplished by screening the pipeline intakes or blow-off pipes or by discharging blow-off water behind levees, so that fish cannot enter Pacheco Creek.

4) Raising the elevation of the Miller Canal outflows with a sill, an inflatable dam, or removable flashboards would increase the water depth in San Felipe Lake and flood the fields to the east of the lake. This may improve water quality in the lake by lowering turbidity levels due to reduced ability for mechanical mixing of bottom sediments. Increased water depth and subsequent flooding of adjacent fields may provide additional spawning habitat for fish species such as Sacramento blackfish in newly created shallow water vegetated areas. Structures that could be removed or lowered would neither reduce winter flood attenuation capabilities in the upper Soap Lake basin nor negatively impact steelhead migration. They could be raised or installed in April to improve lake habitat in late spring and summer. Any efforts to restore the historic upper Pajaro River channel should not significantly reduce steelhead migration flows in Miller

Canal. Miller Canal currently functions as an effective migration corridor for steelhead in and out of the Pacheco Creek watershed (Smith 2007a).

5) Manage carp populations to improve water clarity and reduce competition with native species such as Sacramento sucker and Sacramento blackfish. Experimental carp biomanipulation studies (i.e., exclusion or varied stocking densities) have demonstrated that reductions in the number of carp can decrease sediment resuspension and turbidity, promote the growth of aquatic macrophytes, and in some cases reduce nutrient enrichment and affect plankton and macroinvertebrate abundance and diversity (McCrimmon 1968; Roberts et al. 1995; Barton et al. 2000; Lougheed and Chow-Fraser 2001; Parkos et al. 2003). The reduction of carp in San Felipe Lake, by commercial or experimental netting or trapping would likely improve water clarity and may also improve food availability for native benthic feeding fish such as Sacramento sucker. Even with the reduction of carp in the lake, extensive growth of aquatic macrophytes might not occur, as the water would probably remain relatively turbid due to resuspension of bottom sediments by mechanical wind mixing and the shallow depth of water.

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Figures

FIGURE 1.—Location of San Felipe Lake in central California.

FIGURE 2.—San Felipe Lake showing water quality sampling sites, tributaries, outflow canals, and surrounding features.

FIGURE 3.—Generalized vegetation of San Felipe Lake and surrounding habitat.

FIGURE 4.—Daily precipitation for the 2005 water year. Data from California Irrigation Management System Station #126.

FIGURE 5.—Daily precipitation for the 2006 water year. Data from California Irrigation Management System San Benito Station #126.

FIGURE 6.—Monthly rainfall in 2005 and 2006, and 1875 to 2007 mean monthly rainfall. Data from California Irrigation Management System San Benito Station #126 and San Benito County Water District.

FIGURE 7.—San Felipe Lake water elevation in 2005 and 2006. At a stage of 1.5 m, the lake is approximately 1.2 m deep.

FIGURE 8.—Daily mean discharge from 1940 to 1982 at the USGS Pacheco Creek gauging station #11153000. Note: Values greater than 25 ft³/s were omitted from the graph to highlight dry season flow.

FIGURE 9.—Discharge data (July 2008 through September 2008) for the USGS Pacheco Creek gauging station #11153000.

FIGURE 10.—Bathymetric transect of San Felipe Lake at mid-lake from west to east on 31 March 2005.

FIGURE 11.—Bathymetric transect of San Felipe Lake at mid-lake from north to south on 31 May 2005.

FIGURE 12.—Chlorophyll *a* concentration for samples collected from Miller Canal at Frazier Lake Road from August 2005 through November 2006 (Los Huertos unpublished data 2006).

FIGURE 13.—Chlorophyll *a* concentration for samples collected from Miller Canal at Frazier Lake Road (Los Huertos unpublished data 2006) versus turbidity in San Felipe Lake from August 2005 through November 2006.

FIGURE 14.—Turbidity versus the zooplankton biomass index in San Felipe Lake from June 2005 through June 2006.

FIGURE 15.—Chlorophyll *a* concentration for samples collected from Miller Canal at Frazier Lake Road (Los Huertos unpublished data 2006) versus the zooplankton biomass index in San Felipe Lake from October 2005 through June 2006.

FIGURE 16.—Water temperature profiles at 0.1, 0.25, 0.5, and 1.0 m depth in San Felipe Lake in 2005. Missing data are due to temperature logger failure: a) April 2005 to June 2005; b) July 2005 to September 2005; and c) October 2005 to December 2005.

FIGURE 17.—Water temperature profiles at 0.1, 0.25, 0.5, and 1.0 m depths in San Felipe Lake in 2006. Missing data are due to logger failure: a) January 2006 to March 2006; b) April 2006 to June 2006; and c) July 2006 to September 2006.

FIGURE 18.—Pacheco Creek inflow water temperatures, Miller Canal outflow water temperatures, and air temperatures in 2005. Missing data are due to logger failure: a) April 2005 to June 2005; b) July 2005 to September 2005; and c) October 2005 to December 2005.

FIGURE 19.—Pacheco Creek inflow water temperatures, Miller Canal outflow water temperatures, and air temperatures in 2006. Missing data are due to logger failure: a) January 2006 to March 2006; b) April 2006 to June 2006; and c) July 2006 to September 2006.

FIGURE 20.—Mid-lake temperature and dissolved oxygen profiles on 31 May 2005. The weather was sunny and calm during the morning, breezy during early afternoon, and windy during late afternoon.

FIGURE 21.—Mid-lake temperature and dissolved oxygen profiles on 17 June 2005. The weather was overcast with light showers during the morning and cleared with a light breeze during the early afternoon.

FIGURE 22.—Mid-lake temperature and dissolved oxygen profiles on 30 June 2005. The weather was sunny, calm, and warm during the morning, breezy during early afternoon, and windy during late afternoon.

FIGURE 23.—Mid-lake temperature and dissolved oxygen profiles on 23 July 2005. The weather was sunny and calm during the morning and windy in the afternoon.

FIGURE 24.—Mid-lake temperature and dissolved oxygen profiles on 27 July 2005. The weather was foggy and calm during the early morning and sunny, calm, and warm during the late morning.

FIGURE 25.—Mid-lake temperature and dissolved oxygen profiles on 18 August 2005. The weather was foggy with a light breeze during the morning and sunny and windy in the afternoon.

FIGURE 26.—Mid-lake temperature and dissolved oxygen profiles on 1 October 2005. The weather was partly sunny with a light breeze in the morning, and sunny and windy in the afternoon.

FIGURE 27.—Mid-lake temperature and dissolved oxygen profiles on 20 October 2005.

FIGURE 28.—Mid-lake temperature and dissolved oxygen profiles on 12 November 2005.

FIGURE 29.—Mid-lake temperature and dissolved oxygen profiles on 29 December 2005.

FIGURE 30.—Mid-lake temperature and dissolved oxygen profiles on 16 February 2006.

FIGURE 31.—Mid-lake temperature and dissolved oxygen profiles on 4 March 2006.

FIGURE 32.—Mid-lake temperature and dissolved oxygen profiles on 7 April 2006.

FIGURE 33.—Mid-lake temperature and dissolved oxygen profiles on 5 May 2006. The weather was overcast with a light breeze in the morning and early afternoon.

FIGURE 34.—Mid-lake temperature and dissolved oxygen profiles on 29 May 2006. The weather was sunny and warm with a light breeze in the late morning and early afternoon.

FIGURE 35.—Mid-lake temperature and dissolved oxygen profiles on 14 June 2006. The weather was sunny and warm with a light breeze in the afternoon.

FIGURE 36.—Mid-lake temperature and dissolved oxygen profiles on 23 June 2006. The weather was sunny and hot with only a very light breeze in the late morning and early afternoon.

FIGURE 37.—Mid-lake temperature and dissolved oxygen profiles on 12 July 2006. The weather was sunny and warm with a light breeze in the late morning and early afternoon.

FIGURE 38.—Mid-lake temperature and dissolved oxygen profiles on 8 August 2006.

FIGURE 39.—Mid-lake temperature and dissolved oxygen profiles on 3 November 2006.

FIGURE 40.—Monthly mean wind speed (miles per hour [mph]) for the 2005 and 2006 water years (WY) at the California Irrigation Management System San Benito Station #126.

FIGURE 41.—Mean hourly wind speed (miles per hour [mph]) from October 2004 through November 2006 at the California Irrigation Management System San Benito Station #126.

FIGURE 42.—Zooplankton biomass index (surface sampling) in San Felipe Lake in 2005 and 2006.

FIGURE 43.—Zooplankton density index (surface sampling) for different zooplankton in San Felipe Lake in 2005 and 2006.

FIGURE 44.—Surface versus bottom zooplankton biomass index in San Felipe Lake in 2005 and 2006.

FIGURE 45.—Macroinvertebrate relative percent abundance during five sampling events in 2005 and 2006: a) Benthic (Ekman grab sampler) at mid-lake buoy (Site 1); b) Epibenthic (D-frame net) along shoreline with no vegetation; c) Epibenthic (D-frame net) along shoreline with vegetation; and d) Benthic and epibenthic (kick-sample with D-frame net) at the Pacheco Creek confluence.

FIGURE 46.—Seasonal benthic macroinvertebrate abundance using an Ekman grab sampler at the mid-lake buoy (Site 1) in 2005 and 2006: a) Chironomidae and b) Oligochaeta.

FIGURE 47.—Seasonal epibenthic macroinvertebrate abundance using a D-frame net near the shoreline with no vegetation in 2005 and 2006.

FIGURE 48.—Seasonal epibenthic macroinvertebrate abundance using a D-frame net near the shoreline with vegetation in 2005 and 2006: a) *Neomysis* and b) *Chironomidae*.

FIGURE 49.—Seasonal benthic and epibenthic macroinvertebrate abundance by kick-sampling with D-frame net at the Pacheco Creek confluence in 2005 and 2006: a) Ephemeroptera; b) Corophiidae; and c) Chironomidae.

FIGURE 50.—Seasonal benthic and epibenthic macroinvertebrate abundance by kick-sampling with D-frame net at the Pacheco Creek confluence in 2005 and 2006: a) *Neomysis*; b) *Oligochaeta*; and c) *Trichoptera*.

FIGURE 51.—Total gill net catch of fish in San Felipe Lake from December 2004 to November 2006.

FIGURE 52.—Hitch standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006. Dotted line indicates back-calculated growth at end of first growing season based on scale analysis (80 mm).

FIGURE 53.—Percent volume of food items in fish from San Felipe Lake in 2005 and 2006.

FIGURE 54.—Percent frequencies of food items in hitch from San Felipe Lake in 2005 and 2006.

FIGURE 55.—Sacramento sucker standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006. Dotted line indicates back-calculated growth at end of first growing season based on scale analysis (115 mm).

FIGURE 56.—Percent frequencies of food items in Sacramento suckers from San Felipe Lake in 2005 and 2006.

FIGURE 57.—Sacramento blackfish standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006. Dotted line indicates back-calculated growth at end of first growing season based on scale analysis (130 mm).

FIGURE 58.—Percent frequencies of food items in Sacramento blackfish from San Felipe Lake in 2005 and 2006.

FIGURE 59.—Sacramento pikeminnow standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006. Dotted line indicates back-calculated growth at end of first growing season based on scale analysis (85 mm).

FIGURE 60.—Percent frequencies of food items in Sacramento pikeminnow from San Felipe Lake in 2005.

FIGURE 61.—Percent frequencies of food items in prickly sculpin from San Felipe Lake in 2005 and 2006.

FIGURE 62.—Common carp standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006. Dotted line indicates back-calculated growth at end of first growing season based on scale analysis (150 mm).

FIGURE 63.—Percent frequencies of food items in common carp from San Felipe Lake in 2005 and 2006.

FIGURE 64.—Brown bullhead standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006.

FIGURE 65.—Percent frequencies of food items in brown bullhead from San Felipe Lake in 2005 and 2006.

FIGURE 66.—Threadfin shad standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006.

FIGURE 67.—Percent frequencies of food items in threadfin shad from San Felipe Lake in 2005 and 2006.

FIGURE 68.—Goldfish standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006; b) August 2005 and October 2005; and c) November 2005 and November 2006.

FIGURE 69.—Percent frequencies of food items in goldfish from San Felipe Lake in 2005 and 2006.

FIGURE 70.—Bluegill standard lengths (mm) at San Felipe Lake in 2005 and 2006.

FIGURE 71.—Percent frequencies of food items in bluegill from San Felipe Lake in 2005 and 2006.

FIGURE 72.—Largemouth bass standard lengths (mm) at San Felipe Lake in 2005 and 2006: a) June 2005 and June 2006 and b) August 2005 and October 2005.

FIGURE 73.—Percent frequencies of food items in largemouth bass from San Felipe Lake in 2005 and 2006.

FIGURE 74.—Percent frequencies of food items in inland silverside from San Felipe Lake in 2005 and 2006.

FIGURE 75.—Percent frequencies of food items in fathead minnow from San Felipe Lake in 2005 and 2006.

Tables

TABLE 1.—Flows for San Felipe Lake tributaries, Tequisquita Slough and Pacheco Creek, and Pacheco Reservoir estimated mean flow releases in 2005 and 2006. Estimates were based on reservoir capacity data from the Santa Clara Valley Water District ALERT system. The differences in daily reservoir storage capacity were used to calculate the daily flow release. Negative values were assumed to be zero for this analysis. Note: the values for March may have been due to spilling of Pacheco Reservoir and the values in April through June were likely the result of variation in stage levels due to wind and/or evaporation.

Tequisquita Slough Above Confluence With San Felipe Lake			Pachecho Creek Above Confluence With San Felipe Lake		Pacheco Reservoir	
Date		Flow (m ³ /s)		Date	Mean Flow Release Estimate (m3/s)	
				Mar-05	0.18	
				Apr-05	0.03	
				May-05	0.03	
17-Jun-05	0.05	not measured		Jun-05	0.06	
27-Jul-05	0.02	0.08		Jul-05	0.64	
26-Aug-05	not measured	0.20		Aug-05	0.65	
21-Sep-05	not measured	0.24		Sep-05	0.58	
20-Oct-05	not measured	0.28		Oct-05	0.52	
4-Nov-05	0.03	0.18		Nov-05	0.13	
8-Dec-05	not measured	0.22				
29-Dec-05	0.13	0.25				
24-Jan-06	0.23	0.82				
4-Mar-06	est 0.15	est 4.2		Mar-06	0.16	
				Apr-06	0.06	
				May-06	0.01	
				Jun-06	0.01	
				Jul-06	0.19	
8-Aug-06	0.05	0.06		Aug-06	0.35	
31-Aug-06	0.03	0.13		Sep-06	0.32	
				Oct-06	0.16	
				Nov-06	0.13	

TABLE 2.—Average daily water temperature data at the mid-lake continuous data logger array in 2005 and 2006

Depth	Daily Avg	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05
0.1	Mean	17.3	21.1	21.8	23.9	-	-
	Min	16.0	19.7	20.4	22.2	-	-
	Max	19.2	23.1	23.5	25.8	-	-
0.25	Mean	17.4	21.2	21.9	23.8	24.2	-
	Min	16.2	19.9	20.5	22.2	22.4	-
	Max	19.0	23.0	23.5	25.5	26.1	-
0.5	Mean	17.2	21.0	21.8	23.6	22.6	19.8
	Min	16.1	19.5	20.1	21.8	20.8	18.5
	Max	18.5	22.5	23.5	25.4	24.4	21.2
1	Mean	16.6	20.3	Water depth less than 1m			
	Min	15.2	18.6				
	Max	18.0	22.2				
Depth	Daily Avg	Oct-05	Nov-05	Dec-05	Jan-06	Feb-06	Mar-06
0.1	Mean	-	-	-	-	13.2	12.8
	Min	-	-	-	-	12.2	12.1
	Max	-	-	-	-	14.5	13.9
0.25	Mean	-	-	-	-	-	-
	Min	-	-	-	-	-	-
	Max	-	-	-	-	-	-
0.5	Mean	17.0	13.3	11.0	11.3	13.0	12.7
	Min	15.7	12.4	10.5	10.8	12.1	12.1
	Max	18.3	14.2	11.7	12.0	14.0	13.5
1	Mean	Water depth less than 1m		-	-	12.7	12.7
	Min			-	-	12.0	12.0
	Max			-	-	13.6	13.4
Depth	Daily Avg	Apr-06	May-06	Jun-06	Jul-06	Aug-06	Sep-06
0.1	Mean	15.8	20.8	22.8	25.3	22.3	20.2
	Min	14.8	19.3	21.1	23.4	20.5	18.7
	Max	17.1	22.7	24.9	27.6	24.6	22.1
0.25	Mean	-	-	-	25.5	22.3	20.2
	Min	-	-	-	23.4	20.4	18.7
	Max	-	-	-	27.9	24.6	22.0
0.5	Mean	15.6	20.5	22.6	25.0	22.1	19.9
	Min	14.7	19.0	20.3	22.4	19.9	17.9
	Max	16.8	22.3	24.9	27.7	24.6	21.7
1	Mean	15.3	19.9	Water depth less than 1m			
	Min	14.5	18.2				
	Max	16.3	21.7				

TABLE 3.—Turbidity (NTU) at mid-lake and Pacheco Creek and Tequisquita Slough above the confluences with San Felipe Lake and secchi depth measurements for mid-lake in 2005 and 2006

Date	Turbidity (NTU)		Secchi Depth (m)	
	Pacheco Creek	Tequisquita Slough	Mid-Lake	Mid-Lake
31-May-05	53	-	78	0.13
17-Jun-05	-	58	106	0.13
23-Jul-05	22	95	111	0.13
27-Jul-05	47	82	120	-
12-Aug-05	-	-	143	0.10
18-Aug-05	31	-	96	0.13
26-Aug-05	21	43	57	0.15
21-Sep-05	18	60	48	0.15
20-Oct-05	18	78	70	0.14
4-Nov-05	25	75	71	0.20
8-Dec-05	17	54	27	0.25
29-Dec-05	36	59	84	0.20
20-Jan-06	11	45	18	0.45
24-Jan-06	10	39	25	0.35
16-Feb-06	11	80	56	0.20
4-Mar-06	21	102	14	0.45
7-Apr-06	31	48	55	0.22
5-May-06	6	106	53	0.23
29-May-06	20	261	171	0.10
14-Jun-06	33	134	155	0.10
23-Jun-06	45	63	149	0.10
12-Jul-06	29	112	157	0.10
8-Aug-06	32	39	165	0.10
31-Aug-06	18	96	136	0.10
3-Nov-06	19	60	90	0.18
max	53	261	171	0.45
min	6	39	14	0.10
mean	25	82	81	0.20

TABLE 4.—Orthophosphate concentration and conductivity in Pacheco Creek, Tequisquita Slough, and mid-San Felipe Lake in 2005 and 2006

Date	Pacheco Creek		Tequisquita Inflow		Mid-Lake	
	PO4 (mg/L)	Conductivity (uS)	PO4 (mg/L)	Conductivity (uS)	PO4 (mg/L)	Conductivity (uS)
31-May-05	0.3	748	-	1,115	0.3	968
17-Jun-05	-	736	3.0	2,086	0.2	1,032
23-Jul-05	0.3	738	2.5	2,298	0.7	1,113
27-Jul-05	0.4	643	2.5	2,252	0.5	1,126
26-Aug-05	0.2	547	2.0	2,056	0.3	885
21-Sep-05	0.2	488	1.5	1,998	0.4	753
20-Oct-05	0.2	483	1.2	1,672	0.2	686
4-Nov-05	0.1	511	0.7	1,513	0.2	635
8-Dec-05	0.3	542	1.0	-	0.2	688
29-Dec-05	0.6	636	0.9	1,438	0.5	911
24-Jan-06	0.2	426	0.9	998	0.5	639
16-Feb-06	0.2	528	0.4	1,462	0.2	763
4-Mar-06	0.4	277	0.4	1,518	0.3	451
7-Apr-06	0.5	274	1.0	445	0.7	304
29-May-06	0.3	585	0.8	1,694	0.2	830
23-Jun-06	0.2	702	>3.0	1,878	0.2	1,055
12-Jul-06	0.2	710	2.0	1,898	0.0	978
8-Aug-06	0.2	668	1.0	1,834	0.1	1,020
31-Aug-06	0.2	539	0.7	1,999	0.1	-
3-Nov-06	0.1	559	0.7	1,599	0.1	840
max	0.6	748	3.0	2,298	0.7	1,126
min	0.1	274	0.4	445	0.0	304
mean	0.3	567	1.3	1,671	0.3	825

TABLE 5.—Macroinvertebrates collected in San Felipe Lake in 2005 and 2006.

Macroinvertebrates		Shoreline Vegetation	Shoreline No Vegetation	Benthic	Pacheco Confluence
Coleoptera	Elmidae				*
	Hydrophiloidea				*
Trichoptera	Hydropsychidae				*
	Leptoceridae				*
Hemiptera	Corixidae	*			*
	Notonectidae	*			
	Saldidae				*
Ephemeroptera	Baetidae				*
	Leptohyphidae				*
Odonata	Aeshnidae	*			
Diptera	Chironomidae	*	*	*	*
	Ephydriidae				*
	Simuliidae				*
	Tipulidae				*
Collembola					*
Mysidacea	<i>Neomysis</i>	*	*		*
Amphipoda	<i>Corophium</i>	*			*
	Gammaridae	*	*		*
Decapoda					*
Oligochaeta	<i>Branchiura</i>	*		*	*
Hirudinea					*
Bivalvia					*
Gastropoda	Physidae				*
	Planorbidae				*