Aquatic Pesticide Monitoring Program

Field Evaluations of Alternative Pest Control Methods in California Waters

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CHAPTER 1: ENVIRONMENTAL EFFECTS OF MECHANICAL HARVESTING IN FRESHWATER LAKES AND PONDS

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ABSTRACT

This project documents the environmental impacts of mechanical harvesting in several California freshwaters. Research was conducted at the Tahoe Keys, two percolation ponds in the Santa Clara Valley Water District, and a private lake in Petaluma. Sampling focused on harvesting impacts to water chemistry and fish mortality due to incidental removal by the harvesting machine. Dissolved oxygen, temperature, pH, conductivity, turbidity, nutrients (nitrogen and phosphorus), and chlorophyll a were compared under pre-harvest, harvest, and post-harvest conditions. Harvested sites were also compared to reference sites to separate potential effects of mechanical harvesting from baseline variation. The results showed limited effects on water chemistry and varying effects on fish mortality. Turbidity, as well as total suspended solids, increased during the harvesting operations, but dropped back to their original values within three to six days after harvesting ceased. Dissolved nitrate and nitrite, as well as total nitrogen showed a slight increase during harvesting and remained elevated for a three to six day period. Total phosphorus was the only parameter that increased continuously over the study period, although the change was not statistically significant. Fish mortality ranged from zero to over 600 dead fish per harvesting event at different sampling locations. The highest and lowest fish counts were made at two different percolation ponds in the Santa Clara Valley Water District. Primarily bluegill sunfish (*Lepomis macrochirus*), two to four centimeters in size, were removed by the harvester.

INTRODUCTION

Aquatic plant management strives to improve water flow, boat traffic, recreational opportunities, or the aesthetics of a water body. Chemical treatments, dredging, and mechanical harvesting are management tools frequently used to eradicate or reduce plant growth (North American Lake Management Society, 2001). Since 2001, the application of registered aquatic pesticides to water bodies within the States covered by the U.S. Ninth Circuit Federal Court, Constitute a pollutant discharge into waters of the U.S. requires a National Pollution Discharge Elimination System Permit.

As a result pesticide applications have become more expensive and difficult in recent years and mechanical harvesting may be a more cost-effective alternative for many water managers to control aquatic plants. Just like other control methods, harvesting causes environmental impacts and has effectiveness limitations (Madsen 2002).

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Mechanical harvesting is conducted using large machines, which cut and collect aquatic plants. The upper portions of the plants are removed while leaving the lower portion intact. The cut portions of the plants are collected by the harvester and then typically transferred to an upland disposal site. Studies on potential water quality impacts of harvesting have been conducted in the past (e.g., Carpenter and Gasith, 1978; Alam e*t al.*, 1996; Carpenter and Adams, 1976, 1978). However, effects of routine harvesting operations to maintain California waters have not been well represented in the literature. In this study, the environmental impacts of mechanical harvesting on water chemistry and different fish populations in freshwaters were studied at four lakes throughout Northern California.

The objectives of this study were to determine the effects of mechanical harvesting on water quality and fish mortality in different environmental conditions and plant management scenarios. Two components were evaluated:

- Immediate effects on water chemistry after harvesting operations. Nutrient concentrations and other conventional water quality parameters were measured to show potential impacts of mechanical harvesting to the water body.
- Quantification of fish removal by the harvesters. The removed plant material was screened for fish on shore, where fish species were identified, counted, and measured.

SITE DESCRIPTIONS

All sampling sites were located in hard water, mesotrophic water systems. The water bodies were located near San Jose (Santa Clara County), Petaluma (Sonoma County), and South Lake Tahoe (El Dorado County). Except for the Tahoe site, the climate of all sampling locations follows the pattern of coastal California, with winter rainfall and summer dry periods.

Santa Clara Valley Sites

Two harvested sites and one reference site (not harvested) were percolation ponds for groundwater recharge in the Santa Clara Valley. Temperatures in the Santa Clara Valley vary from an average of 10° C in January to an average of 21°C in July. San Jose has an average of more than 300 sunny days per year and an average rainfall of 14.4 inches.

For all Santa Clara Valley sites, water was pumped from a nearby reservoir into the ponds in order to sustain the groundwater supply through these recharge facilities. The pumps caused a flow through the system of several connected ponds. Since the percolation ponds form a contiguous series they were treated as one sampling location. The ponds were harvested multiple times during the summer.

- Sunnyoaks Ponds: Sunnyoaks ponds consist of three connected ponds each 2,000 – 2,800m2 with an average depth of 1.5-2m. Plants collected before harvesting included Chladophora spp., a common filamentous green algae, and Chara spp. or muskgrass.
- Kooser Ponds: Kooser ponds include four ponds, each about 1,200m2 in size. Similar to the Sunnyoaks ponds, the Kooser groundwater recharge ponds are all connected. Since this site was not harvested during the study period, it was used as a reference site. Plants present included Chara spp., Zannechellia spp. (Horned pondweed), and Southern naiad, all native species.
- Oka Ponds: The Oka site exists of four ponds, of which three were treated with Aquashade®. Aquashade® is a blend of blue and yellow dyes specifically designed to screen or shade portions of the sunlight spectrum required by underwater aquatic plant and algae growth. Pond #4 was not treated with Aquashade® and therefore harvested multiple times during the growing season. It is approximately 10,500m2 in size and has an average depth of 1.5-2m. Plants present included Chara spp., Zannechelli spp., Potamogeton crispus (Curlyleaf pondweed), Myriophyllum spicatum (Eurasian watermilfoil), Azolla filiculoides (Pacific mosquitofern), and near shore Ludwigia spp. (Waterprimrose).

Wetmore Lake (Petaluma)

This privately owned lake in Petaluma is about 9,000 m^2 (about 2 acres) and has an average depth of 2.5 meters. This lake was first harvested in September 2003 by Aquatic Environments Inc., and since the harvesting happened later during the growing season, it was the only treatment during the year. The lake surface was mostly covered with *Chladophora spp*.; the bottom was overgrown with *Ceratophyllum demersum* (coontail), *Ranunculus aquatilis* (white waterbuttercup), and *Potamogeton nodosus* (American pondweed), all of which are native species. Vegetation was extremely dense at this lake prior to harvesting. In Petaluma the annual rainfall averages 24 inches and falls primarily between October and April. The average annual temperature is 14°C. July is the warmest month, on average 19°C, and January is the coldest with 8°C.

Tahoe Keys (South Lake Tahoe)

The Tahoe Keys Resort is a private marina community that was developed in 1959. The Upper Truckee River Watershed, adjacent to Lake Tahoe, was dredged for navigable waterways and residential land use. The Keys are at an elevation of 6,300 feet and have an average depth of 2-3m. A series of pumps have been installed at the Tahoe Keys for water circulation in attempt to control algae growth. Harvesting operations took place five days a week during the growing season from May through October. The sampled area included two lagoons, Spinnaker Cove and Main Lagoon. Although both lagoons were part of the Tahoe Keys Resort, Spinnaker Cove and Main Lagoon were treated as different sampling locations due to different development of the East and the West shore of the keys and different plant communities.

- *Spinnaker Cove:* This lagoon covers an area of about 30,000m^2. Coontail and Brazilian elodea (*Egeria densa*) are the most common aquatic plants at Spinnaker Cove.
- *Main Lagoon:* The Main Lagoon is about 6,500m^2 in size. Eurasian watermilfoil was the most abundant plant species, while coontail was present in smaller numbers.

The *Lake Tahoe Basin* has at least 307 days of sun per year. The average temperature in January is -3°C and 16°C in July. Average annual rainfall in the Basin is 8.3 inches and the average annual snowfall is 216 inches or 18 feet, for an annual precipitation of 30 inches.

METHODS

Harvesting Operations

The sampling was conducted from June through September. Visual estimation of the harvested area suggested that approximately 70% of macrophytes were removed in each of the studied water bodies. Harvesting operations were conducted by Aquatic Environments Inc. using the Aquamarine H4-100, which reaches a maximum depth of eight feet. The H4-100 is a small, easily maneuverable machine that works best in confined areas and small ponds. The diesel powered machine uses food grade oil as an environmentally safe alternative. Four inch, zinc plated cutting knives cut the plants and pulled them out of the water onto the harvester. The conveyor belt, on which the plant material was transported, was coated with a metal mesh with a grid size of about one centimeter. Fish smaller than 1 cm may have fallen through the mesh and thus were lost from the sample. The conveyor belt transported the plants to the back of the harvester where they were stored temporarily until the machine reached its loading capacity. Then the harvester unloaded onto a shore conveyor, which took the plant material to an upland site to dry. A day or two later, a dump truck picked up the dry plants and transported them to a final disposal site.

Photo 1. Harvester at Oka Ponds, Santa Clara Valley Water District.

Water Quality

To document potential impacts of harvesting on water quality, water parameters were monitored before, within one hour after, and five days after harvesting operations. In addition, the same parameters were measured at an untreated reference site (reference site) to separate effects of plant harvesting from effects of other factors. Water quality parameters and methods of analysis are listed in Appendices 6 and Glossary.

Samples collected for analysis of water quality parameters were taken from one meter depth by hand submerging bottles directly into the water. Water samples were collected in pre-cleaned High Density Polyethylene (HDPE) bottles. Following collection, water samples were stored on ice and shipped to the analytical laboratory on the same day. Sample analyses occurred within regulatory holding times. Laboratory analyses were conducted for total suspended solids (TSS), total phosphorus, dissolved phosphate (as ortho-phosphate), dissolved nitrate and nitrite, dissolved ammonia, biological oxygen demand (BOD), and total chlorophyll a. Laboratory analytical methods and reporting limits are listed in Table 1. Chlorophyll a samples were taken from grab samples and filtered through 0.8 µm pore sized filters with a hand pump. A WTW Multi 340i Sensor was used to measure water parameters in the field. Conventional water quality parameters measured by the Multi 340i included dissolved oxygen, electrical conductivity (EC), pH, temperature, redox potential, and turbidity. Turbidity was measured with a turbidimeter (Hach, Model 2100P).

Fish Sampling

Four replicate samples of harvested vegetation were analyzed per site for fish counts and fish identification. Each vegetation sample was 0.25 cubic meter (250 liters). Harvested vegetation was pulled from the harvester into sampling containers on shore four separate times during the harvesting operation. Sampling containers were covered to preserve the sample and to keep birds and wasps from feeding on fish. The harvested material was spread onto a tarp and hand sorted by shaking the vegetation over a second tarp. All fish and amphibians were collected for identification to species. Fish were measured for total length and divided into 2cm size classes. Fish that could not be identified were preserved in ethanol and later identified by a fish specialist.

Photo 2: Fish measurements.

Photo 3: The weed disposal site at the Tahoe Keys Resort.

Quality Assurance and Data Analysis

For QA purposes, one field blank and one duplicate sample were taken for each sampling location. All blank target analyte concentrations were below the method detections limits except for dissolved nitrate and nitrite. The relative percent difference (RPD) of all duplicate samples was within 15%, except for one chlorophyll a sample, which was qualified (Appendix 1).

Statistical results were based on parametric t-tests. Because there were missing observations for some of the reference sites, repeated measures ANOVA was not appropriate with this data set. To evaluate for significant change in the experimental sites, paired t-tests were conducted to test for changes in environmental parameters within the sites between each of the three date combinations (pre, immediate post, five day post harvesting). Reference sites were evaluated graphically to determine whether they exhibited similar trends to the treatment sites. For all statistical tests and calculations, values below the reporting limit were replaced with values ½ of the method detection limit.

Table 1. Analytical methods and reporting limits.

	Ammonia	**BOD**	**Ortho-Phosphate**	**Nitrate + Nitrite**	**TSS**	**Total Phosphorus**	**TKN**	**Chlorophyll a**
Unit	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/m^3
Reporting Limit	0.10	2.0	0.01	0.01	1.0	0.05	0.25	2.0
Method *	EPA 350.3	SM5210	QC 10115011M	QC 10107041B	SM 2540C	QC 10115011D	QC 10107062E	SM 10200H2b

* All methods described in Appendix 6C. TKN = total Kjeldahl nitrogen, TSS = total suspended solids

RESULTS

Water Chemistry

An evaluation of pre-harvesting conditions at all four lakes revealed different site characteristics. The following table provides an overview of the mean pre-harvesting concentrations for selective parameters.

In general, all tested water bodies were hard water, mesotrophic to eutrophic lakes with low suspended material. Dissolved oxygen varied substantially among lakes from below 3 mg/L (Wetmore Lake) to above 11 mg/L (Oka reference site) (Table 2).

The impacts of harvesting operations were assessed by evaluating pre-harvesting concentrations, samples taken during the harvesting operation, and the post-harvesting samples, including the standard error (Table 3).

Table 2. Pre-harvesting characterization of water bodies. Data shown are mean concentrations ± standard deviations

Site	**H/R**	**pH**	**EC**	**DO**	**Turbidity**	**BOD**	**ortho-P**	**Nitrate + Nitrite**	**TSS**	**Total P**	**TKN**
Unit			µS/cm	mg/L	NTU	Mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Oka	H	7.85 ± 0.14	372 ± 1.15	6.59 ± 0.78	2.75 ± 0.35	1.8 ± 1.39	0.0238 ± 0.001	0.07 ± 0.0014	8.3 ± 12.44	0.025 ± 0	0.125 ± 0
Oka Reference	R	8.68	299	11.57	2.13	1.0	0.0186	0.08	1.6	0.025	0.125
Sunnyoaks	H	9.17 ± 0.12	259 ± 6.35	9.57 ± 0.25	0.97 ± 0.20	1.0 ± 0	0.0137 ± 0.003	0.04 ± 0.001	0.5 ± 0	0.025 ± 0	NA
Sunnyoaks Reference	R	8.85	271	9.50	2.72	1.0	0.0300	0.07	1.2	0.025	NA
Tahoe Lagoon	H	8.60 ± 0.15	123 ± 6.36	8.59 ± 0.08	3.56 ± 0.45	1.0 ± 0	0.0050 ± 0	0.05 ± 0.015	1.7 ± 0.14	0.025 ± 0	0.310 ± 0.06
Lagoon Reference	R	8.12	95	7.94	0.44	1.0	0.0050	0.04	0.5	0.025	0.125
Tahoe Spinnaker	H	9.36 ± 0.59	121 ± 4.24	10.42 ± 5.01	2.55 ± 1.40	1.0 ± 0	0.0050 ± 0	0.04 ± 0	1.1 ± 0.78	0.025 ± 0	0.305 ± 0.06
Spinnaker Reference	R	8.12	95	7.94	0.44	1.0	0.0050	0.04	0.5	0.025	0.125
Wetmore Lake	H	7.82 ± 0.12	261 ± 0.71	2.98 ± 0.66	2.02 ± 0.16	2.1 ± 1.56	0.0334 ± 0.0003	0.06 ± 0.01	5.4 ± 5.59	0.092 ± 0	1.630 ± 0

Note: H = harvested site, R = reference site, EC = electrical conductivity, DO = dissolved oxygen, ortho-P = ortho-phosphate, TP = total phosphorus, TSS = total suspended solids; TKN = total Kjeldahl nitrogen, BOD = biological oxygen demand

Table 3. Selected attributes over sampling dates.

Parameter	**Units**	**Harvest/ Reference**	**Mean SE**	**Mean SE**	**Mean SE**
			Pre	During	Post
Turbidity	NTU	H	2.37 ± 0.43	4.09 ± 0.45	3.39 ± 1.25
Turbidity	NTU	R	1.76 ± 0.68	2.48 ± 0.29	1.3 ± 0.63
pH		H	8.56 ± 0.32	8.50 ± 0.32	8.67 ± 0.34
pH		R	8.55 ± 0.22	8.93 ± 0.02	8.49 ± 0.37
EC	µS	H	227 ± 48	226 ± 47	228 ± 49
EC	µS	R	222 ± 64	288 ± 18	176 ± 66
DO	mg/L	H	7.63 ± 1.32	7.36 ± 1.11	8.27 ± 1.62
DO	mg/L	R	9.67 ± 1.05	10.83 ± 0.07	8.16 ± 0.24
ortho-P	mg/L	H	0.016 ± 0.006	0.0152 ± 0.005	0.021 ± 0.009
ortho-P	mg/L	R	0.018 ± 0.007	0.023 ± 0.008	0.018 ± 0.010
Total P	mg/L	H	0.038 ± 0.013	0.051 ± 0.020	0.093 ± 0.04
Total P	mg/L	R	0.025 ± 0	0.025 ± 0	0.049 ± 0.020
Nitrate + Nitrite	mg/L	H	0.053 ± 0.005	0.054 ± 0.007	0.056 ± 0.004
Nitrate + Nitrite	mg/L	R	0.064 ± 0.012	0.075 ± 0.0120	0.059 ± 0.009
TKN	mg/L	H	0.593 ± 0.311	0.668 ± 0.328	0.722 ± 0.361
TKN	mg/L	R	0.125 ± 0.311	NA	NA
BOD	mg/L	H	1.38 ± 0.24	1.29 ± 0.29	1.17 ± 0.17
BOD	mg/L	R	1 ± 0	1 ± 0	1 ± 0
TSS	mg/L	H	3.387 ± 1.497	4.3 ± 0.99	3.04 ± 2.12
TSS	mg/L	R	1.1 ± 0.32	1.5 ± 0.08	0.5 ± 0

Note: Mean concentrations from all sampling sites pooled.

Many parameters, including pH, electrical conductivity, dissolved oxygen, BOD, and nitrate + nitrite, did not show significant differences when lakes were evaluated across the three time points (Table 3). Some parameters exhibited high variance, which obscured differences in mean concentrations. For example, the coefficient of variation ranged from 38 to 48% for EC, DO, and BOD.

A t-test on the experimental versus the reference lakes over time for each parameter showed a significant increase in turbidity ($p < 0.001$; not corrected for multiple comparisons). The turbidity values were almost twice as high immediately after the harvesting operation compared to the pre-samples (Figure 1; Table 3). Turbidity at all sites, except for Wetmore Lake, decreased to pre-treatment levels within three to five days after the treatment.

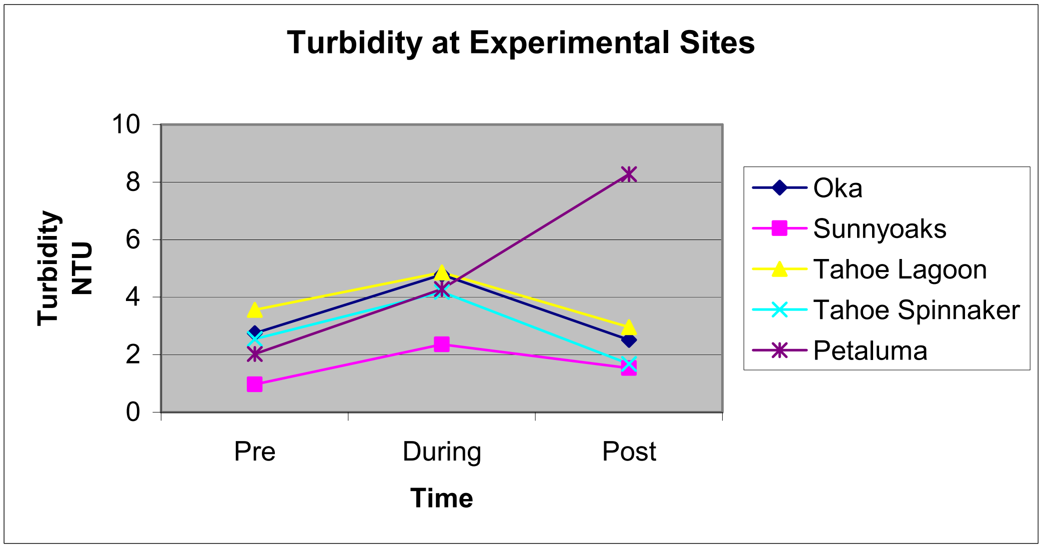

Figure 1: Turbidity change before, during, and 3-6 days after the harvesting operation.

Because of missing observations at some reference sites the data reported showed a limited picture of water chemistry changes at untreated sites. However turbidity changes in reference sites were weaker than in experimental sites with means ± standard deviation overlapping between sampling periods (Table 3). Two reference sites showed minimal changes in turbidity between the first and the second sampling event, and one site indicated a drop in turbidity for the third sampling date.

Regarding ortho-phosphate and total phosphorus, the reference sites again showed minimal changes in concentration between the different sampling events with the exception of the Lake Tahoe reference site. At the Lake Tahoe reference site, an increase in total phosphorus concentration occured over the sampling period of five days. The total phosphorus concentration changed from undetected to 0.073mg/L at this site.

Ortho-phosphate and total phosphorus increased post harvesting, although the change was not statistically significant ($0.1 < p < 0.2$) (Table 2; Figures 2 and 3). Furthermore, a slight increase in total Kjeldahl nitrogen (TKN) could be seen. TKN was added to the list of sampled parameters later during the sampling period when the first results showed numerous values below detection limit for total ammonia, as well as nitrate and nitrite.

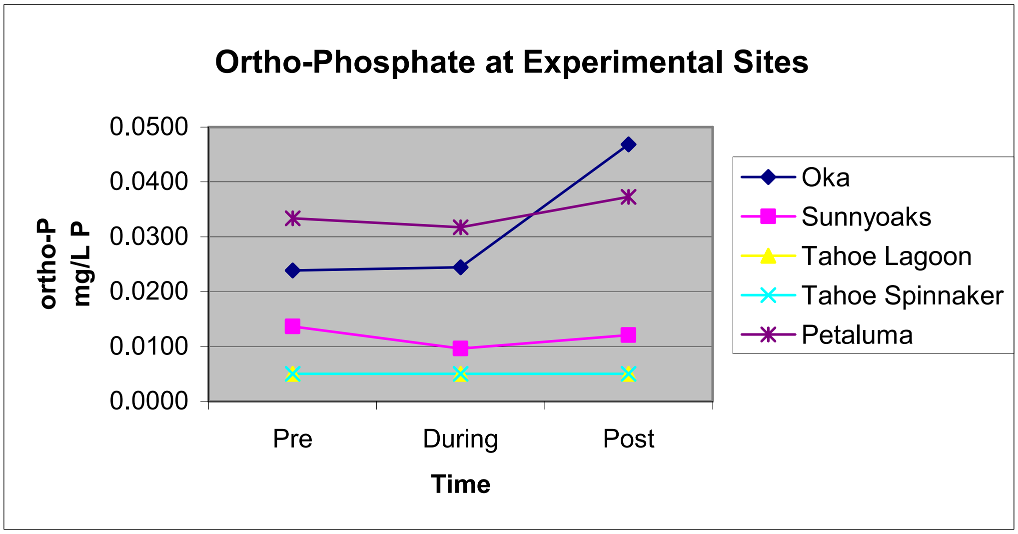

Figure 2: Ortho-Phosphate concentration before, during, and 3-6 days after harvesting operation.

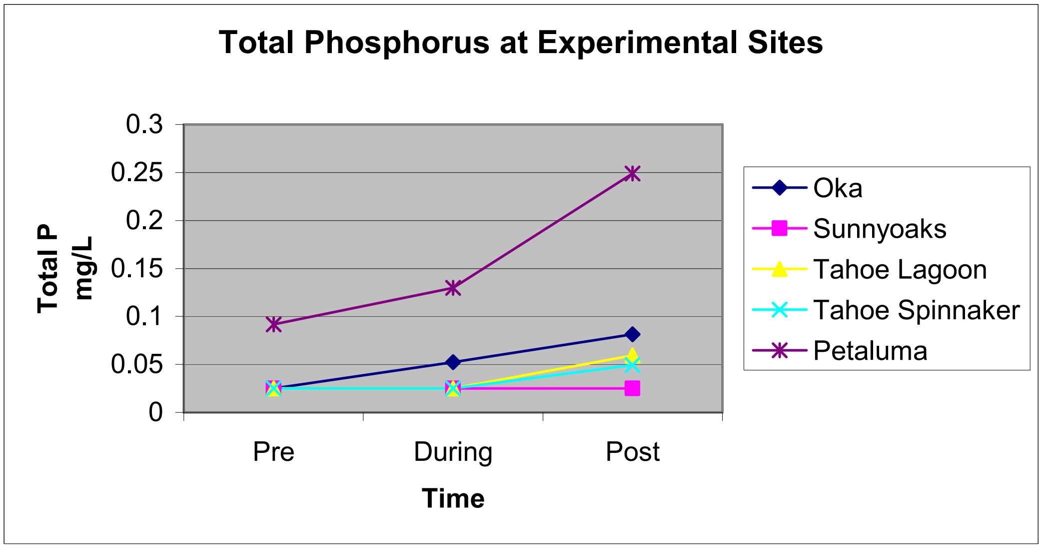

Figure 3: Change in total phosphorus concentration before, during, and 3-6 days after harvesting operation.

An increase in total phosphorus over the sampling period was observable in Figure 3, but was not statistically significant ($0.1 < p < 0.2$) (Table 4). Total phosphorus mean concentrations went from 0.038+/-0.013mg/L prior to harvesting to 0.052+/-0.020 mg/L immediately after the harvesting event and to 0.093+/- 0.040 mg/L five days after the treatment at the experimental sites.

Table 4. Results of pair wise comparisons among dates for harvested water bodies using paired t-tests.

Parameter	**Change Date2 to Date1**		**Change Date3 to Date1**		**Change Date3 to Date2**	
Turbidity	< 0.001	+	0.4<t<0.5	NS	0.5<t<0.9	NS
DO	0.4<t<0.5	NS	0.2<t<0.4	NS	0.2<t<0.4	NS
ortho-P	0.2<t<0.4	NS	0.2<t<0.4	NS	0.2<t<0.4	NS
Nitrate + Nitrite	0.5<t<0.9	NS	0.4<t<0.5	NS	0.5<t<0.9	NS
EC	0.5<t<0.9	NS	0.5<t<0.9	NS	0.4<t<0.5	NS
pH	0.5<t<0.9	NS	0.1<t<0.2	NS	0.2<t<0.4	NS
Total P	0.1<t<0.2	NS	0.1<t<0.2	NS	0.1<t<0.2	NS
TSS	0.4<t<0.5	NS	0.5<t<0.9	NS	0.4<t<0.5	NS
TKN	0.1<t<0.2	NS	0.1<t<0.2	NS	0.2<t<0.4	NS
BOD	0.5<t<0.9	NS	0.2<t<0.4	NS	0.5<t<0.9	NS

NS = not significant

Fish, Crustacean and Amphibian Mortality

A total number of 748 dead fish from all sites were identified in a total volume of approximately 10.5 m^3 (10,500 liters) of wet harvested material. A volume of about 2 m^3 was collected from each site, except for Oka ponds where 2.5 m^3 of wet plant material were screened. The majority of fish removed with the harvested plant material were juvenile bluegill sunfish (*Lepomis macrochirus*) with a size of two to four centimeters (Figure 5). A total of 699 bluegill sunfish were removed at all five locations.

Eighteen juvenile smallmouth bass (*Micropterus dolmieui*) were killed, predominantly in the four to six centimeter size class. Inland silversides (*Manidia beryllina)* accounted for 17 dead fish, most of them two to four centimeters long, and 14 prickly sculpins (*Cottus aleuticus*) were found in the harvested plants, 10 of them two to four centimeters long. Bluegill sunfish comprised 93.4 % of the total fish removed. Smallmouth bass, Inland silversides, and prickly sculpins followed with 2.4, 2.3, and 1.9 %, respectively.

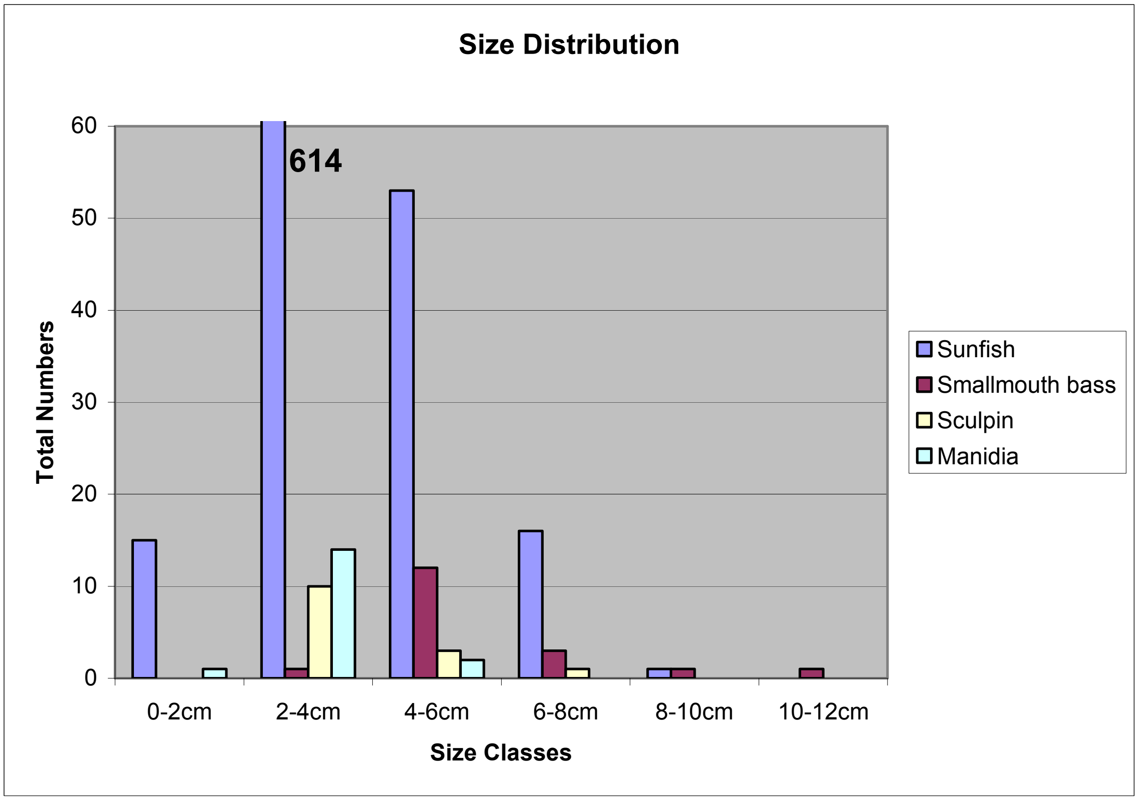

Figure 5. Species and size distribution of removed fish.

Fish mortality was seen at four out of five locations. The location with the highest fish mortality was Oka ponds with a total of 570 removed fish. The Wetmore Lake accounted for 116 dead fish, and both Tahoe locations had less than 10 fish each removed with the plants.

At Sunnyoaks ponds in the Santa Clara Valley no fish were found in the harvested plant material. Concerns about the absence of fish at the Sunnyoaks site initiated an additional one-time sample with a beach seine. Fish were captured at Sunnyoaks ponds. Using an eight meter wide beach seine with 1/16 inch mesh netting, sixteen bluegill sunfish and three prickly sculpins were caught after sampling an area of about 40 m^2.

In addition to the fish, 19 crayfish (decapoda) were found at Spinnaker Cove (Tahoe Keys Resort), 205 tadpoles (American bullfrog - *Rana catesbeiana*) at Oka ponds, and 16 Foothill Yellow-legged frogs (*Rana boylii*) at the Sunnyoaks sites were also removed with the plant material. Since amphibian and crustacean mortality was not an initial goal of this study, this data should be considered qualitative in nature.

DISCUSSION

Water Quality Impacts

The study results suggested that harvesting of selected areas is unlikely to have short-term significant impacts on water quality. Few observable changes in water chemistry were seen at experimental sites that were routinely harvested. The absence of strong patterns may be related to the short time frame and limited data set of this study. Nevertheless, results of a different study on immediate effects on littoral water chemistry after harvesting of small areas also indicate that significant impacts on water quality are very unlikely (Carpenter and Gasith, 1978). Alam et al. (1996) document more significant impacts on water quality parameters at Lake Istokpoga, Florida, where the plant material was so thick that two cuttings had to be made with a cookie cutter before the harvester could function efficiently. During the 25 days of harvesting, minor but statistically detectable increases in DO occurred at harvested sites, as well as significant increases for total phosphorus, total nitrogen, and chlorophyll a (Alam *et al*., 1996). An extended time frame and more substantial harvesting in the Alam study might be the reason for more significant chemistry changes than observed at the five Northern California sites.

Another reason for the lack of distinct patterns in this study could be a difference in experimental water body characteristics and the variety of plants that were harvested. The broad spectrum of plant species included free floating plants, like mosquitofern, coontail, and chladophora, as well as rooted plants that bring up nutrients from the sediment, like pondweeds and watermilfoil.

In this study, a dramatic increase in total phosphorus at the Wetmore Lake site in Petaluma might be related to the highly eutrophic state and infrequent harvesting of this lake. The distinct increase of turbidity five days after the harvesting operation at the same site was most likely related to the increase in total phosphorus. These results suggest that individual harvesting events could more significantly affect water quality where harvesting is less frequent and vegetation in more dense.

Multiple nutrient pools are available for aquatic plants in a water body. This study focused on the water column and short-term changes of nutrients within the water column. Overall nutrient removal from a lake can be evaluated using a mass balance approach (Carpenter and Adams, 1976). When most nutrients are obtained by the shoots from the sediment, macrophyte harvesting in late August can remove nitrogen and phosphorus approximately at 16 and 37 %, respectively from a lake (Carpenter and Adams, 1976). To evaluate overall nutrient removal by harvesting vegetation, whole shoots are sampled, dried, and their tissue analyzed. Carpenter and Adams (1978) also suggested in a later study that thorough harvesting of selected areas removes phosphorus and a wide range of nutrients and metals (including Ca, N, K, Na, Mg, Fe, Mn, Al, Ba, Sr, Cu, B, Zn, and Cr) from the water body.

Incidental Aquatic Organism Removal

A total volume of harvested plant material for all five sampling locations during the sampling events was estimated at 62 m^3 (62,000 L). That means that the total volume of randomly sorted plant material (2 m^3 per sampling location) altogether represented about 17% of the potential amount of fish that were removed from the water by the harvester. If a linear extrapolation is made, the harvesting machines could potentially have removed 4,413 fish from these five locations. Further calculations would indicate that from the total harvested area of approximately 60,000 m^2 for all five sampling locations, a removal rate of 0.074 fish per m^2 (740 fish/ha) of harvested area or 71.2 fish per m^3 (1,000 L) of removed plant material is seen. However, it has to be considered that the plant material that was pulled off the harvester was by the machine during the harvesting operation. Therefore, the density of fish in sampled material is likely to be substantially higher than in the water body.

An evaluation of specialized close-cut mechanical harvesting of milfoil showed low incidental fish mortality accompanying the treatment (Unmuth *et al*., 1998). A removal rate of 36 fish/ha, primarily bluegill sunfish smaller than three centimeters, was reported (Unmuth *et al*., 1998). The close-cut mechanical harvester operates like a conventional harvester with a modified cutting bar. The knives can be lowered near the sediment surface and cut the plants very close to the ground. Conventional harvesters, like the ones used in this study, were shown to remove 2226-7420 fish/ha of plant beds dominated by Eurasian watermilfoil (Mikol, 1985). This equals 0.2226-0.742 fish per square meter. Booms (1999) reported 38.7 vertebrates per cubic meter removed from Lake Keesus, Wisconsin.

Unmuth *et al.* (1999) indicate no significant change in abundance of largemouth bass and bluegill following vegetation removal. It is suggested in this paper that survival increases and population size structure improves for both species as an effect of mechanical harvesting (Unmuth *et al.*, 1999). Changes in fish abundance for water bodies in the present study could not be determined since no previous surveys or fish counts were available. Possibly, the Oka site that exhibited comparatively high numbers of dead fish, had a much higher abundance of bluegill sunfish and smallmouth bass than the other studied water bodies.

Bettoli *et al.* (1992 and 1993) reported that open patches in a water body are used by adult centrachids to move between food patches, since macroinvertebrate prey resources, studied by Sloey *et al.* (1997), are mostly concentrated at plant bed edges. Thus, a reduction in dense vegetation should increase predator-prey interactions and improve fish growth (Bettoli *et al.,* 1992 and 1993).

The actual number of fish being trapped by the harvester is probably higher than shown in this study. Occasionally caught larger fish were easily spotted by the operator of the machine and immediately released back into the water by lowering the cutter bar. Furthermore, an effort was made to release frogs and large tadpoles from the conveyor belt. Possibly injured animals that escaped the harvester are not represented in this study. Generally, results of removed fish at the studied locations are within the range of published results of different previous studies (Mikol, 1985; Booms, 1999; Engel, 1990).

SUMMARY AND CONCLUSIONS

In this project, few water quality impacts associated with mechanical harvesting operations were indicated. For parameters with values consistently above detection limit, a slight increase in nutrients (phosphorus and nitrogen) became apparent. However, this increase did not show statistical significance. Turbidity was the only measured parameter that exhibited a significant increase ($p<0.001$) during the harvesting operation compared to the pre-samples. Within three to six days after the treatment, turbidity values decreased again and no further disturbance of the lakes were observed. The results suggested that mechanical harvesting operations in California waters had fairly limited short-term environmental impacts.

Fish mortality was observed at four out of five sampling sites. Primarily juvenile bluegill sunfish (*Lepomis macrochirus)* were caught with the harvested plant material. Only one adult fish was removed, and no endangered or sensitive species were captured. Future studies could evaluate the effects of harvesting on overall population viability or recruitment.

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CHAPTER 2: EVALUATION OF GYPSUM AND ALUM FOR BENTHIC ALGAE CONTROL IN DRINKING WATER RESERVOIRS.

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ABSTRACT

Taste and odor problems associated with algal growth in surface water bodies supplying domestic water treatment facilities are well documented (Faust and Aly, 1999). Algal growth in most surface waters is phosphorus limited (Cole, 1979). Inactivation of sediment phosphorus in lakes and reservoirs using alum, lime, or iron salts has been successful (Cooke et. al. 1993). After treatment with these chemicals, planktonic algal growth is inhibited through phosphorus limitation. Long term success is dependent on the dose rate and amount of external phosphorus loading that could maintain high water column phosphorus concentrations.

With the exception of a few studies (Robert Gisette, 2003, personal communication), evaluation of benthic algae production after alum addition has not been studied. Gypsum ($\mathrm{CaSO4 \cdot 2H_2O}$) has recently been evaluated as a means to prevent sediment phosphorus release from sediments using isolated test basins in a Finnish lake (Salonen and Varjo 1999). Gypsum is currently under evaluation for phosphorus inactivation to control planktonic algae in Lake Elsinor California (Michael Anderson, 2004, personal communication).

In this study gypsum was applied to the sediment layer in open test plots of oligotrophic Bon Tempe Reservoir in Northern California to test its effectiveness in inhibiting the growth of benthic algae. Gypsum and alum ($\mathrm{Al_2(SO4)_3 \cdot 18\ H_20}$) were evaluated in bench scale laboratory studies in order to better evaluate algal growth and taste and odor compound production.

Results in reservoir tests plots were difficult to evaluate due to a late season start (late June and early August 2003), and problems associated with assessing algal growth at the site by visual observation. No benefit was seen in treated plots over non-treated plots. Results in lab bench tests were contradictory as gypsum treatment showed decreases in benthic algae growth and soluble reactive pore water phosphorus, yet increased production of geosmin, one of two predominant taste and odor compounds produced by algae. Terrestrial grasses sprouted in the bench aquaria and supported growth of *Anabaena*, which likely confounded the expected correlation between algae growth on the sediment surface and measured geosmin concentrations in the water. Since these terrestrial grasses are not supported at Bon Tempe Reservoir, reduction of taste and odor

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compounds using gypsum for reservoir scale treatment might prove effective. At the low doses tested, alum did not reduce algae growth or geosmin production. However, the effectiveness of alum at higher, more optimized doses cannot be ruled out.

INTRODUCTION

Algal growth in domestic drinking water lakes and reservoirs is a serious problem for water suppliers in the United States and worldwide. Algae can produce taste and odor compounds such as methylisoborneol (MIB), and geosmin, which, in concentrations as low as 5 ng/l, can cause consumer complaints. Copper sulfate has been used with significant success to control algal production via copper toxicity. Recent regulatory changes in the states of California and Washington have necessitated the acquisition of permits to apply copper based algaecides to water supply reservoirs. As such, there is renewed interest in evaluating control methods other than algaecides to limit algal growth.

Alum, $(Al_2(SO4)_3)nH2O$ has been used successfully to control algae growth by inactivating phosphorus, typically the limiting nutrient in algal production Welch and Cooke, 1999). Iron salts and lime have also been used to achieve the same goal of phosphorus inactivation (Cooke et. al. 1993). Use of chemical inactivation of phosphorus in lakes and reservoirs has been predominately limited in the U.S. to the Midwest and Eastern states. There has not been a significant number of water bodies in California which been treated with alum. In 1979 a small (3,750 acre-ft) reservoir in Lafayette, California, an emergency water supply reservoir, was treated with alum. Results of the treatment are not known

Recently gypsum $(Ca_2SO4 \cdot 2H_2O)$ has been shown to successfully inactivate phosphorus within isolated test sites in Lake Enajarvi in southern Finland (Salonen and Varjo 1999). Lake Enajarvi is a shallow hypertrophic lake that releases phosphorus during periods of wind driven agitation off the bottom sediments, and also during periods of anoxia. Both phenomena enable subsequent planktonic algae growth.

While studies point to the effectiveness of chemical methods for the inactivation and removal of phosphorus from the water column, with subsequent control of planktonic algae, very few studies document the efficacy of chemical inactivation of phosphorus with the goal of assessing benthic algae growth. Alum has been tested on a limited basis in Washington State (Robert Gissette, Herrara Engineering Seattle Washington, personal communication). Gypsum has not been evaluated for this purpose.

It is probable that benthic algae derive phosphorus from the sediment layer rather than the water column. In Bon Tempe Reservoir the relatively low nutrient status found in the water column (2002 quarterly values ranged from <10 to 11 µg/l) would seem to support this theory. It was felt that both chemical precipitation of phosphorus using gypsum and the formation of a physical barrier at the sediment interface at high enough dose rates (as in Salonen and Varjo 1998), might inhibit benthic algal growth.

Bon Tempe Reservoir (owned and operated by the Marin Municipal Water District, Corte Madera California) has historically supported a benthic *Oscillitoria* population during the summer months. The *Oscillitoria* grow in the lake perimeter from the shoreline to approximately 20 feet (6 meters) of depth, and produce MIB concentrations of up to 15 ng/l, even when copper sulfate is applied. The conventional water treatment processes used at this treatment plant do not remove either MIB or geosmin.

In the last several years, low level (2-6 ng/l) geosmin has also been produced by benthic *Oscillitoria*, and algal surface area coverage of bottom sediments has increased significantly. Conventional treatment with Copper Sulfate has proven somewhat problematic. Observation of algal mass and speciation has not necessarily correlated with MIB and geosmin production, making the decision on whether to treat with copper sulfate a difficult one.

In this study gypsum was applied to field test plots in varying amounts in three different locations. In a parallel laboratory study, gypsum and alum were added to Bon Tempe Reservoir water and sediment contained in aerated beakers, and later aerated aquaria. Bench scale testing was performed because accurate field application was judged to be problematic based on lack of proper equipment and experience. Also MIB/geosmin production could not be measured in an open water system due to hydraulic movement in and out of the open tests plots, and chemical diffusion. These phenomena would make assessing the production of these taste and odor compounds in the test plots impossible. Performing treatment within beakers and aquaria would eliminate these problems.

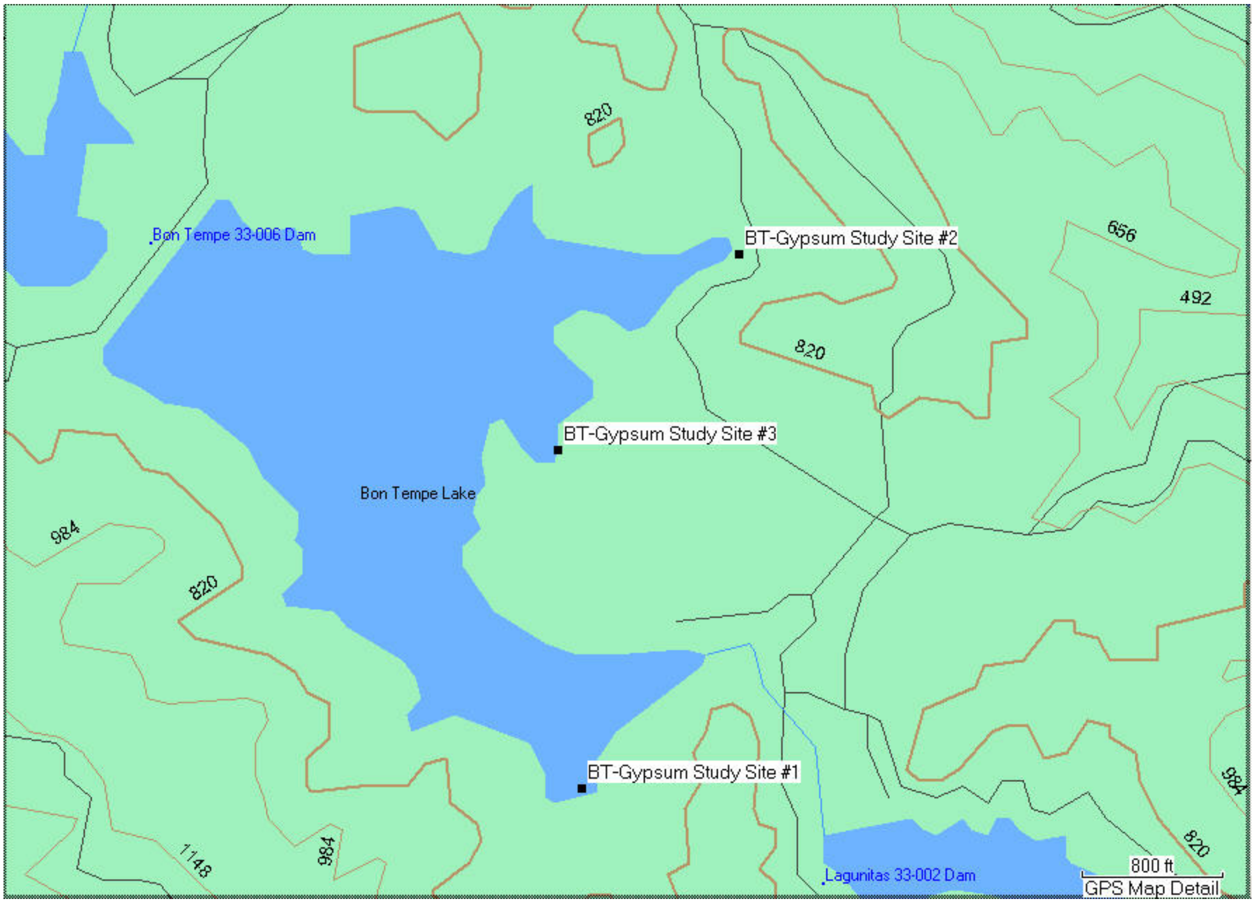
EXPERIMENTAL METHOD

Beaker Study

Setup

Sediment from three sites labeled 1,2, and 3 (see Figure 1), was collected from the upper 5cm of Bon Tempe Reservoir. The sediment from each site was mixed together in equal parts. The mixed sediment was added to fifteen 1400 ml glass beakers until the sediment reached the 300 ml line (3 cm from the base of the beakers). The beakers were placed along a north-facing window exposed to indirect sunlight. Bon Tempe Reservoir water was added to each beaker such that the liquid level reached the 1300 ml mark. One week was allowed between addition of reservoir water and treatment to enable the suspended sediment to settle.

Figure 1. Bon Tempe gypsum study sites.



Aeration was included in the experimental setup to replicate the oxic conditions at the artificially aerated Bon Tempe Reservoir. An aquarium air pump was connected to 0.5 cm inner diameter silicon tubing that was in turn connected to air stone diffusers. One diffuser was placed in each beaker and hung approximately 4 cm below the water surface. Parafilm (Menasha, WI) was placed over each beaker to reduce evaporation.

Treatments

Treatments consisted of two dose rates of alum (Acros Organics) and two dose rates of gypsum (Western Mining and Minerals) in triplicate. Triplicate control beakers were also included. Low dose alum was 2.4 mg/l (0.19 g/m^2), and high dose alum was 4.9 mg/l (0.39 g/m^2). These doses were selected based on historical use of alum with Bon Tempe water. Resultant pH was predicted to be between 6 and 7.5 after dosing, a pH range that would generate insoluble $Al(OH)_3$ the species of aluminum which inactivates phosphorus. Riding and Welch, 1998, and Kennedy and Cooke, 1983 describe methods to determine dose rates for alum treatment of lakes. All dose rates are expressed as Al. Doses for field plots and bench testing are found in Table 1. Alum dosing was performed by dissolving 10 g $Al_2(SO_4)$.18 H2O in 1L water. This solution was applied via pipette in 3ml (low) and 6 ml (high) doses.

Table 1. Doses applied in field plots, beaker, and aquaria experiments.

Low dose gypsum was 4.2 g/l (373g/m^2), and high dose gypsum was 22 g/l (900g/m2).

	mg/L	Dose (g/m2)
Test Plot:		
1	N/A	373
2	N/A	373
3	N/A	373
1A: Low	N/A	950
1A: High	N/A	1900
3A: Low	N/A	950
3A: High	N/A	1900
Beaker:		
Alum Low	2.4	0.19
Alum High	4.9	0.39
Gypsum Low	4200	373
Gypsum High	21500	1700
Aquaria:		
Alum	4	0.59
Gypsum	23333	3400

alum doses expressed as Al
Gypsum dosed expressed as $CaSO_4 . 2H_2O$

V.P. Salonen recommended the low dose as a starting point, and the high dose was simply one that would presumably result in a 0.5 cm bottom layer as a physical barrier. This was estimated first by dosing distilled water with gypsum before the study. All gypsum doses are expressed as $CaS0_{4.}2H_2O$. Gypsum was mixed to 60 ml of water to form a slurry that was then applied to each beaker. Treatments were performed in a repeating sequence of control, alum, and gypsum along the window so that the somewhat lower light penetration on the west end of the window bank would not affect the assessment of triplicates.

Water Quality Analysis

Twenty-four hours after treatment, beakers were sampled for analysis of ortho phosphate (soluble reactive phosphorus), sulfate, and pH. Two control samples were analyzed for alkalinity. Subsequent analyses included conductivity, calcium, algal counts, total phosphorus, and MIB/geosmin determination in addition to the analyses listed above. The majority of these analyses occurred four weeks after treatment Analytical methods are listed in Table 2.

Table 2. Analytical methods used in study.

Analyte	Analytical Method
PH	SM 4500H B
Conductivity	SM 2510B
Turbidity	2130B
Alkalinity	SM 2320B
Calcium	SM 3500Ca D
Phosphorus [1]	SM 4500B & SM 4500-P E
Phosphate	EPA 300.0 / SM 4500-P E
Sulfate	EPA 300.0
Taste and Odor Compounds	Solid Phase Micro Extraction/ GCMS
Algae Count	Described Below

1. See below for pore water extraction method

SM= Standard Methods for the Examination of Water and Wastewater 19th Edition 1995

Areal Count Of Algae

For the beaker and aquaria studies, algae areal count was achieved using the following procedure. A 20 cm by 20 cm glass plate was marked into 1cm grids. The plate was placed over the beaker or aquarium. Benthic algae were counted by marking each square below which algae was visible through the plate. These squares were then totaled. For the beaker study all the surface area of the beaker bottom (144 cm^2) was counted. For the aquarium study the plate was centered over the 40 cm width and spanned the 20 cm depth. Only the 400 cm^2 area was totaled to represent density for the entire aquarium.

Pore water Extraction Method For Phosphorus Analysis

Approximately 50 grams of thoroughly mixed sediment were weighed into acid washed (phosphate free) wide mouth centrifuge bottles and centrifuged at about 4000 RPM (centrifuge used in study rated at max 3100 RPM), for 30 minutes. The pore water (supernatant) was poured off or drawn off with a pipet.

Sediment Analysis

At the end of the test period, all sediment was taken from each beaker and centrifuged for analysis of pore water soluble reactive phosphorus. See Table 3 for sampling and analytical conditions.

Table 3. Sediment phosphorus results and QA data for field plots, beakers, and aquaria.

Sediment Phosphorus Results: sample date 11/3/03 extraction date 11/7/03 analysis

Test	**Old Test**			**New Test Low**		**New Test High**		**Contro**				
	1	2	3	1A	3A	1A	3A	1	2	3	1A	3A
Sediment (ug/L	<10	<10	<10	<10	16	<10	<10	NA	<10	39	27	<10
Average Phosphorus	<10			10*		<10		19				

spike* 83%
crm* 100
ccs* 115
rpd NA (RPD below MDL)

Sediment Phosphorus Results: sample date 8/20/03 extraction date 10/28 analysis

Beaker	**Alum**			**Alum**			**Gypsum**			**Gypsum**			**Contro**		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Sediment (ug/L	23	18	<10	48	19	68	127	234	55	30	88	174	31	43	112
Average Phosphorus	15*			45			139			97			62		

Sediment Phosphorus Results: sample date 11/10/03 extraction date 11/13/03 analysis

Aquari	**Alu**			**Gypsu**			**Contro**		
	1	2	3	1	2	3	1	2	3
Sediment (ug/L	28	33	27	< 10	< 10	21	59	25	82
Average Phosphorus	29			10*			55		

spike* 96%
crm* 100
ccs* 94%
rpd NA (RPD below

NOTE
Detection limit is 3ug/L in undilited samples. Diluted samples have
based on the multiple of the sample aliquot
* Average calculated by calculating < 10 ug/L values as 5 (1/2 the
** spike = matrix spike; crm = certified reference material; ccs = calibration
for standard curve
***Sediment extracted water from beakers was acidified @ 0.2 mls of 1+1
spike=102% crm=100% RPD=1.5%

Quality Assurance

Quality Assurance was documented by the use of conventional quality assurance tests. In general matrix spike (ms) additions, certified reference materials (crm), and duplicate analyses for relative percent deviation (rpd) calculations were used. Quality assurance calculations are found in the data tables presented in this report.

Statistics

Statistical significance testing of results between treatments and controls was generated using the Bonferroni method of simultaneous comparison of means at the 95% confidence interval. Simultaneous comparison (alum, gypsum, control) was used since it is more rigorous than paired testing (alum/gypsum, alum/control, gypsum/control). See Appendix 4 for detailed information.

Aquaria Study

Setup

Sediment from site 1 (see Figure 1) was collected from the upper 5 cm of Bon Tempe Reservoir in three containers. The sediment from each container was mixed together in equal parts. From the mixed sediment 1600 ml were added to the bottom of each (41x25x20cm) aquaria. To each aquaria 4 liters of Bon Tempe Reservoir water was added using a ceramic plate on the surface of the sediment to distribute the pouring energy and lessen sediment disturbance. Twenty-four hours later 6 liters of deionized water and 2 liters of Bon Tempe Reservoir water were added. Staggered additions of Bon Tempe Reservoir and D.I. water were made due to difficulties in attempting to duplicate reservoir water quality (specifically phosphorus, pH, and alkalinity) in the aquaria/sediment systems. An aeration system similar to the beaker study setup was installed immediately after the addition of water. As in the beaker study, aquaria were arranged along the windows so that triplicate treatments or controls were able to eliminate the variable of unequal natural light exposure. The aquaria were set up in a line oriented from west to east and parallel to exterior windows in the order C1 (Control), A1 (Alum), G1 (Gypsum), C2, A2, G2, C3, A3, G3, where 1, 2, and 3 indicate replicates.

Treatments

Aquaria were treated three days after the addition of water to the sediment. Treatments consisted of one dose of alum (Acros Organics), and one dose of gypsum (Western Mining and Minerals). As noted in the Setup section, both treatments were performed in triplicate. Triplicate control aquaria were also included. The Alum dose was 4 mg/l expressed as Al. The Gypsum dose was 280 g/aquaria or 3400 g/m^2 and was chosen to result in a layer of gypsum at the sediment water interface of 1cm.

Alum dosing was performed by dissolving 10 g $AL_2(SO_4)\cdot 18\ H2O$ in 1l water. Seventy ml of this solution was applied via pipette to the aquaria. Gypsum dosing was performed by slurrying 140 g of gypsum with 200 ml of D.I. water and pouring into the aquaria.

Water Quality Analysis

Control, gypsum, and alum treated aquaria were sampled 24 hours before and after treatment to determine pH, conductivity, alkalinity, sulfate, calcium, and total phosphorus. This set of analyses was performed two months later near the end of the study. Total phosphorus was sampled additionally one and two weeks after treatment. Subsequent analyses also included the determination of algal surface area coverage count, and algal species, and MIB/Geosmin determination. Algal count and speciation, and MIB/Geosmin determination were performed eight and ten weeks after treatment.

Sediment Analysis

At the end of the test period, all sediment was taken from each aquarium and centrifuged for analysis of pore water phosphorus and algal identification.

Field Study

Setup

Three test areas were set up and treatments performed on June 5, 2003 in plots measuring 3m X 6m (long dimension paralleling shoreline), using metal fence stakes to mark each corner of the plot. Each test area consisted of a plot to assess treatment effects, and an adjacent control plot.

A subsequent set of test areas was set up on July 23,2004, due to an unexpected reservoir draw down which left the initial test plots partially or totally above the reservoir water line for a period of roughly one month. These two test areas consisted of two 3 x 6 meter plots. Each plot was subdivided to into two 3 x 3 meter adjacent subplots to evaluate two doses. The second set of field site locations correspond to the first set (see Figure 1), except that the subdesignation “a” was used, i.e.1a was located adjacent to the original plot 1. The new test plots had received copper sulfate treatment on June 27,2003, but benthic algae regrowth had already commenced.

Application of gypsum was made in the initial test plots by spreading the dry product with a 1000 ml measuring cup. Application in the second set of plots was made by slurrying a ratio of 5lbs (0.23kg) gypsum in 5 gallons (19L) of reservoir water, and then applied in increments over the plot. After initial treatment with gypsum, control and treated plots were assessed by visual observation every two weeks for algal coverage in two designated corner areas measuring one square meter each. Measurement of benthic algal coverage was also made immediately prior to treatment. Observations were expressed as percent algal coverage of the square meter observation area.

Treatments

Treatments of the original three test plots were at 373g/m^2 gypsum. The subsequent two newer test areas were treated at 950 g/m2 and 1900 g/m2. The 1900 g/m2 dose was slightly less than ½ that of the dose used in the test aquaria.

Sediment Analysis

At the end of the study each test and control plot was core sampled for analysis of pore water phosphorus and algal identification by means of a gravity core sampler (Wildlife Supply Company, Buffalo NY). Samples were obtained from the same areas used for the percentage of algal coverage monitoring.

Areal Count Of Algae

For the study plots in Bon Tempe Reservoir, the following method was used to estimate algae areal abundance. In both control and treated areas, a one meter square was selected to represent areal growth of benthic algae. Percent coverage within the square meter was estimated. Differing depth and water clarity (mostly due to surface rippling) made equivalent observations over time difficult.

RESULTS AND DISCUSSION

Beaker Study

Results of analysis taken the day after treatment indicated that the water chemistry, as measured in the control beakers, was sediment influenced. Alkalinity and conductivity values were approximately double that of Bon Tempe Reservoir water. Total phosphorus levels (as P) in the beaker water ranged from 14-17 µg/l whereas reservoir values range from <3 to 11 µg/l as measured in 2002. Since water was poured directly into the beakers without energy dissipation sediment was suspended for days due to a relatively high clay fraction. This most likely led to high mineral transference from the sediment to the water column. Additionally, fine sediment adhered to the sides of the beakers. This ultimately led to algal growth above the sediment/water interface.

It was quickly apparent that the alum doses were insufficient to have any phosphorus inactivation effects. It was incorrectly assumed that water quality parameters in the beakers would not be significantly different than those of the added reservoir water. In retrospect water quality parameters should have been taken prior to treatment. High alkalinity kept pH levels at 8.0 or above after treatment. Phosphorus values in the alum beakers were not reduced below those of the control beakers (Table 4). Application rates for gypsum with the goal of benthic algal control have no historical guidelines. Doses were based on suggestions of Veli-Pekka Salonen (personal communication 2003). These doses were based on levels that lead to successful sediment phosphorus inactivation in the Finnish research.

Table 4. Results of chemical analyses from beaker test.

Beaker test results - sampled 7/10/2003 (treated 7/9/2003)

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	PO_4 mg/L
AH1	8.14			47		<0.10
AH2	8.20			49		<0.10
AH3	8.18			48		<0.10
AL1	8.00			38		<0.10
AL2	8.17			23		<0.10
AL3	8.26			36		<0.10
C1	8.32		118	21		<0.10
C2	8.14		104	27		<0.10
C3	8.13			24		<0.10
GH1	8.13			1401		<0.10
GH2	8.08			1393		<0.10
GH3	8.18			1477		<0.10
GL1	8.02			650		<0.10
GL2	7.99			681		<0.10
GL3	8.16			756		<0.10
Anal. Date				7/15/03		7/10/03
CRM				TV=16.0		TV=0.80
% recov.				102,101,102,102		100,96,93
DUP				GH3=14.78 0.1% RPD		0.99/0.97 2.0%RPD
SPIKE				GH3=19.58 4.81=96%		1.53 0.49=98%
CCS % recov.				100,101,100		99,97,92
Blank				<1.0		<0.10

Beaker test results - sampled 8/15/2003

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	TP** mg/L
AH1	8.6	222	67	28	16	0.016
AH2	8.6	278	75	28	14	0.014
AH3	8.2	241	58	42	14	0.018
AL1	8.2	216	64	33	15	0.017
AL2	8.4	217	76	20	18	0.033
AL3	8.8	227	92	18	18	0.010
C1	8.7	179	140	10	NA	0.014
C2	8.2	216	72	31	14	0.016
C3	8.4	217	60	26	14	0.017
GH1	7.9	2140	38	1864	586	0.014
GH2	7.9	2150	35	1818	424	0.007
GH3	8.1	3050	40	1750	597	0.008
GL1	7.7	2050	31	1559	473	0.012
GL2	7.9	1570	32	1513	489	0.013
GL3	7.8	1570	42	968	266	0.010
QA: Anal. Date				8/18/03		8/22/03
CRM				TV=16.0		TV=0.075
% recov.				98,98,99,98, 98,98,98		0.077=103%
DUP		GH1=2130 0.5% RPD		GH3=1750 0% RPD	GL3=266 0% RPD	.298/.296 0.7% RPD
SPIKE			GH3 97%	GH3=13.69 99%	GL3 83%	0.395 97%
CCS % recov.				97,100,98,97, 100,100		105
Blank						<0.003

**TP sampled 8/14/2003

Beaker test results - sampled 7/15/2003

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	PO_4 mg/L
C3	8.22	274	99			

CRM = Certified Reference Material
TV = True Value
CCS = Calibration Check Standard

Surface Algae Production in Beakers

Algal "mats" which grew initially on bottom sediments and/or beaker side walls floated to the top in both control and alum treatments. Oscillatoria was the exclusive species of algae found in all beakers. Gas bubbles (most likely from production of oxygen via photosynthesis) were apparent within the algal mass. These floating mats were observed in 4 of 6 alum treated beakers, 3 of 3 control beakers, and 2 of 6 gypsum treated beakers (Table 5). The only significant decrease in sediment algal growth as measured by surface area coverage was in the low level alum dose which was 45% of the control growth as measured from the average of the triplicates (Table 5).

Table 5. Production of algae and taste and odor compounds in beaker study.

JAR	FLOATING SURFACE ALGAE amount	SEDIMENT ALGAE cm squares	MIB ug/L	GEOSMIN ug/L
AH1	high	30	ND	20
AH2	none	33	ND	29
AH3	med	30	2.2	38
AL1	med	4	ND	4.9
AL2	high	0	ND	ND
AL3	none	29	2	32
C1	high	24	ND	5.3
C2	high	17	ND	62
C3	high	18	2.7	31
GH1	low	29	ND	47
GH2	none	7	ND	57
GH3	none	32	ND	9.7
GL1	none	35	ND	16
GL2	none	32	ND	18
GL3	low	12	ND	6.8

note: geosmin/mib sampled on 8/5/03
algal assessment on 8/1/03

Taste and Odor Compound Production in Beakers

Geosmin production was lower in low doses of both alum and gypsum as measured against the control (Table 5). Production of geosmin in low dose alum beakers was 36% of the control, and production of geosmin in low dose gypsum beakers was 42% of the control. MIB production was low, limited to one beaker each of the high and low dose alum triplicates, and one of the control triplicates. No MIB was found at levels greater than the method reporting limit of 2 ng/l in any of the low or high dose gypsum triplicates (Table 5).

Sediment deposition on the beaker walls lead to subsequent algal growth. This growth was not accounted for in the algal counts by area and confounds the interpretation of the results in the beaker studies. Furthermore the high nutrient status of the beakers relative to the reservoir makes predicting success or failure in a full-scale application difficult. As a result of the above-mentioned observations, the decision was made to increase the volume to surface area ratio by a factor of 3 using 5.5 gallon (21 liter) aquaria.

Sediment Phosphorus

Sediment was collected and stored under refrigeration for over two months. Due to the long storage time and the acidification of the extracted water, which changes the amount of reactive phosphorus, it was decided to not use these results in the study.

Aquaria Study

Water Chemistry In Aquaria

Unlike results reported by Salonen and Varjo (1998), sulfate levels after gypsum treatment were higher than in control aquaria (average sulfate in gypsum aquaria = 1810 mg/l, average in control= 5.4 mg/l). Slurry versus dry application, and the lower total water volume above the sediment layer in the aquaria than in the field study by Salonen and Varjo (1998) (i.e., higher surface area to volume ratio) most likely lead to this result. Total water phosphorus levels in both alum and gypsum treated aquaria were lowered after treatment. Average reductions were 91% for both treatments. Significantly elevated sulfate or reduced phosphorus would be unlikely to occur in a full reservoir treatment, since only the perimeter of the reservoir would be treated. Only 3% of the total water volume would reside over the perimeter treated sediment. Allowing for a twenty fold increase in volume to surface area ratio in a reservoir perimeter treatment (as compared to the aquaria study), sulfate addition and phosphorus removal would be negligible due to dilution with the untreated reservoir volume.

The alum dose of 4 mg/l (0.59 g/m^2) appeared to be adequate for at least an initial assessment of effect on benthic algal growth. Initial water chemistry of all test aquaria indicated had conductivity measurements at around 65% of reservoir values. An alum floc of 0.2 cm was observed on the sediment interface after treatment. An optimum alum dose is that which produces a water pH of 6.0 after treatment, as this would produce the most Al(OH)3 available for the inactivation of phosphorus. Treated water pH in the study aquaria ranged from 7.2-7.4 (Table 6). While this did not indicate an optimum alum dose rate (Rydin and Welch 1998), it was within an acceptable range given the initial pH and alkalinity values of 7.7 units and 32 mg/l respectively, (Kennedy and Cooke 1983).

Table 6. Water chemistry data from the aquaria study.

Pre-treatment samples taken on 8/27/2003

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	TP mg/L
C1	7.78	87	32	3.14	4.8	0.014
A1	7.73	88	32	3.14	4.4	0.021
G1	7.73	86	32	3.11	4.0	0.022
C2	7.73	86	32	3.09	4.4	0.020
A2	7.72	86	32	3.19	4.4	0.025
G2	7.71	90	32	7.60	4.4	0.022
C3	7.71	92	33	5.71	4.8	0.059
A3	7.70	86	33	5.50	4.4	0.021
G3	7.70	89	32	5.94	4.4	0.021
QA: Anal. Date	8/27	28-Aug	8/28/03	8/27/03	9/5/03	9/19/03
CRM	TV=7.00	TV=503	TV=29	TV=16	TV=20	TV=0.050
% recov.	7=100%	523=104%	30=103%	98,98,97	20=100%	.0464=93%
DUP			C2(8/28)=32	C1=3.15	A1(8/27)=4.4	.2870/.2903
			3.2% RPD	0.3% RPD	0% RPD	1.1% RPD
SPIKE			G3(8/28)=80	C1=8.14	C2(8/27)=13.2	0.3821
			94%	100%	101%	95%
CCS %recov.				100,101,100		105
Blank				<1.0	0	<0.003

Post-treatment samples taken on 8/28/2003

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	TP mg/L
C1	7.84	102	31	3.18	4.8	0.019
A1	7.21	95	14	23.4	4.8	0.005
G1	7.71	1740	34	1319	593	0.015
C2	7.72	80	31	3.14	4	0.019
A2	7.36	91	13	22.6	4.4	<0.002
G2	7.74	1610	30	1358	545	0.007
C3	7.82	85	30	5.94	4.4	0.014
A3	7.33	94	11	25.9	4.4	0.003
G3	7.73	1530	33	1417	577	0.008
QA: Anal. Date	8/28/03		8/28/03	9/2/03	9/5/03	9/19/03
CRM	TV=7.00	TV=503	TV=29	TV=16	TV=20	TV=0.050
% recov.	7.00=100%	523=104%	30=103%	98,98,98,98,98	20=100%	.0464=93%
DUP			C2(8/28)=32	G1=1316	A1(8/27)=4.4	.2870/.2903
			3.2% RPD	0.2% RPD	0% RPD	1.1% RPD
SPIKE			G3(8/28)=80	G1	C2(8/27)=13.2	0.3821
			94%	99%	101%	95%
CCS %recov.				97,99,97,97,97,97		105
Blank				<1.0	0	<0.003

Post-treatment TP sampled:

Dose	9/4/2003 TP mg/L	9/11/2003 TP mg/L
C1	0.022	0.023
A1	0.005	0.003
G1	0.003	0.002
C2	0.024	0.026
A2	<0.002	0.003
G2	0.002	0.006
C3	0.017	0.018
A3	<0.002	0.003
G3	<0.002	0.003
QA: Anal. Date	9/23/03	
CRM	TV=0.050	
	0.0465 = 93%	
DUP	0.251/0.252	
	0.4% RPD	
	0.328	
SPIKE	102%	
CCS % recov.	100	
Blank	<0.003	

Post-treatment samples taken on 10/22/2003

Dose	pH	Conductivity uS/cm	Alkalinity mg/L	Sulfate mg/L	Ca mg/L	TP mg/L	Turbidity NTU
C1	8.23	74	20	4.22	3.2	0.009	3.23
A1	7.67	116	12	28.7	4.8	0.002	0.40
G1	7.93	1770	29	1810	621	0.002	0.18
C2	8.03	75	23	3.73	4	0.006	1.83
A2	7.67	112	12	28.2	4.8	<0.002	0.30
G2	7.89	1760	25	1823	621	0.009	0.28
C3	8.14	79	20	8.25	4.8	0.004	2.00
A3	7.57	124	12	32.6	4.8	<0.002	0.51
G3	8.21	1640	24	1811	641	<0.002	0.26
QA: Anal Date	10/22/03		10/22/03	10/28/03	11/3/03	11/20/03	
CRM	TV=7.00		TV=30.6	TV=16	TV=13.1	TV=0.2	
	7.00=100%		31=101%	100,100,100	12.8=98%	.2306=115%	
DUP			C1=20	G1=1816	G1=621	.3621/.3487	
			0% RPD	0.3% RPD	0% RPD	3.8% RPD	
SPIKE			G3+25	G1	G2=20.1	0.4852	
			48=96%	93%	100%	82%	
CCS % recov.				100,100,100		96	
Blank				<1.0		<0.002	

TV = True Value CRM = Certified Reference Material CCS = Calibration Check Standard

The gypsum layer was approximately 0.5 cm in depth after slurry application, with 98-99% total coverage of the bottom sediment. This depth of coverage declined to about 0.2 cm of depth by the end of the study period. Shortly after dosing, grasses sprouted through the sediment interface in all treated and control aquaria. These terrestrial grasses were of the same type found above water level after reservoir draw down, due to lowered pumping rates into Bon Tempe Reservoir, and are not typical of the benthic interface. Sediment samples for the aquaria study were taken below the water level at the time of collection, but above the level of maximum reservoir draw down. The direct air exposure of roughly one month to this collected sediment likely accounts for the germination of grasses in the laboratory study. The grasses raised up the gypsum layer in a conical fashion in many locations during and after germination, so that a water gap formed between the gypsum layer and the sediment. It was also noted that the gypsum layer acted like a stretchable membrane as the grass blades extended upward. The gypsum layer observed at the end of the study period was similar in consistency to that of the sediment except that there was a thin "crust", possibly calcium carbonate, on top.

Surface Algae Production in Aquaria

Surface algae production as measured by square centimeters of coverage was essentially the same for the control and alum treatments. Due to diminishing light conditions at the end of September, 50 watt incandescent lights were placed on top of the acrylic covers on each aquarium. These lights were installed with a timer to provide 13 hours illumination per day. Mean algal coverage of the gypsum treated aquaria was 36 percent of the control (Table 7). These figures are an average of two assessments, which took place seven and nine weeks after treatment. Algae observed were exclusively of the species *Oscillatoria*. Algae masses also grew in web-like formations above the sediment layer on and between the terrestrial grass blades. While algae grew on grasses in all aquaria, growth seemed to be most predominant in the gypsum treated aquaria. With water total phosphorus levels at 3 µg/l (the analytical detection limit) or lower, it is unclear as to why algal growth would occur unless facilitated by some mechanism enabled by the grasses. The predominant type of algae found growing between grass blades was a species of *Anabaena* with minor amounts of two types of *Oscillatoria*. When harvested these algal masses had a very high geosmin odor.

Table 7. Algal coverage of aquaria, as number of squares containing algae. Results are the average of two counts. First assessment count: 10/21/03; Second:11/7/03

	Algal Count cm squares	Standard Deviation
C1	43.5	7.6
C2	47	
C3	58	
A1	80.5	24
A2	37	
A3	41.5	
G1	7.5	14
G2	14	
G3	35	

Gypsum treatment caused a noticeable reduction in benthic algal growth. The 62% average reduction in surface coverage was significant at the 95% confidence interval when compared to alum and control data. (Appendix 4). Both gypsum and alum had more light penetration, as the turbidity values for gypsum (0.24 NTU), and alum (0.40 NTU) were lower than that of the control (2.35 NTU). Therefore, when considering available light, both gypsum and alum aquaria would be expected to optimize the potential for algal growth. If full-scale reservoir treatment were to be limited to the perimeter, turbidity over the perimeter would be expected to be similar to the untreated section of the reservoir over time, as water would move between the untreated and the treated zone.

Taste and Odor Compound Production in Aquaria

Like surface algal production, differences in taste and odor compound production between the controls and alum treated aquaria were not apparent. However mean geosmin production in the gypsum treated aquaria was 131 % higher than the control (Table 8). MIB was below detection in all of the test aquaria.

Results seemed contradictory between the low surface algal counts and high geosmin production in the gypsum treated aquaria. However as noted above, the observation of algae growing on and between grass blades could account for geosmin production, especially if the *Anabaena* identified as the predominant algal species are high geosmin producers.

Table 8. Geosmin concentrations in different aquaria.

	Geosmin ng/L	Standard Deviation
C1	1.75	15.9
C2	7	
C3	31.5	
A1	6.75	11
A2	23.5	
A3	3.2	
G1	35.5	12
G2	37.5	
G3	15.5	

Note: Results are the average of two assessments, the first on 10/22/03 and the second on 11/05/03. Geosmin value of ND is computed as 1 ng/l or one half of the detection limit.

Sediment Phosphorus

Sediment Phosphorus was reduced by 82% in the gypsum treated aquaria, and by 47% in the alum treated aquaria (Table 3). The reduction in the gypsum treated aquaria was significant at the 95% confidence interval when assessed simultaneously with control and alum data.

Field Study

In the field, uniform treatment could not be achieved by distributing gypsum by hand while in a boat. After treatment it was noted that gypsum was observed in some locations in the treated plots, but not in others. The highest field dose was ½ that of the aquaria studies, and may be too low to be effective. No visible gypsum was observed in any of the test plots at the end of the study. Core samples from the plots also showed no visible gypsum layer.

During the study the three original test plots went partially or completely dry as the transfer pump delivering water into Bon Tempe Reservoir from the adjacent Alpine Reservoir was removed for repair. The replacement pump pumped at a lower rate and could not maintain the water level in the reservoir. As a result two new test sites located down slope from test sites 1 and 3 were established on August 6, 2003. These new sites were adjacent 3m x 3m plots treated at two higher treatment doses than the original plots, and were located adjacent to 6 x 3 m control plots.

Surface Algae Production in Field Trials

Assessment of sediment surface algal coverage proved to be very difficult. Bottom visibility varied with surface chop and light conditions. Since observations were not made until benthic algal growth had already commenced, there was no zero baseline from which to start. Additionally, later in the study it was obvious that some of the benthic algal "mats" had broken off from the sediment water interface and floated to the surface. Sediment surface algal cover was thereby reduced and could not be accounted for, so reporting underestimated the cover percentage. Results from counting proved to be highly erratic and the data were of little or no value (Appendix 6). Core sampling of sediment in the 1m^2 algal observation area indicated that blue green algae numbers were low, and that the upper layer of sediment consisted predominately of pennate and concentric diatoms, and organic debris. As sampling was performed at the end of the algae growing season, the lack of blue green algae found was most likely due to earlier die off, translocation and decomposition (see Appendix 6).

Sediment Phosphorus

Mean sediment soluble reactive phosphorus was 47% lower in treated plots than in the controls. Since 8 of the 11 measurements were below the detection limit of 10 µg/l, this reduction should not be seen as significant. The lack of certainty in field plot comparison is further increased when considering the lack of precision in application. The assessment areas were located in the corners of the plot. It was noted that uneven coverage and gypsum drift off the plot site was not uncommon.

Economic Evaluation

Estimates for alum and gypsum treatments were produced from a lake restoration company in the San Francisco Bay Area. Cost details are included in attachment. Estimates were based on a perimeter treatment only using alum or gypsum aquaria data to estimate chemical costs.

The cost of one alum application was estimated at $25,000. As the treatment was not optimized in the aquarium study, the cost of alum should be increased by roughly one-third to reflect an estimated optimal dose. This brings the cost of alum treatment to $29,600. One gypsum treatment was estimated at $24,400.

The current cost per year to treat Bon Tempe Reservoir with copper sulfate is $15,900. Treatment has had varying levels of success, and during most summer seasons, low levels (2-5µg/l) of either MIB or geosmin are detected sporadically.

Cost of alum or gypsum treatment would become considerably more favorable if treatment lasts for more than one year. Duration of treatment is currently impossible to predict as external nutrient inputs (e.g., sediment from Lagunitas Reservoir located upstream) have not been characterized. Successful lake treatments with alum have been documented to last 10 or more years (Welch and Cooke (1999) Longevity of gypsum treatments is not yet known.

Given the above cost estimates and variables, treatment with either alum or gypsum could be in the range of current conventional copper sulfate treatment, and more importantly, should not be ruled out on an economic basis.

CONCLUSIONS

Results of field plots and laboratory beaker studies were inconclusive due to problems associated with the experimental setups. Field plots were initiated after benthic algal growth had already started. Application of gypsum was difficult due to inadequate equipment, and the method of benthic algal growth documentation was inadequate. In the beaker study initial water quality parameters differed significantly from reservoir values and dose rates for alum were inadequate. Aquaria study results showed that at a lower than optimal alum dose, there was no reduction of benthic algae growth or taste and odor compound production. However this does not rule out the effectiveness of alum at higher dose rates that may more successfully inactivate available phosphorus in sediment pore water. Gypsum reduced mean benthic algae growth by 62%, compared to controls. This reduction was significant at the 95% confidence interval. . Inhibition of algal growth was most likely caused by the mean reduction of soluble reactive phosphorus in interstitial water, which was reduced by 82% over the controls. This reduction was also significant at the 95% confidence interval. The mechanism for phosphorus binding is most likely the formation of apatite $Ca(PO_4)_6(OH)_2$ (Salonen and Varjo, 1998).

The germination of terrestrial grasses that supported *Anabaena* growth within the aquaria resulted in geosmin concentrations significantly higher than the controls. Since Bon Tempe Reservoir does not support these grasses it is likely that geosmin and/or MIB production at full-scale would be reduced compared to historical values given the other bench scale observations of decreased available phosphorus in the sediment, and decreased benthic algal growth.

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CHAPTER 3: EVALUATION OF MECHANICAL EXCAVATION, MANUAL CUTTING, AND GOATS FOR VEGETATION REMOVAL IN BAY-DELTA STREAMS

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1. ABSTRACT

During the summer and fall of 2003 non-chemical control (NCC) as alternatives to the use of aquatic pesticides was evaluated for emergent, floating and terrestrial weeds at six locations in northern California. Targeted pest species include: emergent weeds cattails (*Typha latifola*) and bulrush (*Scirpus acutus*); floating weeds primrose (*Luwigia peploides*) and duckweed (*Lemna minor*); and the terrestrial weed blackberry (*Rubus armeniacus*). In one case Eurasian watermilfoil (*Myriophyllum spicatum*), a submersed weed, was targeted with floating weeds. Herein all pest species will be referred to by common name, cattail and bulrush will collectively be referred to as “Tules”. Evaluation focused on water quality impacts, efficacy, and cost-effectiveness.

Techniques evaluated were goat grazing, mechanical removal, chemical treatment followed by mechanical removal, and manual removal by labor crews using power equipment. Water quality impacts observed during the implementation of these non-chemical controls were largely transitory. The most significant impacts to water quality during weed abatement with goats were the temporary presence of coliform and *E. coli* above maximum concentrations allowed for recreation. If short-term increases in coliform and *E. coli* are acceptable, the use of goats is a viable alternative. The use of goats for selected terrestrial weeds is probably more effective and economical than the use of chemicals. Both of these techniques are preferable to the use of manual removal techniques. Although effective, manual weed removal is expensive, extremely labor intensive, subjects workers to a high injury potential, and must be repeated every year.

No significant differences in water quality were noted during or after the removal of floating aquatic weeds using mechanical removal and chemical application followed by mechanical removal. The combination of chemical/mechanical removal was the most effective technique observed. Because significant re-growth was observed after mechanical removal, this technique is not viable. In the presence of moving water, the use of chemical control alone is likely the most effective and cost effective method.

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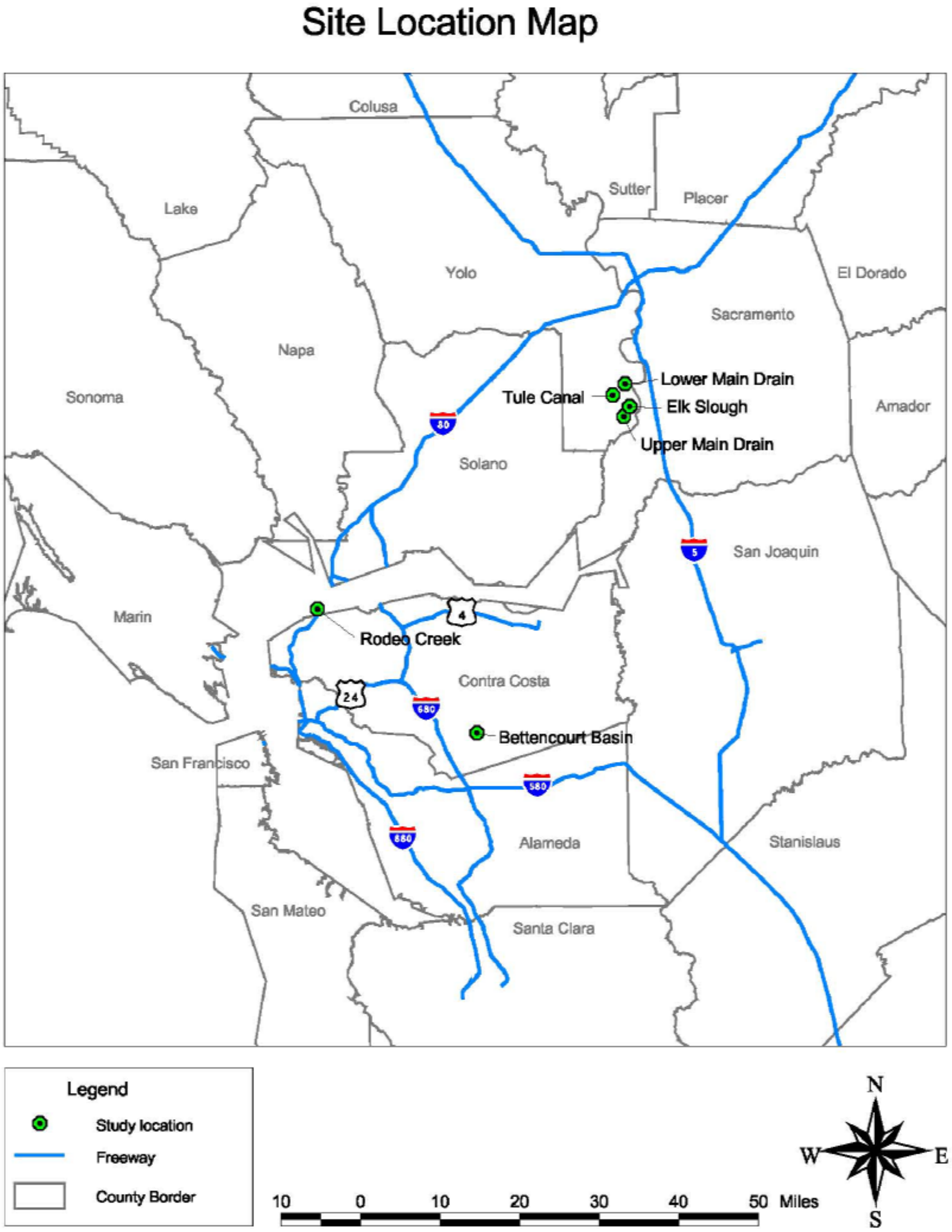
2. INTRODUCTION AND PURPOSE

Since the 2001 *Talent* decision, the use of aquatic pesticides in California requires a National Pollution Discharge Elimination System (NPDES) permit. This NPDES permit is issued by the California State Water Resources Control Board (SWRCB). In 2001, as a result of a settlement between the SWRCB and the Waterkeepers of Northern California, the San Francisco Estuary Institute (SFEI) was contracted by the SWRCB to undertake the Aquatic Pesticide Monitoring Program (APMP).

A part of the APMP is the evaluation of aquatic pesticide alternatives for the control of aquatic vegetation. A critical objective of this aquatic pesticide alternatives program is to obtain data on alternatives to aquatic pesticides in three primary areas: environmental impacts, efficacy, and cost-effectiveness.

This report describes field work performed by Blankinship and Associates between July 29 and December 11, 2003 that utilized two (2) study locations divided into six (6) study sites (Figure 2.1) to obtain data on the aquatic pesticide alternatives program's three primary areas of interest.

Figure 2.1. Map of study site locations.



3. METHODS

Environmental Impacts

Environmental impacts were evaluated solely through the analysis of surfacewater quality. Surfacewater was monitored before during and after weed abatement both up- and downstream of the plots on each site to assess immediate and medium-term impacts to water quality. Samples were analyzed depending on the activity at each site as described in Table 3.1**.** For a detailed description of methods unique to each site see the Study Sites section (section 4).

Table 3.1. Analyses conducted for environmental impacts.

Location	Abatement Method	Dissolved Oxygen	Turbidity	Electric Conductivity	Total Petroleum Hydrocarbons	Nitrate	Nitrite	Ammonia	Total Kjeldahl Nitrogen	Total Phosphorus	Total Coliform	Fecal Coliform	E. Coli
Contra Costa County	Goats	x	x	x		x	x	x	x	x	x	x	x
	Manual Removal	x	x	x	x	x	x	x	x	x			
Reclamation District 999	Goats	x	x	x					x		x	x	x
	Chem/Mech	x	x	x		x	x	x	x	x			
	Mechanical	x	x	x		x	x	x	x	x			
	Control	x	x	x		x	x	x	x	x			

Notes:

(1) Analyses Done at the Following Laboratores:

California Department of Fish and Game, Ranco Cordova, CA
California Laboratory Services, Rancho Cordova, CA
Cerco Analytical Inc., Pleasanton, CA
McCampbell Analytical Inc., Pacheco, CA
SFEI, Oakland, CA

(2) Dissolved Oxygen and Electric Conductivity field-measured by Blankinship and Associates using a YSI model 85 Portable Meter

Sample collection, shipping and chain-of-custody procedures followed quality assurance and quality control guidelines presented in the SFEI Aquatic Pesticide Monitoring Plan (APMP) Quality Assurance Project Plan (QAPP). Quality assurance and quality control (QA/QC) was accomplished in the form of field duplicates and field blanks. Prior to use, all data underwent validation. This work is summarized in Tables 3.2, 3.3, and 3.4. These tables are for quality assurance purposes only and are not intended to provide monitoring results. For full monitoring results see the Results section (section 5).

Table 3.2 QA/QC Summary for Bettencourt Basin

1) Turbidity

Location	**Date Sampled**	**Time Sampled**	**Lab**	**Turbidity**	**Valid**	**RPD**
Downstream	10/21/03	940	MAI	2.00	Yes	N/A
Downstream Duplicate	10/21/03	940	Cerco	**250.00**	No	
Upstream	10/21/03	950	MAI	1.20	Yes	22.2
Upstream Duplicate	10/21/03	950	Cerco	1.50	Yes	
Downstream	10/30/03	1525	MAI	**0.40**	No	0.5
Downstream Duplicate 1	10/30/03	1525	Cerco	20.00	Yes	
Downstream Duplicate 2	10/30/03	1525	SFEI	19.90	Yes	
Upstream	10/30/03	1550	MAI	**0.80**	No	19.4
Upstream Duplicate 1	10/30/03	1550	Cerco	3.20	Yes	
Upstream Duplicate 2	10/30/03	1550	SFEI	2.66	Yes	
Upstream Duplicate 2	10/30/03	1550	SFEI	3.23	Yes	
Downstream Split	11/11/03	1255	MAI	1.30	Yes	16.7
Downstream Split	11/11/03	1255	Cerco	1.20	Yes	
Downstream Split	11/11/03	1255	SFEI	**1.63**	No	
Downstream Duplicate Split	11/11/03	1305	MAI	1.10	Yes	
Downstream Duplicate Split	11/11/03	1305	Cerco	1.10	Yes	
Downstream Duplicate Split	11/11/03	1305	SFEI	**1.67**	No	
Upstream Split	11/11/03	1230	MAI	1.30	Yes	0.0
Upstream Split	11/11/03	1230	Cerco	1.30	Yes	
Upstream Split	11/11/03	1230	SFEI	**2.53**	No	
Blank Split	11/11/03	1215	MAI	0.20	Yes	22.2
Blank Split	11/11/03	1215	Cerco	0.16	Yes	
Blank Split	11/11/03	1215	SFEI	**0.36**	No	

2) Other Parameters

Parameter	**11/11/03 Downstream**	**11/11/03 Downstream Duplicate**	**RPD**	**Valid**
Dissolved Oxygen (% Saturation)	78.2	71.2	9.4	Yes
Dissolved Oxygen (mg/L)	8	7.28	9.4	Yes
Electric Conductivity	581	582	0.2	Yes
Electric Conductivity @ 25 C	731	731	0.0	Yes
Salinity (ppt)	0.4	0.4	0.0	Yes
Temperature (C)	14.2	14.3	0.7	Yes
Total Coliform (colilert)	6488	6867	5.7	Yes
E.Coli (colilert)	156	203	26.2	Yes
Total Coliform (SM 9221B)	24000	800	187.1	Yes
Fecal Coliform (SM 9221E)	500	300	50.0	Yes
Phosphorus (mg/L)	0.35	0.35	0.0	Yes
Total Kjeldahl Nitrogen (mg/L)	0	0	0.0	Yes

Notes:

(1) RPD = Relative Percent Difference = [(Max Value - Min Value)/(Average of Max Value and Min Value)]*100

(2) Invalid Data are **BOLD** and were not used

(3) Invalid Data have an RPD > 25

(4) E.Coli (colilert), Total Coliform (SM 9221B) and Fecal Coliform (SM 92212E) are considered valid despite a RPD > 25 because of natural high variation in these parameters.

(5) Treatment Occurred 10/12/03 - 10/16/03

Table 3.3 QA/QC Summary for Rodeo Creek

1) Turbidity

Location	Date Sampled	Time Sampled	Lab	Turbidity	Valid	RPD
Downstream	10/8/03	1425	MAI	9.8	Yes	72.3
Downstream	10/8/03	1425	SFEI	**20.9**	No	
Downstream 1	10/8/03	1445	MAI	2.5	Yes	111.4
Downstream 1	10/8/03	1445	SFEI	**8.79**	No	
Downstream 2	10/8/03	1455	MAI	3.2	Yes	141.3
Downstream 2	10/8/03	1455	SFEI	**18.6**	No	
Downstream 3	10/8/03	1510	MAI	1.2	Yes	123.8
Downstream 3	10/8/03	1510	SFEI	**5.1**	No	
Downstream 4	10/8/03	1525	MAI	1	Yes	141.7
Downstream 4	10/8/03	1525	SFEI	**5.86**	No	
Upstream	10/8/03	1420	MAI	1	Yes	154.6
Upstream	10/8/03	1420	SFEI	**7.81**	No	
Downstream 3	11/4/03	930	MAI	2.3	Yes	95.7
Downstream 3	11/4/03	930	SFEI	**6.52**	No	
Downstream 4	11/4/03	1005	MAI	2.4	Yes	18.2
Downstream 4	11/4/03	1005	SFEI	13	No	
Downstream 4 Duplicate	11/4/03	1015	MAI	2	Yes	
Downstream 4 Duplicate	11/4/03	1015	SFEI	**8.98**	No	
Upstream	11/4/03	840	MAI	1.9	Yes	66.9
Upstream	11/4/03	840	SFEI	**3.81**	No	

2) Other Parameters

Parameter	11/04/03 Downstream 4	11/04/03 Downstream 4 Duplicate	RPD	Valid
Dissolved Oxygen (% Saturation)	40.3	42.5	5.3	Yes
Dissolved Oxygen (mg/L)	4.43	4.67	5.3	Yes
Electric Conductivity	987	988	0.1	Yes
Electric Conductivity @ 25C	1350	1350	0.0	Yes
Salinity (ppt)	0.7	0.7	0.0	Yes
Temperature (C)	10.9	11	0.9	Yes
Total Petroleum Hydrocarbons (mg/L)	0	0	0.0	Yes
Phosphorus (mg/L)	0.27	0.27	0.0	Yes
Total Kjeldahl Nitrogen (mg/L)	0	0	0.0	Yes

Notes:

(1) RPD = Relative Percent Difference = [(Max Value - Min Value)/(Average of Max Value and Min Value)]*100
(2) Invalid Data are **BOLD** and were not used
(3) Invalid Data have an RPD > 25
(4) Turbidity results from the SFEI Lab is considered invalid because:
  (a) SFEI values are systematically greater than MAI values.
  (b) MAI data exists for all other samples.
  (c) Cerco supports MAI results in Bettencourt Basin data, see Bettencourt Basin Quality Assurance Table
  (d) RPD > 25
(5) Treatment Occurred 10/6/03 - 10/10/03

Table 3.4 QA/QC Summary for Reclamation District 999

1) Turbidity

Location	Date Sampled	Turbidity Replicates					RPD
		I	II	III	IV	V	
MDrn-1	7/29/03	12.90	10.40	11.90			21.5
MDrn-2	7/29/03	**15.80**	10.70	10.80			0.9
MDrn-3	7/29/03	**10.60**	**15.30**	**28.70**			92.1
MDrn-3 after	7/29/03	6.96	6.83	7.23			5.7
MDrn-4	7/29/03	**43.50**	**64.80**	**26.40**	**57.80**	**36.80**	84.2
MDrn-4D	7/29/03	**24.60**	**33.40**	**41.40**			50.9
Lab Blank	8/5/03	0.30	0.35	0.33			15.4
TC-3during-80503	8/5/03	80.30	93.40	92.70	94.30		16.0
TC-3-80503	8/5/03	73.80	76.90	78.30			5.9
TC-2during-80503	8/5/03	64.80	69.70	69.70	73.40		12.4
TC-2-80503	8/5/03	48.30	50.90	50.10	51.10		5.6
MD-2-80503	8/5/03	56.70	61.80	51.50	**105.00**		18.2
MD-3-80503	8/5/03	**9.83**	10.80	12.80	12.30		16.9
ES-2-after-81403	8/14/03	11.6	12				3.4
MD-4-before-81203	8/12/03	7.93	9.32				16.1
827 0920 LMD4B	8/27/03	17.3	16.8	17.05			2.9
9250950-UMD2d	9/25/03	31.9	33.6				5.2

2) Other Parameters

Parameter	07/29/03 MDrn-4	07/29/03 MDrn-4D	RPD	Valid	Notes
Ammonia (mg/L)	0	0		Yes	
Total Kjeldahl Nitrogen (mg/L)	4.82	2.94	48.5	No	Values Averaged and Data Used
Nitrite+Nitrate (mg/L)	0.0566	0.0666	16.2	Yes	
Total Phosphorus (mg/L)	0.778	0.353	75.2	No	Values Averaged and Data Used
Dissolved Oxygen (mg/L)	9.63	8.36	14.1	Yes	
Electric Conductivity	100.7	100	0.7	Yes	
Electric Conductivity @ 25 C	168	167.7	0.2	Yes	
pH	6.97	6.96	0.1	Yes	
Temperature (C)	4.5	3.9	14.3	Yes	

Notes:

(1) RPD = Relative Percent Difference = [(Max Value - Min Value)/(Average of Max Value and Min Value)]*100

(2) Invalid Data are **BOLD** and were not used, unless otherwise noted

(3) Invalid Data have an RPD > 25

(4) Treatment Occurred 8/1/03 - 9/17/03

Efficacy

The efficacy of the each technique was evaluated during the collection of surface water samples. For example, the degree of weed removal and the extent of reestablishment were visually noted and documented with digital photographs during and after treatment. Estimation of the degree of weed removal was semi-quantitative in nature and involved visual observation of the backhoe bucket's efficiency in grasping and holding onto weeds during removal. Also, once removed, the relative size of the pile of removed weeds was noted. Refer to Figure 4.1. Similarly, the degree of weed re-establishment was semi-quantitative in nature and involved visual observation and photodocumentation of vegetative regrowth. Refer to Figure 5.12.

Economic Analysis

The following cost data were collected and normalized on a per acre basis for each test site:

1. Manpower, including estimated worker's compensation fees
2. Equipment and materials, including hauling and disposal
3. Regulatory Compliance, including permitting fees
4. Chemical costs

4. STUDY SITES

Reclamation District (RD) 999

Reclamation District (RD) 999 is located in south Sacramento County (Figure 2.1) and operates over 200 miles of canals that are critical to the conveyance of water to farmers in the district during the summer and are equally critical for conveyance of stormwater in the winter.

The objective of weed control in these canals is to remove sufficient weeds to achieve unimpeded water flow. Typical floating aquatic weeds that slow water and clog pumps include primrose and duckweed. Control of these weeds was evaluated at three (3) separate locations. Terrestrial weeds that encroach on slough and ditch banks include blackberry. Control of this weed was evaluated on two (2) plots at one (1) location. Each of the four locations had a control plot associated with it. Refer to Figures 4.3 and 4.4.

Floating Aquatic Weed Control

The following two (2) different techniques for the control of the floating aquatic weeds primrose and duckweed were evaluated:

1. Mechanical Removal. This technique involved the use of an extended reach backhoe fitted with a modified bucket capable of collecting weeds and allowing water to pass through (Figure 4.1). Once removed, weeds were placed on the bank and allowed to decompose.

Figure 4.1. Mechanical removal of floating weeds at RD999.

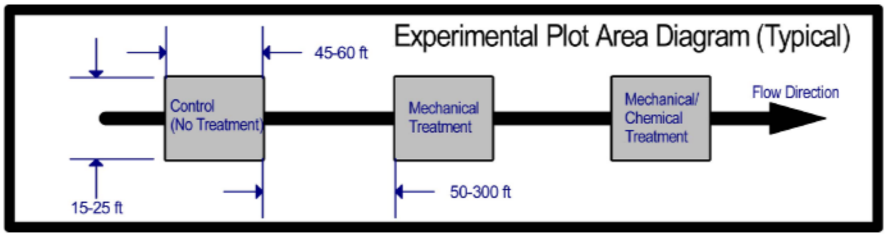
2. Chemical Application Followed by Mechanical Removal. This technique involved the application of a systemic herbicide (glyphosate) followed 2 weeks later by the mechanical removal of dead of dying plant material (Figure 4.2).

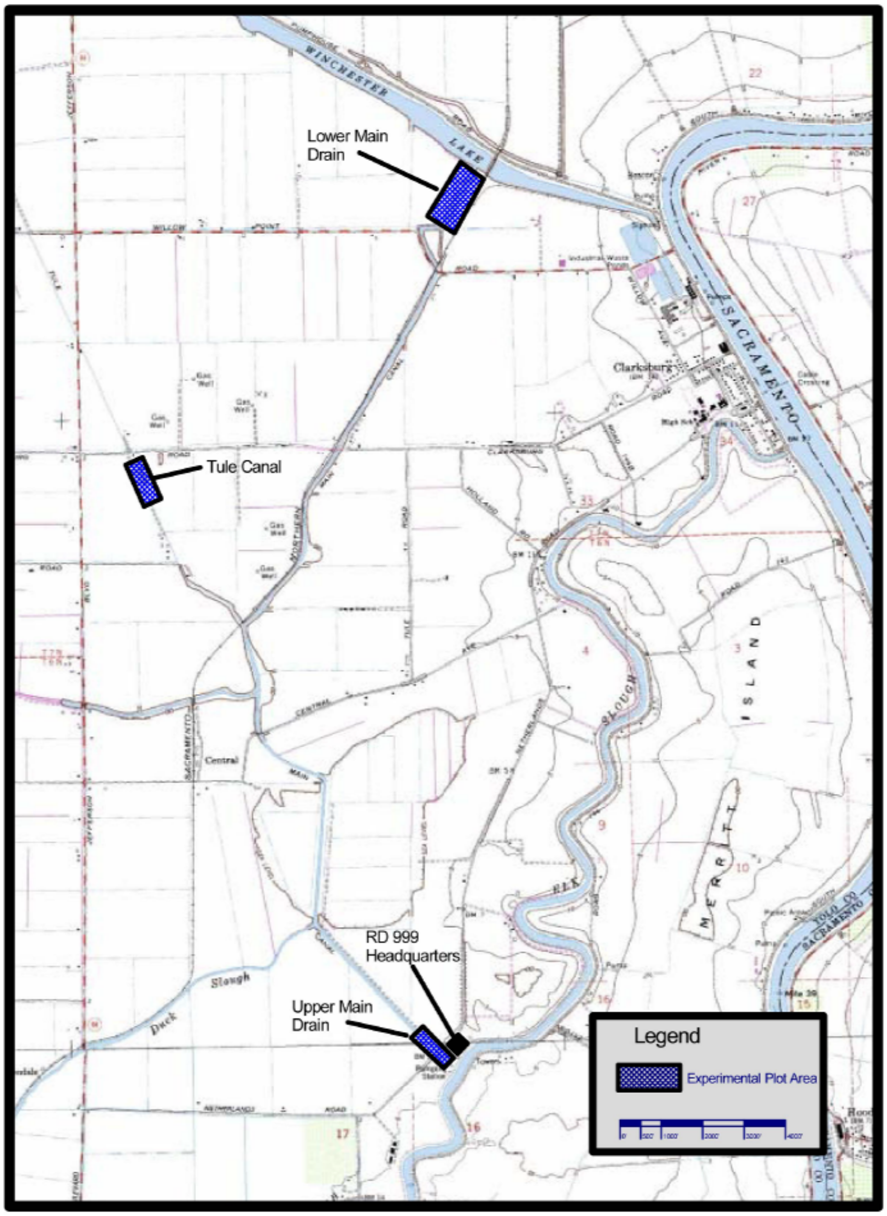
Figure 4.2. Glyphosate application at RD999.

Surfacewater samples were collected and over a dozen observations of the degree of weed control were made over an eight (8) week period from July 29 to September 25, 2003. Three (3) sites were used (Figure 4.3).

3. Upper Main Drain (UMD). This location is off of Netherlands Road and is close to the source of irrigation water pumped into the district from Elk Slough. Water flowed into the UMD throughout the duration of the trail. Test plots were located in the heavy primrose infestation present along the eastern shore of this drain.
4. Lower Main Drain (LMD). This location is approximately 5 miles downstream of the UMD off of Willow Point Road. Like the UMD, this drain was heavily infested with primrose. Water flowed into the LMD from Winchester Lake throughout the duration of the trail.
5. Tule Canal. This location is off of Clarksburg Road and takes water from the Main Drain. Water was not flowing in this canal during the trial. A mix of weeds were present that included milfoil and duckweed. Primrose was largely absent.

Figure 4.3 (Following page). Experimental plot design and sample site location for RD999 evaluation of mechanical excavation and excavation in combination with chemical application.





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Project SFEI APMP NCC Study	Figure
Date November 24, 2003	
Scale As Shown	

Each test site was isolated from the other to prevent one site from impacting data collected at another site. At each of the three test sites, three (3) plots were established (Figure 4.3). Each plot was approximately 50 feet long and separated from other plots by 50 feet or greater. A schematic of the plot layout is provided at the top of Figure 4.3. The plots are described below:

Plot 1. Control:

Weeds were left alone in order to assess baseline conditions.

Plot 2. Mechanical Removal:

Weeds were removed with an extended reach backhoe outfitted with a specially modified bucket (Figure 4.1). Removed weeds were left on the bank of the canal to decompose.

Plot 3. Chemical Treatment followed by Mechanical Removal (Chemical/Mechanical):

Weeds were treated with a systemic herbicide (glyphosate), allowed to sit for two (2) weeks, and then removed with the extended reach backhoe and modified bucket (Figures 4.1 and 4.2). Removed weeds were left on the bank of the canal to decompose.

Chemical treatment in plot 3 occurred after mechanical removal in plot 2 to ensure that there would be no chemical effects on plot 2. Mechanical removal in plot 3 occurred 3 to 4 weeks after mechanical removal in plot 2. Due to this time lapse the treatment of plot 2 did not influence the monitoring results of plot 3.

Terrestrial Weed Control

Goats were evaluated for the control of terrestrial weeds, including blackberry, on the banks of Elk Slough (Figure 4.4). This weed poses problems to the district because it encroaches into the waterway and may impede flow. Further, its growth obstructs easy view of soil conditions on the levee, hampering levee inspection.

Goats were confined by electric fences into specific areas and allowed to graze until adequate control as judged by District personnel was obtained (Figure 4.5). Once the desirable level of control was achieved, fences were relocated and the goats were moved into that location. The cross-sectional area of goat grazing on levees adjacent to Elk Slough is shown on the top of Figure 4.4. Approximately 1,000 goats grazed plot 2 for four days from 8/5/03 to 8/8/03. Approximately 1,000 goats grazed plot 3 for two days from 8/11/03 to 8/12/03.

Figure 4.4 (Following page). Experimental plot design and sample site location for evaluation of goat grazing at RD999.

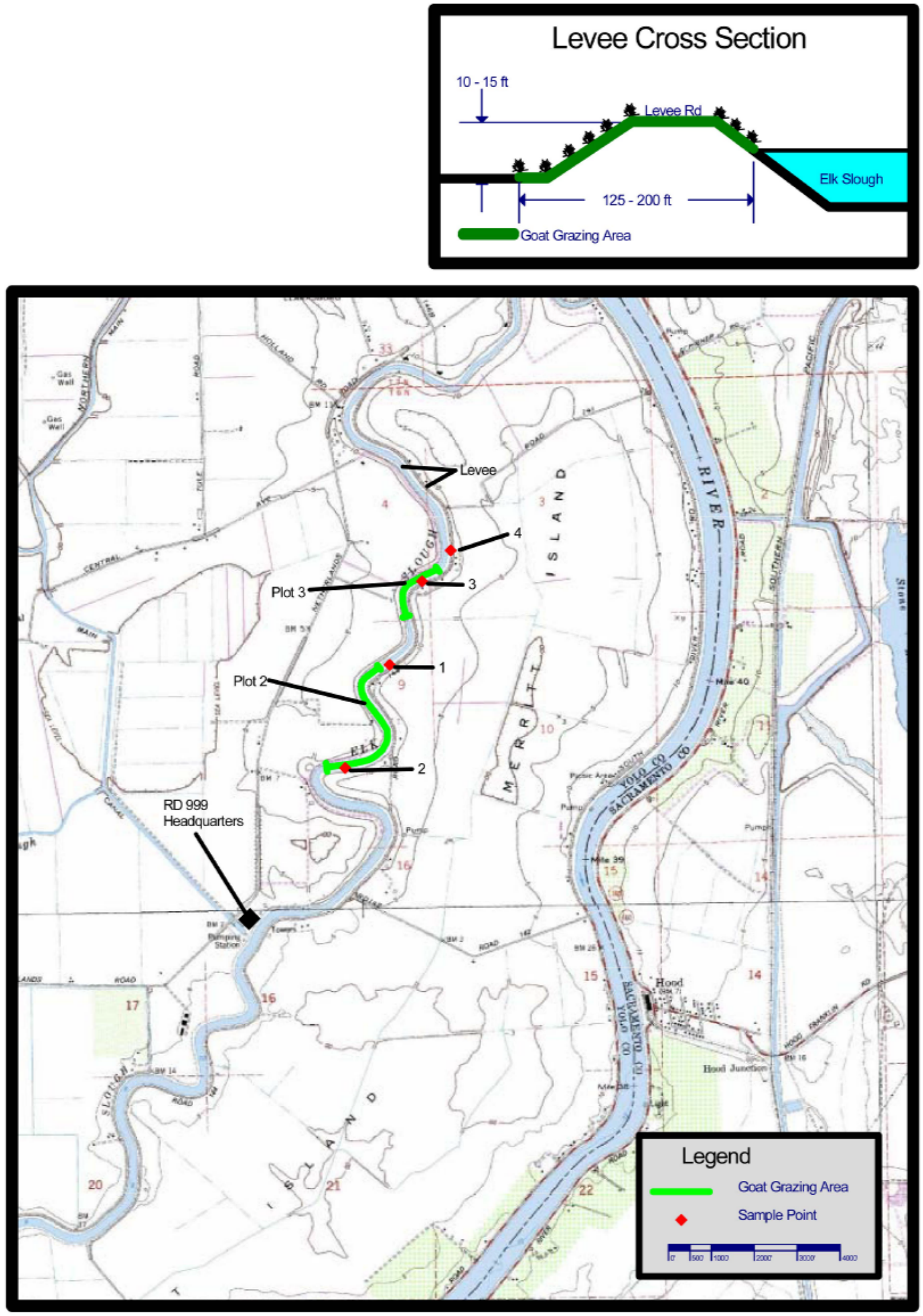

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Figure 4.5. Goat grazing for control of emergent vegetation at Bettencourt Basin

Six (6) observations of the degree of weed control were made over a nine (9) day period from August 5-August 14, 2003. Two (2) test sites (Plots 2 and 3 shown on Figure 4.4) were isolated from the other to prevent one site from impacting data collected at the other site.

Contra Costa County

The Contra Costa County Public Works Department (PWD) manages emergent aquatic weeds such tules in drainage basins and unlined floodwater conveyances throughout the county. These weeds are referred to as "emergent" because they typically root in water and "emerge" as they grow. At a minimum, emergent aquatic weeds require very moist soil and thrive in waterlogged or submerged soil. Flood control facilities are critical for the protection of infrastructure (roads, bridges, etc) and private property. The objective of aquatic weed control in these flood control facilities is to remove weeds so that design stormwater flows are achieved.

Emergent Aquatic Weed Control

The following two (2) different techniques for the control of tules were evaluated:

1. <u>Manual Removal</u>. This technique involved 3-5 man crews equipped with power brush cutters who typically cut tules at or near their base while wading through water

up to knee depth (Figure 4.6). After cutting, the crew rakes and stacks the cut tules onto canvas webbing that is then hoisted by crane onto 9 cubic yard capacity stakebed trucks (Figure 4.7). Once loaded, these trucks dispose of the cut tules at the local landfill. Tule cuttings are prohibited from green waste disposal diversion programs because of their slow rate of degradation and poor mulching quality.

2. Goats. Herds of goats were penned into specific areas and allowed to freely graze as described at Reclamation District 999.

Figure 4.6. Manual removal of tules using power brush cutters.

Figure 4.7. Hauling tules out of the removal site using a crane.

Approximately 12 observations of the degree of weed control and surface water sampling took place over a nine (9) week period from October 6 to December 9, 2003. The following two (2) sites were used:

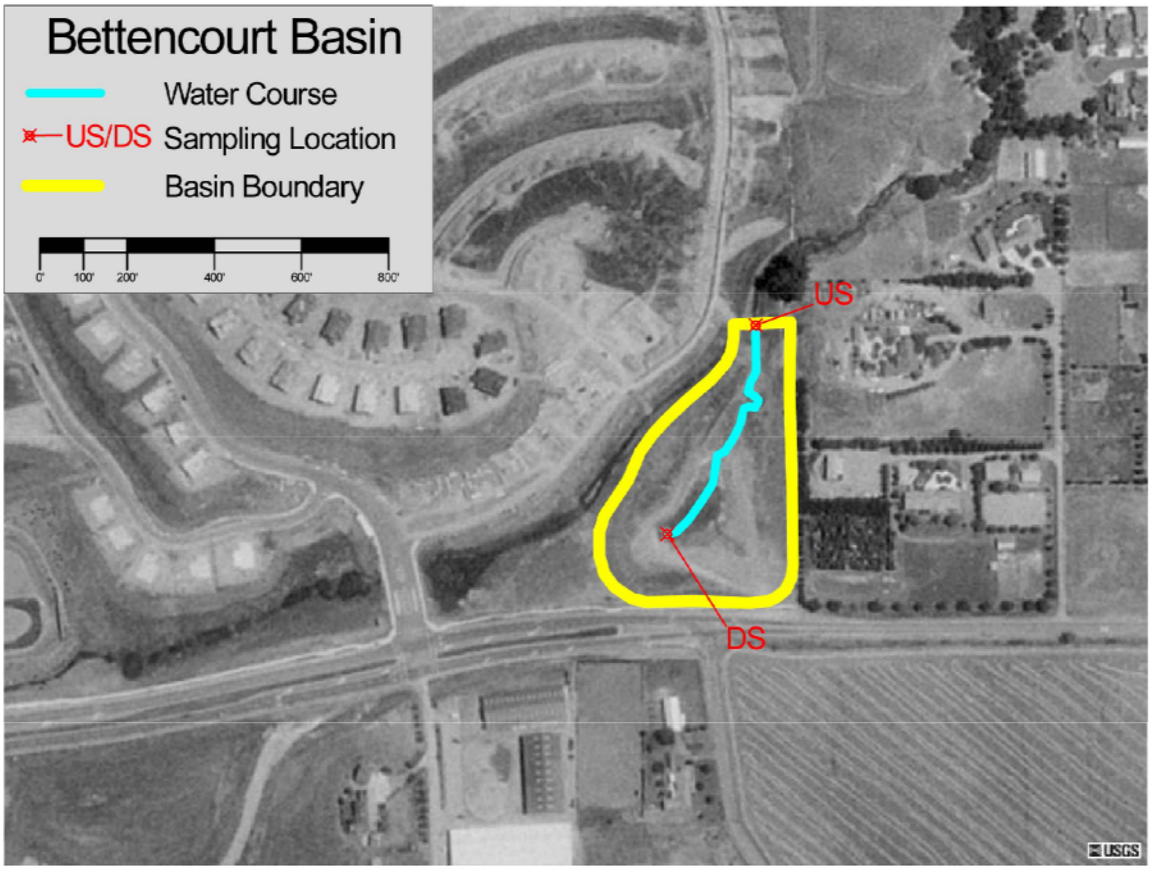
3. <u>Bettencourt Basin</u>. Bettencourt Basin is located off of Camino Tasajera in a residential area of Danville. Runoff enters the one (1) acre basin to the north and leaves the basin through a large trash rack structure located at the bottom portion of the basin. During the summer incidental residential runoff enters the basin. During the winter, stormwater flows into the basin and is detained to allow for percolation and evaporation.

   Significant tule growth in the basin impedes flow during peak flow events. Shallow water depth in the basin during weed abatement did not prevent goats from moving freely within the pen (Figure 4.5). Had the water depth been in excess of approximately one (1) foot, goats may have not entered areas where tules were present, or entered that area and gotten stuck and either became disabled or died. 500 goats were used to abate tules in this location for five days from October 12-16, 2003.

   Five surfacewater samples were collected upstream (US) and downstream (DS) of the basin from starting on October 12 and ending on December 9, 2003 (Figure 4.8).

Goat grazing activity was confined to the area downstream of the DS location and upstream of the US location.

Figure 4.8. Sample site location for evaluation of goat grazing at Bettencourt Basin.



4. Rodeo Creek. Rodeo Creek is an approximately 1 mile long urban creek located in the City of Rodeo (Figure 4.9). The creek's bank width varies from approximately 20 to 100 feet across. Nominal amounts of summer flow are a result of urban runoff. The creek's ability to convey winter stormwater flows may be impeded by the significant tule growth in and on the banks of the creek.

   County labor crews equipped with gas-powered cutters, cranes and trucks cut, loaded and hauled tules in this location on three (3) separate occasions from October 6-10, 2003. In contrast to Bettencourt Basin, Rodeo Creek was too deep in many locations to be effectively abated by goats without the loss of some animals.

   Seven (7) locations along the creek were sampled to gauge both temporal and spatial changes in water quality during mechanical abatement (Figures 4.9 and 4.10). An US sample was also collected to assess water quality before entering the area being manually abated and assessed. For example, sample locations were selected up stream, within, and downstream of areas being abated to assess water quality before, during and after abatement. The number and frequency of sample collection is described in the Figure 5 series.

Figure 4.9. Sample site location for evaluation of manual removal using hand-held weed cutters at Rodeo Creek.

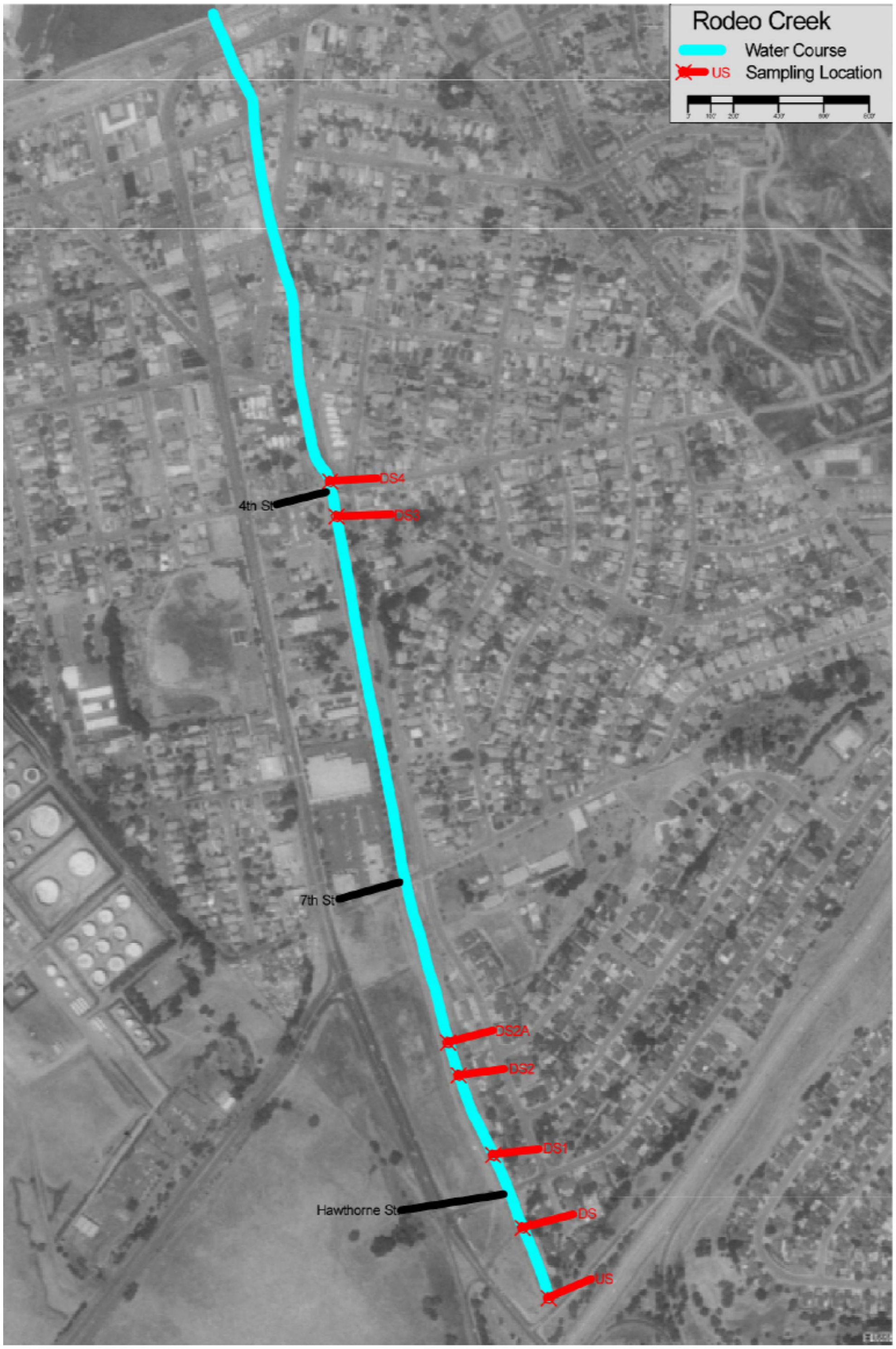
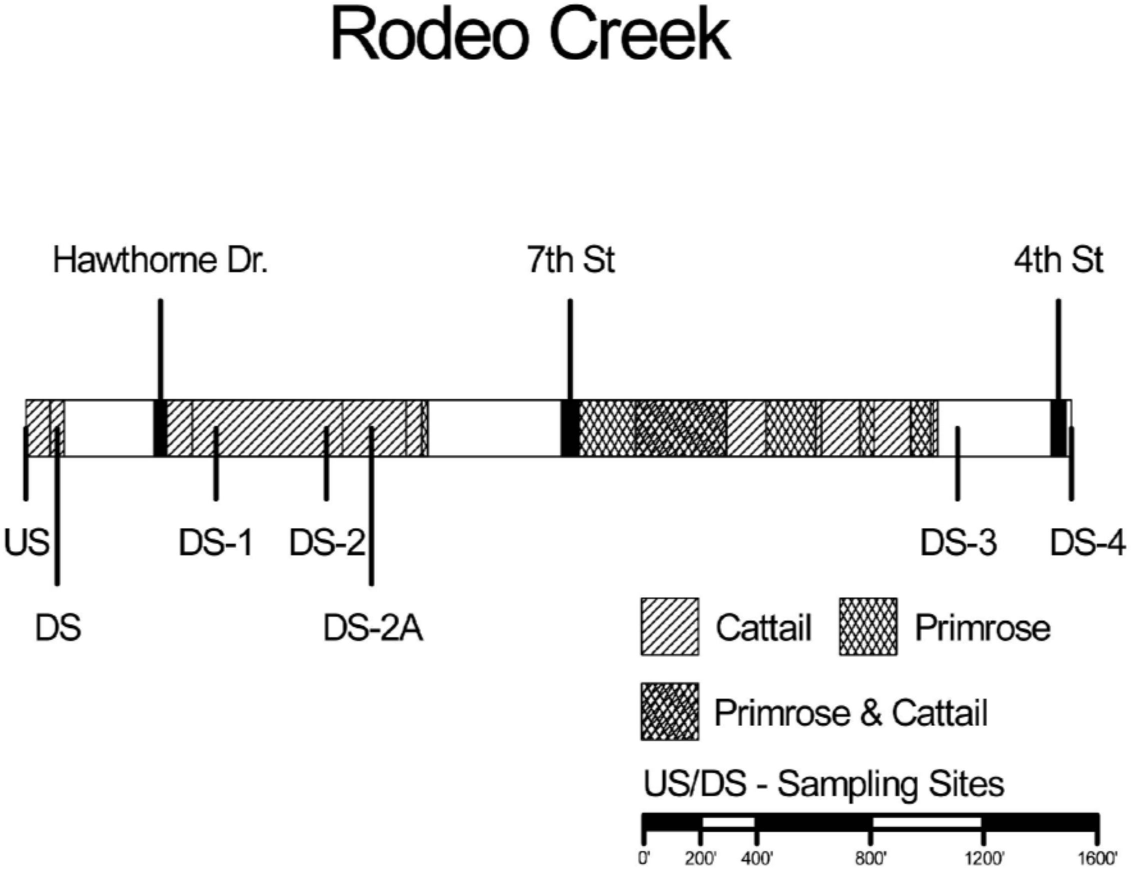


Figure 4.10. Schematic sampling design for evaluation of manual removal using hand-held weed cutters at Rodeo Creek.



5. RESULTS

Emergent Aquatic Weeds

Environmental Impacts

Varying degrees of primarily short-term impacts to water quality were observed.

Observations and the collection of surface water samples took place during, and after goats grazed at Bettencourt Basin; and before, during, and after crews equipped with power equipment worked in Rodeo Creek. Because no sampling was done before goats arrived at Bettencourt Basin, sampling continued until downstream parameters equaled or exceeded upstream parameters. The upstream location is isolated from downstream conditions by a 15 ft high spillway, making it an adequate benchmark to compare the effects of goats to water quality.

Electrical conductivity (EC), phosphorous (P) and turbidity went up and then dropped shortly after goats finished Bettencourt Basin (Figure 5.1, 5.2, and 5.3). This may be attributed to the agitation and suspension of sediment as a result of goats wading through the shallow water of the basin.

Figure 5.1. Bettencourt Basin Electric Conductivity

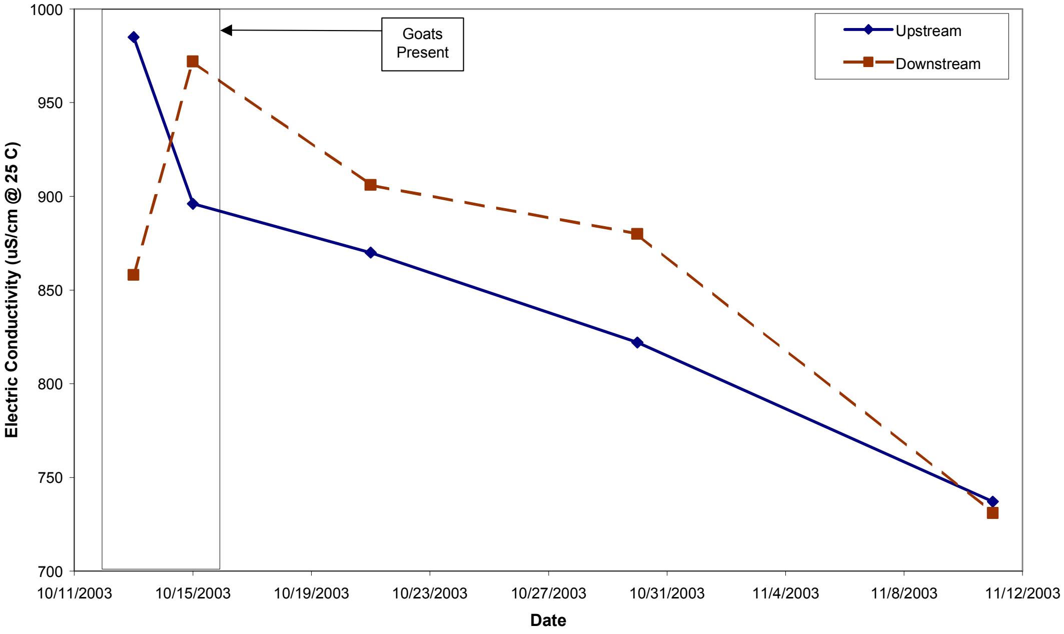


Figure 5.2. Bettencourt Basin Phosphorus

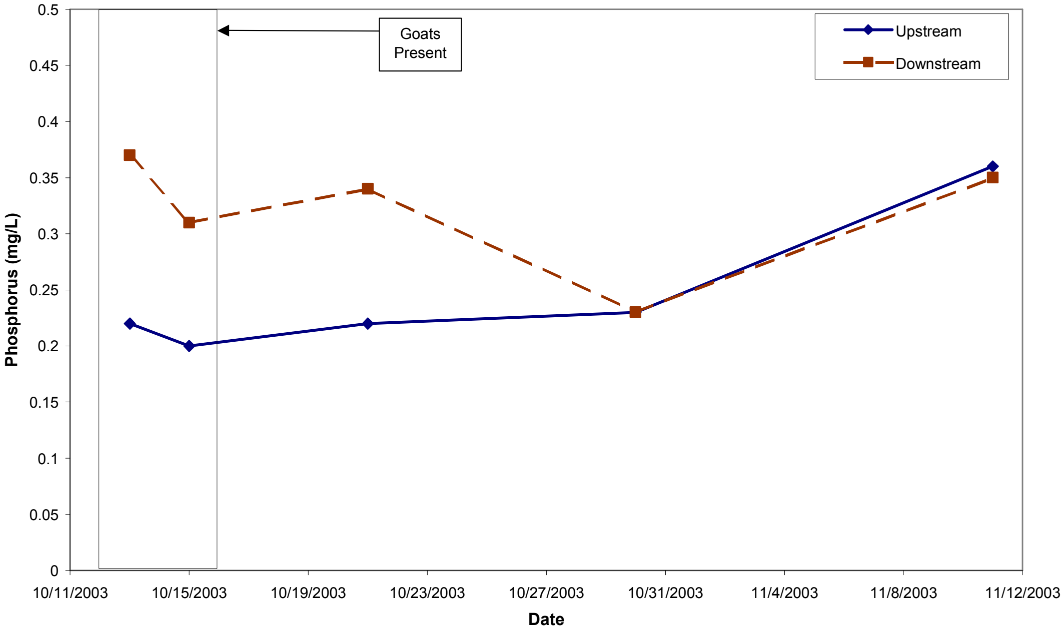
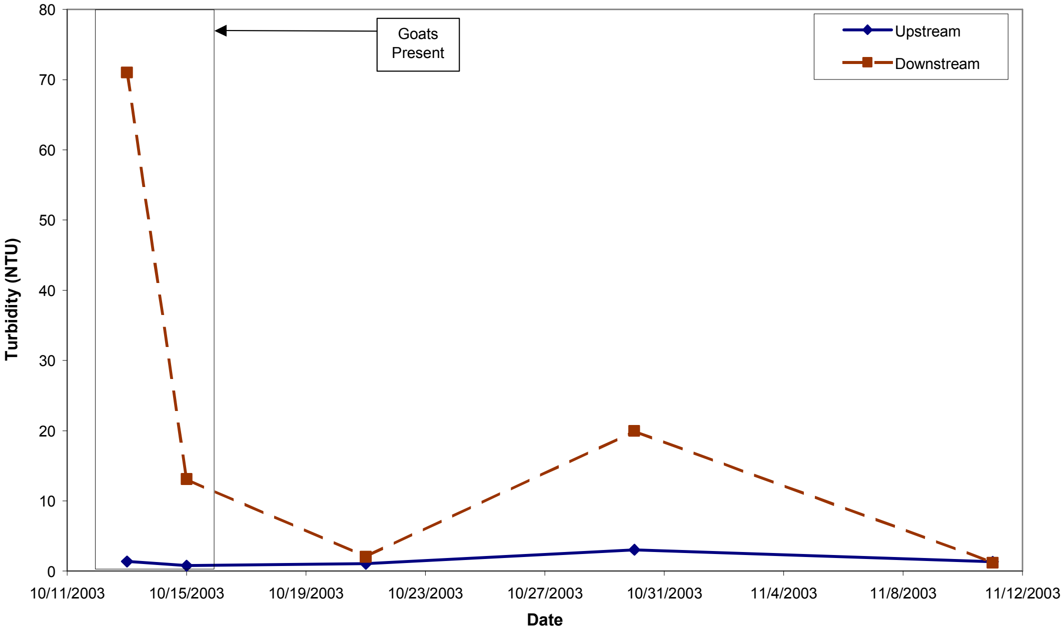
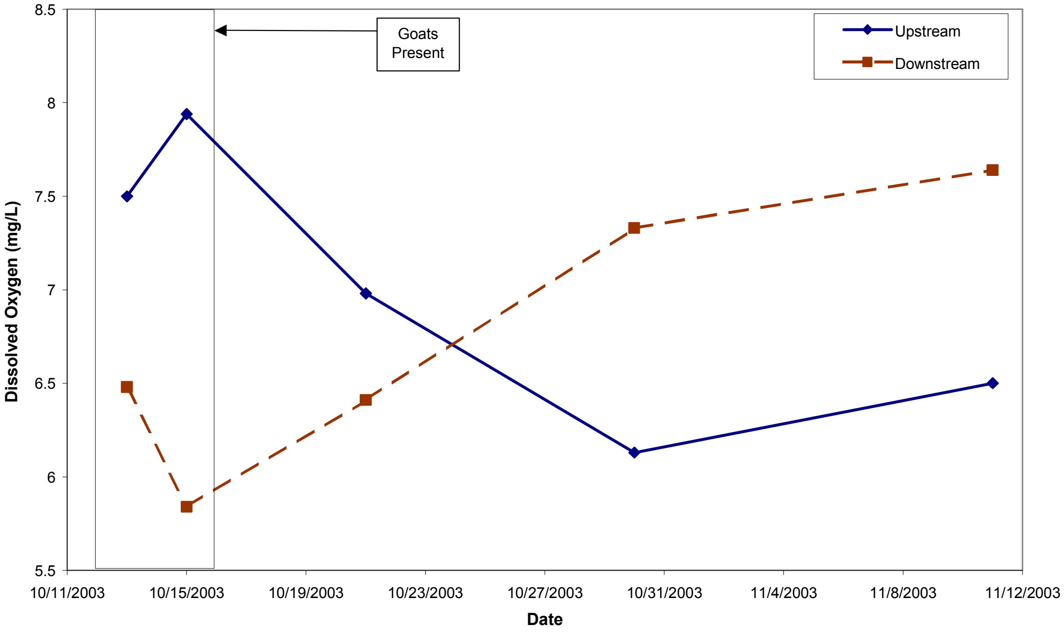


Figure 5.3. Bettencourt Basin Turbidity



In the Bettencourt Basin downstream location, dissolved oxygen (DO) initially dropped and then increased and stayed higher than the upstream (US) location (Figure 5.4).

Figure 5.4. Bettencourt Basin Dissolved Oxygen



Inputs to Rodeo Creek resulted in a one-time spike of ammonia and a subsequent detection of total Kjeldahl nitrogen (TKN) in the US sample (Figures 5.5 and 5.6).

Figure 5.5. Rodeo Creek ammonia by date.

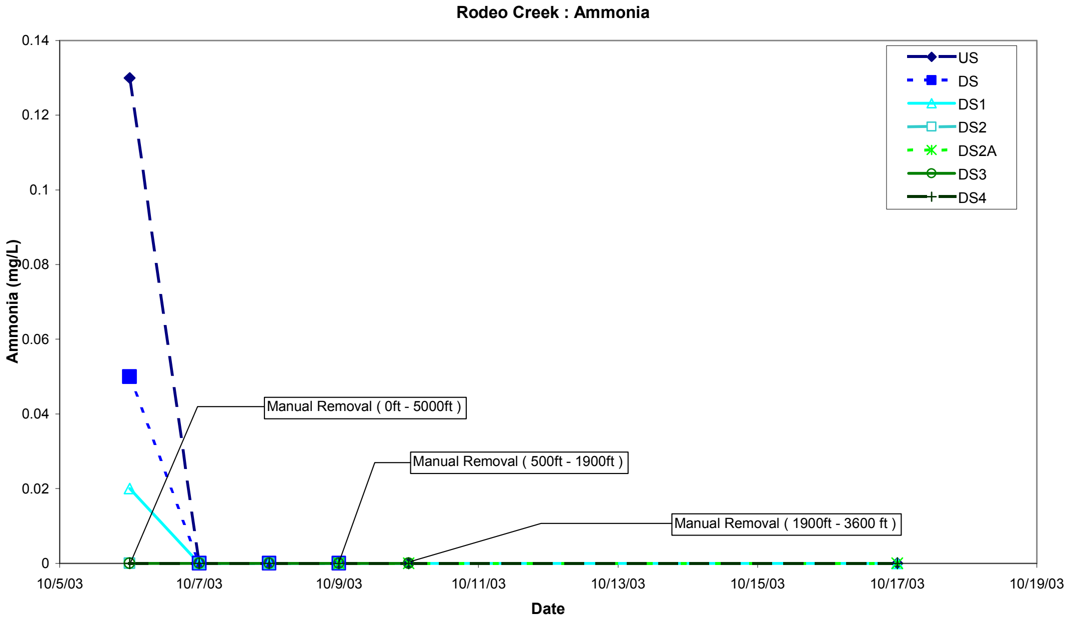
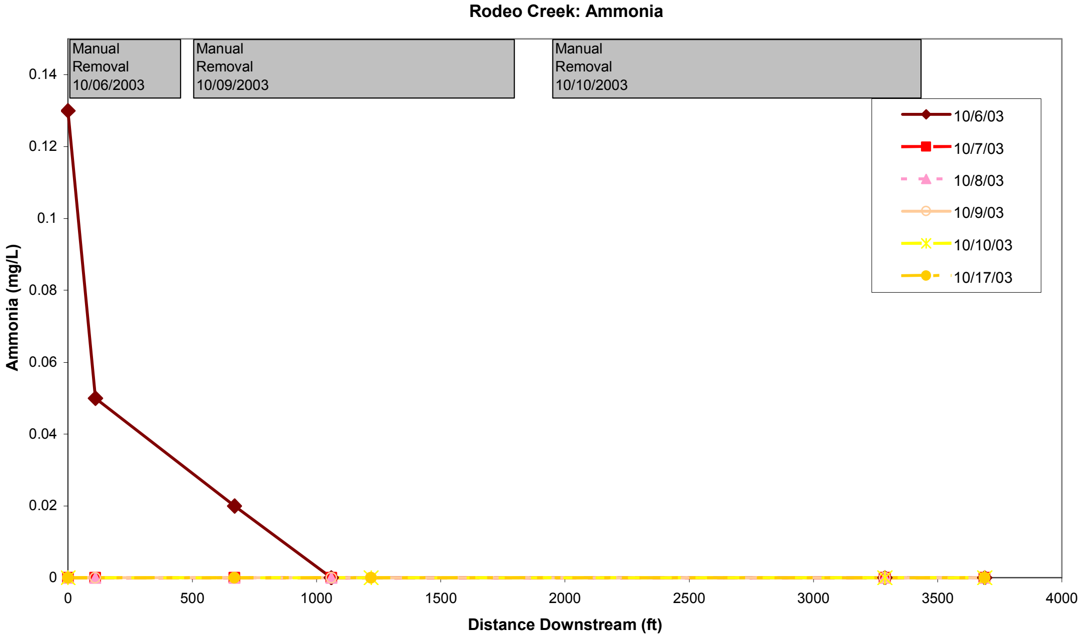


Figure 5.6. Rodeo Creek ammonia by distance downstream.



In Rodeo Creek, DO increased shortly after manual abatement and then decreased with time and distance downstream (Figures 5.7 and 5.8). Once abatement ceased, DO appeared to return to near pre-abatement concentrations (Figure 5.7).

Figure 5.7. Rodeo Creek dissolved oxygen by date.

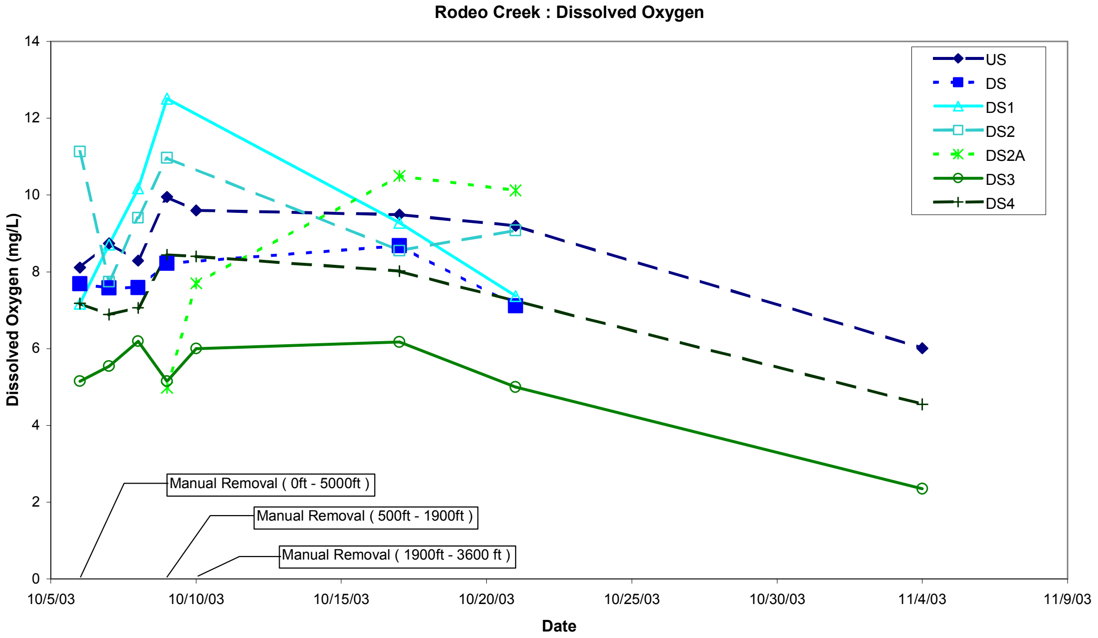
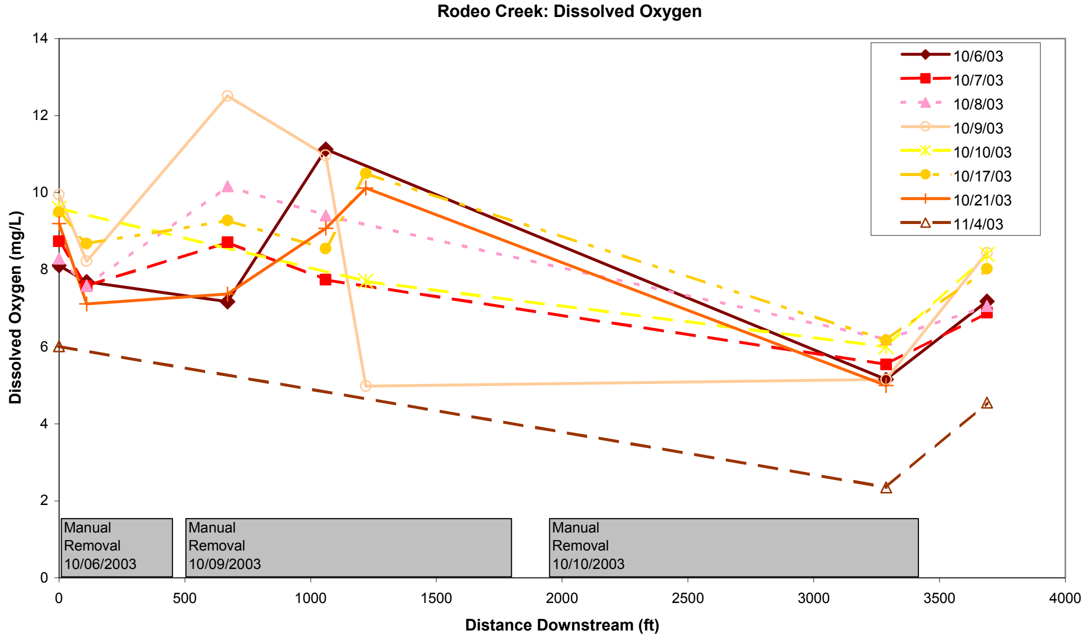


Figure 5.8. Rodeo Creek dissolved oxygen by distance downstream.



For Rodeo Creek, both EC and turbidity increased at and downstream (DS) of abatement sites and remained elevated for only short periods (Figures 5.9 and 5.10).

Figure 5.9 Rodeo Creek EC. First panel is by date. Second panel is by distance downstream.

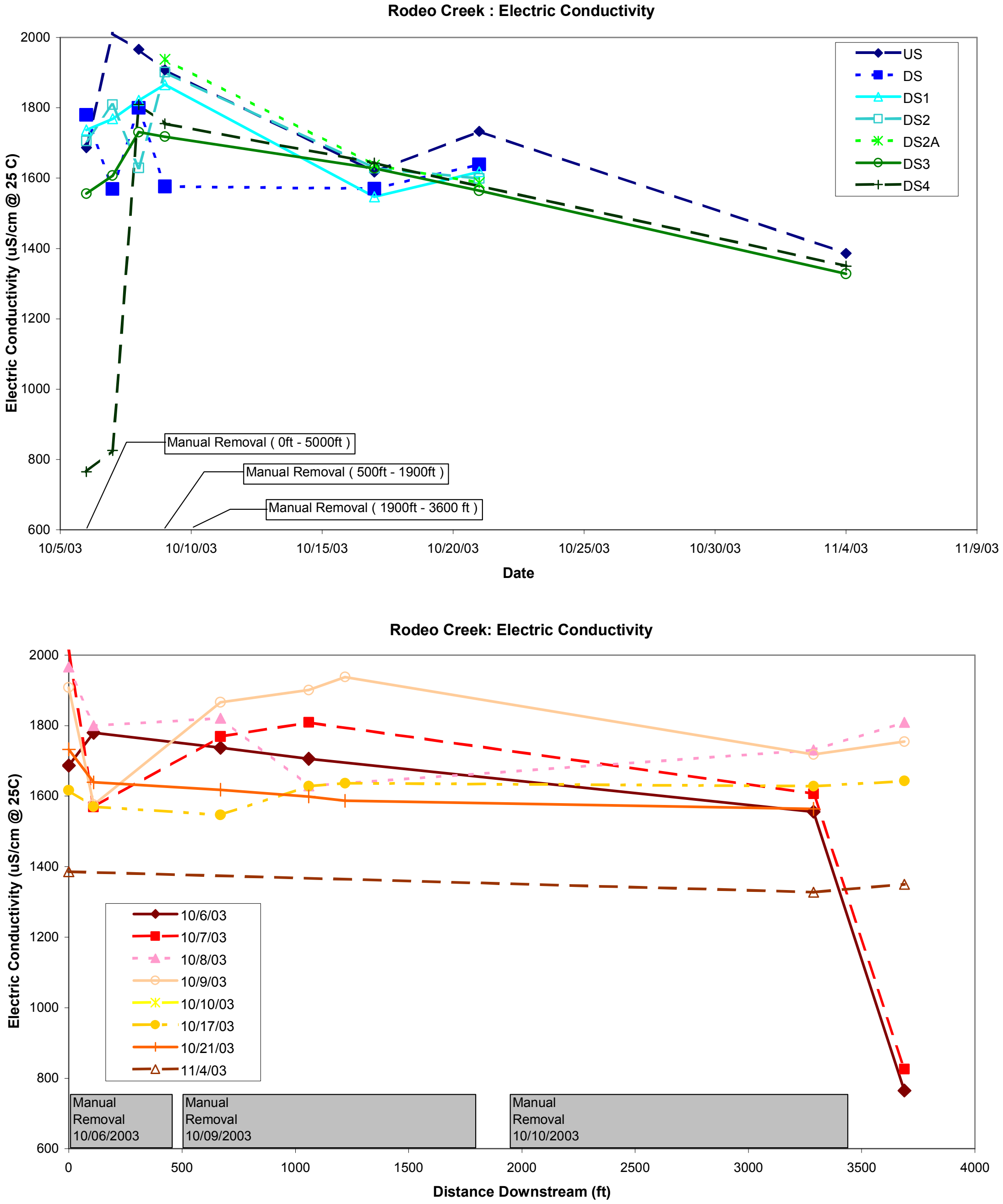
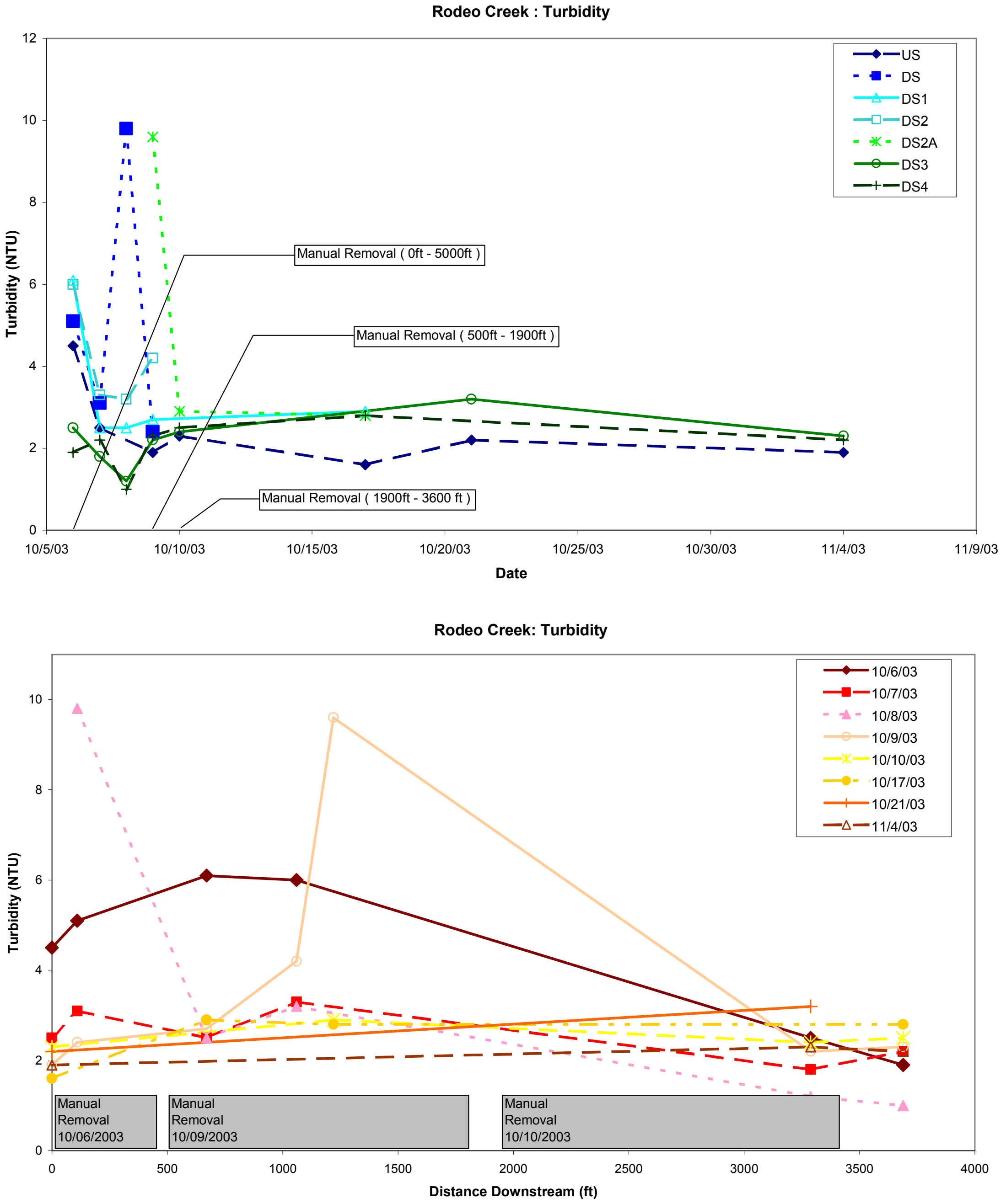


Figure 5.10 Rodeo Creek turbidity. First panel is by date. Second panel is by distance downstream.

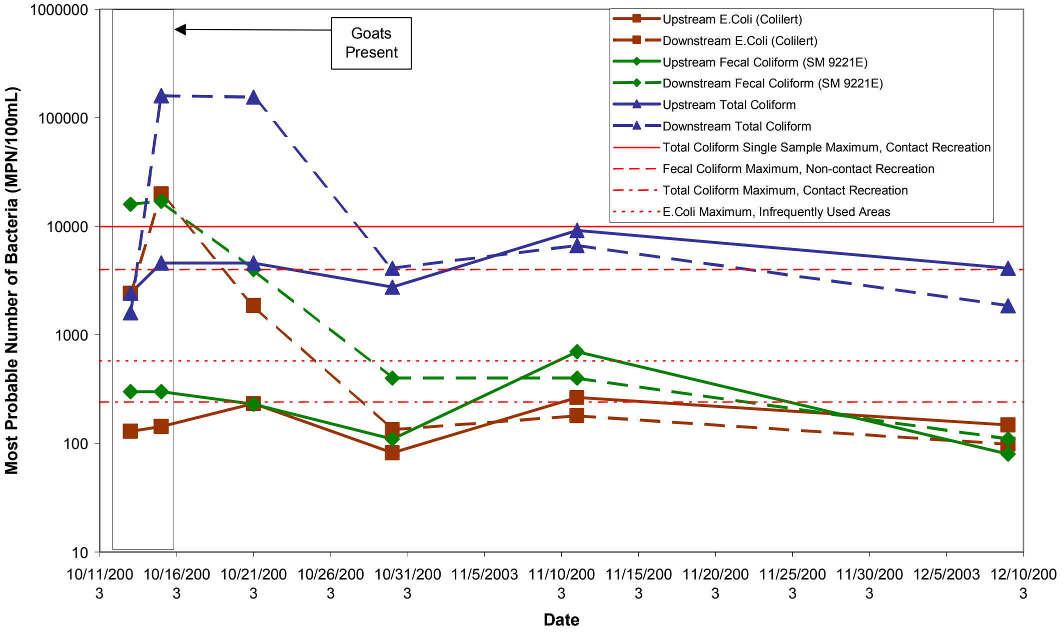


Although crews in Rodeo Creek used power equipment, no petroleum hydrocarbons were detected in water sampled in and downstream of the sites being abated. Within 2 weeks of cutting, re-growth was noted where manual cutting had been done.

A transient but significant increase in coliform (total and fecal) and *E. coli* from goat feces followed the presence of the goats in Bettencourt Basin (Figure 5.11). After goats left, the concentration of coliform and *E. coli* dropped below levels generally considered acceptable by the Central Valley (Region 5) and San Francisco (Region 2) Regional

Water Quality Control Boards (RWQCBs) and the U.S. Environmental Protection Agency (USEPA) (Figure 5.11; Table 5.1).

Figure 5.11. Bettencourt Basin Total Coliform, Fecal Coliform and E. Coli



Fecal coliform bacteria are a subgroup of total coliform bacteria, and *Escherichia coli* (*E. coli*) is a particular genus and species of fecal coliform. Fecal coliform bacteria depend on their host environment for survival and reproduction and found in the intestinal tracts of warm-blooded animals. The presence of fecal coliform bacteria in a water body can indicate the presence of animal waste and may indicate the presence of pathogens.

These organisms die after remaining outside their host organisms, through physical/chemical processes such as hydrolysis, sunlight degradation, and protozoan consumption. Aquatic and wetland environments are hostile to these organisms and have been shown to greatly reduce most pathogenic biological agents, with numbers decreasing as a function of retention time (Krishnan and Smith 1987; Garvey et al. 1988). For example, biofilters operating under conditions similar to those at Bettencourt Basin typically achieve between 90 and 99% removal efficiencies of fecal coliform (Reed and Brown 1992).

Regulatory values for fecal and total coliform and *E. coli* are summarized in Table 5.1. The USEPA recommends that *E. coli* be used as an indicator of fecal contamination in recreational waters. For example, the concentration of 126 Most Probable Number (MPN) of colonies per 100 milliliters (mL) is correlated with a gastrointestinal illness rate of about 8 individuals per 1,000 swimmers. Fecal coliform densities show little or no relation to gastrointestinal illness in swimmers.

Table 5.1. Bacteria water quality criterion established by Regional Water Boards and USEPA.

		All Values in MPN/100mL			
	Beneficial Use or Area	**FC**	**EC**	**TC**	**Note**
Region 5 - Central Valley	Contact Recreation (Rec-1)	200			Geometric mean
		400			90th percentile
	Folsom Lake	100			Geometric mean
		200			90th percentile
Region 2 - Bay Area	Contact Recreation (Rec-1)	200[b]		240[c]	b log mean; c median
		400[d]		10000[e]	d 90th percentile; e maximum single sample value
	Non-Contact Recreation (Rec-2)	2000			mean
		4000			90th percentile
	Municipal Supply Surface Water	20		100	log mean
	Municipal Supply Ground Water			1.1	based on multiple tube fermentation technique
EPA Water Contact Rec	Steady State (All Areas)		126		Geometric mean
	Max designated beach		235		based on 75% one sided confidence level of geometric mean
	Max moderately used area		298		based on 82% one sided confidence level of geometric mean
	Max lightly used area		406		based on 90% one sided confidence level of geometric mean
	Max infrequently used area		576		based on 95% one sided confidence level of geometric mean

Notes:

[a] based on minimum of 5 samples in a 30 day period
MPN - Most Probable Number
FC - Fecal Coliform
EC - E. Coli
TC - Total Coliform

Efficacy

The use of goats to graze Bettencourt Basin was moderately effective. Virtually all brushy vegetation within the reach of the goats was denuded. However, tules were the last food source to be eaten and clearly were not preferred by the goats. Essentially all of Bettencourt Basin was accessible to the goats and no goats were stuck or drowned.

Manual removal of tules in Rodeo Creek was effective but extremely labor intensive. In most cases, crews required frequent rests due to the very physical and strenuous nature of the work. In addition, numerous slip, trip and fall hazards existed for the work crew because steep slopes had to be ascended and descended and wet or submersed surfaces were regularly encountered. Within 2 weeks of cutting, re-growth was noted where manual cutting had been done (Figure 5.12). As a result of this re-growth, manual removal is required on an annual basis.

Figure 5.12. Site of manual cutting 2 weeks after removal completed.

Economics

Data on costs is summarized in Table 5.2 and Figure 5.13**.** For comparison purposes, the use of goats was compared to the application of a systemic herbicide (glyphosate). Further, manual abatement was compared to the application of a systemic herbicide (glyphosate) and also compared to another site for which cost data was available (Canyon Lakes). The data reflect the substantial level of effort expended by manual crews. The cost for goat grazing and chemical application were calculated to be roughly the same.

It must be noted that comparison of goat cost data to any other cost data should take into account the goat's appetite (or lack thereof) for the weed, any ingress/egress problems goats may have that may result in injury or death, and the impacts to water quality caused by goat feces.

Table 5.2 Control cost data for various methods of controlling emergent aquatic weeds.

Test Plot			BC Basin		Rodeo Creek[7]		Canyon Lakes[8]		Typical[6]	
Abatement Method			Goats		Manual		Manual		Chemical	
Weed Type			Emergent Aquatic		Emergent Aquatic		Emergent Aquatic		Emergent Aquatic	
Test Plot Size (Acres)			0.75		2.8		1.7		1.7	
Category	Cost	/Unit	# Units	Cost	# Units	Cost	# Units	Cost	# Units	Cost
Labor										
Management Time	$99.75	/hr			27.4	$2,733.15	33	$3,291.75		
Field Labor Time	$60.00	/hr			205.5	$12,330.00	330	$19,800.00		
Equipment Operator	$82.94	/hr			68.5	$5,681.39	82.5	$6,842.55		
Workers Compensation	$145.00	/man*hours			274	$39,730.00	412.5	$59,812.50		
Equipment										
Utility Truck	$20.00	/hr			68.5	$1,370.00	82.5	$1,650.00		
Dump Truck	$35.00	/hr			68.5	$2,397.50	82.5	$2,887.50		
Boom Truck	$30.00	/hr			68.5	$2,055.00	82.5	$2,475.00		
Car	$6.00	/hr			27.4	$164.40	33	$198.00		
Excavation Equipment + Operator	$60.00	/hr								
Goat Rental (T&V Livestock)	$0.40	/head/day	2500	$1,000.00						
Disposal										
Landfill Tipping Fees[1]	$15.00	/ton			40	$600.00	39	$585.00		
Chemical Application										
Medium Weed Density	$197.00	/acre								
Heavy Weed Density	$1,374.00	/acre							1.7	$2,335.80
Permits										
Aquatic Pesticides[9]	$2,000.00	/65 acre							1.7	$52.31
CDFG Permit										
COE Permit										
Desilt Permit										
Total Cost				$1,000.00		$67,061.44		$97,542.30		$2,388.11
Cost Per Acre				**$1,333.33**		**$23,950.51**		**$57,377.82**		**$1,404.77**

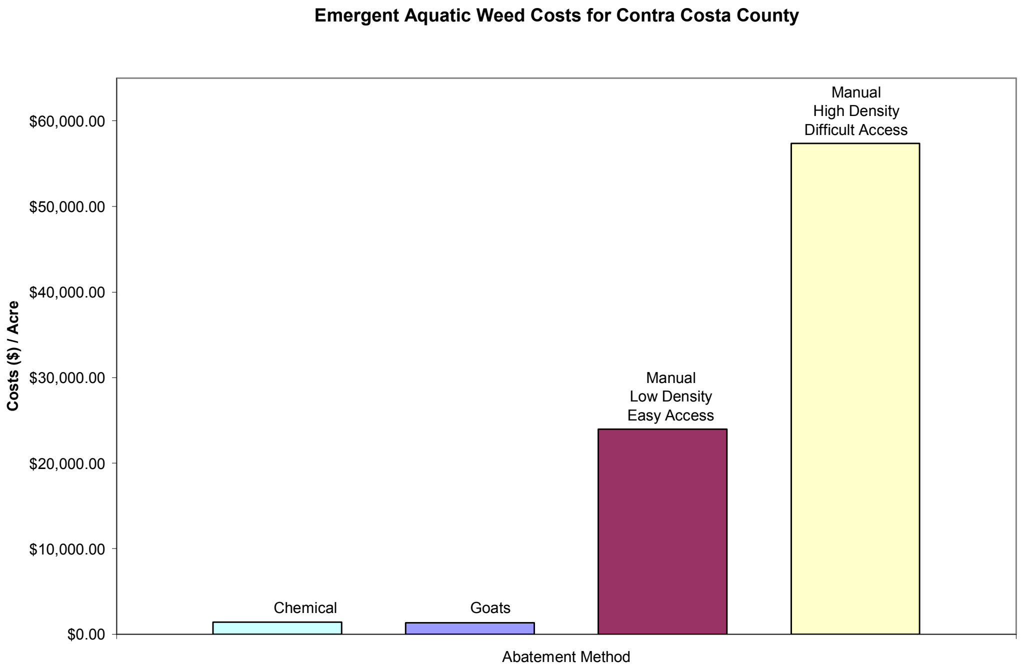
General Notes and Footnotes:

(1) Tules are not greenwaste and can't be diverted
(2) Typical test plot represents chemical abatement cost for heavy weed density
(3) Cost of field labor includes equipment and disposables (brush cutters, gloves, fuel, travel, etc.)
(4) Manual Abatement is material removal with a combination of hand labor and equipment (brush cutters, cranes, etc.)
(5) Mechanical Abatement is material removal with excavators, No hand labor used
(6) No workers compenstation costs attributed to this technique based on claim history over last 13 years
(7) Rodeo Creek site is easy to access with low density weeds
(8) Canyon Lakes site is difficult to acess with high density weeds. Included for comparison purposes only. No observation or sampling done.
(9) Assumes 65 acres treated and a permit fee and compliance cost of $2,000

Workers compensation costs were calculated from Contra Costa County Public Works Department cost records for manual removal of tules. A total of 400 man-hours were used to do this work and resulted in four (4) workers compensation claims at an average of $15,000 each. Therefore the workers compensation cost is for this type of work only, and does not average the cost with other, less hazardous, tasks that crews may perform year-round. Hazards for crews working on manual removal include:

1) Trip, Slip and Fall Hazards compounded by steep and uneven terrain on the banks and slippery, hidden terrain features underwater.
2) Injury by use of hand-held powered brush cutters with an open blade, compounded by high noise and multiple workers in the same location
3) Operating overhead equipment
4) Heat fatigue, this work is typically done in the summer, rubber hip waders compound the heat.

Figure 5.13. Cost effectiveness for various methods of controlling emergent aquatic weeds.



Floating Aquatic Weeds

Environmental Impact

Observations and the collection of surface water samples took place before, during, and after mechanical removal, and chemical application followed by mechanical removal of floating aquatic weeds at the Upper Main Drain (UMD), Lower Main Drain (LMD), and Tule Canal (TC) within Reclamation District 999.

The LMD and UMD locations exhibited similar water quality characteristics during weed abatement. For example, no significant changes were observed in EC or DO at either location. At both locations during the mechanical treatment of plots 2 and 3 water samples showed slight, transient increases in P, TKN and turbidity (Figures 5.14, 5.15, 5.16, 5.17, 5.18, and 5.19). A transient increase in nitrate/nitrite was observed after mechanical treatment of plot 2 at LMD (Figure 5.20). The reason(s) for these transient increases are unknown, but may include the close proximity of the test plots.

Figure 5.14. Upper Main Drain Phosphorus

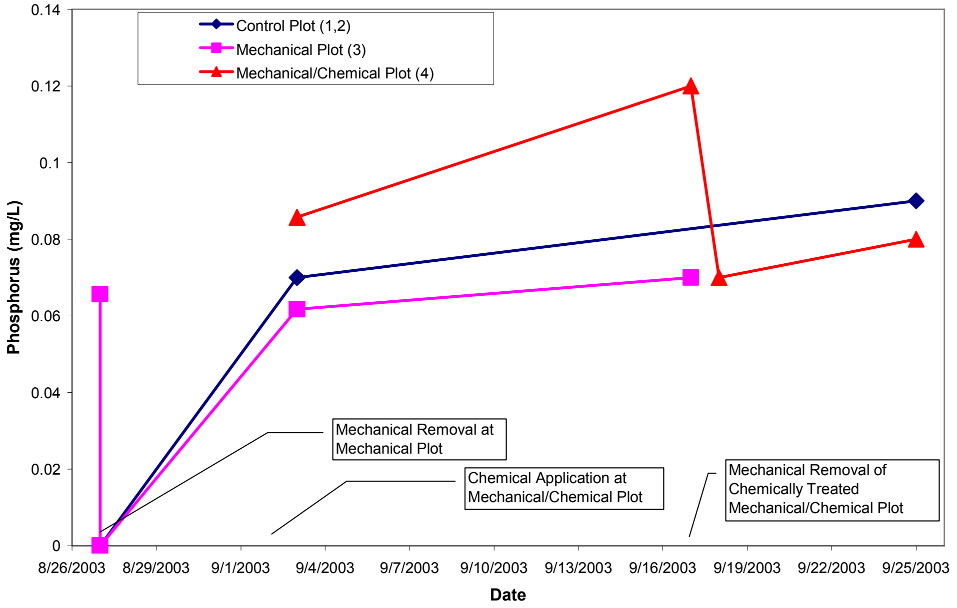


Figure 5.15. Lower Main Drain Phosphorus

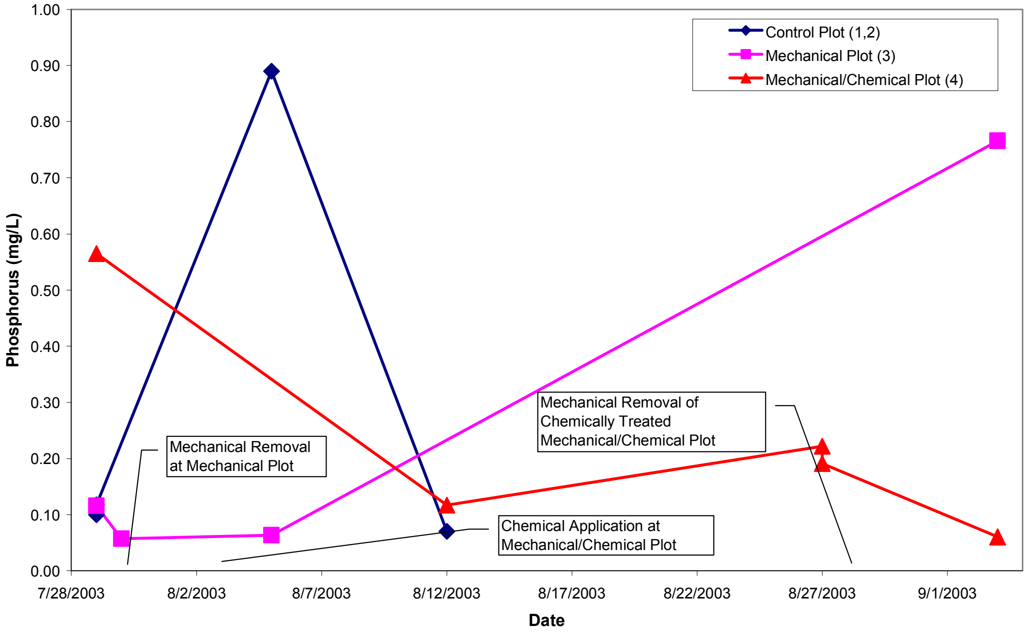


Figure 5.16. Upper Main Drain Total Kjeldahl Nitrogen

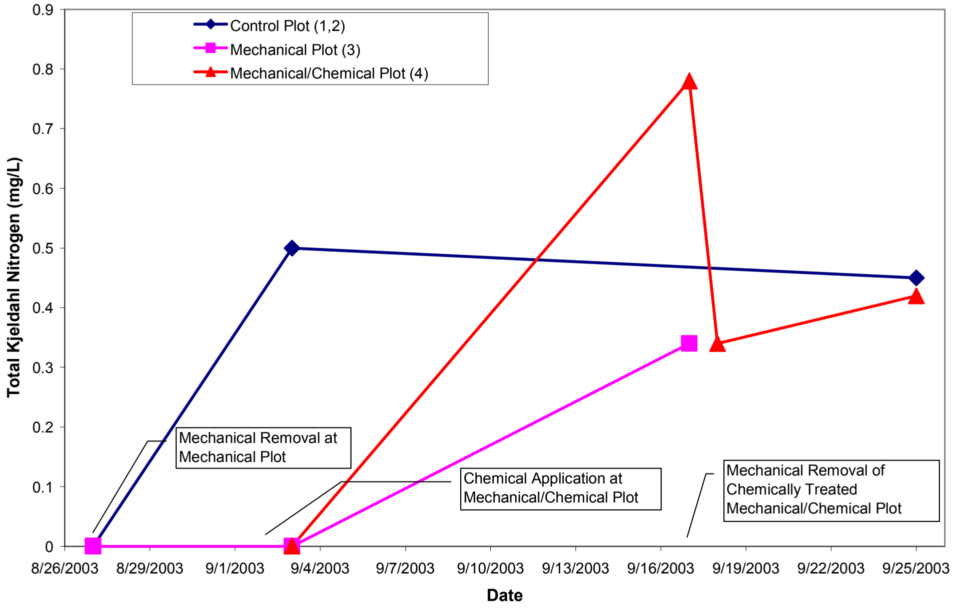


Figure 5.17. Lower Main Drain Total Kjeldahl Nitrogen

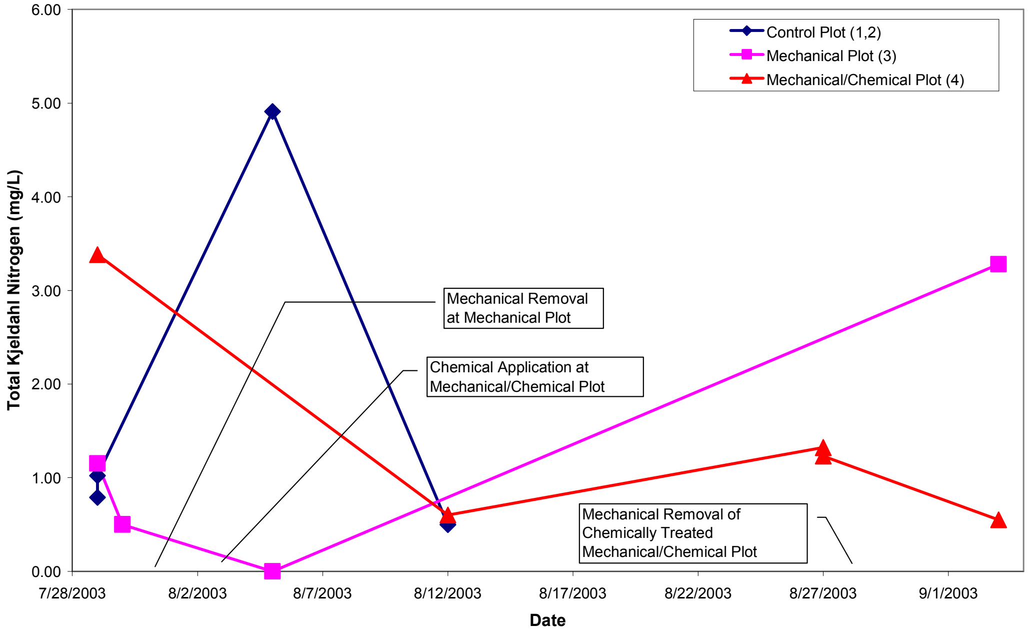


Figure 5.18. Upper Main Drain Turbidity

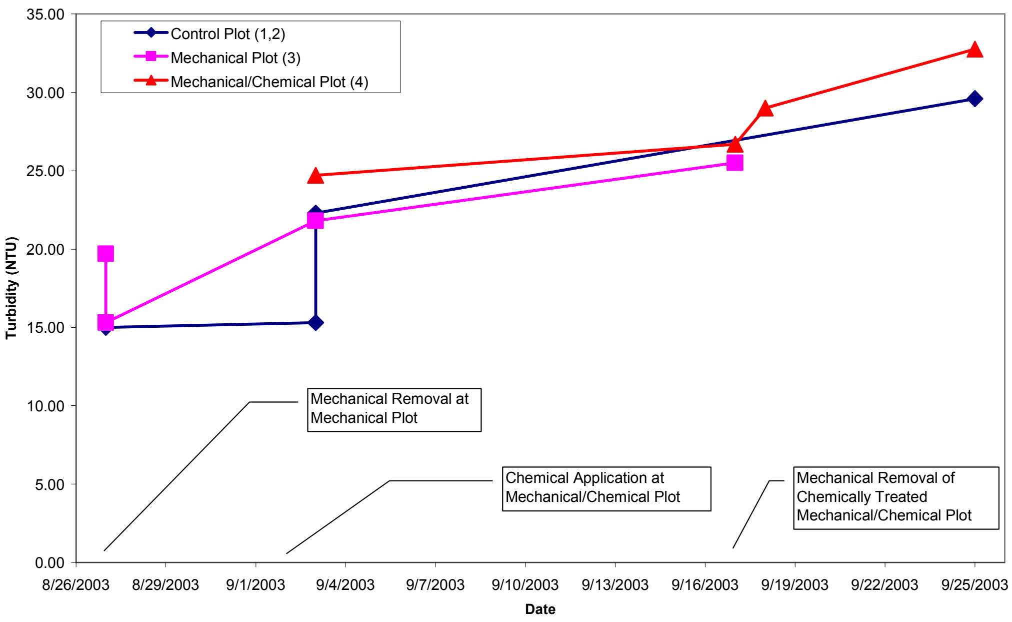


Figure 5.19. Lower Main Drain Turbidity

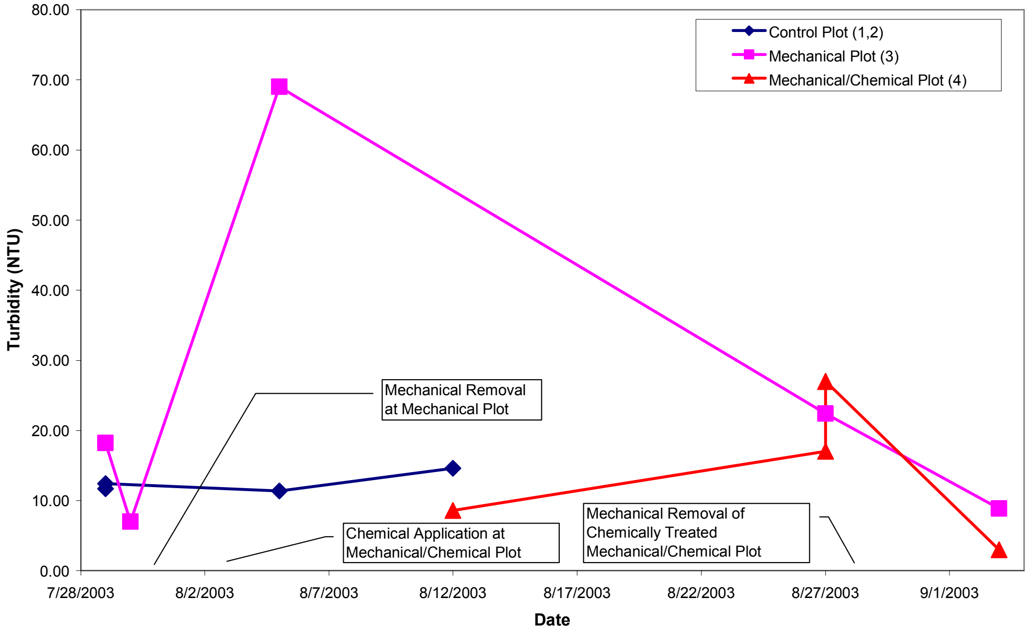
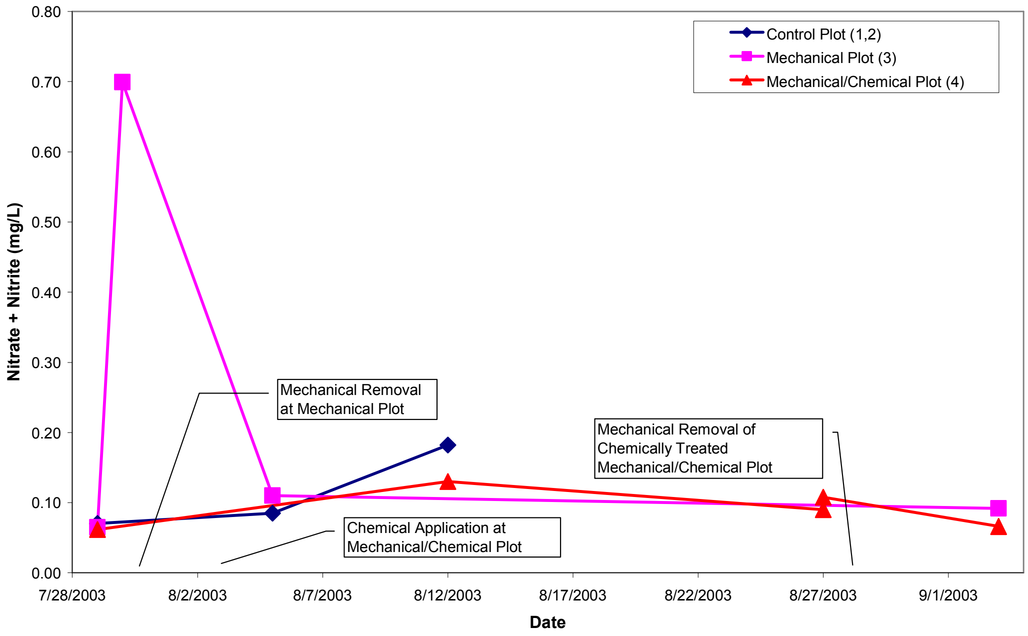


Figure 5.20. Lower Main Drain Nitrate + Nitrite



Other than an unexplained increase in TKN and P at the US location, no significant changes in water quality parameters were apparent at any of the test plots throughout the duration of the trial at the TC location. The reason(s) for these increases are unknown, but may include the close proximity of the test plots.

Efficacy

The combination of chemical/mechanical removal was the most effective technique observed. Minimum weed re-growth was observed during the 2003 sampling events after this technique. In 2003, only slightly less re-growth was observed after chemical treatment alone.

Even with an extended reach backhoe, it was not possible to remove all of the weed root structure to stop re-growth. As a result, significant re-growth was observed after mechanical removal. Mechanical removal of primrose at the UMD and the LMD was significantly more effective than the removal of milfoil at the TC. The modified backhoe bucket used was not effective at removing milfoil because it was not densely vegetated and in contrast to primrose, milfoil does not form dense interwoven floating mats on the water surface.

Upon revisiting the site in May, 2004, it appeared that the chemical/mechanical combined approach was much more effective than either treatment alone. Areas that were subjected to only one treatment (either chemical or mechanical) were reinfested with water primrose. In contrast, water primrose was absent from the combined treatment plot (Figure 5.21).

Although not part of this study, according the Reclamation District personnel, the use of chemical control alone is likely the most effective in cases where moving water transports and agitates dead plant material so that it no longer floats and obstructs flow.

Figure 5.21. Reclamation District 999, Lower Main Drain (LMD) chemical/mechanical evaluation site, May 4, 2004. Primrose is absent in the treatment site but extensive in the surrounding channel.

Economic Analysis

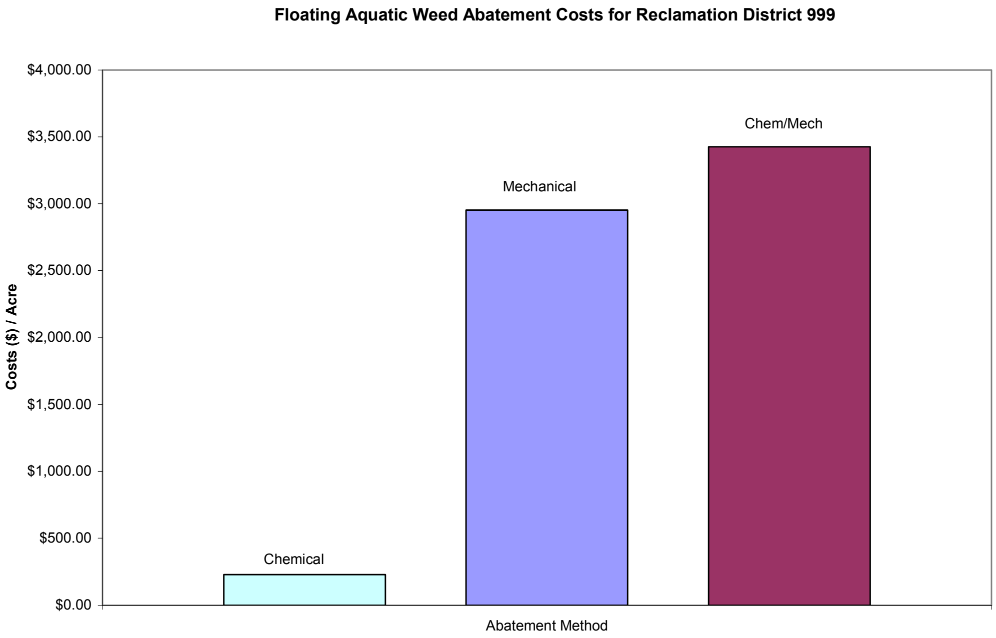
Data on costs are presented in Table 5.3 and Figure 5.22. The chemical/mechanical treatment was the most expensive, followed by mechanical, and then chemical treatment. Far better long-term control was achieved with the chemical/mechanical technique as re-growth occurred after only mechanical removal.

Table 5.3 Control cost data for various methods of controlling floating aquatic weeds.

Test Plot			RD999		RD999		RD999	
Abatement Method			Chemical		Mechanical		Chem/Mech	
Weed Type			Floating Aquatic		Floating Aquatic		Floating Aquatic	
Test Plot Size (Acres)			0.075		0.075		0.075	
Category	Cost	/Unit	# Units	Cost	# Units	Cost	# Units	Cost
Labor								
Management Time	$99.75	/hr						
Field Labor Time	$60.00	/hr						
Equipment Operator	$82.94	/hr						
Workers Compensation	$150.00	/man*hours			1.08	$162.00	1.17	$175.50
Equipment								
Utility Truck	$20.00	/hr						
Dump Truck	$35.00	/hr						
Boom Truck	$30.00	/hr						
Car	$6.00	/hr						
Excavation Equipment + Operator	$60.00	/hr			1.08	$64.80	1.17	$70.20
Goat Rental (T&V Livestock)	$0.40	/head/day						
Disposal								
Landfill Tipping Fees[1]	$15.00	/ton						
Chemical Application								
Medium Weed Density	$197.00	/acre	0.075	$14.78			0.075	$14.78
Heavy Weed Density	$1,374.00	/acre						
Permits								
Aquatic Pesticides[2]	$2,000.00	/65 acre	0.075	$2.31			$0.08	$2.31
CDFG Permit								
COE Permit								
Desilt Permit								
Total Cost				$17.08		$226.80		$262.78
Cost Per Acre				**$227.77**		**$3,024.00**		**$3,503.77**

Notes:
(1) Tules are not greenwaste and can't be diverted
(2) Assumes 65 acres treated and a permit fee and compliance cost of $2,000
(3) Cost of field labor includes equipment and disposables (brush cutters, gloves, fuel, travel, etc.)
(4) Manual Abatement is material removal with a combination of hand labor and equipment (brush cutters, cranes, etc.)
(5) Mechanical Abatement is material removal with excavators, no hand labor used
(6) All Mechanical Abatement sites are easy to access

Figure 5.22. Cost effectiveness for various methods of controlling floating aquatic weeds.



Terrestrial Weeds

Environmental Impacts

Observations and the collection of surface water samples took place before, during, and after goats were grazed along the banks of Elk Slough in Reclamation District 999.

As shown in Figures 5.23 and 5.24**,** Plots #2 and #3 produced similar results. Transitory increases in total and fecal coliform and *E. coli* were observed shortly after goats had grazed near water. It took between 4 and 7 days after the goats departed for the concentrations of coliform and *E. coli* to return to pre-goat levels. At test site #2, turbidity increased and stayed elevated coincidentally with the presence of goats (Figure 5.23), perhaps as a result goat traffic on the banks of the levee, which after the goats had left, continued to erode. Dissolved oxygen appeared unaffected at either site.

In contrast to Bettencourt Basin, in Elk Slough, the concentration of total or fecal coliform or *E. coli* never exceeded any water quality objective presented in Table 5.1. In contrast to the slow moving water of Bettencourt Basin, the water in Elk Slough is significantly deeper and wider and was moving faster. As a result, coliform and *E. coli* in Elk Slough was quickly diluted.

Figure 5.23. Elk Slough Plot #2 Goat Study

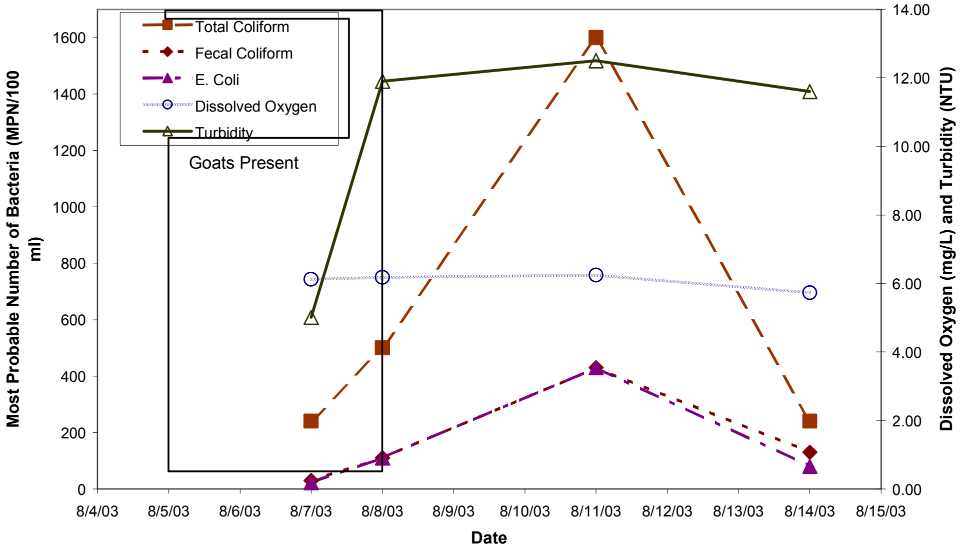
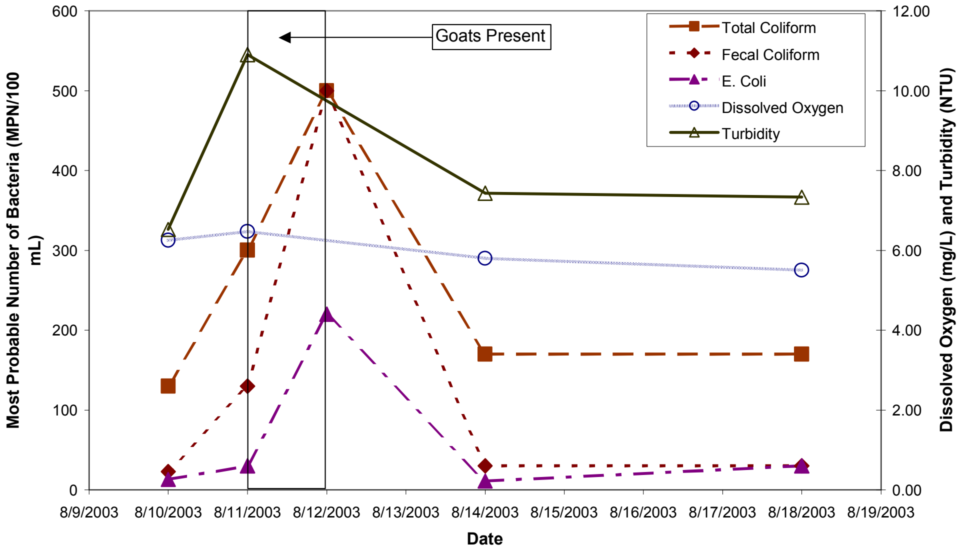


Figure 5.24. Elk Slough Plot #3 Goat Study



Efficacy

The use of goats to graze the banks of Elk Slough was very effective. Virtually all vegetation within the reach of the goats was denuded. The effectiveness of goat grazing was enhanced by the presence of desirable food sources. The majority of the levee slopes were accessible to the goats. However, several goats either got stuck near the water's edge and drowned when the tide rose or fell into the water and drowned.

Economics

Data on costs are calculated in Table 5.4 and summarized in Figure 5.25. For comparison purposes, the use of goats was compared to the application of a systemic herbicide (glyphosate). The cost for chemical treatment was slightly higher than that for the use of goats. Although not evaluated during this project, chemical treatment of brushy terrestrial vegetation such as that encountered at Elk Slough is not typically as complete or thorough as that achieved by goats.

Figure 5.25:

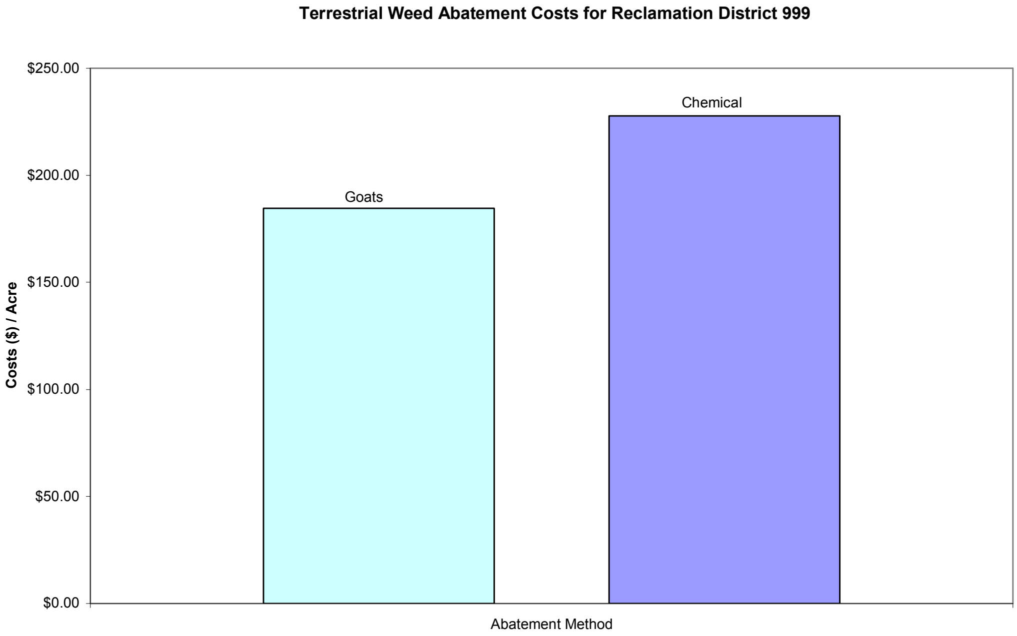


Table 5.4. Control cost data for goats vs. chemical control of terrestrial weeds.

Test Plot			Elk Slough		Typical[6]	
Abatement Method			Goats		Chemical	
Weed Type			Terrestrial		Terrestrial	
Test Plot Size (Acres)			13		13	
Category	Cost	/Unit	# Units	Cost	# Units	Cost
Labor						
Management Time	$99.75	/hr				
Field Labor Time	$60.00	/hr				
Equipment Operator	$82.94	/hr				
Workers Compensation	$145.00	/man*hours				
Equipment						
Utility Truck	$20.00	/hr				
Dump Truck	$35.00	/hr				
Boom Truck	$30.00	/hr				
Car	$6.00	/hr				
Excavation Equipment + Operator	$60.00	/hr				
Goat Rental (T&V Livestock)	$0.40	/head/day	6000	$2,400.00		
Disposal						
Landfill Tipping Fees[1]	$15.00	/ton				
Chemical Application						
Medium Weed Density	$197.00	/acre			13	$2,561.00
Heavy Weed Density	$1,374.00	/acre				
Permits						
Aquatic Pesticides[8]	$2,000.00	/65 acre			13	$400.01
CDFG Permit						
COE Permit						
Desilt Permit						
Total Cost				$2,400.00		$2,961.01
Cost Per Acre				**$184.62**		**$227.77**

General Notes and Footnotes:
(1) Tules are not greenwaste and can't be diverted
(2) Typical test plot represents chemical abatement cost for medium weed density
(3) Cost of field labor includes equipment and disposables (brush cutters, gloves, fuel, travel, etc.)
(4) Manual Abatement is material removal with a combination of hand labor and equipment (brush cutters, cranes, etc.)
(5) Mechanical Abatement is material removal with excavators, no hand labor used
(6) No workers compenstation costs attributed to this technique based on claim history over last 13 years
Cost based on typical chemical application for this type of weed, no actual chemical application made.
(7) All Mechanical and Manual Abatement sites are easy to access
(8) Assumes 65 acres treated and a permit fee and compliance cost of $2,000

6. CONCLUSIONS

An overall summary of the environmental impacts, efficacy, and economics of study is presented in Table 6.1.

Table 6.1. Qualitative summary of environmental impacts, efficacy, and relative costs of different control methods evaluated in this study.

Weed Type	**Floating Weeds**			**Emergent Weeds**			**Terrestrial Weeds**	
Abatement Method	**Chemical**	**Mechanical**	**Chem/Mech**	**Chemical**	**Goats**	**Manual**	**Chemical**	**Goats**
Environmental Impact	Low	Med.	Med.	NA	Med.	Low	NA	Med.
Efficacy	High	Med.	Very High	Med.	Med.	Med.	Med.	High
Relative Cost	Low	Med.	High	Low	Low	Low	Low	Low

NA = not evaluated as part of this study.

Emergent Weeds

Water quality impacts observed during the implementation of non-chemical control techniques were largely transitory. The most significant impacts to water quality were related to the temporary presence of total and fecal coliform and *E. coli* above maximum concentrations allowed for recreation. However, neither Bettencourt Basin nor Elk Slough are used this purpose; therefore no apparent risk was created by the use of goats.

When compared to the use of goats for terrestrial weed abatement, more significant adverse impact to water quality was seen with emergent weeds as a result of goats standing in the water during grazing. The use of goats to graze terrestrial vegetation ranged from moderately to highly effective depending on goat “appetite”.

Manual removal of tules is effective, but is expensive, extremely labor intensive, and is prone to worker slip, trip, and fall-related injuries. Because re-growth occurs so quickly, this weed management option provides no more than seasonal control at best and must be done every season. During manual removal, no indication was found that the use of gasoline-powered equipment resulted in the presence of petroleum hydrocarbons in surface water.

If a particular site can tolerate a temporary increase in coliform and *E. coli*, the use of goats is a viable alternative to the use of chemicals. Both of these techniques are preferable to the use of manual removal techniques.

Floating Aquatic Weeds

No significant differences in water quality were noted during or after the removal of floating aquatic weeds using mechanical removal and chemical application followed by mechanical removal.

The combination of chemical/mechanical removal was the most effective technique observed. Because significant re-growth was observed after mechanical removal, this technique is not viable. In cases where moving water transports and agitates dead plant material so that it no longer floats and obstructs flow, the use of chemical control alone is likely the most effective method. Although the control cost of chemical control is less than that of the chemical/mechanical option, only the combined option exhibited plant control until the following growing season. This difference in effectiveness indicates that the annual averaged costs between chemical alone vs. chemical/mechanical combined may be relatively similar. Additional long term monitoring would be required to further evaluate this. In cases were water is stagnant or slow moving, chemical treatment followed by mechanical removal is a viable alternative to the use of chemicals if increased BOD can be tolerated.

Terrestrial Weeds

Similar to the use of goats for emergent weeds, transitory increases in total and fecal coliform and *E. coli* were observed. Unique to goat use in a terrestrial environment, turbidity increased and stayed elevated perhaps as a result goat traffic and resulting erosion.

The use of goats to graze a terrestrial environment that has a desired food source is very effective, and is probably more effective and more economical than the use of chemicals.

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CHAPTER 4. MECHANICAL SHREDDING DEMONSTRATION PROJECT

Ben K. Greenfield, San Francisco Estuary Institute, Oakland, CA [4]

INTRODUCTION

For large infestations of water hyacinth, targeted herbicide application has been considered substantially more cost-effective than mechanical removal methods, and is currently the preferred method if acceptable to the public (Thomas and Anderson, 1984; Cofrancesco, 1996; Haller, 1996). However, in the western United States, the Talent decision (U.S. Ninth Circuit Court of Appeals, 2001) has altered the regulatory requirements for chemical pesticide applications and, thereby, the costs and benefits of different pest control methods. With NPDES permits now required for aquatic pesticide applications, the cost-effectiveness of chemical pesticides relative to mechanical methods is being revisited. Control cost effectiveness frequently influences the method selected for aquatic plant control. Two primary factors that determine cost-effectiveness are the area of infestation controlled per unit effort and the frequency the control method must be implemented (Holdren et al., 2001).

In the Sacramento-San Joaquin Rivers Delta, in northern California (the Delta), substantial infestations of water hyacinth (*Eichhornia crassipes*) have been routinely controlled for decades, using chemical herbicide applications, introduction of insects for biocontrol, and limited mechanical control trials (Thomas and Anderson 1984). Given the regulatory burden of NPDES permitting, in addition to pressure from local advocacy groups, alternative methods are being evaluated. The California Department of Boating and Waterways (CDBW) is conducting mechanical harvesting on a limited basis, but disposal time and landfill costs are significant (California Department of Boating and Waterways, 2001). Some local stakeholders have pushed for evaluation of mechanical shredding of aquatic vegetation, allowing the vegetation to remain in the water, as a less cost-prohibitive alternative to vegetation harvesting. However with mechanical shredding, there is concern that the method will produce viable fragments that simply increase the spread of the infestation. There is also concern that if the shredded vegetation is allowed to remain in the water, it will adversely impact water quality due to large inputs of organic material.

The purpose of this study is to thoroughly evaluate mechanical shredding as a method for controlling water hyacinth on Delta water bodies. The final reporting of this evaluation will address three issues: 1) project set-up and operational constraints, including technical feasibility and permitting issues); 2) environmental impacts of the method; and 3) cost-effectiveness, including the rate of regrowth. The study is currently underway and only preliminary interpretations can be drawn at this time.

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STUDY APPROACH AND PRELIMINARY OBSERVATIONS

Two sites were chosen for shredding evaluation, the Stone Lakes National Wildlife Refuge and Dow Wetlands. These sites were selected to evaluate the full range of conditions found in the Delta. The Dow Wetlands site is strongly tidally influenced, difficult to access, and densely infested with water hyacinth. The Stone Lakes Site has readier access, limited tidal flux, and contains long narrow irrigation ditches. The Dow site is more characteristic of the conditions that the California Department of Boating and Waterways must contend with in controlling hyacinth. Stone Lakes is more representative of waterways that local landowners (irrigated agriculture and vineyards) must manage.

PROJECT SET-UP AND OPERATIONAL CONSTRAINTS

For a new method to be widely applicable in California waters, it must undergo significant environmental permitting. Permitting required for widespread application of mechanical shredding would include the Biological Opinion process to evaluate impacts on endangered and threatened species, and the NEPA/CEQA process to evaluate discharge of pollutants into the water body. Other potential permitting issues (e.g. Army Corps of Engineers streambed alteration permits or California Department of Fish and Game contact) were not addressed in this pilot-scale project. The NEPA/CEQA permitting was simplified, after personnel from the Central Valley Regional Water Quality Control Board indicated that the proposed research operation would not require formal application, provided that impacts were clearly documented and provided to the regulatory agencies.

Endangered species permitting presents a significant challenge for any large scale management action in the Delta, where there are a number of listed sensitive species. In May 2003, a consultation was initiated with USFWS and NMFS to evaluate impact on endangered species. Within several months of initial contact, both agencies provided official letters indicating that formal consultation was not required, and permitting the project provided that: 1) efforts are made to minimize impacts on listed species; and 2) the project must occur within the dates when sensitive species are least likely to be adversely affected (between July 15 and October 31). With approval given, a fall evaluation was conducted in late September, 2003.

A second evaluation is planned for the later spring/ early summer of 2004. This evaluation occurs during the active movement and spawning stages of sensitive fish species and the giant garter snake. It requires a formal consultation, including a written Biological Opinion. This consultation was begun in November 2003 and will hopefully be completed by spring of 2004.

For the fall evaluation, a contract was established with Master's Dredging, a contractor that designs, builds and operates a mechanical shredder specialized for control of dense water hyacinth infestations. This contractor was selected based on review of studies on the contractor's prior performance (e.g., Stewart and McFarland, 2000; James et al., 2002) and checking references with agency personnel having prior experience with the contractor. The contractor has two types of shredders. The "AquaPlant Terminator" is a boat that is 28 ft. long and 8 ½ ft. wide, requiring 2-3 feet of water depth. Weighing 6 tons, it is equipped with sets of shredding blades at the front and rear of the boat, and separate engines to operate each set of blades. The "Amphibious Terminator" is a modified airboat, having a set of flail chopper blades, and a standard airboat fan to propel the vessel. The airboat shredder is considerably less maneuverable, but it only requires about ½ ft. of draft to operate. An additional local contractor (Clean Lakes, Inc.) has been in contact with the project manager regarding evaluation of the "Cookie Cutter," a commercially available shredding vessel. The Master's Dredging shredders were evaluated in the fall of 2003. It is expected that both contractors' shredders will be evaluated in spring, 2004.

A number of operational constraints have been determined to limit the circumstances where the Master's Dredging shredders may be appropriately applied to control water hyacinth. Boat ramps used to launch the shredders must have a packed gravel or concrete surface and have sufficient draft in the vicinity (approximately 5 feet of depth). Otherwise, cranes should be used. The airboat shredder (Amphibious Terminator) was generally not successful at shredding hyacinth greater than 2 ½ ft. in stalk length (a size frequently encountered in late summer), and actually got stuck in taller hyacinth on two separate occasions. The airboat also could not handle the strong winds or wave conditions characteristic of open waters of the central Delta. Finally, the airboats had a very wide turning radius and could not operate in reverse, significantly limiting the circumstances in which operation could occur. Generally, the project experience suggested that the technical constraints of many California waters typically having water hyacinth were too great for the airboat shredder late in the water hyacinth growing season.

ENVIRONMENTAL IMPACTS

A primary concern regarding this control method is the significant input of organic material into the water column, in the form of shredded aquatic plants. This is particularly important in operations such as this one, where the shredded material is not removed from the water body. Potential impacts include increased water column nutrients, dissolved organic carbon, and biochemical oxygen demand, resulting in anoxic conditions. The resuspended material and anoxic conditions could potentially increase mercury concentrations and bioavailability in the ecosystem. Previous studies have indicated that the same shredding operation caused dissolved oxygen increases in water chestnut stands (James et al., 2000; James et al., 2002).

In this research program, extensive water quality data were collected in 2003, including analysis of nutrients, dissolved oxygen, turbidity, and biological oxygen demand. Water quality was collected at replicate shredded sites in both Dow Wetlands (N = 2 shredded sample locations) and Stone Lakes Refuge (N = 3). Control (unshredded) sites were also monitored at both locations (Dow N = 7; Stone Lakes N = 1). For all sites, sampling was conducted on at least two dates prior to shredding and several dates following shredding. The following parameters were collected for laboratory analysis: total Kjeldahl nitrogen, dissolved nitrates, total phosphorus, dissolved orthoreactive phosphate, biochemical oxygen demand, dissolved organic carbon, and turbidity. Additionally, temperature, dissolved oxygen, pH and conductivity were collected in the field.

In addition to conventional water quality analysis, a collaborative project between SFEI and Dr. Joy Andrews, of CSU-Hayward, is examining whether shredding of hyacinth changes the sequestration and speciation of mercury. This includes measurement of mercury in sediments, water, and hyacinth plant material, to develop a simple mercury mass budget for the system. To determine whether shredding of hyacinths would affect mercury speciation (e.g., worsen methylation of mercury), shredded hyacinth shoots are also being collected to study with X-ray Absorption Spectroscopy (XAS). This work is being complemented by laboratory experiments on cut hyacinth, including evaluations of mercury uptake and release by cut vs. control plants. These projects are being conducted as part of the graduate research of several Masters program students working with Dr. Andrews, with SFEI serving in a collaborative capacity.

COST EFFECTIVENESS

This project will calculate cost effectiveness as area controlled over a given time period per dollar spent. Therefore the cost effectiveness evaluation includes two components: assessment of treatment area per money spent, and also assessment of regrowth rate of the plants. The shredding rate was evaluated at four locations varying in access difficulty and plant size. Acres shredded were estimated using georeferenced aerial photography, with aerial fly-overs both before and after shredding. Preliminary evaluations of the September shredding experiment indicated that control costs ranged widely, depending on the density and plant size of the stand (Table 1). Shredding efficiency was very low at the Dow Wetland, where dense plant stands and very tall vegetation severely impeded shredding rate. It is anticipated that the shredding evaluation in the spring will have much lower control costs, because of the smaller plant size at that time.

Table 1. Preliminary estimates of control cost at three locations on Stone Lake National Wildlife Refuge, and one location in Dow Wetlands.

Site	Conditions	Shredded Area (acres)	Time (hr)	Acres/hr	Control Cost $/Acre
Stone Lake (East Lambert)	Dense 2' Stem Height	3.5	3	1.18	$338
Stone Lake (West Lambert)	Dense 3'-4.5' Stem Height	11.7	49.5	0.24	$1,686
South Stone Lake	Unknown	1.8	7.5	0.25	$1,625
Dow Wetland	Dense 4'-4.5' Stem Height	0.9	17	0.05	$7,441

The rate of shredding of the large plants was relatively slow, compared to research conducted on shredding in other parts of the country. An unpublished study conducted by the US Army Corps of Engineers and Vermont Department of Environmental Quality indicated that the Master's Dredging system was able to shred approximately three acres of water chestnut per hour (Stewart and McFarland, 2000). In an extremely dense stand of hyacinth the Dow site, it took 2 full days to shred 0.9 acre (Table 1).

In this dense hyacinth, the shredding left behind a thick root mass and many large plant fragments. Regrowth success rate is being evaluated in a greenhouse study of fragments collected from shredded area, and confirmed by monitoring individual plants in mesocosms set up at the cutting site in the field. These tests are being conducted by Dr. David Spencer (USDA-ARS Ecologist). Preliminary results indicate significant plant regrowth. These preliminary findings suggest that shredding would need to be conducted several times per season to maintain control. They also suggest that there may be a relatively high risk that released fragments could infest new locations. The regrowth rate may be lower during the spring evaluation, when plants are smaller and have lower stored carbohydrate density in their roots.

CURRENT STATUS OF THE STUDY:

Planning for the spring 2004 evaluation is currently being done. In depth data analysis and reporting will be done following the second evaluation and included in the 2004 Aquatic Pesticides Alternative Program Annual Report.

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APPENDIX 1. HARVESTING STUDY CHEMICAL DATA

Harvested Sites

* Redox Potential Reading taken with pH meter

Location	Station	Pond #	Date	Time	Event	Timing	Air Temp.	Surface Temp.	Weather	Sampl. Depth	Vis	Temp.	DO 1 m	DO surface	EC 1 m	EC surface	pH 1 m	pH surface	Turbidity I	Turbidity II	Turbidity III
Unit				24 hour			C	C		m	m	C	mg/L	mg/L	µS/cm	µS/cm			NTU	NTU	NTU
Sunnyoaks	S-01	1	7/9/2003	10:10	pre	Pre	30	24.5	sunny	1	2	23.2	9.4	.	270	.	8.9	.	2.43	2.57	2.62
Sunnyoaks	S-04	1	7/9/2003	11:01	pre	Pre	30	24.5	sunny	1	2	23.2	9.6	.	271	.	8.8	.	2.94	2.94	-
Sunnyoaks	S-02	2	7/9/2003	11:19	pre	Pre	32	25.0	sunny	1	2	24.6	9.6	.	263	.	9.1	.	1.11	1.12	-
Sunnyoaks	S-05	2	7/9/2003	11:49	pre	Pre	32	25.3	sunny	1	2	24.6	9.8	.	263	.	9.1	.	1.03	1.07	1.05
Sunnyoaks	S-03	3	7/9/2003	12:12	pre	Pre	32	26.6	sunny	1	2	25.4	9.3	.	252	.	9.3	.	0.73	0.71	0.78
Kooser	K-C	2	7/9/2003	13:46	control	Pre	33	22.5	sunny	1	2	20.8	15.8	.	504	.	9.2	.	2.47	2.51	2.65
Sunnyoaks	S-01	1	7/11/2003	13:41	control	Post 1	34	24.8	sunny	1	2	24.1	10.2	.	265	.	8.9	.	2.66	2.64	2.75
Sunnyoaks	S-04	1	7/11/2003	14:06	control	Post 1	33	25.6	sunny	1	2	24.4	10.7	.	266	.	8.9	.	3.10	2.94	2.94
Sunnyoaks	S-02	2	7/11/2003	12:00	harvest	Post 1	32	25.0	sunny	1	1.5	24.7	10.0	.	262	.	9.1	.	2.51	2.52	2.38
Sunnyoaks	S-05	2	7/11/2003	12:29	harvest	Post 1	32	25.1	sunny	1	1.5	24.8	9.7	.	264	.	9.1	.	2.94	2.28	2.30
Sunnyoaks	S-03	3	7/11/2003	12:48	harvest	Post 1	32	27.1	sunny	1	1.5	26.6	9.5	.	256	.	9.3	.	1.60	2.51	2.18
Sunnyoaks	S-01	1	7/17/2003	9:46	post	Post 2	28	25.0	sunny	1	1.5	24.8	8.0	.	257	.	9.0	.	1.85	2.02	1.97
Sunnyoaks	S-04	1	7/17/2003	10:34	post	Post 2	29	25.3	sunny	1	1.5	25.0	8.9	.	256	.	8.9	.	2.03	2.39	2.18
Sunnyoaks	S-02	2	7/17/2003	11:06	post	Post 2	30	26.2	sunny	1	2	25.7	9.7	.	260	.	9.1	.	1.34	2.15	2.05
Sunnyoaks	S-05	2	7/17/2003	11:56	post	Post 2	32	26.5	sunny	1	2	26.0	10.2	.	258	.	9.0	.	1.34	1.62	1.62
Sunnyoaks	S-03	3	7/17/2003	12:50	post	Post 2	33	27.8	sunny	1	2.5	26.9	8.7	.	262	.	9.2	.	1.21	1.20	1.21
Sunnyoaks	S-03-Dup	3	7/17/2003	12:55	post	Post 2	33	27.8	sunny	1	2.5	26.9	8.7	.	262	.	9.2	.	1.70	1.78	1.48
Sunnyoaks	S-03-Bl	3	7/17/2003	12:59	post	Post 2	33	27.8	sunny	-	-	-	-	.	-	.	-	.	0.14	0.07	0.07
Oka	Oka-1	4	8/14/2003	9:52	pre	Pre	28	20.6	partly cloudy	1	2	20.2	5.72	7.96	373	375	7.8	7.8	2.41	-	-
Oka	Oka-2	4	8/14/2003	10:30	pre	Pre	29	21.4	sunny	1	2	21.0	7.2	7.9	373	374	7.8	7.8	3.11	-	-
Oka	Oka-3	4	8/14/2003	10:52	pre	Pre	30	21.9	sunny	1	1	21.4	6.86	11.46	371	368	8.0	8.5	2.72	-	-
Sunnyoaks	C-S-01	1	8/14/2003	12:26	control	Pre	31	23.9	sunny	1	1.5	23.6	11.57	11.04	299	299	8.7	8.7	2.13	-	-
Oka	Oka-1	4	8/20/2003	13:20	harvest	Post 1	30	22.6	sunny	1	1	22.2	6.55	6.7	370	370	8.2	8.2	5.62	-	-
Oka	Oka-2	4	8/20/2003	13:41	harvest	Post 1	31	24.9	sunny	1	1.5	21.8	6.6	8.87	364	358	8.6	8.9	1.85	-	-
Oka	Oka-3	4	8/20/2003	14:02	harvest	Post 1	30	23.8	sunny	1	1	21.8	4.52	11.19	366	347	7.9	9.1	6.86	-	-
Sunnyoaks	C-S-01	1	8/20/2003	14:54	control	Post 1	31	26	sunny	1	2	25.3	11.2	9.93	310	309	8.95	9.0	2.31	1.92	-
Oka	Oka-1	4	8/25/2003	13:44	harvest	Post 2	32	25.8	sunny	1	1	23.9	6.18	6.59	368	361	8.32	8.6	2.55	2.17	-
Oka	Oka-2	4	8/25/2003	14:37	harvest	Post 2	33	26.8	sunny	1	1	24.2	5.28	6.15	376	376	7.96	8.2	2.58	-	-
Oka	Oka-3	4	8/25/2003	15:01	harvest	Post 2	33	26.9	sunny	1	1	24.4	4.04	5.11	375	377	7.78	7.8	2.58	-	-
Oka	Oka-3-Dup	4	8/25/2003	15:02	harvest	Post 2	33	26.9	sunny	1	1	24.4	4.04	5.11	375	377	7.78	7.8	3.51	-	-
Oka	Oka-3-Bl	4	8/25/2003	16:33	harvest	Post 2	33	26.9	sunny	.	.	.	.	.	.	.	.	.	0.84	-	-
Sunnyoaks	C-S-01	1	8/25/2003	NA	control	Post 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Petaluma	Pet-01	Lake	9/9/2003	9:52	pre	Pre	18	19.9	cloudy, rainy	1	1.5	19.6	2.51	2.69	260	260	7.73	7.8	1.91	-	-
Petaluma	Pet-02	Lake	9/9/2003	10:13	pre	Pre	18	19.3	cloudy, rainy	1	1	18.9	3.45	4.09	261	260	7.9	7.9	2.13	-	-
Petaluma	Pet-01-H	Lake	9/9/2003	14:03	harvest	Post 1	19	20.2	cloudy, windy	1	0.5	20.0	3.32	3.82	261	261	7.61	7.7	2.73	-	-
Petaluma	Pet-02-H	Lake	9/9/2003	14:22	harvest	Post 1	19	20.6	cloudy, windy	1	0.5	19.1	4.16	8.49	266	261	7.51	8.7	5.82	-	-
Petaluma	Pet-01	Lake	9/15/2003	11:53	post	Post 2	26	22.5	partly cloudy	1	1.5	22.4	4.95	4.98	268	269	7.73	.	2.94	-	-
Petaluma	Pet-02	Lake	9/15/2003	12:12	post	Post 2	26	22.3	partly cloudy	1	1	22.4	3.75	6.13	269	270	7.79	.	8.49	-	-
Petaluma	Pet-02-Dup	Lake	9/15/2003	12:26	post	Post 2	26	22.3	partly cloudy	1	1	22.4	3.75	6.13	269	270	7.79	.	13.4	-	-
Tahoe Keys	T-1-01	Lagoon	9/19/2003	7:28	pre	Pre	-1	15.9	sunny	1	1	15.6	6.87	6.9	118	118	8.94	8.9	3.57	3.52	-
Tahoe Keys	T-1-02	Lagoon	9/19/2003	7:52	pre	Pre	2	15.9	sunny	1	1.5	15.8	13.96	13.75	124	124	9.78	9.8	1.56	-	-
Tahoe Keys	T-2-01	Lagoon	9/19/2003	8:12	pre	Pre	12	15.3	sunny	1	0.5	15.1	8.53	8.13	118	116	8.49	8.3	3.87	-	-
Tahoe Keys	T-2-02	Lagoon	9/19/2003	8:35	pre	Pre	14	14.3	sunny	1	0.3	14.3	8.65	8.71	127	129	8.7	8.7	3.24	-	-
Lake Tahoe	T-C	Lake	9/19/2003	8:59	control	Pre	14	15.1	sunny	1	>2.0	15.1	7.94	8.02	95	95	8.12	8.1	0.44	-	-
Tahoe Keys	T-1-01-H	Lagoon	9/19/2003	10:34	harvest	Post 1	18	16.4	sunny	1	0.3	16.1	7.95	7.24	117	118	8.93	8.9	3.77	-	-
Tahoe Keys	T-1-02-H	Lagoon	9/19/2003	11:01	harvest	Post 1	20	16.3	sunny	1	1	16.1	10.25	10.61	124	124	9.63	9.7	4.58	-	-
Tahoe Keys	T-2-01-H	Lagoon	9/19/2003	11:45	harvest	Post 1	21	16.4	sunny	1	0.5	16.2	8.05	7.25	114	115	8.05	8.0	4.86	-	-
Tahoe Keys	T-2-02-H	Lagoon	9/22/2003	10:29	harvest	Post 1	20	15.5	sunny	1	0.3	15.3	8.65	8.4	128	128	8.5	8.5	4.86	-	-
Tahoe Keys	T-1-01	Lagoon	9/22/2003	9:36	post	Post 2	18	16.6	sunny	1	2	16.5	13.23	12.36	119	119	9.5	9.5	1.96	2.08	-
Tahoe Keys	T-1-02	Lagoon	9/22/2003	9:50	post	Post 2	18	16.7	sunny	1	1	16.7	12.86	13.23	125	125	9.76	9.8	1.34	-	-
Tahoe Keys	T-2-01	Lagoon	9/22/2003	10:14	post	Post 2	20	16.5	sunny	1	1	16.4	9.45	9.58	117	116	8.85	8.8	2.96	-	-
Tahoe Keys	T-1-02-Dup	Lagoon	9/22/2003	9:56	post	Post 2	19	16.5	sunny	1	1	16.4	9.45	9.58	117	116	8.85	8.8	1.47	-	-
Tahoe Keys	T-1-02-Bl	Lagoon	9/22/2003	11:48	post	Post 2	23	16.5	sunny	.	.	.	.	.	.	.	.	.	0.08	-	-
Lake Tahoe	T-C	Lake	9/22/2003	10:50	control	Post 2	22	16.6	sunny	1	>1.5	16.1	7.87	7.86	96	95	8.04	8.04	0.53	-	-

Location	Station	Pond #	Date	Time	Event	Timing	Air Temp.	Surface Temp.	Weather	Sampl. Depth	Vis	BOD	Total Phosphorus	Dissolved ortho-Phosphate	Dissolved Nitrate + Nitrite	Dissolved Ammonia	TSS	Total Kjeldahl Nitrogen
Unit				24 hour			C	C		m	m	mg/L	mg/L P	mg/L P	mg/L N	mg/L N	mg/L	mg/L
Sunnyoaks	S-01	1	7/9/2003	10:10	pre	Pre	30	24.5	sunny	1	2	ND	ND	0.03	0.0707	ND	1.2	NA
Sunnyoaks	S-04	1	7/9/2003	11:01	pre	Pre	30	24.5	sunny	1	2							NA
Sunnyoaks	S-02	2	7/9/2003	11:19	pre	Pre	32	25.0	sunny	1	2	ND	ND	0.0161	0.0431	ND	ND	NA
Sunnyoaks	S-05	2	7/9/2003	11:49	pre	Pre	32	25.3	sunny	1	2							NA
Sunnyoaks	S-03	3	7/9/2003	12:12	pre	Pre	32	26.6	sunny	1	2	ND	ND	0.0112	0.042	ND	ND	NA
Kooser	K-C	2	7/9/2003	13:46	control	Pre	33	22.6	sunny	1	2	ND	0.0735	0.0477	0.491	ND	3.7	NA
Sunnyoaks	S-01	1	7/11/2003	13:41	control	Post 1	34	24.8	sunny	1	2	ND	ND	0.0326	0.0997	ND	1.4	NA
Sunnyoaks	S-04	1	7/11/2003	14:06	control	Post 1	33	25.6	sunny	1	2							NA
Sunnyoaks	S-02	2	7/11/2003	12:00	harvest	Post 1	32	26.0	sunny	1	1.6	ND	ND	0.0142	0.0573	ND	1.8	NA
Sunnyoaks	S-05	2	7/11/2003	12:29	harvest	Post 1	32	25.1	sunny	1	1.5							NA
Sunnyoaks	S-03	3	7/11/2003	12:48	harvest	Post 1	32	27.1	sunny	1	1.5	ND	ND	ND	0.01	ND	2	NA
Sunnyoaks	S-01	1	7/17/2003	9:46	post	Post 2	28	25.0	sunny	1	1.5	ND	ND	0.0302	0.0707	ND	ND	NA
Sunnyoaks	S-04	1	7/17/2003	10:34	post	Post 2	29	26.3	sunny	1	1.6							NA
Sunnyoaks	S-02	2	7/17/2003	11:06	post	Post 2	30	26.2	sunny	1	2	ND	ND	0.0192	0.0638	ND	ND	NA
Sunnyoaks	S-05	2	7/17/2003	11:56	post	Post 2	32	26.5	sunny	1	2							NA
Sunnyoaks	S-03	3	7/17/2003	12:50	post	Post 2	33	27.8	sunny	1	2.6	ND	ND	ND	0.066	ND	ND	NA
Sunnyoaks	S-03-Dup	3	7/17/2003	12:55	post	Post 2	33	27.8	sunny	1	2.5	ND	0.0502	ND	0.0524	ND	ND	NA
Sunnyoaks	S-03-Bl	3	7/17/2003	12:59	post	Post 2	33	27.8	sunny	-	-	ND	0.0565	ND	0.0528	ND	ND	NA
Oka	Oka-1	4	8/14/2003	9:52	pre	Pre	28	20.6	partly cloudy	1	2	3.4	ND	0.0221	0.0562	ND	1.2	ND
Oka	Oka-2	4	8/14/2003	10:30	pre	Pre	29	21.4	sunny	1	2	ND	ND	0.0251	0.064	ND	1.1	ND
Oka	Oka-3	4	8/14/2003	10:52	pre	Pre	30	21.9	sunny	1	1	ND	ND	0.0243	0.0628	ND	22.7	ND
Sunnyoaks	C-S-01	1	8/14/2003	12:26	control	Pre	31	23.9	sunny	1	1.5	ND	ND	0.0186	0.0796	ND	1.6	ND
Oka	Oka-1	4	8/20/2003	13:20	harvest	Post 1	30	22.6	sunny	1	1	3	0.0592	0.025	0.0505	ND	5.1	ND
Oka	Oka-2	4	8/20/2003	13:41	harvest	Post 1	31	24.9	sunny	1	1.6	ND	ND	0.0199	0.0551	ND	3.6	ND
Oka	Oka-3	4	8/20/2003	14:02	harvest	Post 1	30	23.8	sunny	1	1	3.3	0.0731	0.0284	0.0738	ND	6.3	0.62
Sunnyoaks	C-S-01	1	8/20/2003	14:54	control	Post 1	31	26	sunny	1	2	ND	ND	0.0138	0.051	ND	1.6	ND
Oka	Oka-1	4	8/25/2003	13:44	harvest	Post 2	32	26.8	sunny	1	1	ND	0.0868	0.0684	0.0703	ND	2	0.53
Oka	Oka-2	4	8/25/2003	14:37	harvest	Post 2	33	26.8	sunny	1	1	ND	0.0733	0.0289	0.0718	ND	1.5	ND
Oka	Oka-3	4	8/25/2003	15:01	harvest	Post 2	33	26.9	sunny	1	1	ND	0.0844	0.0533	0.0678	ND	2.3	ND
Oka	Oka-3-Dup	4	8/25/2003	15:02	harvest	Post 2	33	26.9	sunny	1	1	ND	0.0967	0.0538	0.0653	ND	2	ND
Oka	Oka-3-Bl	4	8/25/2003	16:33	harvest	Post 2	33	26.9	sunny	.	.	ND	ND	ND	0.0725	ND	ND	ND
Sunnyoaks	C-S-01	1	8/25/2003	NA	control	Post 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Petaluma	Pet-01	Lake	9/9/2003	9:52	pre	Pre	18	19.9	cloudy, rainy	1	1.5	ND	0.0915	0.0336	0.0575	ND	1.4	1.63
Petaluma	Pet-02	Lake	9/9/2003	10:13	pre	Pre	18	19.3	cloudy, rainy	1	1	3.2	0.092	0.0332	0.0675	ND	9.3	1.63
Petaluma	Pet-01-H	Lake	9/9/2003	14:03	harvest	Post 1	19	20.2	cloudy, windy	1	0.6	ND	0.167	0.0403	0.0819	ND	6	1.79
Petaluma	Pet-02-H	Lake	9/9/2003	14:22	harvest	Post 1	19	20.6	cloudy, windy	1	0.5	ND	0.0929	0.0232	0.0758	ND	9	1.75
Petaluma	Pet-01	Lake	9/15/2003	11:53	post	Post 2	26	22.5	partly cloudy	1	1.5	ND	0.203	0.0411	0.0502	ND	4.3	1.66
Petaluma	Pet-02	Lake	9/15/2003	12:12	post	Post 2	26	22.3	partly cloudy	1	1	ND	0.32	0.0344	0.0581	ND	14.7	2.17
Petaluma	Pet-02-Dup	Lake	9/15/2003	12:26	post	Post 2	26	22.3	partly cloudy	1	1	3.6	0.224	0.0364	0.0508	ND	15.4	1.97
Tahoe Keys	T-1-01	Lagoon	9/19/2003	7:28	pre	Pre	-1	15.9	sunny	1	1	ND	ND	ND	0.0407	ND	1.6	0.35
Tahoe Keys	T-1-02	Lagoon	9/19/2003	7:52	pre	Pre	2	15.9	sunny	1	1.5	ND	ND	ND	0.0408	ND	ND	0.26
Tahoe Keys	T-2-01	Lagoon	9/19/2003	8:12	pre	Pre	12	16.3	sunny	1	0.6	ND	ND	ND	0.0399	ND	1.6	0.27
Tahoe Keys	T-2-02	Lagoon	9/19/2003	8:35	pre	Pre	14	14.3	sunny	1	0.3	ND	ND	ND	0.0609	ND	1.8	0.35
Lake Tahoe	T-C	Lake	9/19/2003	8:59	control	Pre	14	15.1	sunny	1	>2.0	ND	ND	ND	0.0409	ND	ND	ND
Tahoe Keys	T-1-01-H	Lagoon	9/19/2003	10:34	harvest	Post 1	18	16.4	sunny	1	0.3	ND	ND	ND	0.0379	ND	1.7	0.27
Tahoe Keys	T-1-02-H	Lagoon	9/19/2003	11:01	harvest	Post 1	20	16.3	sunny	1	1	ND	ND	ND	0.062	ND	3.4	0.37
Tahoe Keys	T-2-01-H	Lagoon	9/19/2003	11:45	harvest	Post 1	21	16.4	sunny	1	0.5	ND	ND	ND	0.0413	ND	4.7	0.26
Tahoe Keys	T-2-02-H	Lagoon	9/22/2003	10:29	harvest	Post 1	20	15.5	sunny	1	0.3	ND	ND	ND	0.0558	ND	4.4	0.32
Tahoe Keys	T-1-01	Lagoon	9/22/2003	9:36	post	Post 2	18	16.6	sunny	1	2	ND	0.0741	ND	0.048	ND	1.1	0.36
Tahoe Keys	T-1-02	Lagoon	9/22/2003	9:50	post	Post 2	18	16.7	sunny	1	1	ND	ND	ND	0.0494	ND	ND	0.32
Tahoe Keys	T-2-01	Lagoon	9/22/2003	10:14	post	Post 2	20	16.5	sunny	1	1	ND	0.0594	ND	0.0503	ND	ND	0.36
Tahoe Keys	T-1-02-Dup	Lagoon	9/22/2003	9:56	post	Post 2	19	16.5	sunny	1	1	ND	ND	ND	0.0491	ND	ND	0.33
Tahoe Keys	T-1-02-Bl	Lagoon	9/22/2003	11:48	post	Post 2	23	16.5	sunny	.	.	ND	ND	ND	0.0545	ND	ND	ND
Lake Tahoe	T-C	Lake	9/22/2003	10:50	control	Post 2	22	16.6	sunny	1	>1.5	ND	0.0729	ND	0.0479	ND	ND	ND

ND - Not Detected/Below Detection Limit
NA – Not Available

APPENDIX 2. HARVESTING STUDY. FISH DATA.

Fish count at Oka Ponds (Santa Clara Valley).

	0-2 cm	2-4 cm	4-6 cm	6-8 cm	8-10 cm	Total
Bluegill sunfish	12	484	28			524
Smallmouth bass		1	11	3		15
Mosquitofish						
Prickly sculpin		10	3	1		14
Inland silversides	1	14	2			17
Fragments	18					
American bullfrog (tadpoles)			305 (2-10 cm)			
Site Total						**570**

Fish count at Petaluma.

	0-2 cm	2-4 cm	4-6 cm	6-8 cm	8-10 cm	Total
Bluegill sunfish		126	17	16	1	160
Smallmouth bass					1 (16.2 cm)	1
Mosquitofish						
Prickly sculpin						
Inland silversides						
Fragments						
Site Total						**161**

Fish count at Spinnaker Cove (Tahoe Keys Resort).

	0-2 cm	**2-4 cm**	**4-6 cm**	**6-8 cm**	**8-10 cm**	**Total**
Bluegill sunfish		2	6			8
Smallmouth bass			1		1	2
Mosquitofish						
Prickly sculpin						
Inland silversides						
Fragments	1 (crayfish)					
Crayfish (decapoda)		2	8	6	2	
Site Total						**10**

Fish count at Main Lagoon (Tahoe Keys Resort).

	0-2 cm	**2-4 cm**	**4-6 cm**	**6-8 cm**	**8-10 cm**	**Total**
Bluegill sunfish	3	2	2			7
Smallmouth bass						
Mosquitofish						
Prickly sculpin						
Inland silversides						
Fragments						
Crayfish (decapoda)						
Site Total						**7**

APPENDIX 3. HARVESTING STUDY. GLOSSARY OF PLANTS COLLECTED, WATER QUALITY PARAMETERS, AND ANALYTICAL METHODS

Plants

Azolla filiculoides or pacific mosquitofern is a small free-floating fern that often occurs in colonies. They are annual to perennial depending on environmental conditions. Upper leaf lobes are typically colonized by the nitrogen fixing cyanobacterium *Anabaena azollae*. Mosquitoferns are native species that occur in many Western states. Dense colonies can become a nuisance by excluding other aquatic vegetation, enhancing algae growth, and clogging up water pumps (DiTomaso and Healy, 2003).

Ceratophyllum demersum or coontail is a submersed annual to perennial with firm, forked bottle-brush like leaves and stems to 2.5 cm long. Plants lack roots and exist free-floating or anchored to the substrate by specialized buried stems. Coontail is native to many areas nearly worldwide, but can become a problem in controlled aquatic systems with high nutrient contents. There it can create subsurface mats of dense vegetation that cause obstruction for boat traffic and recreation as well as inhabiting an increased risk for swimmers.

Chara spp. *Chara* or muskgrass are multicellular, green, macroalgae with whorled, branchlike filaments at the nodes of a central axis. They can easily be mistaken for vascular aquatic plants. Several *Chara* species exist in the Western United States, all of them are native (DiTomaso and Healy, 2003).

Chladophora spp. is a common filamentous green algae that typically anchor to a substrate with rhizoidlike filaments. *Chladophora* often forms long, trailing mats (DiTomaso and Healy, 2003).

Egeria densa or Brazilian egeria was introduced from Eastern South America and is now distributed through most of the United States, except for some Northern and Midwestern states. It inhibits acidic to alkaline waters and is highly susceptible to iron deficiency. Plants are leafy with leaves being about 15-40 mm long and 3-6 whorled. Egeria flowers commonly with glossy white flowers (DiTomaso and Healy, 2003).

Ludwigia spp. or waterprimrose is a floating to emergent perennial. In irrigation channels and ditches this widespread species can form tangled mats of stems that grow up to three meters long and impair water flow drastically. One of the three subspecies is native to California, the other two subspecies have been introduced to the West coast (DiTomaso and Healy, 2003).

Myriophyllum spicatum or eurasian watermilfoil is a noxious perennial with rhizomes and finely dissected whorled submersed leaves. It can develop colonies that form large subsurface mats. Mats impede water flow, interfere with boat traffic and recreational activities, create mosquito habitat, and displace native aquatic vegetation.

Potamogeton crispus or curlyleaf pondweed is an aquatic perennial, most with rhizomes. Pondweeds are highly plastic, changing their appearance according to environmental conditions, and widely distributed. Curlyleaf pondweed is introduced from Eurasia. In most natural areas, pondweeds are a desirable component of the aquatic community but can become problematic in drainage canals, irrigation ditches, and other controlled aquatic systems.

Potamogeton nodosus or American pondweed is a long-leaved, widespread native in Northern America. Like many other pondweeds it is desirable in the aquatic ecosystem but can cause numerous problems when it forms thick colonies in irrigations canals and lakes. (DiTomaso and Healy, 2003).

Ranunculus aquatilis or white waterbuttercup is also a native species in all Western States and throughout California that forms submerged mats. These can become a nuisance in canals and ditches. Waterbuttercup has alternate, fan-shaped dissected leaves and is rooted or free-floating.

Najas guadalupensis (Southern naiads or Southern waternymph) are submersed annual plants with stems to 0.6 m long and opposite to subopposite leaves. Plants grow rooted in the substrate. Southern naiad is a common widespread native of North and South America. It is usually not considered a weed in natural habitats, but can become troublesome in ditches, human-made ponds, and disturbed or controlled aquatic systems (DiTomaso and Healy, 2003).

Zannichellia is a submersed perennial plant with creeping rhizomes, linear leaves, and stems to 0.5 m long. Plants are annual where standing water is seasonal. They are widespread native plants throughout most temperate to tropical regions of the world (DiTomaso and Healy, 2003).

Water Quality Parameters

Biological Oxygen Demand (BOD) is a measure describing the oxygen needed to breakdown material. A high BOD is usually found in waters with sewage pollution and eutrophic lakes.

Dissolved oxygen (DO) is a very important indicator of a water body’s ability to support aquatic life. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae as a product of photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter. Oxygen concentrations greater than 5 mg/L are generally considered safe for aquatic biota.
Electrodes of the DO meter measure the partial pressure of oxygen in water, which is converted to oxygen mass weight concentration. The amount of oxygen dissolved in water is expressed as a concentration, in milligrams per liter of water.

Electrical Conductivity (EC) is a measure of how well water can conduct an electrical current. Conductivity increases with increasing amount of mobility of ions. These ions, which come from the breakdown of compounds, conduct electricity because they are negatively and positively charged when dissolved in water. Therefore, EC is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution. De-ionized water has a EC of at least 1µS/cm.

Nitrate (NO_3^-) is highly soluble in water and is stable over a wide range of environmental conditions. It is easily transported in streams and groundwater. Nitrates feed plankton, aquatic plants, and algae. Nitrate sources include inorganic fertilizers, poultry manure, and septic tanks. Nitrate alone is measured as another key indicator for water quality due to its bioavailablity.

pH is a general indicator for the acidity of a water body as measured by the proton (H+) concentration: pH=-log [H+]. A measurement of pH<7 is considered acidic, pH=7 is neutral, and pH>7 is basic. pH represents the effective activity of hydrogen ions (H+) in water. The pH scale ranges from 0 to 14. Very high (>9.5) or very low (<4.5) pH values are unsuitable for most aquatic organisms. Changes in pH can also affect aquatic biota indirectly by altering other aspects of water chemistry. Low pH levels accelerate the release of metals from rocks or sediments in the stream that could potentially cause toxicity.

Phosphate is one of the inorganic nutrients that provide the chemical constituents on which the entire food chain is based. It is one of the key indicators for water quality because of its bioavalability (Horne and Goldman, 1994).

Redox potential: Oxidation is a process in which a molecule or ion loses electrons. Reduction is a process by which electrons are gained. A measurement of the potential for these processes to occur is called ORP (Oxidation Reduction Potential). The redox potential is a measure (in volts) of the affinity of a substance for electrons - its electronegativity - compared with hydrogen (which is set at 0). A high redox potential is known to be enhancing algae growth than a lower one.

Temperature of water is an important factor for aquatic life. It controls the rate of metabolic and reproductive activities, and determines which aquatic biota can survive. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria and toxic chemicals in water. Temperature preferences among aquatic species vary widely, but all species tolerate slow, seasonal changes better than rapid changes.

Total ammonia (NH_3), another inorganic form of nitrogen, is the least stable from in water. Ammonia is easily transformed to nitrate in waters that contain oxygen. Nitrate is relatively short-lived in water because it is quickly converted to NO_3^- by bacteria.

Ammonia can also be transformed to nitrogen gas (N_2) in waters that are low in oxygen. Ammonia is found in water in two forms: dissolved as ammonia gas (NH_3), and as ammonium ion (NH_4^+). Unionized ammonia (NH_3) is much more toxic to aquatic organisms that the ammonium ion (NH_4^+). Total ammonia is the sum of NH_4^+ and NH_3. The dormant from depends on the pH and temperature of the water. NH_3 in freshwater exists mostly in the ionic form as NH_4^+. NH_4^+ is an important source of nitrogen for bacteria, algae, and macrophytes.

Total chlorophyll a is a key biochemical substance in the process of photosynthesis. It is found with photosynthesizing organisms and is used as a measure of the concentration (mg/L) of green plants (phytoplankton) in the water column. Chlorophyll a is a surrogate indicator of phytoplankton biomass, the amount of unattached single-celled algae present in water

Total phosphorus (TP) is a measure of all the forms of phosphorus, dissolved or particulate, that are found in a sample. Phosphorus is derived from soil erosion, precipitation (rain and snow), surface and deep drainage, organophosphate fertilizers and organic wastes. Phosphorus input into a water body causes eutrophication, which can be detrimental to aquatic organisms. Phosphorus in natural water is usually found in the form of phosphates (PO_4^{3-}). Phosphates can be in inorganic form (including orthophosphates and polyphosphates), or organic form (organically-bound phosphates). Organic phosphate is bound to plant or animal tissue and is formed primarily by biological processes. Inorganic phosphate is not associated with organic material. Types of inorganic phosphate include orthophosphate and polyphosphates. Orthophosphate is the most stable kind of phosphate, and is the form used by plants. Orthophosphate is produced by natural processes and is found in sewage. Polyphosphates are strong complexing agents for some metal ions. Polyphosphates are used for treating boiler waters and in detergents. In water, polyphosphate are unstable and will eventually convert to orthophosphate. EPA recommends that total phosphate should not exceed 0.05 mg/L in a stream at a point where it enters a lake or reservoir

Total Suspended Solids (TSS) include the organic and inorganic residue of all sizes that are suspended in a measured volume of water that is non-filterable. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. The flow rate of the water body is a primary factor in TSS concentrations. Fast running water can carry more particles and larger-sized sediment. Increases in flow rate also resuspend sediment, which increase the TSS in the water column.

Turbidity is a measure of the cloudiness of water. It is caused by suspended matter, such as clay, silt, organic matter, plankton, and other microscopic organisms that interfere with the passage of light through water. Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms.

C. Methods of Analysis for Water Quality Parameters

Ammonia – EPA 350.3
Ammonia was determined by use of an ion selective electrode (ISE) specific for the ammonium ion. The electrode used a hydrophobic, gas permeable membrane, which separated the sample from an internal ammonium chloride solution. The sample ammonia diffused through the membrane and adjusted the pH of the internal solution. This change was translated into a relative millivolt reading displayed on the pH/ISE meter.

BOD – SM 5210
The method calls for inoculating various dilutions of sample with viable bacteria and measuring the oxygen depletion after 5 days of incubation at 20°C. The dissolved oxygen was measured with an oxygen probe before and after incubation and the BOD was determined according to the net oxygen depletion due to the sample.

Ortho-phosphate – QC 10115011M
Ortho-phosphate was determined using an automated colorimetric method accomplished by flow injection analysis. The ortho-phosphate in the sample reacted with ammonium molybdate and antimony tartrate under acidic conditions. The product was then reduced by ascorbic acid to produce a blue color read at 880nm.

Nitrate + Nitrite as N – QC 10107041B
Nitrate plus nitrite was determined using an automated colorimetric method accomplished by flow injection analysis. The sample was passed through a cadmium column and the nitrate was reduced to nitrite. The nitrite then reacted with sulfanilamide and N-(1-naphthyl)ethlyenediamine dihydrochloride forming a pink color which is read at 520 nm.

TSS – SM 2540 C
A representative sample aliquot was filtered through a glass fiber filter and the captured residue is dried to constant weight at 103 to 105°C.

Total Phosphorus - QC 10115011D
The sample was subjected to a stringent digestion under high heat and acidic conditions. The phosphorous was converted to the orthophosphate ion and then analyzed using an automated colorimetric method accomplished by flow injection analysis. The ortho-phosphate in the sample reacted with ammonium molybdate and antimony tartrate under acidic conditions. The product was then reduced by ascorbic acid to produce a blue color read at 880nm.

Total Kjeldahl Nitrogen – QC 1010707062E
The sample was subjected to a stringent digestion under high heat and acidic conditions. The nitrogen compounds of biological origin were converted to ammonia. The ammonia was then analyzed using an automated colorimetric method accomplished by flow injection analysis. The ammonia reacted with salicylate and hypochlorite to form a blue color read at 660nm.

Chlorophyll a – SM 10200H2b

This method makes use of the known spectrophotometric absorbances of chlorophyll a and pheophytin a at 664nm and 665nm respectively, a turbidity correction (750nm), and the conversion of chlorophyll a to pheophytin a under mild acidic conditions to determine the concentrations of both pigments. A recorded volume of sample is filtered through a 0.7 µm filter. The filter is then homogenized and pigments extracted from the filter into an acetone solution. The absorbance of the clarified extract is determined using a narrow-bandwidth spectrophotometer at 664 nm and 750 nm. The extract is then mildly acidified to convert any chlorophyll a to pheophytin a, and the absorbance again determined, but using 665 nm and 750 nm. Concentrations of chlorophyll a and pheophytin a are calculated from these absorbances, the cuvette width, the initial sample volume, and the extract volume.

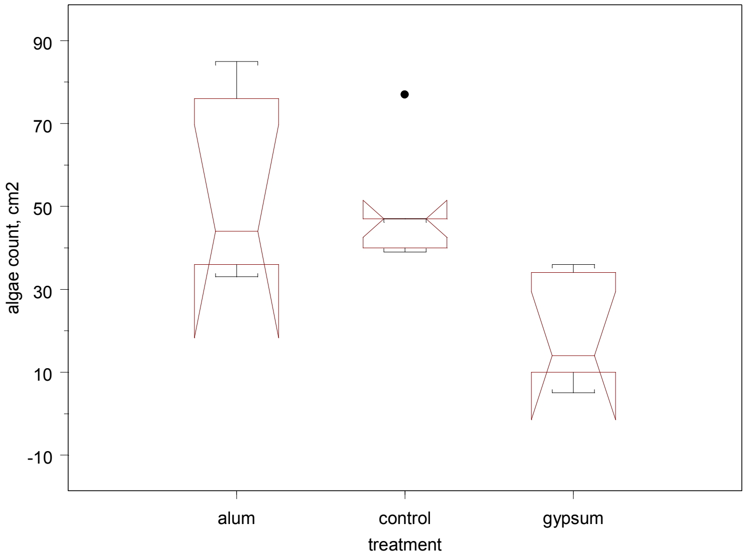
APPENDIX 4: GYPSUM AND ALUM STUDY. STATISTICAL ANALYSIS OF PHOSPHORUS AND ALGAL COVERAGE DATA

Phosphorus data is soluble reactive phosphorus in interstitial (pore) water

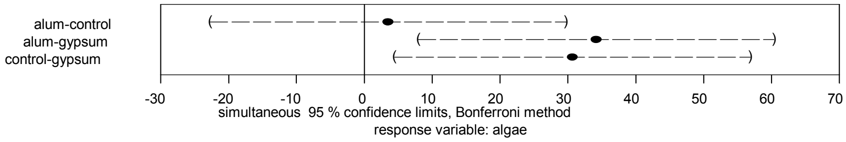
Algae data is by surface area count in cm^2

Algal Surface Coverage

Notched Box Plots (n=6 per treatment/control)
(If notch does not overlap horizontally with adjacent notch; results are different)



Bonferroni Analysis
(If results don't cross 0; treatments/controls are different)



```
      *** One-Way ANOVA for data in algae by treatment ***

Call:
   aov(formula = structure(.Data = algae ~ treatment, class = "formula"), data
= aquaria)

Terms:
                treatment Residuals
 Sum of Squares  4240.111  4256.333
Deg. of Freedom         2        15

Residual standard error: 16.84505
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value      Pr(F)
treatment  2  4240.111 2120.056 7.471415 0.00560387
Residuals 15  4256.333  283.756


95 % simultaneous confidence intervals for specified
linear combinations, by the Bonferroni method

critical point: 2.6937
response variable: algae

intervals excluding 0 are flagged by '****'

               Estimate Std.Error Lower Bound Upper Bound
  alum-control      3.5      9.73      -22.70        29.7
   alum-gypsum     34.2      9.73        7.97        60.4 ****
control-gypsum     30.7      9.73        4.47        56.9 ****
```

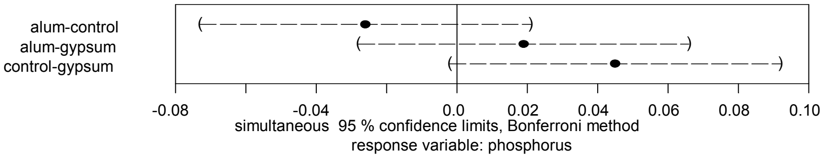
Interstitial Soluble Reactive Phosphorus

(Note: box plots excluded due to only 3 data points per treatment /control)

```
Terms:
                Treatment Residuals
 Sum of Squares  0.003062  0.001836
Deg. of Freedom         2         6

Residual standard error: 0.01749286
Estimated effects are balanced

          Df Sum of Sq  Mean Sq  F Value     Pr(F)
treatment  2  0.003062 0.001531 5.003268 0.0526698
Residuals  6  0.001836 0.000306


95 % simultaneous confidence intervals for specified
linear combinations, by the Bonferroni method

critical point: 3.2875
response variable: phosphorus

intervals excluding 0 are flagged by '****'

               Estimate Std.Error Lower Bound Upper Bound
  alum-control   -0.026    0.0143    -0.07300       0.021
   alum-gypsum    0.019    0.0143    -0.02800       0.066
control-gypsum    0.045    0.0143    -0.00195       0.092
```

Bonferroni Analysis

If results don't cross 0; treatments/controls are different
(note with rounding to alpha=0.05 control-gypsum does not cross 0)



APPENDIX 5: GYPSUM AND ALUM STUDY. COST ESTIMATES FOR STUDIED TREATMENT ALTERNATIVES

Cost Estimates for Alum and Gypsum are based on treatment in the 25 ft perimeter zone only. This zone totals 11 surface acres. It is not know how long treatment would last, or whether alum and/or gypsum treatment would require supplemental copper sulfate treatment. It is also not known whether treatment over a larger zone than that which experiences active growth would be beneficial in extending the period of effective treatment. Cost estimates are based on the doses used in the aquaria study.

Alum Treatment: at 60 mg/l

17,952 lbs Alum @ $ 0.51/lb	$10,355.52
Delivery Cost of Alum	1,200.00
Application Costs (Labor & Equipment Rental)	$14,614.32
Total	**$24,969.84**

Gypsum Treatment @ 3,000 lbs/surface acre

33,000 lbs Gypsum @ $ 0.10825/lb	$4,772.25
Delivery Cost if Gypsum	$1,200.00
Application Costs (Labor & Equipment Rental)	$19,650.00
Total	**$24,422.25**

Cost Estimates for Current Treatment and Monitoring

Bon Tempe Lake: Single Treatment (complete lake)

2600 pounds Copper Sulfate ($CuSO_4$) @ $0.81/lb. = $2106
Labor = two people @ 10 hours each = $130.20/hr. (combined wages) x 10hrs. = $1302
Boat = $1265.68/yr. X 0.33 (based on 3 treatments per year) = $421.89
Trucks = Two X 10hrs/truck = 20hrs. X $12/hr. = $240
Total Single Treatment = $4,069.89

Bon Tempe Lake: Summer Treatment (Based on three treatments)

$CuSO_4$ = $10,000 (1/2 our $20,000 budget)
Labor = two people @ 30 hours each = $130.20 X 30hrs. = $3906

Boat = $1265.68/yr.
Trucks = two @ 30hrs. each = 60hrs. X $12 /hr. = $720
Total Summer Treatment Cost = $15,891.68

Bon Tempe Summer Monitoring Cost (May – October)

18 Monitoring Trips X Two people @ 5 hrs. each = 18 X 5hrs. X $130.20/hr. = $11,718
Boat = 18 X $23.15/trip = $416.70
Truck = 5 hrs. /trip X 18 trips X $12/hr. = $1080
Total Summer Monitoring Cost = $13,214.70

Nicasio Lake: Single Treatment (1/3 of total lake)

3100 pounds of CuSO4 @ $0.81/lb. = $2106
Labor = two people @ 10hrs. each = $130.20/hr. (combined wages) X 10hrs. = $1302
Boat = $1,089.14 X 0.33 (bases on 3 treatments per year) = $363.05
Trucks = Two X 10hrs. /truck X $12/hr. = $240
Total Single Treatment = $4,416.05

Nicasio Lake: Summer Treatment (Based on three treatments)

Labor = two people @ 30hrs. /man X $130.20/hr. (combined wages) = $3906
CuSO4 = $10,000 (1/2 annual budget)
Boat = $1089.14/yr. (based on 10 yr. Operating life)
Trucks = two @ 60hrs. X $12/hr. = $720
Total Summer Treatment Cost = $15,715.14

Nicasio Lake Summer Monitoring Cost (May – August)

10 Trips X two people @ $130.20/hr. (combined wages) X 5hrs. /trip = $6,510
Boat = 10 trips X $23.15/ trip = $231.50
Truck = 5hrs. /trip X 10 trips X $12/hr. = $600
Total Lake Monitoring Cost = $7,341.50

*These costs only represent Bon Tempe and Nicasio Lakes. At a minimum we monitor Alpine and Kent Lakes at least once a month during summer months (8 total) to stay on top of potential algae problems in these lakes. There are six hours /monitoring trip for each lake (6hrs X $130.20/hr. combined wages = $781.20 labor/monitoring). Treatment would be extra and based on a 10 hour treatment day/lake w/two people.

Treatment / Monitoring Cost Data:

CuSO4 annual budget = $20,000($0.81/lb.), Supervisor Water Quality Inspection hourly rate = $70.77, Water Quality Technician hourly rate =$59.43, Pontoon Boat =

$1,265.68/yr., Scout Boat = $1,089.14/yr., Sampling Boat = $625.05/yr., Trucks = $12/hr. (charge out).

APPENDIX 6: GYPSUM AND ALUM STUDY. ALGAL COVERAGE DATA (% COVERAGE OF SQUARE METER OBSERVATION AREAS)

Summary of Original and New Field Test Plot Algae Coverage

	Site #1 Test Left Shallow Corner	Site #1 Test Right Deep Corner	Average	Site #1 Control Left Shallow Corner	Site #1 Control Right Deep Corner	Average
6/5/03	20%	65%	43%	ND	75%	75%
6/20/03	50%	70%	60%	60%	60%	60%
7/3/03*	60%	20%	40%	10%	80%	45%
7/17/03*	ND	ND		ND	ND	
7/23/03*	ND	ND		ND	ND	
8/6/03	NA	NA		NA	NA	
8/20/03	NA	NA		NA	NA	
9/3/03	98%	98%	98%	95%	100%	98%
9/19/03	95%	100%	98%	95%	100%	98%
10/1/03*	50%	70%	60%	NA	100%	100%
10/17/03	95%	90%	93%	85%	95%	90%

	Site #2 Test Left Shallow Corner	Site #2 Test Right Deep Corner	Average	Site #2 Control Left Shallow Corner	Site #2 Control Right Deep Corner	Average
6/5/03	50%	ND	50%	50%	ND	
6/20/03	35%	35%	35%	40%	ND	
7/3/03*	20%	15%	18%	25%	ND	
7/17/03*	ND	20%	20%	ND	ND	
7/23/03	NA	NA		NA	NA	
8/20/03	NA	NA		NA	NA	
9/3/03	25%	75%	50%	30%	ND	
9/19/03	20%	20%	20%	40%	ND	
10/1/03	70%	95%	83%	40%	ND	
10/17/03	95%	80%	88%	85%	ND	

	Site #3 Test Left Shallow Corner	Site #3 Test Right Deep Corner	Average	Site #3 Control Left Shallow Corner	Site #3 Control Right Deep Corner	Average
6/5/03	20%	60%	40%	75%	10%	43%
6/20/03	35%	70%	53%	15%	30%	23%
7/3/03*	25%	15%	20%	0%	60%	30%
7/17/03*	ND	ND		ND	ND	
7/23/03	ND	ND		ND	ND	
8/20/03	NA	NA		NA	NA	
9/3/03	95%	25%	60%	100%	100%	100%
9/19/03	90%	35%	63%	100%	95%	98%
10/1/03*	NA	80%	80%	NA	65%	65%
10/17/03	60%	20%	40%	65%	65%	65%

* denotes test and sample sites were either partially or completely out of the water.
** Treatment occurred on 6/5/03 and the treatment dose was 15 pounds of Gypsum per 10' X 20' treated plot.

NEW TEST SITES

New test sites; Site 1 and 3 are deeper in same lateral location as Old site 1 and 3.
Site 1a and 3a are treated ate new higher dose rate

	New Site #1 Test Left Shallow Corner	New Site #1 Test Right Deep Corner	Ave	New Site #1 Control Left Shallow Corner	New Site #1 Control Right Deep Corner	Ave
7/23/03	80%	65%	73%	20%	80%	50%
8/6/03	30%	50%	40%	25%	10%	18%
8/20/03	90%	90%	90%	90%	95%	93%
9/3/03	70%	85%	78%	20%	95%	58%
9/19/03	65%	80%	73%	30%	25%	28%
10/1/03	98%	95%	97%	65%	70%	68%
10/17/03	50%	98%	74%	80%	95%	88%

	New Site #1a Test Left Shallow Corner	New Site #1a Test Right Deep Corner	Ave
7/23/2003	80%	80%	80%
8/6/03	25%	50%	38%
8/20/03	90%	90%	90%
9/3/03	70%	75%	73%
9/19/03	65%	55%	60%
10/1/03	85%	90%	88%
10/17/03	85%	100%	93%

	New Site #3 Test Left Shallow Corner	New Site #3 Test Right Deep Corner	Ave	New Site #3 Control Left Shallow Corner	New Site #3 Control Right Deep Corner	Ave
7/23/03	20%	65%	43%	7%	3%	5%
8/6/03	60%	70%	65%	55%	40%	48%
8/20/03	80%	70%	75%	20%	60%	40%
9/3/03	75%	75%	75%	40%	75%	58%
9/19/03	80%	90%	85%	50%	85%	68%
10/1/03	100%	100%	100%	70%	85%	78%
10/17/03	85%	70%	78%	85%	70%	78%

	New Site #3a Test Left Shallow Corner	New Site #3a Test Right Deep Corner	Ave
7/23/03	10%	45%	28%
8/6/03	70%	75%	73%
8/20/03	90%	90%	90%
9/3/03	65%	95%	80%
9/19/03	60%	80%	70%
10/1/03	90%	100%	95%
10/17/03	75%	90%	83%

New test plots were set up on 7/23/03
New treated test sites are 10' X 10'
w Site #1 was treated with 42.5 pounds, and new Site #1a was treated with 85 pounds of Gypsum
Likewise for new site 3 and 3a (dose within 10' x10' section)