University of California
Santa Barbara

A Cost and Environmental Analysis of Aquatic Plant Management in California

A group project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Donald Bren School of Environmental Science and Management

By

Geoff M. Frieman

Garrett V. Lehman

Julie D. Quinn

Marion E. Wittmann

Committee in Charge:
Chris A. Marwood, Ph.D.

June 2004

A COST AND ENVIRONMENTAL ANALYSIS OF AQUATIC PLANT MANAGEMENT IN CALIFORNIA

As authors of this Group Project report, we are proud to archive it on the Bren School's web site such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Donald Bren School of Environmental Science & Management.

Geoff M. Frieman

Garrett V. Lehman

Julie D. Quinn

Marion E. Wittmann

The mission of the Donald Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. The final Group Project report is authored by MESM students and has been reviewed and approved by:

Christopher A. Marwood, Ph.D.

Dean Dennis Aigner, Ph.D.

June 3, 2004

Acknowledgements

We would like to thank Ben Greenfield, Geoff Siemering and members of the San Francisco Estuary Institute, our advisor Chris Marwood, Karyn Moskowitz and Christine Glaser of the GreenFire Consulting Group, Roger Mann, Cynthia Gause, Julie Owen, and Marcia Carlock of the California Department of Boating and Waterways, Clay Courtright and Tom Harvey from the Stone Lakes NWR, Steve Andrews of UC Berkeley Extension, George Forni of AEI, Arturo Keller, John Melack, and Tom Dunne of the Bren School for their help on the external review committees and comments on the BOD models, and Bruce Kendall of the Bren School for his comments on our data analysis.

Abstract

Herbicides have traditionally been the preferred method for controlling nuisance aquatic plants, because of low cost, ease of application, effectiveness, and availability of information. However, the recent policy change requiring National Pollution Discharge Elimination System (NPDES) permits for herbicides in aquatic systems has made non-chemical management more attractive. To help managers choose the best control techniques, various chemical and non-chemical management strategies were compared with respect to implementation costs and unaccounted costs of environmental impacts. Depending on objectives and site-specific restrictions, either chemical or non-chemical control may be the most appropriate approach. A cost-effectiveness analysis of various management techniques revealed that chemical treatments are more expensive when the treated acreage is small, and that costs of non-chemical techniques are generally low, regardless of area. Detailed analyses for two water bodies (Stone Lakes, Big Break) are presented to illustrate how managers must consider both the direct costs for permitting and implementation and the indirect environmental costs of any management option. A model created to predict dissolved oxygen decreases due to plant shredding practices revealed significant impacts on fish populations may occur from some non-chemical control techniques. This report provides guidance for managers of water bodies for minimizing both direct and indirect environmental costs of controlling nuisance aquatic plants.

Executive Summary

The control of invasive aquatic plants in California has become an important issue. The impairment of waters throughout the state has lead to research, as well as litigation, focused upon solving the problem. There is a general consensus that the removal of nuisance aquatic plants is necessary, but there exists a great deal of disagreement as to which method of removal is most appropriate. The main conflict is between the use of chemical and non-chemical mechanisms. Environmental advocacy groups feel that non-chemical methods are not utilized enough, whereas many aquatic herbicide users feel that non-chemical methods are either ineffective or too costly. It is likely that there are inaccuracies on both sides of this argument due to a lack of information and prejudices.

As a result of a 2001 legal decision in the U.S. Ninth Circuit court (Chapter 1.1), *Talent v. Headwaters*, the use of aquatic herbicides is now governed by the National Pollution Discharge Elimination System (NPDES). Water body managers now must obtain an NPDES permit for any chemical plant control strategy they employ. The cost of obtaining an NPDES permit ranges from $5,000 to $10,000, and monitoring costs for different herbicides range from $25,000 to $1 million (Chapter 5.6, Tables 6-11) depending on the size of the water body. The increased costs associated with the permit make chemical management strategies uneconomical for most small water bodies (the permit price is not based on acreage) and a much more attractive strategy for larger water bodies. There has been little to no research conducted on the cost effectiveness of the chemical or non-chemical techniques used to control various plants in California. Information of this type would be a valuable asset to California's water body managers.

In addition to the investigation of cost effectiveness, there is a need to quantify environmental impacts and increased regulatory costs of different chemical and non-chemical aquatic plant management strategies associated with management. This valuation can help managers consider the costs to the environment, as well as management control costs. The objective of this study was to integrate control, regulatory, and environmental costs of various aquatic plant management strategies to assist aquatic plant managers in their decisions.

Input for his document was generated from an extensive literature review, surveyed water body managers from California and Washington states, and stakeholder interaction. Two case studies were used as examples to exhibit and quantify some of the environmental impacts and increased regulatory costs associated with different plant management strategies. The case studies involved sites from the Sacramento/San Joaquin Delta area in California.

The study is comprised of *three* general sections. The *first* section addressed the control costs of a variety of chemical and non-chemical aquatic plant control techniques. It also included analyses that reveal the most cost-effective approach to

managing aquatic plants at four specific sites based solely on control cost. The *second* section is a case study that incorporated regulatory costs and replacement costs for fish killed from specific aquatic plant management techniques at Big Break. The *third* section contained a case study that evaluated the cost-effectiveness of several aquatic plant control strategies at Stone Lakes National Wildlife Refuge (SLNWR). It also modeled decreases in dissolved oxygen (DO) from different management scenarios to determine replacement costs for killed fish.

Control Cost Analysis

The control cost study compared the cost-effectiveness of various aquatic plant control methods in different management scenarios. It used a structured set of questions to conduct an economic analysis of chemical and non-chemical treatments. The cost-effectiveness analysis only considered the private control costs paid to meet a management objective. The cost did not include estimates of damage or environmental costs. The methodology used to acquire cost information included an initial establishment of contact with managers and practitioners, the creation of a survey to guide the phone interviews, and writing explanatory letters describing the project.

The cost-effectiveness study concluded that for chemical management techniques, control costs per surface acre are very high for a low acreage area and decrease with increasing treated area (Figure 5). This trend resulted from the set-up and NPDES permitting costs incurred for any herbicide application to a water body in California. For non-chemical techniques, the rates of control cost per unit area are similar for both small and large acreage, as there are no permitting and few monitoring costs that are required when employing these techniques.

In addition to the collection of general cost effectiveness data, four management scenarios were evaluated in detail: (1) the control of emergent vegetation at the Kern National Wildlife Refuge (Chapter 4.3.), (2) the control of Eurasian water milfoil, curly leaf pondweed, and algae at the Big Bear Lake Municipal Water District (Chapter 4.4.), (3) the control of water hyacinth at the Stone Lakes National Wildlife Refuge, Elk Grove, CA (Chapter 6.0), and (4) the control of *Egeria densa* (Brazilian elodea) and water hyacinth at Big Break (Chapter 5.0), located on the Sacramento-San Joaquin Delta. The most cost effective management technique for the Kern NWR is mowing, given that no more than four mowing events per season occur. The most cost effective management technique for Big Bear Lake is the application of Sonar™ (Fluridone) in combination with some harvesting. The most cost effective technique at both Stone Lakes NWR and Big Break are the application of herbicides.

Case Study: Big Break

The Big Break location is the first of two case study sites that were used to examine aquatic plant removal on a more specific per site basis. The Big Break study provides an analysis of management practices associated with the eradication of *Egeria densa* and water hyacinth. In addition to control costs from aquatic plant management, both environmental costs and additional regulatory costs that mitigate environmental impacts were calculated (Table 6). The environmental impact at Big Break was quantified using a fish kill valuation. The fish species that have been known to inhabit the plant beds are: threadfin shad, killifishes, largemouth bass, bluegill, inland silverside, and western mosquitofish. Chinook salmon are a threatened fish species that are not known to inhabit the plant beds, but were also valued to present a worst-case scenario. When mechanical harvesting occurs, there is a risk associated with killing fish residing in the plant beds. The estimated replacement value for fish killed by harvesting was $321. Chemical management strategies have been restricted to prevent fish kills. The cost associated with killing fish is an externality that most mangers do not consider when choosing a management strategy.

As part of the NPDES permit obligation, regulatory costs are required to mitigate adverse water quality conditions and were analyzed in this study to assess additional costs associated with the mitigation. The three areas of mitigation that were examined were: sampling, monitoring, and treatment restriction cost. This analysis yielded mitigation costs ranging from $163,000 to $1,476,500 (Table 11). The range includes costs associated with three chemical options; chelated copper, diquat dibromide, and fluridone, as well as the non-chemical option which is mechanical harvesting. All management strategies were rated based on the cost to obtain the management goal, cost of fish killed due to harvesting, and costs of monitoring, surveying, and sampling required to avoid environmental damage caused by both chemical and non-chemical management. The management strategy that resulted in the lowest overall cost was the use of diquat dibromide at Big Break.

Case Study: Stone Lakes National Wildlife Refuge

The Stone Lakes NWR case study incorporates site characteristics from South Stone Lake to model how water hyacinth management impacts aquatic habitat (Chapter 6.4). Predicting the effects that plant management activities have on dissolved oxygen, and ultimately fish habitat, can provide valuable information about the magnitude and duration of potential environmental impacts. Mechanical shredding of water hyacinth temporarily increases biochemical oxygen demand in a water body as a result of decaying plant material left in the water body after treatment. The biodegradation of plant material depletes ambient dissolved oxygen levels in the water body. Large-scale treatment events can create long periods of very low dissolved oxygen levels. Dissolved oxygen levels that fall below minimum concentrations that are essential for fish survival will create an environmental impact in the form of a fish kill.

The ability to predict whether hypoxia and anoxia would occur is crucial for planning the total size, number of treatments, and intervals between treatments, in order to minimize the total environmental cost from aquatic plant management. The model predicted the effects that three 33-acre treatment events would have on lake dissolved oxygen levels given a treatment interval of 7 and 15 days. Results from the 7-day treatment interval (Figure 6) predicted hypoxia at day 6, days 10 to 14, and days 17 to 24, considering re-aeration and immediate mixing within the water column. Anoxia occurred from days 19 to 21 when re-aeration was not considered. Results from the 15-day treatment interval predicted hypoxic conditions on day 6, days 20 to 21, and days 35 to 36, considering re-aeration and immediate mixing throughout the water column (Figure 7).

Fish not adapted for surface film respiration would likely die during anoxia, while all fish would experience increased respiration and reduced growth during hypoxia. Surveyed fish species that would die from the 7-day scenario are: the black crappie, largemouth bass, bluegill, warmouth, brown and black bullhead, and the white catfish. In order to determine the environmental impact from a fish kill, the replacement value of killed fish was considered. Replacement prices per pound per fish were multiplied by the total weight for each fish species encountered in the lake. The total cost to re-stock the South Stone Lake fishery with fish species that would likely die under the 7-day treatment interval is $41,200 (Chapter 6.4). Plant management that requires a treatment interval duration of 15-days, as opposed to 7-days, may incur higher treatment costs, but would result in a smaller environmental cost associated with low dissolved oxygen concentrations causing massive fish kills.

This analysis employed a comprehensive approach to determine the cost-effectiveness of chemical and non-chemical aquatic plant management strategies. The analysis is unique because it considered environmental, regulatory, and control costs. Few environmental cost analyses have been performed for aquatic plant management practices.

Primary research has begun to value the environmental cost to incidental take of endangered species and its habitat, but there are knowledge gaps about how incremental degradation of environmental amenities should be valued. Future research could include: a more comprehensive economic valuation of environmental impact costs, a study on cost savings from the formation of herbicide management groups, addressing accuracy issues with the BOD model parameters, and a cost determination of various management strategies in different aquatic settings.

This document has compared the overall costs of several management techniques, and has made recommendations based on the most cost-effective alternative. This report will hopefully improve aquatic plant management decisions by accounting for not only control costs, but also costs from potential environmental damages.

Commonly Used Acronyms and Trade Names

APMP	*Aquatic Pesticides Monitoring Program*
BCF	*Bioconcentration Factor*
BOD	*Biochemical Oxygen Demand*
CDBW	*California Department of Boating and Waterways*
CDFA	*California Department of Food and Agriculture*
DO	*Dissolved Oxygen*
EC50	*Concentration producing an effect in 50 percent of the organisms tested*
EIR	*Environmental Impact Report*
HROM	*Hydrolysis Resistant Organic Matter*
Komeen™	*Chelated copper*
LC50	*Concentration lethal to 50 percent of the organisms tested*
MCL	*Maximum Contaminant Level*
NPDES	*National Pollution Discharge Elimination System*
NMFS	*National Marine and Fishery Service*
NPV	*Net Present Value*
NWR	*National Wildlife Refuge*
Reward™	*Diquat-dibromide*
Sonar™	*Fluridone*
SLNWR	*Stone Lakes National Wildlife Refuge*
SLBWHCG	*Stone Lakes Basin Water Hyacinth Control Group*
SWRCB	*State Water Resources Control Board*
USFWS	*United States Fish and Wildlife Service*
WAPMS	*Western Aquatic Plant Management Society*
WHCP	*Water Hyacinth Control Program*

Table of Contents

Table of Figures

Table of Tables

1. Introduction

1.1. *History/Background*

On January 1st, 2002, a new research and monitoring effort began at the San Francisco Estuary Institute (SFEI) under the direction of the California State Water Resource Control Board (SWRCB). This project involves the investigation of the behavior of aquatic herbicides in the environment throughout the state and is known as the Aquatic Pesticide Monitoring Program (APMP). This project looks exclusively at herbicides applied directly to bodies of water and not at herbicides that were initially used on land. The Bren Master's Group known as "PEST" participated in this study as an academic third party.

The APMP arose from a 2001 legal decision in the U.S. Ninth Circuit court (*Headwaters, Inc. v. Talent Irrigation District*). Its interpretation required aquatic herbicide users to obtain a National Pollution Discharge Elimination System (NPDES) permit prior to discharging herbicides to U.S. waters. Previously, herbicide use was governed only under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA). In order to keep aquatic herbicide use legal after the recent court decision, the SWRCB issued an emergency permit:

> "…Because of the serious public health, safety, and economic implications of delay in such applications, [the State] developed a general application on an emergency basis in order to provide coverage for broad categories of aquatic pesticide use in California."
>
> *California SWRCB fact sheet, Headwaters vs. Talent Irrigation District, 2001*

However, the advocacy group Waterkeepers felt that this permit did not require adequate monitoring and challenged the permit in court. As a settlement with Waterkeepers, the SWRCB agreed to fund two years of research and monitoring to provide the state with enough information to develop a good general NPDES permit when the current emergency permit expires.

Costs associated with NPDES permits have increased the appeal of non-chemical plant control alternatives, such as mechanical harvesting, hand removal, and biological control. However, because non-chemical methods are often considered unfeasible, due to plant characteristics or requirements from stakeholders, it is important to identify circumstances where they may or may not be suitable. The APMP, funded by the SWRCB, has conducted a detailed cost analysis to compare non-chemical versus chemical methods in California waters. Case studies included control projects underway in California, as well as demonstration projects for new approaches. Ultimately, the study intended to document the economic feasibility of different control methods on a variety of sites (lakes, irrigation and storm water canals, wetlands, and the Sacramento-San Joaquin Delta). The APMP project also compared the potential environmental threats posed by chemical toxicity versus threats of non-chemical methods to local water quality and wildlife.

Because of SFEI's experience in conducting and managing large-scale monitoring plans, the SWRCB selected SFEI to run the APMP. This work complemented the water quality monitoring that individual permit applicants must already conduct. The APMP's efforts were directed in two distinct areas: methods development, and the pilot testing of monitoring techniques and methods.

One part of this research and monitoring effort involves gaining a better understanding of the costs of non-chemical plant control methods. This may be accomplished by studying sites where non-chemical controls are currently being used and comparing them to sites treated chemically or by arranging for and conducting independent demonstration projects. Non-chemical methods include such techniques as mechanical harvesting, biological control, and physical barriers. Detailed cost analyses have not been conducted on many of these methods for California water bodies. Environmental advocacy groups feel that non-chemical methods are not utilized enough, whereas many aquatic herbicide users feel that these methods are either ineffective or too costly. It is likely that there are inaccuracies on both sides of this argument that need to be resolved.

1.2. ***Problem Statement***

As a result of *Talent v. Headwaters* decision, aquatic herbicide usage is now governed by the NPDES. This is to say that aquatic plant managers will now have to obtain an NPDES permit for any chemical plant control strategy they employ. The cost of obtaining a NPDES permit is in the 5 to 10 thousand-dollar range, and some of monitoring costs associated with different herbicides may range from $50,000 to $1 million. There has been little to no research conducted on the cost effectiveness of chemical or non-chemical techniques used to control various plants in the water bodies of California. Information of this type would be a valuable asset to California's water body managers.

In addition to the investigation of cost effectiveness, there is a need to quantify environmental impacts and increased regulatory costs of different chemical and non-chemical aquatic plant management strategies associated with management. This valuation can help managers consider the costs to the environment, as well as management control costs. The goal of the "PEST" group was to integrate control, regulatory, and environmental costs of various aquatic plant management strategies to assist aquatic plant managers in their decisions. The group conducted an extensive literature review, a survey of water body managers to quantify cost effectiveness data, and two case studies in an attempt to quantify some of the possible environmental impacts and increased regulatory costs associated with different plant management strategies.

1.3. ***Methodology***

Attempting to assign values to environmental assets, services, or quality presents several challenges. First, environmental assets or amenities typically provide several functions at the same time. Second, there is no single method that captures all of the values that can be attributed to environmental goods. Different environmental amenities can sometimes only be expressed in non-monetary units making it difficult to assign a monetary to them. The process of converting environmental goods to a standard unit like dollars is subjective and requires personal judgments to be made. Third, values are often not additive, and 'double counting' is an ever-present problem. Finally, the argument that it is morally wrong to value something which is by definition invaluable is always a point of contention (Fausold 1996).

Two types of values traditionally assigned to environmental goods are use and non-use. Use values are attributed to any activity that uses the environmental good, whether it is consumptive or non-consumptive. For example: fishing and boating, or watching fish. Non-use values are applied to the value of environmental goods either for their future use (option value) or for their altruism (existence value). Option values are defined by the amount of money people are willing to pay to have the option to enjoy an environmental good in the future. Existence values are determined by the amount of money people are willing to pay to know that an environmental good exists even though they may never use it (Fausold 1996). The most commonly used methods for pricing non-market environmental goods are benefit transfer, contingent valuation, hedonic pricing, and damage cost avoidance (King 2003).

The benefit transfer method transfers values used in economic studies of similar environmental goods to the environmental goods in question. Benefit transfer can quickly and cheaply come up with a rough estimate for an environmental good. The more studies that are used in conducting a benefits transfer analysis the less biased the benefit transfer will be. The benefit transfer method relies on others' work and research. It can only be as reliable as the initial study that it is based upon (King 2003). Benefit transfer studies have been used to value many different kinds of environmental goods. (Hushak 1998).

Contingent valuation involves surveying people about their willingness to pay for improvement of or for acceptance of environmental changes. Contingent valuation can be used to appraise both use and non-use values. Survey responses are contingent upon a hypothetical situation described in the survey. The description of the hypothetical situation and the fact that survey responses may not actually represent real life choices are always points of contention when conducting a contingent valuation survey (King 2003). Contingent valuation is a particularly popular method for valuing the non-use values of environmental goods.

Hedonic pricing assigns economic values to environmental services that directly affect the market prices of other goods. It is based on the theory that the price of a market good is based on its characteristics and can be used to estimate benefits or costs associated with environmental quality or environmental amenities. The most common method of applying hedonic pricing to environmental amenities or quality is through the housing market. In theory, if two housing markets are similar, except for differences in an environmental amenity or a level of environmental quality, then the difference in their prices can be attributed to these differences (King 2003).

Damage cost avoidance is a method that assigns environmental costs according to the cost of either avoiding environmental damages, the cost of replacing the environmental services that are lost, or providing substitute environmental services. This valuation technique assumes that the cost of avoiding an environmental damage or replacing the environmental service that was damaged is equal to the cost of that environmental amenity or service. This method is best applied to situations where potential environmental damages can be mitigated. It can then be assumed that the environmental amenity or service that is being protected is worth at least the cost of mitigation or the agency involved would replace the damaged environmental service/amenity at a cost less than the mitigation (King 2003). The city of New York used information from the American Water Works Journal stating that the most effective way to ensure the long-term protection of water supplies is through land ownership (Stapleton 1997).

When environmental damages cannot be mitigated, as in the case of fish kills at Big Break, it is possible to use a replacement cost to value the environmental good. In this exercise, fish stocking replacement values were used to place a dollar value on the loss of fish species. These values are essentially replacement costs, obtained through a survey of hatcheries that reported prices based on the basic principle of supply and demand (American Fisheries Society 1993). Applying the dollar value to an estimated number of fish killed yields a total cost associated with the replacement cost of fish. The cost to replace the existing fish stock after harvesting can be considered an additional cost of harvesting.

The Big Break case study also employed a benefit-transfer to assess the amount of fish killed from a harvesting event, as well as the amount of time required to survey sensitive habitat in the management area. After adding the increased regulatory, environmental, and control costs to a management strategy, a resultant total management cost was derived for different strategies at Big Break.

The exercise for the Stone Lakes National Wildlife Refuge (NWR) used a similar approach by using replacement prices for fish that would die as a result of mechanically shredded, water hyacinth decaying in-situ. Fish loss was modeled by calculating decreases in dissolved oxygen levels as a result of the shredding event. Large amounts of decaying plant material decrease dissolved oxygen levels, which has the ability to harm aquatic life.

2. **Aquatic Exotic Plants**

The following section will describe the aquatic plants located at both Big Break and Stone Lakes NWR. These plants are exotic and have the ability to grow exponentially as a result of the lack of natural checks associated with their native habitats. Invasive species' growth must be controlled to keep the human-desired functions of water bodies from degrading.

2.1. ***Egeria***

Egeria densa Planch. (Brazilian elodea) was introduced to California more than 30 years ago. A lack of grazers and prime habitat has allowed this plant to grow rapidly in many California water bodies. *Egeria* has the potential to obstruct navigation, slow water flows, plug water inlets for drinking and irrigation water, reduce water-holding capacity, and disrupt the ecosystems in which it is present.

Figure 1. A handful of Egeria.
Photo: A. Murray, University of Florida.

Egeria is a perennial submersed aquatic herb native to Southeast Brazil. Its stems are usually one to two feet long with small strap shaped whorls of three to six leaves around the stem. Its flowers are white, about 2 centimeters in diameter, and sit on short stalks about 2.5 centimeters above the water surface (Washington State Department of Ecology 2003b). Most of the biomass in *Egeria* is produced near the waters surface with stems continuing down to depths of 6 meters. *Egeria* can either anchor itself in the bottom substrate or survive as a floating plant mass (California Department of Boating and Waterways 2001). Even though *Egeria* flowers, no female flowers have been seen in the United States, and no seeds have ever been collected. *Egeria*'s main method of reproduction is vegetative, through fragmentation. *Egeria* has the ability to fragment readily at its double nodes. These double nodes also have the ability to form root crowns along a stem that has sunk and attached to the bottom substrate. Plant portions that are removed from the plant are able to float to new locations and establish a new plant mass in a previously unexploited portion of the water body (Washington State Department of Ecology 2003b).

Egeria tends to grow in spurts with a flush of growth in the spring and the fall. These growth spurts appear to be the largest in periods of drought. During the summer, profuse branching forms a dense tangled mat of plants (Washington State Department of Ecology 2003b). Like most introduced species, *Egeria* has the ability to rapidly colonize large areas. The *Egeria* beds in the Sacramento-San Joaquin Delta are large beds that contain few other plant or algae species. The *Egeria* beds contain many invertebrate species that the Delta fish feed on. Obrebski et al. (1998) states that the invertebrate communities in *Egeria* beds in the Delta are characteristic of most fresh water macrophyte invertebrate communities in the continental Unites States. The five most abundant groups of organisms that create this characterization are:

- Dipteran larvae
- The amphipod *Hyalella azteca*
- *Cladocera*
- The snails *Physa sp*. and *Gyraulus sp*.
- The oligochaete *Stylaria*

Fish that either live in or migrate near *Egeria* beds consume several of these species. Some species that depend on these invertebrate populations are species of concern, like the Chinook salmon, splittail, and delta smelt.

The shallow waters in which *Egeria* grows, and the dense cover it creates, would seem to be ideal habitat for native fish spawning and rearing. However, studies of the *Egeria* beds in the Delta have shown otherwise (McGowan 1998). McGowan studied the use of *Egeria* beds as habitat for special status species such as splittail, Chinook salmon, and delta smelt in 1998. In those studies, he reported these species did not use *Egeria* beds as habitat. McGowan used pop-nets to trap fish in the *Egeria* beds and recorded his findings. The species he found to be most abundant in *Egeria* beds were:

- Bluegill (non-native)
- Largemouth bass (non-native)
- Inland silverside (non-native)
- Killifish (non-native)
- Mosquito fish, (non-native)
- Threadfin shad (non-native)

As noted above, all of the most abundant fish species found in the *Egeria* beds were non-native species. Only one native fish, the prickly sculpin, was found in the *Egeria* beds (McGowan 1998). Studies suggest that the depressed levels of dissolved oxygen and reduced temperatures that are characteristic of these beds are limiting to some species (Cook 1984). Another study by Grimaldo and Hymanson (1999) reported similar findings of an abundance of introduced fish and Chinese mitten crabs.

2.2. ***Water Hyacinth***

Water hyacinth (*Eichornia crassipes* (Mart.) Solms) was introduced to North America from South America in the 1880's in Louisiana. A member of the pickerelweed family (Pontederiaceae), water hyacinth is a floating plant with leaves up to 25 centimeters in diameter. The leaves are held upright and act as sail to facilitate movement throughout water bodies. Its height above the water surface can reach over a meter when dense mats are formed. Below the water surface, the plant produces a root mass that can compose up to 50% of the plants biomass for nutrient absorption and rhizome or stolon production (Batcher 2003).

Hyacinth has grown relatively unchecked on this continent because of its ability to rapidly reproduce. It can grow in many different water bodies including wetlands, lakes, and irrigation canals. Small mats of water hyacinth can create habitat for aquatic life, but large mats have the ability to create costly economic damage. These mats are tightly intertwined and are able to competitively exclude native submersed and floating plants. It can also reduce a water body's ability to hold water and thus create the potential for flooding, and reduce navigation. Water hyacinth is one of the most productive plants on Earth, and an individual can produce up to 5,000 seeds which can remain viable for up to 20 years (Gopal 1987). However, the main method of reproduction is vegetative. The plants can create rhizomes and stolons, which have the ability to become new viable plants (Batcher 2003). Hyacinth populations have been shown to double in as little as 6-18 days (Mitchell 1976).

Figure 2. Water hyacinth at Stone Lakes National Wildlife Refuge, Summer 2003. Photo: Ben Greenfield, San Francisco Estuary Institute.

Water hyacinth plants initiate growth in the spring by producing daughter plants from parent plants that over-wintered in old plant stems. Water hyacinth plants increase in size and number until their maximum biomass is reached in late summer. Flowering occurs in summer and seeds are produced in submersed withering flowers. The plant mass begins to die back in late fall and usually by January all plants have died back (Washington State Department of Ecology 2003a).

Figure 3. Flowering water hyacinth patch, Stone Lakes National Refuge.

The large mats formed by water hyacinth impede water flow, decrease dissolved oxygen levels, and increase inputs from plant detritus (Lynch 1947, Gopal 1987). One study showed that the average dissolved oxygen levels under the mats were below 5 mg/l (Madsen 1997). Research conducted in the Sacramento-San Joaquin Delta showed that dissolved oxygen levels below water hyacinth mats in sloughs can reach 0 mg/l for three days out of the week during the month of June (Toft 2000).

Water hyacinth mats also have the ability to reduce fish spawning areas, reduce waterfowl habitat (Schmitz 1993), and significantly alter the invertebrate and vertebrate communities (Batcher 2003). A study in which fish near and under water hyacinth mats were collected showed that only 24% of the fish nearby and 2% of the fish living underneath the mats were native species (Toft 2000).

3. **Impacts**

3.1. ***Overview***

In this section, a discussion of potential impacts resulting from management strategies will be addressed. Both chemical and non-chemical management options result in impacts, which can be described both qualitatively and quantitatively. The general areas where there is a potential for impact include:

- Water quality
    - Decreases in dissolved oxygen
    - Increases in turbidity
    - Chemical re-introduction in the water column
    - Chemical accumulation in the sediment
- Wildlife
    - Non-target plant species
    - Invertebrates
    - Fish, their habitat, and food sources
    - Amphibians and reptiles
    - Birds
- Humans
    - Drinking water
    - Agriculture
    - Recreation

3.1.1. **Water quality**

There are many issues surrounding the effects to water quality for different management techniques. Basin Plan Standards for water quality in the Sacramento-San Joaquin Delta have been established by the USEPA, as well as management strategies for aquatic plant removal. The four Basin Plan Standards most relevant to the analysis include:

- *Chemical Constituents*: Waters shall not contain chemical constituents in concentrations that adversely affect beneficial uses
- *Toxicity*: All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life
- *Pesticides*: Discharges shall not result in pesticide concentrations in bottom sediments…that adversely affect beneficial uses
- *Dissolved Oxygen*: Within the legal boundaries of the Delta, the dissolved oxygen concentration shall not be reduced below 7.0 mg/l in the Sacramento River…and in the Delta waters west of Antioch Bridge; 6.0 mg/l in the San

Joaquin River…and 5.0 mg/l in all other Delta waters except those bodies of water which are constructed for special purpose.

Decreases in dissolved oxygen are a concern when using herbicides on large areas of aquatic plants. Rapid plant degradation can cause a drop in dissolved oxygen levels, which have the potential to violate Basin Plan Standards and cause invertebrate and fish kills. Increases in turbidity can limit the water's use for agriculture or drinking water. In addition, some herbicides have the potential to accumulate in the sediment. Over time, these cumulative herbicide application events can reach concentrations that are toxic to benthic organisms (CDBW 2001).

3.1.2. **Wildlife**

There are a number of ways aquatic plant control methods can affect wildlife. There is potential to create direct, as well as secondary impacts on wildlife from different control methods. The following case studies will discuss species that inhabit treatment areas and the effects of plant management on them. Impacting early life stages can have significant implications for populations, as the new population pool is reduced and thus contributing to an overall decline in population. Potential effects to lifecycles would have to be mitigated, which would involve taking steps to specifically prevent or remediate controlled areas to pre-treatment status.

For example, Stone Lakes NWR contains habitat for the giant garter snake, a federally threatened species. Mechanical shredding has the potential to kill, injure, disturb, and harass the snake since it may reside on floating hyacinth mats. In addition, the shredder is noisy and wave action can disturb the surface, forcing the snake to flee into less suitable habitat where it is at a higher risk of predation.

The shredding of water hyacinth could also result in reduction of aquatic vegetation cover and temporary decrease in the prey base (Sacramento Fish and Wildlife 2001). Even though the snake is at risk over the short-term, maintenance of vegetation cover could result in long-term benefits to the species and its aquatic habitat. The removal of dense vegetation could free space for macro-invertebrates, small fish, and native aquatic plants. A greater availability of the snake's food sources has the potential for long-term benefits to the snake.

Mechanical shredding equipment has the potential to increase vehicle traffic on roads and levees in the management area. The construction of boat ramps could impact near shore nesting habitat for waterfowl.

3.1.3. **Humans**

Aquatic plant control has the potential to affect humans as well as the ecosystem in specified plant control area. There are three categories for which plant control strategies may have potential impacts:

- Drinking water
- Agricultural irrigation water
- Recreation

Once plants are treated there are usually residual plant material or fragments that are not readily collectable. If left in place, this waste material can clog pumps preventing the conveyance of drinking and agricultural waters.

Chemical treatment creates concern due to the potential for exposure to humans that is created from treatment events. Some chemicals have the possibility to accumulate in sediments and could potentially end up re-suspended in the water column, which is a perceived risk for some water users. Chemical constituents in drinking, agricultural, or recreational water present the opportunity for human exposure. Although some herbicides have tested to be registered for use near water inlets, there are still concerns about others in use for plant removal.

Again, these are general impact categories that shall be discussed in greater detail in accordance to individual management scenarios for specific case study sites.

3.2. ***Chemical control***

Chemical control is the most widely used from of plant control in the Unites States. In California three of the most commonly used herbicides registered for the control of *Egeria densa* are chelated copper, diquat-dibromide, and fluridone. These three chemicals come in many different formulations and are sold under many different trade names, but Reward™ (diquat-dibromide), Sonar™ (fluridone), and Komeen™ (chelated copper) are three of the most widely used. These three herbicides have been known to achieve control of *Egeria densa* and have been chosen by the Department of Boating and Waterways for use in the *Egeria densa* Control Program. Of the aforementioned herbicides only diquat-dibromide is registered in California for the control of Water hyacinth. Glyphosate and 2,4-D are two frequently used herbicides to control Water hyacinth plant problems. Glyphosate is sold under the trade name Rodeo™ for use in aquatic environments.

Contact and systemic herbicides are two kinds of chemical herbicides that are defined by their physical modes of action. Contact herbicides kill portions of the plant with which they come in contact and are not translocated throughout the plant. In other words, the herbicide does not enter the vascular system of the plant (University of Florida 2003a). Diquat-dibromide is a contact herbicide, as it moves through the leaf cuticle and targets specific cells through a specific chemical reaction. Systemic herbicides, or translocated herbicides, move through the vascular system of the plant (University of Florida 2003a). Fluridone is an example of a systemic herbicide as it enters a plant through its roots or leaves and then migrates to the vascular system where it is translocated to all portions of the plant.

Another way to define herbicides is by categorizing them as selective and non-selective. Selective herbicides are chemicals that are generally more toxic to some plant species than others (University of Florida 2003a). 2,4-D is a selective herbicide because it only kills broadleaf plants and leaves grasses unaffected. Non-selective herbicides are chemicals that are generally toxic to all plants. Their toxicity may be a function of many different variables such as mode of action, dose, or application method (University of Florida 2003a). Chelated copper is an example of a non-selective herbicide. When chelated copper is added to the water column in high concentrations, it is toxic to some degree to most plants. Each of these types of chemicals will have different environmental effects. For example, systemic herbicides generally provide longer lasting control, but also have the ability to create a much larger impact on the non-target species that are affected. Environmental impacts created by using these chemicals are a function of their chemical properties, but also application method, timing of application, concentration, and properties of the water bodies in which they are applied.

3.2.1. **Diquat-dibromide**

Diquat-dibromide (hereafter referred to as 'Diquat') is one of three chemicals registered in California for control of aquatic plants. Diquat is registered under the trade names Quacide™, Aquakill™, Dextrone™, Reglone™, and Reward™. It is a moderately toxic compound listed in EPA toxicity class II. Diquat is a desiccant, which means that it causes the portions of the plant it contacts to dry out and die quickly. It is non-selective and quick acting. Although diquat is rapidly absorbed into plant tissue, it kills the tissues necessary for translocation too quickly to move throughout the plant (EXTOXNET 1996b).

MCL = maximum permissible level, national criteria established by the EPA, for a contaminant in water which is delivered to any user of a public water system

Effective control of *Egeria* can be obtained at levels of 0.37 ppm in the water column. This concentration of diquat in the water column is 18.5 times the California EPA maximum contaminant level of 0.02 ppm for drinking water. Diquat also contains an "inert ingredient" that is known to cause cancer; but because it is an "inert ingredient" there is no information listed on its identity or concentration (CDBW 2001).

Diquat's persistence in the water column is relatively short. The amount of turbidity in the water column and density of plant mass in the treatment zone determine the herbicide's persistence. Once diquat has bound itself to plant tissue or particles in the water column, it becomes immobile and biologically unavailable. In addition, microbes and sunlight degrade immobile diquat molecules and reduce their presence in the water body (CDBW 2001).

There is little chance that diquat would create adverse impacts to benthic organisms. Diquat may accumulate in the sediments on a short-term scale, but once bound to particulate matter is biologically unavailable. Immobilized diquat molecules will be degraded by microbes in the sediment and will not accumulate over long time periods (CDBW 2001).

Diquat is applied directly to the water's surface or through underwater tubes trailing the application boat above the bottom of the water body. There is no registered application technique or control mechanism that would increase turbidity in the water column.

3.2.2. **Chelated copper**

Chelated copper is one of three registered chemicals that achieve effective control of aquatic plants (CDBW 2001). Chelated copper is a broad-spectrum herbicide that kills by interfering with plant enzymes, enzyme co-factors, and plant metabolism. Chelating copper ions with organic molecules (triethanoloamine or ethylenediamine) reduces the copper's toxicity to aquatic life, helps the herbicide remain in solution longer in hard water, and increases the herbicidal activity of the copper (CDBW 2001; University of Florida 2003b). Empirical studies have shown that chelated copper appears to be an order of magnitude less toxic to fathead minnows (an indicator species for toxicity) than ionized copper for water with similar hardness (Huang 1998).

The effectiveness of chelated copper is related to its penetration into plant tissue. Therefore, proper placement of the chemical is essential. Effective control of plants is achieved when the chelated copper is in contact with plant tissues for at least 12 to 24 hours. After the initial application of herbicide plants should drop below the surface of the water within 3 to 7 days. The complete effect of the treatment will occur with in 4 to 6 weeks.

3.2.3. **Fluridone**

Fluridone is a slow acting systemic herbicide that affects carotene synthesis in plants. Carotene-deficient plants produce white chlorotic growing points that cannot contribute to the plants carbon storage. Fluridone effectively starves the plant (Pesticide Management and Education Program at Cornell University 1986); without carotene, chlorophyll is rapidly degraded by sunlight. The death and decay of these plants is slow and reduces the potential of decreasing dissolved oxygen from large plant mass decay.

Fluridone enters the plant through the shoots in the water column. Once within the plant, it can begin to attack the plant and is able to affect all portions of a plant because it is translocated throughout the entire plant. Herbicides that work this way leave no viable fragments of plant mass (CDBW 2001). Fluridone is slow acting and must be absorbed by plants to be effective. Fluridone is sold under the trade name Sonar™ and comes in many different formulations including liquid, and slow release pellets. Slow release pellets periodically release fluridone in concentrations of 10 to 40 ppb over a period of 40 days. Slowly releasing fluridone in flowing water reduces the chance of diluting the herbicide to levels below efficacy. Under optimal conditions, fluridone takes 30 to 90 days to reach desired control levels. To obtain effective control at a site like Big Break, fluridone would need to be applied twice a week for 4-6 weeks. Slow release pellets may be able to keep fluridone concentrations in an effective herbicidal range while avoiding the costs of reapplication (CDBW 2001).

The maximum application rate for fluridone in lakes is 0.15 ppm. The maximum concentration for fluridone in drinking water is 0.015 ppm, which is an order of magnitude less than application rates. Fluridone cannot be applied closer than 400 meters from a drinking water inlet. There are no standards set for fluridone in waters used for swimming or fishing.

Fluridone is rapidly degraded in the water column. Degradation is primarily due to photolysis, but dissipation and plant uptake both affect fluridone's concentration decrease in the water column. Turbidity and dissolved oxygen play a role in the rate at which fluridone is degraded. Turbidity has a negative effect on degradation where dissolved oxygen has a positive effect on degradation.

Fluridone does not accumulate in the sediment. West (1979) conducted studies on fluridone accumulation in small ponds and large lakes. In small ponds he found that the average half-life of fluridone in pond sediment was three months. Considering that treatments only occur in an area once per year, and usually provide multi-year control, this provides adequate time to diminish fluridone levels in the sediment before the next application. In large lakes where only small plots were treated (0.8-4 ha), negligible residues were found in the sediment. The lack of accumulation of fluridone in the sediment to is likely due to dissipation and dispersal by water currents before deposition (West 1983).

Toxicity studies have shown that fluridone presents a favorable margin of safety between fluridone concentrations that affect non-target organisms and that needed to control *Egeria* (Hamelink 1986). Bioconcentration is not a significant problem when using fluridone. The bioconcentration factor (BCF) for fluridone is very low, about 8-10. The low BCF in fish is due to the low n-octanol/water partitioning coefficient of 1.87 for fluridone. Maximum overall concentrations in fish occur about 14 days after treatment at 0.399 ppm (West 1979). These herbicide levels in fish do not last long because fluridone is rapidly metabolized in fish tissue. Fish samples from ponds taken four months after treatment showed only 0.037 ppm in fish tissue. Fish samples from lakes were lower (West 1979).

> BCF = the ability of a chemical to reach a higher concentration in a living organism than in the surrounding medium

Aquatic invertebrates will likely not be harmed by the application of fluridone. Research has shown that fluridone only becomes toxic to aquatic invertebrates at levels much higher than application rates. Hamelink et al. (1986) found that daphnids, amphipods, and midge larvae suffered chronic effects at rates of 0.2 ppm and above, at least 10 times higher than the application rate, in the water column. This same study showed that the 48-hour or 96 hour LC50 or EC50 depending on the organism (amphipods, daphnids, midges, crayfish, blue crabs, eastern oysters, and pink shrimp) was 4.3 ppm +/- 3.7 ppm. The LC50 or EC50 reported by Hamelink et al. (1986) for aquatic invertebrates are much higher than the effective herbicidal rate required for fluridone. One study by Parka et al. (1978) showed that fluridone concentrations did not cause significant reductions in invertebrate population size compared to a control population until they reached levels of 1 ppm in the water column. Because a significant loss to invertebrates is unlikely, the application of fluridone will likely not affect fish species prey base (CDBW 2001).

3.2.4. **Glyphosate**

Glyphosate is a broad-spectrum, nonselective systemic herbicide used for control of annual and perennial plants including grasses, sedges, broad-leaved plants, and woody plants. Unlike most contact herbicides, the effects of glyphosate are slow and may take up to 7 days for visual signs to appear, which can be slowed by cool or cloudy weather (Schuette 1998).

Glyphosate is slightly toxic to humans; the maximum contaminant level of glyphosate in drinking water is set at 700 ppb (U.S. Environmental Protection Agency 1978). The oral LD50 for rats is 5600 mg/kg and the toxicities for the formulated product Roundup™ are nearly the same (University of Florida 2003a; Monsanto Company 1985). Glyphosate also has almost no toxic effects through skin exposure. In a study including human volunteers there were no visible skin changes or sensitization produced from patch tests (University of Florida 2003a). Glyphosate is poorly absorbed from the digestive tract and is largely excreted unchanged by mammals. At 10 days after treatment, there were only minute amounts in the tissues in rats fed glyphosate for 3 weeks (U.S. Environmental Protection Agency 1978). Cows, chickens, and pigs fed small amounts of glyphosate had low levels (less than 0.05 ppm) in muscle tissue and fat. Levels in milk and eggs were also undetectable (less than 0.025 ppm). Glyphosate has no significant potential to accumulate in animal tissue (Malik 1989).

Glyphosate is practically non-toxic to fish and may be slightly toxic to aquatic invertebrates. The 96-hour LC50 is 120 ppm in bluegill sunfish, 168 ppm in harlequin, and 86 ppm in rainbow trout (University of Florida 2003a). The 96-hour LC50 for Chinook salmon is 130 to 210 ppm depending on water hardness. The application rates of glyphosate are one to two orders of magnitude lower than those expected to be acutely toxic (National Marine Fisheries Service 2003). The 48-hour LC50 for glyphosate in daphnia (water flea), an important food source for freshwater fish, is 780 ppm (University of Florida 2003a). Glyphosate is slightly toxic to wild birds; the dietary LC50 in both mallards and bobwhite quail is greater than 4500 ppm (Kidd 1991).

In water, glyphosate is strongly adsorbed to suspended organic and mineral matter and is broken down primarily by microorganisms (USFS 1984). Its half-life in pond water ranges from 12 days to 10 weeks (USEPA 1992). Glyphosate may be translocated throughout the plant, including the roots. It is extensively metabolized by some plants and remains intact in others (Kidd 1991). In a study conducted by Goldsborough (1989), glyphosate was applied to six small ponds at a rate of 2.6 kilograms of active ingredient per surface acre. The half-life of glyphosate was found to be 5.8 days and concentrations never reached above 58 ppb in any pond.

3.2.5. **2,4-D**

2,4-D, a chlorinated phenoxy compound, is used in many commercial herbicidal products. Commercial names for products containing 2,4-D include Aqua-Kleen™, Barrage™, Planotox™, Weedgard™, Weedone™, and Planttrine-II™. 2,4-D functions as a systemic herbicide and is used to control many types of broadleaf plants. It is used in cultivated agriculture, in pasture and rangeland applications, forest management, home, garden, and to control aquatic vegetation (EXTOXNET 1996a). 2,4-D mimics naturally occurring plant auxins and causes over-stimulation of young cells and eventually plant death (Mullison 1987). 2,4-D is categorized by the EPA as a General Use Pesticide (GUP) in the United States. The diethylamine salt is toxicity class III (slightly toxic) orally, but toxicity class I (highly toxic) by eye exposure. There are many forms or derivatives of 2,4-D including esters, amines, and salts.

The acid form of 2,4-D is moderately toxic to humans and mammals. The maximum contaminant level for 2,4-D in drinking water is 70 ppb, but NPDES permits may reduce the maximum allowable concentration to 20 ppb (National Marine Fisheries Service 2003). Fish mortality may be of concern when using 2,4-D where some formulations of 2,4-D are highly toxic to fish and others are less so. The median LC50 for Chinook salmon is 14.8 ppm and the median LC50 for rainbow trout is 27.3 ppm. When applied at the application rate 2,4-D is expected to have an instantaneous concentration of 3.1 ppm in the water column and after mixing be at least 32 times lower than the LC50 for the most sensitive salmonid species (National Marine Fisheries Service 2003).

Laboratory studies using mice, rats and guinea pigs found the LC50 to be as low as 320 mg/kg in these animals (University of Florida 2003a; U.S. National Library of Medicine 1995). The absorption of 2,4-D in mammals is almost complete after ingestion. The half-life of 2,4-D in mammals is between 10 and 20 hours, creating little to no risk for accumulation (Howard 1991). Birds are slightly susceptible to 2,4-D poisoning: the LD50 is 1000 ppm in mallards, 272 ppm in pheasants, and 668 ppm in quail and pigeons (University of Florida 2003a; Kidd 1991; U.S. National Library of Medicine 1995).

2,4-D in its water-soluble salt form has a very low bio-concentration factor and there is little if any risk of bioaccumulation in organisms (Walters 2004). In fish, accumulated 2,4-D is rapidly broken down into hydrocarbon fragments, which are utilized by the fish for synthesis of normal body tissue and/or eliminated (Ghassemi 1981). Rates of breakdown increase with increased nutrients, sediment load, and dissolved organic carbon. Under oxygenated conditions the half-life is one to several weeks (Howard 1991). Breakdown in plants is through a variety of biological and chemical pathways (U.S. Environmental Protection 1987).

3.3. *Non-Chemical Treatment*

There are three major types of retroactive non-chemical management strategies for aquatic plant control:

1. Biological
2. Mechanical
3. Physical

Biological control methods include the introduction of insect species, sterile grass carp, microbial bio-control agents, enzymes, and/or the addition of organic material. Biological control involves increasing or augmenting the naturally occurring enemies of the plant that is to be managed (Department of Entomology Texas A&M University 2003). This type of plant control is attractive to many interest groups because it does not involve the use of heavy machinery, nor does it physically disturb the natural habitat during application.

Biological control can involve the maintenance of the plant population for natural enemies to survive on. However, it also can create a fluctuating plant and enemy population that may not be suitable for the uses of the water body. In addition, signs of effectiveness may also be slower than what is desired by the water body managers. The risk of a host shift when introducing a new species is a major concern any time importation is implemented. An introduced enemy can become just as disruptive to the natural environment, through the displacement of other native species, or the reduction of desirable plants (Department of Entomology Texas A&M University 2003).

Mechanical control methods include harvesting, cutting, pulling, rolling, rotovation, diver dredging, the placement of barriers to inhibit growth and excavation. Among non-chemical plant control methods, mechanical methods are the most widely applied. They do not involve control over the ecological features of the water body nor do they rely upon introducing an insect species or one that is already present. Using either people (as in the case of hand pulling or diver dredging) or machinery (rollers, harvesters, and shredders), mechanical control can eradicate or reduce plant problems similar to chemical control.

There are many problems associated with mechanical plant control that make it undesirable in some management situations. Mechanical control can involve removing portions of the plant or the entire plant. Plants that reproduce through vegetative means often have to be entirely removed to achieve effective control and many methods of mechanical removal are not applicable to achieve these results. Mechanical control methods often involve large disruptions in the sediment and harm to the benthic communities due to the nature of the removal. The disruption of large areas of sediment can also lead to water quality problems. The cost of owning mechanical machinery is sometimes prohibitive. The availability of contract help may also limit the ability of a water body manager to use mechanical control as a viable method (U.S. Army Corps of Engineers Jacksonville District 2003).

Examples of **physical control methods** include shading, water level draw-down, and the use of dyes. All of these methods alter the physical habitat of the pests. The use of dyes reduces light penetration that reaches submersed plants. Shading works through the same principle as the use of dyes, reducing the amount of light that reaches plant plants. Shading can be achieved by floating an opaque plastic tarp on top of the plant population. Shading can be used for submersed as well as floating plant populations. Water level draw down requires that the water body manager have control over the water level and is able to lower water levels to expose pests to freezing, drying, and/or heat. Drawdown has been proven to be an effective method in controlling *Egeria densa*. Water draw-down alters the plant community and can produce changes that are undesirable including reduction of desirable species, increase of tolerant pests, movement of undesirable plant species, loss of water storage capacity, and recreation (Center 1997).

3.3.1. Mechanical harvesting

Mechanical harvesting involves physically cutting the above-sediment portion of the submersed or floating aquatic plant. A typical mechanical harvester has articulating bars that can achieve cutting depths of up to ten feet below the water surface (CDBW 2001).

Limitations of harvesting

Harvesting leaves plant fragments in the water body that can possibly form viable outgrowths. Viable fragments from broken plants are able to spread infestations to new un-infested areas and reduce the efficiency of harvesting. Plant fragments also have the potential to clog irrigation and drinking water screens. One way to reduce this problem is by dragging a collection net behind the harvester. A collection net might not eliminate the problems created from viable fragments, but it does greatly reduce them.

Figure 4. Mechanical harvester cutting an algae infestation.
Photo: Dave Omoto, Solano Irrigation District.

Using a large harvester increases the amount of plant material that can be harvested and the speed with which it can be removed. In some cases a larger harvester will not be able to maneuver into all spaces where the target plant is present. If the harvesting occurs while plants are actively growing, harvesting may actually increase the growth rate (CDBW 2001). If plant growth rates are increased, they can grow back to levels present prior to harvesting in a single season.

Plant removal through mechanical harvesting occurs in the spring when the submersed plants have reached the water surface. Removal during this period in the plant's lifecycle allows managers to remove large portions of the infestation without having to deal with an entire season's growth. Plants are not removed until they reach the water surface for ease of infestation area identification. The more time that passes between the beginning of the management season and the control action increases the quantity of biomass that must be removed.

Drinking water sources located near a mechanically harvested site could be adversely impacted due to the temporary increase in turbidity. The California Department of Health Services has set MCLs for water bodies. There are MCLs for taste, odor, and appearance, which could all be impacted by the increased turbidity associated with mechanical harvesting. The California Department of Health Services lists the Secondary MCL for turbidity as 5 units. A turbidity unit is a measurement of the optical property of water that causes light to scatter and absorb rather than transmit straight through a water sample (Ankcorn 2003).

When mechanical harvesting occurs, there is an associated risk of removing fish that are trapped in the plant bed. Harvesting also removes fish egg masses that are attached to plant leaves or in the substrate inside plant beds. In some studies, harvesting has had a minimal effect in this regard (CDBW 2001).

Disposal of plants after harvesting is a major drawback to this mechanism of plant control. Plant masses can be as dense a 3,000-4,000 kilograms per acre (CDBW 2001). The high water content of some plants, like hyacinth, does not allow for disposal at a class three landfill, but once dried, hyacinth is well-suited as compost material, and in fact, the final compost meets the U.S. EPA 503 pathogen and metals requirements for Class A compost (Water Pollution Control Federation 1989). Composting can reduce the volume between wet plant material and compost by 99%. Transport costs and finding an acceptable disposal site are some of the increased costs associated with harvesting as a management strategy.

3.3.2. **Hand pulling**

The California Department of Boating and Waterways conducts hand-pulling treatments in the Delta, and their most recent reports suggest the hand pulling was an effective means of eradicating water hyacinth. If the plants are in deeper waters it may be necessary to use divers to pull the plants from the sediments.

Hand pulling of water hyacinth becomes the management alternative of choice after the allotted chemical spraying period from late June through October 15 ends for the Water Hyacinth Control Program (WHCP). There are restrictions on the time frames of legal chemical spraying, as the federal and state Endangered Species Acts (FESA/CESA) prohibits activities that lead to a "take" of sensitive delta species. Hand pulling is accomplished by using the chemical spray vessels with a two-man crew equipped with a rake tool for assistance in pulling.

Although hand pulling is physically effective at removing the entire plant, it is a labor-intensive process. Hand pulling can be a very effective way to reduce small infestations of plants. If the plant removal occurs before seed production, it removes all viable reproductive mechanisms for the plant. In deeper waters hand pulling becomes more difficult and less cost-effective. Waters deeper than about three feet slow down the ability of a hand pulling crew to remove hyacinth. Some of the advantages of hand pulling are that it:

- Does not create changes in dissolved oxygen
- Removes the entire plant and all of its reproductive parts
- Can be very selective
- There is little harm to non-target species
- Can be preformed during seasons when chemical use is prohibited.

Some of the disadvantages of hand pulling include:

- Treatment may need to be repeated a few times a season
- Not very practical for large areas or thick plant beds
- Disturbs benthic organisms
- Is very labor intensive
- Is less effective after seed production
- Problem with disposal if done on a large scale (Western Aquatic Plant Management Society 2003)

3.3.3. **Herding**

Herding is a method of removing hyacinth from an area that involves "herding" or wrangling the hyacinth into open areas where the plant masses can be washed out into open waters of the bay. This method involves outfitting a spray vessel with a U-shaped cage mounted to the front of the boat. The boat approaches the problem hyacinth patch and physically pushes the mass towards an open channel which discharges to the open bay. In these open saltier waters the nuisance plants die, because they cannot survive in the saltier water (U.S. Department of Agriculture 2002). Herding can only be accomplished during periods with the proper tidal influence. Any plants that escape during a herding event or are able to float back into waters with lower salinity before dying pose a threat of spreading the infestation.

3.3.4. **Shredding**

Shredding involves cutting plants either a few feet below the water's surface or at the water's surface. Generally, a boat is configured with cutting blades splayed across the front of the boat, which extend one foot below the water surface. Another set of blades extends three feet below the water surface on the back of the boat. A second type of configuration involves a set of cutting blades mounted on an airboat. These boats are quite versatile, and a high degree of control is possible to allow the operator to avoid objects or quickly turn-off the blades (USFWS 2001). Once plants are cut, they are shred into smaller plant fragments that are left on the water's surface to decompose. Leaving the shredded plant material in-situ reduces the disposal costs but does create some problems such as clogging waterways and providing opportunity for re-growth of viable fragments. When shredding machines are used on species that spread by fragmentation (e.g., *Egeria densa,* Eurasian water milfoil, hydrilla), there is substantial risk that the shredded material will spread to other locations and actually increase infestations. Mechanical shredding without removal is more appropriate for species that do not spread by fragmentation, such as water hyacinth (Greenfield 2003).

The shredders themselves can create water quality problems. Re-suspension of sediment after a shredding event can create very turbid water (James 2002). Turbid water can hinder the natural processes, particularly photosynthesis and predator prey interaction, that take place in an aquatic environment. The shredders also may remove or harm non-target species in the plant beds.

Plant material that is left to decompose on the water surface has the ability to affect water quality parameters. Shredding events can drive dissolved oxygen levels down to 0 mg/l in the water column where the shredding event took place (James 2002). Decomposing plant material can also increase the nitrogen and phosphorus levels in the water column. Anoxia created from the biochemical oxygen demand for the plant material also allows phosphorus to release from the sediments (James 2002). The increased nutrients in the water column can create algae blooms and/or eutrophic situations in water bodies.

4. Cost Effectiveness of Different Control Methods

4.1. *Introduction*

The purpose of this analysis is to explore the feasible options that aquatic plant managers have at their disposal based on estimation and comparison of control costs for several management alternatives. The method of analysis was designed to consider only control costs paid to meet a management objective. It does not include estimates of damage or environmental costs, nor is it a benefit/cost analysis.

The methods used to acquire the data for this analysis included:

- Initial establishment of contact with managers and practitioners,
- Creation of a survey to guide the phone interviews,
- Phone interviews.

A cost analysis has been carried out for four study sites. The selected site analyses considered: (1) the control of alkalai bulrush (*Scirpus maritimus*) and cattail (*Typha latifolia*) at the Kern National Wildlife Refuge and (2) the control of Eurasian water milfoil (*Myriophyllum spicatum*), curly leaf pondweed (*Potamogeton crispus*), and various species of planktonic, filamentous and blue green algae at the Big Bear Lake Municipal Water District, (3) the control of Eurasian water milfoil and water hyacinth at the Stone Lakes National Wildlife Preserve in Elk Grove, CA and (4) the control of Eurasian water milfoil and water hyacinth at Big Break, located on the Sacramento-San Joaquin Delta in Antioch, CA.

The cost analyses demonstrated that, depending on various circumstances, a variety of non-chemical and chemical alternatives are possible as the most effective methods for the treatment of the aquatic plant problem. For chemical management techniques, the control costs per surface acre are very high for a low acreage area and decrease with increasing area. This trend can be attributed to the fact that set up and NPDES permitting costs are incurred for any herbicide application that occurs. For non-chemical techniques, the rates of control cost per unit area is about the same for both small and large acreage, as there are no permitting or monitoring costs required using these techniques. The most cost effective management technique for the Kern NWR is mowing, given that no more than four mowing events per season occur. The most cost effective management technique for Big Bear Lake is the application of Sonar™ (fluridone) and some harvesting.

4.2. *Methods: Preparation and Data Collection*

In this section the steps taken in the preparation and collection of the data to be used for the cost analysis are outlined.

4.2.1. **Establishing contact with managers and practitioners**

An initial contact with practitioners or managers was established through the Aquatic Plant Monitoring Program (APMP) via phone calls and meetings. This contact information was collected while gathering information to investigate the needs and practices of aquatic plant managers in and outside of California. In addition, practitioner contacts were also acquired via NPDES permit applicant listings.

4.2.2. **List of possible managers to contact**

Based on these initial contacts, a database of potential practitioners to contact for cost related information based was compiled including information on their aquatic plant concerns, location, past and present management practices, and interests in management strategies. Approximately 50 practitioners in California and Washington were identified as possible contacts for the cost analysis. The range of practitioners or managers included groups and individuals from a variety of water and aquatic plant management organizations such as various irrigation districts, lake managers, State and Federal Wildlife refuges, California Department of Boating and Waterways, California Department of Fish and Game, California Department of Food and Agriculture, private aquatic plant contractors, homeowner associations, and research centers.

4.2.3. **Survey and letter design**

In order to acquire the most useful information possible, a survey was designed to guide the analyst through a call or meeting with the practitioner. The main objectives of the survey were to gain an understanding of a few basic aspects of each manager's practice including:

- Target plant,
- Location-specific details such as system type or use characterization of the water body,
- Elements of chemical and/or non-chemical controls of aquatic macrophytes,
- Methods for algae control,
- Feasibility and variability of each of the techniques and their possible alternatives.

Once these items were determined, the analyst made inquiries regarding the costs of each of the control methods including elements such as equipment, materials, labor costs, disposal, permitting fees, monitoring, and research. Essentially, any direct costs involved in the management of the aquatic plant problem were accounted for.

The survey was designed to gather specific cost information in a form that would allow the analyst to present it as a rate, specifically as cost of area treated per hour/season. In addition the *total* cost per season was elicited. Total cost include initial fixed costs, set-up costs, as well as ongoing costs per treatment strategy. The survey differentiated between chemical, non-chemical and algae techniques, and handled them as three unique strategies. The survey is attached as Appendix A.

A letter was created to invite practitioners and managers to the phone interview and/or personal meeting where the survey was administered to acquire the cost related information regarding their management technique. The letter described the position of the analyst and relation to the APMP as well as explaining the objective of the cost analysis. The letter also informed the recipient of the person who recommended them as a participant in the project and also offered a summary of findings from the project when available. The letter was sent either as hard copy or electronically to most managers on the contact list. Approximately half of the managers on the contact list were contacted, but did not respond. A generic copy of the letter is attached as Appendix B.

4.2.4. **Interviews, data assemblage, and results**

The phone interviews were conducted over a one-month period during July and August 2003. Calls lasted from 15 minutes to more than one hour.

The data were assembled in an effort to estimate the unit and total costs of each management alternative. Where possible, the data were expressed in terms of cost per treatment per season per area. This allowed for a comparison of costs across different techniques. The data are presented in tabular form as Appendix C, which provides a full list of the data collected and accompanying notes regarding elements such as special circumstances and the success of varying control techniques given variable environmental conditions.

4.2.5. **Cost effectiveness information gathered**

There were approximately 35 cost estimations collected. Many methods, pests and system types were represented. In an effort to standardize the data it was categorized by method and plant. The data were expressed as the cost per treatment per season per area for each available technique. In addition, the total cost per season is included for each management alternative, as rate information may not accurately address the effectiveness of each cost per alternative. Total costs per season ranged from approximately $1,000 to $300,000 and per-area costs ranged from $6 per acre to greater than $12,000 per acre.

System types ranged from irrigation canals, reservoirs, “afterbays”, seasonal wetlands, lakes, lagoons, service ditches and ponds. Many of the data are based on an estimation of total control costs per season and their relation to the number of acres treated per season. There are fixed costs and set up fees which have been included in the rates. Figure 5 shows an average cost per acre for each management technique.

Table 1. Estimates of costs per surface acre for aquatic plant management techniques, with the name of practitioners (from CA and WA states) who provided the estimate in parentheses.

Practice	Target Plant	Cost/ acre
Hand pulling (O'Connell)	Hydrilla	$12,190
Komeen™ (O'Connell)	Hydrilla	$643
Mechanical harvesting	Eurasian water milfoil	$1818
Grass carp including grate (Derma)	Submersed vegetation	$723
Excavator, "moss rake" (Kellet)	Curly leaf pondplant, elodea	$137
Aerial application of AquaMaster (Hardt)	Alkalai bulrush, cattail	$48
Mowing (Hardt)	Alkalai bulrush, cattail	$7[a]
Mowing, Discing and Plowing (Hardt)	Alkalai bulrush, cattail	$24[a]
Mowing, Discing, Plowing and Floating (Hardt)	Alkalai bulrush, cattail	$31[a]
Mechanical Harvesting (Omoto)	Elodea, milfoil, pondplants, Primrose, coontail, naiad	$500
Harvesting (Martin)	Milfoil	$344
Sonar™ (Fluridone) (Martin)	Milfoil	$1000
Excavator (Brueggeman)	Water primrose	$1,636
Backhoe with fabricated rake (Brueggeman)	Water primrose	$979
Round-Up Pro 2.5% (Brueggeman)	Water primrose	$94-$178
Mechanical Excavation (Cook)	Submersed plants	$557
Shredding (Penny)	Water hyacinth	$817
Mechanical Harvesting (Lake Leland, WA)	Floating plants	$875
Mechanical Harvesting (WA)	Floating plants	$650
Rotovation (Lake Leland, WA)	Hydrilla	$1450
Mechanical Harvesting H-7, 400 cu ft. (AEI)	Floating and submersed plants	$700-1000
Mechanical Harvesting H-5, 200 cu ft. (AEI)	Floating and submersed plants	$500-$700
Goats (Blankinship)	Emergent plants	$1333
Backhoe (Blankinship)	Emergent plants	$3024
Manual Removal/Cutting: Rodeo Creek (Blankinship)	Emergent plants	$23,950
Manual Removal/Cutting: Canyon Creek (Blankinship)	Terrestrial plants	$53,378
Goats (Blankinship)	Terrestrial plants	$188
Handpulling (Gibbons et al.)	Floating/Emergent plants	$500-$2500[b]

[a] Requires frequent passes
[b] Per day

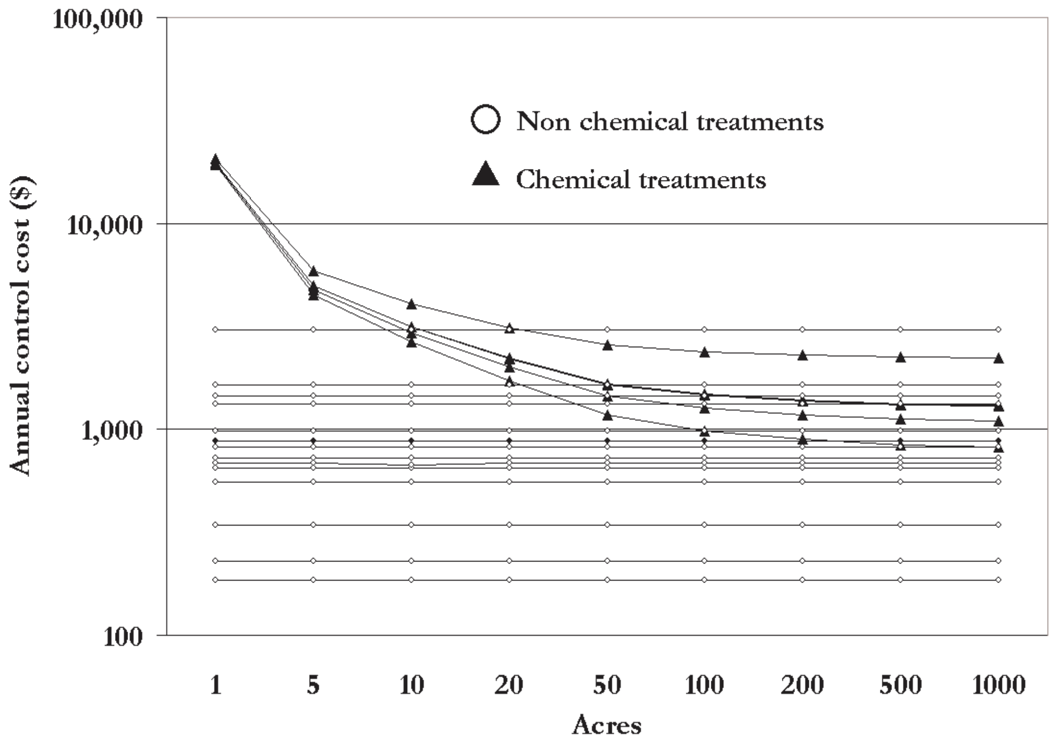


Figure 5. Average cost ($) per acre for chemical and non-chemical aquatic plant management techniques.

Estimations of the cost components of the various chemical treatments (glyphosate, fluridone, chelated copper, copper sulphate, endothall, and copper-ethylenediamene) shown in Figure 5 were provided by Roger Mann. Roger Mann obtained these estimations from literature, reports, and quotes. The costs of chemical treatments include set-up costs, NPDES permitting costs, materials and application and sampling requirements for both pre- and post treatment. Estimations of cost/acre for non-chemical techniques were provided by various managers and practitioners and include operation and material costs, fixed costs, and labor costs. In some cases, these rates were estimated based on a total cost per season divided by the acreage managed, without a thorough breakdown of the various component costs described above.

There were two management scenarios that have been selected from this set of data points to investigate using the Type A analysis. These are the Kern National Wildlife Refuge and the Big Bear Municipal Water District. They were chosen based on the management scenario at each site, as well as the availability of a complete data set of costs and options for each manager. At both sites, a variety of methods are being used without a complete understanding of which is most cost effective, considering the limitations of the respective systems.

4.3. *Control Cost Analysis: Kern National Wildlife Refuge*

Characterization of Kern NWR site

The Kern National Wildlife Refuge (KNWR) is located 18 miles west of the city of Delano at the southern end of the San Joaquin Valley of California. The 10,618-acre site consists of natural valley grasslands, a relict riparian corridor, and developed marsh. The refuge is south of the original Tulare Lake Bed in the southern San Joaquin Valley of California. This lake covered almost one half million acres during flood years and was home to millions of fish, amphibians, reptiles, birds, and mammals. One hundred-fifty years ago, this area was covered by an inland lake and wetland system totaling up to 625,000 acres. Each year the arrangement of marshes and lakes would vary due to drought and flood cycles. The refuge was the first effort to preserve wetland habitat in the area. In addition, this area was important habitat for wintering birds along the Pacific flyway in the southern San Joaquin Valley.

The refuge is intensively managed to produce habitat for migrating and wintering waterfowl and other water birds. Marsh habitat is maintained to provide a continuing food source for the birds and other wildlife. About 50% of the refuge is currently maintained with diked impoundments. Grain plantings of wild millet (watergrass) and swamp timothy are managed in a 1,200-acre area.

1. Summary of Results

The area of concern in the Kern National Wildlife Refuge (KNWR) includes 800 acres of seasonal wetland "management units" which are shallow, flooded areas irrigated in the spring and summer seasons. Alkali bulrush and cattail are the problem species that successfully grow in these areas during the warmer months of the year.

The best alternative for this entire area is mowing four times per season, at a cost of $21,730 per year.

2. Remaining Uncertainties and Issues

Despite the fact that the use of AquaMaster™ once every five years and one mowing event per year is most effective in terms of control and costs, the KNWR manager suggests, "Due to Fish and Wildlife Service internal regulations, the use of aerially applied herbicides is very time consuming to implement…doubt[s] that herbicides will ever become [the] first choice of control options…" (Hardt 2003).

The time and cost involved in obtaining and implementing permit requirements makes the herbicide alternative less attractive to the Kern managers. If implementation time decreases, herbicides could become a viable management alternative.

An integrative approach might work best for this area, as some regions are more overgrown than others. Only mowing might be the most viable alternative for the sparse areas, herbicide treatment in addition to mowing might be more suitable for areas with denser growth. Amount of growth in each area is dependent on environmental conditions of the season. A survey of which areas are prone to higher growth might be of use in determining how much management is applied in which areas.

In addition, there will be 1,100 additional acres of moist soil wetlands added to the management program in 2004, which could increase rates of control costs per acre (Hardt 2003). With the added treatment acres at the site, a different management alternative may replace the current mowing option in the future.

3. Identify the Aquatic Plant Problem

There is an extensive aquatic plant problem on the wetland areas of the Kern NWR. The plant species are cattail, alkali bulrush, and tamarisk in the upland areas. This analysis will deal only with the control of cattail and bulrush.

In the past, chemical controls such as Arsenal™, Round Up™ and Garland 4™ have been successfully implemented, although it has been found to be very costly and time consuming.

The refuge managers have switched to more extensive use of mechanical control because exclusive chemical control was too expensive at this site. In some cases, chemical control was not effective at label recommended concentrations. The aerial application of herbicides would require permits from USFWS, which would add to the cost and implementation time for the site managers. The difficulty in obtaining the aerial herbicide application permit was a main factor in not choosing the alternative at this site.

There have been mixed results with integrated approaches to cattail control. Managers at Kern NWR have combined aerial "fly-overs" of Rodeo with wetland draining, followed by mowing and discing. It has been found that the most effective control occurs after the area is left dry for 3 months, which is not feasible because of the need to maintain sufficient waterfowl habitat. Also, plowing followed by drying is more effective than discing. They are currently using the discing technique on the main unit to maintain lower biomass; this practice is likened to "mowing the lawn" by Kern NWR managers. It is not possible to keep the main unit dry for more than 3 or 4 weeks because some sensitive bird species need the wetlands.

They have a number of different treatments that have already been conducted. These include areas mowed and disced but not sprayed, areas sprayed two years ago, and areas not treated at all.

4. Potential Economic Costs and Benefits

Uncontrolled plant growth diminishes the value of the area as a wildlife refuge as overgrowth impedes the area inhabited by sensitive waterfowl species.

5. Management Objective

The management objective for the Kern NWR is to control but not eradicate the growth of cattail and alkali bulrush to preserve sufficient waterfowl habitat.

6. Identifying Management Alternatives

Management alternatives are specified in Entry Tables 3, Numbers 1-5 provided in Appendix D.

7. Economic Perspective

A private perspective will be used, as the control concerns of the refuge managers are the only being represented in this analysis.

8. Type of Analysis

The type of analysis performed is a cost analysis; environmental costs are not considered.

9. Period of Analysis, Discount Rate, and Price Level

The analysis uses a 50-year period of analysis, a 5% discount rate and a 2002 price level. The discount rate brings future prices to present values, i.e. people tend to value money today higher than money tomorrow; the discount rate accounts for this.

10. Specifying Management Alternatives

Management alternatives are specified in Entry Tables 3, Numbers 1-5 with the help of David Hardt, Kern NWR manager.

11. Feasibility Tests

- Technical Feasibility: All five alternatives are physically possible to perform on the areas of concern. The two alternatives that involve the aerial application of AquaMaster™ have been found to be quite time consuming to implement the permit and helicopters necessary for application.
- Legal feasibility: All five alternatives area allowed by local, State and federal laws, and all necessary permits can be obtained.
- Financial feasibility: All five alternatives are financially feasible under the budget constraints for the area.
- Social/cultural feasibility: Social acceptance of all alternatives involves public perception of impacts. The perception differs between community sectors but it is generally accepted that the plants need to be removed.

12. Costs of Each Practice in Each Management Alternative

The cost of the aerial application of AquaMaster™ is estimated to be $47.87 per acre and includes rates per acre of helicopter time (2000 rates), AquaMaster™ (2003 costs), surfactant, Load Management Staff, and planning/permits. AquaMaster™ needs to be applied once per five years. The cost of mowing includes labor, fuel and equipment service and is $6.97 per acre, and may be required 1-4 times per season depending on seasonal conditions. The cost of mowing, discing, and floating only is $23.89 per acre and includes labor to disc, fuel, equipment service and floating costs. Finally, the cost to mow, disc, plow, and float is $30.56 per acre. The cost of management alternative 2, AquaMaster™ with one plowing event is $54.84 per acre and was estimated by combining costs listed above ($47.87 + $6.97). As mentioned above, the frequency of each treatment varies with differing environmental conditions in the reserve.

The net present and annual payment values were derived over a 50 year period by implementing a cost per season, depending on treatment method and frequency requirement, and using a 5% discount rate to calculate the value in terms of a 2003 value.

13. Entry Tables

Summary table for Kern NWR treatment costs for control, the net present value (NPV) and feasibility tests are also presented; all entry tables used for this analysis are provided as Appendix D.

Table 2. Comparison of management alternatives for alkali bulrush management at Kern NWR.

Type of Analysis: Control Cost										
	Economic costs				Meets management objective?		Feasibility tests			
	Control costs		Total costs							
Management alternative	NPV, 1000$	Annual value, 1000$	NPV, 1000$	Annual value, 1000$		Describe other benefits and costs and other considerations that affect the selection of a management alternative	Tech	Legal	Financial	Soc/C
AquaMaster™	$153.79	$8.42	$153.79	$8.42	yes	The use of aerially applied herbicides is very time consuming to implement due to FWS internal regulations; the refuge manager doubts it will ever become first choice of control.		x	x	x
AquaMaster™ and mowing (1 time/season)	$252.96	$13.86	$252.96	$13.86	yes	This option produces better results than just mowing, is less labor intensive. See Comments for "AquaMaster™" alternative.	x	x	x	
Mowing (4 times/season)	$396.66	$21.73	$396.66	$21.73	yes	Could operate more or less times per season depending on conditions—costs increase significantly with increased mowing events.	x	x	x	x
Mowing, discing, floating (2 times/season)	$697.81	$38.22	$697.81	$38.22	yes	Could operate more or less times per season depending on conditions; costs increase with number of mowing events.	x	x	x	x
Mowing, discing, plowing, floating (1 time/season)	$446.32	$24.45	$446.32	$24.45	yes		x	x	x	x
Management Alternative Selected: Mowing, given that there are no greater than 4 mowing events per season. If conditions are such that growth is extreme, the "Combined Mowing, Discing, Plowing, Floating" option is most cost effective. "AquaMaster™ and mowing once per season" is the most effective, possibly not feasible because of permitting time constraints.										

4.4. ***Control Cost Analysis: Big Bear Lake Municipal Water District***

Big Bear Lake is a reservoir located in San Bernardino County within the San Bernardino Mountains. Big Bear Lake is widely used as a recreational area supporting boating, fishing, water-skiing, and site seeing. In addition, there are large areas of the shoreline developed for residential or resort property, including many privately owned docks. The lake has experienced a major aquatic plant problem for many decades. In the 1970's, the invasive Eurasian water milfoil was introduced and is now a major plant of concern in addition to various pondweeds and other algae (McNabb 2001). Eight types of aquatic plants have been identified in Big Bear Lake, of which coontail and milfoil are the most abundant and the most troublesome to navigation, fishing and aesthetics. District records indicate that of the plants harvested, 73% is coontail, 20% is milfoil and the remaining 7% is a combination of other types (BBMWD 2003).

Big Bear Municipal Water District operates three aquatic plant harvesters and one Aquamog (a harvester with more precise movement capabilities) on the lake for the purpose of removing plants, primarily from around docks and major boating areas. The harvesting program currently removes about one thousand tons of plants from the lake annually. Approximately 86% of the plant cutting occurs around private docks, with the remaining 14% occurring in areas where improved public access is needed or navigational hazards must be removed. Some chemical plant treatment has been performed in the past; however mechanical harvesting has been determined to have fewer adverse impacts and is now the method preferred by District Staff (Martin 2003). Occasionally, when the situation demands, chemicals are used to treat excessive algae blooms.

The Aquamog is a 10' wide barge with a cab for the operator, is paddle wheel driven, 35' in length and has an excavator arm that accepts a number of different attachments. The attachment used for this program is the tiller which is similar to the rototiller used in the garden, except on a larger scale. It is 10' wide and weighs about 2,000 pounds. It has 4 rows of spring steel tines that are offset to get maximum digging on the bottom of the Lake to dislodge the aquatic plants. Each dock area takes about 30 minutes to complete and one lap around the lake is completed each spring.

In the summer of 1996, the District completed an experimental application of a product called Sonar™ (fluridone) in Grout Bay. Grout Bay, on the north shore of the lake, was selected as the test area as it is protected from the wind and also from plant harvesting operations. This 35-acre area was initially treated during the first week of August 1996, with additional applications approximately every three weeks throughout the remainder of the summer. District staff monitored the test area following the applications and concluded that the product results were unsatisfactory. Upon further evaluation, it was determined that the applications occurred too late in the growing season to achieve maximum results. A second series of applications took place in 1998 in the same area of the Lake. The cost for these treatments was approximately $1,000 per acre and the result was nearly three years of plant-free access in Grout Bay. Based on these results, the District developed a plan to treat specific areas of the lake again in 2000.

In December of 2001, the District decided to move forward in the spring of 2002 with an aggressive program for herbicide treatments. Following three dry years with less than normal inflow to the lake, and a lake that was 9'6" below full, it was determined that applications in the east end of the Lake, in Boulder Bay and in the Mallard Lagoon/Canvasback Cove areas could achieve many years of relief from the infestation of Eurasian water milfoil. The cost of the applications was projected at $264,000 (BBMWD 2003).

The control cost analysis example is provided through the analysis report and the entry table below.

1. Summary of Results

According to the APME cost analysis, Management Alternative 2: Sonar™ and some harvesting is the best management alternative for the control of Eurasian water milfoil and curly leaf pondweed on Big Bear Lake with an annual cost of $249,000. A manager at BBMWD suggests that this option is the most effective in terms of control of milfoil and requires a lesser time commitment during the management season at Big Bear Lake.

2. Identify the Aquatic Plant Problem

Eight types of aquatic plants have been identified in Big Bear Lake, of which coontail and milfoil are the most abundant and the most troublesome to navigation, fishing and aesthetics.

3. Remaining Uncertainties and Issues

One issue raised was that in years of low water level at the lake (in 2003, water levels reached a record 14 feet below the full elevation) allows for a natural drawdown. In this case, it is both cost saving and effective to follow the drawdown and apply Sonar™ to the exposed milfoil for a thorough eradication of the milfoil in those areas. Performing a manual drawdown during wetter periods would not be possible as a result of the water rights and purchases that the BBMWD is responsible for.

A second concern brought up by the BBMWD is that as a result of the extreme effectiveness of the Sonar™ treatment on milfoil, a resultant abundance of curly leaf pondweed has grown in its place due to a lack of biological competition. A management strategy is necessary to control for both target pests.

4. Potential Economic Costs and Benefits

The presence of the vascular rooted aquatic plants has some environmental benefits to Big Bear Lake. They can serve to provide essential habitat for fish life, as well as habitat for organisms eaten by the fish. Aquatic plants are also utilized to a significant extent as food by migratory waterfowl and often serve as some control of shoreline erosion (BBMWD 2003).

However, the overgrowth of these aquatic plants inhibits navigation, fishing, recreation and aesthetic values on the lake. Control without complete eradication is central to the management technique at this site.

5. Management Objective

The objective of aquatic plant removal is to control plant growth and to facilitate access to the lake. The short-term objective of aquatic plant management in the lake is to maintain beneficial uses. The long-term objective, whenever feasible, is to substantially reduce the milfoil populations in the lake and encourage the reestablishment of native aquatic plant communities (McNabb 2001).

6. Identifying Management Alternatives

Management alternatives available in the Big Bear Lake include harvesting, AquaMogging™, Sonar™ (Fluridone) application, and suction dredging using divers and vacuums (McNabb 2001). Drawdown is not an available technique as the manipulation of water levels in Big Bear Lake is not under the control of the Big Bear Municipal Water District.

7. Economic Perspective

A private perspective will be used for this analysis as only the manager's control concerns are being considered.

8. Type of Analysis

This is a cost analysis because only control costs and not damage or environmental costs are being considered.

9. Period of Analysis, Discount Rate, and Price Level

A 50-year period, a 5% discount rate and a 2003 price level are being used for this analysis.

10. Specifying Management Alternatives

See entry table 3, in Appendix E, numbers 1-3 for the specification of management alternatives.

11. Feasibility Tests

- Technical Feasibility: All three alternatives are physically possible to perform on the areas of concern.
- Legal feasibility: All three alternatives area allowed by local, State and federal laws, and all necessary permits can be obtained.
- Financial feasibility: All three alternatives are financially feasible under the budget constraints for the area.

- Social/cultural feasibility: All three alternatives are socially and culturally feasible in the Big Bear Area. However, the environmental impacts of suction dredging are more severe than the other alternatives. This may have an effect on a decision of whether or not to use this technique. This element can be further explored via an environmental analysis.

12. Costs of Each Practice in Each Management Alternative

Costs were estimated with the help of Gene Martin, Manager BBMWD and a ReMetrix report titled, "Vegetation Assessment and Management Plan for Big Bear Lake (San Bernardino County, California)", completed 2001. For harvesting, per season costs were estimated to be $250,000 to $300,000. The costs for the application were estimated to be $1000 per acre for a 240-acre area, with additional costs for permitting and monitoring to give a season total of $225,000 to $270,000 depending on year of application. The costs for suction dredging range from $1,500 to $2000 a day with actual removal rates varying from 0.25 to 1 acre per day to give an average season total of $285,000. See entry tables in Appendix E for a complete cost break down.

13. Damage Costs and Environmental Costs

No damage costs or environmental costs were assessed for this analysis.

14. Entry Tables

Table 3 is provided below, complete entry tables are provided as Appendix E.

Table 3. Summary table for Big Bear Lake treatment costs for control of Eurasian water milfoil. The net present value (NPV) and feasibility tests are also presented.

Type of Analysis: Control Cost										
	Economic costs from Entry Table 6				Meets manage-ment objec-tive?	Describe other benefits and costs and other considerations that affect the selection of a management alternative	Feasibility tests			
	Control costs		Total costs							
Management alternative	NPV, 1000$	Annual value, 1000$	NPV, 1000$	Annual value, 1000$			Tech	Legal	Finance	Soc/C
Harvesting, Aquamog	$5020.38	$275.00	$5020.38	$275.00	yes	Harvesting allows some fragments of plant material to escape, which can contribute to re-growth. Yearly application of harvesting is necessary and time consuming.	x	x	x	x
Sonar™ and some harvesting	$4548.96	$249.18	$4548.96	$249.18	yes	Sonar™ has to be applied at the correct time, otherwise is ineffective.	x	x	x	x
Suction dredging	$5202.94	$285.00	$5202.94	$285.00	yes	Has many undesirable effects on environmental quality of the water body by increasing turbidity and nutrient release from disturbed sediments. Sediment curtains can curb this problem, but are costly.	x	x	x	x
Management Alternative Selected: Fluridone (Sonar™) and some harvesting (8-10 days per season to control curly leaf pondweed which arises as a result of the eliminated milfoil).										

4.5. ***Discussion***

It is important to recall that the cost analysis is the minimum economic analysis possible given the types of economic data that are likely to be available (Mann 2003). This analysis has merely provided an approximation of relative control costs for a variety of different chemical and non-chemical techniques based mostly on the estimations of managers and practitioners.

4.5.1. **Differing chemical and non-chemical alternative costs**

As a result of these cost analyses, it has been shown that a variety of non-chemical and chemical alternatives are possible as cost effective methods for the treatment of an aquatic plant problem. For chemical management techniques, it is shown that the control costs per surface acre are very high for a low acreage area and decrease with increasing area. This trend can be attributed to the fact that set-up and NPDES permitting costs are incurred for any herbicide application that occurs, regardless of water body type or size. These fixed costs become distributed as the area of treatment increases, thus making chemical treatment more economically feasible for a large water body. For non-chemical techniques, the rates of control cost per area are fairly constant for both small and large acreage, as there are no permitting or monitoring costs that are required for using these techniques.

A further investigation of the breakdown of non-chemical control costs is necessary to get a better understanding of how these rates differ with different acreage. The current limitation to do this is the lack of information on the total amount spent for the technique used over a certain area and different component costs.

4.5.2. **Environmental conditions**

Variable environmental conditions in any given season may render aspects of the cost analysis ineffective as a predictor of future control costs. Yearly fluctuations in temperature, precipitation and available nutrients have significant effects on the amount of growth and ease of control.

For example, as a result of particularly low water levels in 2003, the control of Eurasian water milfoil has been more effective because of the exposure of the plant to air. During wetter years, water levels are higher and therefore management costs will increase. In addition, the control season begins in Big Bear when temperatures reach 55 degrees and subsequently, plants begin to grow. This can significantly alter the duration of the control season, and thus costs.

Another example of the environmental limitations of control cost considerations is apparent in the Kern NWR example. The most cost effective alternative selected was mowing, given that there are no greater than four mowing events per season on the wetland. Dave Hardt said that the plant problems in 2003 had been especially bad due to the warm temperatures and wet conditions, creating a significant overgrowth that has not been easily controlled with the status quo management techniques.

Should environmental conditions continue to be advantageous for the growth of bulrush and cattail on the management units, costs will likely increase and the mowing alternative would no longer be the optimal method for control. In addition, Mr. Hardt commented that the acquisition of an additional 1100 acres of moist soil wetlands would be added in the future, which will most likely increase the rates of control. He states that he will have to "…wait and see what kind of vegetative response [there is] before making any firm plans".

To summarize, the cost of a management technique can vary drastically depending on the amount of growth that occurs during any particular season, which is usually due to uncontrollable factors such as temperature, amount of precipitation or water levels in a particular water body/region.

5. Case Study: Big Break

5.1. *Introduction*

Big Break is a large tidally influenced water body in the Sacramento-San Joaquin Delta north of the town of Oakley (Slack 2003). This shallow lake was created seventy-two years ago when a wall in an agricultural levee failed and flooded the bottomland with up to 10 feet of water. This 1,758-acre backwater provides habitat for birds, fish, mammals, invertebrates, and endangered species (CSU Hayward 2001). Big Break is the third largest tidal marsh in the western delta. The area consists of shallow water with abundant vegetation, supporting areas of tidal marsh, seasonally inundated floodplain, riparian forest, and Antioch dune scrub (Small 2002).

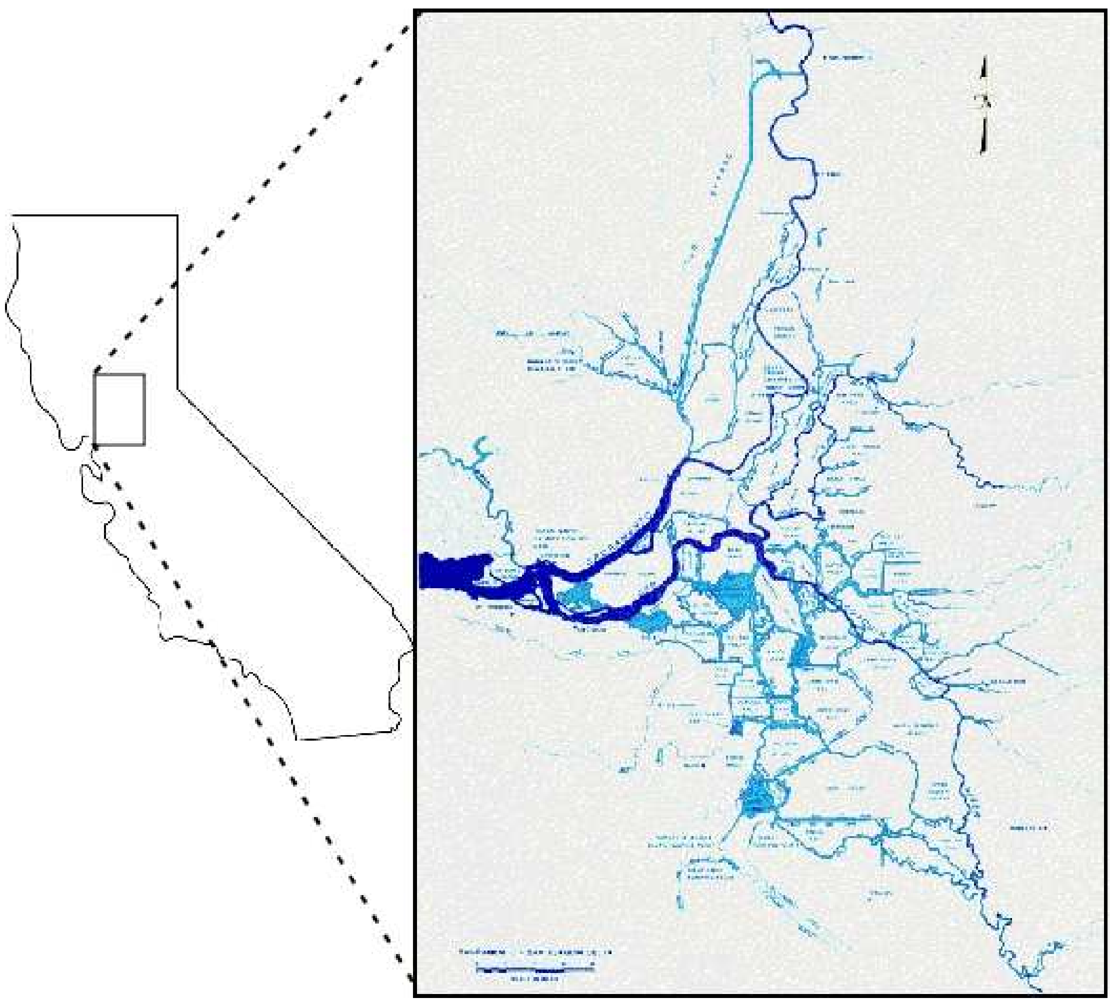


Figure 6. Sacramento-San Joaquin Delta, California.

Two non-native plant species have invaded Big Break: *Egeria densa* and water hyacinth.
Grimaldo and Hymanson (1999) found that *Egeria* was the dominant submergent vegetation type in shallow waters of the central Delta. Although *Egeria* is able to dominate entire areas of the Delta, there are still some native plants and algae that reside in these beds.

In 1997 the *Egeria* infestation at Big Break had become widespread and Assembly Bill 2193 was enacted, which enabled CDBW to create the *Egeria densa* Control Program (EDCP) for the Delta. The Water hyacinth Control Program (WHCP) was instituted under legislative mandate in 1983 (CDBW 2002). These two programs authorize CDBW to use chemical and non-chemical methods of control for *Egeria* and water hyacinth.

In 1997, CDBW, with the Romberg Tiburon Center for Environmental Studies, began a program to study growth of *Egeria* at Big Break. During the first year of the study aerial photos revealed that *Egeria* covered 37.8% of the waters surface in Big Break (563.46 acres). By 2000 *Egeria* coverage had increased to 52.1% covering 724 acres (Obrebski 1998). In 2001 CDBW had completed its initial Environmental Impact Report (EIR) on the EDCP. In the EIR the Department investigated the impacts of using Sonar™ (fluridone), Reward™ (diquat), Komeen™ (chelated copper), and mechanical harvesting as options for control of *Egeria*.

CDBW applied chelated copper to test sites in the Delta at a rate of 0.75 ppm for *Egeria* control. To achieve a chelated copper concentration of 0.75 ppm the Department applied 6,075 gallons of chelated copper to 150 surface acres each of two years. Different per acre application rates were used at each site depending on water depth (CDBW 2001).

The control of aquatic plants at Big Break may have unintended consequences on the plants and animals of the area. Many different species use Big Break as habitat. Mammals such as the river otter, beavers, and bats have all been observed (Slack 2003). Over 150 bird species including several CALFED and CVIPA priority targets have been recorded at Big Break (Small 2002). List 1 in Appendix F shows the bird species, including a distinction of species using Big Break for breeding.

The water in Big Break has less than 1 in 40 salinity, which allows it to provide habitat for many freshwater and andronomous fish species (CSU Hayward 2001). Native species include splittail, juvenile salmon, black rail, and pond turtles (Small 2002). Many fish species use Big Break either as their primary habitat (largemouth bass, striped bass, blue gill, Prickly sculpin, and carp) while others use it as a migration route to their spawning beds (Chinook salmon, splittail, and delta smelt) (CDBW 2001). Big Break is one of the only locations where adult splittail congregate in large numbers (Small 2002). *Egeria* mats form walls that reduce the ability of juvenile salmonid to access their preferred shallow water habitat along channel edges.

These *Egeria* mats also create great habitat for non-native ambush species to prey on young salmonid (NMFS 2003).

Both native and non-native fish inhabit Big Break. The fish species listed in Appendix G were identified from a twenty-one year long study that focused on Suisun Marsh, an area that is very similar to Big Break (Moyle 2003).

Big Break is a favorite site for Delta anglers. Its large *Egeria* beds create habitat that allows young bass to hide and grow into prize size adults. The shallow water, tidal influence, which helps to replenish zooplankton, and dense mats of plants create ideal conditions for rearing large sport fish. Removal of *Egeria* and water hyacinth could have a substantial impact on the angling in the area (CDBW 2001).

Management of the large *Egeria* and water hyacinth beds at Big Break has the potential to disrupt the ecosystem in the area. Any adverse impact to one part of this ecosystem has the potential to disrupt many of the sensitive native and non-native species that inhabit Big Break. The potential for environmental impacts created by different control methods make Big Break an appropriate site for an initial case study.

5.2. *Potential Impacts for All Strategies*

This section will list the impacts that arise from each management strategy that is being evaluated. Appendix H has impact summary tables specific to Big Break and Stone Lakes, respectively. These tables provide an overview of the impacts associated with each management strategy, the likelihood of those impacts, as well as mitigation measures and impact likelihood expected with mitigation. Below the details of each impact are described.

5.2.1. **Diquat-dibromide**

Application of diquat at levels sufficient to kill aquatic plants would be 18-20 times above the maximum concentration level allowable by the California EPA in drinking water. This creates a situation that must be mitigated; diquat applications will either have to be excluded from areas around drinking water inlets until it dissipates to acceptable levels.

Additionally, there is the potential for trihalomethane production as a result of diquat application. This is an impact that will have to monitored or mitigated (CDBW 2001).

Finally, adverse impacts could be created from levels of low dissolved oxygen due to large decaying plant masses. Sites with limited tidal flow and lower ambient dissolved oxygen levels would have to monitored to make sure that treatment of *Egeria* beds does not result in a violation of Basin Plan Standard for dissolved oxygen (CDBW 2001).

Diquat is a non-selective herbicide and could result in the death of plants other than *Egeria*, including native plants. The desired effect of diquat use would be to remove *Egeria*, making more available habitat for native plant species. However, this phenomenon will not necessarily occur; diquat could kill the *Egeria* or native plants, and *Egeria* or native plants could recolonize. Diquat is also an algaecide. The acute EC50 for diquat for algae, as well as plants, is highly to moderately toxic (Syngenta 2002). The EC50 is an effect concentration that causes 50 % of the target population to loose cell multiplication abilities. The application of diquat should create a temporary decrease in localized algal abundance, but floating algae cells should be able to quickly recolonize any affected area. In addition, clearing the *Egeria* would increase light penetration, allowing algae to increase (CDBW 2001).

There will be adverse impacts to the aquatic invertebrate communities as a result of diquat application. Diquat is moderately toxic to aquatic invertebrates with the 96-hour LC50 of 0.42 ppm for mysid shrimp being close to application rates (CDBW 2001) and the 96-hour LC50 for *Hyalella azteca* of 0.048 ppm, much lower than application rates of diquat (Wilson 1969). Due to the highly turbid waters of Big Break, the efficacy of diquat is only expected to be about 50 %. This is to say that there will only be a 50% reduction in *Egeria* mass each year. This would leave half of the plant habitat each year for invertebrate recolonization.

One particular invertebrate of concern at Big Break is the elderberry beetle. If diquat kills elderberry bushes along treatment area shorelines, it could affect beetles by removing habitat. This is of major concern for the CDBW because the elderberry beetle is an insect of special status; it is listed as a "threatened" species under the Endangered Species Act (ESA).

Diquat might pose a threat to juvenile and other early life stages of certain game fish (Paul 1994) though there is little concern about the potential for adverse impacts occurring to fish communities. A study on the toxicity of diquat to fish found that it was slightly to moderately toxic. The study found that the fish species most sensitive to diquat was largemouth bass with a 96 hour LC50 of 0.74 ppm, which is almost double the application rate. However, because the difference between the application rate and 96 hour LC50 is not orders of magnitude different, there could be a serious chance of mortality occurring at the application rate.

Removal of *Egeria* beds could also reduce habitat for the prey base fish, insect, and invertebrate species, and directly reduce the numbers of species these fish depend upon (Moyle 1976; Wang 1986; Herbold 1987).

Diquat is slightly to moderately toxic to birds. The reported acute LC50 for young male mallards is 564 ppm (U.S. National Library of Medicine 1995). Treatments of diquat could possibly result in adverse impacts to young mallards (U.S. EPA 1986).

Applications of diquat could potentially harm agricultural crops if water with diquat is used for irrigation. The diquat label recommends a waiting period of five days after diquat application to use water for irrigation (Zeneca Ag. Products 1999).

5.2.2. **Chelated copper**

Background levels of copper in the Delta sometimes exceed the limit set by the Basin Plan. Background levels of copper in the Delta do not allow for any significant additional inputs of copper without exceeding the limit set in the Basin Standard Plan. The application of chelated copper would exceed the Basin Standards set for copper for a short period of time (CDBW 2001).

Application of chelated copper at label rates will be toxic to *Egeria* and other aquatic wetland and terrestrial plants, some fish and aquatic invertebrates. The dynamic water flow of the Delta helps to reduce copper concentrations through tidal mixing and dilution. Rapid uptake through plant tissue and binding and export to minerals in the Deltas waters all lead to a rapid decrease in the copper concentrations (Anderson 1998). The rapid dissipation of copper in the water column would create a short-term violation of Basin Plans Standard (CDBW 2001).

Although chelated copper dissipates in the water column, it eventually ends up in sediments and does not degrade (Leslie 1992). A 1998 study was conducted to examine the potential for copper to accumulate in sediments (Huang 1998). The results showed that the potential of chelated copper to accumulate in the sediment and its toxicity from that accumulation is still unknown. CDBW (2001) assumed that chelated copper use has the potential to create adverse impacts on aquatic life through its accumulation in the bottom sediments.

Fast acting herbicides such as chelated copper have the potential to decrease dissolved oxygen levels due to the decomposition of organic matter. However, data from previous chelated copper trials suggest that this is not the case (USDA 1999, Janik 1996). Thus, chelated copper applications are unlikely to cause decreases in dissolved oxygen that would violate Basin Plan standards (CDBW 2001).

Applying chelated copper to control *Egeria* has other potential setbacks. Drinking water quality could be affected if chelated copper were applied near a drinking water inlet. In addition, the potential formation of trihalomethanes is possible. Both of these impacts can be mitigated by not applying chelated copper near or around drinking water inlets, by taking pre- and post-treatment samples if applications were to be made within the ¼ mile buffer zone established for drinking water inlets, and not using affected inlets until copper levels are below maximum contaminant levels.

The effects of chelated copper on biological resources in the delta could be great if not mitigated properly. Even with proper measures in place to ensure that large adverse impacts do not occur there will be some impacted organisms that must be accounted for to evaluate the total impact of the application of chelated copper. This section will address the potential impacts to plants, invertebrates, fish, and wildlife from chelated copper use. Chelated copper is not manufactured as an algaecide, but can be toxic to algae. Because chelated copper does not specifically target algae, impacts should be minimal (CDBW 2001).

There are three intertidal wetland communities for which impacts have to be considered when applying contact herbicides like chelated copper:

- Herbaceous intertidal, including special status plants like:
  - Mason's lilaeopsis (*Lilaeopsis masonii*)
  - Rose mallow (*Hibiscus lasiocarpus*)
  - Delta mudwort (*Limosella subulata* Ives.*)*
  - Delta tule pea (*Lathyrus jespsonii* Greene *ssp. Jepsonii*)
  - Rushes and sedges
- Riparian communities that would include the Northern California Black Walnut (*Juglans californicus dimorphus*), cottonwoods, and willows
- Marsh communities including tules and cattails (CDBW 2001)

Application of a contact herbicide, such as chelated copper, could easily spread to these intertidal communities in harmful concentrations during a high tide event or through wave wash. Chelated copper can be taken up quickly by the edge species of these communities and kill the contacted plants. Non-target areas that are affected by herbicidal application will leave open space free of invasive species. The desired effect would be recolonization of native plants (CDBW 2001). However, there is also the possibility that *Egeria* will re-colonize instead of the native plants. Evaluating the impacts of chelated copper application on native plants and intertidal communities is outside the scope of this study, but is in fact an important consideration for using the herbicide.

Invertebrates that inhabit *Egeria* beds could be directly impacted by chelated copper applications. Chelated copper can create a temporary decrease in invertebrate populations in treatment areas. Studies have shown that the label application rates of chelated copper cause complete mortality of *C. dubia* within 3 hours of the application (Trumbo 1997). The label application rate for *Egeria* is 0.50-0.70 ppm (Griffin 2003). After 24 hours chelated copper concentrations had decreased to levels that created a less than significant impact on invertebrate species (Trumbo 1997). These decreases in invertebrate communities are expected to be temporary. Tidal motion should quickly reintroduce planktonic invertebrates, and benthic and plant dwelling invertebrates should quickly recolonize treatment areas once new plant growth has commenced (CDBW 2001).

Chelated copper can adversely affect developing insect larvae that are present in treatment areas. The impacts to insect communities in the Delta are expected to be minimal because open water areas of the Delta also provide habitat for insect larvae. The elderberry beetle is a special status insect that could be affected by chelated copper application. The effects of chelated copper on this insect can be easily mitigated by not applying chelated copper near elderberry bushes (CDBW 2001).

Chelated copper applications for *Egeria* control occur between the months of March and November. During part of this time period critical spawning and migration occurs for a number of native and special status fish species. These special status fish are either already listed as threatened or endangered, or are federally listed candidates to become listed if population numbers continue to decrease. The special status fish at Big Break include; delta smelt, splittail, longfin smelt, and prickly sculpin, all spawn during the application season (San Francisco Bay Area Wetlands Ecosystem Goals Project 1997; Wang 1986). The striped bass has the potential to incur the largest impacts from the application of chelated copper, because its peak spawning period is during the middle of the application season, May through June (San Francisco Bay Area Wetlands Ecosystem Goals Project 1997). Chinook salmon are also likely to incur detrimental effects due to application of herbicides. Winter-run and spring-run Chinook adults migrate during the application season and the winter-run Chinook juvenile emigration occurs during the application season (CDBW 2001). The incipient lethal level for chelated copper in Delta waters has been observed around 2,300 ppb (Huang and Guy 1998). Considering the variable water hardness for Big Break it is possible for mortality to occur at copper levels of 1,200 ppb, which is below application levels. Salmonid species are some of the most sensitive fish species to copper toxicity, but the effects of copper do not begin to occur until copper reaches levels of about 4 ppm in the water column (Huang and Guy 1998). Low application rates of copper and the rapid decrease of copper in the water column leave little chance for copper to affect even salmonid species.

Acidic waters increase the toxicity of chelated copper. The waters of the delta have annually averaged a pH of 7.7 over a period from 1970 to 1993 (California Department of Water Resources 1996). The neutral to basic waters in the delta reduce the chance for adverse impacts to fish from chelated copper application (CDBW 2001).

Bioaccumulation is an increase in the concentration of a chemical in a biological organism due to intake and storage (EXTOXNET 1993). Bioaccumulation of copper to toxic levels is a concern. Copper does not degrade, so the potential for bioaccumulation exists. A study by Trumbo (1998) showed increased copper concentrations in snails at test sites compared to control sites. Another study in a north Alabama reservoir showed increased copper concentrations in fish and mollusks after elevating copper concentrations in the water column (Rodgers 1992). Flowing waters of the delta could somewhat reduce the bioaccumulation of copper in the organisms that reside in the area due to dilution. Bioaccumulation cannot be mitigated against, but the potential impacts from bioaccumulation of copper can be mitigated through monitoring. If copper is shown to be accumulating during monitoring its use can be discontinued before impacts are created.

The toxicity of chelated copper to reptiles and amphibians is unknown; therefore the direct impact of copper to these organisms will not be considered. Even though the toxicity of chelated copper to reptiles and amphibians is not known the loss of crucial intertidal wetlands and habitat could create a potentially large, adverse impact on these populations.

Other wildlife, such as various bird species, would not be directly affected by the chelated copper applications. However, birds like the Swanson's hawks would have a higher chance of being harmed because they nest during the application season in riparian trees at the waters edge. These Hawks tolerate a relatively high degree of human activity near their nests (CDBW 2001) and herbicide application should not impact their nesting activities. Some birds may also be impacted through the loss of intertidal wetlands. No mammals are expected to be harmed from the application of chelated copper (CDBW 2001).

There are few potential human impacts that could occur under normal copper applications. The label states that waters can be used for swimming and recreating immediately after copper application (Griffin Corporation 2003). The most severe impacts from copper application could come from its entrance into agricultural intakes. The possibility for copper to enter an agricultural intake exists. If water containing high levels of copper is applied as irrigation water, significant crop loss could occur (CDBW 2001). This effect can be mitigated through the creation of memorandums of understanding, standard operating procedures, and monitoring intake areas.

5.2.3. **Fluridone**

The use of fluridone at Big Break would result in a temporary violation of the General Water Quality Basin Plan. Due to the tidal influence of Big Break, fluridone concentrations dissipate very quickly. Photodegredation, dissipation, plant uptake, and tidal movement keep fluridone levels between 10 to 20 ppb during the application period.

In addition, the application of an herbicide to the water column could have possible effects on the drinking water supply. The maximum concentration limit set by the EPA for fluridone is 0.15 ppm, which is 7-15 times larger than the target application rate. Any herbicide application near a drinking water intake has the potential for trihalomethane production. The effect of fluridone on water quality will be minimal (CDBW 2001).

The potential for insect harm as a result of fluridone treatment is created through loss of habitat. The Elderberry Longhorn Beetle could be harmed if elderberry bushes, a riparian shrub, are affected by the fluridone application (CDBW 2001).

Sensitive fish species do not use *Egeria* beds as habitat, but that does not mean that the removal of plant beds will not create negative impacts for these fish species. The loss of native plant coverage during *Egeria* removal could reduce fish habitat, spawning, and rearing areas. The removal of *Egeria* beds could also reduce the reproduction areas used by the prey base fish, insect, and invertebrate species and directly reduce the numbers of species these fish depend upon (Moyle 1976; Wang 1986; Herbold 1987).

Removing large *Egeria* beds could have adverse impacts on aquatic fish species in the area. Large decaying masses of *Egeria* should not create low dissolved oxygen levels due to its slow decay. The loss of these beds should not change any other water quality parameters that would adversely affect fish species (Arnold 1979). The loss of large areas of habitat will only be a concern for the fish species that inhabit them. Adverse impacts created from loss of habitat should be offset by the creation of viable habitat area for native plant species (CDBW 2001).

Fluridone could potentially harm agricultural crops if it is in the water column at levels that are herbicidally effective at an agricultural intake. The Sonar™ label recommends suspending irrigation activities for a period that ranges from 7 to 30 days depending on the crop and its establishment (SePRO Corporation 1994).

Impacts to human health are by consumption in drinking water, swimming or recreation, and eating fish that have accumulated fluridone. The levels at which fluridone will be applied will be an order of magnitude lower than the California MCL. California MCLs are set below levels that pose any risk to humans through consumption of drinking water. Previous studies (West 1983) and the low toxicity of fluridone are all contributing factors to the extremely low potential for human harm through fluridone application.

5.2.4. **Harvesting**

Mechanical harvesting can result in the disruption of various aspects of water quality. For this reason the method is reserved for more immediate and emergency situations. The parameters of greatest impact from a harvesting event would be turbidity, dissolved oxygen, residual fragments, disturbance to sediment and shore dwelling species, and incidental fish kills.

The Basin Plan lists turbidity as one of its five water quality parameters of concern, and is expected that the maneuvering of the harvester would result in temporary increases that would violate the Basin Plan (CDBW 2001).

In terms of the spread of viable fragments, flow at Big Break is usually low enough that the problem of these fragments should not be a concern to surrounding water bodies. The threat of spreading the fragments to surrounding water bodies is low because of low tidal influence, but the fragments must be collected within Big Break itself as to avoid re-infestation locally.

Some sensitive fish species would be impacted by the loss of invertebrates, which preside in *Egeria* beds. In a series of sampling events at Big Break and other Delta sites, the CDBW found that the five most common invertebrate species were: Dipteran larvae, the amphipod *Hyalella azteca*, *Cladocera*, the snails *Physa sp.* and *Gyraulus sp.*, and *Oligochaete stylaria*. None of the invertebrates discussed previously are classified as sensitive species, but are a common food source for some sensitive fish species. The sensitive fish species that feed on the invertebrates include splittail, juvenile Chinook salmon, and delta smelt (CDBW 2001). Mechanical harvesting would remove these invertebrates along with the target *Egeria*; although in cases where the *Egeria* is cut above root sediment levels, this problem may not be as pronounced.

Amphibians and reptiles residing on banks near harvesting areas could also potentially be impacted by *Egeria* control. When the harvester maneuvers, it could result in the harm, disturbance of loss of individual species. In the water column, it is assumed that reptiles and amphibians would be able to escape areas of active harvesting; thus reducing the impact (CDBW 2001).

Birds that nest near banks of *Egeria* infested areas where harvesting occurs may also be at risk. Equipment could disturb or destroy habitat, along with individual animals themselves. These events would be avoidable if proper precaution is taken (CDBW 2001). Mitigation techniques to reduce the impact of harvesting will be discussed in the mitigation section.

Another potential environmental damage associated with mechanical harvesting is loss of habitat. By cutting the nuisance species, we may be destroying an area of cover or spawning used by another ecosystem member.

5.2.5. **Hand pulling**

Hand pulling may cause a temporary increase in turbidity as a result of disturbance caused on the bottom by the presence of the hand-puller. It is unlikely that plant removal by hand pulling would create any long-term changes in water quality at Big Break.

The Water Hyacinth Control Program (WHCP) at Big Break is much less extensive than the *Egeria* control project, but there are still consequences to wildlife associated with the manual hand removal of hyacinth. At Big Break, hand pulling is done from aboard a WHCP vessel, which has the potential to disrupt sensitive habitat simply by maneuvering. Removing the hyacinth may inadvertently lead to a taking of another native species. The potential for adverse impacts affecting native species of flora and fauna is slight. Hand pulling is slow and precise. Impacts to non-target flora will be minimal.

Impacts to invertebrates due to hyacinth removal could occur from habitat loss. There should be a minimal disruption to the invertebrate community in terms of death caused directly from hand pulling. Fish species should also be minimally impacted from hand pulling. As was discussed with the previous mechanical removal management option, removing the hyacinth will temporarily disrupt the sediments. This event leads to a disruption in the invertebrate communities, which could temporarily lead to shortages in fish prey.

5.3. *Mitigation*

All of the plant management strategies used at Big Break create some environmental impacts that must be mitigated. The mitigation measures that are employed to reduce environmental impacts reduce the potential for environmental damage, and thus the potential total cost of each strategy. The mitigation measures themselves have costs that must be incorporated into the total cost of using a plant management strategy.

Only impacts that can be mitigated, or that are significant enough to warrant mitigation, will be incorporated into this study. Some mitigation measures have an exact dollar amount associated with them while others must have dollar amounts estimated.

5.3.1. **Water quality**

To reduce the potential for adverse effects on wildlife due to low dissolved oxygen levels from decaying plant material, dissolved oxygen levels will have to be measured before any herbicidal treatment occurs at the treatment site. In addition to taking dissolved oxygen measurements, during late summer, only 20 acres per day can be treated. During fall, treatment of 20 acres may be treated every 14 days. (CDBW 2001).

Chelated copper is the only herbicide that has shown the potential to accumulate in the bottom sediments. If copper is used, the managing party must monitor the sediments. While there are no measures to mitigate against the possible accumulation of copper in the sediment, monitoring sediment concentrations would allow chelated copper treatments to halt before copper concentrations reached harmful levels in the sediment (CDBW 2001).

To increase the effectiveness of harvesting *Egeria* and keep the possibility of spreading the infestation low, a collection vessel follows the harvester operating at a treatment site. Treatments will not occur on windy days to reduce the possibility of *Egeria* fragments eluding the collection team (CDBW 2001).

All treatment sites that occur near drinking water inlets will require mitigation measures to reduce the potential of contaminated water, water with increased turbidity, and/or water containing elevated levels of trihalomethanes. The department will contact the California Department of Health Services (CDHS) and the appropriate drinking water utilities to inform them of any treatment that is occurring within a one-mile buffer zone of the intake. Treatment will only occur if the DHS and the appropriate utilities agree that treatment within the buffer will not adversely affect drinking water quality. In addition to the regular monitoring activities conducted by the department will coordinate with the DHS to monitor BOD, TOC, DOC, and UVA-254 as necessary (CDBW 2001).

5.3.2. **Wildlife**

5.3.2.1. Plants

To reduce potential adverse affects from plant treatment, a qualified botanist surveys channel banks for sensitive plant species located along the banks of treatment sites. If the site contains a high percentage of sensitive plants, treatment will not be allowed. Treatment sites that contain sensitive plant species will have treatment only occur at low tide and the herbicide treatment focus on the middle of the channel to reduce the potential of herbicides spreading and impacting sensitive plant species. These mitigation measures reduce the efficiency of the herbicides being used. Following treatment channel banks will be surveyed again to assess the loss of sensitive plant species. Prior to treatment with a mechanical harvester, any areas containing sensitive plants will be flagged and no staging or movement of harvester equipment will be allowed in these areas (CDBW 2001).

5.3.2.2. Invertebrates

Diquat and mechanical harvesting are the two treatments that have potential impacts that need to be mitigated. Diquat has been shown to be moderately toxic to aquatic invertebrates. The same mitigation measures imposed to reduce adverse effects from decreased dissolved oxygen levels will be employed to reduce impacts to aquatic invertebrates. No more than 20 acres will be treated in a day. Downstream treatment sites will not be treated within 14 days of treatment of an immediately adjacent upstream site. The impacts from mechanical harvesting will be mitigated by only allowing 10 acres of treatment per day. Harvesters will not cut vegetation more than 5 feet below the water level, leaving one to three feet of standing vegetation. The tidal influence of the delta will replenish the invertebrate communities that were harmed by treatment.

Harm to insects will be reduced or eliminated during mitigation measures for sensitive plant communities. A botanist will survey treatment sites for sensitive insect habitat. Where sensitive insect habitat is observed, treatment will not occur along those channel bluffs (CDBW 2001).

5.3.2.3. Fish

Mitigation measures for fish species mainly involve "do not treat" periods. Some of the additional mitigation measures that could be required are pre-treatment fish surveys using pop-nets and an analysis of any harvest material for sensitive fish species. Impacts to fish habitat would be mitigated through the minimization of treatment areas: 20 acres per day for herbicides and 10 acres per day for harvesting.

The reduction in prey base due to treatment will be mitigated while mitigating impacts to insect and invertebrate populations (CDBW 2001).

5.3.2.4. Reptiles and amphibians

Mechanical harvesting has the potential to adversely impact sensitive reptiles and amphibians. Prior to treatment a qualified biologist will survey channel banks for sensitive species, critical habitat, and or evidence of their presence. The biologist will flag these areas and harvesting activities will not occur within 50 ft of these areas. Herbicides have been shown to have the potential to adversely impact reptile and amphibian communities. The mitigation measures applied to decrease the potential for these impacts will be similar to those used to reduce the potential for harm to sensitive plant species. Herbicidal treatment will only occur at low tide and in the mid-channel where sensitive reptile or amphibian habitat is found (CDBW 2001).

5.3.2.5. Birds

The mitigation measures for treatments to reduce adverse impacts to birds will be the same as those for plants, reptiles, and amphibians (CDBW 2001).

5.3.2.6. Mammals

There are no mitigation measures necessary for mammals (CDBW 2001).

5.3.2.7. Humans

To avoid any potential impacts to agriculture in the area, the DBW contacts the County Agriculture Advisor. Landowners could then be informed of "do not irrigate" periods. Post treatment mitigation measures will include water column samples for herbicides and a site check of intake grates for *Egeria* fragments. Mitigation measures for drinking water inlets were discussed in the water quality section. Potential effects to humans from recreational activities at treatment sites will be mitigated by a by a DBW staff member patrolling the site to inform individuals that treatment is occurring (CDBW 2001). The cost of the DBW staff member to patrol treatment sites will be incorporated into the cost of having a staff member present during the application period. The unmitigated effects of stakeholders having to deal with changes in their irrigation schedule and normal use of the delta will not be addressed in this project.

5.4. *Cost and Environmental Analysis: Big Break, San Joaquin-Sacramento Delta*

This section can be used as a template for managers making aquatic plant control plans. The analyses provide a step-by-step procedure for pricing a management decision. The first costs considered will be the costs of control; next values will be calculated for potential environmental impacts. Including the value of an environmental impact will attempt to account for previously unaccounted for cost in the management decision.

The control cost analysis example is provided through the analysis report and the entry table below.

1. *Summary of Results*

If only control costs are considered, herbicide treatment is the optimal method. The cost analysis shows that it is a more expensive option, but it is the most efficient due to the environmental conditions at the site.

2. *Identify the Aquatic Plant Problem*

Both Water hyacinth and *Egeria densa* are invasive species that are currently affecting navigation, recreational boating, and fishing at Big Break. In 1997 the CDBW in conjunction with the Romberg Tiburon Center for Environmental Studies began a program to study growth of *Egeria,* the main plant, at Big Break. That same year the *Egeria* infestation at Big Break had become such a problem that Assembly Bill 2193 was enacted, which enabled the Department of Boating and Waterways to create the *Egeria Densa* Control Program (EDCP) for the Delta (DBW 2001). During the first year of the study aerial photos revealed that *Egeria* covered 37.8% of the waters surface in Big Break (563.46 acres). Over the next three years the Department in conjunction with other interested parties created an EIR/EIS for the EDCP. By 2000 *Egeria* coverage had increased to 52.1% (723.77 acres) of the surface waters at Big Break (CDBW 2001). In 2001 the CDBW had completed its initial EIR on the EDCP. In the EIR the Department investigates the impacts of using Sonar™ (Fluridone), Reward™ (Diquat), Komeen™ (chelated copper), and mechanical harvesting as options for control of *Egeria.*

3. *Potential Economic Costs and Benefits*

Benefits of leaving the *Egeria* and Hyacinth in place include an increased habitat for various aquatic invertebrates as well as various species sport fish, which are sought by anglers who visit Big Break. In addition, it has been postulated that hyacinth are efficient at the uptake and storage of contaminants, namely mercury, along with their required nutrients (Andrews 2003a). Plants thought to be a nuisance are taking up high levels of mercury from the sediments; essentially making them unavailable in the remainder of the ecosystem. Levels of mercury in sediments were found to be 200-600 ppb, and levels in the Hyacinth tissues ranging from 100-20,000 ppb in the same areas (Andrews 2003a).

4. *Management Objective*

The management objective at Big Break is to control plants for ease of navigation and to stop the increase in rate of growth of *Egeria.* The percentage cover of the aquatic plants has been increasing since 1997. Retarding this increase has been a main goal of the control program.

5. *Identifying Management Alternatives*

Currently there are two management alternatives for the control of *Egeria* including (1) the use of Sonar™ (Fluridone), Reward™ (Diquat), Komeen™ (chelated copper), (2) mechanical harvesting and hand pulling. These options are considered the two alternatives because they are actually occurring at Big Break, making their costs available for analysis.

6. Economic Perspective

A private perspective will be used in this analysis.

7. Type of Analysis

This is a cost and environmental analysis because both control costs and environmental costs are being considered.

8. Period of Analysis, Discount Rate, and Price Level

A 50-year period, a 5% discount rate and a 2003 price level are being used for this analysis.

9. Specifying Management Alternatives

See Appendix I for complete entry tables for Big Break.

10. Feasibility Tests

- Technical Feasibility: All three alternatives are physically possible to perform on the areas of concern. However, it is often difficult to carry out harvesting on Big Break as a result of windy conditions mentioned above.
- Legal feasibility: All three alternatives are allowed by local, State and federal laws, and all necessary permits can be obtained.
- Financial feasibility: All three alternatives are financially feasible under the budget constraints for the area.

Social/cultural feasibility: All three alternatives are socially and culturally feasible on at Big Break. Social acceptance of all alternatives involves public perception of impacts. The perception differs between community sectors but it is generally accepted that the plants need to be removed.

11. Costs of Each Practice in Each Management Alternative

According to the CDBW *Egeria densa* EIR, chemical treatments at Big Break include the use of Sonar™ (fluridone), Reward™ (Diquat-dibromide), and Komeen™ (chelated copper). The cost of Sonar™ is estimated to be $800-1000/acre, Reward™ is $75/acre, and Komeen™ at $450/acre. It is assumed that each acre treated requires one pass with each chemical, giving a season total of $1,096,860 for the 724-acre management area at Big Break. Mitigation costs for chemical treatments are estimated to be $22,265, which includes mitigation costs calculated in Section 6.7. Harvesting costs are also high at Big Break. Using estimates from Aquatic Environments, Inc., the cost of having two H-7, 400 cubic foot harvesters operating full time, completing two passes over the Big Break area would have a cost of $2,033-2,148/acre with a total season cost of $1,471,563-1,555,041 (the low estimates do not include disposal costs, the high estimates do). When mitigation and environmental costs (fish kills) are incorporated into the analysis total, season costs are $163,082-1,476,332. Finally, hand pulling has an estimated cost of $500-2,400 per day (Gibbons et al, 1999), which gives a rate of $695-$3229/acre and a season total of $503,536-$2,337,670.

12. Mitigation costs

Mitigation costs were estimated to be $22,586 for harvesting at Big Break, which includes the environmental cost of fish kills. Damage and mitigation costs for chemical treatment were estimated to be $1,356,496; 106,986; and 106,986 respectively for chelated copper, fluridone, and diquat. No other environmental costs were estimated as a result of the management alternatives. See Section 6.7 for assessment of mitigation costs as a result of this treatment on Big Break. These values were calculated with the help of CDBW analyst Julie Owen, based on 2003 sampling and control estimates for Water hyacinth. The mitigation efforts for *Egeria* are similar enough to those for the Water hyacinth program, so a benefits transfer was conducted. Therefore, it is assumed that these costs are transferable between control programs.

13. Remaining Uncertainties and Issues

Big Break is located at a very windy point along the Delta, making harvesting a less attractive option for managers. In addition, *Egeria* fragments left behind as a result of harvesting further propagate the growth of the plant and render the treatment less effective.

Hand pulling has also been used as an effective means of treatment for Water hyacinth at Big Break. This season's "pulled" hyacinth and *Egeria* are currently lying on a barge in the middle of the Break, drying and waiting to be disposed of. This option is less attractive because disposal of the plant material can be expensive.

14. Entry Tables

Table 4 summarizes the control cost analysis, complete entry tables are provided in Appendix I. The calculations of environmental costs are detailed in sections 6.5-6.6.

Table 4. Summary table for Big Break treatment costs for control of Egeria densa *and water hyacinth. The net present value (NPV) and feasibility tests are also presented.*

Type of Analysis: Control and environmental cost										
	Economic costs from Entry Table 6					Describe other benefits and costs and other considerations that affect the selection of a management alternative	Feasibility tests			
	Control costs		Total costs		Meets manage-ment objective?					
Management alternative	NPV, 1000$	Annual value, 1000$	NPV, 1000$	Annual value, 1000$			Tech	Legal	Finance	Soc/C
Herbicide treatment: diquat bromide, fluridone, chelated copper	$21,121	$1157	$53,866	$2951	Yes	This seems to be the only effective treatment method at Big Break for *Egeria*.	x	x	x	x
Harvesting	$28,336-$29,943	$1552-$1640	$29,260-$30,868	$1603-$1691	Yes	Harvesting is difficult to carry out at Big Break because of the extremely windy conditions that are unpredictable, but it is still technically feasible.	x	x	x	x
Hand pulling	$27,355	$1498	$27,355	$1498	Yes		x	x	x	x
Management Alternative Selected: Herbicide treatment if only control costs are considered, harvesting if control and environmental costs are considered.										

5.5. *Fish Kill Valuation for Big Break*

The following valuation exercise calculates the cost of fish kills during aquatic plant removal events, specifically mechanical harvesting of *Egeria* at Big Break. The outline for this particular event can be adjusted to apply to other aquatic plant removal scenarios. The "cost" of an aquatic plant removal event can be determined with the following information: what species reside in the aquatic plant area, how much removal will occur, the numbers of species in the harvested or potentially harvested plant material, and market values of fish species.

The following exercise presents only one way of calculating the monetary environmental costs of an aquatic plant removal event. There are other valuation techniques such as: non-use, contingent valuation, existence value, hedonic pricing, and benefits transfer. However, here we use a replacement cost approach to assign values to the loss of fish, translating the loss into a dollar cost. Determining a dollar cost associated with a fish kill event will help managers to assess the true costs of management options.

The valuation exercise considers the six most abundant fish present in aquatic plant beds at Big Break. These species were identified from biological surveys conducted by the California Department of Boating and Waterways in association with the *Egeria densa* Control Program. In addition, the Chinook salmon, a species that does not inhabit *Egeria* plant beds, was included in the valuation, since its juveniles can be found around the edges of the mats. The harvesting of this protected migratory fish constitutes a worst-case scenario that needs to be included. The Chinook salmon is a "threatened species" under the Endangered Species Act, with high use and existence values. In a survey of Pacific Northwest anglers, the willingness to pay for a steelhead - an andronomous fish comparable to a Chinook salmon - had a "gain value" of $88.40 (Loomis 1996). In other words, anglers would be willing to pay $88.40 for a gain of one steelhead.

The six most common species found inhabiting the *Egeria* beds were: blue gill, largemouth bass, inland silverside, killifish, mosquito fish, and threadfin shad. Values for the species were derived from an American Fisheries Society sourcebook, which denotes values for fish obtained through the survey of hatcheries in accordance with the basic principles of supply and demand market pricing. As stated initially, this replacement value is best described as the market value for fish stocks; and may leave out values associated with existence, accessibility, and recreation, which are more difficult to determine.

The fish-pricing scheme is separated into size and species-specific categories, which allows a more accurate depiction of values for Big Break fish. An *Egeria* harvesting study suggested that 1% of the fish in an over-grown area will be killed during a harvesting event (McGowan 1998). The total number of fish counted from the McGowan study was divided by 30% and multiplied by the total acres harvested to determine the fish mortality for the treated acres. Multiplying this number of fish killed by the replacement cost, adjusted to 2003 dollars, yielded the cost for each species.

Table 5 presents the results of the fish valuation exercise. Note that the cost associated with the fish kill can be added to the overall treatment costs for mechanical harvesting. This is only one aspect of total environmental costs; see the previous "impacts" section for other impacts that could have additional costs.

Table 5. Total Cost for the six most common fish found in Egeria densa *beds killed during harvesting at Big Break using replacement cost valuation. Prices taken from "Sourcebook for investigation and valuation of fish kills" (American Fisheries Society, 1993), with the exception of the Chinook salmon (Loomis 1996).*

Fish	Replacement value($)	2004-Adjusted value ($)	Size (inches)	Fish killed	Cost ($)
Threadfin shad	0.35	0.45	11 to 13	25	11
Killifishes	0.08	0.10	Each fish/all	0	0
Largemouth bass	4.02	5.12	12	0	0
Bluegill	1.50	1.91	9	0	0
Inland silverside	0.08	0.10	Each fish/all	222	22
Western mosquitofish	0.08	0.10	Each fish/all	2	0
Chinook salmon (threatened)	88	132	16	2	287
Total cost					321

The total replacement cost for a fish kill after harvesting at Big Break could result in a total cost of $321. This cost can be considered an environment cost that is added to the previous control cost analysis.

5.6. *Regulatory/Mitigation Cost*

An assessment of regulatory costs can be completed for Big Break based on mitigation measures required by the Regional Water Quality Control Board's permit issued to the Department of Boating and Waterways. There are two main categories that will be considered when assessing the costs of a management strategy related to avoiding damages to the environment: sample costs (the laboratory cost of the samples), and monitoring costs.

Laboratory costs for the samples are a significant environmental cost to consider when choosing a management strategy. The NPDES permit mandates the number and frequency of samples required for an aquatic plant removal project. A calculation of the number and frequency of samples, multiplied by the cost per sample, will yield a monetary cost associated with the plant removal practice in question.

A permit is required for the use of all chemical herbicides. Table 6 in this section outlines the average costs estimated for a plant removal event to meet the requirements stated in the permit. The total cost calculated from this exercise includes an additional monetary cost of avoiding damage caused by the management strategy. In the control cost analysis section of the Big Break Case study, the cost of the permit is shown as an agency cost, not an environmental cost. In addition, there are the monitoring and mitigation costs associated with the requirements in the permit. Essentially this exercise considers the mitigation or regulatory costs, as costs of avoiding environmental damages.

Table 6. Typical costs incurred as a result of NPDES-mandated actions in response to chemical treatments. The number of samples is an average taken for 6 treatment sites. The costs per sample are taken from SFEI estimates.

Analysis	Samples per treatment site	Explanation	Treatments per season	Cost per sample ($)	Total Cost ($)
Dissolved oxygen	5	Pre-application (1 hour prior to treatment)	1	1	5
Dissolved oxygen	5	Post-application (1 hour after treatment)	1	1	5
Dissolved oxygen	5	Follow-up sampling weekly until dead plants are no longer observable on the surface and the readings within and downstream of the treatment area within 0.5 mg/L of the upstream reading.	1	1	5
Chemical(s) applied	5	Pre-application sediment samples	1	215	1,075
Chemical(s) applied	5	Pre-application water sample	1	150	750
Chemical(s) applied	5	Post-application sediment samples	1	215	1,075
Chemical(s) applied	5	Chemical samples taken 2 hours post treatment in areas where water is being pumped.	1	150	750
Toxicity	5	Pre-application water flea and fathead minnow	1	660	3,300
Toxicity	5	Post-application water flea and fathead minnow	1	660	3,300
Toxicity	5	10-day sediment test	1	800	4,000
Toxicity	5	28-day sediment test	1	1600	8,000
Total cost					22,265

From Table 6, the compliance cost for one treatment plot is estimated as $22,265. For quantitative comparison, Big Break encompasses a treatment area of 170 acres treated for hyacinth and 724 acres treated for *Egeria*. This total cost can be added to the total cost for chemical control; including the initial permit fees, and any mitigation requirements like replacing a fish, so that a more accurate depiction of a chemical management strategy can be evaluated. It is also important to note that different treatments have different costs. For example, because copper has been shown to accumulate in sediments, additional sediment toxicity tests must be conducted. For the other herbicides that do not contain copper, these additional costs are not applicable. Table 6 gives a general overview of sampling costs, using an average between all chemical sample costs. Tables 8-10 provide a sampling cost breakdown in terms of each treatment method used. These clarifications to Table 6 provide a more chemical-specific breakdown for the sampling component of damage cost avoidance. For non-chemical treatments, chemical sample costs are not applicable, though other water quality sampling still remains.

The sampling costs for non-chemical treatments are much cheaper than chemical treatments. This is mostly from the lower cost of dissolved oxygen sampling. Also, dissolved oxygen sampling is done with a Multimeter probe that also samples for temperature, conductivity, pH, salinity, and redox potential. The initial cost of the Multimeter is $2,200, and has an average lifespan of four years (Siemering 2004). All treatment options, both chemical and non-chemical, require the additional sampling readings that are obtained with the Multimeter probe, but for simplicity just "Dissolved Oxygen" is shown in Tables 6-10.

Table 7. Sampling costs for chelated copper.

Analysis	Cost per sample ($)[1]	Samples required per site[2]	Treatments per season [3]	Site visits per season[4]	Total cost ($)
Chemical conc. in water	50	5	1	85	21,250
Chemical conc. in sediment	80	5	1	85	34,000
Toxicity water flea	330	5	1	85	140,250
Toxicity fathead minnow	330	5	1	85	140,250
Toxicity-10 day sediment test	800	5	1	85	340,000
Toxicity-28 day sediment test	1600	5	1	85	680,000
Dissolved oxygen	1	5	1	85	425
Total cost					1,356,175

[1]Cost per sample based on estimates from SFEI
[2]Average number of samples taken for six Big Break Sites
[3]Treat same sample plot area once a year
[4]Site visits to Big Break for one season for the Water Hyacinth Control Program

From Table 7 it is clear that there are high sampling costs associated with the use of copper based herbicides. Herbicides like chelated copper require toxicity and sediment tests because of their tendency to accumulate in sediments. Other organic herbicides have different individual sampling costs because they do not call for sediment and toxicity monitoring. Tables 8 and 9 present sampling costs for fluridone and diquat dibromide, the organic herbicides.

Table 8. Sampling costs for fluridone

Analysis	Cost per sample ($)[1]	Samples required per treatment site[2]	Treatments per season[3]	Site visits per season[4]	Total cost ($)
Chemical concentration in water	250	5	1	85	106,250
Dissolved oxygen	1	5	1	85	425
Total cost					106,675

[1]Cost per sample based on estimates from SFEI
[2]Average number of samples taken for 6 Big Break Sites
[3]Treat same sample plot area once a year
[4]Site visits to Big Break for one season for the Water Hyacinth Control Program

Table 9. Sampling costs for diquat dibromide

Analysis	Cost per sample ($)[1]	Samples required per treatment site[2]	Treatments per season[3]	Site visits per season[4]	Total cost ($)
Chemical concentration in water	250	5	1	85	106,250
Dissolved oxygen	1	5	1	85	425
Total cost					106,675

[1]Cost per sample based on estimates from SFEI
[2]Average number of samples taken for 6 Big Break Sites
[3]Treat same sample plot area once a year
[4]Site visits to Big Break for one season for the Water Hyacinth Control Program

Table 10. Sampling costs for harvesting

Analysis	Cost per sample ($)[1]	Samples required per treatment site[2]	Treatments per season [3]	Site visits per season[4]	Total cost ($)
Dissolved Oxygen	1	5	1	85	425
Total cost					425

[1]Cost per sample based on estimates from SFEI
[2]Average number of samples taken for 6 Big Break Sites
[3]Treat same sample plot area once a year
[4]Site visits to Big Break for one season for the Water Hyacinth Control Program

Monitoring costs include the cost of conducing surveys of special status species and habitat areas as well as collecting water samples required by the NPDES permit. This study assumes that a full-time state level C environmental scientist conducts all of the monitoring and sampling. To determine the cost of monitoring, the average salary for this position was used: $50,000 (California State Personnel Board 2004). This number is then divided by 2080 hours worked per year, to get an hourly pay rate ($24.03/hr). The hourly wage is then applied to the hours spent monitoring, collecting samples, and application time.

It is assumed that monitoring time is the same for chemical and mechanical treatment options and will take two employees to monitor an area. Every site visit requires about 2.25 hours of monitoring (Owen 2004). There were a total of 328.5 hours of monitoring, plus a total of 239 hours of application time in the WHCP in 2003, because of the total number of visit made to the sites. The total monitoring and application cost for this project is $14,941.

Many of the hours from monitoring arose from increasing the number of trips (85) to treatment areas due to treatment restrictions. Without treatment restrictions - limitations on the daily allowable treated acreage- the application hours for chemical treatment could possibly be reduced to 101.85 hours or 13 trips. This reduction assumed a maximum boat speed of 8kph and a treatment width of 30 feet to cover the entire treatment area. Reducing the treatment time to 101.85 hours for the entire 170-acre site is extremely optimistic though, as wind conditions, label restrictions, and dense plant infestations all reduce the efficiency of an application crew. To account for the reduction in efficiency, the maximum number of application hours during the day was reduced by 40%. This increased the non-mitigated number of control trips to 22. Chemical control could be completed in 22 visits as opposed to 85. This would reduce the cost of management by reducing the total time for monitoring and application; the new monitoring cost would be $2,380. The cost of the monitoring and application without mitigation would be $4,214.

The cost to survey the water's edge for sensitive species habitat must be considered with the monitoring costs. To estimate this, a benefit transfer was applied from a habitat-monitoring program on the Trask River in Oregon (Plawman 2000). Big Break was considered to be comparable to the Trask River in order to determine mitigation costs associated with surveying habitat. After adjusting survey time for differences in total variables surveyed the between the two areas, 0.43 acres per hour can be surveyed for chemical treatment and 0.25 acres per man hour can be surveyed for mechanical treatments. Non-chemical management mitigation involves flagging habitat before treatment, removing flags after treatment, and surveying harvested material for sensitive species. Two variables were added to the percentage of total survey time to account for the time to install flagging around habitat. When the survey hours were applied to chemical plant control the total increased cost is $113.07 per acre for both pre and post surveys. This is an increase of $19,221 for chemical treatment at Big Break. Surveying mechanical treatment areas increased cost of control by $188.45 per acre, or $32,036 for all of Big Break.

Treatment restrictions raised the cost of chemical treatment by increasing the amount of trips to Big Break by 63 trips. Restricting the number of acres that can be treated in an area increased the number of trips an employee must make. If area restrictions were removed, managers could treat and monitor Big Break in 22 total chemical events. These restrictions increased the travel time to Big Break by 197.5 hours. This translated into a cost increase of $9,495.19 for 2 employees over the management season. This does not include the costs of fuel, vehicle, and boat travel time to the site.

An increased cost due to treatment restrictions is not always the case. For non-chemical strategies, where harvesting rates only approach 2 acres per day (Mann 2003), the treatment restrictions do not increase the number of trips made needed due to the physical limitations of harvesting.

The total cost for mitigation that arises from the categories, sampling, monitoring, and treatment restrictions is shown in Table 11.

Table 11. Total regulatory cost for sampling, monitoring, and treatment restrictions for chemical and non-chemical control.

	Cost ($)			
	Chemical			Non-Chemical
	Diquat dibromide	Fluridone	Chelated copper	Harvesting
Sampling	106,675	106,675	1,356,175	425
Monitoring	14,941	14,941	14,940	14,941
Surveying	19,221	19,221	19,221	32,036
Treatment restrictions	9,495	9,495	9,495	0
Total cost	150,332	150,332	1,399,832	47,401

Mitigation measures increase the cost of chemical treatment. The majority of the cost increase is from chemical sampling. The costs of chemical treatments are also increased due to treatment restrictions, whereas non-chemical methods are not. Treatment restrictions not only increase monitoring time, but also travel time and total samples taken.

5.7. *Omissions*

Due to limitations in time and data this study did not address costs associated with a plant management plan. Some of these include: boat travel time to the site, travel time to the lab, preparation of water samples, equipment costs, back office tracking, increased training hours for employees, some mitigated externalities, and time developing memorandums of understanding and standard operating procedures with different agencies involved with management at Big Break.

5.8. *Conclusions*

The cost of mitigating environmental damages arising from plant control does not have a huge effect on the difference in cost between chemical and non-chemical strategies. After incorporating the cost of an NPDES permit and mitigating for all of the factors involved with obtaining the permit, the optimal management decision based on cost would not change. The control cost analysis choice would be diquat dibromide treatment, and the choice after mitigation and environmental damages would still be diquat dibromide treatment. For chemicals that have the potential to create major environmental impacts, the incorporation of environmental costs into a management decision will play a significant role in the decision.

Chelated copper costs only 20% as much as harvesting in the control cost analysis. After incorporating environmental damage and mitigation, harvesting costs only 27 % of the total of chelated copper application. The total costs for the management strategies analyzed in the Big Break case study are shown in Table 12.

Table 12. Summary of chemical and non-chemical effects.

	Cost ($)			
	Chemical			Non-chemical
Source	Reward	Sonar	Komeen	Harvesting
Control	12,750	153,000	76,500	357,000
Fish Kill	0	0	0	287
Regulatory	150,332	150,332	1,399,832	47,401
Total	163,082	303,332	1,476,332	406,882
Cost per acre	959	1,784	8,684	2,393

6. Case Study: Stone Lakes National Wildlife Refuge

6.1. *History*

The Beach-Stone Lakes Basin includes Beach Lake, North and South Stone Lakes, and several sloughs. During the winter, floods in the basin can extend ten miles south from Morrison Creek. The expanding lakes and seasonal wetlands once supported tens of thousands of migratory birds.

In the mid 1800's levees were constructed along the Sacramento River. The land was then drained and converted to farmland. The next major change to the basin occurred when the completion of a railroad drained many of the seasonal lakes. Increasing urbanization in the 1960's prompted the United States Army Corps of Engineers (ACE) to build channels in the basin to contain potentially harmful floodwaters. A flood control study of Morrison Creek in 1972 (by the ACE) recommended the establishment of a national wildlife refuge in the Stone Lakes Basin. In 1994 the United States Fish and Wildlife Service (FWS) established Stone Lakes National Wildlife Refuge (SLNWR).

The FWS manages the 94 million acre National Wildlife Refuge System, and is authorized to protect and manage a total of 4,065 acres at Stone Lakes. The 4,065 acres at the refuge were acquired under cooperative agreements, fee title ownerships, and easements (United States Fish and Wildlife Service 2002). Another 5,000 acres are owned by Sacramento County and several state agencies. The FWS has the authorization to purchase up to 18,000 acres within the refuge boundary.

The Stone Lakes Basin contains many of the different habitats that naturally occur in the Central Valley: grasslands, permanent and seasonal wetlands, vernal pools, riparian habitat and oak forest, to name a few. The refuge supports a broad range of flora and fauna, including many threatened and endangered species. Approximately 7,000 naturalists, birdwatchers, and students observe the refuge annually. Fishing and hunting are currently prohibited.

6.2. *Wildlife*

The Pacific flyway is the seasonal migratory route for millions of birds as they travel from their winter grounds in South America to their breeding grounds in the Artic Circle. A critical stopover for migratory birds is SLNWR. Its seasonal wetlands, mudflats, and lakes, are the focal point for migrant species.

The refuge is home to over 213 species of birds and 24 other wildlife species (Stone Lakes National Wildlife Refuge 2003). The diverse habit at the refuge is able to maintain a high degree of biodiversity. Waterfowl, shorebirds, and wading birds take advantage of the abundant mudflats, lakes, and wetlands. Riparian corridors in the refuge support egret, heron, and cormorant rookeries. In the woodlands, migratory birds and resident mammals, like opossums, raccoons, and skunks, are quite common. More than 15 species of birds of prey patrol the grassy uplands, which are home to coyotes, western meadowlarks, and rodents.

6.3. *Aquatic Plants*

Land conversions from urban growth and agriculture pose the most severe threats to the refuge. Much of the refuge project boundary area is adjacent to 3,000 acres of cultivated vineyards. The open space that is converted to urban and agricultural land diminishes critical buffer zones between developed areas and wildlife habitat.

Urban and agricultural run-off from surrounding areas generally drains into the lower refuge. This run-off is often high in sediment and nutrient concentrations. The additions of pollutants to the refuge can create adverse impacts like algae blooms and increased water turbidity.

Native aquatic plant species are an important component of lake ecosystems. Aquatic plants provide habitat for benthic and pelagic organisms, stabilize sediments, and form the basis of food chains in shallow estuarine environments. Invasive aquatic species often out-compete native species. The increasing exotic plant population can alter the natural nutrient cycles in the environment. These damaging infestations can create vector habitat, restrict access to waterways, and destroy native habitats. The aquatic species of concern in the SLNWR is water hyacinth (*Eichornia crassipes*).

6.4. *Cost and Environmental Analysis: Stone Lakes National Wildlife Refuge*

Characterization of Stone Lakes NWR site (from Courtright 2004)

In both the North and South Stone Lakes, as well as in surrounding sloughs there are over growths of water hyacinth. Water hyacinth treatment by the Stone Lakes Basin Water Hyacinth Control Group (SLBWHCG) is conducted under a National Pollution Discharge Elimination System permit held by the California Department of Boating and Waterways (CDBW). The total number of treatment days in 2003 was three times as great as 2002, resulting in substantial progress at checking the expansion of hyacinth. Spray activities in 2004 will begin on April 1, about one month earlier than 2003. Earlier start dates enable field crews to control hyacinth before the height of its ten-month growing season and increase the efficacy of treatment (Courtright 2003).

Whether spraying can be conducted on any given date depends on a variety of factors including: dissolved oxygen levels, wind speed, or boat/sprayer maintenance. Spraying is conducted in areas established by CDBW. All spray areas receive multiple treatments, in an effort to reduce the number of viable plants for the following season. Areas that were difficult to treat include sites with shallow water conditions, dense emergent vegetation, or where winds concentrated hyacinth, creating dense mats. Due to the anticipated earlier start date and longer spray season in 2004, additional resources will be needed to maintain an adequate level of control. A 23% percent increase in time and resources is predicted for next year's treatment period (Courtright 2004).

Traditionally, managers at Stone Lakes have controlled the hyacinth by means of herbicide treatment. With the aid of supplemental labor during the management season, employees have spent approximately four days per week during a 5 month period manually applying Weedar64® and AquaMaster®. In addition, hand pulling has also been used as a management technique in places where infestations are very dense. 2003 was the first time that "shredding" had been used on the Stone Lakes as a management technique. A pilot study to test this technique was conducted by the San Francisco Estuary Institute and Master's Dredging, Inc. in conjunction with the Stone Lakes Refuge Managers and Vino Farms. Costs were estimated with the help of Clay Courtright, U.S. FWS Biologist at the Stone Lakes NWR (Courtright 2003).

The Control Cost Analysis example is provided through the analysis report and the entry table below.

1. *Summary of Results*

Out of the four management alternatives considered (herbicide treatment, shredding, hand pulling and harvesting) herbicide treatments with Weedar64®, AquaMaster® with surfactant R-11 is the most cost effective strategy for the Stone Lakes NWR at this time.

2. *Remaining Uncertainties and Issues*

This is the first time that shredding has been carried out at the Stone Lakes. It was noted by operators that the shredding was done too late in the season, as the plants had grown too large for shredding to be effective. This could have a significant effect on the cost and effectiveness of this strategy. Another shredding event was carried out in spring of 2004 on younger, less mature plants.

In addition, managers at Stone Lakes would like to find non-chemical alternatives for treatment of water hyacinth in the interest of ecosystem health. This may have an effect on future decisions of whether or not to use this technique. This element can be further explored via an environmental cost analysis.

3. *Identify the Aquatic Plant Problem*

The aquatic species of concern in the Stone Lakes NWR is the water hyacinth (*Eichornia crassipes*). As a result of the invasion and overgrowth of the hyacinth, there has been a decrease in the amount of flow in surrounding sloughs and waterways because of physical clogging as well as uptake. As a result of water hyacinth's high rate of water use, one acre of the plants cause a loss of up to 39 acre inches of water per month. (CDBW).

4. Potential Economic Costs and Benefits

One benefit of the growth of water hyacinth on Stone Lakes is that it may provide habitat for various species of fish and invertebrates that could support the ecosystem that is present on the refuge.

However, much of the overgrowth occurs in the canals and sloughs in the area, therefore hindering flow to surrounding vineyards and other croplands.

5. Management Objective

The objective is to eradicate the plants in functional waterways, and to control (not necessarily eliminate) the plant on Stone Lakes proper.

6. Identifying Management Alternatives

There are four management alternatives to be considered on Stone Lakes NWR (1) herbicide application using Weedar64® and AquaMaster® with surfactant, (2) Shredding, (3) Harvesting, and (4) Hand-pulling. These alternatives were chosen by their status as existing methods currently in use, as well as an un-used alternative that has potential as a successful treatment on Stone Lakes.

7. Economic Perspective

A private perspective will be used in this analysis.

8. Type of Analysis

This is a control cost analysis because only control costs and not damage or environmental costs are being considered.

9. Period of Analysis, Discount Rate, and Price Level

A 50-year period, a 5% discount rate and a 2003 price level are being used for this analysis.

10. Specifying Management Alternatives

See Appendix K, entry table 3, numbers 1-3 for the specification of management alternatives.

11. Feasibility Tests

- Technical Feasibility: All four alternatives are physically possible to perform on the areas of concern.
- Legal feasibility: All four alternatives are allowed by local, State and federal laws, and all necessary permits can be obtained.
- Financial feasibility: All four alternatives are financially feasible under the budget constraints for the area.
- Social/cultural feasibility: All four alternatives are socially and culturally feasible on the reserve.

12. Costs of Each Practice in Each Management Alternative

For herbicide treatment, per season costs for 2003 were estimated to be $94,442 at a rate of $315/acre with a predicted increase of 23% for 2004. Shredding costs were estimated to be $245,106-$286,295 or $817-$954/acre for the 300-acre area. The costs for harvesting range from $205,016 to $208,177 per season at a rate of $683-693/acre based on variable disposal costs associated with the removal of the hyacinth from the water body. Finally, the cost of hand pulling has been estimated to be approximately $100,000-$480,000 per season, at a rate of $333-$1600 per acre.

13. *Damage Costs and Environmental Costs*

Environmental costs ranged from $0-$41,189 for the shredding alternative. If shredding occurs at a 15-day interval, there are no damages incurred ($0). If shredding occurs on a 7-day interval, damages equal $41,189. No environmental costs are incurred as a result of the other treatments according to our study. See below for a detailed assessment of environmental damages as a result of this treatment on Stone Lakes NWR.

14. Entry Tables

Table 13 is provided below, complete entry tables are provided in Appendix K.

Table 13. Management alternatives for Stone Lakes National Wildlife Refuge for control of water hyacinth, including net present value (NPV), and feasibility tests for each alternative.

Type of Analysis: Control and environmental cost										
	Economic costs from Entry Table 6				Meets manage-ment objec-tive?	Describe other benefits and costs and other considerations that affect the selection of a management alternative	Feasibility tests			
	Control costs		Total costs							
Management alternative	NPV, 1000$	Annual Value, 1000$	NPV, 1000$	Annual Value, 1000$			Tech	Legal	Finance	Soc/C
Herbicide treatment (Weedar64®, AquaMaster® plus surfactant R-11)	221.51	12.13	221.51	12.13	yes	The use of applied herbicides is time consuming for managers, but seems to be the most inexpensive option. Refuge manager is interested in non-chemical options for the preservation of natural status of the reserve.	x	x	x	x
Shredding	471.97	25.85	551.29	30.20	yes	Very expensive option, dissolved oxygen in slough dropped to zero after treatment. In addition, operated very late in the season, will try again next year when plants are smaller and less mature.	x	x	x	x
Harvesting (H-5 Harvester)	400.86	21.96	400.86	21.96	yes	Harvested materials can sometimes be sold as composting materials	x	x	x	x
Handpulling	558.42	30.59	558.42	30.59	yes	Most expensive option	x	x	x	x
Management Alternative Selected: Herbicide treatment with Weedar64® and AquaMaster® and surfactant R-11.										

6.5. *Modeling the Fluctuations of Biochemical Oxygen Demand in Stone Lakes National Wildlife Refuge: An Approach to Valuating Environmental Impacts from Aquatic Plant Management*

6.5.1. **Purpose**

The following analysis incorporates site characteristics from South Stone Lake; a water body located within the Stone Lakes NWR, as an example to model the changes in biochemical oxygen demand and dissolved oxygen from in-situ water hyacinth treatment. Decaying plant tissue has the ability to alter the concentrations of dissolved oxygen in the water column. This model predicts the magnitude and duration of the impact. This analysis could be used to help water body managers choose the duration and time between treatment events that is cost-effective and that internalizes the costs of environmental degradation from fish kills.

6.5.2. **Introduction**

An aquatic plant management strategy that leaves plant material to decay in place, such as mechanical shredding and herbicide application, can pose a risk to aquatic organisms by depleting water of dissolved oxygen (DO). Biochemical Oxygen Demand (BOD) is the amount of oxygen consumed by biological processes to naturally degrade organic matter. It is the water quality parameter that measures the effect that decaying plant material has on dissolved oxygen levels. The short-term loading of biochemical oxygen demand to a system is an important consideration when reviewing aquatic plant management options.

The saturation concentration of oxygen in water is directly related to atmospheric pressure, and indirectly related to temperature (University of California Cooperative Extension 1999). As temperatures rises and atmospheric pressure declines, the saturation concentration of dissolved oxygen is reduced. Typically, DO concentrations decrease with depth; it is not uncommon to find bottom waters depleted in DO. Water bodies depleted in DO are replenished by aeration at the waters surface. Aeration occurs as oxygen transfers from the atmosphere into the water body. The oxygen flux from the atmosphere into the water body is augmented as the concentration gradient between the surface and air interface becomes greater. At standard pressure, 760 mm Hg, and 25°C, the DO saturation concentration is 8.24 mg L^{-1} (Tchobanoglous 1985). Hypoxic conditions are defined when DO concentrations are less than 50% of saturated conditions (4.12 mg L^{-1}@ 25°C), while anoxia refers to water depleted of DO (0 mg L^{-1}). The sources of dissolved oxygen to a water body include turbulent water inflows, aeration, and photosynthesis. Decaying organic matter, respiration by plants and fish, chemical oxidation, and water outflow, deplete dissolved oxygen.

Dense aquatic plant beds influence DO levels by photorespiration, shading, restricting water movement, and increasing stagnant water temperatures. The physical structure of aquatic beds, however, offsets some of the negative effects of these beds by providing shelter and sources of food for fish. A reduction in the aquatic plant density can improve dissolved oxygen deficits, and in return, provide a long-term benefit to aquatic organisms that are sensitive to low DO conditions.

Fish depend on dissolved oxygen to survive. Some species are sensitive to hypoxia, whereas other fish species like the Common carp, can tolerate anoxic conditions. Although concentrations vary, an adequate supply of DO is necessary for embryo and fry development (Reiser 1979). Immediate reductions in DO levels can alter the spatial distribution of fish and invertebrates by forcing them to retreat into more favorable areas (Townsend 1992). Lower levels of dissolved oxygen have been related to a decline in species richness, abundance, and fish size, which would suggest a threshold DO response level. It also has been found that species that have adapted to aerial and surface film respiration dominated waters with low DO (Killgore 2001).

Fish sensitivity to low DO levels is a function of exposure time, the type of species, and its life stage. Research has been conducted to identify the lethal dissolved oxygen concentration criteria for marine and estuarine fish species using values ranging from 95% to 5% survival rates (Miller 2002). These criteria are essential for developing and implementing policy in order to protect fish habitat. Localized fishery impairments could have severe economic consequences on commercial and sport fishing industries, in addition to the health of wildlife refuges and marine sanctuaries.

A simple model was developed to quantify BOD accumulation, and depletion of dissolved oxygen, in a water body from mechanical shredding or similar aquatic plant management practice that retains decaying water hyacinth *in situ*. Modeled results will be compared to minimum (critical) DO concentrations for different fish species. Critical is defined as the DO concentration where fish mortality would likely occur. The magnitude and cost of fish mortality represents the total environmental impact associated with this type of management practice. In order to minimize the impact, the user of the model can alter the treatment size and the time between treatment events. The results can be used to compare the different economic costs from plant management projects that vary in duration and number of treatment events, while including the environmental impact that may occur from fish mortality.

6.5.3. **Methods**

Background information specific to each study site is imperative for an accurate representation of the model. Input parameters that are necessary to run the model include the water body's surface area and depth, estimated inflow and outflow dissolved oxygen load, and the background DO concentration of the water body.

The model utilizes the total wet mass or treated surface area of water hyacinth as the basis for calculating the BOD. Using the total wet mass and percent moisture content, the dry mass of dead plant material is calculated. Each type of aquatic plant will have a different decay coefficient. A decay coefficient is the maximum daily rate of decomposition, which is based on the cellulose/lignin content of plant material. Cellulose/lignin is hydrolysis-resistant organic matter (HROM) that is not readily degradable. This material will settle to the bottom of the water body and undergo long-term aerobic and anaerobic decomposition. On a percent basis, this HROM is deducted from the total dry mass in the model. The remaining dry plant material is considered the total BOD, which is available for natural biodegradation. The model does not predict the effects from long-term decomposition of this HROM.

The following assumptions are made in the model:

- The system is in a steady-state with respect to dissolved oxygen; no oxygen is lost from respiration;
- The day that aquatic plant treatment occurs, all plant material dies immediately and is available for biodegradation immediately;
- The system is not oxygen-limited, which would slow the decay process;
- Nutrient recycling and chemical interactions are negligent;
- The water body is well-mixed. Treatment that occurs in one region of the water body will have an effect on dissolved oxygen over the entire water body,
- Plant material will decay in the same place it was killed. No consideration will be made for wind or current driven displacement of material into "hot spots."

Dissolved oxygen equation is as follows:

$$DO = DO_{background} + DO_{inflow} - DO_{outflow} + Aeration - \left(BOD\, e^{-kt} - BOD\, e^{-k(t+1)}\right) \quad \textit{(Eq.1)}$$

Where

DO=DO concentration (mg L^{-1})	Aeration=rate of aeration (mg L^{-1} d^{-1})
$DO_{background}$=lake DO (mg L^{-1})	BOD concentration (mg L^{-1})
Outflow=outflow velocity (cfs)	k=hyacinth decay coefficient (d^{-1})
Inflow =inflow velocity (cfs)	t=time (d)

There are several steps needed to determine BOD of the shredded hyacinth. First, the surface area of the lake covered by living plant material can be estimated by plant surveys in the field, or by high-resolution imagery. The latter will be discussed in greater depth in the next section. With the surface area and approximate depth of the floating hyacinth mats, the total mass of the hyacinth can be calculated using its wet density. The wet density of water hyacinth ranges from 2 to 16 lbs ft^{-3}, which is temperature dependent, and dry mass ranges from 5 to 7 % of the total wet plant weight (Crites and Tchobanoglous 1998). The wet density used in this example run was 35 kg m^{-2}, which was representative of a pilot study conducted by SFEI at DOW wetlands (Andrews 2003).

Plant assays have determined the cellulose/lignin content of hyacinth to range from 37% to 48% (Battle 2000). Material composed of cellulose/lignin will likely settle to the bottom of the lake, while decomposing at a much slower rate. The remaining plant material will account for the dry mass of BOD readily available for decomposition. The decay coefficient (k) for hyacinth at water temperatures from 25 to 34 ^{0}C is -0.03 d^{-1} (Howard-Williams and Junk 1976). This temperature range is suitable for SLNWR during the early spring when hot temperatures coexist with rapid hyacinth growth in the Delta region.

Aeration equation (Tchobanoglous 1985) is as follows:

$$\text{Aeration} = k_2 \left(C_s - C_{O_2}\right) \qquad \textbf{\textit{(Eq.2)}}$$

Where

Aeration=rate of re-aeration (mg L^{-1} d^{-1})
k_2=re-aeration constant (d^{-1})
C_s=dissolved oxygen saturation concentration (mg L^{-1})
CO_2=dissolved oxygen concentration (mg L^{-1})

The re-aeration constants at 20^{o}C for a large lake range from 0.23 d^{-1} to 0.35 d^{-1} (Tchobanoglous 1985). The constant is corrected for temperature by the following equation:

$$k_{2T} = k_{2_{20}} \cdot 1.024^{T-20} \qquad \textit{(Eq.3)}$$

The re-aeration constant used in the model is 0.23 d^{-1}. Adjusted for 25^{o}C, the value is 0.26 d^{-1}.

These variables are used in the model to observe the gradual trends in DO levels over time. *First* the total BOD mass is divided by the lake volume to obtain the BOD concentration. The lake volume can be estimated, unless specific information is available. Multiplying the surface area by the maximum depth and dividing by two will calculate the lake volume. *Second*, the DO concentration is calculated by subtracting the difference between the BOD at time t and the BOD at time t+1 from the background DO concentration. This value is the DO concentration without re-aeration. *Third*, the DO concentration without aeration is applied to the re-aeration component of the model to determine the daily flux of atmospheric DO into the water body. Finally, the DO concentration without re-aeration is added to the daily DO flux from the atmosphere, to calculate the final DO concentration in the water body. When the BOD concentration is equal to 0, the duration of the impact is complete. The time it takes DO concentrations to rebound to its original background concentration can be considered the system recovery time. The model's fixed, input, and output parameters, and the model output for the 7 and 15-day treatment interval is displayed in Appendix J.

6.5.4. **Results**

The model simulated the DO response at South Stone Lake after mechanical shredding, which covers approximately 643 acres in the Stone Lakes National Wildlife Refuge. The maximum depth of South Stone Lake is 8 feet. The total treated plant surface area was estimated to be 100 acres (Courtright 2004). The 100-acre treatment area was divided into three equal treatment events (33.3 acres) spaced evenly throughout a hypothetical aquatic plant management season. The model simulated the DO response in South Stone Lake over a 7-day treatment event interval, and a 15-day treatment event interval. The results are intended to document how a shorter treatment interval (7-days between events) may be inadequate to protect aquatic habitat from hypoxic or anoxic conditions.

The treatment activities were not exclusive to South Stone Lake since they included portions of outlying sloughs. For simplicity, the model takes into account the surface area of South Stone Lake only. In addition, current aquatic plant management at South Stone Lake involves herbicides, which cause plant material to die over a several day period. This analysis, however, assumed immediate death of hyacinth by mechanical shredding on the first day of treatment. It was assumed that the shredding event was 100% effective in killing the hyacinth.

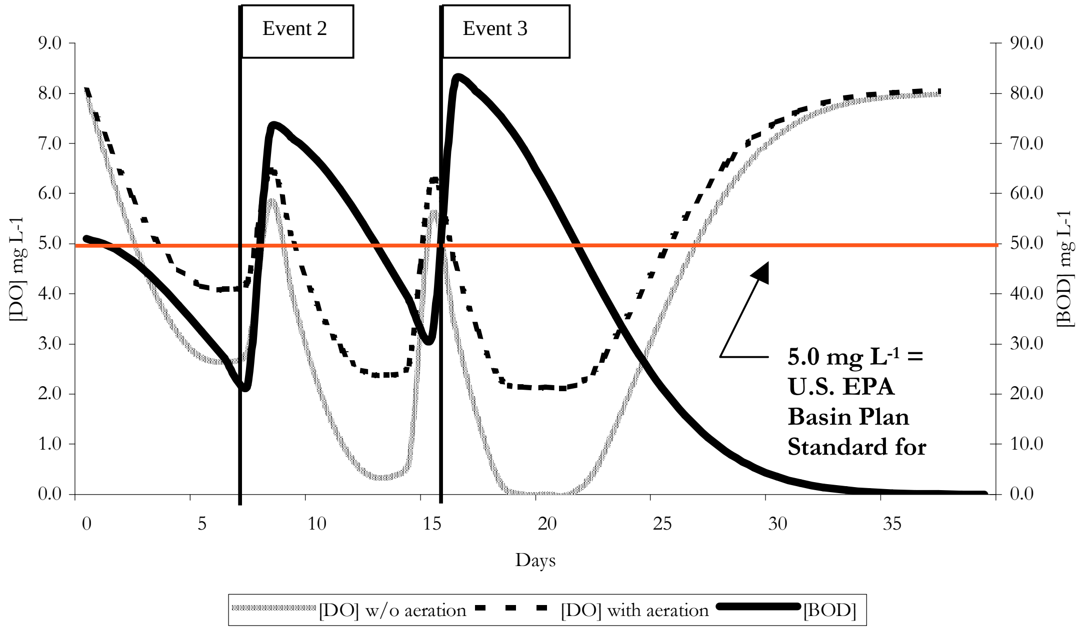


Figure 7. BOD and DO concentration after three mechanical shredding events with a 7-day interval between events.

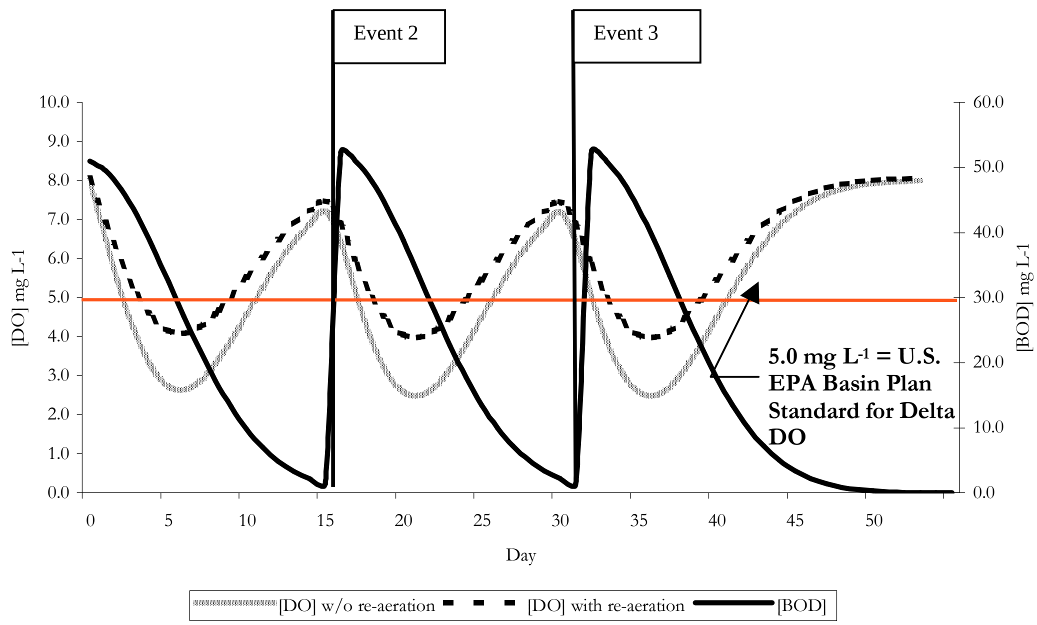


Figure 8. BOD and DO concentration after three mechanical shredding events with a 15-day interval between events.

Most inflows and outflows within the southern portions of the refuge are tidally influenced. In order to utilize the model's inflow and outflow parameters, a hypothetical daily inflow was assumed to originate from Morrison Creek into South Stone Lake. During September, the average discharge from the Creek was approximately 5 cfs (USGS 1999). The outflow was assumed to equal the inflow. The DO concentration was set to 8 and 5 mg/L for the inflow and outflow, respectively. No information is available for inflow and outflow DO concentration; however, given that plant management activities are occurring within South Stone Lake, it is likely that the outflow concentration will average the lake's background DO over the duration of the project. At a similar site within the Delta region, the DOW wetlands experienced diurnal DO fluctuations ranging from 1.0 to 2.0 mg L^{-1} during low tide, and 4.0 to 5.0 mg L^{-1} during high tide (Andrews 2003). The inflow and outflow parameters are better suited for water bodies that have well-documented inflows, outflows, and water quality data. In this example, the inflow and outflow velocities are relatively small, so the impact is negligent.

Results from the 7-day treatment interval at South Stone Lake predicted hypoxia on days 6, 10 to 14, and 17 to 24. Anoxia occurred from days 19 to 21 when re-aeration was not considered. However, the re-aeration flux was calculated to be 2.13 mg L^{-1} during these anoxic conditions. A more conservative description of re-aeration during an anoxic day would consider a thin, surface layer of water replenished by atmospheric oxygen. Therefore, it is likely that the DO in the water column would range from anoxic bottom waters, to surface waters with DO concentrations of 2.13 mg L^{-1}. The duration of biodegradation, the time when BOD=0 mg L^{-1}, was 37 days. The lake did not return to its initial background DO concentration of 8 mg L^{-1} until day 35. The mean dissolved oxygen concentration over the entire 37-day event was 5.11 mg L^{-1}.

Results from the 15-day treatment interval, with re-aeration and immediate mixing throughout the water column, predicted that South Stone Lake would harbor hypoxic conditions on day 6, days 20 to 21, and days 35 to 36. The model predicted that anoxic conditions would not develop during the 15-day treatment interval scenario. The lowest observed DO concentration was 3.98 mg L^{-1} on days 21 and 36. The duration of biodegradation was 53 days. The lake did not return to its initial background DO concentration of 8 mg L^{-1} until day 50. The mean dissolved oxygen concentration over the entire 53-day event was 5.96 mg L^{-1}. A plot of the DO and BOD response for the 7-day and 15-day intervals are displayed in Figures 1 and 2.

6.5.5. **Discussion**

This model allows the user to estimate the total environmental impact associated from fish kill. Given that no data was available for South Stone Lake, this example uses the fish population data from North Stone Lake and assumes the same population and diversity as South Stone Lake. Given the greater tidal influence and its larger size, it is likely that South Stone Lake has a larger fish population and greater diversity than North Stone Lake (Courtright 2004). The South Stone Lake fish population data is estimated from a survey conducted during the North Stone Lake fish rescue in 1972 (Table 14).

Table 14. Number and weight of fish salvaged from North Stone Lake, summer 1992. Information derived from Table 4F-2 in Final Environmental Impact Statement, Stone Lakes NWR (Jones & Stokes Associates, 1992).

Fish Species	Number	Weight (lbs)
Black crappie	34,363	6,233
Largemouth bass	311	1,089
Bluegill	2,122	530
Warmouth	1,823	479
Brown bullhead	2,955	1,142
Black bullhead	2,342	1,450
White catfish	28	68
Sacramento blackfish (carp habitat)	5,037	11,610
Carp	4,457	10,350
Goldfish (carp habitat)	1,100	550

Each fish species in Table 14 is adapted to a particular habitat, which has certain dissolved oxygen limitations. As shown in Table 15, some fish species are able to survive waters with lower dissolved oxygen concentrations. Warm water species can tolerate lower DO concentrations than cold water species. Assuming complete mixing within the water body of concern, this model assumes any time at which the DO concentration drops below the critical value will result in a complete die-off of the listed fish species.

Table 15. Dissolved oxygen requirements for fish species located in North Stone Lake. All Data is Derived from the Habitat Suitability Index Model Series Published by the U.S. Fish and Wildlife Service (USFWS 1981).

Fish Species	Adequate [DO] (mg L^{-1})	Critical [DO] (mg L^{-1})
Black crappie	5.0 (Stroud 1948)	1.4 (Sigler 1963)
Largemouth bass	8.0 (Stewart 1967)	1.0 (Moss 1961)
Bluegill	>5.0 (Petit 1973)	1.5 - 3.0 (Whitmore 1960)
Warmouth	3.6 (Baker 1941)	0.7 - 1.3 (Larimore 1957)
Brown bullhead (Black bullhead ref)	7.0	3.0
Black bullhead	7.0 (Carlson, Siefert et al. 1974)	3.0 (Moore 1942)
White catfish (Channel catfish ref)	5.0 - 7.0 (Andrews 1973)	< 3.0 (Simco 1966)
Sacramento blackfish (carp habitat)	6.0-7.0	0.5
Carp	6.0 - 7.0 (Huet 1970)	0.5 (Yashouv 1956)
Goldfish (carp habitat)	6.0-7.0	0.5

Typically, fish will exhibit some negative affects as DO concentrations begin to decline below adequate levels within its habitat, as listed in Table 15. Although stressed, some fish can tolerate near anoxic conditions since they are able to rise to the surface and gulp air. Modeled results suggest that a large-scale fish kill would occur if 33.3 acres of water hyacinth were treated every 7-days for a total of three treatment events. The fish species that are adapted for surface film respiration, such as the carp, Sacramento blackfish, and Goldfish, may survive the 3-day anoxic event. However, the other species would likely not survive. Referencing the 1990 restocking prices for fish, adjusted for inflation in 2004, Table 16, a total value can be assessed to the fish that would be killed in this scenario.

Table 16. Restocking prices for fish species located in North Stone Lake. Prices obtained from American Fisheries Society Publication (American Fisheries Society 1993). The 1993 prices are adjusted for inflation (U.S. Department of Labor 2004).

Fish Species	1993 Cost ($ lb^{-1})	2003 Cost ($ lb^{-1})
Black crappie	3.68	4.68
Largemouth bass	3.87	4.93
Bluegill	2.28	2.90
Warmouth	2.28	2.90
Brown bullhead	1.1	1.40
Black bullhead	1.1	1.40
White catfish	1.1	1.40
Sacramento blackfish (carp ref)	0.27	0.34
Carp	0.27	0.34
Goldfish (carp ref)	0.27	0.34

The fish that would likely die are: the black crappie, largemouth bass, bluegill, warmouth, Brown and black bullhead, and the white catfish. The total value to re-stock the South Stone Lake fishery with the fish species that would likely die under the 7-day treatment interval is $41,189. This is a conservative estimate since North Stone Lake is much smaller than South Stone Lake, hence the fishery likely would be much larger. Modeled results from treating 33.3 acres of water hyacinth every 15-days for a total of three treatment events, suggest that the South Stone Lake fishery would not be severely compromised. Fish, such as the brown and black bullhead, would likely experience some deleterious effects as mentioned above. However, it is unlikely that a large-scale fish kill would occur.

Mitigation for mechanical shredding is required to avoid massive fish kills. The best alternative is to select a treatment size or treatment duration that reduces the impact from low dissolved oxygen levels. An aquatic plant management program, such as the three, 15-day treatment event used in the example above, will maintain adequate dissolved oxygen levels for all listed fish species within South Stone Lakes.

6.5.6. **Uncertainties**

The variables used in this model have a high degree of uncertainty. More site-specific, climatic information is necessary to gain better knowledge about hyacinth plant density, the percent HROM, and the appropriate decay coefficient. The percent HROM and decay coefficient were taken from a study site in southern Louisiana. A study conducted in California would refine these variables even further. The wet density of hyacinth was taken from a pilot study within the Delta region in California where the hyacinth grew four to five feet above the water surface (Andrews 2003). Given that shredding hyacinth in this condition is quite arduous, it would be more appropriate to propose a management alternative much earlier in the growing season when the hyacinth mats are less dense, effectively changing the outcome of the model.

The North Stone Lake fish population may not be representative of South Stone Lake. In addition, threatened and endangered fish species such as the winter-run Chinook salmon and the Delta smelt have a chance to enter South Stone Lake through the many control and water diversion structures. Furthermore, portions of South Stone Lake contain habitat for the giant garter snake. The economic value of these endangered species must be incorporated. As outlined in the incidental take process for endangered species, the permit requires adequate mitigation during activities that would compromise the listed species. A simple valuation method would include an estimation of the extra man-hours necessary to survey and flag potential habitat areas to limit access. Other valuation techniques have been used for similar threatened and endangered species. Monetary values from these studies could be incorporated into this assessment to further quantify the environmental impact. Nonetheless, it is often difficult to capture the true value of an endangered species, especially when the incidental take of one member could compromise the viability of the remaining population. This infers that the values of an endangered specie likely increase as more are taken out of the existing population.

6.5.7. **Refining model parameters**

One of the most important components of the model is the ability to determine aquatic plant coverage over the study site. Using field survey methods, water body managers can estimate plant coverage. These methods are time-consuming, laborious, and not very exact. For these reasons, natural resource agencies have only mapped a small fraction of aquatic plants. Typically, treatments are based on aesthetics or a seasonal schedule. It is problematic estimating large mats comprised of both exotic and native plants within the same study area, and the model is not flexible enough to consider varying plant densities and plant decay rates. The future for estimating emergent and submersed aquatic vegetation will utilize high-resolution, spectral imagery.

In September 1999, Space Imaging launched the IKONOS-2 satellite. Each data scene by IKONOS covers approximately 11x11 km areas. "Each application attempts to take advantage of the increased spatial resolution and the multi-spectral properties of the data to digitally classify aspects of the environment that have not been possible to this degree of detail with satellite imagery in the past" (Sawaya 2003). IKONOS data requires two procedures for classifying aquatic plants. First, the image features are separated into discrete units, and secondly, the pixels in each unit need to be identified by field reference.

Qualitative field reference is important to identify plant types and locations based on the different spectral characteristics. The extra time lost from these field surveys is gained in accurately quantifying plant treatment acreage. This is accomplished using a global positioning system (GPS). The ability to process the GPS information on a computer in the field is helpful since the data can be plotted directly on top of the satellite image. The field GPS information is used to construct polygons that bound plant regions, and can differentiate aquatic plants from on-shore vegetation. "Pixels with unique spectral qualities can then be targeted, and borders between terrestrial features and wetland features are easily differentiated" (Sawaya 2003). Once collected, the field and satellite data is classified using several steps. Differences in spectral characteristics and field descriptions are used to progressively delineate plant types among different regions. Based on spectral differences, the terrestrial features are excluded from the wetland features. The stand-alone wetland feature is used to classify emergent and submersed vegetations, and finally, the spectral properties of the emergent vegetation class are used to identify the plant species. Plotting spectral responses of each plant signature will show a correlation between higher spectral response and greater plant density.

This emerging technology is complex in its application. Some disadvantages include:

- The cost of this information is better suited for cities and public agencies that can use this imagery for various applications within its different departments, thus sharing the expense;
- Similarities in spectral responses make classifying arduous;
- Shadows in the imagery complicate classification;
- Matching field reference data with the image at the pixel level is not always clear.

Advantages of high-resolution imagery include:

- Can also be used for land classification, lake clarity assessment
- IKONOS shares similar spectral relationships with Landsat TM imagery, which already exists and can be used to fill in image voids
- GIS-ready, time-efficient, repeatable, and reliable

High-resolution imagery has shown the ability to accurately estimate nuisance aquatic plant coverage in valuable water bodies. This tool can be used as a management device to accurately plan the cost and implementation of management activities, and to quantify the amount of plant material that will impact a water body from mechanical shredding or herbicide application.

6.6. **Conclusion: Stone Lakes NWR**

Forecasting the effects that aquatic plant management activities have on dissolved oxygen, and ultimately fish habitat in water bodies, can provide valuable information about the magnitude and duration of potential impacts. Aquatic plant management, such as mechanical shredding of water hyacinth, temporarily increases biochemical oxygen demand in a water body as a result of decaying plant material retained *in-situ* after treatment. The biodegradation of plant material depletes background levels of dissolved oxygen within the water body. Large-scale treatment events can prolong the consumption of dissolved oxygen, thus affecting the habitat of fish. Dissolved oxygen levels, which fall below minimum concentrations that are essential for fish survival, would cause an environmental impact as a result of a fish kill. The ability to accurately predict whether hypoxia and anoxia would occur is crucial for planning the total size, number of treatments, and intervals between treatments, in order to minimize the total environmental cost from aquatic plant management activities. Plant management that requires treatment interval durations of 15-days, as opposed to 7-days, may incur higher operating and labor costs, but may result in smaller environmental costs associated with low dissolved oxygen concentrations causing massive fish kills.

7. Project Conclusions

This report has taken a thorough, comprehensive approach to determine the cost-effectiveness of chemical and non-chemical aquatic plant management strategies. The analysis is unique because it considers environmental costs in addition to control costs. Few environmental impact cost analyses have been performed for aquatic plant management practices. This analysis can serve as an aquatic plant management strategy template. Using the concepts and valuation exercises described and carried out in this report, managers can make decisions that not only incorporate their management costs, but also the environmental externalities associated with management.

The findings of the control cost analysis indicate chemical management options are more expensive than non-chemical alternatives. The large cost of chemical management results from a high upfront cost to acquire an NPDES permit. The cost of chemical treatment decreases with increasing acreage, while non-chemical control costs stay constantly low. In some cases such as Big Bear Lake, a combination of chemical and non-chemical techniques may be the most cost-effective. The control cost analysis does not consider costs from environmental damages caused by the plant management activity.

The environmental damage costs incurred from aquatic plant management differ according to site-specific characteristics, such as type of plant, site size, and environmental conditions. One way to value an environmental damage is to assess a replacement cost for wildlife that dies as a result of aquatic plant management. The case study at Big Break considered the incidental harvesting of fish during a mechanical management event. Another example considered a mechanical shredding event of hyacinth at Stone Lakes that caused a temporary reduction in dissolved oxygen contributing to a fish kill.

Another way to value the environmental damage cost from plant management is to assess the total cost to mitigate for the environmental damage. This is classified as a compliance or regulatory cost. Assigning a dollar amount to compliance measures evaluate the true cost of a management alternative. The mitigation required for chemical treatment can be very expensive. In general, the cost is greater for herbicides like chelated copper, which persist and bioaccumulate in the environment. More persistent chemicals require a larger number of samples and at a greater frequency. These chemicals, such as Komeen®, require both biota and sediment samples during application.

When real-time data is not available, the potential environmental impact for fish and water quality can be extracted using a model. A model was developed to forecast the changes in dissolved oxygen when plant material is shredded and killed in-place. Decaying plant material exerts a biochemical oxygen demand on a water body. As BOD is consumed, oxygen is depleted. Water body managers can use the model as a tool to plan the size of non-chemical treatment events, and the time interval between events, to develop a management plan that minimizes fish kills from depleted dissolved oxygen levels.

The science of aquatic plant management is complex. There are many benefits to keeping lakes and reservoirs accessible for recreation, and irrigations canals free flowing for agriculture. There are also potential benefits to ecosystem health by treating aquatic plant infestations, especially the exotic species mentioned in this report. To realize these benefits, however, practitioners must consider control and environmental damage costs. This report has compared the control and environmental damage costs of several management techniques, and has made recommendations based on the most cost-effective alternative. This type of analysis will hopefully drive the science of aquatic plant management and change the way decisions are made by accounting for not only control costs, but also the internalized cost from environmental degradation.

8. Recommendations for Future Research

Aquatic plant management would benefit from research in the following areas: (1) expansion of our assessment to include a more comprehensive quantification of environmental impact costs, (2) estimation of cost savings from the formation of herbicide management groups, (3) addressing accuracy issues with the BOD model, and (4) expanding research to quantify costs of different management strategies in different aquatic settings.

In order to account for the total cost of any aquatic plant management action, the environmental impact cost should also be considered. At present, there is a lack of information in the field about the costs of environmental degradation. This report will add to the current knowledge base, but future research should focus on compiling a more complete list of environmental impact costs. Primary research has been conducted to value the cost of endangered species and its habitat, but there are knowledge gaps about how the incremental degradation of environmental amenities should be valued. Information is also lacking about how slight changes in environmental amenities affect the entire ecosystem, or how an impact to a predator or prey population will spread through out the food web in that ecosystem. Without accurate price indicators, proper management decisions based on total strategy cost will be assumptions at best.

An expansion of the BOD model would be useful if it included: rates of mixing within the water column, a consideration of the spatial transport and distribution of BOD and DO in the system, and the inclusion of more plant species with different biodegradation capabilities. Refining these parameters would help to more accurately predict the environmental impact from management strategies that retain dying plant material *in-situ*. Pre- and post water quality treatment data could be used to quantify the total amount of biologic stress that occurs when aquatic plants are killed. An extension of this analysis could focus on the potential benefits from aquatic plant management, for not only recreational users but to biologic communities and ecosystem health.

In addition, future research should consider expanding the scope of this report and applying similar environmental economic evaluation techniques to other types of pests, management strategies, and water bodies. Additional information should be collected on how the public values different environmental amenity levels pertaining directly to aquatic plant management.

9. References

American Fisheries Society (1993). Sourcebook for Investigation and Valuation of Fish Kills. The Society, Bethesda, Maryland.

Anderson, L.W.J., C. Pirosko, D. Homberge, D. Gee and R. Duvall (1998). Dissipation and movement of Sonar, and Komeen, following typical applications for control of *Egeria densa* in the Sacramento-San Joaquin delta; and production and viability of *E. densa* fragments following mechanical harvesting (1997/1998), USDA-Agricultural Research Service, Aquatic Plant Control Research Laboratory, Invasive Plant Research Unit, UC Davis: 16.

Andrews, J. (2003). Contaminant Accumulation in Water Hyacinth, Lecture at San Francisco Estuary Institute, July 2003.

Andrews, J., T. Murai, G. Gibbons (1973). "The Influence of Dissolved Oxygen on the Growth of Channel Catfish." Transactions of the American Fisheries Society 102(4): 835-838.

Andrews, S. (2003b). Coordinator, Environmental Sciences Teaching Program, UCB. Personal communication.

Ankcorn, P. (2003). "Clarifying Turbidity- The Potential and Limitations of Turbidity as a Surrogate for Water-Quality Monitoring." Georgia Water Resources Conference, April 23 - 24, 2003. University of Georgia, Athens, Georgia.

Arnold, W. (1979). "Fluridone - A New Aquatic Herbicide." Journal of Aquatic Plant Management 17: 30-33.

Artz, T. (2003). Memorandum: "Aquatic Plant Control of Water Hyacinth and *Egeria densa*." California Department of Boating and Waterways. Accessed May 5, 2004. <http://www.dbw.ca.gov/aquatic.htm>

Baker, C. L. (1941). "The Effects on Fish of Gulping Atmospheric Air from Waters of Various Carbon Dioxide Tensions." Journal of the Tennessee Academy of Science 17: 39-50.

Barrens, R., P. Ganderton, C. Sliva (1996). "Valuing the Protection of Minimum Instream Flows in New Mexico." Journal of Agricultural and Resource Economics 21(2): 249-309.

Batcher, M. (2003). *Eichhornia crassipes* (Martius) Solms water hyacinth: Element Stewardship Abstract. In: Wildland Invasive Species Program, Weeds on the Web. The Nature Conservancy. Accessed May 5, 2004. <http://www.tnc.org/>

Battle, J., T. Mihuc (2000). "Decomposition Dynamics of Aquatic Macrophytes in the Lower Atchafalaya, a Large Floodplain River." Hydrobiologia 418: 123-136.

Big Bear Municipal Water District. (2003). Accessed May 5, 2004. <http://www.bbmwd.org/>

Brookshire, D., M. McKee, G. Watts (1993). "Proposed Determination of Critical Habitat for the Colorado River Endangered Fishes: Razorback Sucker, Colorado Squawfish, Humpback Chub, Bonytail Chub." Federal Register 58 (18):6578-6597.

Buhl, K. J., S.J. Hamilton (1990). "Comparative Toxicity of Inorganic Contaminants Released by Placer Mining to Early Life Stages of Salmonids." Ecotoxicology and Environmental Safety 20: 325-342.

California Department of Boating and Waterways (2001). EIR for the *Egeria densa* Control Program, Aquatic Weed Program, California Department of Boating and Waterways, 2000 Evergreen Street, Suite 100 Sacramento, California 95815-3896.

California Department of Boating and Waterways (2002). Memorandum: "Cal Boating Resumes Water Hyacinth Control Program in Delta." #G-12-02. Accessed May 5, 2004. <http://dbw.ca.gov/PDF/G-12-02.pdf>

California Department of Water Resources (1996). "Water Quality Conditions in the Sacramento-San Joaquin Delta 1970-1993." California Department of Water Resources, Sacramento, CA.

California State Personnel Board (2004). Job Stats & Pay Class Information, California State Personnel Board. Sacramento, California.

Carlson, A. R., R. E. Siefert, L.J. Herman. (1974). "Effects of Lowered Dissolved Oxygen Concentrations on Channel Catfish (*Ictalurus punctatus*) Embryos and Larvae." Transactions of the American Fisheries Society 103(3): 623-626.

Carpenter, L. A., D.L. Eaton (1983). "The Disposition of 2,4-Dichlorophenoxyacetic Acid in Rainbow Trout." Archives of Environmental Contamination and Toxicology 12: 169-173.

Center, T. D., D.L. Sutton, V.A. Ramey, K.A. Langeland (1997). "Other Methods of Plant Management." Aquatic Plant Control Applicator Training Manual, University of Florida, Gainesville, Florida.

Chilton II, E. W. (2002). Rio Grande Exotic Plant Report and Action Plan, Texas Parks and Wildlife Department on Behalf of the Region M Planning Committee Aquatic Weed Task Force, September 2002.

Cook, C. D. K., K. Urmi-Kong (1984). "A Revision of the Genus *Egeria* (Hydrocahritaceae)." Aquatic Botany 19: 73-96.

Courtright, C. (2004). Refuge Operations Specialist. Personal communication.

Courtright, C. (2003). Refuge Operations Specialist. Personal communication.

Crites, R., G. Tchobanoglous (1998). Small and Decentralized Wastewater Management Systems, WCB McGraw-Hill, Boston, Massachusetts.

CSU Hayward (2001). "Scientists get 'Big Break' on the Delta Research." The California State University Newsline, CSU Hayward.

EXTOXNET (1993). Extension Toxicology Network Toxicology Information Briefs, A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University.

EXTOXNET (1996a). Pesticide Information Profiles 2,4-D, A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University.

EXTOXNET (1996b). Pesticide Information Profiles Diquat Dibromide, A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University.

EXTOXNET (1996c). Pesticide Information Profiles Glyphosate, A Pesticide Information Project of Cooperative Extension Offices of Cornell University, Oregon State University, the University of Idaho, and the University of California at Davis and the Institute for Environmental Toxicology, Michigan State University.

Fausold, C. J., R. J. Lillieholm. (1996). "The Economic Value of Open Space: A Review and Synthesis." Lincoln Institute of Land Policy Research Paper. Environmental Management, 23(3): 307-320.

Finlayson, B. J., K.M. Verrue (1982). "Toxicity of Copper, Zinc, and Cadmium Mixtures to Juvenile Chinook Salmon." Transactions of the American Fisheries Society 3: 645-650.

Ghassemi, M., L. Fargo, P. Painter, S. Quinlivan, R. Scofield, A. Takata (1981). Environmental Fates and Impacts of Major Forest Use Pesticides. U.S. EPA Office of Pesticides and Toxic Substances, Washington D.C.: A-101-148.

Glover, S. (2003). Re: Big Break Birds, Contra Costa Breeding Birds Atlas. Personal communication.

Goldborough, L. G., A.E. Beck (1989). "Rapid Dissipation of Glyphosate in Small Forest Ponds." Archives of Environmental Contamination and Toxicology 18: 537.

Gopal, B. (1987). Aquatic Plant Studies 1. Elsevier, New York.

Greenfield, B. K., N. David, J. Hunt, M. Wittmann, G. Siemering (2003). "Review of Alternative Aquatic Plant Control Methods for California Waters." San Francisco Estuary Institute. Richmond, CA.

Griffin Corporation (2003). Komeen Label, Griffin Corporation. Accessed May 5, 2004. <http://www.cygnetwest.com/komeenlabel.pdf>

Hamelink, J. L., D.R Buckler, F.L. Mayer, D.U. Palawski, H.O. Sanders (1986). "Toxicity of Fluridone to Aquatic Invertebrates and Fish." Environmental Toxicology and Chemistry 5: 87-94.

Hardt, D. (2003). Manager, Kern National Wildlife Refuge. Personal Communication 8/2003.

Herbold, B. (1987). "Patterns of Co-occurrence and Resource use in a Non-coevolved Assemblage of Fishes." Thesis (Ph.D.), University of California Davis. Davis, CA.

Howard, P. H. (1991). Handbook of Environmental Fate and Exposure Data and Organic Chemicals: Pesticides. Lewis Publishers, Chelsea, MI.

Howard-Williams, C., W. J. Junk. (1976). "The Decomposition of Aquatic Macrophytes in the Floating Meadows of a Central Amazonian Varzea Lake." Biogeographica 7: 115-123.

Huang, C., D. Guy (1998). "Environmental Monitoring for Chemical Control of *Egeria densa* in the Sacramento-San Joaquin Delta." California Department of Fish and Game, Aquatic Toxicity Laboratory. Elk Grove, California.

Huet, M. (1970). Textbook of Fish Culture: Breeding and Cultivation of Fish, Fishing News, London, U.K.

James, W. F., J.W. Barko, H.L. Eakin. (2002). "Water Quality Impact of Mechanical Shredding of Aquatic Macrophytes." Journal of Aquatic Plant Management 40: 36-42.

Janik, J. (1996). Memorandum: Clifton Court Plant Control Results, California Department of Water Resources, Environmental Assessment Branch. Sacramento, California.

Julien, M.H., M.W. Griffiths (1998). Biological Control of Plants: A World Catalogue of Agents and Their Target Plants. CABI Publications, Oxon, U.K..

Kidd, H., D.R. James (1991). The Agrochemicals Handbook. Royal Society of Chemistry Information Services. Cambridge, U.K.

Killgore, K.J., J.J. Hoover (2001). "Effects of Hypoxia on Fish Assemblages in a Vegetated Waterbody." Aquatic Management 39: 40-44

King, D., M. Mazzotta, K. Markowitz (2003). Ecosystem Valuation, U.S. Department of Agriculture, Natural Resources Conservation Service, and National Oceanographic and Atmospheric Administration. Accessed May 5, 2004. <http://www.ecosystemvaluation.org/index.html>

Larimore, R. W. (1957). "Ecological Life History of the Warmouth (Centrarchidae)." Illinois Natural History Survey Bulletin 1(27): 1-83.

Larsen, R. E., (1999). Fact Sheet No. 29: "Fishery Habitat." University of California Cooperative Extension, San Bernardino County, CA. Accessed May 5, 2004. <http://danr.ucop.edu/uccelr/h29.htm>

Leslie, A. J. (1992). "Copper Herbicide Use-patterns in Florida Waters." Bioavailability and Toxicity of Copper Workshop, Florida Department of Natural Resources, Tallahassee, FL.

Loomis, J. B., S.D. White (1996). "Economic Benefits of Rare and Endangered Species: Summary and Meta-analysis." Ecological Economics 18: 197-206.

Lynch, J. J., J.E. King, T.K. Chamberlin, A.L. Smith (1947). "Effects of Aquatic Plant Infestations on the Fish and Wildlife of the Gulf States." U.S. Department of the Interior Fish and Wildlife Service, Washington D.C., Report 39.

Madsen, J. D. (1997). "Methods for Management of Nonindigenous Aquatic Plants." Assessment and Management of Plant Invasions. Editors: Thieret, J. W., Luken, J. O. Springer, New York: 145-170.

Malik, J., G. Barry, G. Kishore (1989). "Minireview: The Herbicide Glyphosate." BioFactors 2(1): 17-25.

Mann, R. (2003). Chapter 3: Methodology for aquatic plant management economics, Aquatic pesticide monitoring program. San Francisco Estuary Institute, Richmond California. Accessed May 5, 2004. <http://www.sfei.org/apmp/reports/PestAlternatives_econ.pdf>

Mapquest (2004). Driving Directions "Sacramento to Oakley", Mapquest. 2004.

Martin, G. (2003). Big Bear Municipal Water District Manager. Personal communication.

McGowan, M. F. (1998). "Fishes Associated with Submersed Aquatic Vegetation, *Egeria densa*, in the Sacramento-San Joaquin Delta in 1998 as Sampled by Pop Nets." Romberg Tiburon Center, San Francisco State University, 10 pgs.

McLaren/Hart Environmental Engineering Corporation (1995). "Use of the Registered Aquatic Herbicide Fluridone (Sonar) in the State of New York; Generic Environmental Impact Statement." McLaren/Hart Environmental Engineering Corporation. Warren, N.J.

McNabb, T., D. Henderson (2001). Vegetation Assessment and Management Plan for Big Bear Lake. Remetrix, Inc. San Bernadino County, California.

Miller, D. C., S. L. Poucher, L. Coiro (2002). "Determination of Lethal Dissolved Oxygen Levels for Selected Marine and Estuarine Fishes, Crustaceans, and a Bivalve." Marine Biology 140: 287-296.

Mitchell, D. S. (1976). "The Growth and Management of *Eichornia crassipes* and *Salvinia* spp. in Their Native Environment and in Alien Situations." Aquatic Plants in Southeast Asia. Editors J. Rzoska., C. K., Vashney. Dr. W. Junk, 396 pgs.

Monsanto Company (1985). Toxicology of Glyphosate and Roundup Herbicide. Monsanto Company, St. Louis, Missouri.

Moore, W. G. (1942). "Field Studies on the Oxygen Requirements of Certain Freshwater Fishes." Ecology 23: 319-329.

Moss, D. D., D.C. Scott (1961). "Dissolved Oxygen Requirements of Three Species of Fish." Transactions of the American Fisheries Society 90: 377-393.

Moyle, P. B. (1976). Inland Fishes of California, University of California Press. Berkeley, California. p. 405.

Moyle, P. B. (2003). Big Break Fish. Personal communication.

Mullison, W. R. (1987). Environmental Fate of Phenoxy Herbicides, Agricultural fate of pesticides in the environment. Series editors: Biggar, J. W., Sieber, J. N. University of California, Division of Agriculture and Natural Resources, Oakland, CA. Pub. 3320, 157 pgs.

National Marine Fisheries Service. (2003). Biological Opinion, National Marine Fisheries Service, Southwest Region. Report SWR-01-SA-6117:JSS, 69 pgs.

Northeast-Midwest Institute and National Oceanic and Atmospheric Administration (2001). "Revealing the Economic Value of Protecting the Great Lakes." ISBN: 1-882061-86-1, pg. 90

Obrebski, S., T. Irwin, J. Pearson (1998). Effects of Control Methods on the *Egeria densa* Community. San Francisco, Romberg Tiburon Center, 36 pgs.

Owen, J. (2004). Water Hyacinth Control Program. Personal Communication.

Pesticide Management and Education Program at Cornell University (1986). Fluridone (Sonar, Brake, Pride) herbicide profile, Pesticide Management and Education Program at Cornell University, Chemical fact sheet 81. Accessed May 5, 2004. <http://pmep.cce.cornell.edu/profiles/herb-growthreg/fatty-alcohol-monuron/fluridone/herb-prof-fluridone.html>

Petit, G. D. (1973). "Effects of Dissolved Oxygen on Survival and Behavior of Selected Fishes of Western Lake Erie." Ohio Biological Survey Bulletin: 1-76.

Plawman, D., B. Thom, (2000). "Report of Habitat Monitoring Conducted on The East Fork of the South Fork Task River Between 1998 and 2000." Oregon Department of Fish and Wildlife, Jobs in the Woods Program. Accessed May 5, 2004. <http://pacific.fws.gov/jobs/orojitw/proj-info/tillamook/summary/document/trask-river.pdf>

Reiser, D. W., T.C. Bjornn (1979). "Habitat Requirements of Anadromous Salmonids." In: Meehan, W.R., Technical Editor. Influence of Forest and Rangeland Management on Anadromous Fish Habitat in the Western United States and Canada, USDA Forest Service. Report GTR PNW-96: 54 pp.

Rodgers, J., E. Deafer, A. Dunn, T. Surges, B. Suede (1992). The Bioavailability and Toxicity of Copper in Aquatic Systems - Some Theory, Evidence and Research Needs. Bioavailability and Toxicity of Copper Workshop 1992, Gainsville, FL.

San Francisco Bay Area Wetlands Ecosystem Goals Project (1997). "Wetland Goals: Draft Species Narratives for Fish and Macroinvertebrates." San Francisco Estuary Institute. Accessed May 5, 2004. <http://www.sfei.org/sfbaygoals/docs/goals1997/goalsproject/about.html>

San Francisco Estuary Institute (1994). 1993 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute. Richmond, CA.

San Francisco Estuary Institute (1997). 1996 Annual Report: San Francisco Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute. Richmond, CA.

San Francisco Estuary Institute (1999). 1997 Annual Report: San Francisco Estuary Regional Monitoring Program for Trace Substances. San Francisco Estuary Institute. Richmond, CA.

Sawaya, K., L. Olmanson, N. Heinert, P. Brezonik, M. Bauer (2003). "Extending Satellite Remote Sensing to Local Scales: Land and Water Resource Monitoring using High-resolution Imagery." Remote Sensing of Environment 88: 144-156.

Schmitz, D. C., J.D. Schardt, S.J. Leslie, F.A. Dray Jr., J.A. Osborne, B.V. Nelson (1993). "The Ecological Impact and Management History of Three Invasive Alien Aquatic Plant Species in Florida." Biological Pollution: the control and impact of invasive exotic species. Edited by B. N. McKnight. Indiana Academy of Science, Indianapolis, Indiana.

Schuette, J. (1998). Environmental Fate of Glyphosate, Environmental Monitoring and Plant Management. California Department of Pesticide Regulation, Sacramento, California. Accessed May 5, 2004. <http://www.cdpr.ca.gov/docs/empm/pubs/fatememo/glyphos.pdf>

SePRO Corporation (1994). Specimen Label, Sonar AS Form No. A-72-MC-01. SePRO Corporation. Carmel, Indiana.

Siemering, G. (2004) "Chemical Monitoring Costs." San Francisco Estuary Institute, Personal communication.

Sigler, W. J., R.R. Miller (1963). "Fishes of Utah." Utah Dept. of Fish Game, Salt Lake City: 203 pp.

Simco, D. A., F. B. Cross (1966). "Factors Affecting Growth and Production of Channel Catfish, *Ictalurus punctatus*." University of Kansas Museum of Natural History Publication 17(4): 191-256.

Slack, G. (2003). Between River and Bay: The Delta's Big Break. Bay Nature. Accessed May 5, 2004. <http://www.baynature.com/2003janmarch/delta_2003janmarch.html>

Small, M. (2002). Big Break and Marsh Creek Water Quality Habitat Restoration Program, California Bay-Delta Authority. Proposal #29-DA. Accessed May 5, 2004. <http://calwater.ca.gov/Programs/EcosystemRestoration/2002_Proposals/BigBreakProposal_29DA.pdf>

Stapleton, R. M. (1997). Protecting the Source: How Land Conservation Safeguards Drinking Water, Trust for Public Land. Accessed May 5, 2004. <http://www.tpl.org/tier3_cd.cfm?content_item_id=1337&folder_id=195>

Stewart, N. E., D.L. Shumway, P. Doudoroff (1967). "Influence of Oxygen Concentration on the Growth of Juvenile Largemouth Bass." Journal of Fisheries Research Board of Canada 24: 475-494.

Stone Lakes National Wildlife Refuge (2003). Refuge handout, Bird List, 4 pp.

Stroud, R. H. J. (1948). "Growth of the basses and black crappie in Norris Reservoir, Tennessee." Journal of the Tennessee Academy of Science 23: 31-99.

Syngenta. (2002). "Reward Landscape and Aquatic Herbicide." Syngenta Group Company Product Label. Wilmington, Delaware.

Tchobanoglous, G., E.D. Schroeder (1985). Water Quality, Addison-Wesley Publishing Company, Inc., Redding, MA.

Texas A&M University (2003). "Control of Plants in Texas." Department of Entomology, Texas A&M University. Accessed May 5, 2004. <http://bc4plants.tamu.edu/faq.html>

Toft, J. (2000). "Community Effects of the Non-Indigenous Aquatic Plant Water Hyacinth (*Eichornia crassipes*) in the Sacramento/San Joaquin Delta." University of Washington. Seattle, Washington.

Townsend, S. A., K.T. Boland, T.J. Wrigley (1992). "Factors Contributing to a Fish Kill in the Australian Wet/dry Tropics." Water Resources 26(8): 1039-1044.

Trumbo, J. (1997). "Environmental Monitoring of Hydrilla Eradication Activities in Clear Lake 1996." California Department of Fish and Game, Office of Spill Prevention and Response, Sacramento, CA.

University of Florida (2003a). Herbicide Handbook of the Plant Science Society of America, Florida Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Gainesville, Florida.

University of Florida (2003b). "Plant Management in Florida Waters." University of Florida. Gainesville, Florida. Accessed May 5, 2004. <http://aquat1.ifas.ufl.edu/guide/sup3herb.html#copherb>

U.S. Army Corps of Engineers (2003). Mechanical Control of Exotic Aquatic Plants, U.S. Army Corps of Engineers Jacksonville District, Jacksonville, FL. Accessed May 5, 2004. <http://www.saj.usace.army.mil/conops/apc/plant_mech.html>

U.S. Department of Agriculture (2002). "Proposed Winter Season Non-Chemical Control Methods." Agricultural Research Science and California Department of Boating and Waterways Sacramento, CA.

U.S. Environmental Protection Agency (1980). "Ambient Water Quality Criteria for Copper." p. 162. Washington D.C., EPA Number: 440580036.

U.S. Environmental Protection Agency (1986). "Guidance for Reregistration of Pesticide Products Containing as the Active Ingredient Diquat Dibromide." Office of Pesticide Programs, Washington D.C.. Report# 10-92.

U.S. Environmental Protection Agency (1988a). Health Advisory: Glyphosate. Pp 1-12., Office of Drinking Water EPA, Washington D.C. Number: 820K88005.

U.S. Environmental Protection Agency (1988). Health Advisory Draft Report: Chloramben. Office of Drinking Water, Washington D.C. EPA Number: 820K88101

U.S. Environmental Protection Agency (1992). Final Drinking Water Criteria Document for Glyphosate. Washington D.C., U.S. NTIS # PB92-173392.

U.S. Fish and Wildlife Service (2001). Mechanical Shredding Research Pilot of Water Hyacinth on Stone Lake NWR. Sacramento, CA.

U.S. Fish and Wildlife Service (2002). Stone Lakes National Wildlife Refuge, Planning Update #1. Elk Grove, CA.

U.S. Forest Service (1984). Pesticide Background Statements Vol. I: Herbicides. Washington D.C.

U.S. National Library of Medicine (1995). Hazardous Substances Databank. Bethesda, MD.

USGS (1999). Water Resources of California, California Hydrologic Data Report. Accessed May 5, 2004. <http://ca.water.usgs.gov/archive/waterdata/99/11336580.html>

Walters, J. (2004). Environmental Fate of 2,4-Dichlorophenoxyacetic Acid, Environmental Monitoring and Plant Management, California Department of Pesticide Regulation, Sacramento, CA.

Wang, C.S.J., (1986). "Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A guide to the early life histories." The Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Berkley, California.

Washington State Department of Ecology (2003a). "General Information about Water Hyacinth (*Eichornia crassipes*)." Water Quality Home. Accessed May 5, 2004. <http://www.ecy.wa.gov/programs/wq/plants/plants/hyacinth.html>

Washington State Department of Ecology (2003b). "Technical Information about *Egeria densa* (Brazilian Elodea)." Water Quality Home. Accessed May 5, 2004. <http://www.ecy.wa.gov/programs/wq/plants/plants/aqua002.html>

Washington State Department of Ecology (2003c). Technical Information about *Eichornia crassipes* (Water Hyacinth), Water Quality Home. Accessed May 5, 2004. <http://www.ecy.wa.gov/programs/wq/plants/plants/aqua010.html>

Washington State Department of Health (2000). "Fluridone (Sonar) Fact Sheet." Accessed May 5, 2004. <http://www.doh.wa.gov/ehp/ts/Fluridone.doc>

Water Pollution Control Federation (1989). Natural Systems for Wastewater Treatment, Manual of Practice. Alexandria, VA.

Wauchope, R. D., T.M. Buttler, A.G. Hornsby, P.M.W. Augustijin Beckers, J.P. Burt (1992). SCS/ARS/CES Pesticide Properties Database for Environmental Decision Making: 123:1-157. USDA Agricultural Research Service, Tifton, GA.

West, S. D., E.D. Day, R.O. Burgen (1979). "Dissipation of the Experimental Aquatic Herbicide Fluridone from Lakes and Ponds." Journal of Agriculture Food Chemistry 27: 1067-1072.

West, S. D., R.O. Burger, G.M. Poole, D.H. Mowrey (1983). "Bioconcentration and Field Dissipation of the Aquatic Herbicide Fluridone and its Degradation Products in Aquatic Environments." Journal of Agricultural Food Chemistry 31: 579-585.

Western Aquatic Plant Management Society (2003). "Description of Methods – Handpulling." Accessed May 5, 2004. <http://www.wapms.org/management/manual.html>

Whitmore, C. M., C. E. Warren, P. Doudoroff (1960). "Avoidance Reactions of Salmonids and Centrarchid Fishes to Low Oxygen Concentrations." Transactions of the American Fisheries Society 89: 17-26.

Wilson, D. C., C.E. Bond (1969). "The Effects of the Herbicide Diquat and Dichlobenil (Casoron) on Pond Invertebrates, Part I: Aquatic Toxicity." Transactions of the American Fisheries Society 98: 438-443.

Wu, J. J., S.H. Cho (2003). "Estimating Households' Preferences for Environmental Amenities Using Equilibrium Models of Local Jurisdictions." Scottish Journal of Political Economy 50(2): 189.

Yashouv, A. (1956). "Problems of Carp Nutrition." Bamidgeh 8(5): 79-87.

Zeneca Ag. Products (1999). Material Safety Data Sheet: Reward Landscape and Aquatic Herbicide. Wilmington, DE.

Zeneca Professional Products (1998). Ecofacts: Reward Landscape and Aquatic Herbicide, Zeneca Professional Products.

10. Appendices

A. *Survey Questionnaire*

APMP Survey Questionnaire: Cost Analysis

Date:
Applicator Entity:
Contact Person:
Phone Number:

In conjunction with Geoff Siemering and Ben Greenfield at the San Francisco Estuary Institute, I am a UCSB graduate student conducting a research project to evaluate the cost effectiveness of various aquatic plant management control strategies as a part of a master's thesis project. We will compile a detailed analysis of control strategies across a range of water bodies and aquatic pests.

Since there have been few comprehensive studies, this survey is intended to capture a better understanding of how costs vary across different control strategies. It will serve as a framework to compile a guide for all water body managers so that they may use it as a management tool when deciding which pesticide or mechanical control method results in the greatest cost savings. As a result of your participation in this survey, we could present you a summary of our findings by March 2004.

We are calling based on the recommendation of _________________________ or from the listing of NPDES permit applicants. This call is a follow up to the letter we sent you on _____________. I was wondering if it would be possible to obtain information from you on the different costs involved in conducting distinct aquatic plant control methods.

How much time do you have for the survey?

Location Specific Details

1. Water body characterization – depth, size, and use classification:

2. What are your targeted pests, excluding algae? What are your normal plant management seasons? (Start and end month)

3. What are your control methods? Chemical, non-chemical, both? Do methods vary from year to year? If so, what does the variability depend on?

If Chemical Proceed as Follows

1. What is the size of the area where you will be applying herbicides this season?

2. Which herbicides will you apply?

3. What is the estimated amount? How often? (Find a rate: specifically area treated/gallon or hour, etc.) Are these herbicides different from last season?

4. What equipment and materials are used for the application? Is it owned or rented? If rented, how much are rental costs?

5. Do you hire laborers to apply the herbicides? How much does this cost? How many hours do they work? How frequently?

6. For water bodies designated for recreational use, is the water body closed after application or does it require a recovery period before recreation can resume?

7. Is water quality sampling included in your chemical control method? If so, what type of sampling? What are the costs of this sampling? How often do they occur throughout the season?

8. What type of surfactants do you use, if any? (Not Applicable for Fluridone, Acrolein, or Copper) What is the cost of the surfactant? How often? On what sized area?

For Non-chemical Control proceed as follows

1. Which method do you employ?

2. **For Grass Carp/Biological Users:** How much did your permit cost? How much does each fish cost? Set up costs? (Filters, barriers to escape) Maintenance costs?

3. What is the size of the area that you apply this method to?

4. **For mechanical/manual harvesting:** Are there any purchase or rental costs that are associated with related tools/machines that apply? Are there any typical maintenance costs associated with these tools?

5. Do you hire anybody to carry out this task? Are there any set up costs? Base costs? Overhead? How many labor hours does it require?

6. How long is a typical treatment period? How frequently are the treatments applied?

7. Are there other major operational or material costs associated with your method (gas, electricity, etc.)?

8. What is your method and cost of plant disposal? (Hauling, labor, drying, incineration…)

For Algae control proceed

1. Are algae a management concern in your water body? Do you monitor for algae problems? If so,

   a) How?

   b) How often?

   c) What are costs associated with this monitoring? Have you hired anyone to assess algae?

2. Do you use chemical control methods such as copper sulfate (bluestone) or Cutrine-Plus to control any algae problem you may have? If so,

   a) Do you have any permitting costs?

   b) What are your application rates?

   c) How is it applied?

   d) How often must you apply chemicals during the season?

   e) What are your costs of application? Cost of chemical? Labor?

3. If chemical methods are not used, why not? What other strategies do you consider?

4. Do you use any non-chemical methods to control algae, such as aeration, barley straw, bacteria addition, nutrient limitation, application, gypsum, or any other techniques?

   a) What are the costs of control?

   b) How often must you apply or use these techniques in a season?

B. *Letter to Practitioners*

San Francisco Estuary Institute

7770 Pardee Lane, 2nd Floor
Oakland, CA 94621-1424
Office (510) 746-SFEI (7334)
Fax (510) 746-7300

June 4, 2004

Dear Ms. Practitioner:

I am a graduate student from University of California, Santa Barbara working with Geoff Siemering and Ben Greenfield of the Aquatic Pesticide Monitoring Program (APMP). We are carrying out an investigation of the respective costs and effectiveness of various aquatic management control strategies. One of the objectives of the APMP is to gather information related to non-chemical alternatives for chemical aquatic plant management.

To date, there have been few comprehensive studies related to this issue. Many practitioners have indicated a need for thorough determination of cost effectiveness where this information is not available. This survey is intended to capture a better understanding of how costs vary across different control strategies. It will lead to a guide for water body managers to help decide which herbicide or mechanical control method is most cost effective. In addition, we will compile a detailed analysis of control strategies across a range of water bodies and aquatic pests.

Ben Greenfield has provided us with your contact information and has indicated that you would be willing to provide our group with cost effectiveness information in order to help understand the effectiveness of different control strategies. The requested data will not be used for site-specific evaluations, but your organization would be formally recognized in our final report, unless you wish otherwise. We will honor any other requests you may have regarding the use of sensitive cost information. We would present you a summary of our findings by March 2004.

Unless I hear from you first, I will contact you by phone or email during the first week of _____, to set up a phone discussion with you. Please do not hesitate to contact me if you have any questions. Thank you for considering this data request.

Sincerely,

Marion Wittmann
Master's Student of Environmental Science and Management
(510) 746-7341

C. *Cost information data tables*

See separate Excel File.

D. *Kern NWR Entry Tables*

Entry Table 1. **Define the Aquatic Plant Problem.**
Name of Water Body: **Kern NWR**
1a. Location: **Kern National Wildlife Refuge (KNWR) is located 18 miles west of the city of Delano at the southern end of the San Joaquin Valley of California.**
1b. Water Body Type (identify and describe at least 1)
Small pond
Large lake
Delta
Irrigation canal
Stormwater
EstuarineWetlands: 7000 acres of Seasonal Wetlands, also, 2400 acres of "Management Units": shallow, flooded plains, 2-6 inches deep, units irrigated in Spring/Summer. Current concern is the management of 800 acres of marshland unleveled units. Will begin to manage an additional 1100 acres of moist soil wetlands next fall.
Wildlife Refuges: The 10,618-acre Kern refuge consists of natural valley grasslands, a relict riparian corridor, and developed marsh
1c. Aquatic Plant Type (identify and describe at least 1)
Floating
Submersed
Emergent **Alkalai Bulrush (*Scirpus maritimus*), Cattail (*Typha latifolia*)**
Algae
1d. Potential Economic Costs (identify and describe at least 1) KNWR provides wintering habitat for migrating birds, shorebirds, marsh and waterfowl in the southern San Joaquin Valley. The refuge also provides habitat for upland species. Overgrowth of the bulrush and cattail cause "crowding" problems in the wetland areas. There are also hunting opportunities for waterfowl that are jointly managed by refuge staff and the California Dept. of Fish and Game that could be affected by general overgrowth problems.
History of Control costs, or Control Expected: Many different kinds of control methods have been used, including mowing, plowing, disking, floating, herbicide application—still trying to determine most effective method.

The have switched to more extensive use of mechanical control because exclusive chemical control has been too expensive at this site. In some cases, chemical control wasn't effective at label recommended concentrations. Also, most applicators don't have aircraft permitting for herbicide application to USFWS refuges. David Hardt (Kern NWR Manager) described extensive mechanical control for salt cedar, bulrush and cattail. They have had mixed results with integrated approaches on cattail control. They have combined aerial fly-over applications of Rodeo or AquaMaster with wetland draining, followed by mowing and disking. The most effective control occurs after the area is left dry for 3 months which isn't feasible because of the need to maintain sufficient waterfowl habitat. The also found that plowing followed by drying is more effective than disking. They are currently using disking on the main unit just to maintain lower biomass ("mowing the lawn"). It is not possible to keep the main unit dry for more than 3.4 weeks because some sensitive bird species need the wetlands. They have a number of different treatments that have already been conducted. These include areas mowed and disked but not sprayed, areas sprayed two years ago, and areas not treated at all.
Types of Damage Costs
Contributes to flooding/drainage/storm water problems
Water supply quantity
Water supply quality
Impedes navigation
Impedes/limits recreation/parks values
Reduces aesthetic/environmental values: The refuge values the wetland "management units" as habitat for sensitive species; the overgrowth of plant plant species impedes these units as effective areas for fowl.
1e. Management Objective: To control, not necessarily eliminate, target pests—there is value in keeping some of the plants around as habitat for sensitive bird species and other animals in the refuge
1f. Stakeholders: Users of Kern NWR, ecosystem participants

Entry Table 3. Number 1 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Mowing, Discing, Floating, Plowing		
Name of Practice: Aerial Application of AquaMaster		
General description of Practice	**Spray herbicide, AquaMaster, over open water and seasonal wetland**	
When during the season will practice be applied?	**During the management period late spring/early summer**	
Where within the location this practice is to be applied?	**800 acres of open water, wetland area**	
How much will be applied?	**Once per 5 years**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	Dollars/years	$38,296/0.2
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	280
Helicopter Time	$/acre	$13.40
AquaMaster	$/acre	$30.00
Surfactant	$/acre	$0.90
Load Mgt. Staff	$/acre	$1.00
Planning/Permits	$/acre	$2.57
Total Estimated Cost	**Average, Dollars/acre**	**$47.87/acre**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 2 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Mowing, Discing, Floating, Plowing		
Name of Practice: Aerial Application of AquaMaster and One Mowing		
General description of Practice	**Spray herbicide, AquaMaster, over open water and seasonal wetland and mow once per season**	
When during the season will practice be applied?	**During the management period late spring/early summer**	
Where within the location this practice is to be applied?	**800 acres of open water, wetland area**	
How much will be applied?	**AquaMaster once per 5 years, Mowing each year**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known		
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	280
Helicopter Time	$/acre	$13.40
AquaMaster	$/acre	$30.00
Surfactant	$/acre	$0.90
Load Mgt. Staff	$/acre	$1.00
Planning/Permits	$/acre	$2.57
Mowing	$/acre	$6.79/acre
Total Estimated Cost	**Average, Dollars/acre**	**$54.66/acre**
Go to next practice, or if all practices are done and this is a control analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 3 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: AquaMaster, Discing, Floating, Plowing		
Name of Practice: Mowing		
General description of Practice	**Mowing over seasonal wetland area to control bulrush, cattail**	
When during the season will practice be applied?	**During the management season, April-September**	
Where within the location this practice is to be applied?	**800 acres of seasonal wetland area**	
How much will be applied?	**Four applications per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	Dollars/year	$21,728
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	700
Labor	$/acre	$5.52
Fuel	$/acre	$1.02
Equipment Service	$/acre	$0.25
Total cost per unit	**$/acre**	**$6.79**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 4 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: AquaMaster, Discing, Floating, Plowing		
Name of Practice: Combined Mowing, Discing and Floating		
General description of Practice	**Mowing, Discing and Floating only**	
When during the season will practice be applied?	**During the management period late spring/early summer**	
Where within the location this practice is to be applied?	**800 acres of seasonal wetland area**	
How much will be applied?	**Twice per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**Dollars/year**	**$38,224**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	150
Mowing	$/acre	$6.79
Labor to Disc	$/acre	$3.07
Fuel	$/acre	$0.57
Equipment Service	$/acre	$0.13
(Discing Subtotal x 2 passes)	$/acre	$7.54
Floating (leveling)	$/acre	$9.56
Total cost per unit	**$/acre**	**$23.89**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 5 **Costs of a Management Practice.** **For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.**		
Management Alternative Names: AquaMaster, Mowing, Discing, Floating, Plowing		
Name of Practice: Combined Mowing, Discing, Floating, and Plowing		
General description of Practice	**Mowing, discing, floating and plowing over seasonal wetland management units**	
When during the season will practice be applied?	**During the management period late spring/early summer**	
Where within the location this practice is to be applied?	**800 acres of seasonal wetland area**	
How much will be applied?	**Once per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	Dollars/year	**$24,448**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	100
Mowing	$/acre	$6.79
Plowing	$/acre	$6.67
Discing 2 Passes	$/acre	$7.54
Floating	$/acre	$9.56
Total cost per unit	**$/acre**	**$30.56**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Aerial Application of AquaMaster

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		AquaMaster						
1		$38,296						$38,296
2		0						0
3		0						0
4		0						0
5		0						0
6		$38,296						$38,296
7		0						0
8		0						0
9		0						0
10		0						0
11		$38,296						$38,296
12		0						0
13		0						0
14		0						0
15		0						0
16		$38,296						$38,296
17		0						0
18		0						0
19		0						0
Etc		0						0
Last Yr		$38,296						$38,296
NPV(.05, Yr1..,Yr50), 1000 $								**$153.79**
-PMT(.05,Last Yr.,NPV), 1000 $								**$8.42**

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Aerial Application of AquaMaster and Mowing

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		AquaMaster and Mowing						
1		$43,728						$43,728
2		$5,432						$5,432
3		$5,432						$5,432
4		$5,432						$5,432
5		$5,432						$5,432
6		$43,728						$43,728
7		$5,432						$5,432
8		$5,432						$5,432
9		$5,432						$5,432
10		$5,432						$5,432
11		$43,728						$43,728
12		$5,432						$5,432
13		$5,432						$5,432
14		$5,432						$5,432
15		$5,432						$5,432
16		$43,728						$43,728
17		$5,432						$5,432
18		$5,432						$5,432
19		$5,432						$5,432
Etc		$5,432						$5,432
Last Yr		$43,728						$43,728
NPV(.05, Yr1..,Yr50), 1000 $								**$252.96**
-PMT(.05,Last Yr.,NPV), 1000 $								**$13.86**

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Mowing

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		Mowing (4 times)						
1		$21,728						$21,728
2		$21,728						$21,728
3		$21,728						$21,728
4		$21,728						$21,728
5		$21,728						$21,728
6		$21,728						$21,728
7		$21,728						$21,728
8		$21,728						$21,728
9		$21,728						$21,728
10		$21,728						$21,728
11		$21,728						$21,728
12		$21,728						$21,728
13		$21,728						$21,728
14		$21,728						$21,728
15		$21,728						$21,728
16		$21,728						$21,728
17		$21,728						$21,728
18		$21,728						$21,728
19		$21,728						$21,728
Etc		$21,728						$21,728
Last Yr		$21,728						$21,728
NPV(.05, Yr1..,Yr20), 1000 $								**$396.66**
-PMT(.05,Last Yr.,NPV), 1000 $								**$21.73**

Entry Table 6. Costs of Management Practices by Year for a Management Alternative								
Management Alternative: Mowing, Discing and Floating								
		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		Mowing, Discing and Floating						
1		$38,224						$38,224
2		$38,224						$38,224
3		$38,224						$38,224
4		$38,224						$38,224
5		$38,224						$38,224
6		$38,224						$38,224
7		$38,224						$38,224
8		$38,224						$38,224
9		$38,224						$38,224
10		$38,224						$38,224
11		$38,224						$38,224
12		$38,224						$38,224
13		$38,224						$38,224
14		$38,224						$38,224
15		$38,224						$38,224
16		$38,224						$38,224
17		$38,224						$38,224
18		$38,224						$38,224
19		$38,224						$38,224
Etc		$38,224						$38,224
Last Yr		$38,224						$38,224
NPV(.05, Yr1..,Yr20), 1000 $								**$697.81**
-PMT(.05,Last Yr.,NPV), 1000 $								**$38.22**

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Combined Mowing, Discing, Floating and Plowing

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		Mowing, Discing, Floating, Plowing						
1		$24,448						$24,448
2		$24,448						$24,448
3		$24,448						$24,448
4		$24,448						$24,448
5		$24,448						$24,448
6		$24,448						$24,448
7		$24,448						$24,448
8		$24,448						$24,448
9		$24,448						$24,448
10		$24,448						$24,448
11		$24,448						$24,448
12		$24,448						$24,448
13		$24,448						$24,448
14		$24,448						$24,448
15		$24,448						$24,448
16		$24,448						$24,448
17		$24,448						$24,448
18		$24,448						$24,448
19		$24,448						$24,448
Etc		$24,448						$24,448
Last Yr		$24,448						$24,448
NPV(.05, Yr1..,Yr20), 1000 $								**$446.32**
-PMT(.05,Last Yr.,NPV), 1000 $								**$24.45**

E. *Big Bear Lake Entry Tables*

Entry Table 1. Define the Aquatic Plant Problem.
Name of Water Body: **Big Bear Lake**
1a. Location: **Big Bear Lake is located in Southern California between the San Bernardino Mountains**
1b. Water Body Type (identify and describe at least 1)
Small pond
Large lake: Big Bear Lake is eight miles long and approximately one mile across at its widest point. It has about 23 miles of shoreline and is located at an elevation of 6,743.2 feet. The present dam, built in 1912, replaced the original dam, which was built in 1884. The new dam impounds more than 73,000 acre-feet of water with a height of 72'4". The Lake is not a source of water for the local water supply. The only water taken locally is by the two ski resorts for making artificial snow. They may each purchase up to 500-acre ft. per ski season. The Municipal Water District manages the lake. Private homes, several marinas, public parks and some hotels and lodges surround the south side of the lake.
Delta
Irrigation canal
Stormwater
EstuarineWetlands:
Wildlife Refuges
1c. Aquatic Plant Type (identify and describe at least 1): Eight types of aquatic plants have been identified in Big Bear Lake, of which coontail and milfoil are the most abundant and the most troublesome to navigation, fishing and aesthetics. District records indicate that of the plants harvested, 73% is coontail, 20% is milfoil and the remaining 7% is a combination of other types.
Floating **Smartplant (*Polygonum hydropiperoides Michx)***
Submersed **Coontail (*Ceratophyllum demursum*), Eurasian Water Milfoil (*Myriophyllum spicatum*), Curly leaf pondplant (*Potamogenton crispus*), American Elodea (*Elodea canadensis*) Sago pondplant (*Potamogenton pectinafus*), Leafy-pondplant (*Potamogenton foliosus*), Widgeon Grass (*Ruppia maritime*), Spikerush (*Eleocharis spp.*)**
Emergent
Algae **Planktonic Algae, common genera: Anabaena, Chlorella, Pediastrum, Scenedesmus, Oocystis; Filamentous Algae, common genera: Spirogyra, Cladophora, Rhizoclonium, Mougeotia, Zygnema and Hydrodictyon; Toxic Algae; Blue Green Algae (*Lyngbya spp.*)**

1d. Potential Economic Costs (identify and describe at least 1): The lake is widely used as a recreational area supporting boating, fishing and other recreational activities. The overgrowth of aquatic plants inhibits the facilitation of access to the lake. Eight types of aquatic plants have been identified in Big Bear Lake, of which coontail and milfoil are the most abundant and the most troublesome to navigation, fishing and aesthetics. District records indicate that of the plants harvested, 73% is coontail, 20% is milfoil and the remaining 7% is a combination of other types.
History of Control costs, or Control Expected: Big Bear Municipal Water District operates three aquatic plant harvesters and one Aquamog on the Lake for the purpose of removing plants, primarily from around docks and major boating areas. Approximately 86% of the plant cutting occurs around private docks, with the remaining 14% occurring in areas where improved public access is needed or navigational hazards must be removed. The harvesting program currently removes about one-thousand tons of plants from the Lake annually. Some chemical plant treatment has been performed in the past; however the method of mechanical harvesting has been determined to have less adverse impacts and is now the preferred method used by District Staff. Occasionally, when the situation demands, chemicals are used to treat excessive algae blooms. The Aquamog, a 10' wide barge with a cab for the operator, is paddle wheel driven, 35' in length and has an excavator arm that accepts a number of different attachments. The attachment used for this program is the tiller which is similar to the rototiller used in the garden, except on a larger scale. It is 10' wide and weighs about 2,000 pounds. It has 4 rows of spring steel tines that are off-set to get maximum digging on the bottom of the Lake to dislodge the aquatic plants. Each dock area takes about 30 minutes to complete and one lap around the Lake is completed each spring. The Aquamog program is geared to remove the rooted plants around residential docks to improve recreational access during the summer season. The District sends letters in the fall to each residential dock owner to advise them of the Aquamog program and schedule, and to recommend that they move their dock at least 50' off the shore or to a marina for storage. The Aquamog program begins on April 1 and continues until the water temperatures reach an average of 55 degrees, as determined by readings taken at a depth of two-feet of water at ten locations around the Lake. In the summer of 1996, the District completed an experimental application in Grout Bay of a product called Fluridone. After many weeks of studying case histories regarding the use of Fluridone and actually visiting sites where Fluridone had been used, the District determined that a test in Big Bear Lake was the appropriate first step in analyzing Fluridone's potential. Grout Bay, on the north shore of the Lake, was selected as the test area as it is protected from the wind and also from plant harvesting operations. This 35 acre area was initially treated during the first week of August 1996, with additional applications approximately every three weeks throughout the remainder of the summer. District Staff monitored the test area following the applications and concluded that the product results were unsatisfactory. Upon further evaluation, it was determined that the applications occurred too late in the

growing season to achieve maximum results. A second series of applications took place in 1998 in the same area of the Lake. The cost for these treatments was approximately $1,000 per acre and the result was nearly three years of plant-free access in Grout Bay. Based on these results, the District developed a plan to treat specific areas of the Lake again in 2000. In December of 2001, the District decided to move forward in the spring of 2002 with an aggressive program for herbicide treatments. Following three dry years with less than normal inflow to the Lake, and a Lake that was 9'6" below full, it was determined that applications in the east end of the Lake, in Boulder Bay and in the Mallard Lagoon/Canvasback Cove areas could achieve many years of relief from the infestation of Eurasian water milfoil. A consultant was retained to coordinate the permit process work with the Santa Ana Regional Water Quality Control Board. The cost of the applications was projected at $264,000 with funding provided from the District's Lake Improvement Fund. (BBMWD web site)
Types of Damage Costs
Contributes to flooding/drainage/storm water problems
Water supply quantity
Water supply quality: The excessive vegetation leads to a change in localized levels of nutrients and turbidity in the lake (either as a result of management practices, or damages from the plants themselves).
Impedes navigation: This is one of the main reasons for management; open areas where boaters traverse are impacted by heavy levels of vegetation, private dock owners pay an annual fee to cover the cost of mechanical harvesting to keep the areas free.
Impedes/limits recreation/parks values: Coontail and milfoil are the most abundant and the most troublesome to boating, jet skiing, paddling, fishing, etc.
Reduces aesthetic/environmental values: Yes.
1e. Management Objective: To reduce the overgrowth of plants and to facilitate access to the lake without the eradication of all plants.
1f. Stakeholders Big Bear Municipal Water District, The Fishing Association of Big Bear Lake, Santa Ana Regional Water Quality Control Board, Western Aquatic Plant Management Society, local property owners, private dock users, recreators on the lake

Entry Table 3. Number 1 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Fluridone		
Name of Practice: Status Quo: Harvesting, Aquamogging		
General description of Practice	**Have three harvesters (H-650), and one Aquamog which works similarly to a rototiller to remove plants from around dock areas.**	
When during the season will practice be applied?	**Plant harvesting program begins June 15 with most heavily planted areas being treated first, continues through end of season, September 15.**	
Where within the location this practice is to be applied?	**Aquatic plants cover about 800 acres around the perimeter of big bear lake. The district controls 240 acres of the growth with harvesters.**	
How much will be applied?		
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known		**$250,000-$300,000 per season**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a Type A analysis, go to Entry Table 6. If this is a Type B or C Analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	240 (website) or 800 (Gene)
Maintenance/storage machines	Dollars/Year	$25,000
Operating costs	Dollars/year	$225,000-$275,000
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 2 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Harvesting, Aquamogging		
Name of Practice: Fluridone and some Harvesting		
General description of Practice	**Application of herbicide, Fluridone and use of harvester for curly leaf pondplant that grows once milfoil is eradicated**	
When during the season will practice be applied?	**Early in the growing season, June**	
Where within the location this practice is to be applied?	**Boulder Bay and Mallard Lagoon/Canvasback Cove**	
How much will be applied?	**145 acres one year, approximately 100 acres the following year**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$268,530-$273,725**	
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	145 acres
Cost per acre	$/acre	$1000
Permitting/Monitoring	$	$100,000
Department of F&G Permit	$	$154
Operation Costs for harvesters	$/season (8 days, Gene Martin)	$23,377-$28,571 (est. as a proportion of Gene Martin estimation of total control cost/season)
Total Cost	**$/season**	**$268,530-$273,725**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

<table>
<tr><td colspan="3">Entry Table 3. Number 3
Costs of a Management Practice.
For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.</td></tr>
<tr><td colspan="3">Management Alternative Names: Fluridone, Harvesting, Aquamogging</td></tr>
<tr><td colspan="3">Name of Practice: Diver Dredging</td></tr>
<tr><td>General description of Practice</td><td colspan="2">Diver-operated suction dredging uses divers equipped with suction dredge hoses that vacuum the plant material out of the lake.</td></tr>
<tr><td>When during the season will practice be applied?</td><td colspan="2">During the growing season: late spring-late summer.</td></tr>
<tr><td>Where within the location this practice is to be applied?</td><td colspan="2">Along the 240 acres of treatment zone as indicated by the BBMWD and ReMetrix, Inc. consultants</td></tr>
<tr><td>How much will be applied?</td><td colspan="2"></td></tr>
<tr><td>Measurable Attributes of this Practice</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Total Control Cost, if known</td><td>$90,000-$480,000</td><td>$375-$2000/acre</td></tr>
<tr><td colspan="3">If Total Control Cost was known, go to next practice, or if all practices are done, and this is a Type A analysis, go to Entry Table 6. If this is a Type B or C Analysis, go to Entry Table 4.</td></tr>
<tr><td>If Total Control Cost not known, name factors that affect cost (See Information Table 2)</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Acreage to be treated</td><td>Acres</td><td>240</td></tr>
<tr><td>Cost</td><td>$/day</td><td>$1,500-$2,000/day</td></tr>
<tr><td>Removal Rates</td><td>acre/day</td><td>0.25-1.0</td></tr>
<tr><td>Total cost</td><td>$/season</td><td>$90,000-$480,000</td></tr>
<tr><td colspan="3">Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.</td></tr>
</table>

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Aerial Application of AquaMaster

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		Harvesting/ Aquamogging						
1		$275,000						$275,000
2		$275,000						$275,000
3		$275,000						$275,000
4		$275,000						$275,000
5		$275,000						$275,000
6		$275,000						$275,000
7		$275,000						$275,000
8		$275,000						$275,000
9		$275,000						$275,000
10		$275,000						$275,000
11		$275,000						$275,000
12		$275,000						$275,000
13		$275,000						$275,000
14		$275,000						$275,000
15		$275,000						$275,000
16		$275,000						$275,000
17		$275,000						$275,000
18		$275,000						$275,000
19		$275,000						$275,000
Etc		$275,000						$275,000
Last Yr		$275,000						$275,000
NPV(.05, Yr1..,Yr50), 1000 $								**$5020.00**
-PMT(.05,Last Yr.,NPV), 1000 $								**$275.00**

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Mowing

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alter-native by Year
		Sonar™ and some Harvesting						
1		$271,128						$271,128
2		$226,129						$226,129
3		$271,128						$271,128
4		$226,129						$226,129
5		$271,128						$271,128
6		$226,129						$226,129
7		$271,128						$271,128
8		$226,129						$226,129
9		$271,128						$271,128
10		$226,129						$226,129
11		$271,128						$271,128
12		$226,129						$226,129
13		$271,128						$271,128
14		$226,129						$226,129
15		$271,128						$271,128
16		$226,129						$226,129
17		$271,128						$271,128
18		$226,129						$226,129
19		$271,128						$271,128
Etc		$226,129						$226,129
Last Yr		$271,128						$271,128
NPV(.05, Yr1..,Yr20), 1000 $								**$4548.96**
-PMT(.05,Last Yr.,NPV), 1000 $								**$249.18**

Entry Table 6.
Costs of Management Practices by Year for a Management Alternative

Management Alternative: Combined Mowing, Discing, Floating and Plowing

		Quantified Control Costs, Damage Costs, and Environmental Costs, In 2003 Dollars						
Year	Source of Data (Tables, number)	Name of Control Cost, Damage Cost, or Environmental Cost						Total Cost of Alternative by Year
		Suction Dredging						
1		$285,000						$285,000
2		$285,000						$285,000
3		$285,000						$285,000
4		$285,000						$285,000
5		$285,000						$285,000
6		$285,000						$285,000
7		$285,000						$285,000
8		$285,000						$285,000
9		$285,000						$285,000
10		$285,000						$285,000
11		$285,000						$285,000
12		$285,000						$285,000
13		$285,000						$285,000
14		$285,000						$285,000
15		$285,000						$285,000
16		$285,000						$285,000
17		$285,000						$285,000
18		$285,000						$285,000
19		$285,000						$285,000
Etc		$285,000						$285,000
Last Yr		$285,000						$285,000
NPV(.05, Yr1..,Yr20), 1000 $								**$5202.94**
-PMT(.05,Last Yr.,NPV), 1000 $								**$285.00**

F. *Bird Species in Big Break.*

Adopted from a 1998-2000 Mount Diablo Audubon Society Survey

Bird Species Inhabiting Big Break with nests, eggs, or fledglings	Pied-billed Grebe Green Heron Canada Goose Mallard Gadwall Cinnamon Teal White-tailed Kite American Avocet Black-necked Stilt Killdeer Mourning Dove Barn Owl Downy Woodpecker Nuttall's Woodpecker Black Phoebe Loggerhead Shrike Western Scrub-Jay American Crow Tree Swallow Cliff Swallow Barn Swallow Bushtit Marsh Wren Northern Mockingbird European Starling Common Yellowthroat Blue Grosbeak Spotted Towhee Song Sparrow Savannah Sparrow Red-winged Blackbird Brewer's Blackbird House Finch House Sparrow Clark's Grebe American Bittern Black-crowned Night Heron Snowy Egret Great Egret Great Blue Heron Turkey Vulture Blue-winged Teal Northern Shoveler Ruddy Duck

	Wood Duck Northern Harrier Red-shouldered Hawk Red-tailed Hawk Swainson's Hawk American Kestrel Ring-necked Pheasant California Quail Virginia Rail Sora Black Rail Common Moorhen American Coot Caspian Tern Forster's Tern Rock Dove Great Horned Owl White-throated Swift Anna's Hummingbird Belted Kingfisher Northern Flicker Western Kingbird Common Raven Northern Rough-winged Swallow Bewick's Wren American Robin Orange-crowned Warbler Yellow-breasted Chat Black-headed Grosbeak Western Meadowlark Yellow-headed Blackbird Tricolored Blackbird Brown-headed Cowbird Bullock's Oriole American Goldfinch

G. *Fish Species Associated with Big Break Habitat*

Adapted from Table 2. in Native and Alien Fishes in a California Estuarine Marsh: Twenty-One Years of Changing Assemblages. Transactions of the American Fisheries Society, 2002, 131: 797-816. (Matern 2002). The method for collecting the fish was trawling, and to a lesser extent seining for edge habitat. The two methods of collection opted very different numbers of species in some cases, therefore this will summarize the fish counts for both methods of collection.

*Fish with asterisks denote native species.

Species	**Otter Trawl Number**	**Otter Trawl %**	**Beach Seine Number**	**Beach Seine %**
Striped Bass (*Morone saxatilis)*	46125	36	5497	12
*Threespine stickleback (*Gasterosteus aculeatus)*	13128	10	1955	4
Yellowfin goby (*Acanthogobius flavimanus)*	12470	10	8551	19
*Tule perch (*Hysterocarpus traski)*	11069	9	817	2
*Spittail (*Pogonichthys macrolepidotus)*	10770	8	1358	3
*Longfin smelt (*Spirinchus thaleichthys)*	7514	6	20	<1
*Prickly sculpin (*Cottus asper)*	7017	6	311	1
Shimofuri goby (*Tridentiger bifasciatus)*	6044	5	698	2
Common carp (*Cyprinus carpio)*	2732	2	250	1
*Sacramento sucker (*Catostomus occidentalis)*	2114	2	72	<1
*Pacific staghorn sculpin (*Leptocottus armatus)*	1630	1	1704	4
Threadfin shad (*Dorosoma petenense)*	1369	1	1180	4
*Starry flounder (*Platichthys stellatus)*	1302	1	213	<1
White catfish (*Ameiurus catus)*	1038	1	71	<1
*Delta smelt (*Hypomesus transpacificus)*	442	<1	69	<1
Inland silverside (*Menidia beryllina)*	335	<1	21843	47
American shad (*Alosa sapidissima)*	263	<1	24	<1
Black crappie (*Pomoxis nigromaculatus)*	235	<1	10	<1
*Northern anchovy (*Engraulis mordax)*	224	<1	0	0
*Pacific herring (*Clupea harengus)*	208	<1	54	<1
Goldfish (*Carassius auratus)*	162	<1	11	<1
Channel catfish (*Ictalurus punctatus)*	123	<1	6	<1
*Hitch (*Lavinia exilicauda)*	99	<1	13	<1
*Sacramento pikeminnow (*Ptychocheilus grandis)*	96	<1	85	<1
Black bullhead (*Ameriurus melas)*	90	<1	2	<1
White crappie (*Pomoxis annularis)*	88	<1	0	0
*White sturgeon (*Acipenser transmontanus)*	43	<1	0	0
*Pacific lamprey (*Lampetra tridentata)*	38	<1	0	0
*Chinook salmon (*Oncorhynchus tshawytscha)*	34	<1	183	<1
Brown bullhead (*Ameiurus nebulosus)*	19	<1	0	0
Fathead minnow (*Pimephales promelas)*	16	<1	23	<1
Bigscale logperch (*Percina macrolepida)*	15	<1	5	<1
Western mosquitofish (*Gambusia affinis)*	15	<1	215	<1
Rainwater killfish (*Lucania parva)*	15	<1	24	<1

*Sacramento blackfish (*Orthodon microlepidotus)*	15	<1	78	<1
*Shiner perch (*Cymatogaster aggregate)*	14	<1	0	0
Bluegill (*Lepomis macrochirus)*	11	<1	12	<1
*Plainfin midshipman (*Porichthys californicus)*	10	<1	0	0
*California halibut (*Paralichthys califorinicus)*	3	<1	0	0
Green sunfish (*Lepomis cyanellus)*	3	<1	2	<1
Golden shiner (*Notemigonus crysoleucas)*	3	<1	2	<1
*Green sturgeon (*Acipenser medirostris)*	3	<1	0	0
*Rainbow trout (*Oncorhynchus mykiss)*	3	<1	2	<1
*Speckled sanddab (*Citharichthys stigmaeus)*	3	<1	0	0
*Bay pipefish (*Syngnathus leptorhynchus)*	2	<1	0	0
Redear sunfish (*Lepomis microlophus)*	2	<1	0	0
*Surf smelt (*Hypomesus pretiosus)*	2	<1	0	0
Shokihaze goby (*Tridentiger barbatus)*	1	<1	0	0
*Longjaw mudsucker (*Gillichthys mirabilis)*	1	<1	0	0
*Pacific sanddab (*Citharichthys sordidus)*	1	<1	0	0
Wakasagi (*Hypomesus nipponensis)*	1	<1	1	<1
*White croaker (*Genyonemus lineatus)*	1	<1	0	0
Warmouth (*Lepomis gulosus)*	1	<1	0	0
Largemouth bass (*Micropterus salmoides)*	0	0	2	<1

H. *Impact Tables*

Big Break Summary Impact Tables

The following tables present a summary of the impacts incurred for each management strategy at Big Break or Stone Lakes respectively. Before referring to the tables, an explanation of probabilities should be explained:

- **High** indicates that the specified impact will most likely occur unless the mitigation suggested is actually carried out. Although some instances, the impact will not be reduced by mitigation, for example turbidity will probably occur temporarily and there is not a readily available mitigation to lessen the impact.
- **Moderate** indicates that the impact may occur, but usually only if assumed precautions about the operation or application of the management strategy are ignored or disregarded. Un-frequent instances like mis-use of suggested herbicide use, or maneuvering of a harvester are some examples. These events are avoidable when proper technique is exercised.
- **Low** indicates that the impact should not occur, or is not known to occur. For instance, the chemical properties of a herbicide are not known to cause toxicity. Or for harvesting, an impact would only be expected if the harvester maneuvered unexpectedly.

Table 1. <u>Non-chemical Control of *Egeria densa* at Big Break</u>

Plant Control Method	Cost of Control Method	Physical Impacts	Probability	Mitigation	Probability with Mitigation	Social Costs	Monetization Method
Harvesting	-Cost of equipment $35,000-$110,000 plus O&M. -Cost per acre is $500-$800 not including mobilization. Costs as low as $250 per acre have been reported.[1] $5,000-$6,000 per acre[2].	-Decrease DO -Spread of viable fragments -Increase turbidity -Fish kill -Non-target species also harvested -Disturbance to sediment dwelling species -Disturbance of shore dwelling birds	High High High Moderate Moderate High Low	-Remove decaying plant material from water after harvesting event. -Drag net to collect fragments. -Careful maneuvering of harvester to avoid bird nesting and habitat areas when entering and exiting water.	Moderate Moderate High Low Low High Very Low	-Loss of recreation or use days as the harvester operates in the treatment area.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

Table 2. <u>Non-chemical control of hyacinth at Big Break</u>

Plant Control Method	Cost of Control Method	Physical Impacts	Probability	Mitigation	Probability with Mitigation	Social Costs	Monetization Method
Hand pulling with rake	-Rake cost $95-$125[3] -$500-$2,400 per day for 100 acres[4] -$130 for average waterfront lot for a hired commercial puller[5].	-Increased turbidity -Disturbance to sediment dwelling species	Moderate Moderate	-Cautious maneuvering of vessel.	Low	-Loss of recreation or use days as field crew pulls plants in the treatment area.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

---

[1] Gibbons et al, 1994. (Roger Mann's APME Ch.3)
[2] Carlock, Marcia DBW, email 12/17/03.
[3] Gibbons et al, 1994. (Roger Mann's APME Ch.3)
[4] Taylor and Gately, 1998. (Roger Mann's APME Ch.3)
[5] Gibbons et al, 1994. (Roger Mann's APME Ch.3)

Table 3. Chemical control of *Egeria densa* at Big Break

Plant Control Method	Cost of Control Method	Physical Impacts	Probability	Mitigation	Probability with Mitigation	Social Costs	Monetization Method
Diquat	$169-$542 per acre per year[6]	-Accumulation of chemical in sediments -Decreased DO due to decaying plant material -Fish kill due to lack of oxygen created by decaying plant masses. -Disturbance of wetlands -Harm to early life stages in ecosystem	Low High Moderate Low High	-Apply herbicide when plants are actively growing, so that the nuisance plants take up the chemical instead of having it escape and accumulate in sediments. -Monitoring -Monitoring -One mile buffer zone	Low High Moderate Low	-Loss of recreation or use days as sprayers treat in the treatment area.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost
Fluridone	$900-$1000 per acre[7].	-Accumulation of chemical in sediments -Decreased DO due to decaying plant material -Fish kill due to lack of oxygen created by decaying plant masses. -Accumulation of chemical in fish that could potentially be caught soon after treatment and eaten by humans. -Disturbance of wetlands	Low High High Low Low	-Monitoring -Monitoring -Monitoring -Warnings/advisories -One mile buffer zone	Low High High Very Low Low	-Loss of recreation or use days as sprayers treat in the treatment area.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost
Komeen™ (chelated copper)	$169-$542 per acre per year[8].	-Decreased DO due to decaying plant material -Fish kill due to lack of oxygen created by decaying plant masses. -Harm to endangered fish	High High Moderate	-Monitoring. -Monitoring -Biologist survey	High High Low	-Loss of recreation or use days as sprayers treat in the treatment area.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

[6] Shireman, Colle, and Canfeld, 1986 (Roger Mann's APME Ch.3)
[7] Gibbons et al, 1994. (Roger Mann's APME Ch.3)
[8] Shireman, Colle, and Canfeld, 1986 (Roger Mann's APME Ch.3)

		-Disturbance of wetland, riparian, and marsh communities which contain numerous sensitive, special status, and endangered species. -Complete mortality of invertebrate community	Moderate High	-One mile buffer zone	Low		

Table 4. Non-chemical control of hyacinth at Stone Lakes NWR

Plant Control Method	**Cost of Control Method**	Physical Impacts	**Probability**	**Mitigation**	**Probability with Mitigation**	**Social Costs**	**Monetization Method**
Shredding	-50 acres, 30 hours, $45 per acre. -Portable boat mounted unit costs $400-$3,000. -Specialized underwater cutters cost $11,000. The Swordfish battery operated cutter retails for $1,995.[9]	-Decrease DO -Spread of viable fragments. -Increase turbidity -Fish kill -Non-target species also shredded -Disturbance to sediment dwelling species	High High High Moderate High Moderate	-Remove decaying plant material from water after harvesting event. -Drag net to collect fragments. -Shred only upper water column.	-Moderate -Moderate -Low	-Damage to bird habitat. -Less bird watching days.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

Table 5. Chemical control of hyacinth at Stone Lakes NWR

Plant Control Method	**Cost of Control Method**	Physical Impacts	**Probability**	**Mitigation**	**Probability with Mitigation**	**Social Costs**	**Monetization Method**
Glyphosate	-$250 per acre[10]. -$300 per	-Decreased DO due to decaying plant material -Fish kill due to lack of oxygen	High -High	-Monitoring -Remove	-High -Moderate	-Damage to bird habitat. -Less bird watching	-Contingent Valuation -Benefits transfer

---

[9] Gibbons et al, 1994. (Roger Mann's APME Ch.3)
[10] Gibbons et al, 1994. (Roger Mann's APME Ch.3)

	acre[11]. -$800-$3,200 for 2,000 feet of stream[12].	created by decaying plant masses. -Harm to endangered fish -Disturbance of wetland, riparian, and marsh communities: Contain numerous sensitive, special status, and endangered species. -Complete mortality of invertebrate community	 -Moderate -Low -Moderate	decaying plant materials from water. -Monitoring -One mile buffer zone. -	 -Moderate -Very Low -Moderate	days.	-Hedonic Pricing -Replacement Cost
2,4-D	-$300-$400 per acre[13]. -$65 per acre for water hyacinth[14]. -Granular 2,4-D $169-$542 per acre per year[15].	-Decreased DO due to decaying plant material -Fish kill due to lack of oxygen created by decaying plant masses. -Harm to endangered fish -Disturbance of wetland, riparian, and marsh communities which contain numerous sensitive, special status, and endangered species. -Complete mortality of invertebrate community	-High -High -Moderate -Low -Moderate	-Monitoring -Remove decaying plant materials from water. -Monitoring -One-mile buffer zone. -	-High -Moderate -Moderate -Very Low -Moderate	-Damage to bird habitat. -Less bird watching days.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

[11] Taylor and Gately, 1998. (Roger Mann's APME Ch.3)
[12] Taylor and Gately, 1998. (Roger Mann's APME Ch.3)
[13] Gibbons et al, 1994. (Roger Mann's APME Ch.3)
[14] Lembi, 2002. (Roger Mann's APME Ch.3)
[15] Shireman, Colle, and Canfeld, 1986 (Roger Mann's APME Ch.3)

Table 6. Non-chemical control of hyacinth at Dow Wetlands

Plant Control Method	Cost of Control Method	Physical Impacts	Probability	Mitigation	Probability with Mitigation	Social Costs	Monetization Method
Shredding		-Decrease DO -Long term Biochemical Oxygen Demand (BOD) damage -Spread of viable fragments and floating masses after shredding event -Increase turbidity -Fish kill -Non-target species also shredded (Willow) -Disturbance to sediment dwelling species	-High -High -High -Moderate -High -High -Very High	-Remove decaying plant material from water after harvesting event. -Capture floating plant masses. -Drag net to collect fragments. -Careful maneuvering of shredder and avoidance of areas with sensitive or native species.	-Low -Moderate -Low -Low -Moderate -Low -Moderate	-Damage to bird habitat. -Less bird watching days.	-Contingent Valuation -Benefits transfer -Hedonic Pricing -Replacement Cost

I. *Big Break Entry Tables*

Entry Table 1. Define the Aquatic Plant Problem.
Name of Water Body: **Big Break, Sacranento-San Joaquin Delta**
1a. Location: **Big Break is located 40 miles inland from the Golden Gate in the Sacramento-San Joaquin Delta (Gordy 2003). It lies in Contra Costa County and is located directly north of the town of Oakley in the western Delta area (Small).**
1b. Water Body Type (identify and describe at least 1)
Small pond
Large lake
Delta
Irrigation canal
Stormwater
EstuarineWetlands: **The area is considered to be a shallow water body with abundant vegetation; supporting areas of tidal marsh, seasonally inundated floodplain, riparian forest, and Antioch dune scrub (Small).**
Wildlife Refuges
1c. Aquatic Plant Type (identify and describe at least 1)
Floating **Water hyacinth (*Eichhornia crassipes*)**
Submersed ***Egeria densa* (Brazilian elodea)**
Emergent
Algae
1d. Potential Economic Costs (identify and describe at least 1) **Clogged waterways: as a result of the invasion and overgrowth of *Egeria densa* and Water hyacinth, there has been a decrease in the amount of flow in surrounding sloughs and waterways. In addition, fishing and recreation have been impeded as a result of the vast amount of plant overgrowth.**
History of Control costs, or Control Expected:
Types of Damage Costs
Contributes to flooding/drainage/storm water problems
Water supply quantity
Water supply quality
Impedes navigation **Especially to fisherman, other boaters in the area**
Impedes/limits recreation/parks values **See above**
Reduces aesthetic/environmental values
1e. Management Objective **To eliminate plants in order to clear clogged waterways, make navigation and recreation possible for users of the Big Break area**
1f. Stakeholders **California Department of Transportation; California Department of Parks and Recreation; California Department of Water Resources; California Department of Boating and Waterways, DeltaKeepers, BayKeepers**

Entry Table 3. Number 1 **Costs of a Management Practice.** For Each Unique Management Practice from All Entry Table 2s		
Management Alternative Names: Harvesting, Handpulling		
Name of Practice: Herbicide Treatment: Fluridone, Diquat bromide, and chelated copper application, with use of R-11 surfactants		
General description of Practice	**Aquatic plant herbicides and surfactants are applied to the Egeria and Water hyacinth**	
When during the season will practice be applied?	**May-October, during the treatment season**	
Where within the location this practice is to be applied?	**In heavily infested areas in Big Break, approximately 724 acres need application**	
How much will be applied?		
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$1,096,860**	**$1515/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a Type A analysis, go to Entry Table 6. If this is a Type B or C Analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	724
Fluridone	Cost/acre	$900
Diquat bromide	Cost/acre	$75
Chelated Copper	Cost/acre	$540
Total	**Dollars/year**	**$1,096,860**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental cost or cost benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 1 **Costs of a Management Practice.** For Each Unique Management Practice from All Entry Table 2s		
Management Alternative Names: Harvesting, Handpulling		
Name of Practice: Herbicide Treatment: Fluridone, Diquat bromide, and chelated copper application, with use of R-11 surfactants		
General description of Practice	**Aquatic plant herbicides and surfactants are applied to the Egeria and Water hyacinth**	
When during the season will practice be applied?	**May-October, during the treatment season**	
Where within the location this practice is to be applied?	**In heavily infested areas in Big Break, approximately 724 acres need application**	
How much will be applied?		
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$1,096,860**	**$1515/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	724
Fluridone	Cost/acre	$900
Diquat bromide	Cost/acre	$75
Chelated Copper	Cost/acre	$540
Total	**Dollars/year**	**$1,096,860**
Go to next practice, or if all practices are done and this is a Type A analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 2 **Costs of a Management Practice.** **For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.**		
Management Alternative Names: Herbicide Application, Handpulling		
Name of Practice: Harvesting, H-7 Harvester		
General description of Practice	**400 cubic foot harvester(s) removes the water hyacinth from the water body at a rate of approximately 2-3 acres per day (AEI, 2003)**	
When during the season will practice be applied?	**May-October, during the treatment season**	
Where within the location this practice is to be applied?	**In heavily infested areas in Big Break, approximately 724 acres need application**	
How much will be applied?	**Dependant on environmental conditions; most likely 2 passes per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$1,471,563-$1,555,041**	**$2032-2147/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is a an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	724
(Operation) Days required	Days	362
Set up	$/Job/Harvester	$1,064
Operating Cost	$/day/Harvester	$1000
Labor Cost	**$/day/Harvester**	**$520**
Total Cost with 2 harvesters, 4 passes per season (No Disposal costs)	**$**	**$1,471,563**
Total Cost w/2 harvesters, 4 passes per season (Disposal costs included)	**$**	**$1,555,041**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 2 **Costs of a Management Practice.** **For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.**		
Management Alternative Names: Herbicide Application, Handpulling		
Name of Practice: Harvesting, H-7 Harvester		
General description of Practice	**400 cubic foot harvester(s) removes the water hyacinth from the water body at a rate of approximately 2-3 acres per day (AEI, 2003)**	
When during the season will practice be applied?	**May-October, during the treatment season**	
Where within the location this practice is to be applied?	**In heavily infested areas in Big Break, approximately 724 acres need application**	
How much will be applied?	**Dependant on environmental conditions; most likely 2 passes per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$1,471,563-$1,555,041**	**$2032-2147/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is a an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	724
(Operation) Days required	Days	362
Set up	$/Job/Harvester	$1,064
Operating Cost	$/day/Harvester	$1000
Labor Cost	**$/day/Harvester**	**$520**
Total Cost with 2 harvesters, 4 passes per season (No Disposal costs)	**$**	**$1,471,563**
Total Cost w/2 harvesters, 4 passes per season (Disposal costs included)	**$**	**$1,555,041**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is a an environmental or cost-benefit analysis, go to Entry Table 4.		

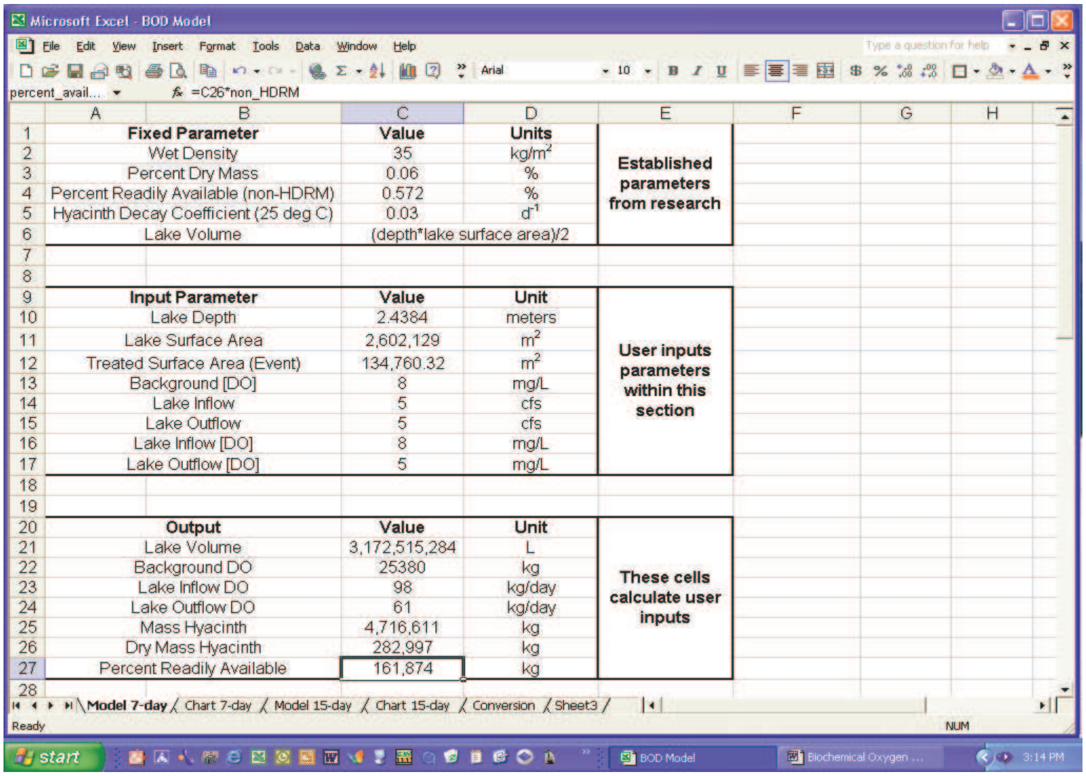
Entry Table 5. Big Break, Harvesting **Environmental Cost Data** **Type B or C Analysis. For Each Environmental Cost Type Expected Following a Practice, Complete One of These Tables**		
See Section 6.7 for cost break down		
Management Alternative Name: Herbicide Treatment, Handpulling		
Name of Practice: Mechanical Harvesting		
Type of Environmental Cost: Fish Kill		
Describe the environmental cost	As a result of mechanical harvesting, there will be fish incidentally killed. These fish may be presiding in the *Egeria densa* beds and could be harvested along with the plant materials.	
Describe linkages between the affected resource and human interests	Humans value fish for recreational fishing use, existence value, access value, and ecosystem value.	
Describe the persons affected	Anglers, recreational fish users, ecosystem structure.	
Measurable Attributes of this Environmental Cost	**Measure**	**Amount**
When following practice will environmental cost occur	Yes	Varies by number of species presiding in *Egeria* as habitat.
Fish Kill	$	$287
Mitigation Costs	$	$47,401
Dollar amount of environmental cost	$	**$47,988**
Total cost/season (Including environmental damages)	$	**$1,519,551-1,603,029**

<table>
<tr><td colspan="3">Entry Table 5. Big Break, Harvesting
Environmental Cost Data
For Each Environmental Cost Type Expected Following a Practice, Complete One of These Tables</td></tr>
<tr><td colspan="3">See Section 6.7 for cost break down</td></tr>
<tr><td colspan="3">Management Alternative Name: Harvesting, Handpulling</td></tr>
<tr><td colspan="3">Name of Practice: Chemical Treatment including Komeen, Sonar and Reward</td></tr>
<tr><td colspan="3">Type of Environmental Cost: Fish Kill</td></tr>
<tr><td>Describe the environmental cost</td><td colspan="2">As a result of mechanical harvesting, there will be fish incidentally killed. These fish may be presiding in the Egeria densa beds and could be harvested along with the plant materials.</td></tr>
<tr><td>Describe linkages between the affected resource and human interests</td><td colspan="2">Humans value fish for recreational fishing use, existence value, access value, and ecosystem value.</td></tr>
<tr><td>Describe the persons affected</td><td colspan="2">Anglers, recreational fish users, ecosystem structure.</td></tr>
<tr><td>Measurable Attributes of this Environmental Cost</td><td>Measure</td><td>Amount</td></tr>
<tr><td>When following practice will environmental cost occur</td><td>Yes</td><td>Varies by number of species presiding in Egeria as habitat.</td></tr>
<tr><td>Mitigation cost: Reward™</td><td></td><td>$150,332</td></tr>
<tr><td>Mitigation cost: Komeen™</td><td>$</td><td>$1,476,332</td></tr>
<tr><td>Mitigation cost: Sonar™</td><td>$</td><td>$150,332</td></tr>
<tr><td>Dollar amount of environmental cost</td><td>$</td><td>$1,700,496</td></tr>
<tr><td>Total cost/season (Including environmental damages)</td><td>$</td><td>$2,797,356</td></tr>
</table>

Entry Table 3. Number 3 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Herbicide Application, Harvesting		
Name of Practice: Handpulling (estimations according to Gibbons et al, 1999)		
General description of Practice	**Manual removal of Hyacinth and Egeria plants from the area, placed on barge to dry out and disposed**	
When during the season will practice be applied?	**Spring-late Summer during the treatment season**	
Where within the location this practice is to be applied?	**Along the plant infested perimeter of the Big Break area**	
Measurable Attributes	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$503,536-$2,337,670**	**$695-$3229/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Treatment Area	Acres	724
Labor Cost	$/day	$500-2400
# of Treatment Days (according to harvesting estimate)	Days	241
Total Cost	**$/Treatment Season**	**$503,536-$2,337,670**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is a an environmental or cost-benefit analysis, go to Entry Table 4.		

J. *BOD Model Inputs*

Fixed, Input, and Output Model Parameters

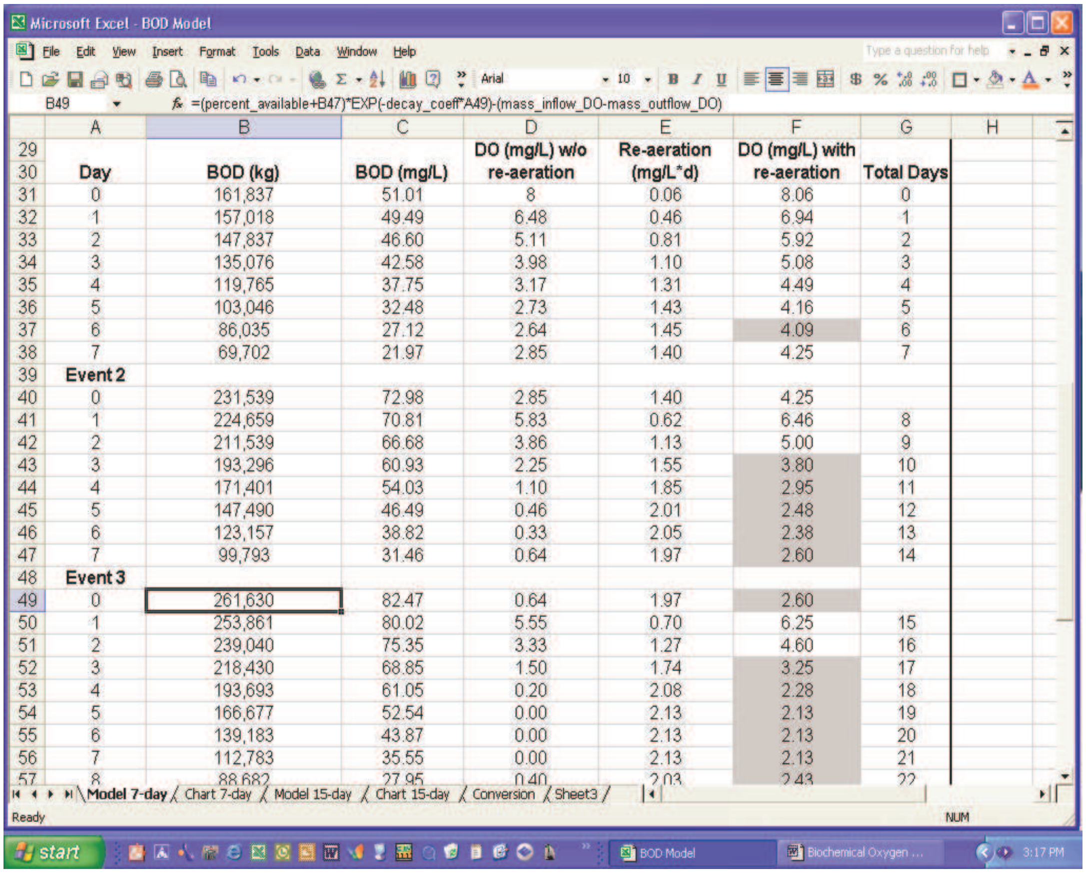


Fixed Parameter	Value	Units	
Wet Density	35	kg/m^2	Established parameters from research
Percent Dry Mass	0.06	%	
Percent Readily Available (non-HDRM)	0.572	%	
Hyacinth Decay Coefficient (25 deg C)	0.03	d^{-1}	
Lake Volume	(depth*lake surface area)/2		

Input Parameter	Value	Unit	
Lake Depth	2.4384	meters	User inputs parameters within this section
Lake Surface Area	2,602,129	m^2	
Treated Surface Area (Event)	134,760.32	m^2	
Background [DO]	8	mg/L	
Lake Inflow	5	cfs	
Lake Outflow	5	cfs	
Lake Inflow [DO]	8	mg/L	
Lake Outflow [DO]	5	mg/L	

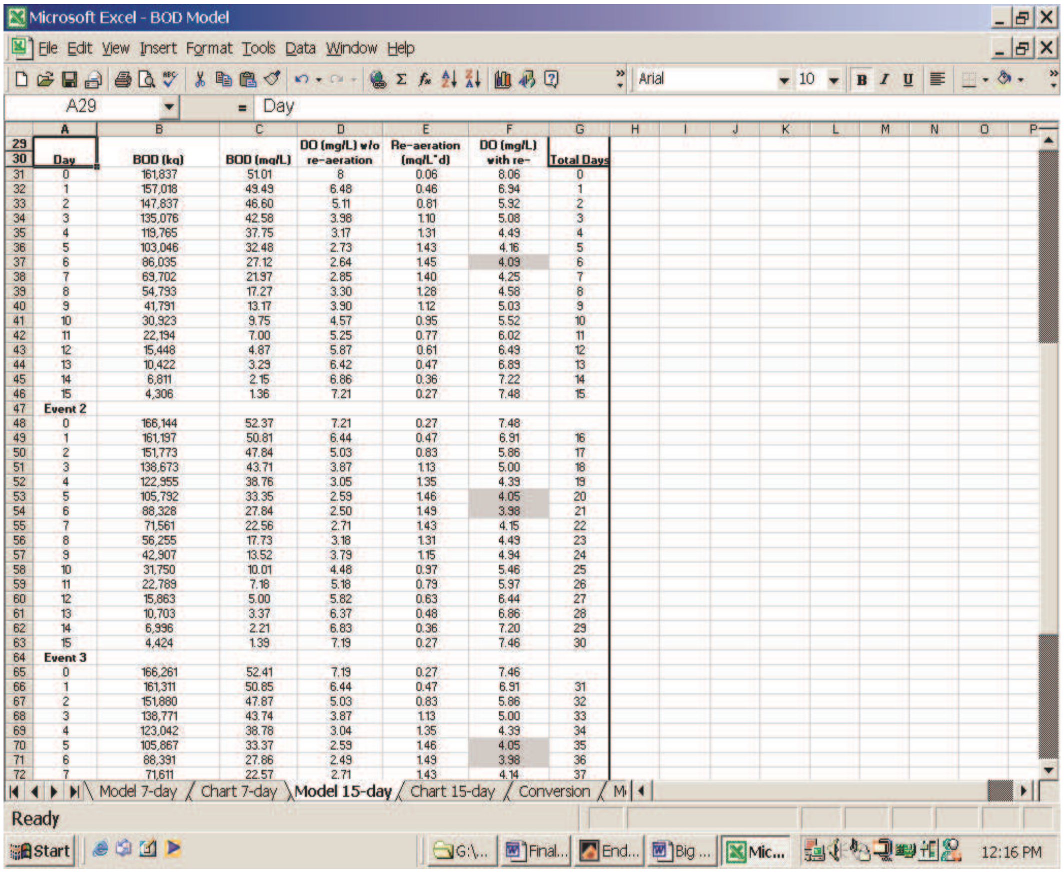
Output	Value	Unit	
Lake Volume	3,172,515,284	L	These cells calculate user inputs
Background DO	25380	kg	
Lake Inflow DO	98	kg/day	
Lake Outflow DO	61	kg/day	
Mass Hyacinth	4,716,611	kg	
Dry Mass Hyacinth	282,997	kg	
Percent Readily Available	161,874	kg	

Model output for 7-day treatment interval



Row	Day	BOD (kg)	BOD (mg/L)	DO (mg/L) w/o re-aeration	Re-aeration (mg/L*d)	DO (mg/L) with re-aeration	Total Days
31	0	161,837	51.01	8	0.06	8.06	0
32	1	157,018	49.49	6.48	0.46	6.94	1
33	2	147,837	46.60	5.11	0.81	5.92	2
34	3	135,076	42.58	3.98	1.10	5.08	3
35	4	119,765	37.75	3.17	1.31	4.49	4
36	5	103,046	32.48	2.73	1.43	4.16	5
37	6	86,035	27.12	2.64	1.45	4.09	6
38	7	69,702	21.97	2.85	1.40	4.25	7
39	Event 2						
40	0	231,539	72.98	2.85	1.40	4.25	
41	1	224,659	70.81	5.83	0.62	6.46	8
42	2	211,539	66.68	3.86	1.13	5.00	9
43	3	193,296	60.93	2.25	1.55	3.80	10
44	4	171,401	54.03	1.10	1.85	2.95	11
45	5	147,490	46.49	0.46	2.01	2.48	12
46	6	123,157	38.82	0.33	2.05	2.38	13
47	7	99,793	31.46	0.64	1.97	2.60	14
48	Event 3						
49	0	261,630	82.47	0.64	1.97	2.60	
50	1	253,861	80.02	5.55	0.70	6.25	15
51	2	239,040	75.35	3.33	1.27	4.60	16
52	3	218,430	68.85	1.50	1.74	3.25	17
53	4	193,693	61.05	0.20	2.08	2.28	18
54	5	166,677	52.54	0.00	2.13	2.13	19
55	6	139,183	43.87	0.00	2.13	2.13	20
56	7	112,783	35.55	0.00	2.13	2.13	21
57	8	88,682	27.95	0.40	2.03	2.43	22

Model output for 15-day interval



	Day	BOD (kg)	BOD (mg/L)	DO (mg/L) w/o re-aeration	Re-aeration (mg/L*d)	DO (mg/L) with re-	Total Days
31	0	161,837	51.01	8	0.06	8.06	0
32	1	157,018	49.49	6.48	0.46	6.94	1
33	2	147,837	46.60	5.11	0.81	5.92	2
34	3	135,076	42.58	3.98	1.10	5.08	3
35	4	119,765	37.75	3.17	1.31	4.49	4
36	5	103,046	32.48	2.73	1.43	4.16	5
37	6	86,035	27.12	2.64	1.45	4.09	6
38	7	69,702	21.97	2.85	1.40	4.25	7
39	8	54,793	17.27	3.30	1.28	4.58	8
40	9	41,791	13.17	3.90	1.12	5.03	9
41	10	30,923	9.75	4.57	0.95	5.52	10
42	11	22,194	7.00	5.25	0.77	6.02	11
43	12	15,448	4.87	5.87	0.61	6.49	12
44	13	10,422	3.29	6.42	0.47	6.89	13
45	14	6,811	2.15	6.86	0.36	7.22	14
46	15	4,306	1.36	7.21	0.27	7.48	15
47	**Event 2**						
48	0	166,144	52.37	7.21	0.27	7.48	
49	1	161,197	50.81	6.44	0.47	6.91	16
50	2	151,773	47.84	5.03	0.83	5.86	17
51	3	138,673	43.71	3.87	1.13	5.00	18
52	4	122,955	38.76	3.05	1.35	4.39	19
53	5	105,792	33.35	2.59	1.46	4.05	20
54	6	88,328	27.84	2.50	1.49	3.98	21
55	7	71,561	22.56	2.71	1.43	4.15	22
56	8	56,255	17.73	3.18	1.31	4.49	23
57	9	42,907	13.52	3.79	1.15	4.94	24
58	10	31,750	10.01	4.48	0.97	5.46	25
59	11	22,789	7.18	5.18	0.79	5.97	26
60	12	15,863	5.00	5.82	0.63	6.44	27
61	13	10,703	3.37	6.37	0.48	6.86	28
62	14	6,996	2.21	6.83	0.36	7.20	29
63	15	4,424	1.39	7.19	0.27	7.46	30
64	**Event 3**						
65	0	166,261	52.41	7.19	0.27	7.46	
66	1	161,311	50.85	6.44	0.47	6.91	31
67	2	151,880	47.87	5.03	0.83	5.86	32
68	3	138,771	43.74	3.87	1.13	5.00	33
69	4	123,042	38.78	3.04	1.35	4.39	34
70	5	105,867	33.37	2.59	1.46	4.05	35
71	6	88,391	27.86	2.49	1.49	3.98	36
72	7	71,611	22.57	2.71	1.43	4.14	37

K. *Stone Lakes NWR Entry Tables*

Entry Table 1. **Define the Aquatic Plant Problem.**
Name of Water Body: **Stone Lakes National Wildlife Refuge**
1a. Location: The Stone Lakes National Wildlife Refuge is located south of Sacramento in Elk Grove California. The refuge is situated within the Sacramento-San Joaquin Delta along the Pacific Flyway, the destination of thousands of migrating waterfowl, shorebirds, and other water birds.
1b. Water Body Type (identify and describe at least 1)
Small pond
Large lake: The Stone Lakes Basin is located in the Cosumnes and Mokelumne River watersheds and the Sacramento-San Joaquin River Delta. Floodwaters from these river systems and the 180-square mile Morrison Creek watershed replenish the basin's large lakes, wetlands and riparian streams during winter storms. Construction of the Sacramento River flood control system has helped to reduce extensive flooding caused by heavy winter rains and spring thaws.
Delta
Irrigation canal
Stormwater
EstuarineWetlands:
Wildlife Refuges **As of 1994; the Stone Lakes Basin has recently been converted into a national wildlife refuge.**
1c. Aquatic Plant Type (identify and describe at least 1) **Two types of aquatic plants have been identified as problem plants in the Stone Lakes.**
Floating **Water hyacinth (*Eichhornia crassipes*)**
Submersed **Eurasian Water Milfoil (*Myriophyllum spicatum*)**
Emergent
Algae
1d. Potential Economic Costs (identify and describe at least 1): Clogged waterways: as a result of the invasion and overgrowth of the plant plants, there has been a decrease in the amount of flow in surrounding sloughs and waterways. Because of Water hyacinth's high rate of water use, one acre of the plants cause a loss of up to 39 acre inches of water per month over the rate of an acre open water. (CDBW)
History of Control costs, or Control Expected: Managers at Stone Lakes NWR have traditionally controlled these plants by spraying either 2,4-D or Glyphosate, or have done some harvesting and hand pulling. This has proven to be costly and time-consuming. As a result of a pilot program, funded by the SFEI, shredding will be attempted at Stone Lakes on

the East and West portions of Lambert Slough, as well as the Stone Lake proper.
Types of Damage Costs
Contributes to flooding/drainage/storm water problems
Water supply quantity
Water supply quality
Impedes navigation
Impedes/limits recreation/parks values
Reduces aesthetic/environmental values
1e. Management Objective: To eliminate plants in order to clear clogged waterways, irrigation canals, and to avoid the overgrowth of these invasive species on the lake.
1f. Stakeholders: California Department of Transportation; California Department of Parks and Recreation; California Department of Water Resources; California Waterfowl Association; Ducks Unlimited; National Audubon Society; Sacramento Regional County Sanitation District; Sacramento County Department of Parks, Recreation and Open Space; Sacramento Open Space; Stone Lakes Alliance; The Nature Conservancy and Trust for Public Lands; U.S. Bureau of Reclamation, Vino Farms

Entry Table 3. Number 1 Costs of a Management Practice. For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.		
Management Alternative Names: Shredding, Handpulling		
Name of Practice: Herbicide/surfactant application		
General description of Practice	**Weedar64® and AquaMaster® are applied, in addition to a surfactant (R-11) with the labor from 2 additional employees hired for the hyacinth control program**	
When during the season will practice be applied?	**May-October, four days a week**	
Where within the location this practice is to be applied?	**Sloughs, waterways, canals, and Stone Lakes proper**	
How much will be applied?	**Approximately 160 gallons Weedar64, and 95 gallons AquaMaster, 50 gallons R-11**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$94,442**	**$314/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors/contributions that affect cost: Equipment, Labor, Chemicals	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	300
USFWS	Dollars/Year	$35,642
SRCSD	Dollars/year	$24,000
CO WRD	Dollars/year	$18,600
DBW	Dollars/year	$1500
Wildlands, Inc.	Dollars/year	$1000
SFEI	Dollars/year	$6000
Vino Farms	Dollars/year	$5700
Sutter Home	Dollars/year	$2000
Total	**Dollars/year**	**$94,442**
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 3. Number 2 **Costs of a Management Practice.** **For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.**		
Management Alternative Names: Herbicide Treatment, Handpulling		
Name of Practice: Shredding		
General description of Practice	**A large mechanical shredder mulches the plants as it makes its way through the waterways.**	
When during the season will practice be applied?	**Early in season when the plants are small enough to not clog shredding machine; spring**	
Where within the location this practice is to be applied?	**Sloughs, waterways, canals, and Stone Lakes proper**	
How much will be applied?	**Dependant on environmental conditions; most likely a few times per season**	
Measurable Attributes of this Practice	**Measure/Units**	**Answer/Number of Units**
Total Control Cost, if known	**$245,106-$286,295***	**$817-954*/acre**
If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.		
If Total Control Cost not known, name factors that affect cost (See Information Table 2)	**Measure/Units**	**Answer/Number of Units**
Acreage to be treated	Acres	300
Treatment Rate	Acres/hour	0.5
Cost per acre	$/acre	$817-$954*
Total Cost	**$/season**	**$245,106-$286,295***
Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is a an environmental or cost-benefit analysis, go to Entry Table 4.		

Entry Table 5. Number 1 Environmental Cost Data: Stone Lakes National Wildlife Refuge Environmental Cost Type Expected Following a Practice, Complete One of These Tables		
Row Numbers from Entry Table 2 (1st, 2nd, etc) ____		
Management Alternative Name: Shredding w/ 15-day interval b/n events		
Name of Practice: Shredding w/ 7-day interval b/n events		
Type of Environmental Cost: Fish Kills		
Describe the environmental cost	Fish kills would result from depleted dissolved oxygen levels causing anoxia within the water body.	
Describe linkages between the affected resource and human interests	Fish provide food for Refuge waterfowl. Around 6,000 naturalists and bird-watchers visit annually.	
Describe the persons affected	Fishermen, although fishing is prohibited in the Refuge.	
Measurable Attributes of this Environmental Cost	**Measure**	**Amount**
When following practice will environmental cost occur	Time Units	
Approximate number of fish affected	43,944	$1.4 to 4.93 per pound
Dollar amount of environmental cost, if it can be measured (see Section 3.8)	Dollars (average)	**$41,189**
Total Cost,with Environmental Costs Included	**$**	**$245,106-$286,295**

<table>
<tr><td colspan="3">Entry Table 3. Number 3
Costs of a Management Practice.
For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.</td></tr>
<tr><td colspan="3">Management Alternative Names: Shredding, Herbicide Application</td></tr>
<tr><td colspan="3">Name of Practice: Harvesting, H-5 Harvester</td></tr>
<tr><td>General description of Practice</td><td colspan="2">A 200 cubic foot harvester removes the water hyacinth from the water body at a rate of approximately 1-2 acres per day</td></tr>
<tr><td>When during the season will practice be applied?</td><td colspan="2">Spring-late Summer during the treatment season</td></tr>
<tr><td>Where within the location this practice is to be applied?</td><td colspan="2">Sloughs, waterways, canals, and Stone Lakes proper</td></tr>
<tr><td>How much will be applied?</td><td colspan="2">Approximately 200 days are necessary for harvesting Stone lakes</td></tr>
<tr><td>Measurable Attributes of this Practice</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Total Control Cost, if known</td><td>$205,016-208,177</td><td>$683.39-693.92/acre</td></tr>
<tr><td colspan="3">If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.</td></tr>
<tr><td>If Total Control Cost not known, name factors that affect cost (See Information Table 2)</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Treatment Area</td><td>Acres</td><td>300</td></tr>
<tr><td>Set up (one time cost $967-1064 per job)</td><td>$/Job</td><td>$1,016</td></tr>
<tr><td>Operating Cost</td><td>$/Day</td><td>$500</td></tr>
<tr><td>Labor Cost</td><td>$/Day</td><td>$520</td></tr>
<tr><td>Treatment Rate</td><td>Acres/Day</td><td>1.5</td></tr>
<tr><td>Cost/Acre</td><td>$/acre</td><td>$683.39</td></tr>
<tr><td>Total Cost</td><td>$</td><td>$205,016</td></tr>
<tr><td>If Disposal Costs Considered</td><td>$</td><td>$208,177</td></tr>
<tr><td colspan="3">Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.</td></tr>
</table>

<table>
<tr><td colspan="3">Entry Table 3. Number 3
Costs of a Management Practice.
For Each Unique Management Practice from All Entry Table 2s, Complete One of These Tables.</td></tr>
<tr><td colspan="3">Management Alternative Names: Herbicide Application, Harvesting, Shredding</td></tr>
<tr><td colspan="3">Name of Practice: Handpulling (estimations according to Gibbons et al, 1999)</td></tr>
<tr><td>General description of Practice</td><td colspan="2">Manual removal of Water hyacinth plants from the area</td></tr>
<tr><td>When during the season will practice be applied?</td><td colspan="2">Spring-late Summer during the treatment season</td></tr>
<tr><td>Where within the location this practice is to be applied?</td><td colspan="2">Stone Lakes proper and surrounding sloughs and waterways</td></tr>
<tr><td>How much will be applied?</td><td colspan="2"></td></tr>
<tr><td>Measurable Attributes of this Practice</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Total Control Cost, if known</td><td>$100,000-$480,000</td><td>$333-$1600/acre</td></tr>
<tr><td colspan="3">If Total Control Cost was known, go to next practice, or if all practices are done, and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.</td></tr>
<tr><td>If Total Control Cost not known, name factors that affect cost (See Information Table 2)</td><td>Measure/Units</td><td>Answer/Number of Units</td></tr>
<tr><td>Treatment Area</td><td>Acres</td><td>300</td></tr>
<tr><td>Labor Cost</td><td>$/day</td><td>$500-2400</td></tr>
<tr><td>Number of Treatment Days required (according to harvesting estimate)</td><td>Days</td><td>200</td></tr>
<tr><td>Total Cost</td><td>$/Treatment Season</td><td>$100,000-$480,000</td></tr>
<tr><td colspan="3">Go to next practice, or if all practices are done and this is a cost analysis, go to Entry Table 6. If this is an environmental or cost-benefit analysis, go to Entry Table 4.</td></tr>
</table>