KRIS edition

Stemple Creek/Estero de San Antonio Watershed Enhancement Plan

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Prepared for:

Marin County Resource Conservation District
and
Southern Sonoma County Resource Conservation District

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Cover Photo: Dairy farming at the John Poncia ranch, Tomales-Petaluma Road near Twin Bridge Road. Circa 1910. Courtesy of the Tomales History Center.

1. Executive Summary

The Stemple Creek/Estero de San Antonio Enhancement Plan grew out of two-and-a-half years of effort on the part of two Resource Conservation Districts -- Marin County and Southern Sonoma County, watershed residents, public agencies and local individuals and organizations. The primary goal of the plan is to conserve and, where possible, improve the natural resources of the watershed while maintaining a vigorous agricultural economy.

The Plan began as an exploration into the causes of the sedimentation and apparent decline in tidal function of the Estero de San Antonio. The Estero is a treasured coastal resource. It is included in the Gulf of the Farallones National Marine Sanctuary and has been used by generations of Californians, from the Coast Miwok to modern-day ranchers, for harvesting food and for recreation. Its many diverse habitats, ranging from eelgrass beds to coastal terrace prairie, support an equally rich fauna. Three federally-listed endangered species live in or near the Estero -- the Tidewater Goby (*Eucyclogobius newberryi*), Myrtle Silver Spot butterfly (*Speyeria zerene myrtleae*), and the freshwater shrimp (*Syncaris pacifica).* The watershed draining into the Estero is almost entirely in agricultural use, primarily as dairy and livestock ranches.

As the project staff met with watershed residents, individually and in three public meetings, listened to the Advisory Committee and conducted field studies, other issues besides soil erosion and its impact on the Estero emerged. Seriously degraded water quality, the construction of a large dam to impound treated wastewater within the watershed, loss of wildlife, threats to the economic stability of the region and ever-increasing pressure from regulatory agencies are widespread concerns. On the plus side are motivated residents who are ready to join in conservation efforts, and a coalition of supportive government agencies who are helping to secure funding and find ways to ease the regulatory burden for resource enhancement projects.

The Enhancement Plan attempts to pull together the concerns identified and the resources available to address them into an integrated plan of action. The appendices contain five technical reports on the biology, vegetation, erosion and sedimentation, water resources and the hydrology of the Estero. Appendix F is a summary of individual landowner meetings.

The technical reports along with input from the Advisory Committee and watershed residents were used to develop the following ten Enhancement Recommendations.

Enhancement Recommendations

1. Encourage the local community to take the lead in developing and implementing enhancement projects.

2. Assist agricultural producers with practices that promote the conservation and enhancement of natural resources.

3. Reduce pollutants entering Stemple Creek and the Estero.

4. Reduce soil erosion.

5. Encourage environmentally-sound management of rangeland.

6. Conserve and enhance existing natural habitats.

7. Restore the riparian corridor.

8. Develop a long-term monitoring program.

9. Support agriculture as the major land use in the watershed.

10. Request additional investigation by the Santa Rosa Subregional Water Reclamation System on the potential impacts of the proposed West County Alternative on agriculture and natural resources.

Funding for the Enhancement Plan came from the State Coastal Conservancy, the Marin Community Foundation and the Dean Witter Foundation, along with generous in-kind contributions from the Soil Conservation Service and project consultants.

2. Guide to the Enhancement Plan

This Enhancement Plan is intended to be used at multiple levels. Some readers may have limited time and want only to absorb the main points, while others will be able to read every Appendix.

For those who only have a half an hour or so:

- ❑ Read Section 1, the Executive Summary;
- ❑ Read the shaded paragraphs in Section 4, Enhancement Recommendations; and
- ❑ Review Section 5, Summary of Long-term and Short-term Goals.

For those who want to delve more deeply into the research behind the Plan, the Appendices are either attached or available through the Southern Sonoma or Marin County Resource Conservation Districts.

3. The Watershed

The Stemple Creek Watershed (see Figure 1) begins just west of Petaluma and empties into the Pacific Ocean through the Estero de San Antonio. It encompasses 50 square miles, almost all of it in agricultural production. The towns of Two Rock and Fallon once provided basic services to local ranchers, but little remains of either except a few buildings and a sense of place.

Dairies and livestock ranches, both beef and sheep, are the mainstay of the watershed economy. There are currently 32 dairies and at least twice as many livestock ranches. The Coast Guard training facility at Two Rock houses about 370 people, but most of them move rapidly in and out of the area.

The drainage is cut almost exactly in half by the Sonoma-Marin county line. On the most eastern and western ends of the watershed, outside of Petaluma and at Dillon Beach, rural residential development is encroaching on the watershed. A golf course with a hotel and restaurant complex is proposed for the sheep ranch just north of the mouth of the Estero. Much of the remaining land in both counties is covered, at least for now, by agricultural zoning. The Marin Agricultural Land Trust holds easements on two ranches within the watershed. The proposed extension of the Point Reyes National Seashore along the east shore of Tomales Bay up to Bodega would provide agricultural easements on many more properties.

The land draining into Stemple Creek is largely gently-sloped grassland. Willows once grew thickly along the streams, and oaks and bays still occur in some of the higher tributaries. Eucalyptus, planted in rows for windbreaks and fuel, is now one of the most common trees.

Stemple Creek itself was once a marginal coho salmon (*Oncorhynchus kisutch)* and steelhead trout *(Salmo gairdneri)* stream. A small dam for livestock built in the Button Ranch in the early 1960's closed off the last available spawning areas. Residents tell of dense flocks of waterfowl but as in most areas along the Pacific flyway their numbers have dropped precariously in recent years. Farm ponds, especially those with shallow edges, now provide some of the best remaining habitat for waterfowl, Western Pond Turtles (*Clemmys marmorata)* and other aquatic species.

Many of the deep holes in Stemple Creek have filled in within the last twenty years, and the water quality is now so poor that residents who grew up swimming and fishing in the creek no longer let their children play in it.

The watershed changes sharply from Highway 1 west. Slopes increase in steepness, coastal scrub and dense stands of native perennial grasses take over the hills. There is no longer any road access to the Estero; the old ranch roads that once led there are overgrown. Visitors must either hike in through private property or come by water. The Estero is part of the Gulf of the Farallones National Marine Sanctuary and included in the Central California Coast Biosphere Reserve (UNESCO Man and Biosphere Program). The California Department of Fish and Game has identified it as one of the most significant habitat areas in the State. It is a remarkable mosaic of intermingling habitat types -- densely wooded riparian ravines, saltgrass areas, mudflats, eelgrass beds, even two small freshwater ponds. Fish, bird and invertebrate species that use the Estero are listed in Appendix A. Watershed habitat types are explained in more detail in Appendix B.

4. Enhancement Recommendations

The recommendations represent the collective findings, observations and creativity of the project technical team; an Advisory Committee, which included landowners, agency representatives, local supervisors and environmental organizations; and the watershed residents themselves.

Each recommendation is followed by a list of goals and ongoing activities. The short-term goals are intended to be completed within one year of securing the necessary funding. The long-term goals are projected to take five to ten years. Both are dependent upon receiving continuing community support and additional funding through grants and cost-share programs.

Section 5 is a table showing all of the long- and short-term goals, who is responsible for completing each one, possible funding sources and required permits.

- **Enhancement Recommendation 1: Encourage the local community to take the lead in developing and implementing enhancement projects.**

MCRCD, SCCRCD, and all the agencies and organizations involved in resource management can make recommendations, encourage action and some can even regulate against gross violations of public laws; but ultimately, the enhancement of the Stemple Creek watershed and Estero de San Antonio will be done ranch by ranch, landowner by landowner.

The most important goal of this Enhancement Plan is to encourage those who live and work in the watershed to take pride in their land, to improve it where necessary and to keep it healthy for future generations. The remaining nine recommendations cover specific ways to accomplish this, including providing planning, permitting and financial assistance to residents. The following four goals are specific to fostering community ownership of the Enhancement Program.

Short-Term Goals:

- ❑ Modify the Advisory Committee to include mostly watershed residents. Include student representatives from local schools. Have committee members elect a chairperson to lead the group.

- ❑ Develop a watershed newsletter to keep residents updated on enhancement activities and to share information on technical, economic and regulatory issues that affect them.

Ongoing Activities:

- ❑ Involve community children in watershed projects through local schools.
- ❑ Use signs visible from roads that explain demonstration projects, newspaper coverage and movable displays at public events to increase community awareness of the enhancement program.
- ❑ Encourage cooperative projects between landowners and projects that involve local volunteers, such as FFA, 4H and other community organizations.

- **Enhancement Recommendation 2: Assist agricultural producers with practices that promote the conservation and enhancement of natural resources**.

One of the most cost-effective actions that the Resource Conservation Districts can take is to make it easier for private landowners to implement conservation practices themselves. When project staff asked landowners what would help them undertake more conservation practices, two of the most frequently heard requests were assistance with the regulatory process and more one-on-one technical assistance.

The process of finding out which regulations might apply, connecting with a genuine human voice on the other end of the telephone, preparing the permit application (which often requires detailed construction drawings), paying the fees, and waiting, for months or in some extreme cases, even years, for a response has thwarted many good projects. A livestock crossing, for example, that allows a rancher to exclude cattle from a section of stream near freshwater shrimp (*Syncaris pacifica)* habitat will probably require permits from the California Department of Fish and Game, the Marin or Sonoma County Public Works Department and the U.S. Army Corps of Engineers in consultation with the U.S. Fish and Wildlife Service. Instead of supporting urgently-needed restoration efforts, regulations sometimes defeat them.

Although some regulatory agencies have a terrific track record of quickly responding to information requests and permit approvals, many are overwhelmed by an increasing work load coupled with decreasing staff. In order to decrease the time and effort involved in obtaining permits for each project, the Advisory Committee recommended securing watershed-wide permits from each permitting agency for all practices that are included in the Enhancement Plan.
Because individual conservation plans, developed with the rancher, consider all aspects of ranching -- economics, quality of life, site conditions -- they effectively focus one-on-one technical assistance where the rancher needs it most and where it can provide the greatest long-term benefit to natural resources. Conservation plans help producers define long-term goals for production, conservation and quality of life. They can also help with securing cost-share funds and complying with environmental regulations.

The call for conservation plans on individual ranches has recently gained new urgency. By July 1995, Congress has mandated that state resource agencies have a plan to treat all non-point pollution sources by the year 2003. Although California's plan is not completed, it is likely that the range management component of that plan will strongly recommend that ranchers have plans that address water quality.

Short-Term Goal:

- ❑ Secure watershed-wide permits from all responsible agencies for projects that are covered in this Enhancement Plan. These would include, but not be limited to, erosion control, cattle crossings in conjunction with riparian fencing, removal of exotic plants, and other activities that enhance the natural environment and frequently require permits and/or environmental review.

Long-Term Goals:

- ❑ Assist at least 35% of the watershed's major producers with the development of comprehensive conservation plans to coordinate range management, animal waste management, erosion control, wildlife habitat, economics and other factors. These plans may be as simple or detailed as each individual rancher wants.

- ❑ Encourage cooperative planning and projects between neighboring producers.

Ongoing Activities:

- ❑ Sponsor workshops, meetings, tours and other forums to provide training and foster information exchange between producers, regulators and educators.
- ❑ Use RCD access to public agencies, universities and other resources to bring free or low-cost technical assistance to watershed residents.

Ongoing Activities (continued):

- ❑ Promote cost-share programs and grants for conservation projects.
- ❑ Use the watershed newsletter and other newsletters to share information on techniques, funding, new regulations and basic habitat requirements for wildlife species, especially those that landowners have expressed interest in encouraging.

- **Enhancement Recommendation 3: Reduce pollutants entering Stemple Creek and the Estero.**

Stemple Creek and the Estero de San Antonio are listed as impaired water bodies by the North Coast Regional Water Quality Control Board. They suffer from high temperatures, low oxygen, high salt content, high sediment loads and excessive nutrients, primarily nitrogen.

High temperatures, although not pollutants in themselves, decrease the amount of oxygen dissolved in the water. Combined with low flows and a high biological oxygen demand (BOD) from decomposing organic matter, they help to create an oxygen shortage that severely limits the wildlife that can survive in Stemple Creek. High temperatures also allow more rapid conversion of nitrogen into its toxic form that is lethal to all aquatic animals.

Heavy metals, agricultural chemicals and nutrients tend to accumulate in an aggrading stream system such as Stemple Creek. We don't know the potential toxic effects of this accumulation in the Estero or Stemple Creek because cumulative impacts have not been addressed in past monitoring programs. In other watersheds, these pollutants have been proven to have serious, long-lasting and detrimental effects on the environment.

Because surface and groundwater are so closely linked in the watershed, certain pollutants can readily enter groundwater and contaminate the shallow wells along Stemple Creek. Many residents interviewed stated that their drinking water quality has grown much worse in the last ten years. One well has recently been condemned because of nitrate contamination.
Many watershed landowners expressed concern over pollutants from the Sonoma County Landfill and the Coast Guard Training Station. Although water quality data from monitoring wells below the landfill and Regional Water Quality Control Board testing stations do not indicate excessive levels for the parameters tested, residents are worried that the type of pollutants produced, particularly at the landfill, may not be showing up in the monitoring data.

Short Term Goals:

- ❑ Demonstrate development of model waste management plans as recommended by the Sonoma Marin Animal Waste Committee on one or two dairies within the watershed.

- ❑ Provide testing kits and training in self-monitoring techniques to dairy operators.

Long-Term Goals:

- ❑ Consistently achieve or exceed minimum water quality standards as defined in the Water Quality Control Plan for the North Coast Region (the Basin Plan).

- ❑ Offer assistance to all dairy producers and others with confined animal facilities to develop waste management plans.

- ❑ Provide training and demonstrations on nutrient budgeting, self-diagnosis, reducing livestock access to streams, the use of wetlands to improve water quality and enhance wildlife habitat, and other practices to better manage animal wastes. Explore techniques that serve groups of producers.

Ongoing Activities:

- ❑ Foster proactive, cooperative approaches between agriculture and agencies to meet clean water goals. Encourage the Agricultural Stabilization and Conservation Service (ASCS) to coordinate programs with other federal and state resource agencies.

- ❑ Expand and coordinate surface and groundwater monitoring by both public agencies and private landowners. Encourage the use of self-monitoring as a tool to measure and encourage success. (See Enhancement Recommendation 8.)

- ❑ Encourage regulatory agencies to uniformly enforce water quality standards for all activities in the watershed.

- ❑ Provide information through newsletters and other forums on what constitutes water pollution and what effect it has on Stemple Creek and the Estero.

- **Enhancement Recommendation 4:** **Reduce soil erosion.**

The Estero de San Antonio has lost 80% of its historic volume due to sedimentation. Soil corings indicate that the original marshplain close to the mouth of the Estero is buried under two to three feet of sediment. Although much of this sediment came during the last century when annual crops were widely grown in the area, erosion continues today, particularly in the steep, Franciscan-derived soils west of Highway 1. Almost 60% of all the current sediment produced comes from gullies and eroding tributaries in the lower watershed.

The mouth of the Estero closes due to a complex interaction between wave and tide conditions, and the volume of the tidal prism, or the amount of water flooding and ebbing through the entrance channel. Bathymetric surveys of the Estero conducted before and immediately after the 1992/93 winter, a fairly normal rainfall year following six years of drought, showed that up to five feet of scour occurred in parts of the lower Estero. We can't do anything to alter tides or wave energy, but this data indicates that rigorous erosion control could eventually lead to an increase in the tidal prism and help to at least maintain the existing closure cycle. Without erosion control, the Estero will continue to fill in at an accelerated rate and the mouth will remain closed for increasingly longer periods of time, resulting in conditions of low oxygen, toxic accumulation and possible hypersalinity.

Along with erosion control, the Enhancement Plan also recommends a thorough monitoring program of the Estero to determine if sediment reduction alone is enough to maintain the current tidal prism. (See Enhancement Recommendation 8.)

<u>Long-Term Goals:</u>

- ❑ Repair all major, active gullies and bank erosion in the lower watershed. Incorporate native vegetation, especially woody plants, into erosion control wherever feasible to increase wildlife habitat.

- ❑ Repair significant, active erosion sites in the middle and upper watershed.

- ❑ Demonstrate conservation tillage, filter strips and other methods to reduce cropland erosion. Provide follow-up monitoring to measure effectiveness.

<u>Ongoing Activity:</u>

- ❑ Incorporate erosion control into comprehensive conservation plans for individual ranches. (See Enhancement Recommendation 2.)

- **<u>Enhancement Recommendation 5:</u> Encourage environmentally-sound management of rangeland.**

About 80% of the Stemple Watershed is rangeland. Improving the quality of grazing lands has important benefits to both the rancher and the environment. Healthier soil and grass, a longer growing season and greater control over livestock use patterns increase agricultural production. The SCS Erosion and Sediment Study for the watershed (Appendix C) estimates that if range improvement practices were applied to the nine percent of rangeland with the lowest residual dry matter (RDM), the discharge during a two-year rainfall event could decrease by as much as six percent. Although a seemingly small number, this six percent reduction could have a significant impact on reducing gully and stream channel erosion. The lower runoff rate would also increase infiltration into the groundwater which would ultimately increase base flow into Stemple Creek.

Productive rangeland supports more than livestock. Many of the watershed's wildlife species are dependent upon grasslands. Grazing practices that promote a diversity of plants including native grasses and forbes, protect waterways and reduce erosion are fundamental to the long-term health of Stemple Creek and the Estero de San Antonio.

Long-Term Goals:

- ❑ Assist ranchers to develop and demonstrate economically viable and environmentally friendly range management practices that are adapted to local conditions. Follow up with monitoring and tours.
- ❑ Develop self-monitoring and diagnosis guidelines to help ranchers find and correct potential problems.
- ❑ Assist at least 35% of the watershed's major producers with the development of comprehensive conservation plans. (See Enhancement Recommendation 2.)

Ongoing Activities:

- ❑ Promote efforts to educate the general public about how managed grazing and resource enhancement can work hand-in-hand.
- ❑ In the words of a watershed rancher, "Encourage people to take chances, to be willing to fail." The interaction between an individual piece of land and grazing animals is amazingly complex. There is much yet to be discovered.

- **Enhancement Recommendation 6: Conserve and enhance existing natural habitats.**

Conservation of remaining natural habitat is not an esoteric quest. There are many practical things to learn from these places -- how native grasslands, for example, affect runoff rates and erosion; how micro-organisms in the soil enable plants to more efficiently use nutrients; and ultimately, how we can produce the food and fiber we need without destroying our natural resource base. These dwindling areas are also a small legacy, for this generation to pass on to the next, of the wild beauty and abundance that once existed in the watershed.

The Stemple Creek watershed supports a surprisingly rich variety of natural areas, especially at its east and west ends. The Estero de San Antonio intermingles extensive coastal terrace prairie, riparian woodland, coastal scrub, freshwater marsh, brackish marsh, eelgrass beds and open water into one of the richest natural areas along the California coast.

The Button Ranch and several of the south-side tributaries contain areas of native grassland, oak and bay forests, and dense stands of riparian vegetation. These areas provide most of the watershed's surface water, and once supported steelhead and small coho salmon runs. The bay woods at the Button Ranch are believed to be a remnant of an ancient forest that once covered vast areas of the region. Recently two crustacean species were found there -- one known from only five other sites and another that is apparently a new discovery. Golden eagles have nested in the Button Ranch for as long as local residents can remember.

The California freshwater shrimp (*Syncaris pacifica)* is both a state- and federally-listed endangered species. It was once common in many streams in Sonoma, Marin and Napa Counties. For a long time, it was thought to be extirpated from Stemple Creek, but a small population has been found near Highway 1. The shrimp stay near undercut banks, overhanging vegetation and exposed root systems. Willow and alder roots, blackberries, sedges and stinging nettles are commonly associated with freshwater shrimp habitat.

The shrimp are small, about an inch to an inch-and-a-half long, and some can be quite beautiful with a clear reddish body and rust-colored markings. They are detritus feeders, eating mostly bits of dead vegetation. They have few native predators, but introduced members of the sunfish family, such as bluegill, aggressively pursue and eat them.

Students at Brookside Elementary School in Sleepy Hollow have formed the Shrimp Club to educate people about this small animal and to enhance its habitat. The Club recently won a national award from Anheuser Busch for their work. The members want to use some of their prize money and additional grants to help interested Stemple watershed landowners restore trees and shrubs to creek banks.

Long-Term Goals:

- ❑ Demonstrate and monitor at least three different methods for controlling livestock access to the Estero. These could include placement of water, feed and nutrient supplements; controlling timing and duration of grazing; and various types of fencing. Encourage neighboring landowners through technical and financial assistance to utilize successful methods along the entire Estero.

- ❑ Restore riparian habitat adjacent to areas where freshwater shrimp are currently present (near Highway 1). Monitor shrimp populations after the restoration work.

- ❑ Restore additional riparian habitat along at least 50% of Stemple Creek and its tributaries. (See Enhancement Recommendation 7.)

Ongoing Activities:

- ❑ Continue to work with the Shrimp Club in its efforts to restore freshwater shrimp habitat.

- ❑ Assist the State Coastal Conservancy, Marin Agricultural Land Trust, Sonoma County Open Space District or other appropriate entity in the purchase of wetland areas or conservation easements from willing sellers.

Ongoing Activities (continued):

- ❑ Help landowners identify and keep track of important habitat areas, such as healthy riparian corridors, dense stands of native grasses or stockponds with shallow edges that support a variety of aquatic life. Include management recommendations for these areas in the Ranch Conservation Plans (Enhancement Recommendation 2).

- ❑ Encourage use of grazing management practices that promote native grasses over introduced annuals. (See Enhancement Recommendation 5.)

- ❑ Provide information to appropriate landowners on the most effective methods to control invasive weedy plants.

- ❑ Restore instream summer pools. If sediment reduction alone is not effective, demonstrate the creation of one or more pools utilizing natural hydraulic processes.

- **Enhancement Recommendation 7: Restore the riparian corridor.**

The riparian corridor is the area next to a stream. Along mainstem Stemple Creek, willows and tules were once dominant plants. Up higher in the tributary channels, bay trees, box elders, live oaks and native shrubs would have been common. The plants in a riparian corridor are vital to the health of the entire watershed. They cool water in the stream, filter runoff from pastures and paddocks, utilize nutrients before they enter the water, protect banks from erosion and provide essential habitat for many wildlife species. A vigorous riparian forest can substantially increase the rate of summer flow in a stream channel.

Stemple Creek has lost much of its historic riparian vegetation. Only 20% of the stream channels now have willows or other woody plants growing along them. Erosion in many tributaries, high water temperatures, low water quality and a significant decline of key wildlife species are results of this loss.

Exclusionary fencing has been the standard solution for protecting riparian areas from livestock damage. Yet many watershed residents have expressed serious reservations about this solution. First, it is extremely expensive. Second, especially in the flat terraces near the Estero, the fence must either be placed above the highwater mark, in which case much of the best grazing land is lost to production, or continually maintained because of rusting from salt water, damage from trees, or debris carried in flood flow or burying from sedimentation.

Some landowners also expressed concern about willows growing into the channel, and exacerbating flooding and bank erosion as the stream cuts a new path around them. Maintenance of the low-flow channel for several years to keep willows confined to the banks should be an integral part of a replanting or fencing project. Once the trees grow high enough to shade the low-flow channel, willows should no longer colonize it. In addition, as streambanks and gullies upstream become stabilized, they will no longer produce as much sediment to fill in downstream channels.

Another worry we heard is that coyotes and foxes may hide in thick riparian growth. Predation is a serious problem for many of the watershed's sheep herds and warrants that careful attention be given to designing riparian restoration on or near sheep ranches.

In response to these concerns, the project team, SCS and landowners have developed a number of options to protect and restore the riparian corridor. They include:

1. Exclusion Fencing. Many ranchers have already fenced off streams throughout the watershed, most with traditional field fencing or five-strand barbed wire fences. Seasonal single- or double-strand electric fencing that can be

easily unstrung before the flood season is another option that has been suggested by landowners for use in the middle and lower reaches of Stemple Creek. Livestock crossings and off-stream water development, as well as cost-share programs, are usually essential components of any exclusion approach.

In many situations, riparian plants will return by themselves, but planting achieves faster results and better control over which plants become established. Willows are not the only plant choice, although they are the native pioneering species in the watershed. Certain grasses, such as creeping wild rye *(Leymus triticoides)*, also native to the area, have been used successfully in other areas to stabilize banks, filter runoff and provide some overhanging cover. Species lists and planting methods are included in Appendix B, Watershed Vegetation and Habitat Restoration. Livestock crossings and water development are critical components to most fencing projects.

Landowners also suggested that making the lot line adjustment process easier might help ranchers better manage their riparian corridors in some situations.

2. <u>Riparian pastures.</u> Riparian pastures would encourage larger areas to be fenced by allowing seasonal, carefully regulated grazing in the riparian area. This method, or variations of it, is already practiced by some watershed residents. Livestock would need to be completely excluded for two to three years until vegetation was established, or temporary fencing could be used to protect woody plants along the channel while the remaining grassy areas are grazed. Carefully monitored demonstrations of riparian pastures are needed to assess their effectiveness and develop grazing strategies that sustain riparian vegetation.

3. <u>Grazing management.</u> There remain a few examples of vigorous riparian forest along Stemple Creek that are not excluded from livestock. However, grazing in these areas is carefully managed and alternate water sources are usually available. Cross-fencing, for example, could allow rest periods to sections of riparian corridor while livestock have access to others. This option may not be effective in denuded areas until new plants have become firmly established.

4. <u>Development of alternative water sources.</u> As a minimal remedy, off-stream water and shade sources can help reduce the time livestock spend in and near streams.

Long-Term Goal:

- ❑ Re-establish riparian vegetation along 50% of watershed stream channels. This will include existing riparian habitat on the mainstem and tributaries, which now covers approximately 20% of the corridor. The Estero (downstream of Highway 1) is not figured into the total length of stream channel because the dominant habitat changes from riparian forest to brackish wetland. Tributaries to the Estero, however, are included.

- ❑ Landowners also recommended that priority be given to stream protection projects where long, contiguous stretches of creek with neighboring landowners can be restored.

- **Enhancement Recommendation 8: Develop a long-term monitoring program.**

Monitoring, combined with clear performance goals, is essential to effective enhancement programs. We recommend three monitoring categories:

1. Sediment deposition and ecological health of the Estero de San Antonio;
2. Water quality for both surface and groundwater; and
3. Population of freshwater shrimp, *Syncaris pacifica.*

Appendix E, Geomorphic and Hydrodynamic Analysis of the Estero de San Antonio, recommends a ten-year monitoring program be implemented. The program would assess whether erosion control measures are effective in maintaining the current tidal prism, better define mouth closure conditions, and assess the physical evolution of the lagoon should it be considered desirable to use more drastic measures, such as artificial opening or dredging, to reduce the length and frequency of closure. Monitoring of the Estero for water quality and ecological changes should also be included.

Both the California Department of Fish and Game and The North Coast Regional Water Quality Control Board regularly test surface water in Stemple Creek. However, additional information would help to better pinpoint and correct water quality problems. For example, current testing methods for some heavy metals cannot detect the maximum allowable levels.

The Regional Water Quality Control Board maintains eight monitoring wells adjacent to the Sonoma County landfill site to test for contamination in the groundwater, but no other monitoring wells exist in the watershed. A specific study in 1982, which included two shallow wells in the upper Two Rock Valley, indicated nitrate levels that exceeded drinking water standards. Studies conducted by the Santa Rosa Subregional Water Reclamation System showed that most wells had acceptable drinking water, but some of the shallow, hand-dug wells along Stemple Creek had high levels of nitrates, coliform bacteria and total dissolved solids. Several residents in that area said that their drinking water quality has declined seriously in the past ten years. Brown, smelly water sometimes comes out of their faucets.

Self-monitoring by residents of both surface and groundwater is an invaluable management tool. Groundwater samples need to be taken to qualified laboratories, but many surface water quality parameters, such as nitrogen levels, can be tested easily with inexpensive test kits. Self-monitoring results do not have to be shared with regulatory agencies. Their purpose is to help residents find and fix potential problems, and to learn which pollution control methods work best for them.

Freshwater shrimp populations are not currently monitored on a regular basis. As more riparian habitat is returned to the watershed, particularly in the areas where shrimp have been observed, monitoring would help to measure success and/or modify restoration techniques.

<u>Long-Term Goals:</u>

- ❑ Establish a monitoring program to determine the impacts of enhancement measures on water quality, ecology, bathymetry (to see if net scour or deposition is occurring) and mouth closure in the Estero de San Antonio.
- ❑ Provide training, test kits and other critical information to landowners to enable them to self-monitor stream water.
- ❑ Expand and coordinate surface and groundwater monitoring by public agencies. Keep watershed residents well-informed of monitoring results. Encourage the use of monitoring as a tool to measure and foster success.

- ❑ Monitor water quality upstream and downstream of enhancement projects.
- ❑ Request that the Department of Fish and Game implement a regular monitoring program for freshwater shrimp in Stemple Creek.

Ongoing Activity:

- ❑ Encourage regulatory agencies to use monitoring fairly throughout the watershed, including on non-agricultural entities. ❑

- **Enhancement Recommendation 9: Support agriculture as the major land use in the watershed.**

Agriculture provides the economic and social base for the Stemple Creek watershed. With good practices, agriculture can also sustain and enhance the natural environment. Like any beautiful rural area close to a major urban center, the Stemple watershed is threatened by development pressure and rising land prices. Already, local ranchers are having a difficult time out-competing wealthy investors for large tracts of land. Although current zoning is designed to protect farmlands, many residents fear that it allows the splitting of ranches into parcels that are too small to sustain economically viable operations.

One of the best ways to strengthen the local agricultural economy and provide resources and incentives for good stewardship is to develop broad public support. It has become a truism to state that most Americans, even most Sonoma and Marin County residents, are many generations removed from the farm. People often don't realize the hard work and complex ecological relationships that go into producing their food.

In California, agricultural producers are often held to higher environmental standards than those in other areas. If we want a healthy environment and high quality products, we need to support local farmers and ranchers. We need to begin educating local consumers that they can use their food dollars to encourage sustainable agricultural practices.

<u>Ongoing Activities:</u>

- ❑ Support zoning and new development that strengthen the agricultural economy and protect natural resources.
- ❑ Provide education for watershed producers, regulators and others about sustainable agriculture, including workshops and demonstrations.
- ❑ Support programs by the Marin Agricultural Land Trust, the Sonoma County Open Space District and others to protect farmland.
- ❑ Support programs that promote public education about agriculture and the consumption of local products.

- **<u>Enhancement Recommendation 10:</u> Request additional investigation by the Santa Rosa Subregional Water Reclamation System on the potential impacts of the proposed West County Alternative on agriculture and natural resources.**

The City of Santa Rosa is currently engaged in a process to select alternatives for storing and utilizing reclaimed wastewater. One of the current alternatives includes one or more storage sites in the Stemple watershed and distribution of the treated water to agricultural operations within the Stemple and Estero Americano drainages.

On one hand, the West County alternative would bring much-needed water to many of the region's dairy farms for growing hay, irrigating pastures and more efficiently utilizing animal wastes. The water could be used to create treatment wetlands and help re-establish riparian forest. On the other hand, the construction of the dam or dams, especially at the Button Ranch site, the wastewater itself, and the accompanying changes in agriculture could have profound and long-lasting impacts on the ecology of the watershed and the community structure.

Ongoing Activities:

- ❑ Request that, if a West County alternative is selected, the environmental review include additional investigation on the impacts on agriculture and natural resources, including groundwater and surface water quality, soil erosion, the endangered freshwater shrimp, on-site wildlife habitat, and the overall hydrology and ecology of Stemple Creek and the Estero de San Antonio.

- ❑ Urge the City of Santa Rosa to keep the public well-informed and to provide generous opportunities for meaningful public input, particularly for the residents of those watersheds which will be directly affected.

6. Public Participation

Public participation was critical to developing the Enhancement Plan and it will continue to remain vital to the Plan's effective implementation. Most of the participation took place through four avenues -- the Advisory Committee, three open public meetings, one-on-one meetings with watershed residents, and articles and announcements in local newspapers.

Advisory Committee

The Advisory Committee included watershed landowners, regulators, U.C. Cooperative Extension advisors, SCS Field Office staff, representatives from environmental organizations, interested citizens and others. A membership list is included in Section 8.

The Committee met seven times (including one watershed tour) throughout the course of the plan preparation. They reviewed all the technical reports and the draft enhancement recommendations. Each of the technical consultants made a presentation to the Committee regarding their respective reports. Besides their comments and insight into the Plan itself, the committee members created an invaluable support network, transferring information to and from their agencies and constituencies. Their personal experience with watershed individuals and issues was immensely helpful.

Public Meetings

Three public meetings were held. The first was held in Petaluma, and its purpose was to present the initial work on erosion, water quality and watershed habitat, and to solicit input on issues and concerns. The second was a Saturday workshop at the Two Rock Union School to get feedback on the draft Enhancement Recommendations and also to get help prioritizing the Recommendations. The last, another Saturday event in Tomales, was to present the Recommendations, as revised by the feedback from the previous workshop and the Advisory Committee, to the community once again for comments.

The first workshop was not in or near the watershed, there wasn't enough time for public comment and the coffee was weak. However, most of the watershed residents who attended did not give up, but came to one or both of the following two workshops. Presentations were kept to a bare minimum at both of these and most of each workshop was devoted to small working groups. Both workshops were very successful in soliciting a tremendous amount of thoughtful, extremely helpful comments. The comments are not presented here separately; rather they are incorporated into the Enhancement Recommendations.

Meetings were advertised through the local newspapers, signs were posted in public places and announcements were mailed to 350 people, 207 of whom were watershed residents.

One-on-one Meetings

Individual meetings were one of the most effective ways to learn what watershed residents perceived as problems, what was working well for them and where they needed some help. Appendix F is a summary of interviews of 25 residents in 19 households.

The impact of Santa Rosa's wastewater was the most frequently voiced concern, with strong opinions expressed on both sides of the issue. Declining water quality, economic viability, soil erosion and rangeland improvement were other concerns identified in many of the households. Ten of the households interviewed were very interested in improvement or protection of wildlife habitat on their ranches.

Five of those interviewed expressed serious frustration with the number of agencies involved in any given project, the time and difficulty involved in obtaining permits, and frequent changes in regulations. Coyote predation on sheep herds was raised by three landowners.

Newspaper Articles and Announcements

Before the public meetings, press releases were sent to the local newspapers and the *Sonoma-Marin Farmer*. Articles about the project appeared in the *Point Reyes Light*, the *Petaluma Argus Courier*, and the *Bodega Bay Navigator*.

7. Santa Rosa Wastewater Proposal

The Santa Rosa Subregional Water Reclamation System treats to a tertiary level and disposes of wastewater from county-wide septic systems, and from the cities of Santa Rosa, Rohnert Park, Cotati and Sebastopol. Past and forecasted future growth in these communities, as well as a public mandate that the system be independent of weather conditions, has resulted in the need for greater storage and reclamation capabilities.

The Subregional System is preparing another Environmental Impact Report (EIR) to study various alternatives. One of the alternatives calls for the construction of a large storage reservoir, 15,000 acre-feet, on the Button Ranch, or smaller sites within the Stemple and Americano watersheds, and distribution of the treated water to dairies and other agricultural operations in both watersheds. The current alternative does not include direct discharge to either Estero, but reservoir leakage and increased soil moisture from irrigation may cause up to a one-foot increase in the summer water level of the Estero de San Antonio (Santa Rosa Subregional System, TM W9, p. 40).

Residents of the Stemple watershed are sharply divided over the issue of bringing the treated wastewater to the West County. One dairyman told project staff that the extra water for waste disposal and irrigating silage crops would make the difference for more than one dairy between staying in business and failing. Other residents are deeply concerned about the impacts of wastewater on the soil, their own drinking water supplies, and on the Estero and the Button Ranch.

The City of Santa Rosa recently hosted a series of public workshops designed to incorporate general public input into the selection of a short list of alternatives. The draft feedback report from the last of these meetings states that "Opposition to storage in the West County, particularly on the Button Ranch, but also on other sites, was strong and clear." (Urban Alternatives, 1994.)

Neither the Southern Sonoma County nor the Marin County Resource Conservation Districts has taken a position on favoring or opposing any of the proposed alternatives. However, during the preparation of the Enhancement Plan, project staff developed the following list of questions regarding the effects of a West County alternative on the Stemple/Estero de San Antonio Watershed:

Reservoir Storage Questions:

1. What are the downstream impacts of a 12% reduction in the total surface runoff (loss of 410 acre-feet/year) from the Button Ranch sub-watershed (Santa Rosa Subregional System, TM R11, Fig. R11-2)?

2. What are the impacts of a 68% reduction (340 acre-feet) in shallow groundwater outflow from the Button Ranch site (Santa Rosa Subregional System, TM R11, Fig. R11-2)?

3. What are the impacts of wastewater in the shallow aquifer immediately downstream of the dam?

4. What are the impacts of infiltration of wastewater into the Wilson Grove aquifer?

5. What are the impacts of hydrogen sulfide and ammonia, produced in the anoxic layer of the reservoir, as they travel into shallow and/or deep groundwater aquifers?

6. To what extent will hydrostatic pressure of the reservoir increase movement of water within and between the three watershed aquifers?

7. What impact will the proposed reservoir on the Button Ranch have in the event of an earthquake? What impact will the weight of the dam itself have upon activity along the underlying fault?

8. What impact will the loss of riparian, upland forest and perennial grassland habitat in the Button Ranch have on wildlife communities within the site and in the larger region? How will the reservoir affect the nesting Golden Eagles?

Irrigation Use Questions:

1. Will high TDS (total dissolved solids) in irrigation runoff raise TDS levels in surface and groundwater so that fish reproduction is inhibited and drinking water standards are exceeded?

2. Currently groundwater discharges into the Estero reduce high salinity; will salinity increases expected in irrigation runoff exacerbate salinity fluctuations or hypersaline conditions?

3. To what extent will groundwater mounding in irrigated areas (as much as a three- to four-foot increase) increase septic system failures and well contamination?

4. To what extent will mounding increase groundwater discharge to the stream during baseflow periods?

5. What are the impacts of increased groundwater discharge to Stemple Creek and the Estero?

6. How many more nutrients (in total amount, not rates or percentages) will reach the creek with the use of reclaimed water?

7. Will future water quality tests for metals have detection limits below the thresholds of the current aquatic life criteria and drinking water standards?

8. Will the total amount of metals leached from soils increase with irrigation? (Rate may remain the same, while the totals increase).

9. What will be the impacts if a high degree of irrigation efficiency is not achieved, as assumed?

10. Given irrigation suitability, the "services of an independent, professional irrigation management service" will be needed at each site to achieve high efficiency irrigation; how will this be accomplished? Who will pay? (Santa Rosa Subregional System, TM R12).

11. How will lands with bedrock less than three feet below the soil surface be excluded from irrigation? Who will delineate and enforce?

12. Will lands with summer groundwater levels within three feet of soil surface (factoring in irrigation mounding) be delineated and excluded from irrigation? Who will delineate and enforce?

13. What are the impacts of controlling grazing and restoring a riparian corridor, independent of wastewater use?

14. Can impacts, demonstrated to occur in the Americano watershed, automatically be extended to the Stemple/Estero de San Antonio watershed?

15. What are the impacts of the estimated 1.05-foot rise in Estero de San Antonio during summer due to reservoir leakage and irrigation effects (Santa Rosa Subregional System, TM W9, pg. 40)?

17. What are the impacts of drain-tile installation?

18. What are the impacts of changes in agricultural practices and products due to availability of reclaimed water?
19. What impact will changes in water quality due to the reservoir and irrigation have on freshwater shrimp and the ecology of the Estero de San Antonio?

8. Advisory Committee Members

Stemple Creek/Estero de San Antonio Enhancement Plan
Advisory Committee to the Marin and Southern Sonoma County RCDs

Name	Affiliation
Rick Bennett	U.C. Cooperative Extension Service
Lisa Bush	Marin Agricultural Land Trust
Andy Camozzi	SSCRCD, Watershed Landowner
Bill Cox	CA Department of Fish and Game
Don DeBarnardi	Watershed Landowner
Phyllis Faber	Wetland Biologist
Charlotte Fisher	Sonoma County Board of Supervisors
Gary Giacomini	Supervisor, 4th District Marin County
John Grissim	Environmental Action Committee of West Marin
Joel Hedgpeth	Aquatic Biologist
Glenda Humiston	AGvocate
Laurel Marcus	CA State Coastal Conservancy
Thomas Moore	CA Department of Fish and Game
Cdr. Robert Peterson	Two Rock Coast Guard Training Center
Al Poncia	Watershed Landowner
Ed Pozzi	MCRCD, Watershed Landowner
Dennis Salisbury	North Coast Regional Water Quality Control Board
Lisa Shanks	U.S.D.A. Soil Conservation Service
Dave Smith	U.S. Environmental Protection Agency
Donald Strong	Bodega Marine Laboratory
Kathy Tresch	Friends of the Estero, Watershed Landowner
Edward Ueber	Gulf of the Farallones National Marine Sanctuary
Karin Urquhart	Marin Conservation League
William Winchester	North Coast Regional Water Quality Control Board

Since the Enhancement Plan recommendations were completed, the following new members have joined the Advisory Committee:

Betsy Martin	Watershed Resident, Petaluma High School
Paul Martin	Watershed Landowner

9. List of Abbreviations

ACE	United States Army Corps of Engineers
ASCS	Agricultural Stabilization and Conservation Service
DFG	California Department of Fish and Game
EPA	United States Environmental Protection Agency
FFA	Future Farmers of America
FWS	United States Department of the Interior - Fish and Wildlife Service
MCRCD	Marin County Resource Conservation District
NOAA	National Oceanic and Atmospheric Administration
NPS	Non-point Source Pollution. A term coined to describe broad-based pollutants that don't come out of the end of a pipe. Examples include storm water from city streets, run-off from fertilized fields and soil erosion.
RCD	Resource Conservation District
RWQCB	California Regional Water Quality Control Board
SCC	California State Coastal Conservancy
SCS	United States Department of Agriculture - Soil Conservation Service
SSCRCD	Southern Sonoma County Resource Conservation District
UC	University of California
UC-Ext.	University of California Cooperative Extension Service
319(h)	Both refer to sections of the Federal Clean Water Act. EPA gives
205 (j)	funding to the State Water Resources Control Board which, in turn, is granted to public agencies and other organizations to plan and demonstrate measures to reduce non-point source pollution.
PL566	SCS administers watershed projects for USDA under Public Law 83-566, the Watershed Protection and Flood Prevention Act of 1954. State agencies and qualified local nonprofit organizations can sponsor projects to protect, improve and develop water and land resources in watersheds of up to 250,000 acres.

10. References

In addition to the technical appendices, the following sources were used in preparation of the Enhancement Plan:

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11. Appendices

Several technical studies were conducted in conjunction with this project. Copies of these reports are available at both the Southern Sonoma and the Marin County Resource Conservation Districts. A summary of the technical appendices follows.

Appendix A
Biological Assessment for Estero de San Antonio - John Maron, 1994

This report analyzes water quality data for the Estero, defines Estero habitats, assesses general habitat conditions and discusses the biological communities supported by these habitats. Three identified threats to the Estero include livestock grazing and trampling, the Santa Rosa Wastewater Reclamation Project and certain agricultural and manure management practices. The highest priority enhancement recommendation for the Estero is livestock exclusion from wetland habitats. In addition, Maron recommends maintaining the tidal opening at the mouth of the Estero to bring stability and predictability to the system.

Appendix B
Vegetation and Habitat Restoration - Marco Waaland, Golden Bear Biostudies, 1993

The report identifies habitat types found in the Stemple Creek watershed and addresses enhancement of terrestrial habitats for wildlife. Habitat restoration would include restoring native plant communities and integrating restoration with farm management practices. Objectives for restoration of native plant communities include using suitable areas of the watershed; using wetlands to improve both wildlife habitat and water quality; and reintroducing extirpated endangered species and expanding existing populations of those present in the study area. Restoration of riparian corridors, oak woodland and marshes will have secondary effects on improving water quality from dairy runoff and inhibiting sedimentation and soil erosion. Waaland includes schematic diagrams showing how wetlands could be incorporated into dairy operations and lists appropriate native plants for different areas of the watershed.

Appendix C
Erosion and Sediment Study **-** U.S.D.A. Soil Conservation Service, 1992

SCS analyzed the sources and quantities of sediment entering Stemple Creek and the Estero de San Antonio. The report concludes that channel erosion, primarily gullies, contributes almost 70% of the total sediment, with over 80% of the sediment coming from the lower watershed. The four identified levels of treating gully erosion range from merely fencing the gully to reshaping and revegetating it. Recommended streambank erosion techniques include riparian pastures and revegetation. The report also recommends implementing various levels of range improvement practices and assisting ranchers to develop conservation plans.

Appendix D
Water Resources Technical Report - M. Kim Cordell, Prunuske Chatham, Inc., 1993

Cordell's report identifies specific water quality concerns of both ground and surface water and presents recommendations for addressing them. Main surface water quality concerns are impacts to human health through recreation, chronic buildup of pollutants in the stream, and condition of the aquatic habitat. The report compares monitoring data from several sources. Water quality problems include the presence of total and un-ionized ammonia, low-dissolved oxygen content, and wide swings in seasonal temperature. All pose threats to aquatic life.

Appendix E
Geomorphic and Hydrodynamic Analysis - Philip B. Williams and C. Kelly Cuffe, Philip Williams & Associates, Ltd., 1993.

This study explores the geomorphology and hydrodynamics of the lagoon, particularly how the opening and closing of the mouth respond to sedimentation within the Estero. Over the last 131 years, sedimentation in the Estero has significantly affected the character and morphology of the lagoon. The lagoon mouth is now usually closed off in the spring or summer. During such time, lagoon circulation is severely reduced and water conditions vary from hypersaline to nearly fresh. The report concludes that without action and with continued levels of sediment delivery, the lagoon would gradually change from a seasonally closed estuary to one that is closed most of the time. Recommendations include reducing sediment delivery to the Estero, conducting a bathymetric and topographic survey of the Estero, establishing a monitoring program to record Estero water levels and Stemple Creek flows, and conducting surveys to determine if net scour or deposition is occurring.

Appendix F
Summary of Watershed Resident Interviews - Liza Prunuske, Prunuske Chatham, Inc.

This is a summary of interviews of 25 residents in 19 households located in the watershed.

APPENDIX A

BIOLOGICAL ASSESSMENT
FOR ESTERO DE SAN ANTONIO
John Maron

BIOLOGICAL ASSESSMENT FOR ESTERO DE SAN ANTONIO

for the

ESTERO DE SAN ANTONIO / STEMPLE CREEK WATERSHED ENHANCEMENT PLAN

prepared by

John Maron

prepared for

Marin County Resource Conservation District

June 1994

ESTERO ENHANCEMENT PLAN

Water Quality

Water quality data for the marine portion of the Estero have been analyzed from water samples taken during the period May 1988 through September 1990 at three stations located 1.5, 3.2 and 6.6 miles from the mouth. Table 1 shows a summary of some of these water quality data; location 1 was 1.5 miles from the mouth, location 2 and 3 were 3.2 and 6.6 miles from the mouth respectively. (Commins Consulting, unpublished data).

Table 1: Water Quality Data

Loc	Date	Station Depth (cm)	Sample Depth (cm)	Secchi (cm)	DO (ppm)	pH	Turb (FTU)	Chl *a* (*u*g/l)	TSS
1	5 Jul 89				8.4	8.2	4.4	2.69	
1	18 Sep 89				6.4	8.2	2.1	.83	
1	28 Nov 89	187	0	175	7.5	7.4	3.8	.92	8.4
1	28 Nov 89		187		7.9				
1	8 Feb 90	>200	0	38	17.2	8.3	16	113.86	19
1	8 Feb 90		100		12.2				
1	8 Feb 90		200		2				
1	8 Feb 90		275		1.2				
1	10 Mar 90	200	0	55	9	7.7	10	5.3	10
1	10 Mar 90		100		7.4				
1	10 Mar 90		200		7.3				
1	6 Apr 90	195	0	140	7.9	8.3	3.8	11.76	16
1	6 Apr 90		195		2		2.4	5.3	48
1	25 May 90	250	0	100	8.9	8.3	5	9.42	25
1	25 May 90		100		7.6				
1	25 May 90		200		7.2				
1	26 Jun 90	>200	0	120	8.6	8.1	4.6	15.18	29
1	26 Jun 90		200		6.2				
1	27 Jul 90	215	0	130	7.6	8.4	4.1	12.53	5.6
1	27 Jul 90		100		7.6				
1	27 Jul 90		200		6.5				
1	19 Sep 90	150	0	50	8.5	8.2	2.7	4	3.2
1	19 Sep 90		150		8.6				
2	16 May 88				4.7	7.25	11	9.48	
2	15 Jun 88				5.5	8	4.4	9.59	
2	21 Jul 88				5.9	8.0	4.1		
2	29 Aug 88				6.3	7.95	7.5	4.16	
2	28 Sep 88				5.4	8.2	7.1	4.22	
2	25 Oct 88				5	8.4	4.7	4.11	

Loc	Date	Station depth (cm)	Sample depth (cm)	Secchi (cm)	DO (ppm)	pH	Turb (FTU)	Chl *a* (*u*g/l)	TSS
2	22 Nov 88				18.9	8.8			
2	20 Dec 88				11.6	8.7	12	177.33	
2	20 Jan 89				12.3	8.75	13	64.55	
2	17 Feb 89				20	8.8	27	242.35	
2	6 Mar 89				7	7.2	51	8.54	
2	4 May 89				14.6	9.2	15	110.92	
2	7 Jun 89				8.4	8.5	15	31.35	
2	5 Jul 89				5.9	8.2	8.3	4.25	
2	18 Sep 89				7.2	8.2	2.2	1.21	
2	28 Nov 89	158	0	98	4.4	7.1	6.27		9.6
2	28 Nov 89		158		4.3			3.16	
2	8 Feb 90	>200	0	25	10.6	7.9	28	149.36	29
2	8 Feb 90		100		4.8				
2	8 Feb 90		200		.7				
2	10 Mar 90	150	0	40	8.7	7.7	16	21.43	20
2	10 Mar 90		150		2.5				37
2	6 Apr 90		0	60	6.6	8.6	4.7	10.43	20
2	6 Apr 90		50		6.5			12.25	
2	6 Apr 90		100		2.1				
2	6 Apr 90		150		2.1		2.6		
2	25 May 90	163	0	85	6.4	8.4	7.2	8.19	23
2	25 May 90		163		4.6				
2	26 Jun 90	165	0	65	9.3	8.7	6.5	44.12	16
2	26 Jun 90		100		9.4				
2	26 Jun 90		165		9.2				
2	27 Jul 90	180	0	60	9.1	8.8	7.6	27.06	14
2	27 Jul 90		100		8.8				
2	27 Jul 90		150		4				
2	19 Sep 90	165	0	120	5.3	8.1	5.4	3.9	4.6
2	19 Sep 90		162		5.3				
3	5 Jul 89				10.4	9	22	80.42	
3	18 Sep 89				4.1	8.2	5.4	9.1	
3	28 Nov 89	145	0	45	2.1	7	16	36.73	24
3	28 Nov 89		145		2.6				
3	8 Feb 90		100		.7			33.91	
3	8 Feb 90		200		.3				
3	10 Mar 90	160	0	30	8.8	7.6	24	22.17	23
3	10 Mar 90		160		8.6				
3	6 Apr 90		0		4				
3	6 Apr 90	170	0	65	8.3	8.2	4.5	22.97	11
3	6 Apr 90		170		.65		2.3	17.67	50
3	25 May 90	194	0	60	>20	9.4	6.6	88.67	28
3	25 May 90		100		8				
3	25 May 90		194		6.7				
3	26 Jun 90	>200	0	50	16.2	9.2	15	91.11	17

Loc	Date	Station Depth (cm)	Sample Depth (cm)	Secchi (cm)	DO (ppm)	pH	Turb (FTU)	Chl *a* (*u*g/l)	TSS
3	26 Jun 90		100		2.5-3.0				
3	26 Jun 90		>200		.3		88	96.44	2
3	27 Jul 90	210	0	40	16.5	9.3	6.4	168.59	24
3	27 Jul 90		100		.9				
3	27 Jul 90		200		.8				
3	19 Sep 90	170	0	22	3.2	8.5	17		22
3	19 Sep 90		170		.6			163	

Dissolved Oxygen

Low levels of dissolved oxygen can have very negative affects on zooplankton survival and can also impact some species of marine invertebrates and fish. Early life stages of marine invertebrates and fish are particularly sensitive to low dissolved oxygen concentrations. The water quality control plan for the North Coast Region states that dissolved oxygen concentrations in cold sea water should be maintained above 6 mg/l. The Estero has dissolved oxygen concentrations spanning this figure. At all depths sampled, dissolved oxygen concentrations range from 1.2-17.2 mg/l at station 1, 0.7-20.0 mg/l at station 2 and 0.3->20 mg/l at station 3. Mean dissolved oxygen concentrations are highest closer to the mouth (7.55 mg/l at station 1) and decline with distance from the mouth (5.75 mg/l at station 3). Dissolved oxygen concentrations are most variable farthest from the mouth.

Turbidity

High turbidity can result from high total suspended solids, which at extremely high levels can greatly hamper feeding efficiency of some filter-feeding marine invertebrates and impair the movement of oxygen across the gills of invertebrates and fish. The turbidity of water in the Estero is generally lower and less variable closer to the mouth compared to sites further upstream. Mean turbidity is 5.3 Formazin turbidity units (FTU) for station 1, 12.7 FTU for station 2 and 18.8 FTU for station 3. At stations 1 and 2, turbidity peaked in February and March of both 1989 and 1990, whereas the turbidity at station 3 was always highest in summer and early fall. High turbidity in summer is probably due to increased phytoplankton activity whereas winter turbidity is caused by high suspended solids from rain runoff.

Chlorophyll

Phytoplankton biomass is often estimated by measuring chlorophyll *a* concentrations. Phytoplankton can provide food for invertebrate grazers and for fish and therefore increase the productivity of estuaries. However, overstimulation of phytoplankton, particularly when it occurs in areas that are not well flushed, can ultimately result in decreased dissolved oxygen (due to the decomposition of phytoplankton) which can have detrimental effects.

At each of the three stations sampled, chlorophyll *a* concentrations were extremely variable. Values ranged from 0.83-113.86 *u*g/l at station 1 (mean 16.52 *u*g/l), 3.16-177.33 *u*g/l at station 2 (mean 44.04 *u*g/l) and 3.9-168 *u*g/l at station 3 (mean 69.23 *u*g/l). Chlorophyll concentrations were highest in winter at stations 1 and 2, whereas station 3 had very high chlorophyll concentrations in summer and early fall.

Table 2 lists concentrations of nitrate ($N0_3$), ammonia and phosphorus in water samples collected at the same three stations (taken from Commins et al., 1990; nd= nondetectable concentrations).

Table 2: Concentrations of Nitrate, Ammonia and Phosphorus

Loc	**Date**	**NO3 (mg N/l)**	**NH3 (mg N/l)**	**Tot. P (mg P/l)**	**Diss. P (mg P/l)**
1	5 Jul 89	.03	nd	.34	.31
1	18 Sep 89	nd	.09	1.1	.96
1	28 Nov 89	.23	.56	.1	.24
1	8 Feb 90	.84	1.2	1	.76
1	10 Mar 90	.67	.73	.71	.51
1	6 Apr 90	nd	.23	.5	.49
1	6 Apr 90	.04	.15	.22	.26
1	25 May 90	.16	nd	.64	.58
1	26 Jun 90	nd	.19	1.3	1.3
1	27 Jul 90	.07	.05	1.6	1.4
1	19 Sep 90	nd	nd	2.1	1.9
2	16 May 88	.3	.22	.7	.57
2	15 Jun 88	nd	.23	1.6	.9
2	21 Jul 88	.09	.27	.95	.95
2	29 Aug 88	nd	.16	1.9	1.8
2	28 Sep 88		.11		2.4
2	25 Oct 88	nd	.19	2.6	2.4
2	22 Nov 88	.12	8.5	4.6	2
2	20 Dec 88	.09	1.1	2.6	2.2
2	20 Jan 89	.73	2.4	2.1	2
2	17 Feb 89	.07	.85	2.3	1.7
2	6 Mar 89	.61	1.1	1.1	.78
2	4 May 89	.57	nd	.94	.51
2	7 Jun 89	nd	.07	-	-
2	5 Jul 89	.17	.05	.69	.63
2	18 Sep 89	nd	nd	1.3	1
2	28 Nov 89	.35	1.3	.9	.6
2	8 Feb 90	.94	2.5	1.7	1.1
2	10 Mar 90	.87	1.2	.92	.9

Loc	Date	NO_3 (mg N/l)	NH_3 (mg N/l)	Tot. P (mg P/l)	Diss. P (mg P/l)
2	10 Mar 90	.47	1.1	.84	.75
2	6 Apr 90	.04	.53	.65	.59
2	25 May 90	.29	.12	1.1	.97
2	26 Jun 90	nd	.1	2.2	2.1
2	27 Jul 90	nd	.05	2.1	1.9
2	19 Sep 90	.18	.14	2	2
3	5 Jul 89	.03	nd	1.2	.88
3	18 Sep 89	.05	.78	2.2	1.5
3	28 Nov 89	.65	3.3	2.5	1.7
3	8 Feb 90	1.5	2.8	1.8	1.5
3	10 Mar 90	1.2	.95	1.4	1.2
3	6 Apr 90	.05	.58	.63	.49
3	6 Apr 90	nd	1.2	1.6	1.2
3	25 May 90	nd	.06	1.7	1.4
3	26 Jun 90	nd	.08	2.3	1.7
3	26 Jun 90	nd	4.4	2.5	3.2
3	27 Jul 90	nd	.05	2.5	2.2
3	19 Sep 90	nd	.07	2.4	1.9

Nitrogen

Extremely high levels of nitrate can be toxic to organisms. More commonly, however, elevated nitrate levels stimulates growth and biomass of phytoplankton and algae. Increased algal productivity can ultimately choke a waterway, reducing water flow and therefore dissolved oxygen concentrations. Moreover, as the algae becomes overgrown it can die back and begin to decompose, which can further depress dissolved oxygen concentrations. Low dissolved oxygen levels greatly reduce the ability of the Estero to support healthy populations of invertebrates and fish. The EPA states that levels of nitrate above 90 mg-N/l will be detrimental to fish populations, although levels well below this would presumably indirectly impact the Estero by increasing phytoplankton and algae abundance and decreasing dissolved oxygen concentrations. Nitrate levels in the Estero are well below 90 mg-N/l and vary from 0.18 mg N/l close to the mouth as station 1, 0.26 mg N/l at station 2 and 0.29 mg N/l at station 3. Nitrate concentrations appear highest in regions further from the mouth, perhaps resulting from increased inputs of animal waste and decreased tidal flushing in these areas.

Ammonia

The EPA criterion for toxic levels of total ammonia in fresh water is 0.5 mg-N/l and .02 mg/l of ionized ammonia in marine waters. Marine waters of the Estero average concentrations of ammonia ranging from 0.29 mg-N/l at station 1 to 0.93 mg-N/l at station 2 and 1.12 mg-N/l and station 3. Samples taken in November-March, 1989, at Station 2 exceeded EPA standards for un-ionized ammonia (Commins et. al., 1990). It is probable that other samples taken at station 2, and station 3 exceed EPA standards for un-ionized ammonia. Clearly, averages for total ammonia (and some samples for un-ionized ammonia) exceed EPA standards, although there is tremendous variability in ammonia content among the samples. Ammonia concentrations in Estero de San Antonio are much greater closer to the ocean compared with Estero Americano. Americano has similar concentrations of ammonia as San Antonio, but further upstream. Much more sampling is needed to resolve the extent to which total ammonia concentrations reach toxic levels in Estero de San Antonio.

Phosphorus

The mean total dissolved phosphorus concentrations were 0.79 mg-P/l at station 1, 1.40 mg-P/l at station 2, and 1.57 mg-P/l at station 3. Dissolved phosphorus concentrations peaked in summer and early fall at stations one and three, whereas concentrations of dissolved phosphorus at station two remained high in fall through winter.

Metals

Table 3 shows concentrations of metals in Estero water samples for 1988-1990 (taken from Commins et. al., 1990; nd= nondetectable concentrations).

Table 3: Concentrations of Metals

Loc	**Date**	**Cd (mg/l)**	**Cr (mg/l)**	**Cu (mg/l)**	**Pb (mg/l)**
1	18 Sep 89	nd	nd	.003	nd
1	28 Nov 89	nd	.006	.001	nd
2	25 Oct 88			nd	nd
2	8 Feb 90	.0006	.0046	.0089	.0005
2	10 Mar 90	.003	.0026	.0055	nd
2	10 Mar 90	.021	.0042	.0023	.0006
2	6 Apr 90	.004	.0061	.0027	.0007
2	25 May 90	nd	.0029	.0008	.0008
2	26 Jun 90	.007	.0044	.0006	nd
2	27 Jul 90	nd	.0032	.0089	nd
2	19 Sep 90	nd	.021	nd	nd
3	18 Sep 89	nd	nd	.002	nd
3	28 Nov 89	nd	.004	nd	nd
3	8 Feb 90	nd	.0078	.012	.0011
3	10 Mar 90	.0005	.0026	.0056	.0006
3	6 Apr 90	.0027	nd	.0029	nd
3	25 May 90	nd	.0029	.0013	.0008
3	26 Jun 90	.0006	.002	.0015	nd
3	27 Jul 90	nd	.0022	.0007	nd
3	19 Sep 90	nd	.0085	nd	nd

Cadmium levels at all three stations are well below standards set by the North Coast Water Quality Control Board (0.0093 mg/l 4-day average), with the exception of one sample taken at station 2 in March of 1990. Similarly, chromium levels are also below the 0.05 mg/l level set by the Water Quality Control Board. Levels of copper ranged from non-detectable to a high level of 0.012 mg/l for one sample at station 3. The EPA states that levels above 0.0203 are toxic, while the NCWQCB stipulates that esturine water should not exceed a 1-hour average of .0029 mg/l of copper. Copper sulfate is commonly used to treat the hooves of cattle to prevent fungal infections and is thus the most likely source of copper into the estero. Most samples had non-detectable levels of lead, although two samples taken at station 3 in February and March, 1990 exceeded the 0.0047 mg/l limit set by the EPA.

Summary

For the marine portion of the Estero, water quality is quite variable, both seasonally and as one proceeds upstream. In general, water quality is poorer upstream, undoubtedly due to decreased mixing with fresh sea water and increased input of nitrates, ammonia and other potentially toxic materials from agricultural waste. Concentrations of heavy metals were generally below toxic levels established by the EPA, although one out of 18 samples exceeded EPA standards for cadmium, 1 out of 19 samples exceeded EPA standards for copper, and two out of 19 samples exceeded EPA standards for lead. EPA standards are generally established in fresh water; toxicity of nutrients and metals may be different at higher salinities.

Although the current data set hints at what some of the water quality problems may be, more sampling needs to be done to adequately describe water quality in the Estero de San Antonio. This is particularly true given the large degree of variability in certain water quality parameters. Indeed, even within the same month and at the same station, values can range by almost an order of magnitude (e.g. 10 March, 1990 samples at station 2 for cadmium). Additionally, more research needs to be conducted to evaluate how changes in water quality affect marine life. Certain groups of invertebrates or fish may be highly susceptible to fairly low concentrations of nutrients or heavy metals. This may particularly be true for early life stages of some invertebrates. A more thorough review of the environmental toxicology literature would undoubtedly shed some light on this issue.

Historical Overview of the Estero

Historically, the Estero de San Antonio has been a small coastal estuary characterized by a relatively restricted mouth and strong seasonal changes in fresh water flow. It was typical of many small estuaries in this region, such as the nearby Estero Americano, in supporting consistent runs of Steelhead and Coho Salmon, and was a potentially important nursery ground for Dungeness Crabs (California Department of Fish and

Game, 1977). Beyond this general picture, more specific predictions about the historic condition of the Estero are difficult without understanding the hydrology of the system. Of particular importance is information concerning sea water influx into the Estero, since the extent of sea water movement into any estuary greatly influences the types of available habitats and the flora and fauna that these habitats can support. The Estero is currently dominated by seasonal shifts in sea water exposure; some years the Estero mouth closes in the summer or early fall, and remains closed until winter storms with heavy surf and associated rainfall together break through the sandbar that closes the mouth. The question is whether this has always been the condition of the Estero.

At least three interacting factors influence the volume and extent of sea water flow into and out of the Estero. These factors include the overall size of the Estero mouth (both width and depth), the elevation of the Estero bottom relative to sea level, and the volume and seasonal variation in fresh water outflow. Historical data pertaining to these variables is scanty, but what little exists is illuminating.

A geodetic survey map dating back to 1862 shows the mouth of the Estero de San Antonio open, and much wider than it is today (Fig. 1, arrow points to the Estero). It also indicates that the beach fronting the Estero was smaller than its present size. Although it is impossible to know if this was the condition year-round, it hints at the possibility that a greater volume of seawater may have been able to move into and out of the Estero.

Additional information on the watershed also seems to support this claim. Over the past 150 years, the watershed surrounding the Estero has changed quite dramatically. Increased agricultural activity on the hills surrounding the Estero, including potato farming in the past and the present sheep and cattle grazing, has increased rates of soil erosion, resulting in increased sedimentation into the Estero (Trussell, 1960; California Department of Fish and Game, 1977). Indeed, at the nearby Estero Americano sedimentation during the past 118 years has reduced the tidal prism (i.e. the volume of water exchange) by 25 percent (Harvey et al., 1990). The increased sedimentation in Estero de San Antonio has probably raised the elevation of the Estero bottom, thereby decreasing the extent of tidal penetration into the Estero. With lowered seawater flows into and out of the Estero, there has probably been a reduction in the amount of tidal scouring occurring on the bottom of the Estero, particularly at the mouth. This would increase the likelihood that the mouth could close, especially in the summer, when fresh water outflow is reduced.

The magnitude of fresh water outflow will partially influence the extent of tidal penetrance into the Estero, thereby influencing the total amount of marine habitat. The volume of fresh water outflow is probably reduced compared to historic levels. Although the amount of rain run-off contributes greatly to fresh water outflow, many small spring-fed streams also provide important fresh water input. Within the past 150 years, water from many of these side streams has been diverted for agriculture, thereby reducing the total amount of fresh water flowing into the Estero. This may have contributed to important changes in the habitats of the Estero. Moreover, both reduced fresh water flows and increased input of agricultural waste have certainly combined to lower the overall water quality in the Estero.

It is quite possible that the combination of a historically larger mouth, deeper bottom and increased tidal scouring resulted in the Estero mouth being open year-round. It could be that the Estero de San Antonio was similar in this respect to the nearby and similar Estero Americano, which was apparently at one time self-maintaining, with the mouth staying open year-round (California State Coastal Conservancy, 1987; Harvey et al., 1990). Although the specifics are unclear as to how a year-round opening in the Estero de San Antonio influenced its biology, greater seawater flows in the summer would have allowed marine habitats to support a more diverse invertebrate and fish fauna.

Marine Habitats

In this report, I consider the marine portion of the Estero de San Antonio to consist of the area between the Estero mouth and Shoreline Highway. This area is composed of seven major habitat types, with each habitat type differing in total area, condition and biological resources. Below I will define each habitat, assess its general condition, and discuss the biological communities supported by these habitats. I urge caution in interpreting much of these data. Information concerning the biotic resources of the Estero is limited, and qualitative in nature. Much of it comes from a single study dating back to 1976 that described the species found in the Estero during a one-year survey (California Department of Fish and Game, 1977). One year of sampling is insufficient to fully characterize the Estero, especially given the large intra and interannual variability in the intensity of fresh water flows and changes brought about by the timing and duration of mouth closure. More intensive quantitative sampling needs to be conducted to understand the seasonal and annual changes in algae, invertebrate, fish and bird densities, as well as overall species diversity.

Rocky Shore

A small portion of rocky intertidal habitat exists on the north side of the mouth of the Estero (Fig. 2, arrow points to small rocky intertidal). This habitat is characterized by rock outcrops extending into the intertidal, which offers a hard substrate on which marine invertebrates and algae can colonize. When the mouth of the Estero is open, as it was in the fall of 1991 when this habitat was examined, the rocky shore habitat looks quite healthy. It is exposed to sea water and the shoreline can support assembledges of intertidal invertebrates and algae. More specifically, small populations of barnacles (both *Balanus glandula* and *Chthamalus dalli*) and mussels (*Mytilis edulis* and *Mytilis californianus*) were found on these rocks, in addition to an occasional sea star (*Pisaster ochraceus*). A more exhaustive survey of these rocks would undoubtedly find many other species as well.

Beach Strand

A small portion of beach strand habitat exists on the south side of the Estero, near the mouth (Fig. 2). This beach strand community boarders a small salt marsh located along the Estero edge and grades into dense patches of introduced European dune grass, *Ammophila arenaria*. Conspicuous perennials in this beach strand community include *Baccharis pilularis, Grindelia stricta*, and *Abronia latifolia*. When annuals are considered, as many as 47 plant species have been catalogued at this site (Thomsen, 1976 as cited in California Department of Fish and Game, 1977).

Open Water, Mud and Sand Bottom

The majority of the Estero consists of open water that flows over a muddy or sandy bottom (Fig. 2). This open water habitat covers an area of approximately 93 acres (California Department of Fish and Game, 1977), with the volume of water in any location influenced by surf conditions, tide height and the amount of freshwater runoff. Physical characteristics of the water, such as salinity and temperature, can change markedly depending on location and season. At a station 3.2 miles from the mouth of the Estero, average water salinity can vary seasonally between 12 and 28 ppt (Commins et al., 1990) but is usually less than 25 ppt (Commins et al., 1990). Water salinity increases as one travels closer to the mouth; at a station 1.5 miles from the mouth, water salinity in 1989 ranged between 29 and 37 ppt (Commins et al., 1990). (Pure sea water has a salinity of 33-34 ppt.) During years when the mouth remains closed during summer and fall, portions of the open water may become hypersaline, as occured in the fall of 1989. Water temperature also changes seasonally, with temperatures ranging from 8.5 C in December 1988 to 22 C in August 1988 (water temperature sampled 3.2 miles from mouth, Commins et al., 1990).

<u>Marine Invertebrates</u>

A whole suite of organisms, from marine algae to fish and water birds are supported by the extensive open water habitat in the Estero. Many marine invertebrates live in the soft sediments of the Estero bottom, particularly in the sandier regions closer to the Estero mouth. Table 4 lists the species of algae found in the Estero during a survey conducted in 1977 (from California Department of Fish and Game, 1977). More recent information on the distribution or density of various species of marine algae is unavailable.

The open water of the Estero contains zooplankton representing several different phyla (Table 5, taken from Commins et al., 1990; zooplankton sampled at three separate locations within Estero). In the limited samples taken, overall densities of zooplankton were low when sampled, with abundances ranging from 0.04 to 1.79 individuals per m^3 for large zooplankton (taken in 505 *u*m mesh tows) and 6 to 437 individuals per m^3 (taken in 130 *u*m mesh tows) (Commins et al., 1990). Arthropods are particularly well represented in the zooplankton.

Table 4: Algae Species

Chlorophyta	*Enteromorpha flexuosa, Ulvella mirabilis*
Phaeophyta	*Alaria marginata, Hapalospongidion gelatinosum, Leathesia difformis, Ralfsia pacifica, Soranthera ulvoidea*
Rhodophycophyta	*Antithamnion glanduliferum, Bangia fuscourpures, Cryptosiphonia woodii, Dermatolithon dispar, Dilsea californica, Endocladia muricata, Farlowia conferta, Gigartina agardhii, Gloiosiphonia verticillaris, Grateloupia doryphoroa, Grateloupia setchellii, Gymnogongrus leptophyllus, Halymenia californica, Microcladia borealis, Plocamium coccineum* var. *pacificum, Polysiphonia pacifica* var. *pacifica, Pterosiphonia gracilis, Rhodoglossum americanum, Schizymenia pacifica*

Table 5: Zooplankton in the Estero

Protozoa: Foraminifera
Cnidaria: Leptomedusa, Hydroid polyp
Aschelminthes: Roundworm, unknown worm
Rotifera: *Brachionus plicatilis*
Mollusca: Gastropods
Phoronida: *Phoronida actinotroch*
Bryozoa: Bryozoan colony
Annelida: Polychaete larvae
Arthropoda: Crustacea
Copepoda: Oithona, Unknown Cyclopoid, *Arcartia spp., Calanoid spp., Calanoid copepodites, Harpacticoid spp.*
Ostracoda: Unidentified
Cirripedia: Thoracica: Barnacle nauplii, Barnacle cypris
Malacostraca
Isopoda: Unidentified
Amphipoda: *Anisogammarus confervicolus, Corophium spp.*
Mysidacea: Unidentified

Table 6 lists species of nektonic and benthic invertebrates found in the Estero (California Department of Fish and Game, 1977; Commins et al., 1990). Some of these species, such as Hydroids, Isopods and Amphipods inhabit the open water, and are important food items for fish and water birds. Other species, such as Polychaetes and Bivalves, burrow into the soft sediments. These benthic invertebrates form the prey base for many shorebird predators. Sandier regions near the Estero have historically been important nursery grounds for a variety of Crustaceans (California Department of Fish and Game, 1977), particularly Dungeness Crabs (*Cancer magister*).

Table 6: Nektonic and Benthic Invertebrates

Protozoa:
Zoothamnium spp.
Vorticella spp.
Cnidaria:
Hydrozoa: Tubularia spp.
Schyphozoa: ephyra stage
Platyhelminthes:
Turbellaria: Unidentified
Nemertea: Unidentified
Nematoda: Unidentified
Annelida
Polychaeta: *Glycera capitata, Neanthes limnicola, Streblospio benedicti, Polydora spp.*
Oligochaeta: Unidentified
Arthropoda:
Crustacea: Ostracoda:
Malacostraca: Leptostraca: *Nebalia pugettensis*
Peracarida: Mysidacea: *Neomysis mercedis*
Peracarida: Isopoda: *Gnorimosphaeroma lutea*
Amphipoda: *Corophium spinicorne, Anisogammarus confervicolus*
Decapoda: *Crangon franciscorum, Cancer antennarius, Cancer productus, Cancer magister*, *Cancer jordani*
Mollusca: Gastropoda
Collisella limatula, Hermissenda crassicornis
Bivalvia: *Clinocardium nuttalli, Protothaca staminea, Pisidium spp., Macoma secta, Macoma nasuta, Mya arenaria, Modiolus rectus, Saxidomus spp.*

Much more extensive sampling of benthic invertebrates has been performed in Estero Americano than in San Antonio. Americano sampling has yielded seventy invertebrate taxa, approximately half of which were composed of polychaete species, with large numbers of crustaceans and molluscs also found (Commins et al., 1990). Most of these species were sampled from sites close to the ocean. It may be that with more sampling Estero de San Antonio would be found to support a greater diversity of marine invertebrates.

Fish

Fish occur in both the open water and benthic zones in the Estero. Benthic habitats are comprised of sand/gravel shoals that are more extensive near the Estero mouth, and silt/clay muds that become predominant further upstream. Fishes utilizing these habitats belong to three main groups: gobies, sculpins and juvenile flatfishes. The open water or pelagic zone is utilized primarily by small schooling fishes including herring, smelt, silversides (top and jack smelt) and seasonal predators (e.g. mostly juvenile striped bass, steelhead, and small sharks).

In total, 46 fish species have been caught in or are thought to utilize the Estero de San Antonio and Estero Americano. Of these, 25 species have been found solely in the Estero de San Antonio (Table 7, California Department of Fish and Game, 1977; Commins et al., 1990). The majority are intermittent marine visitors represented by few individual specimens.

Table 7: Fish Species in or using the Estero Americano and Estero de San Antonio

COMMON NAME	SCIENTIFIC NAME	Estero Americano	Estero de San Antonio
Spiny dogfish	*Squalus acanthias*	X	
Leopard shark	*Triakis semifasciata*	X	
Pacific herring	*Clupea pallasi*	X	X
Northern anchovey	*Engraulis mordax*	X	
Steelhead trout	*Oncorhynchus mykiss*	X	
Surf smelt	*Hypomesus pretiosus*	X	X
Longfin smelt	*Spirinchus thaleichthys*	X	
Carp	*Cyprinus carpio*		X
Mosquitofish	*Gambusia affinis*		X
Plainfin midshipman	*Porichthys notatus*	X	X
Pacific tomcod	*Microgadus proximus*	X	
Topsmelt	*Atherinops affinis*	X	X
Jacksmelt	*Atherinopsis californiensis*	X	
Threespine stickleback	*Gasterosteus aculeatus*	X	X
Bay pipefish	*Syngnathus leptorhyncus*	X	X
Striped bass	*Morone saxatilis*	X	X
Shiner surfperch	*Cymatogaster aggregata*	X	X
Striped surfperch	*Embiotoca lateralis*		X
Black surfperch	*Embiotoca jacksoni*	X	
Dwarf surfperch	*Micrometrus minimus*	X	X
White surfperch	*Phanerodon furcatus*		X
Crevice kelpfish	*Gibbonsia montereyensis*	X	
Monkeyface eel	*Cebidichthys violaceus*	X	
Saddleback gunnel	*Pholis ornata*		X
Penpoint gunnel	*Apodichthys flavidus*		X
Arrow goby	*Clevlandia ios*	X	X
Tidewater goby	*Eucyclogobius newberryi*	X	X
Bay goby	*Lepidogobius lepidus*		X
Longjaw mudsucker	*Gillichthys mirabilis*	X	
Cheekspot gody	*Ilypnus gilberti*	X	
Rockfish spp.	*Sebastes spp.*	X	
Opaleye	*Girella nigricans*	X	
Lingcod	*Ohpiodon elongatus*	X	
Staghorn sculpin	*Leptocuttus armatus*	X	X
Prickly sculpin	*Cottus asper*	X	X
Tidepool sculpin	*Oligocottus maculosus*	X	X
Buffalo sculpin	*Enophrys bison*	X	

COMMON NAME	SCIENTIFIC NAME	Estero Americano	Estero de San Antonio
Sharpnose sculpin	*Clinocottus acuticeps*		X
English sole	*Pleuronectes vetulus*	X	X
Starry flounder	*Platichthys stellatus*	X	
Hybrid sole	*Inopsetta ischyra*	X	
Sand sole	*Psettichthys melanostictus*	X	
Pacific sanddab	*Citharichthys sordidus*	X	
Speckled sanddab	*Citharichthys stigmaeus*	X	X
Diamond turbot	*Hypsopsetta guttulata*	X	

Overall, species composition is similar to that found in many estuaries and lagoons along the California coast (Onuf, 1987; Emmett et al., 1991), presumably a reflection of euryhaline conditions. Twelve species comprised 96% of the otter trawl catch from five stations in the Americano on eight dates from December 1988 to September 1989 (Commins et. al., 1990). The catch data from gill net sets over the same period indicates that several pelagic species evade the trawls. The lack of gill net data and limited otter trawl data (from only two dates and two stations) from Estero de San Antonio suggests that several species (especially pelagics) could be added to the species list with more sampling effort.

Waterfowl and Seabirds

The open waters of the Estero offer feeding habitat for a variety of migrant waterfowl and seabirds. With the exception of cormorants, ospreys, herons and egrets, mallards, and some gulls, these birds are exclusively winter residents, utilizing the Estero for feeding during the months from late fall through early spring before departing for breeding grounds in early summer. Table 8 lists the birds found in both the Estero Americano and Estero de San Antonio during surveys in 1975-76 (California Department of Fish and Game, 1977) and censuses during 1990-91. (Maron and Connors, unpublished; census area from bridge at Franklin School Road to Estero mouth; censuses in January, May, August, September and November. Numbers indicate the maximum number of individuals of a given species counted during individual censuses from 1990-91.)

Table 8: Waterfowl and Seabirds

COMMON NAME	SCIENTIFIC NAME	1975-76	1990-91	MAX
Common loon	*Gavia immer*	X		
Red-throated loon	*Gavia stellata*	X		
Horned grebe	*Podiceps auritus*	X		
Western grebe	*Aechmophorus occidentalis*	X	X	1
Pied-billed grebe	*Podilymbus podiceps*	X	X	2
American white pelican	*Pelecanus erythrorhynchos*	X	X	3
Brown pelican	*Pelecanus occidentalis*	X		
Double-crested cormorant	*Phalacrocorax auritus*	X	X	12

COMMON NAME	SCIENTIFIC NAME	1975-76	1990-91	MAX
Pelagic cormorant	*Phalacrocorax pelagicus*	X		
Brandt's cormorant	*Phalacrocorax penicillatus*	X		
Great blue heron	*Ardea herodias*	X	X	5
Great egret	*Casmerodius albus*	X	X	7
Snowy egret	*Egretta thula*	X	X	3
Black-crowned night heron	*Nycticorax nycticorax*	X	X	1
Mallard	*Anus platyrhynchos*	X	X	100
Northern Pintail	*Anas acuta*	X		
Green-winged teal	*Anas crecca*	X	X	25
Cinnamon teal	*Anas cyanoptera*	X	X	2
American widgeon	*Anas americana*		X	2
Greater scaup	*Aythya marila*	X		
Common goldeneye	*Bucephala clangula*		X	22
Bufflehead	*Bucephala albeola*	X	X	560
While-winged scoter	*Melanitta fusca*	X	X	1
Surf scoter	*Melanitta perspicillata*	X	X	12
Black scoter	*Melanitta nigra*	X		
Ruddy duck	*Oxyura jamaicensis*	X		
Red-breasted merganser	*Mergus serrator*	X		
Common merganser	*Mergus merganser*		X	3
Osprey	*Pandion haliaetus*	X		
American coot	*Fulica americana*	X		
Red phalarope	*Phalaropus fulicaria*	X		
Wilson's phalarope	*Phalaropus tricolor*	X		
Red-necked phalarope	*Phalaropus lobatus*	X	X	24
Glaucous-winged gull	*Larus glaucescens*	X	X	3
Western gull	*Larus occidentalis*	X		
California gull	*Larus californicus*	X		
Ring-billed gull	*Larus delawarensis*	X	X	1
Mew gull	*Larus canus*	X	X	90
Bonaparte's gull	*Larus philadelphia*	X		
Elegant tern	*Sterna elegans*		X	5
Belted kingfisher	*Ceryle alcyon*	X	X	2

Estero Americano supports a greater diversity of waterfowl and sea birds than does Estero de San Antonio, perhaps because of its larger size and greater extent of marine habitat. Nevertheless, Estero de San Antonio supports surprisingly large populations of some species, such as Bufflehead and Mallard.

Eelgrass Beds

While the majority of the open water habitat consists of a submerged and relatively bare muddy or sandy bottom, several sections of the Estero contain luxuriant beds of eelgrass (*Zostera marina*) (Fig. 2). Eelgrass is a flowering plant and roots in the soft muddy bottom sediments, providing unique habitat for marine invertebrates and fish. Epiphytic microalgae growing on eelgrass blades can also be an important source of food for grazing gastropods (such as *Phyllaplysia*) and shrimps. Table 9 lists the invertebrates inhabiting the Estero that are most likely to be associated with eelgrass beds (from California Department of Fish and Game, 1977). A variety of fish utilize eelgrass beds including surfperches, sculpins, gobies, pipefish, and "tidepool fishes" (e.g. gunnels and kelpfish). These habitats are typically quite productive and provide a refuge from predation for a variety of invertebrates and fish.

Table 9: Invertebrates Associated with Eelgrass Beds

Arthropoda:
Isopoda: *Idotea montereyensis, Idotea rasecata*
Amphipoda: Caprellidea
Decapoda: *Heptacarpus paludicola, Hippolyte californiensis, Pugettia producta, Crangon nigricauda*
Mollusca:
Gastropoda: *Phyllaplysia taylori*

What little eelgrass exists in the Estero looks quite healthy, and has looked healthy in the past, even after exposure to very high salinity (e.g. in the fall of 1989). This is perhaps not surprising since eelgrass is tolerant of wide salinity fluctuations; it can grow well at a salinity as low as 10 ppt (Ostenfeld, 1908; Phillips, 1984) and can survive a limited summer exposure to salinities as high as 42 ppt (Tutin, 1938).

Mud Margin

Much of the Estero is fringed with small strips of mud margin (not mapped, along entire edge of Estero). This muddy interface between the water's edge and marsh or grassland is relatively devoid of vegetation, and may often become covered with water on a high tide. It is distinct from more extensive, gently sloping intertidal mudflat (discussed below) in that it is often fairly steep and narrow. Because of its steep slope, much of this habitat remains free from cattle trampling and is in reasonable condition. In areas more accessible to cattle, the Estero banks are often eroded and the mud margin is trampled. Despite being limited in extent, this habitat is utilized by shorebirds such as Least Sandpiper (*Calidris minutilla*), Western Sandpiper (*Calidris mauri*) Dunlin (*Calidris alpina*), Short and Long-billed Dowitchers (*Limnodromus griseus and L. scolopaceus*) and Greater Yellowlegs (*Tringa melanoleuca*). In a few areas quite far up the Estero, small patches of the introduced Brass Buttons (*Cotula coronopifolia*) are colonizing the mud margin.

Mudflat

Estero de San Antonio contains small patches of gently sloping intertidal mudflat (Fig. 2), found mostly close to the Estero mouth. Table 10 shows the species of shorebirds found along the Estero during 1975-76 (California Department of Fish and Game, 1977) and maximum numbers of individuals counted in 1990-91 (over six censuses, Maron and Connors unpublished) associated with mud and sandflats and mud margins. With the exception of killdeer, all of these shorebirds are migrants, using the Estero in the fall through spring and then migrating out of the area to breed elsewhere during summer. In Estero Americano, large flocks of Dunlin move into and out of the Estero on a tidal schedule (Maron and Connors, unpublished). These birds are presumably taking advantage of the tide lag between Bodega Harbor and Estero Americano, thereby increasing the amount of time at which they can feed at low tide. Some shorebirds may be using Estero de San Antonio in much the same manner, although San Antonio supports fewer individuals of most shorebird species (Maron and Connors, unpublished).

Table 10: Shorebirds Associated with Mud and Sandflats and Mud Margins

COMMON NAME	SCIENTIFIC NAME	1975-76	1990-91	MAX
Black-bellied plover	*Pluvials squatarola*		X	1
Semipalmated plover	*Charadrius semipalmatus*	X		
Killdeer	*Charadrius vociferus*	X	X	14
Ruddy turnstone	*Arenaria interpres*	X		
Common snipe	*Gallinago gallinago*	X	X	3
Long-billed curlew	*Numenius americanus*	X		
Willet	*Catoptrophorus semipalmatus*	X	X	20
Greater yellowlegs	*Tringa melanoleuca*	X	X	10
Wandering tattler	*Heteroscelius incanus*		X	2
Spotted sandpiper	*Actitis macularia*		X	
Sanderling	*Calidris alba*	X	X	1
Western sandpiper	*Calidris mauri*		X	24
Least sandpiper	*Calidris minutilla*	X	X	164
Dunlin	*Calidris alpina*	X	X	282
Long-billed Dowitcher	*Limnodromus scolopaceus*	X	X	8
Short-billed Dowitcher	*Limnodromus griseus*		X	9
Marbled godwit	*Limosa fedoa*	X	X	3
American avocet	*Recurvirostra americana*	X		

Salt Marsh

Large expanses of saltmarsh border the Estero at many sites between the ocean and the Middle Road bridge (Fig. 2). These marshes vary from site to site in condition, extent and plant species composition, but most (or all) have been affected by livestock grazing and trampling. Plant species diversity is low in most areas, with some sites composed almost entirely of *Salicornia virginica* (pickleweed) and *Distichlis spicata* (saltgrass). *Frankenia grandifolia* is common at some sites, and *Jaumia carnosa* occurs in marshes near the mouth.

Current Threats

There are several actual or potential threats to the general health of the Estero. Below I list these and discuss their impact.

Livestock Grazing and Trampling

Dairy cattle and sheep are abundant on the hills and banks of the Estero and commonly graze and/or trample much of the saltmarsh habitat along the Estero's edge. The combined effects of grazing and trampling have degraded extensive portions of *Salicornia* marsh. In these areas, the vegetation is much reduced and the banks of the Estero have been badly eroded. This acts to increase sedimentation into the Estero which can alter the habitat and negatively affect fish and invertebrate populations. It also reduces its value to shorebirds who occasionally use salt marsh habitat for feeding when it is flooded.

Santa Rosa Waste Water Reclamation Project

Current plans made by the city of Santa Rosa call for building a 250 acre reservoir in the area around Two Rock, which would hold treated waste water from the city of Santa Rosa. Water from this reservoir would be used to irrigate surrounding farm land. The effects of water seepage from this reservoir on Estero de San Antonio are uncertain. It is predicted that groundwater levels may rise between seven to seventeen feet and that this groundwater level rise will translate into additional fresh water being discharged into the Estero (Sukop 1990). Increased fresh water flow can alter the tidal prism and greatly affect habitats and the organisms these habitats support. Whether increased fresh water flowing into the Estero is a threat or an actual improvement will depend on the amount of additional fresh water moving into the Estero and quality of this water relative to current water quality in the Estero. Clearly these issues demand further attention before any detailed enhancement of the Estero is undertaken.

Agricultural Practices/Animal Waste

Animal waste from the hills and banks surrounding the Estero currently wash into the water after rainfall. This increased loading of waste material into the Estero has undoubtedly resulted in the high nitrate and ammonia concentrations that are presently found in Estero water from certain locations. High ammonia and nitrate concentrations in Estero water can be toxic to marine organisms, in addition to having negative indirect affects, by increasing turbidity, and stimulating algal production which ultimately may decrease dissolved oxygen concentrations.

Grazed hillsides may presently contribute to some erosion and sedimentation into the Estero. Over long periods this can have negative affects on marine habitats, in that it can reduce the size of the tidal prism and lead to reduced flows in the Estero. The extent of sedimentation and erosion that directly results from overgrazing should be determined, and where possible reduced.

Enhancement Options

Highest Priorities:

1. Livestock Exclusion from Wetland Habitats

Forage in wetland habitats provides little value to livestock. Exclusion of sheep and cattle from saltmarsh, mudflat and shallow waters of the Estero would provide improvement in saltmarsh vegetation, mudflat stability, and water quality. This, in turn, would benefit populations of animals in these habitats. Much of the beneficial effect would be immediate, as grazing, trampling and deposition of animal wastes cease. Further improvement could be expected over time, however. For example, improved stability of mudflats and sandflats would be beneficial for populations of invertebrates such as ghost shrimp (*Calianassa*) and other species of tube builders and burrowers. Plant communities in saltmarsh and along Estero banks should also improve over a period of years after removal of grazing pressure. Precise changes to be expected are difficult to predict, but a useful example is available from a similar site nearby. At Bodega Harbor, a saltmarsh on the University of California's Reserve was studied by ecologist Dr. Michael Barbour and his students in the late 1960's, shortly after grazing at the site ended. The total plant species list in the saltmarsh at that time numbered 15, including 11 native species (Barbour et al., 1973). By 1991, the plant list for this saltmarsh had increased by six species, and the adjacent strand, at the upper edge of the marsh had added seven more (P.G. Connors, unpublished). Of the six new species, five are native perennial plants characteristic of California saltmarshes. This is a significant improvement in diversity of the saltmarsh, with removal of livestock as the primary suspected factor in this change. All of the new species are potential inhabitants of marshes along the Estero de San Antonio.

Exclusion of livestock from Estero wetland habitat would require a great amount of fencing and possibly some changes in ranching practices. Finding a practical method of achieving this objective may be difficult, but it stands as the highest priority for enhancement of Estero habitats and populations of invertebrates, wetland plants, and birds.

2. Maintain Tidal Opening at Estero Mouth

The prevailing conditions at the Estero mouth (some years open, some years closed) place a level of unpredictability on the ecology of the Estero which probably limits populations of many species of invertebrates and fishes. Actively maintaining the open mouth during years when it would otherwise close would bring stability and predictability to the system, promoting development of populations of fishes and invertebrates that thrive in conditions of free tidal exchange.

Sand bar formation and the concomitant closure of the Estero mouth prevents immigration by marine species into the Estero and produces highly variable, often hypersaline, conditions for fishes. Such an environment typically restricts utilization of the Estero to euryhaline, and mostly benthic, estuarine species including arrow goby, staghorn sculpin, prickly sculpin, starry flounder, threespine stickleback, and bay pipefish.

The potential beneficial impact on fish populations of keeping open the mouth of the Estero de San Antonio can be estimated by comparing fish catch data for the two Esteros. During the summer of 1989 the mouth of the Americano was regularly bulldozed open by a nearby aquaculture facility, whereas the San Antonio was not. Comparison of the otter trawl catch data from July and September, 1989 (Table 11, Commins et al., 1990) suggests that the "open" Americano was utilized by seven more species than the closed San Antonio, the main difference in composition being a lack of surfperch and juvenile flatfish in the San Antonio catch data. Species composition of the San Antonio catch was almost exclusively estuarine species. Thus, maintaining an open channel to Bodega Bay during the summer months may enhance the potential of the Estero de San Antonio as a nursery area for juvenile flatfishes and surfperch.

Table 11: Comparison of 1989 Fish Catch Data

Common Name	Americano July 6	Americano Sept 18	San Antonio July 6	San Antonio Sept 18	San Antonio Nov 24
Pacific herring			X		
Plainfin midshipman	X	X			
Topsmelt	X	X			
Threespine stickleback	X		X	X	
Bay pipefish	X	X	X	X	X
Shiner surfperch	X	X			
Black surfperch		X			
Penpoint gunnel		X			
Arrow goby	X	X	X		
Tidewater goby	X		X	X	
Bay goby			X		
Cabezon	X				
Staghorn sculpin	X	X			X
Prickly sculpin	X	X		X	
Sharpnose sculpin					
English sole	X				
Starry flounder	X	X	X		
Hybrid sole	X				
Pacific sanddab	X				
Speckled sanddab		X			
Total Species	**14**	**11**	**7**	**4**	**4**

Further comparisons between otter trawl samples taken on July 6 and September 18, 1989 in both Esteros, as well as a supplemental sampling trip on November 24, 1991 (Maron and Bennett, unpublished) may help to evaluate enhancement options. (November 24 sampling consisted of three hauls with a modified beam trawl that had a three m. x one m. opening and 20 mm. mesh. Samples were taken within 300 meters of the mouth, to look for the presence of flatfishes and other benthic species. Additionally, four beach seine hauls, two within 300 meters of the mouth and two about a kilometer upstream were also taken.)

Comparisons of the numbers of species between the Esteros may be influenced by an area effect. The Estero de San Antonio is about one-third the size of the Americano, containing approximately 93 acres of open water compared to about 301 acres in the Americano (California Department of Fish and Game, 1977). Often larger areas contain more species than similar but smaller areas in a fairly predictable fashion. A very rough estimate would suggest that an area one-third the size of an identical but larger area should contain about 65% to 85% of the number of species found in the larger area. A comparison of species numbers from the July and September data (Table 11) suggests the San Antonio contains only 50% (in July) and 36% (in September) of the number of species found in the Americano. Thus the Estero de San Antonio contains about 30% fewer species than an area effect would suggest. Such reasoning, though highly speculative, supports the idea that "enhancement" may increase the number of species utilizing the smaller Estero de San Antonio.

In addition to enhancing fish populations, consistent tidal exposure of mudflats and sandflats throughout the year would boost some invertebrate populations, thereby enhancing the Estero as a feeding site for shorebirds. Shorebird species such as Marbled Godwit, Willet, Dunlin, Western and Least Sandpipers exhibit strong site fidelity to specific wintering areas, with individuals returning each year to the same sites. Stability of foraging areas in the Estero could lead to establishment of larger Estero populations of many species.

Keeping the mouth open by bulldozing a channel whenever needed, however, presents a problem of disposal of the sand taken from the mouth. Sand should not be piled up to build an unnaturally high outer bar. Ideally, it should be placed in the ocean outside the bar. At the Estero Americano, an artificial, high mound of sand and gravel has been deposited at the mouth. This has altered the natural, low beach profile, and may represent a potential hazard in some future storm. Waves high enough to wash around the base of the pile may redistribute a large volume of sand inside the mouth.

Lower Priority Enhancements:

1. Enhance Eelgrass Beds

The importance of eel grass (*Zostera marina*) beds in providing cover and food for fishes and invertebrates is well known. Such habitat regularly contains high numbers of species in estuaries. In the Estero de San Antonio the extent of this important habitat may be impacted by agriculture. Agriculture potentially impacts eelgrass by (1) direct disturbance of the stream banks by livestock in upstream areas that increases sedimentation downstream, and (2) the input of livestock wastes by surface runoff that degrades overall water quality.

Maintaining quality eelgrass habitat may be a key factor influencing the small recreational fishery for striped bass in the Estero de San Antonio. Conversations with local fisherman indicate that in most years striped bass are present in the de San Antonio. On November 24, 1991 several fish, tentatively identified as young striped bass, were breaking the surface near the Estero mouth. While most fish caught are juveniles (less than the 18 in. legal limit, and one to two years old), locals regularly catch adults. One group of fishermen claimed to have landed a 24 kg. specimen during the first week of November, 1991. Juvenile and young adult striped bass feed almost exclusively on shrimp (*Neomysis*) in the Sacramento-San Joaquin estuary from which the visitors to the Esteros originate. Striped bass migrants may be drawn to the Esteros because of high shrimp production in the eel grass beds. While a California Department of Fish and Game report (1977) suggests *Neomysis* has been present in the Esteros, shrimps of the genus *Heptacarpus* and *Hippolyte* were abundant in a beach seine haul at the eelgrass bed.

2. Increase Tidal Prism, Increase Freshwater Flow, Increase Channels in Marshes

These potential enhancements are grouped because they all involve topographic changes or changes in water flow within the Estero. Increasing the tidal prism (tidal volume) might require engineering changes (such as dredging) beyond the scope of any probable Estero Project, but it could provide the natural means of maintaining an open mouth to the Estero. It would probably require increasing the depth of the main channel, or creating some wide, deep pools. Disposal of displaced sediment would create another problem to be solved. Additional study and review would be necessary if the system was to be physically altered.

As discussed above, summer freshwater input into the Estero has been reduced by agricultural practices and water development. Replacement of lost freshwater flow is desirable but unlikely under most scenarios. One possible development that could introduce more freshwater into the watershed is the Santa Rosa Waste Water Plan for irrigation of watershed agricultural lands. This project would provide beneficial increases in freshwater flow, but with unknown and potentially harmful changes in water quality, either from the irrigating water or from attendant changes in agriculture.

Many of the *Salicornia* marshes, especially those upstream of the Franklin School Road Bridge, might support more diverse plant communities and greater populations of invertebrates and birds if they were more topographically diverse. Creation of shallow, gradually sloping channels and shallow ponds within the flat, relatively uniform *Salicornia* flats would provide greater tidal flow within the marshes as well as a variety of shallow water and mudflat habitats that are now rare in these mostly vegetated marshes. Such habitats in the Estero Americano are the most heavily used portions of *Salicornia* marshes by shorebirds in that Estero. Similar use is likely in the Estero de San Antonio if these habitats were developed. This enhancement would require bulldozing and short-term disturbance, but with positive longer-term results. Again, further study and review would be necessary if the system was to be physically altered.

Related Enhancements

1. <u>Estero Access</u>

The Estero is a resource of significance to many people in Marin County as well as the adjacent landowners. An informed and aware public familiar with the special attributes and problems of the Estero will, in the long run, be useful in preservation of the Estero and the agricultural lifestyle of the area. Safe access to the water for recreational canoers and kayakers might help in this goal, although this is an obviously controversial option. If public access is to improve the environment, it must be managed intelligently. Uncontrolled random public access would undoubtedly create more problems (including liability to landowners) and not be beneficial to the environment. Carefully managed access, with a strong educational component, might be beneficial. Access is currently limited by fences that cut across the road right-of-ways at the Franklin School Road Bridge and the Middle Road Bridge. A small change in one of these fences would provide a safe access route from the road to the Estero without trespassing and adverse effects on the adjacent grazing land use. This might be as simple as a four-fence-post passageway that can be traversed easily by people but not by livestock and bikes. The best location for such a passageway is the northeast corner of the Franklin School Road bridge, where a safe unloading area for a parked car already exists, and the bank is not unduly steep. In conjunction with improving public access it might be quite desirable to post informative display signs, which could serve to educate the public about the natural resources supported by the Estero.

2. <u>Control of Vegetation</u>

Some effort should be made to control invasive, shrub-sized introduced plants that might otherwise dominate the landscape. For example, at present one or two plants of pampas grass (*Cortaderia*) are growing on hillsides near the Estero mouth. This species will probably spread aggressively over time, but could be easily eliminated now. Gorse (*Ulex europaneus*) is another species becoming common near the Estero Americano that should be controlled if it occurs now or in the future along the Estero de San Antonio.

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APPENDIX B

VEGETATION AND HABITAT RESTORATION - STEMPLE CREEK WATERSHED
Marco Waaland, Golden Bear Biostudies

Vegetation and Habitat Restoration

Stemple Creek Watershed

prepared by

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July 1993

The study area for the enhancement plan is defined by the watershed divide of the Stemple Creek basin. The study area consists of approximately 28,000 acres of rolling hills in an alluvial valley. The present agricultural practice is predominantly dry land farming on dairies. The major types of land use patterns in the area are farmstead, cultivated, improved pasture, and grazed or idle. Figure 1 shows the study area at a scale of 1 inch = 2000 feet.

PURPOSE

The purpose of the ecological component of this study was to provide a means for enhancement of coastal resources consistent with Chapter 6 Public Resources Code (3124131270). Specifically, this section primarily addresses enhancement terrestrial habitats for wildlife. Restoration of riparian corridors, oak woodland and marshes will have secondary effects on improving water quality from dairy runoff and inhibit sedimentation and erosion of the soil resources.

SCOPE

The study is limited to information generated by site specific sampling conducted at an intensity sufficient to develop data for classification of the entire watershed into broad habitats as prescribed in the Wildlife Habitats Relationship Program. Sample points were not evenly distributed across the watershed nor at the same intensity for each habitat type. For instance, the valley bottom was sampled at a greater intensity than upslope areas because of work conducted for a previous wetland survey in the watershed (North State Resources et al, 1990). The source of all wildlife information was generated by the WHR program or prior studies; no independent wildlife research was conducted for this study.

WHRS HABITAT DESCRIPTIONS

During various studies, including this one, vegetation in the project area was sampled over the course of five years between 1989 and 1993. Sampling methods are described in the Appendix. Discreet vegetation units were classified into types conforming with those in the Wildlife Habitats Relationships System (WHRS) (Airola, 1988). These generalized units were further subdivided in to plant communities based on their homogenous floristic composition. WHRS habitat types, acreages and corresponding plant communities are listed Table 1.

Table 1 missing from this edition

Habitat types mapped for the study area are shown in Plate 1 (see map pocket). An inventory of the vegetation samples, including a summary of dominant plant species is also listed in the Appendix.

The distribution of WHR habitats in the Stemple Creek watershed change along a gradient from east to west. The highest elevations in the watershed occur in the east. This area probably also receives the highest rainfall due to orographic precipitation, essentially wringing the clouds of moisture as they pass over the highest elevations encountered landward of the ocean. It is in these headwater areas that the oak woodlands occur in moist, shady east facing slopes. Significant riparian woodlands also occur in the ravine bottoms. To the west, the fog and tidal fluctuations are the predominant influence on the vegetation. The distribution of the coastal prairie corresponds with cool maritime climate. Steep north-facing and/or protected slopes are cloaked with coastal scrub. Salt marsh and brackish marsh flank the estuary to the limit of tidal influence. East of tidal effect occurs freshwater marsh. However, the dominant habitat in the watershed occurs between the east and the west ends, where annual grassland, pasture and cropland cover the landscape, punctuated by linear windbreaks of eucalyptus and cypress trees.

While these non-native habitats comprising the bulk of the watershed are important for wildlife, the middle area was likely much more diverse in the past. Over 800 acres of hydric soils occur in the bottomlands, indicating a high water table that would have sustained extensive riparian woodlands and marshes. Soil borings have unearthed remnants of redwood at 200 feet below the present land surface, obviously indicating severe sedimentation, but also raising questions of whether redwoods were native to the watershed in the past. It is in this middle section where soils are suitable and land is available that the prospects for restoration are the greatest. Although the native habitats in the headwaters and the maritime zone should be expanded through restoration, the most pressing issue in this area is preservation of what presently exists and institution of management practices that ensure their survival.

Following is a detailed discussion of each habitat types and its associated plant communities.

Annual Grassland/Pasture/Cropland (AGS/PAS/CRP) Complex

Together, these habitats account for 30, 864 acres (94 percent) of the study area. These WHRS habitats were combined into one large complex because they differ only slightly in their species composition (are all dominated by a variety of introduced grasses) and they would have been difficult to map as separate entities at the scale of 1"=2000' (Plate 1). In addition, for the purposes of restoration, conversion of these habitats to others have very similar results because they have relatively low initial wildlife diversity (see Restoration Section). Following is a discussion of the WHRS habitats within the complex, as well as the plant communities which occur within them.

Annual Grassland. This WHRS habitat type and plant community is dominated by annual grasses such as Italian rye, slender oats, soft chess, rip gut brome and hare barley. Other broad-leafed annual plants include filaree, cutleaf geranium, mustards, tarweeds and bindweed. Occurs mainly on hillslopes.
'

Within this WHRS habitat type there occurred a "meadow" plant community.

Cropland. Also referred to as "cultivated hayfield," this WHRS habitat consists of silage cultivated on an annual basis, which comprises approximately 2,000 acres (6 percent) of the study area. Runoff from manure nitrogen, sediment, herbicide, and pesticides from this area could result in moderate impacts on the creek and surrounding area due to loadings to the creek.

Eucalyptus. Large groves and windbreaks of blue gum, scattered throughout the watershed. Acreage of this habitat type were included in the AGS/PAS/CRP estimate.

Urban. This WHRS habitat type refers to farmsteads and other developments included in the AGS/PAS/CRP/URB WHRS habitat complex. Approximately 1100 acres (3† percent) of the study area falls in this category. It consists of areas containing houses, sanitary landfill, urban development, feedlots, and dairy parlors. These areas were considered to be impacted by intensive use of humans and animals, especially dairy cows. Feedlot and dairy parlor areas receive high manure loadings, resulting insignificant nitrogen contributions in runoff. Because of the potential for nitrogen runoff, these areas have a high potential to adversely impact the riparian areas and downstream wetlands. Nonpoint source pollution from the sanitary landfill is also a water quality concern.

Lacustrine. Mostly farm ponds which serve as small open water environments. Included in acreage for rest of AGS/PAS/CRP complex.

Plant Communities in the AGS/PAS/CRP Complex Influenced by Wet Soils and/or High Water Tables. Much of the bottom land in Stemple Creek Valley has hydric soils and wetland hydrology, but the vegetation is dominated by marginally hydrophytic grasses with a facultative indicator status for wetlands (North State Resources et al, 1990). Past studies have classified these lands as wet meadows because they would be considered jurisdictional wetlands under

Section 404 of the Clean Water Act. However, the WHR classification scheme excludes Wet Meadow from Sonoma County, indicating its range occurs above 4000 feet elevation in the Klamath Mountains and the Sierra Nevada. Therefore, the wet meadows of Stemple Creek were classified into either of the'

Seasonal Wetland and Vernal Swales. Seasonal wetlands also occurred largely in areas which were once riparian woodlands. This habitat type differs from the marsh in that the water table falls below the rooting zone of most plants during the summer. Most species are weedy annual forbs. For instance, the most common dominant plants were fat hen, spiny cocklebur and fiddle dock. Deeper swales were also characterized by prickle grass, coyote thistle and knotweed. The majority of these species have a facultative indicator status, indicative of their weedy, opportunistic strategy. They exploit were woodlands and seasonal or perennial freshwater marshes.

Perennial Grassland

This habitat occurs at the westernmost end of the watershed in the zone a maritime climate. It accounts for 370 acres (1 percent) of the study area. A more extensive transition zone occurs to the east where native grasses decrease in abundance relative to non-native annual grassland. Isolated, but relatively extensive stands occur throughout the watershed, especially in the headwaters area of the Button Ranch. Pacific hairgrass, needlegrass, California Fescue, California oatgrass.

Coastal Scrub

Occurs on slopes immediately adjacent to the coastline and subject to strong maritime climatic influences. It accounts for 150 acres (0.5%) of the watershed. It includes a range of plants, frequently bush lupine, coyote bush, coffee berry, bushmonkey flower, bracken fern and oatgrass. The coastal strand association may be included in this WHR habitat.

Freshwater Emergent Wetland

Otherwise known as freshwater marsh. It occurs most extensively in the sediment filled floodplain, just upstream of the brackish marshes of Estero de San Antonio. It accounts for 84 acres(0.3%) of the watershed, the least extensive of all the habitat types. Wettest sites include cattails, tule, water plantain. Along marsh margins, saturated or periodically flooded soils: sedges, rushes, sempaphore grass, nutgrass, dock. Occurs mainly in, or adjacent to, channels, but also in depressions subject to ponding or frequent flooding.

This habitat type is constrained to the narrow bottoms of stream channels which remain perennially moist or saturated. Before the onset of widespread grazing and land clearing, this habitat type was most likely riparian woodland. The present herbaceous species, which can tolerate continued grazing, persist in the channel bottoms because woody plants never become established. Two characteristic species, fat hen and barnyard grass are both introduced facultative wetland species. Another characteristic plant, pricklegrass is an introduced obligate wetland species. Swamp knotweed an obligate wetland plant, was a characteristic native species. Water plantain and willow were also natives which occurred occasionally. In the absence of disturbance (i.e. heavy grazing pressure), these habitats would revert to riparian woodland over time.

Saline Emergent Wetland

Otherwise known as salt marsh or brackish marsh, it occurs in areas where water is saline or brackish and subject to tidal influence, virtually all adjacent to the estuary. It accounts for 213 acres (0.7%) of the watershed. Salt marsh occurs in the lower estuary (i.e. subject to greatest inundation) and is dominated by pickleweed in the lower marsh zone and by saltbush and frankenia in the upper marsh zone. Brackish marsh is transitional between salt marsh and freshwater marsh. Dominants'

Valley Foothill Riparian Woodland

These wetlands, dominated by trees and shrubs, occur throughout the watershed. They account for 149 acres (0.5%) of the watershed. Bottomland riparian woodlands are dominated by willows, wild rose, blackberries and sedges. Ravines and canyons of the upper watershed include trees such as live oak, bay and buckeye.

This habitat type represents the remnants of the riparian woodlands that were once widespread in the bottoms of the Stemple Creek watershed. Although the original, climax riparian flora was much more diverse and well developed than the present remnants, the narrow corridors of willows provide a link to the diversity and seed source of the past. The most characteristic, dominant plants were arroyo willow and yellow willow. Variability in the frequency of understory species from site to site resulted in dominance of a species at one sample location, but its absence at another. Nonetheless, other characteristic native plants included hawthorne, wild rose, California blackberry and slough sedge. The willows and the sedge have either obligate or facultative wetland status, indicative of their affinity for wetlands. The two shrub species, wild rose and hawthorne are facultative species, reflecting their ability to thrive on better drained soils also.

Coastal Oak Woodland

This habitat occurs mainly in the eastern headwaters of the watershed, in sheltered pockets and ravines south and north of the valley bottoms. It is the second most extensive habitat type in the watershed, accounting for 1170 acres (4%). Dominated by live oak and bay trees with shrubs of toyon, poison oak and woodland rose. Occurs in protected pocket valleys and slopes of the upper watershed.

Bay forest is a distinct plant community within this habitat type that is widespread in the button ranch area. Unusual, nearly homogenous stands of bay trees provided a very dense canopy with very little understory.

HABITAT RESTORATION

Restoration of Native Plant Communities.

Detailed literature and field research was conducted to develop the restoration plan. Description of the natural resource components of this study are reported in the vegetation section of the enhancement plan. The overall restoration scheme is shown.

Several objectives have been identified that will direct implementation of the enhancement plan. They are:

Objective: Restore native habitat types and plant communities to suitable areas of the watershed.

Policies

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Objective: Utilize wetlands to not only improve wildlife habitat, but also improve water quality.

Policies

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Objective: Reintroduce Extirpated Endangered Species and Expand Existing Populations of Those Present In the Study Area.

One of the benefits anticipated in the restoration of riparian woodland and wetlands in the study area would be the possibility of developing programs with wildlife agencies for there-introduction of endangered species once known to occur there. Extensive restoration in this area would provide a reasonable expectation of returning the endangered California yellow-billed cuckoo. Other rare or endangered species associated with

Policies

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Rationale for a Restoration Plan

Riparian woodland, oak woodland, perennial grassland and freshwater marsh are targeted for restoration, returning some of these habitats back to areas of their former range. Native biodiversity will be increased and a number of rare or endangered species can potentially be reintroduced. The restoration will be largely achieved by converting the wettest areas of grassland and pasture back to riparian woodland and marsh by revegetation with native willows, bulrush, etc. Upland areas will be planted to oaks or native grasses.

As recently as the last half of the nineteenth century, riparian woodland and marsh were more abundant in the floodplain of Stemple Creek. The area had populations of waterfowl, salmonids, elk, and antelope and grizzly bear (Marrayat, 1977). Much of the native biodiversity has been lost and continues to decline as wetlands have disappeared and woodlands cleared (Dodds, 1976; Airola and Messick, 1987; Frayer et al, 1989; Dahl, 1990). For instance, the yellow-billed cuckoo, which is only found in dense riparian woodlands, hasn't been seen in the County since the early 1960's (CNDDB, 1985). Other species such as the yellow warbler and the western pond turtle are declining and may be listed as endangered in the future. Aquatic species, such as steelhead and freshwater shrimp, either have remnant populations or were known to occur within the last several decades.

APPENDIX C

EROSION AND SEDIMENT STUDY
USDA Soil Conservation Service

EROSION AND SEDIMENT STUDY

STEMPLE CREEK WATERSHED

Prepared for and in cooperation with

Marin County Resource Conservation District

Southern Sonoma County Resource Conservation District

California Coastal Conservancy

FEBRUARY 1992

PREPARED BY
USDA - SOIL CONSERVATION SERVICE
DAVIS, CALIFORNIA

Under Authority of
CALIFORNIA SPECIAL STUDIES
BASIN AND AREA PLANNING

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TABLES:

INTRODUCTION

The Stemple Creek Watershed Erosion and Sediment Study (Study) evaluates the erosion and sediment sources in the watershed, and investigates the conceptual designs for erosion control and sediment reduction to Stemple Creek, the Estero de San Antonio, and Bodega Bay. This study was designed to address only the erosion and sediment sources, their scope and methodology for the reduction of sediment reaching the Coastal Zone. These proposed solutions will be evaluated by a local steering committee for incorporation into an Enhancement Plan for the Estero de San Antonio and Stemple Creek.

The study was partially funded by the Marin County Resource Conservation District, and Southern Sonoma County Resource Conservation District through a grant received from the California Coastal Conservancy. The study was done by a USDA Soil Conservation Service (SCS) interdisciplinary team of geologists, soil scientist, biologist, forester, and engineers.

The specific products of the study include:

1. A Hydrology study to predict the 2-, 5-, 10-, 25-, 50-, and 100-year peak discharge at index points along Stemple Creek (Appendix A).

2. An identification and quantification of the sources of sediment reaching Stemple Creek, the Estero de San Antonio, and Bodega Bay.

3. An evaluation of control measures for reduction of erosion and sediment reaching Stemple Creek, the Estero de San Antonio, and Bodega Bay.

4. An evaluation of the cost of selected measures compared to their sediment reduction.

5. A description of the effects of the selected measures on the watershed.

During the investigations for this study additional concerns were discovered. There appears to be pressure for ranchette subdivisions on some of the flatter areas in the watershed, especially in the upper subwatershed. These flatter areas are primarily on the floodplains so development would call for decreasing the frequency and duration of flooding. This would result in more watershed sediment being delivered downstream instead of being stored in the floodplains of the upper subwatershed. A net effect would be an increase in the rate of sedimentation in the Estero and Bodega Bay.

Another concern involved the introduction of reclaimed water into the watershed for irrigating pastures and other crops. Experience from other areas indicates the introduction of additional irrigation water could also increase the amount of sediment reaching the Estero and Bodega Bay. This is due to increased concentrated flows occurring on newly irrigated cropland from both irrigation and rainfall. It is critical to control application of irrigation water on slopes so that concentrated flow does not occur. Concentrated flows may result in gully and channel erosion where no such erosion presently exists.

Additional planning and a study of the effects of development or irrigation on erosion and downstream sedimentation should be made before these land use changes are made.

DESCRIPTION OF THE STUDY AREA

Location

The Stemple Creek watershed, is located in Marin and Sonoma Counties, and covers approximately 51 square miles. It lies between Valley Ford to the north, Tomales Bay to the south, Bodega Bay to the west, and Petaluma to the south and east. It drains into Bodega Bay 1.5 miles northwest of Dillon Beach (Figure_1).

Stemple Creek Watershed is characterized by rolling coastal hills that have average slopes of about 30 percent. Stemple Creek runs from east to west into the Estero de San Antonio and ultimately flows into Bodega Bay and the Pacific Ocean.

Geology

The geology of the Stemple Creek area involves two broadly described formations:

1. The Franciscan Formation is the oldest material and consists of a mixture of rock masses in a sheared, shaley matrix. The formation is Mesozoic in age and is fractured and faulted. These rocks are found mostly at the lower elevations and in the west end of the watershed.

2. The Merced Formation is Pliocene age, mostly marine sediments consisting of sandstones, conglomerates, limestone concretions and tuffs. These rocks make up the largest part of the study area. They are found at higher elevations and are generally in the east end of the watershed.

There are six major faults in the area that have had movement within the last two million years. The two largest of these are the Americano Creek Fault and the Bloomfield Fault. Although no movement has been recorded along these faults in historical times the possibility does exist and should be considered when building structures near them. A greater threat is probably from other large faults outside of the study area, such as the San Andreas Fault, that is located just west of the study area. These faults are more active than those in the watershed and could cause structural damage.

Soils

Soils in the area are primarily Tomales and Steinbeck soils in the uplands and Blucher, Cole, and Rodeo in the alluvial valleys. Tomales and Steinbeck soils are deep with loam or silt loam surfaces on 10 to 40 percent slopes. Blucher, Cole, and Rodeo are all very deep with silt loam or silty clay loam surfaces and are found on 2 to 5 percent slopes.

The Humaquepts and Hydraquent soils associated with the Estero serve as wildlife habitat for wetland species and offer poor grazing when dry enough for livestock. (See Sonoma and Marin County Soil Survey Reports, USDA).

Wildlife

Stemple Creek watershed is a highly diversified watershed, encompassing 14 different habitat types and a variety of terrestrial, aquatic, and marine species. The most significant habitat being the riparian areas, which are the focal point of any watershed. Riparian areas are ecosystems that occur along watercourses or waterbodies, that are distinctly different from the surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Riparian ecosystems occupy the transitional area between the terrestrial and aquatic ecosystems.

At least 75% of all wildlife depend on riparian areas while it only comprises about 1% of the watershed. The high use of riparian areas are due to its' availability of food, water, cover, resting, and breeding sites. Care must be given to Stemple Creek's riparian areas where grazing and urban uses have degraded the natural state of the various systems. Accounts must be made for the wildlife in the grazing cycle especially in the Stemple Creek watershed where 87 plant and animal species of special concern reside. The riparian areas are especially difficult to manage because they are small, complex, and diverse. But the whole stream integrity depends upon the water-loving streambank vegetation in the riparian zone.

Currently, Stemple Creek is suffering from water quality problems related to sedimentation and eutrophication. Much of the creek vegetation has been lost to grazing and physical trampling. A stream devoid of habitat values can be healed by controlling access of livestock. Proper grazing management can recreate a healthy riparian system. Terrestrial and aquatic species will benefit, including the annual return of a healthy population of anadromous fish.

Land Use

Presently the two main land uses in the watershed are grazing and cropland. The amounts of land in each use is in Table 1. These areas impact Stemple Creek and the Estero differently depending on their distance from the open water areas.

The rangeland areas were evaluated on the amount of Residual Dry Matter (RDM) at the end of the grazing season in October, 1989.

TABLE 1 - COVER CLASSIFICATION

TYPE	Lower Subwatershed (acres)	Middle Subwatershed (acres)	Upper Subwatershed (acres)	TOTAL
Low RDM	416	496	1,431	2,343
Moderate RDM	5,098	10,083	11,270	26,451
High RDM	754	759	671	2,189
Cropland	132	412	1,478	2,022
TOTAL	6,400	11,750	14,850	33,000

Figure 1 - Location Map

back of location map

EROSION AND SEDIMENTATION

The Stemple Creek Watershed Erosion and Sediment Study was conducted to evaluate the sediment yield produced by the major erosion sources within the watershed. The total sediment yield from the watershed to the Estero is estimated to be about 51,000 tons per year with 6,000 tons per year being deposited in the Estero and the remaining 45,000 tons going on to the ocean.

The amount of sediment yield was estimated using four different methods. Channel erosion was estimated using the Direct Volume Method. Sheet and Rill erosion were estimated using the Universal Soil Loss Equation (USLE): Pacific Southwest Interagency Advisory Committee (PSIAC): measured total sediment yield; and pond surveys measured sheet, rill, and gully erosion. Sediment yields from each source were routed through three subwatersheds (Figure 1) to derive the amounts entering the Estero and ultimately the ocean.

The cross sectional area of the Stemple Creek channel is fairly normal, holding a little less than a 2 year flow in most reaches. This allows as much as 90 percent of flood flows to overflow out of the bank depositing as much as 0.24 inches per year of sediment on the floodplain in the lower subwatershed. At the present rate, as much as 2 feet of sediment could deposit on the floodplain over the next 100 years.

Channel Erosion

Channel erosion is the major sediment contributor to the Estero de San Antonio, producing about 68 percent of the total sediment yield in the watershed, or about 30,300 tons per year (Tables 2 and 3). Channel erosion includes streambank erosion along Stemple Creek and its' tributaries, and erosion in gullies.

Of the 30,300 tons per year, 2 percent or 570 tons per year comes from the upper subwatershed, 16 percent or 4,740 tons per year from the middle subwatershed, and 82 percent or 25,010 tons per year comes from the lower subwatershed. The most critical area is the lower subwatershed for channel erosion. The lower subwatershed is closest to the Estero, has steeper slopes, and its floodplain areas are smaller than those in the upper and middle parts of the watershed.

The streambank erosion along Stemple Creek itself is minimal throughout the watershed. Only about 9 percent of the total sediment yield appears to be from erosion of Stemple Creek banks.

About 45 percent of the sediment produced by channel erosion in the lower subwatershed is from gullies, 30 percent is from tributary stream banks and 9 percent is along Stemple Creek.

Table 2. Average Annual Sediment Yield To The Ocean

Source	Subwatersheds	Total

Sheet & Rill Erosion	Lower (tons)	Middle (tons)	Upper (tons)	(tons)	(percent)
Cropland	480	1,080	1,730	3,290	7
Rangeland					
high & medium RDM	3,600	4,480	1,670	9,700	21
low RDM	300	550	790	1,640	4
Subtotal	4,380	6,110	4,760	14,680	32
Channel Erosion					
Gullies	13,500	1,880	250	15,64035	
Streambanks	8,870	1,700	100	10,670	24
Stemple Creek	2,640	1,160	220	4,020	9
Subtotal	25,010	4,740	570	30,320	68
Total	29,390	10,850	4,760	45,000	100

Table 3. Percent of Sediment Yield From Subwatersheds

Source	Subwatershed Lower (percent)	Middle (percent)	Upper (percent)
Sheet and Rill Erosion			
Cropland	2	10	36
Rangeland			
high & medium RDM	12	40	28
low RDM	24	6	1
Subtotal	15	56	88
Channel Erosion			
Gullies	46	17	5
Streambanks	30	16	2
Stemple Creek	9	11	5
Subtotal	85	44	12
Total	100	100	100

Sheet And Rill Erosion

Sheet and Rill erosion produces almost 32 percent of the total sediment yield in the watershed or about 14,680 tons per year. Most of this sediment (40 percent) originates in the middle subwatershed. The other two subwatersheds each contribute about 30 percent of the total sediment from sheet and rill erosion.

Sediment from sheet and rill erosion is divided into cropland and rangeland sources. Although cropland comprises only about six percent of the total acreage, it contributes about 22 percent (3,290 tons) of the total sheet and rill sediment yield in the watershed.

Accelerated Erosion

Accelerated erosion is the erosion caused by man that is over and above the background or geologic rate of erosion. About 70 percent of the sediment yield to Stemple Creek is due to accelerated erosion. About 60 percent of the sediment from sheet and rill erosion and about 75 percent of the sediment from channel erosion is due to accelerated erosion.

Accelerated erosion in the Stemple Creek Watershed probably began over 100 years ago when much of the land was cleared of native vegetation to make way for cultivated crops. This removed the valuable vegetative cover and destroyed roots that protected the soil and held the soil in place. Native grasses also had a deeper root system than the introduced species which replaced them in much of the watershed. Because this area is characterized by a combination of highly erodible soil, steep slopes and unstable geologic material, it was not long before concentrated flows began to generate an increase in erosion and eventually formed large gullies and degraded the stream channels in the upland portions of the watershed and Stemple Creek tributaries. Historical practices and reoccurring large storm events like those in 1982 and 1986 create the visible effects in the watershed.

Today most of the land in the watershed has been converted back to rangeland and only about 2,200 acres out of 32,000 acres are now cultivated, but many of the gullies and streambanks are still actively eroding. The erosion that occurred when the land was cleared cut deep gullies and stream channels, leaving high vertical banks and large headcuts. In places, the erosion has cut through the soil layer into the soft underlying bedrock. A combination of gravity and subsurface seepage causes the vertical banks to fall into the channels where the material enters the system and is carried downstream. Unstable or unnatural conditions around the stream banks allows continuous removal of material from the toe of the banks, causing them to remain vertical longer than normal, and making it harder to reach a stable condition. There is an almost cyclic process that occurs as the gullies and streambanks are made unstable, then nearly reach a stable condition and then are made unstable over and over again. Analysis of the soils in some of the headcuts indicate that some of the gullies in the uplands are being rejuvenated for the third time. Eventually under natural conditions these banks would find their stable positions relatively soon, but several factors account for the unstable conditions that continue.

Present day factors accounting for unstable conditions include:

1. Soils in the area have a relatively impermeable subsurface layer caused by natural conditions. This causes lateral movement of subsurface water leading to piping and erosion. As the water seeps through the banks, they are

undercut by piping, creating overhangs which fall as blocks of soil. This is especially effective in causing continued headcut movement even in areas where the surface flow is not being concentrated. The lateral flow often times is transmitted through tunnels created by rodent burrowing and this leads to gullying. Continual grazing can cause compaction and accelerate or aggravate these conditions, especially when the soil is wet.

2. Cattle and wildlife in the riparian zones may trample the banks, pushing sediment into the channels and causing the toes of the banks to erode away. The banks then become vertical. The trampling also reduces much needed vegetation on the banks which is important for stabilizing the slopes.

3. Concentrated flow caused by the lack of vegetation due to overgrazing or artificial changes in the drainage paths for water causes increased erosion and creates new gullies or reactivates old ones. This also causes degradation of the stream channels by increasing the amount of water that the channels carry.

SUMMARY

The cross sectional area of the Stemple Creek channel is fairly normal. Channel erosion is the major sediment contributor to the Estero de San Antonio, of the 30,300 tons per year, 82 percent comes from the lower subwatershed. The streambank erosion along Stemple Creek itself is minimal throughout the watershed. About 45 percent of the sediment produced by channel erosion in the lower subwatershed is from gullies. Sheet and Rill erosion produces almost 32 percent of the total sediment yield. About 70 percent of the sediment yield to Stemple Creek is due to accelerated erosion.

The continued erosion of streambanks and gullies in the Stemple Creek Watershed causes:

1. Decreased productivity of agricultural land.

2. A loss of valuable property due to erosion.

3. An unnaturally high amount of sediment to be deposited in the Estero de San Antonio at the mouth of Stemple Creek before it empties into the ocean, shortening its lifespan as an estuary.

4. Loss and destruction of habitat for fish, waterfowl, and other wildlife.

5. Additional flooding problems on the floodplains along Stemple Creek.

SCOPE AND INTENSITY

Erosion along streambanks and gullies was estimated using the Direct Volume Method. Slide photographs of erosion sites provided by a consulting company, Prunuske-Chatham, and aerial photographs were used to estimate eroding area and lateral recession rates. Lateral recession rate is the average annual thickness of soil eroded from a bank surface (perpendicular to the face) in an average year. For this study these rates were split into non-eroding (0 ft/yr), slightly eroding (0.02 ft/yr), moderately eroding (0.12 ft/year) and severely eroding (0.4 ft/yr).

The sites were plotted on an aerial photography overlay of the watershed showing location and lateral extent of the eroded area for gullies, tributaries and Stemple Creek. The aerial photos were also used to identify erosion in the watershed that was not inventoried as a specific site by the consultant.

The amount of sediment from sheet and rill erosion in the watershed was estimated using three different procedures. One method was Wischmeir's Universal Soil Loss Equation (USLE). Current land use practices were provided by the Petaluma field office staff and were split into three groups: cropland, rangeland with high RDM and rangeland with low RDM. These areas are assumed to remain the same in the future for the purpose of this study. Cover, rainfall, soil erodibility and slope factors were used to estimate the erosion from the three sources.

The second method used was the Pacific Southwest Interagency Advisory Committee (PSIAC) procedure to estimate total sediment yield from the watershed. This was done in the field for 14 areas that were representative of that respective part of the watershed. The amount of sediment produced from channel erosion which was determined by the Direct Volume Method was then subtracted from the PSIAC results to derive the sheet and rill component. Sheet and rill results using this method were compared to those using USLE.

The final procedure was to measure sediment accumulations in farm ponds where the primary source of sediment is from sheet and rill erosion. Four ponds with known capacities were surveyed to find the present capacity. The change in capacity was used to determine a sediment yield rate to the pond.

All of these methods were compared for consistency and appropriate adjustments made. Sediment from each source was routed through the subwatersheds and a final sediment yield to the Estero and to the ocean was calculated.

SOLUTIONS FOR SEDIMENTATION SOURCES IN STEMPLE CREEK

The sources of sediment reaching Stemple Creek and the Estero de San Antonio come from three major sources: (1) sheet and rill erosion on rangeland with low Residual Dry Matter and cropland, (2) gully erosion, and (3) streambank erosion. Solutions offered for these sources should be included in a Conservation Plan, developed with the landowner. The Conservation Plan will look at the causes of the erosion on the specific site and make recommendations for treatment alternatives. Plans should be cost effective and not impact (or at least offset) the number of grazing animals grazed on the site. Animal performance should be improved or maintained.

Technical assistance in the Stemple Creek watershed will be different depending on which alternative is selected. The average farm size in the watershed is assumed to be 300 acres. It takes approximately two staff weeks to develop a conservation plan and an additional one staff week of follow-up with the landowner to refine and modify the plan. Design and construction of measures will take an additional two staff weeks per plan. This totals five staff weeks per landowner. Using an average of five weeks per 300 acres, it would take 544 staff weeks to treat the entire watershed. This is a total of 10.5 staff years. At $50,000 per staff year (including benefits), the cost in technical assistance in the entire watershed would be $525,000. Two workshops per year are planned for the five year period. These will cost an additional $83,000 for the project. The annual cost of technical assistance in the watershed would be $1.57 acre/year for 25 years, assuming the work was done over 5 years and amortized over 25 years. If a reduced area is treated, the cost per treated acre would be higher due to the fixed number of workshops.

The Stemple Creek Erosion and Sediment Study is predicated on the assumption that future planning efforts within the watershed will employ the best structural and management techniques currently feasible, and that the planning will be conducted in a comprehensive manner with the landowner/manager. Conservation plans to conserve, protect, and enhance the resources within the watershed should be equivalent to the SCS Field Office Technical Guide and Planning Manual model.

After a careful assessment of resources and alternatives practical at the ranch level, local input, and the consent of the landowner are paramount. The plan must blend best available technology and an economic solution.

RANGELAND TREATMENT

There are about 26,000 acres of rangeland in the Stemple Creek Watershed. About 2,350 acres of this rangeland is considered low RDM. This is rangeland that has less than 1,000 pounds of residual dry matter (RDM) remaining after the grazing season which can cover the soil surface during critical months.

Figure 2 shows rangeland residue levels, remaining at the end of the 1989 grazing season. Depending on rainfall and stocking rate these areas could increase or decrease. Moderate residue (1000-1500 pounds/acre of residual dry matter on October 1) is the desired level. Low RDM reduces the fertility of the site, reduces the infiltration rate, and exposes the soil to more rainfall which increases sheet and rill erosion and runoff. On the other hand, too much residue (high level) may induce an undesirable shift in species composition, may cause decreased productivity in the next growing season, as well as, under-utilizing valuable livestock forage.

If range improvement measures (Partial Improvement, PI) are applied to all the rangeland with low RDM to restore it to moderate condition the discharge from actual rangeland could decrease by as much as 6 percent (120 cfs) in a two year event (See Figures 3). The reduction in discharge is a result of improved cover so less sheet and rill erosion also will occur. In addition, the effect of the reduction in discharge, especially at the two-year level, must be considered for its effect on channel morphology since streambank and channel erosion along Stemple Creek and its' tributaries would be reduced. The change in the storm hydrograph also provides an increased opportunity for infiltration and an increase in the creek base flow (Figure 4).

Low and high residue areas are scattered in the watershed and to correct this condition these areas need to be treated as part of a comprehensive range management plan for a farm or ranch operation. The objective is to improve livestock distribution and forage utilization, as well as, controlling the duration and timing of grazing to improve productivity and species composition.

The actual treatment for the areas with low RDM will cost $30 per acre. Treatment includes site preparation (if needed), seeding and fertilization, and increased grazing management. This is an average annual cost of $8 per acre since it is anticipated that the practice will need to be repeated every five years until the inherent fertility of the area improves or other areas which are not presently below the desired RDM threshold are discovered. Treatment for high RDM includes fencing, water development andFigure 2 - Range Residue Levels

back of foldout
Figures 3 and 4

increased grazing management to help improve livestock distribution and forage utilization. In addition, demonstration projects for improved range management should be pursued in different areas of the watershed and workshops should also be offered for landowners.

Grazing management is a critical component of the management plan for treatment of rangeland on the Stemple Creek Watershed. Since plant species respond differently to grazing over the growing season, a well managed grazing system will allow as little impact as possible during those times when the plant community or the pasture will be harmed. Grazing during seedling establishment, green-up periods, and during flowering and seed-set, will adversely impact the desirable species on rangeland. Continual access to creekside vegetation will reduce or eliminate its' ability to protect the banks from flowing water and eventual slope failure. Management practices such as deferred grazing and planned grazing systems used in conjunction with other recommended practices like cross fencing, range seeding, fertilization, soil mechanical treatment, and stream channel revegetation will produce a number of beneficial effects which are interrelated.

Compaction of wet rangeland soils from grazing may result in increased runoff, erosion, and reduced productivity. Depending on soil depth and fertility, soil features such as soil porosity, population of soil microorganisms, and plant root mass will show increases in five years after adoption of **deferred grazing**. Deferred grazing is the postponing of grazing or resting of grazing land for a prescribed period of time. These improvements will support an increase in forage yields, an increase in more desirable species, and positively impact both wildlife and livestock.

A **planned grazing system** results in a more uniform use of the plant species in the pasture. A planned grazing system is the alternate resting and grazing of two or more grazing units in a planned sequence for a period of years, and rest periods may be throughout the year or during the growing season of key plants. During rest periods, the plants will have more leaf area and recover quicker resulting in increased forage production. Seed production is also increased with better chances for seedling success during rest periods.

Stream channel fencing should be incorporated into the planned grazing systems to maximize the benefits of the fencing systems. The increase in stream channel vegetation will provide more cover for wildlife and still allow seasonal use by livestock. Application of conservation planning in riparian areas will allow an integrated improvement of range resources, stream biota, water quality, riparian, and marsh corridor resources. Exclusion of livestock from areas of low or little forage productivity, such as salt marsh tidal plain, will improve the wildlife values and increase the sediment trapping efficiency of the marsh system.

With improved grazing management, the population of perennial grasses should increase. Although perennial grass yields are variable, depending on soil depth and rainfall, forage production may improve because the perennials may enable a range site to achieve the greatest potential productivity. Diversity provided by mixture of annual and perennial grasses will provide more reliable forage throughout the year. This creates a more diverse food source for all animal populations. Site conditions may also improve and production increase under a deferred grazing system compared to continuous year-long grazing. Improved residue levels on rangeland will also result in improved hydrologic characteristics reducing the rate and volume of runoff.

Fertilization impacts will continue to provide improvement from present production beyond the second year. The applications, if continued, will result in significant improvements in total yield, seed production, species composition, and plant vigor. Legume production will be considerably higher if sulfur and phosphorus fertilizers are used. However, if poor fertilization practices occur, there is increased potential for fertilizers reaching the creek and Estero. Increased RDM will also increase the fuel load and fire hazard.

Costs associated with these solutions are the actual cost of construction or installation, the annual operation and maintenance cost of the practice, and the cost of the lost opportunity for grazing if an area is fenced out or the increased cost associated with more intense management practices. The average annual cost of installation was developed from an assumed ten percent interest rate over a 25 year project life. The average annual cost includes the average annual installation cost and the annual operation and maintenance cost.

Other costs which are not included in the installation of the practices are: training offered to the landowners and other interested parties, technical assistance from engineers, soil conservationists, range conservationists, biologists, and the administrative costs associated with their employment.

CROPLAND TREATMENT

Cropland in the watershed is primarily hay production. The practice of increasing the amount of crop residue on the soil surface at planting (Conservation Tillage) will reduce the amount of sediment from this source. Conservation tillage is a system where at least 30 percent of the soil surface is covered by plant residue to reduce soil erosion by water. This practice has been shown to be cost effective in other areas. To encourage the trial and adoption of the practice in the Stemple Creek watershed an incentive of $15 per acre is proposed for three years. This will accelerate the adoption of the practice by local farmers. The average annual cost of this practice over the life of the project is $4.25 per acre.

Some areas presently used as rangeland could be converted to hayland. This practice combined with other range management practices will increase feed efficiency. The major cost associated with this practice would be the fencing of the new fields. This can be incorporated with either of the practices associated with gully or streambank erosion control. The installation would be part of a conservation plan developed with the landowner and the Resource Conservation District.

GULLY EROSION TREATMENT

Erosion in gullies is associated with three mechanisms:

1. Migration of the start of the gully (the headcut) further up slope.

2. Deepening of the gully from concentrated flows, and

3. Lateral recession, either through slope failure or surface erosion of the banks,

These mechanisms are exacerbated by the action of grazing animals through the removal of vegetation or the physical trampling of the banks. Treatment is aimed at reducing all of these mechanisms. Gullies have been classed into small, medium, and large. The average dimensions of each group is shown in the following table.

Table 4. Typical Gully Dimensions

Class	Length	Depth	Width
Small	680 feet	4 feet	10 feet
Medium	580 feet	8 feet	20 feet
Large	1500 feet	19 feet	65 feet

Level 1: The first level of treatment considered for gully erosion is fencing. This removes the effect of trampling, and allows the vegetation to recover undisturbed. Recovery is expected to take up to ten years. Grass, brush and tree cover established in the old gully will provide food and cover for wildlife and further stabilize the gully. The area enclosed by the fence is not available for grazing. These areas may be available for short duration grazing in certain situations. Leasing the fenced areas for wildlife or dedicating the area to wildlife or tree cover could make the loss more palatable to the landowner.

Level 2: The next level of treatment would be the addition of a rock apron at the headcut. Water reaching the headcut area can be diverted onto the rock which will stop the gully from advancing further up slope. This would control the migration of the headcut and help establish a stable point and stop the gully from advancing further up slope. The rock can be placed with local labor and minimal shaping and grading.

Level 3: The third level of treatment would be the addition of a grade control or stabilization structure (GSS) at the outlet. This would raise the bottom of the gully and reduce its slope. The resulting wider bottom would be more stable. The bank height would be less. Less bank height would reduce the sediment from lateral recession. This improves conditions for vegetation establishment and speeds the healing process. The area behind the GSS will also store some sediment but this storage is minor compared to the volume of sediment produced by the lateral recession of the gully.

Level 4: The last level of treatment is to physically reshape and revegetate (Critical Area Treatment, CAT) the gully, which would reduce healing time to two years. Another alternative is the installation of a lined waterway. The area still needs to be protected due to the increased palatability of the new plantings.

Table 5. Gully Treatment Summary

	Level 1 Fencing	Level 2 + Inlet	Level 3 +GSS	Level 4 + CAT
Small Class				
Installation Cost	$4,200	$5,300	$7,600	$10,100
Average Annual Cost $/yr.	$ 464	$ 585	$ 838	$1,114
Operation and Maintenance	$ 14	$ 64	$ 114	$ 114
Grazing Area Loss/yr.	$ 4	$ 4	$ 4	$ 4
Medium Class				
Installation Cost	$3,800	$5,500	$8,700	$13,500
Average Annual Cost $/yr.	$ 418	$ 606	$ 959	$ 1,489
Operation and Maintenance	$ 13	$ 63	$ 113	$ 113
Grazing Area Loss/yr.	$ 4	$ 4	$ 4	$ 4
Large Class				
Installation Cost	$6,600	$10,100	$35,100	$68,100
Average Annual Cost $/yr.	$ 728	$1,114	$ 3,868	$ 7,614
Operation and Maintenance	$ 33	$ 83	$ 133	$ 133
Grazing Area Loss $/yr.	$ 30	$ 30	$ 23	$ 23

The treatment costs increase with the size of the gully. The impacts of reduction also increase. Larger gullies contribute more sediment to Stemple Creek and the Estero.

STREAMBANK EROSION TREATMENT

Eroding streambanks in the watershed are also classed as slight, moderate, and severely eroding. The mechanisms for bank failure are the same as for gullies except that there is generally no headcut process. Eroding banks may or may not be located across the creek from each other. Table 6 summarizes bank condition by class.

Vegetation which becomes established in the critical flow area of the creek needs to be removed so minimum flow areas are maintained (2 year return peak flows). If this is not done the creek could begin a new episode of bank erosion, when during a high flow, it cuts a new channel around the blockage. When properly maintained, the creek will develop cutbanks and riffles in the two year channel. As riparian trees develop, they will shade out the 2 year flow area and reduce the need to control the emergent vegetation.

Table 6. Typical Streambank Dimensions

Class	Length	Depth	Width
Slight	1230 feet	3.5 feet	3.5 feet
Moderate	525 feet	6.0 feet	6.0 feet
Severe	850 feet	17.5 feet	17.5 feet

Level 1: The first level of treatment would be to enclose the entire stream corridor, not just the eroding areas by setting a boundary fence some distance away from the streambank and managing a mile of the corridor to eliminate grazing impact on bank vegetation during critical periods of the year (Riparian Corridor Zone, RCZ). Treatment costs are in dollars per stream mile with the section of eroding bank within the one mile section. The area can be managed as a pasture or converted to another use, depending on the needs of the landowner.

Level 2: The second level of treatment is RCZ plus plantings. It speeds recovery time by planting vegetation in addition to installing the fencing. While much more expensive than treatment of the eroding areas there are significant improvements for the biological resources. Stream corridor fencing also makes management of the stream areas easier for the landowner.

Level 3: The third level is to treat only the eroding areas with fencing (Eroding Area Treatment).

Level 4: The last alternative is to include planting vegetation with the eroding area treatment. There are also grazing opportunity losses associated with fencing out streambanks. However short duration grazing during a defined use period may be allowed. Provisions for watering facilities are included with the costs of installation of all practices. Stream crossing points are also included at intervals so animals can reach areas on both sides of the stream. Treatment costs for Levels 3 and 4 are in dollars per eroding bank mile. The costs for streambank treatments are summarized in Table 7. The difference between RCZ and eroding area treatments is shown in Figure 5.

Figure 5 - Riparian Corridor Zone and Eroding Area Treatment

Table 7. Streambank Treatment Summary

	Level 1 RCZ	Level 2 RCZ + Plant	Level 3 Fence	Level 4 Fencing + Plant
Slight Class				
Installation Cost	$22,000	$22.320	$5,500	$6,850
Average Annual Cost $/yr.	$ 2,424	$ 2,579	$ 606	$ 758
Operation and Maintenance	$ 100	$ 100	$ 26	$ 26
Grazing Area Loss $/yr.	$ 260	$ 260	$ 65	$ 65
Moderate Class				
Installation Cost	$22,000	$32,320	$2,750	$3,975
Average Annual Cost $/yr.	$ 2,424	$ 2,579	$ 304	$ 439
Operation and Maintenance	$ 100	$ 100	$ 13	$ 13
Grazing Area Loss$/yr.	$ 260	$ 260	$ 35	$ 35
Severe Class				
Installation Cost	$22,000	$25,200	$4,400	$7,600
Average Annual Cost $/yr.	$ 2,424	$ 2,777	$ 486	$ 838
Operation and Maintenance	$ 100	$ 100	$ 21	$ 21
Grazing Area Loss $/yr.	$ 260	$ 260	$ 60	$ 60

It is recommended that installation of streambank erosion treatments should be incorporated into the Conservation Plan to maximize the use of the practices in the range management systems.

Woody Vegetation Treatment

The establishment of woody vegetation will enhance the effectiveness of the sediment reduction alternatives. There are presently some good examples of successful gully and streambank protection with woody vegetation in the watershed. Most of these plantings are about 40 years old and were blue gum eucalyptus.

Monterey cypress has been used for windbreaks. In addition, there are naturally occurring stands of willow, baccharis, California bay, and live oak in the watershed. The use of any appropriate trees and shrubs in combinations suited to the specific site or landowners preferences can further reduce erosion and sedimentation, especially when planted in filter strips along the streams.

Planting for erosion control should be fairly close (6' x 6' spacing or about 1200 trees per acre) then thinned about every 10 years to allow for growth. This gives good cover and root mass over time, and yields a pole or firewood crop as a by-product. Initial planting should consider how the area will look in 20+ years or more, and it is important to note that planting trees is not something to be done and then left for nature to take its course. Some monitoring and maintenance will be needed to prevent or correct disease and insect problems or to replace trees lost due to storm damage or other natural mortality. Interplanting with shrub species like baccharis or toyon may be needed to keep windbreaks and shelterbelts effective as the tree species mature.

Besides reducing erosion and sediment movement, there are other benefits from planting woody vegetation. These depend on the species chosen and the planting configuration, but include reduced energy needs at farmsteads, crop and animal protection, improved wildlife habitat, noise reduction along roads, and improved aesthetics.

COST EFFECTIVENESS OF SOLUTIONS

Cost effectiveness is one criterion which can be used to select practices to be installed. The practices developed for the sediment source areas were arrayed in a spreadsheet. The available treatments for each source were applied and evaluated for effectiveness in each of the treatment subareas. For example, for small gullies in the lower subwatershed, 25 percent of all the gullies were treated with the Level 1 treatment of just fencing. In addition, 25 percent were treated with the Level 2 treatment, 25 percent with the Level 3 treatment, and 25 percent with the Level 4 treatment. In this way, the costs associated with treating one-fourth of the gullies can be compared with the reduction of sediment from one fourth of the gullies. This lets the four treatments be compared on the basis of cost per ton of sediment reduced to the ocean from that subwatershed. By repeating this for all practices, the comparison of sediment reduction for each treatment in each subarea to the cost per ton of sediment reduction for the 25 year life of the project was developed. Cost effectiveness is defined as the average annual cost of the measure divided by the tons of sediment reduction due to installing the measure and maintaining it over the 25-year life of the project.

The effectiveness of range and cropland treatment is shown in Table 8. If additional range is converted to cropland, care needs to be taken to minimize sediment from these areas. If additional irrigation water is introduced into the area, sediment effects will need to be addressed.

Table 8. Effectiveness of Range and Cropland Treatment Cost per Ton of Sediment Reduction

Area Treated	Range Treatment	Cropland Treatment
Lower Subwatershed Area	$ 5.75	$ 1.14
Middle Subwatershed Area	$ 8.86	$ 1.58
Upper Subwatershed Area	$21.66	$ 3.55

The effectiveness of gully treatment in the watershed is summarized in Table 9. In the watershed areas where no gully of that size exists, no value is given.

Table 9. Gully Treatment Effectiveness Summary Cost per Ton of Sediment Reduction

	Level 1 Fencing	Level 2 + Apron	Level 3 +GSS	Level 4 + CAT
Small Class				
Middle Subwatershed Area	$ 85.20	$131.30	$166.25	$186.63
Lower Subwatershed Area	$ 78.31	$120.68	$152.81	$171.53
Grazing Area Loss	$ 4.00	$ 4.00	$ 4.00	$ 4.00
Medium Class				
Upper Subwatershed Area	$ 27.75	$ 51.75	$ 74.69	$ 97.95
Middle Subwatershed Area	$ 10.50	$ 19.59	$ 28.26	$ 37.07
Lower Subwatershed Area	$ 7.55	$ 14.09	$ 20.33	$ 26.66
Grazing Area Loss	$ 4.00	$ 4.00	$ 4.00	$ 4.00
Large Class				
Lower Subwatershed Area	$ 3.61	$ 6.62	$ 21.03	$ 33.55
Grazing Area Loss $/yr.	$ 30.00	$ 30.00	$ 23.00	$ 23.00

The grazing loss cost associated with the treatments were not included in the evaluation because the loss only occurs if the area is permanently fenced and no grazing is allowed. The exclusion of grazing and the inclusion of the gully fencing in a Conservation Plan will maximize the effectiveness of the selected practices.

Selection of different levels of treatment does not need to be based on effectiveness of sediment reduction alone. Beneficial effects on wildlife habitat, aesthetic values, and other non-quantifiable values need to be considered when selecting the level of treatment desired. Public participation in conservation easements through cost share input can encourage landowner selection of treatments which maximize all benefits.

Streambank treatments were also evaluated in the different areas of the watershed. The effectiveness of the various levels of treatment for streambanks are shown in Table 10. The Riparian

Corridor Zone treatment is consistently more expensive but has the best wildlife habitat benefits.

Fifty eight treatments or measures were evaluated in the study. When the evaluation was done the treatments were ranked in order of cost of sediment reduction. The range was from $1.14 per ton to $512.59 per ton. If equal amounts of all treatments were applied to all sources the net sediment reduction would be 34.6 percent and the installation cost would be $4,121,103.

Table 10. Streambank Effectiveness Summary
Cost per Ton Reduction

	Level 1 RCZ	Level 2 RCZ + Plant	Level 3 Fence	Level 4 Fencing + Plant
Slight Class				
Lower Subwatershed Area	$189.43	$141.21	$ 81.55	$ 98.57
Middle Subwatershed Area	$285.76	$213.01	$123.02	$148.69
Upper Subwatershed Area	$512.58	$382.10	$220.66	$266.71
Grazing Area Loss $/yr.	$260.00	$260.00	$ 65.00	$ 65.00
Moderate Class				
Lower Subwatershed Area	$ 24.13	$ 16.19	$ 10.18	$ 15.14
Middle Subwatershed Area	$ 61.44	$ 41.22	$ 25.91	$ 38.55
Grazing Area Loss $/yr.	$260.00	$260.00	$ 35.00	$ 35.00
Severe Class				
Lower Subwatershed Area	$ 11.27	$ 7.03	$ 3.52	$ 7.30
Middle Subwatershed Area	$ 8.39	$ 5.23	$ 2.62	$ 5.44
Grazing Area Loss $/yr.	$260.00	$260.00	$ 60.00	$ 60.00

FORMULATION OF ALTERNATIVE PLANS

Plan formulation was accomplished in three phases: (1) the identification of measures which would solve the erosion and sediment problem; (2) determining the cost effectiveness of each measure and; (3) combining of measures into alternatives. These measures were selectively applied to the watershed and evaluated for the amount of sediment reduction produced for the amount of money spent.

ALTERNATIVES

Alternative 1: This alternative would include treating all subareas in the Stemple Creek Watershed with the most cost effective measure for each source of sediment. Sources treated would be cropland, low RDM rangeland, all streambanks, and all gullies. Rangeland with medium and high residue levels and eroding areas on Stemple Creek would not be treated. Conservation tillage would be done on cropland. Range treatment would be done on rangeland with low RDM, and adjacent areas.

Management plans for all rangeland would be provided. Fencing of entire gullies would be done on small, medium and large gullies. Eroded areas along streambanks would be fenced where slightly, moderately and severely eroding streambanks occur. Installation costs would be about $3.8 million for a decrease in sediment of 32 percent or 18,400 tons in the entire watershed. Table 11 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the measures, and the cumulative reductions and costs of the alternative. Figure 6 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 2: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures would be used for each source and not all sources included in Alternative 1 would be treated. Sources of sediment treated would be all cropland, all low RDM rangeland, moderate and severe streambanks, and medium and large gullies. Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Range treatment would be done on rangeland with low residue levels and adjacent areas. Management plans for all rangeland would be provided. Fencing of entire gullies would be done on medium and large gullies. Eroded areas along streambanks would be fenced for moderately and severely eroding streambanks. Installation costs would be about $1.5 million for a decrease in sediment of 30 percent or 17,1040 tons per year in the entire watershed. Table 12 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 7 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 2A: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures, excepting gullies, would be used for each source and not all sources included in Alternative 1 would be treated. Sources of sediment treated would be cropland, low RDM rangeland, moderate and severe streambanks, and medium and large gullies. Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Management plans for all rangeland would be provided. Range treatment would be done on rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies. Fifty percent of the gullies would be treated with the most cost effective practice and fifty percent would be treated with practice level 3. During planning of the area the treatment would be designed and implemented. Installation costs would be about $2.2 million for a decrease in sediment of 33 percent or 17,000 tons per year in the entire watershed. Table 13 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 8 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 2B: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures, excepting streambanks, would be used for each source and not all sources included in Alternative 1 would be treated. Sources of sediment treated would be cropland, low RDM rangeland, moderate and severe streambanks, and medium and large gullies. Rangeland with medium residue level, Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Range treatment would be done on all rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies. Riparian Corridor Zone around eroded areas would be established. Installation costs would be about $3.2 million for a decrease in sediment of 31 percent or 17,900 tons per year in the entire watershed. Table 14 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 9 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 2C: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures, excepting streambanks, would be used for each source and not all sources included in Alternative 1 would be treated. Sources of sediment treated would be cropland, low RDM rangeland, moderate and severe streambanks, and medium and large gullies. Rangeland with medium residue level, Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Range treatment would be done on all rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies. Eroded areas along streambanks would be fenced and planted for moderately and severely eroding streambanks. Installation costs would be about $1.8 million for a decrease in sediment of 31 percent or 17,900 tons per year in the entire watershed. Table 15 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 10 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 3: This alternative would be identical to Alternative 2 except it would be restricted to treating only the lower and middle subwatersheds of Stemple Creek except for cropland and rangeland in the upper subwatershed. Installation costs would be about $1.4 million for a decrease in sediment of 29.5 percent or 17,000 tons per year in the entire watershed. Table 16 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the measures, and the cumulative reductions and costs of the alternative. Figure 11 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 4: This alternative is identical to Alternative 2 except it would restrict streambank, and gully treatment to the lower subwatershed only. Installation costs would be about $1,046,000 for a decrease in sediment of 27 percent or 15,400 tons per year in the entire watershed. Table 17 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 12 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 4A: This alternative would also include all areas of the lower the Stemple Creek Watershed but only the most cost effective measures, excepting gullies, would be used for each source and not all sources included in Alternative 1 would be treated. Sources of sediment treated would be cropland, low RDM rangeland in the entire watershed, moderate and severe streambanks, and medium and large gullies in the lower subwatershed. Conservation tillage would be used to treat all cropland. Management plans for all rangeland would be provided. Range treatment would be done on rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies in the lower subwatershed. Fifty percent of the gullies would be treated with the most cost effective practice and fifty percent would be treated with practice level 3. During planning of the area the treatment would be designed and implemented. Installation costs would be about $1.7 million for a decrease in sediment of 29.5 percent or 17,000 tons per year in the entire watershed. Table 18 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 13 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Table 11 - Alternative 1
Figure 6 - Alternative 1
Table 12 - Alternative 2
Figure 7 - Alternative 2
Table 13 - Alternative 2A
Figure 8 - Alternative 2A
Table 14 - Alternative 2B
Figure 9 - Alternative 2B
Table 15 - Alternative 2C
Figure 10 - Alternative 2C
Table 16 - Alternative 3
Figure 11 - Alternative 3
Table 17 - Alterative 4
Figure 12 - Alternative 4
Table 18 - Alternative 4A
Figure 13 - Alternative 4A
Table 19 - Alternative 4B
Figure 14 - Alternative 4B
Table 20 - Alternative 4CFigure 15 - Alternative 4C

Alternative 4B: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures, excepting streambanks, would be used for each source and not all sources would be treated. Sources of sediment treated would be cropland, low RDM rangeland in the entire watershed, moderate and severe streambanks, and medium and large gullies in the lower subwatershed. Rangeland with medium residue level, Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Range treatment would be done on all rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies in the lower subwatershed. Riparian Corridor Zone around eroded areas in the lower subwatershed would be established. Installation costs would be about $1.9 million for a decrease in sediment of 28 percent or 16,000 tons per year in the entire watershed. Table 19 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 14 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Alternative 4C: This alternative would also include all areas of the Stemple Creek Watershed but only the most cost effective measures, excepting streambanks, would be used for each source in the lower subwatershed. Sources of sediment treated would be cropland, low RDM rangeland in the entire watershed, moderate and severe streambanks, and medium and large gullies in the lower watershed. Rangeland with medium residue level, Stemple Creek, small gullies and slightly eroding streambanks are not treated. Conservation tillage would be used to treat all cropland. Range treatment would be done on all rangeland with low residue levels and adjacent areas. Fencing of entire gullies would be done on medium and large gullies in the lower subwatershed. Eroded areas along streambanks would be fenced and planted for moderately and severely eroding streambanks. Installation costs would be about $1.5 million for a decrease in sediment of 28 percent or 16,000 tons per year in the entire watershed. Table 20 is a summary of the measures, where they are applied, the number of units applied in the alternative, the cost effectiveness of the treatment, and the cumulative reductions and costs of the alternative. Figure 15 shows the cumulative plot of dollars spent for installation vs percent sediment reduction.

Effects of Installation

The net effects will vary by alternative depending on the level of treatment selected. The erosion and sediment reductions are summarized in the descriptions of each alternative. The selected plan will have major beneficial effects on the range, wildlife, riparian and plant communities. The more aggressive treatments will have correspondingly greater positive water quality impacts.

Table 21 gives a summary of source treatments for all alternatives. Table 21 - Sources Treated by Alternative

Brief Assessment of Alternatives

Control of sediment and appropriate management of livestock in riparian areas are of primary importance at this time. The greatest amount of sediment reduction can be gained by treating the gullies and fencing damaged riparian areas. Additional water quality benefits will be gained by improved grazing management. Plants and wildlife will benefit from improved management of watershed lands. Table 22 compares cost, fencing amounts, sediment reduction and riparian habitat.

Table 22 - Comparison of Alternatives

Alternative # Million ($)	Cost (Miles)	Fencing Sed. Red.	Annual Reduction (Tons)	Percent (Acres*)	Riparian Habitat
1.	3.8	2,020	18,400	32	2,400
2.	1.5	870	17,100	30	510
2A.	2.3	870	19,000	33	440
2B.	3.2	1,130	17,900	29	440
2C.	1.8	970	17,900	29	510
3.	1.4	920	17,000	29.5	440
4.	1.0	820	15,400	27	290
4A.	1.7	820	17,000	29.5	290
4B.	1.9	1,050	16,000	28	390
4C.	1.5	820	16,000	28	290

* Area enclosed in Riparian Corridor. Riparian Zone will be controlled by soil and water conditions in the water course and surrounding soil profile.

All alternatives offer a significant reduction in sediment reaching Stemple Creek and the Estero de San Antonio. The reduction in sediment and improvement in vegetation may be large enough to benefit the aquatic ecosystem in varying degrees. Vegetative recovery is dependent upon either rest by fencing or changes in grazing management. Fencing, seeding, and fertilizing, water development, and planting are tools which are used in conjunction with the landowner's management style.

Initially all of Stemple Creek's riparian areas would benefit from rest. This would allow for shrub regeneration and restoration of seed production. Where grazing occurs in riparian areas, a variety of management strategies may be combined for riparian protection and to eliminate the need for fencing. These practices include: deferment, herding, late season grazing, and short-duration/low intensity grazing. Consideration should be given to animal breeding seasons and plant seed-set when implementing these practices.

Areas with high wildlife values might be left in exclusion from grazing. Sites with high salinity levels should also remain excluded, since their biological integrity is valuable and those areas provide little value as forage.

There is some debate on the benefits of planting vs. no planting. Often vegetation is placed in spots not suitable for growth and the success rate is very low. If areas are allowed to rest, the recovery time may be almost as fast without planting as not. On the gentle sloping reaches planting should be minimal. The areas where benefits can be maximized are the steep sites where large strong roots are needed for bank protection. If it is decided to plant, plants should be used vs. cuttings. Also careful site evaluation must be done to determine optimal planting sites to increases survival rates.

Large willow cuttings can be used as fence posts, after a couple of years they provide a "living" fence. This has been tried in a few coastal areas similar to Stemple Creek with success.

Labor costs can be minimized by using environmental groups and other volunteer groups. An adopt-a-stream program might also be implemented to facilitate the organization of the volunteer efforts.

Finally, in choosing an alternative highest priority should be given to provide the largest portions of protected riparian corridor. With this effort the plant and animal communities will recover and provide a high value habitat.

Water Development

Provision for water access in the stream corridor and development of water sources in pastures created away from the stream system will result in a more even distribution of livestock use while minimizing negative impacts from random access to the stream corridor. With removal of this disturbance, plant succession on the banks should progress rapidly. Within five years disturbed shorelines can be well vegetated with emergent vegetation and provide food and cover for wildlife. The increased cover in the stream corridor will also provide a cooler environment where water exists above the surface.

Socioeconomic

The selected plan will result in an enhancement of the economics of the range use in the watershed. It will also improve the wildlife resource in the area. Opportunities exist for landowners to utilize these wildlife resources for additional farm income. Conservation easements for wildlife and open space in areas where livestock is excluded for certain critical seasons could also become part of the total farm income. Any selected plan should support the life style and values of the community.

Monitoring Project

To monitor the project's progress, the acreage of riparian corridor vegetation (percentage vegetative cover), increases or decreases, and the RDM mapping could be continued on five-year intervals. An annual sampling of macroinvertebrates at reference points in the stream system could also be done to assess the water quality of the system.

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APPENDIX A

Table A-1 has the peak discharge results for the 100, 50, 25, 10, 5 and 2 year flood events at the six main cross sections. The results in the table are for current range land conditions. The low RDM rangeland if changed to high RDM rangeland conditions throughout the watershed would decrease peak discharge results in Table A-1 for 100, 50, 25, 10, 5 and 2 year flood events at the six main cross sections. In Figure 3 and 4, the current rangeland and high RDM rangeland conditions peak discharge results are graphically compared to one another at the six cross sections for the 2 year and 50 year flood events. The largest decrease in peak discharge is at the Alexander Road cross section for the 2 year flood event of 12.8 percent and 5.2 percent for the 50 year flood event. The peak discharge results for all 71 subwatersheds within the Stemple Creek watershed are available at the Field Office and State Office.

The geology maps detailing critical eroding areas can also be found at the Field Office and State Office.
Table A-1 - TR 20 Flood Events

APPENDIX D

WATER RESOURCES TECHNICAL REPORT
M. Kim Cordell, Prunuske Chatham, Inc.

Estero do San Antonio/Stemple Creek Enhancement Plan

Water Resources Technical Report

Prepared by

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September 1993

Estero de San Antonio/Stemple Creek Enhancement Plan

Water Resources Technical Report

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I. Introduction

Looking at a map of the Stemple Creek basin, a clear division appears between the upper and lower watersheds. For once, a political boundary coincides well with an actual physical division. The upper basin, lying east of the Marin-Sonoma county line, has gentle topography, a branch-like drainage system, and most of the basin's population. Downstream of the boundary in Marin County, the drainage pattern is trellis-like, the main stem takes large, dramatic meanders, the relief and rainfall increase, and the population decreases. On visiting the area, these differences are even more pronounced. The upper valley is broad, and the actual stream channel appears to be small by comparison. This watershed is the reverse of a typical basin where a rugged upper drainage flows into a broad alluvial valley. At Stemple, it is the upper watershed that is gently sloping and open; whereas the lower watershed becomes increasing rugged and inaccessible. These differences have their basis in the geologic history of the area. They also affect the availability and quality of water in the basin.

Geomorphology. The watershed is entirely underlain by Franciscan formation, a hard, metamorphic rock with frequent and deep fractures. This rock forms the Coast Range of California. In the watershed, Franciscan rocks are exposed at the surface along a north-south axis that runs from Deer Valley (near Walker Road), through Two Rock (where the resistant material gives the community its name), to the south of Spring Hill Road. The ends of this axis form the highest points of the watershed, 715 feet elevation on the north, and 853 feet on the south. Water flows into the Franciscan formation and travels along its many fractures. Groundwater discharge occurs when a slope or stream channel cuts across the fractures; thus, the "springs" of Spring Hill. Because water flows through the Franciscan formation relatively slowly, it is a good source of summer baseflow in the steam, as well as perennial springs that water small tributaries.

Franciscan rocks are also exposed at the lower end of the Estero, from its mouth to approximately two miles upstream. This area has the highest relief (steepest slopes) of anywhere in the watershed. The deeply fractured nature of the Franciscan formation is shown by the trellis drainage pattern of the Marin County portion of the basin. All tributaries there have a north-south pattern in narrow, steep-sided valleys. Peak flows from winter storms rise quickly in these canyons, reaching the main channel and the Estero considerably ahead of the peak flow from the upper watershed. The rapidly flowing streams have a high potential for delivering a large sediment load directly to the Estero (see Erosion and Sedimentation section).

The main stem of Stemple Creek in Marin County shows a pronounced meander pattern that also reflects the north-south orientation of the resistant rock. As the stream hits a resistant outcrop, it must turn north or south to get around the obstacle before turning west again. This geologic control creates very long stream distances and very low gradients. The shallow gradient allows tidal influence to extend seven stream miles above the mouth of the Estero, an extraordinary distance for a small West Coast estuary. The length of stream channel compared to the size of the watershed also affects the minimum flows in Stemple Creek. At even one or two cubic feet per second (cfs), the total volume of water within Stemple Creek at any one time is much larger than for a less meandering stream such as Green Valley Creek in Sonoma County or Salmon Creek in Marin County. Because the watershed area is undersized compared to stream length, it is likely that even before the land use changes of the last century, there was very little summer baseflow in Stemple Creek. The valley probably resembled the slow moving water/wetland/pond system that characterized the Laguna de Santa Rosa. This supposition is indirectly confirmed by the name of the Mexican land grant in the Two Rock area--Laguna de San Antonio. It is further supported by the fact that seven percent (7%) of Two Rock area soils are hydric--that is, they formed under saturated, wetland conditions. (S.R. Subregional System, TM W-11, p. 5) Restoration efforts should take into account that Stemple Creek more resembles Atascadero Creek, Chileno Creek and the Laguna de Santa Rosa, rather than the cool, fast- flowing coastal streams like Lagunitas and Austin Creeks.

A closer look at the geology of the upper watershed further confirms this similarity. The Franciscan formation is exposed at the points noted above. The remainder of the watershed is overlain by the Wilson Grove formation (formerly Merced formation), which extends north and east from the Stemple Creek basin and includes the areas around Valley Ford, Freestone, Sebastopol and Graton. The formation is a moderately consolidated sandstone conglomerate that weathers into soft rounded terrain, with wide valley bottoms filled with Quaternary (Recent) alluvium. The bedrock weathers into well-drained sandy loam soil which supports the orchards and vineyards of Sebastopol, and the early potato farms of the coastal valleys.

The Wilson Grove formation stores a large amount of groundwater, especially where the sandstone is massive (thick/deep) and not excessively interbedded with shale lenses. However, the formation is a poor source of stream baseflow during the summer. Groundwater in the Wilson Grove rocks is not confined to fractures as it is in the Franciscan formation. Therefore, water flows more evenly downslope. Unless it meets a geologic intrusion that forces flow to the surface, the water tends to stay below ground. However, the near-surface flow that occurs in the Wilson Grove formation and the valley alluvium can support lush riparian vegetation. In such habitat, when geologic conditions do cause surface flow, the water is relatively cool and of high quality.

The drainage of the upper watershed, unlike the lower portion in Marin County, is arranged in a dendritic (branch-like) pattern. The north and south branches, as noted above, rise from the Franciscan formation and provide perennial streamflow where they meet near the entrance of the Two Rock Coast Guard facility. The middle branch, which would normally be considered the main stem of the creek, is a small channel with intermittent flow in a broad valley. The drainage divide at the hydraulically most distant point in the basin is near Stony Point Road. This divide has a relatively low elevation, and is physically on such a gentle slope that it is difficult to locate on topographic maps or in the field. This head of the watershed is relatively new geologically. Before the Pleistocene (3 million years ago), the headwaters of Stemple Creek were in the Sonoma Mountains to the east. The watershed area was at least double its current size. (Higgins 1952) The larger basin area and greater flow would account for the broad alluvial valley in which the current Stemple Creek channel is clearly underfit. It would also explain why what appears to be the main stem is no longer the major source of baseflow to the stream.

Climate. In addition to resembling the geologic areas of Sebastopol, Stemple Creek also resembles that area in terms of rainfall. The 30-inch *isohyet*, indicating an average of 30 inches of rainfall a year, cuts across the basin along the county boundary (see Figure 1). East of the line, average annual rainfall is less than 30 inches; west of the line, rainfall is slightly more than 30 inches a year. Only the highest elevations in the basin receive 35 inches or more. This rainfall pattern is similar to the area between Santa Rosa and Sebastopol. However, because of Stemple's narrow, east-west orientation, it is much windier than the Santa Rosa Plains, and tends to be significantly cooler in the summer because of the off-shore breeze and late morning/early afternoon fog.

Knowing the rainfall pattern and the fast draining nature of the Wilson Grove formation, we can extrapolate the condition of Stemple Creek before European settlement. During the summer it was probably a slow-moving stream, dominated by ponds and seasonal wetlands. The channel was probably not too distinct, but rather a series of swales winding through willow thickets and reeds. During high winter flows, water probably spread across the valley floor, depositing sediment and flowing relatively slowly until reaching a point near the Alexander Road bridge where the channel became more defined and flow became more confined due to geologic control. The benches above the channel and the south-facing slopes were probably covered with perennial grasses and coastal scrub. Mixed riparian species were probably confined to the tributary canyons whose north-south orientation provided protection from the wind. Oak/bay/madrone woodland were probably found on the north- and east-facing slopes, with Douglas fir at higher elevations where annual rainfall exceeds 30 inches a year.

Water Quality. The water resources of the Stemple Creek basin consist of closely linked surfacewater and groundwater systems. Water quality problems in one system are likely to affect the other.

Numerous water quality regulations have been developed at the federal and state levels. Some legislation establishes standards that are directly enforceable. An example is the Safe Drinking Water Act (1974) which establishes pollutant levels for certain contaminants in water

Figure 1 here

supplies. The state and county departments of public health are responsible for enforcing these standards. In Stemple Creek, the standards apply to the groundwater; selected standards are shown in Table 1 in comparison to well test results.

Other federal laws that affect water quality are the National Environmental Policy Act (NEPA), and a series of laws collectively known as the Clean Water Act. As a result of these laws, the Environmental Protection Agency (EPA) issued "Quality Criteria for Water" (1976, rev. 1986). Because the EPA Ambient Water Quality Criteria for Protection of Aquatic Life apply to the surface waters of the Stemple Creek basin, they are listed in Tables 2 and 3 as a comparison to actual monitoring results. These criteria are advisory, but they are used by the State Water Resources Control Board and the Regional Water Quality Control Boards as a basis for establishing enforceable standards in basin plans (required by the Porter-Cologne Water Quality Control Act, 1969).

The basin plan for the North Coast Region deals in a narrative fashion with most of the constituents of concern in Stemple Creek. (North Coast Regional Board 1988, section III) Toxic constituents, such as heavy metals, are discussed more specifically in the Inland Surface Waters Plan of 1991 (which is incorporated as part of the basin plan). The federal criteria and basin plans are also used by the Department of Fish and Game to establish violation limits.

In summary, there are three overall objectives of the existing legislation: (1) to prevent deterioration of existing water quality, (2) to ensure continued beneficial use of the water, and (3) to enhance existing water quality when impaired. The Regional Water Quality Control Board identifies the beneficial uses in lower Stemple Creek as cold freshwater habitat, fish spawning, fish migration, wildlife habitat, water contact recreation, and non-contact water recreation. (Water Body Fact Sheet, 3-14-90, Region 1) These beneficial uses apply to surface waters only. The basin plan lists additional, potential beneficial uses for coastal streams such as Stemple Creek: municipal and domestic water supply, agricultural and industrial water supply, and groundwater recharge. (North Coast Regional Board 1988, p II-5) These beneficial uses apply to surface and ground waters.

The Regional Board, State Water Resources Control Board and EPA identify Stemple Creek as an "impaired water body" and therefore in need of enhancement. The primary causes of these impacts are sedimentation and high ammonia levels from non-point source (NPS) discharges, leading to lower dissolved oxygen levels through eutrophication. (State Water Resources 1990)

The specific areas of concern for water quality in the watershed are:

- high temperature
- high pH (alkalinity)
- turbidity, especially suspended sediment
- total dissolved solids (TDS) indicating mineral content or "hardness"
- low dissolved oxygen caused by high biological oxygen demand (BOD)
- nutrients, especially nitrogen and phosphorus compounds
- organic chemicals, especially un-ionized ammonia
- heavy metals, especially copper, cadmium and lead
- biological contamination, indicated by the presence of coliform bacteria
- salinity
- low flows, allowing concentration of pollutants.

Each will be discussed in the next two sections on groundwater and surfacewater resources.

II. Groundwater Resources

Location and Uses. The three geologic formations in the watershed contain three distinct *aquifers*, or groundwater basins. The near-surface waters are carried primarily in the alluvium on the valley floor. Because it can been less than five feet below the surface in some locations, this groundwater is easily contaminated by land use activities. The quantity of water stored in this aquifer is relatively small, and is continually recharged from above by surface flow and from below by the other two aquifers. Therefore, water quality can vary greatly depending on time of year and source of recharge.

The Wilson Grove formation is one of the best water-bearing formations in coastal California. Because of its permeability and massive size, this formation produces good quality water at high yield rates, and is relatively unaffected by seasonal fluctuations. Naturally occurring constituents that affect water quality in the Wilson Grove formation are boron and dissolved mineral solids (TDS). The quantity of water stored in the Wilson Grove formation is high, but the water does not discharge readily into surface waters or the near-surface aquifer. Exceptions occur immediately during and after winter storms, and where geologic obstructions force the water to flow to the surface. In Stemple Creek, discharge from this formation occurs mostly in the lower basin. The good quality of this discharge probably accounts for the relative improved water quality in the Estero compared to upstream.

Deep groundwater is held in the cracks and fissures of the Franciscan formation. Water flows into the aquifer from catchment basins at higher elevations. The quantity of water stored in the formation is relatively small because flow is restricted to the fractures between rocks. Its discharge rate is also relatively slow, thereby conserving flow and providing perennial discharge at seeps and springs. Water quality from the formation can reflect high background levels of mercury, chromium and nickel which occur naturally in the rock. Flow between Franciscan and Wilson Grove formations is known to occur, although the nature and quantity of that flow is not understood.

The groundwater resources of Stemple Creek are used for domestic and agricultural water supply. Wells in the basin vary from hand-dug, unlined shallow wells in the valley bottom, to drilled and lined wells more than 400 feet deep. The variability in yield and quality among wells occasionally causes water shortages in some locations. Poor water supply is often cited as one reason for lack of suburban development in the upper watershed. The most intensive development is the Coast Guard training facility which houses about 2,000 people and imports its domestic water from the Petaluma municipal system.

Monitoring Results. The Regional Water Quality Control Board maintains eight monitoring wells adjacent to the Sonoma County landfill site at Meacham Road. Samples from the wells are taken quarterly and analyzed to detect contamination of the groundwater from the landfill. No contamination has been detected so far. Because these are the only monitoring wells in the Stemple basin, the groundwater quality problems have not been identified or defined to the extent of surface water problems.

Prior to 1988, groundwater investigations in Stemple watershed were done by the California Department of Water Resources (DWR). Water from the three aquifers was characterized by DWR as good to excellent quality (DWR 1975). However, a specific study of nitrates in groundwater included two shallow wells in the upper Two Rock Valley, and showed nitrate levels exceeding drinking water standards (DWR 1982).

In 1988, a groundwater characterization program was undertaken by consultants to the Santa Rosa Subregional Water Reclamation System. The consultants searched the DWR Water Data Information System, and found that the five wells included in the database from the Two Rock area showed good quality water, with no parameters exceeding drinking water standards. (S.R. Subregional System, TM R-1, p. 20) The consultants then chose 12 wells in the valley to sample. Seven of the wells were hand dug, drawing from the Quaternary Alluvium. One was drilled 460 feet deep, probably tapping the Franciscan aquifer. The remaining four wells were drilled to depths ranging from 80 to 169 feet, likely drawing from the Wilson Grove formation. Six of the dug wells were sampled twice, in April/May and November 1988; whereas only two of the drilled wells were sampled twice. Having at least two sampling periods is important to characterize the variability in shallow groundwater, and act as a check for sampling and testing errors. Table 1 shows the results of the water tests.

This table presents information that is worth a detailed look. All of the dug wells are shallow and show the greatest seasonal variation in water quality. They also have the highest values of (1) bacterial contamination (coliform), (2) nitrates and (3) hardness (total dissolved solids).

(1) The sources of coliform can be either human or animal waste. Because the tests did not distinguish between human and animal coliform, it is not possible to quantify the contributions from failed septic systems and dairy waste systems. Elevated coliform in water represents increase risk of diseases spread by intestinal micro-organisms.

Table 1

1988 WELL TEST RESULTS**
TWO ROCK AREA

Description	Drinking Water Stnrds.*	Sample Date	Well Numbers 1	3	6	7	8	9	18	2	17	18	4	5
Well Type			dug	dug	dug	dug	dug	dug	dug	drilled	drilled	drilled	drilled	drilled
Well Depth (ft.)			19	20	nd	16	nd	nd	25	460	169	100	110	80
pH			6.7	7.3	7.4	6.9	6.5	6.9	7.5	nd	7.6	7.5	7.2	7.9
Total Coliform	**1**	Apr/May	<2	280	2	>2,400	<2	130		220			<2	<2
(MPN/100ml)		Nov	2	350	>2,400	540	>2,400	220	170		<2	170	920	49
Nitrates	**10**	Apr/May	0.17	16	4.3	5.6	22	53		0.17			40	7
(mgN/l)		Nov	21	13	1.3	3.5	31	67	1.5		0.06	1.5	43	2.9
TDS	**500 -**	Apr/May	3,000	2,100	490	570	460	2,400		820			930	230
(mg/l)	**1,000**	Nov	2,700	1,400	550	510	740	2,700	790		250	790	1,300	240
Cadmium (µg/l)	**10**	no test												
Chromium (µg/l)	**50**	no test												
Copper (µg/l)	**1,000**	no test												
Cyanide (µg/l)	**200**	no test												
Lead (µg/l)	**250**	no test												
Mercury (µg/l)	**2**	no test												
Silver (µg/l)	**50**	no test												

*From State of California, Title 22, Sect. 64435, and the Federal Safe Drinking Water Act of 1976, as amended.

(2) The likely sources of nitrates are animal waste and fertilizers. High nitrates can pose a health risk to infants and the elderly by reducing oxygenation of the blood. The risk to healthy adults and livestock is slight. (Pers. comm., Bruce Gwynn, RWQCB, 3/30/92)

(3) High total dissolved solids (TDS) do not generally pose a health risk, but relate more to the esthetic quality of water, especially taste and odor. The elevated levels of TDS in three shallow wells indicate a contribution from human activities above the natural background level.

Despite the high levels of these constituents in the samples, we cannot conclude that they are generally representative of water from the Quaternary Alluvium aquifer. The wells may be contaminated by surface runoff or other sources. The data developed by the Subregional System consultants is not sufficient to define the baseline characteristics of the shallow aquifer. Instead, a more controlled sampling program needs to be developed. Monitoring wells need to eliminate outside sources of contamination, and samples need to be taken at least quarterly in order to eliminate bias in the results.

Of the two drilled wells that were sampled twice, #4 exhibits wide seasonal fluctuations similar to the dug wells discussed above. It is likely that well #4 has a faulty or non-existent sanitary seal. Therefore the sampling results cannot be considered representative of water from the Wilson Grove aquifer. Only well #5 appears to have sufficient data and consistent results to be considered representative of water in the aquifer. The samples show quality within the parameters of the drinking water standards for which they were tested.

What remains undefined is the relative importance of each aquifer for domestic and agricultural water supply. The consultants did not survey the total number of wells in the watershed, their yield and their use. Nor did the consultants test their samples for heavy metals. These are of concern in the watershed because they are naturally occurring or may have been introduced through human activities. In addition, the drinking water standards place strict limits on the quantity of heavy metals in drinking water. Any comprehensive test of water quality needs to include levels of cadmium, copper, cyanide, lead, mercury, and silver.

We do not have enough valid information to characterize the current state of the groundwater system in the Stemple watershed. The tests to date indicate that quality is generally good except where human activities have locally affected some groundwater sources. These impacts have degraded water quality in some wells, but their extent is unknown.

The quality of shallow groundwater is important because it maintains the water quality in streams by providing summer baseflow and by filtering winter runoff. An example of the importance of groundwater is the Chino basin in southern California. That area is the site of intensive feedlot dairies. The nitrate content of the groundwater has quadrupled since 1950. This impact is intensified as the groundwater seeps into the Santa Ana River. Groundwater makes up 5 to 10 percent of the river's flow, but contributes 30 to 40 percent of the nitrate load and 50 percent of the TDS. (EPA, 1991)

It appears that shallow groundwater is at least as important in the Stemple Creek system. Consultants to the Subregional System have developed a water budget for a subbasin in the upper watershed. (S.R. Subregional System, Tech. Memo. R11, Fig. 2, rev. 7/91) The model describes existing conditions of a three-square-mile area called Deer Valley, the site of the proposed T-5 reservoir (see watershed map). The model assumes 35 inches of annual rainfall, which produces 3,280 ac.ft./yr. of surface runoff, 90 percent of which occurs between October and March. Baseflow in the tributary comes from 455 ac.ft./yr. of shallow groundwater and partly from 135 ac.ft./yr. of deeper water (Wilson Grove and Franciscan formations). Extrapolating this Deer Valley water budget to the whole watershed, we estimate that groundwater contributes up to 15 percent of the total flow of the stream. The impact of this groundwater is significant because it contributes 100 percent of whatever summer flow occurs, at a time when temperature, pH, TDS, nutrient and BOD problems tend to be at their greatest, and dilution is at a minimum.

III. Surfacewater Resources

Distribution. The streams of Stemple watershed can be divided into three subbasins (see watershed map). The upper subbasin consists of three branches that meet near Two Rock. Most of these upper streams are *ephemeral,* flowing only during and immediately after storm events, or *intermittent,* flowing throughout the rainy season and often retaining year-round water in protected pools. Ephemeral streams can support a robust but narrow band of riparian vegetation, and can be an important source of seasonal water for terrestrial wildlife. Intermittent streams can support a larger, more diverse riparian corridor, and summer pools provide important rearing habitat for aquatic species, as well as a dry season water source for terrestrial species. The drainage area of the upper subbasin is 14,850 acres (23.2 square miles), making it the largest of the three.

The middle subbasin contains the main channel of Stemple Creek, a *perennial* or year-round stream. The drainage area is 11,750 acres (18.4 square miles). This middle reach flows through a valley that becomes increasingly confined downstream. The drainage pattern changes from branchlike to trellis, and the gradient flattens, allowing considerable deposition of suspended sediment onto the channel and overbank. None of the riparian forest survives in this reach, and livestock are allowed unrestricted access to the channel.

The lower subbasin is downstream of the Highway 1 bridge where the tidal influence begins. This subbasin covers 6,400 acres (10 square miles), and is the most remote and rugged part of the watershed. When the Estero mouth is open, usually from mid-winter to early summer, water levels in the reach rise and fall with the tides. When the Estero mouth is closed, water can back up to a depth of 13 feet at the Valley Ford-Franklin School Road Bridge (personal communication, Kelly Cuffe, Philip Williams Assocs., 7/1/92). Eventually, the sand bar at the mouth is breached, and the tidal cycle begins again.

Flow Regime. The water year begins October 1, coinciding with the beginning of the rainy season in coastal California. The first storm events of the year tend to flush out contaminants that have accumulated in the stream system during the summer. If early season storms are intense, they can also cause severe overland erosion because the annual grasses that cover much of the watershed have not grown enough to protect the soil. The runoff from these events, carrying a pulse of contaminants, moves through the stream system and backs up behind the bar that develops annually at the mouth of the Estero. This ponded water drops part of its suspended sediment and any pollutants attached to the sediment particles. When the bar is breached, usually by February, some of this sediment is flushed out to the ocean. But much remains and is incorporated into the estuarine and riparian systems. The amount of annual sedimentation and its impact on the long-term health of the estuary are unknown.

By April, 90 percent of the year's total rainfall has occurred, and stream levels begin dropping. As the dry season proceeds and evaporation increases, surface runoff ceases and the stream is fed entirely by groundwater discharge. Water quality problems associated with higher temperatures and low flow occur during this season.

Imported Water. About 175 acre-feet of water are imported annually into the Stemple Creek basin for domestic water supply at the Coast Guard Training Center. (Steve Simmons, City of Petaluma, pers. comm., 6/18/92.) Wastewater from the facility is treated on-site to secondary standards and disposed by spraying on fields within the facility. These fields are leased for hay production, but the water is applied to maximize disposal, not agricultural use. It is possible that irrigated wastewater flows through the soil and discharges into the south fork of Stemple Creek adjacent to the spray fields. However, water quality samples taken by the Regional Water Quality Control Board do not indicate increased pollutants from this possible discharge. (Dennis Salisbury, RWQCB, pers. comm. 7/14/93;

and 1993 RWQCB water quality data.) Water quality in this reach should continue to be monitored, however; and the situation re-evaluated if illegal discharges occur, or if the amount of water imported to the facility increases.

At the present time the Coast Guard lacks incentive to view its wastewater as a resource for local farmers. With better continuity in federal management and improved communication with local residents, the treated wastewater could be used to irrigate a larger area for the primary benefit of agriculture.

Water Quality Concerns. Pollution in Stemple Creek causes three major concerns. The first is for human health. The North Coast Regional Water Quality Control Board considers any stream in the region a potential source of drinking water. Stemple Creek surface waters are not currently used for drinking water by humans, but the creeks are used extensively for watering livestock. Nearly 100 farm ponds dot the hills around Two Rock. The mainstem creek in the middle subbasin is also used for watering sheep and cattle. Contamination of this water can enter the food chain and indirectly affect human health. A more direct impact on human health is through recreation. Biological contamination is the biggest threat to human health during water-oriented recreation such as canoeing and fishing.

The second concern is for a chronic buildup of pollutants in the stream environment. Heavy metals, agricultural chemicals and nutrients tend to accumulate in an aggrading stream system such as Stemple Creek. The potential toxic effects of this concentration are unknown because cumulative impacts have not been addressed in past monitoring programs.

The third concern is for aquatic habitat. The EPA aquatic life criteria (see Section I above) apply to Stemple Creek because its beneficial uses include fish spawning, fish migration, freshwater habitat, and wildlife habitat. All 11 impacts listed at the end of Section I can reduce or eliminate these beneficial uses.

Monitoring Results. Table 2 shows monitoring results at three sites on Stemple Creek. The most frequent problems relate to the presence of total ammonia and un-ionized ammonia, NH_4OH. The latter is ammonia dissolved in water and is extremely toxic to aquatic life. Total ammonia is also a toxicant. This excess nutrient appears to be present in Stemple Creek throughout the year. Even the greater dilution of wet season flows does not reduce it. In fact, some of the highest values for ammonia occur during winter, indicating that the source is not fertilizer (used during the summer growing season) but may be overflow from dairy waste ponds and animal confinement areas. The highest values of un-ionized ammonia occur during the spring (March through May), as rising water temperature and pH increase the conversion of ammonia to its un-ionized form.

Site 2, near Petaluma/Valley Ford Road, indicates low dissolved oxygen occurring throughout the year. This may also relate to the nutrient loading. Animal waste carries a high BOD (biological oxygen demand) because of its organic content. The nitrogen in animal waste can further reduce dissolved oxygen by encouraging algal blooms. Dissolved oxygen of less than 5.0 milligrams per liter will kill fish and other aquatic animals. Values of less than 7.0 milligrams per liter reduce the beneficial uses of cold-water and spawning habitats in lower Stemple Creek.

Temperature appears to be another subject of concern. Wide swings in seasonal temperature harm aquatic life by reducing diversity and encouraging those species that can tolerate the variation. For most species, temperatures greater than 24°C. are unacceptable. In Stemple Creek, seasonal variations are great and summer water temperatures are high due to the absence of streambed and riparian vegetation. The DF&G operations manual requires that when hatchery releases are made in warm water, then flows must be at least 10 cubic feet per second. The minimum flow guarantees an acceptable level of dissolved oxygen, which declines as temperatures rise. (Pers. comm., DF&G, Susan Mann, 6/92) Summer flows in Stemple Creek do not meet this guideline.

Table 2: MONITORING RESULTS, SURFACE WATER QUALITY

			Date	pH	Temp. (°C.)	Conduct. (μmhos/cm)	D. O. (mg/l)	Turb. (NTU)	TDS (mg/l)	Ammonia (mg-N/l)	NH4OH (mg-N/l)	Fecal Coli. (MPN/100ml)
A	**Comparison Standards**											
1	EPA/Regional Boards			6.6-8.5			6.0-7.0			0.5	0.025	
2	DF&G guidelines				24	2000	5	3000				
3	Drinking water standards					900-2200		5	500-1500			1
B	**Sampling Locations**											
1	**Near Highway 1 Bridge**											
	**	(a)	11/28/89	7.5	10.9	700	9.6	7.8	590	0.11	0.0007	
			1/16/90	7	11	307	8.7	-	330	1.9	0.0003	
			2/8/90	7.5	6.8	357	8.4	32	380	2.4	0.0112	1600
			3/10/90	8	9.8	388	9.8	21	320	0.35	0.0063	
			4/6/90	8.2	14	500	9.5	6.3	370	*	-	
			5/25/90	8.6	17	600	9.5	-	390	0.17	0.0204	35000
			6/26/90	8.9	19.5	770	14	19	550	0.1	0.024	
			7/26/90	dry								
	**	(b)	3/7/91	7.5	15.5	320	8.2	44	-	1.6	0.014	
			3/15/91	7.4	13	355	9.2	40	-	1.47	0.009	
			3/27/91	7.5	14	250	8.8	29	-	1.03	0.008	
			4/2/91	7.6	17	355	8.1	27	-	0.92	0.035	
			4/18/91	8.4	17.5	450	11.9	8.8	-	0.6	0.046	
			5/3/91	7.9	17	480	11.6	61	-	1.22	0.03	
			5/23/91	7.5	18	600	8.5	15	-	0.6	0.006	
			6/4/91	7.3	24	750	7.3	15	-	1.89	0.02	
			8/1/91	dry								
	**	(c)	2/13/92	7.5	12.9	310	7.7	-	260	1.2	0.009	

* (below detection limits) - (data not available)

Table 2: MONITORING RESULTS, SURFACE WATER QUALITY

		Date	pH	Temp. (°C.)	Conduct. (µmhos/cm)	D. O. (mg/l)	Turb. (NTU)	TDS (mg/l)	Ammonia (mg-N/l)	NH4OH (mg-N/l)	Fecal Coli. (MPN/100ml)
2	**Near the Petaluma/Valley Ford Road Bridge**										
**	(a)	5/16/88	7.95	15	-	2.5	38	730	1.8	0.037	220
		6/15/88	7.6	16	1020	5.1	-	900	8.4	0.083	-
		7/21/88	7.95	21	1180	-	57	970	*	0.0008	-
		8/29/88	8.6	17.5	1280	2.1	47	1100	0.21	0.019	>2400
		9/28/88	7.8	23.5	1000	2.1	52	1300	0.54	0.013	-
		11/22/88	7.5	12.9	780	3.8	37	690	*	0.0002	-
		12/20/88	7.6	8.5	-	5.7	52	630	8.3	0.047	-
		1/20/89	7.5	7.5	810	2.3	23	870	21	0.087	-
		2/17/89	7.6	9.8	810	3.5	27	750	18	0.115	>2400
		5/4/89	8.7	21	980	9.2	33	750	2.7	0.424	3020
		6/7/89	7.9	14.8	990	5.8	35	780	3.3	0.061	-
		7/5/89	7.8	14.7	103	3.7	51	860	3.1	0.046	-
		9/18/89	7.7	13.5	1080	2.6	54	970	0.39	0.004	4600
		10/23/89	7.4	14.1	322	7.4	-	280	*	-	-
		11/28/89	7.3	8	680	1.6	260	900	7.4	0.024	-
		1/16/90	7.1	9.2	590	1.5	-	550	8.1	0.014	-
		2/7/90	7.1	3.8	570	4.6	31	610	4	0.006	16000
		3/10/90	8	12	900	4.4	23	700	9.7	0.213	-
		4/6/90	7.9	13	1000	2.8	20	750	3.8	0.094	-
		5/25/90	8.2	12	1080	-	50	850	1.3	0.049	350
		6/26/90	8.3	14	970	7.3	38	830	1.2	0.064	-
		7/26/90	8.1	15.2	1080	8.3	37	910	0.14	0.005	540
**	(b)	2/13/91	7.6	14	850	3.9	110	-	6.7	0.067	-
		3/7/91	7.4	14.5	480	7.1	36	-	2.06	0.013	-
		3/15/91	7.3	14	600	6.7	28	-	2.12	0.01	-
		3/27/91	7.5	15.5	425	7	30	-	1.95	0.017	-
		4/2/91	7.5	17	700	5.5	32	-	2.6	0.026	-
		4/18/91	8.2	18.5	1100	7	30	-	2.86	0.153	-
		5/3/91	7.9	17	1110	15.9	24	-	2.6	0.064	-
		5/23/91	8	19.5	1300	11.8	36	-	2.12	0.078	-
		6/4/91	8.3	17.8	1300	16	125	-	2.6	0.166	-
		8/1/91	8.8	18	1500	4	19	-	2.06	0.366	-

* (below detection limits) - (data not available)

Table 2: MONITORING RESULTS, SURFACE WATER QUALITY

			Date	pH	Temp. (°C.)	Conduct. (µmhos/cm)	D. O. (mg/l)	Turb. (NTU)	TDS (mg/l)	Ammonia (mg-N/l)	NH4OH (mg-N/l)	Fecal Coli. (MPN/100ml)
3	**Pepper Road Crossing**											
	upstream											
	**	(b)	2/13/91	7.6	14	350	5.8	55	-	2.4	0.024	-
			3/1/91	7.7	14	700	5.4	125	-	4.8	0.06	-
			3/15/91	7.5	17	680	8.5	41	-	1.36	0.014	-
			3/27/91	7.8	19	450	7.8	120	-	1.79	0.04	-
			4/3/91	7.7	18.5	550	12	6	-	0.81	0.014	-
			4/18/91	8.8	18.5	630	12.7	41	-	0.86	0.157	-
			5/3/91	7	20	1000	15	0	-	0.5	*	-
			5/23/91	7.8	19	285	8	5.9	-	0.03	*	-
			6/4/91	7.7	23	295	9.3	5.1	-	0.04	*	-
			8/1/91	dry					-			-
	downstream											
	**	(c)	2/13/92	7.3	13.8	540	5.2	-	440	1.5	0.008	-

**Data Sources: (a) DWS Consulting & Commins Consulting for S.R. Subregional System;
(b) California Depart. of Fish and Game;
(c) North Coast Regional Water Quality Control Board.

* (below detection limits) - (data not available)

Table 3 shows the monitoring results for heavy metals. In general, it appears that heavy metals are not currently a problem in Stemple Creek. However, the standards for heavy metals are based on the hardness of the water (percentage of calcium carbonate). Since most monitoring data for Stemple Creek do not include this information, a level of 188 milligrams per liter of calcium carbonate was assumed. If actual water hardness is lower, the metals thresholds will drop; if hardness is higher, the thresholds rise. Future monitoring tests should include information about hardness for each sample.

Another problem in monitoring heavy metals is that current standards require thresholds below the detection limits of some testing procedures. A test result showing a constituent is below detection limits does not necessarily mean that the water meets the standard for that constituent. Careful design of the monitoring program, and an adequate budget, will ensure that the appropriate tests are used.

An interesting monitoring result highlighted in Table 3 is a sudden peak in chromium during November of the two years sampled (1988 and 1989). We do not have information at the present time to explain these results.

Despite the problems identified to date by the monitoring programs, the general water quality of Stemple Creek is good. In fact, one agency has reduced its sampling program in order to concentrate on more degraded streams (pers. comm., Mike Rugg, DF&G, 1992). Our conclusion is that enhancement efforts in the watershed will be effective in improving biological productivity and diversity.

TABLE 3. SURFACE WATER MONITORING, HEAVY METALS

			Date	Cadmiu	Chrom.	Copper	Lead	Zinc
				(μg/l)	(μg/l)	(μg/l)	(μg/l)	(μg/l)
	Comparison Standards ◊							
1	EPA			1.9	11	20.3	7.1	181
2	Drinking water standards			10	50	1000	50	5000
	Sampling Location							
1	**Near Highway 1 Bridge**							
	**	(a)	1/16/90	-	-	14	-	-
			2/8/90	0.6	5.8	11	1.1	25
			3/10/90	0.5	2.6	5.8	1	25
			4/6/90	0.5	*	4.5	6.3	13
			5/25/90	0.4	5.5	3.3	3.7	5
			6/26/90	*	*	2.8	7.3	14
			7/26/90	-	-	-	-	-
	**	(c)	2/13/92	*	*	*	*	40
2	**Near the Petaluma-Valley Ford Road Bridge**							
	**	(a)	5/16/88	*	*	*	4	20
			6/15/88	-	-	-	-	-
			7/21/88	-	-	-	-	-
			8/29/88	*	*	*	*	*
			9/28/88	-	-	-	-	-
			11/22/88	*	40	6	*	*
			12/20/88	-	-	-	-	-
			1/20/89	-	-	-	-	-
			2/17/89	*	*	10	*	70
			3/6/89	*	*	16	2	30
			5/4/89	*	*	5	*	110
			6/7/89	*	*	8	*	21
			7/5/89	*	*	9	*	20
			9/18/89	*	*	4	*	40
			10/23/89	-	-	9	-	-
			11/28/89	0.2	40	26	*	55
			1/16/90	-	-	11	-	-
			2/7/90	0.2	6.4	11	1	25
			3/10/90	0.5	1.7	12	2.1	37
			4/6/90	0.4	*	2.9	2	12
			5/25/90	0.3	7.9	6.8	5.4	1.8
			6/26/90	0.3	2.2	5.6	4.7	45
			7/26/90	0.3	5	9	*	68

**Data Sources: (a) DWS Consulting and Commins Consulting for S.R. Subregio

(c) North Coast Regional Water Quality Control Board

◊ Chronic freshwater criteria given. Metals criteria calculated using hardness = 188 mg/l Calcium carbonate. (Thresholds rise for increased hardness.)

* (below detection limits) - (no data available)

Water Resources Recommendations

The following 11 water quality concerns (see also page WR-6) have been identified by the North Coast Regional Water Quality Control Board and the California Department of Fish and Game. Some of the concerns relate to ground water, some to surface water, and others apply to both. All of the concerns can be directly or indirectly traced to human activities, past and present, in the watershed. Whenever these conditions occur, water quality is degraded and beneficial uses are impaired. Consequently, the recommended goals and objectives highlight human activities that can significantly enhance surface and ground water quality.

Water Quality Concerns:

1. high temperature
2. high pH
3. turbidity (esp. suspended sediment)
4. total dissolved solids
5. low dissolved oxygen (high biological oxygen demand)
6. nutrients (nitrogen and phosphorus)
7. organic chemicals (ammonia, un-ionized ammonia)
8. heavy metals (esp. copper, cadmium and lead)
9. biological contamination (fecal coliform)
10. salinity
11. low flows (concentration of pollutants)

Water Quality Goals and Objectives:
(Objectives in italics have been listed previously.)

A. Reduce temperature fluctuations in surface waters (addresses: 1, 2, 5, 6, 7, 9, 10 & 11)

- control animal access using fencing and designated crossings
- develop off-stream watering sites
- revegetate the channel with grasses and wetland plants throughout the length of Stemple Creek
- restore riparian corridor where possible

B. Reduce current erosion and sedimentation rates (addresses: all)

- repair chronic erosion sites such as gullies, headcuts and major streambank failures
- restore wetlands and summer pools by removing sediment and building small detention structures
- *revegetate channel with grasses and wetland plants*
- *restore riparian corridor*
- *control animal access using fencing and designated crossings*
- *develop off-stream watering sites*

C. Reduce pollutants from land use activities (addresses: 2, 3, 5, 6, 7, 8, 9, 10 & 11)

- •uniformly enforce water quality standards for all activities, including farming, confined animal operations and construction
- •universally apply BMPs to all activities, including farming, confined animal operations and construction
- •use demonstration projects that show methods to achieve standards and apply BMPs
- •improve water supply wells and septic systems
- •promote water conservation and reuse approaches
- •*repair erosion sites*
- •*restore wetlands and summer pools*
- •*revegetate channels with grasses and wetland plants*
- •*restore riparian corridor*
- •*control animal access using fencing and designated crossings*
- •*develop off-stream watering sites*

D. Expand surface and groundwater monitoring activities (addresses: all)

- •begin monitoring groundwater in order to characterize the three aquifers and establish baseline conditions
- •test surface and groundwater for all parameters of concern, setting testing thresholds below maximum allowable values
- •coordinate agency monitoring, and integrate results and conclusions
- •monitor water quality upstream and downstream of restoration projects
- •periodically inform residents of the results of all monitoring programs
- •encourage homeowners to self-monitor their domestic water supply wells
- •encourage farmers, businesses and agencies to self-monitor activities that can adversely affect water quality

E. Increase public awareness and knowledge of water quality issues (addresses: all)

- •involve schools and community organizations in educational and restoration activities
- •*use demonstration projects that show methods to achieve standards and apply BMPs*
- •*promote water conservation and reuse approaches*
- •*periodically inform residents of the results of all monitoring programs*
- •*encourage homeowners to self-monitor their domestic water supply wells*
- •*encourage farmers, businesses and agencies to self-monitor activities that can adversely affect water quality*

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APPENDIX E

GEOMORPHIC AND HYDRODYNAMIC ANALYSIS
Philip Williams & Associates, Ltd.

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GEOMORPHIC AND HYDRODYNAMIC ANALYSIS FOR THE ESTERO de SAN ANTONIO ENHANCEMENT PLAN

Prepared for

Marin County Resource Conservation District

Prepared by

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November 30, 1993

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I. INTRODUCTION

The Marin County Resource Conservation District (MCRCD) is in the process of developing a Watershed Enhancement Plan for the 59-square mile Stemple Creek Watershed which drains into the Estero de San Antonio. The goal of the plan is to develop a practical community-based program for protecting ecologic resources while preserving viable agriculture in the watershed.

Estero de San Antonio is a coastal lagoon internationally recognized for its biologic importance. It is included within the Gulf of the Farallones National Marine Sanctuary which is an United Nations International Biosphere Reserve. The character of the Estero has been transformed by historic land use changes within the Stemple Creek watershed and continues to be affected by sedimentation and poor water quality. In addition, future adjacent land use changes and alterations in the hydrology could influence the Estero.

One of the important elements of the Enhancement Plan will be the management of the Estero itself. Its character varies greatly depending on whether the lagoon mouth is open or closed. When it is open, the Estero is tidal, has good circulation, and exhibits a typical estuarine salinity distribution. When the mouth is closed, the lagoon has poor circulation and widely varying salinities.

In order to help guide management decisions, it is important to understand the geomorphology and hydrodynamics of the lagoon, and in particular, how the opening and closing of the mouth responds to sedimentation within the Estero.

Philip Williams & Associates, Ltd. (PWA) was retained by MCRCD to address the following four main objectives:

1. Determine how the historic deposition of sediment in the Estero has affected the hydrodynamics and closure conditions of the lagoon mouth.

2. Analyze the hydrodynamics and circulation with and without the lagoon mouth closed.

3. Project how future rates of sedimentation would alter the hydrodynamics and closure conditions of the lagoon mouth if no watershed enhancement measures are undertaken.

4. Determine the feasibility of artificially opening the lagoon.

The work was carried out under two contracts: the geomorphic analysis (contract dated November 14, 1991) was funded by a grant from the California Coastal Conservancy to MCRCD;

and the hydrodynamic analysis (contract dated March 11, 1993) was funded by a grant from the Marin Community Foundation to MCRCD.

II. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Sedimentation in the Estero over the last 131 years has significantly affected the character and morphology of the lagoon, specifically:

    The potential diurnal tidal prism, the volume between mean higher high water (MHHW) and mean lower low water (MLLW), has been reduced to 7.1 million ft^3 (163 acre-ft), about 20% of the volume that existed in 1862.

    The bed of the lagoon has become shallower and is now typically about -3 ft NGVD or the level of mean lower low water (MLLW).

    Mainly because of this shallow depth, most of the lagoon does not drain below 0 ft NGVD at low tide and the effective diurnal tidal prism is only approximately 4.8 million ft^3, about 15% of the effective prism in 1862.

2. These physical changes have had a substantial impact on the hydrodynamics of the lagoon. Formerly it appears that the Estero's tidal prism was large enough to keep the lagoon fully tidal throughout the year, now the lagoon mouth has become smaller and usually closes off in the spring or summer and remains closed until the first significant flood flow of the winter. During drought periods the lagoon mouth can stay closed for more than a year.

3. Closure occurs when periods of high wave energy coincide with neap tides and low runoff. Based on monitoring in 1993, these conditions are relatively well predicted when the ratio of deep water wave power measured at the Bodega Buoy to potential tidal power exceeds about 35.

4. When the lagoon mouth closes, circulation is practically eliminated and, depending on inflow, water can back up to elevations of up to 10 ft NGVD and vary in salinity from hypersaline to nearly fresh. Anaerobic water quality conditions have also been reported when the lagoon mouth is closed.

5. With the lagoon mouth open, circulation is created directly by tidal exchange and indirectly by the density difference between the fresh water inflow and seawater.

6. If no action is taken and sediment delivery to the Estero continues at historic levels, it is anticipated that additional sedimentation would occur with further reductions in the tidal prism. Under these circumstances, the lagoon would gradually change from a seasonally

closed estuary to one that is closed most of the time. It would then be open only intermittently during and, for a short period, after significant flood flows.

7. If it is desired to completely restore the natural functioning of the lagoon by restoring the tidal prism to its historic conditions, one to two million cubic yards of sediment would have to be excavated.

8. There is some evidence based on surveys taken before and after the 1992-1993 winter floods, that natural scouring of the bed can occur, allowing some recovery of the tidal prism, provided sediment delivery to the Estero is reduced.

9. It is possible to artificially breach the lagoon mouth after it is closed. However, once inflows have declined in the spring, the entrance is likely to close again whenever strong wave action occurs during neap tides. In a typical year it is possible that several breachings would have to be made.

B. RECOMMENDATIONS

Based on this analysis, the following measures are recommended:

1. Undertake effective measures to reduce sediment delivery to the Estero. It is particularly important to reduce the delivery of coarse bedload sediments.

2. Carry out a complete bathymetric and topographic survey of the Estero.

3. Establish a monitoring program to:

    a. Continuously record water levels in the Estero to define closure and opening events.

    b. Install a stream gage on Stemple Creek to measure peak flood flows and low summer flows.

    c. Carry out periodic surveys to determine if net scour or deposition is occurring within the lagoon.

4. Ensure that the existing wave monitoring station off Bodega Bay is maintained.

5. Ensure that monitoring reports are kept in a publicly accessible location such as the Bodega Marine Laboratory Library.

6. After ten years of such monitoring evaluate whether additional management actions are worthwhile. Such actions could include a deepening of the channel to increase the tidal

prism or completely restoring the natural tidal prism by excavation of accumulated sediments.

III. NATURAL PHYSICAL CONDITIONS

Estero de San Antonio was formed over the last 10,000 years as rising sea levels after the end of the last ice age invaded the valley of Stemple Creek. This valley, like the valley of Estero Americano immediately to the north, has unusual geomorphic characteristics. Both Esteros were originally created by larger rivers than flow in them now. Travis (1952) reports that the watershed of Stemple Creek was formerly considerably larger and extended to Santa Rosa Mountain. Stemple Creek as a larger river was able to keep pace with tectonic uplift and incise a steep sinuous canyon in the coastal hills before discharging to the ocean. However, eventually more rapid tectonic uplift occurred inland and truncated the drainage (Prunuske-Chatham, 1992). Stemple Creek now has a watershed area of 59 square miles (see Figure 1), and is undersized for its valley, as can be seen on the topographic map (Figure 2).

Under the natural conditions that existed up to about 200 years ago before European settlers arrived, it is likely that watershed vegetation was largely undisturbed, and with the small sized stream flowing into the Estero, sediment delivery rates would have been low. This would explain why the process of sea level rise which appears to have averaged about 0.5 ft/century over the last 7,000 years (Atwater, 1979) has dominated over the process of sedimentation. Consequently, tidal influence extended about 4 miles inland creating a drowned river valley through the coastal hills.

Unfortunately, there is very little historic information concerning the Estero; however, it appears that in its natural state, the Estero de San Antonio would have been fully tidal year round.

It is significant that the Spanish chose to name both Estero de San Antonio and its twin to the north, Estero Americano, as *Esteros* or estuaries. Elsewhere on the California coast, the usual term used for coastal lagoons was *Laguna* or *Agua. Laguna* or "lagoon" was used to name both fully tidal and seasonally tidal systems; *aqua* or "water" was used for non-tidal lagoons. "Estero" was used for tidal channels such as the Petaluma River.

While it could be argued that the selection of the term Estero implied a fully tidal estuary, what may be more significant is that the same distinctive term was used for both Esteros. There is substantive historical evidence that Estero Americano was fully tidal in the 19th century, and allowed schooners to ship goods from the town of Valley Ford (PWA, 1986). The mouth of Estero de San Antonio is rockier than that of Estero Americano and this may have limited navigation in the same period.

The earliest definitive historic information for Estero de San Antonio is an 1862 topographic map that extends approximately 1¼ miles inland (see Figure 3). Although this map was prepared at a time when watershed characteristics would be changing due to overgrazing (Rowntree, 1973), it would appear to still be representative of the Estero's natural condition. This map shows similar open entrance channels for both Esteros with the width varying from 450 ft at high tide to 165 ft at low tide at the mouth of Estero de San Antonio.

There are several other noticeable features on the 1862 map. Immediately inside the estuary mouth there is a clear delineation of a flood tide bar of beach sands. In common with other tidal estuaries, the morphology of the area inside the mouth is influenced by the deposition of beach sands brought in on the flood tide—this area extends about 700 feet into the Estero. This portion of the Estero is still shallower than the reach further upstream, and it is interesting to note that a ford is indicated across both Estero de San Antonio and Americano at the upper end of this flood tide deposition zone in 1862.

Behind the flood tide bar, and approximately 1,000 ft further upstream, what appear to be tidal marshes are shown. Further upstream, the Estero occupies the entire width of the canyon and lines of high water and low water are shown. With the low sediment delivery from the watershed, it is possible that water depths in the lower part of the estuary could have been quite deep and similar to the 40-foot depths reported historically in the lower part of the Estero Americano (R. Gordon, 1986).

Further upstream, beyond where the Middle Road Bridge is now, the valley becomes wider. An 1857 land ownership map of the upper part of Estero Americano shows that channel to be considerably wider than now. Although not represented on the 1862 map, it is likely that Estero de San Antonio was also wider and fringed by tidal marshes further upstream.

Under natural conditions, the larger tidal prism would cause scouring of a deeper entrance channel allowing more efficient tidal drainage on the ebb tide. This would mean that the low tide elevation within the Estero would have been lower than at present and the tidal range greater.

Circulation within the Estero would have been mainly influenced by freshwater inflow. Because of its long thin configuration and large volume, circulation by tidal exchange by itself would have been fairly limited. However, even small inflows of freshwater would have induced an estuarine circulation system driven by the density differences between fresh and salt water. It is possible that under natural conditions before the watershed was degraded, summer flows would have been higher than now and sufficient to induce salinity gradients and estuarine circulation year round.

IV. HISTORIC CHANGES

Over the last 150 years, major human induced changes have occurred that greatly affect the physical functioning of the estuary. Cattle grazing, and later, arable farming in the watershed, have resulted in accelerated erosion and significant increases in sediment delivery to the Estero (SCS, 1992).

These sediments, mainly eroded by the formation of arroyos and gullies, were conveyed downstream during large flood events. At first, the finer materials were carried through the Estero and discharged to the ocean. However, the coarser sands remained in the Estero, and have filled in the deeper parts of its channel, building up shoals in backwater areas, and depositing natural levees on the edge of the tidal marshes.

Over time, the entire Estero became shallow and the fringing shoals became larger, narrowing the channel. Eventually, the tidal marshes were smothered with sediment, converting them to floodplain meadows. Figure 2 shows the shape of the Estero today, and Figure 4 is a map showing how the Estero has narrowed between 1862 and 1989.

With increased sedimentation, the tidal prism was reduced, which in turn reduced the scouring potential of currents within the entrance channel. Consequently, the entrance channel became narrower and shallower. At some point the entrance channel became small enough to be closed off by beach sand deposited during periods of high wave energy. It is not clear when the first closure occurred, but it was possibly late in the 19th century. The first direct evidence of closure is what appears to be barren, probably hypersaline areas on adjacent marshes in the earliest aerial photos from 1942. A 1930 survey undertaken by the Coast and Geodetic Survey between June and October shows the entrance open. Ed Pozzi (1993) reports that neighbors of his walked across the bar at the mouth of the Estero in about 1910. Other anecdotal evidence (R. Gordon, 1986) indicates that Estero Americano, which had been experiencing similar changes but had a larger tidal prism, first closed in the 1930's.

Once closure occurs, the physical functioning of the Estero is transformed, with the estuary becoming a seasonal lagoon where tidal and estuarine circulation is eliminated. Once the entrance channel closes in the spring or summer, and depending on the amount of freshwater inflow, the lagoon can become hypersaline (California Fish and Game, 1977) or brackish throughout most of its length. The lagoon mouth remains closed until the first significant winter storms fill the lagoon and overtop the beach built up in the summer. Once breaching occurs, a deep channel can be scoured quickly, returning the lagoon to tidal action.

V. EXISTING CONDITIONS

A. LAGOON MORPHOLOGY

Until this study, no bathymetric survey or detailed topographic map of the Estero had been prepared since 1862. Therefore the first task in developing an understanding of the physical processes that occur in the lagoon was to characterize the morphology of the lagoon. Unfortunately, there were insufficient funds in this contract to carry out the detailed mapping that will ultimately be required for making management decisions on the Estero. Nevertheless, sufficient field survey data was collected for this study to estimate key morphometric variables.

Three field surveys were made:

1. To establish benchmarks at the mouth of the lagoon that can also be used in later surveys or monitoring work (see Appendix A).

2. To survey representative cross-sections and channel bed (thalweg) elevations together with beach profiles. This work was carried out in March 1992.

3. A second survey of channel bed elevation after the winter runoff of 1992-1993 together with additional representative cross-sections. This work was carried out in March 1993.

The surveyed cross-sections and thalweg profiles are attached in Appendix B. Figure 5 shows the 1993 channel bed profile.

An aerial photo from May 19, 1989 (enlarged to a scale of 1 inch = 200 feet) was used as a base map and together with the survey data, stage-area and stage-volume relationships were developed.

To estimate the historic changes in morphology, the area mapped in 1862 (downstream of cross-section 4 shown on Figure 2) was compared with the same area in 1993. Morphology in 1862 was developed assuming the mapped high water mark to be equivalent to about MHHW at +3 ft NGVD, and the low water mark to be at about -2 ft NGVD. (Tidal datum is shown in Appendix A.) The area directly compared in this way accounts for about 60% of the Estero's tidal prism. The change in morphology in the remaining 40% was assumed to be proportional to the changes observed in the measured area. Appendix C describes the methods used in determining the 1862 morphology.

Figure 6 shows the measured stage-area relationship for the Estero in 1993. Figure 7 compares the measured stage-volume relationship for 1993 with the estimated value for 1862.

The morphometric analysis shows that significant sedimentation and loss of tidal prism has occurred since 1862. Table 1 summarizes the change in tidal prism. It can be seen that the total loss of potential diurnal tidal prism has been about 1 million cubic yards, averaging about 5 acre-ft/yr. The potential tidal prism is now only about 20% of its original volume.

The massive sedimentation that has occurred during historic time is confirmed by soil corings. Figure 8 shows a surveyed cross-section with three corings made close to the mouth in what was identified as tidal marsh, in 1862. The historic marshplain was found at an elevation of about 2.5 ft NGVD overlain with 2 to 3 feet of sediment. Allowing for some compaction (perhaps about half a foot) due to the overburden, the marshplain surface would have been between MHW and MHHW—a typical elevation for a tidal marsh in a fully tidal system. (Harvey, *et. al.*, 1990)

Other corings made further inland show up to 7 ft of coarser riverine sediment overlying marsh or mudflats (see Appendix D).

Because of hazardous conditions at the entrance, we were not able to obtain direct measurements of the inlet channel geometry. However, channel width can be obtained from aerial photos and prior hydrographic surveys, and channel depth can be estimated from empirical relationships of tidal prism with inlet channel area (Jarrett, 1976) using a width-to-depth ratio of 12 observed at Bolinas Lagoon (Johnson, 1973a).

The entrance channel cross-sectional area, A, below mean sea level (NGVD) is given by

$$A = 1.91 \times 10^{-6} \boldsymbol{P}^{1.1}$$

where, $\boldsymbol{P}$, is the potential diurnal tidal prism. Table 2 summarizes how estimated channel dimensions have changed over time.

B. HYDROLOGY

Average precipitation in the 59-square mile watershed of Estero de San Antonio is approximately 30 inches and is highly seasonal with 90% occurring in the period November to April.

Unfortunately there is no measured stream flow data for Stemple Creek. A recording gage at the Highway 1 Bridge was installed by the Santa Rosa Wastewater Study but this location is influenced by lagoon stages and due to malfunctions did not provide reliable data in the study period. (M. Commins, 1992))

Based on regional flood frequency analysis, 10-year and 100-year flood peaks at Highway 1 would be of the order of 5,800 and 7,500 cfs, respectively, which are sufficient to transport large volumes of bed load into the Estero (Waananen and Crippen, 1977).

Seasonal flows into the Estero have been roughly estimated using a regression model developed by the Santa Rosa Wastewater Study (Dearth, *et. al*. 1988). This model estimates Stemple Creek average monthly flows based on correlation of gaged streamflow measurements and precipitation records from the nearby Salmon Creek Watershed. Appendix E tabulates this computed streamflow data for the historical periods of 1959-1981, and 1989-1993. Figure 9 shows the average monthly hydrograph. It can be seen that in an average year, predicted inflows decline to below about 2 cfs by June and do not substantially increase until at least November. Monthly flows of about generally 100-150 cfs occur during the winter and spring months of November through March.

C. LAGOON HYDRODYNAMICS

The Estero currently functions as a seasonal lagoon in which the typical mode of behavior is as follows: In the winter and early spring the lagoon is fully tidal. Varying amounts of freshwater inflow creates a salinity gradient and estuarine circulation system within the lagoon. Except for a few days during flood peaks, water levels in the Estero are determined by mainly tidal influence. By the summer, the lagoon mouth has closed, estuarine and tidal circulation has ceased, and water levels in the lagoon are dictated by the balance of freshwater inflow, seepage through the beach and evaporation. Eventually, with the advent of winter storms, water levels in the lagoon rise until they overtop the barrier beach, and scour out a new tidal channel, hence restoring tidal circulation.

There had been no water level measurements taken in the Estero prior to this study. A continuous water level monitoring was conducted during the period between January 26 and June 24, 1993 at the Franklin School Road Bridge about 1½ miles above the mouth. Unfortunately, the water level recorder malfunctioned between January 26 and March 9. Nevertheless the monitoring period included a period of fully tidal conditions, the period of closure, and subsequent ponded water level conditions. Figure 10a and b show the monitoring data during lagoon closure event. Appendix F shows the complete monitoring record together with tides adjusted for the mouth of Tomales Bay, and local precipitation.

In the fully tidal period (until about April 1st) it can be seen that the water level fluctuations closely follow the tide in Bodega Bay. The higher high tides in the Estero are sometimes slightly higher than Bodega Bay tides. This could be caused by wave set up in the entrance channel or by streamflow. The lower high tides in the Estero are somewhat lower than Bodega Bay tides—this indicates the constricting effect of the entrance channel that limits inflow until the tide is high enough (at about +2 NGVD). It can also be seen that at low tide the Estero does not drain below about 0 ft NGVD at the Franklin School Bridge.

As part of this study a tidal hydrodynamic model was set up to simulate tidal flows into the Estero calibrated with simultaneous synoptic tide measurements taken at the Franklin School Road Bridge and the Middle Road Bridge, and with visual readings on tide staffs installed at the mouth. Appendix F shows these measurements. Tidal amplitudes and lags are shown in Table 3.

In calibrating this model, which is described in Appendix G, it became evident that the tidal hydrodynamics of the lagoon are strongly dependent on the entrance channel geometry. Moreover, in other small tidal estuaries we have measured significant variations in inlet channel cross-sectional area between the ebb and flood of a single tidal cycle and between spring and neap tides (Goodwin and Williams, 1991). This variation creates considerable uncertainty in a key variable and limits the usefulness of tidal hydrodynamic model predictions for the Estero.

Based on the Franklin School Road Bridge monitoring record it can be seen that the actual tidal prism is about 67% of the potential tidal prism and that the diurnal tidal circulation (actual diurnal tidal prism divided by lagoon volume) is about 60%. Because of the long thin configuration of the Estero, the tidal excursion—the distance up the Estero whose volume is replaced on a tidal cycle—is about 6000 ft out of the total length of 20,000 ft. This means that the water in the upstream 14,000 ft would tend to move back and forth within the Estero on a diurnal tidal cycle. However, whenever there is significant freshwater inflow an estuarine circulation system would develop that would exchange water in the upper part of the Estero with the lower part (Figure 11). Density driven currents can occur one to two orders of magnitude greater than the freshwater inflow rate (McDowell, 1977). If this were true for Estero de San Antonio, inflows of the order of 1 cfs to 10 cfs could be sufficient to exchange the water volume of the Estero within a few days when the entrance channel is open.

Once the entrance closes, the mixing within the Estero is probably dominated by wind driven currents. The water level varies but typically declines over the summer in response to seepage and evaporation until late fall as inflow rates drop to a fraction of a cfs. We have estimated seepage rates of the order of about 0.5 cfs for a similar barrier beach at Big Lagoon in Marin County. Monitoring of the water level at Estero de San Antonio in 1993 indicates a decline of about 0.4 ft in May and June. This indicates that in a dry year once the lagoon mouth closes, water levels can decline about 2 ft by the end of September due to evaporation, reducing the volume by about 40%. If average salinity in the lagoon were close to that of seawater at the time of closure, this reduction in volume is sufficient to cause hypersaline conditions.

Salinity stratification may also occur in Estero de San Antonio once the entrance channel has closed (Figure 12). This has been observed in other closed California coastal lagoons where stratification creates high temperatures and anoxic conditions within most of the water column. (PWA, 1990)

With the first winter runoff, the lagoon fills until the barrier beach overtops. Based on observations by Ed Pozzi of the maximum lagoon water levels reached, it appears that breaching occurs at a maximum elevation of about +10 ft NGVD. Assuming an initial low water level in October of about +2 ft, an inflow of about 35 million cubic ft would be required to fill the lagoon to +10 ft NGVD (see Figure 7). Comparison with typical monthly inflows (Figure 9) indicates that in an average year filling and breaching would occur by mid-December.

D. COASTAL PROCESSES

The entrance to Estero de San Antonio is located within Bodega Bay but exposed to waves from the WNW to the SSW. In general, two types of waves affect the beach at the mouth of the Estero.

Waves known as "seas," generated by local winds, are steep (low wave height to wave length ratio) have short periods, and tend to erode the beach, flattening its profile. As seas tend to be more intense during the winter it is the effect of these types of waves that creates what is sometimes called the "winter" beach. In the summer long period swells dominate which are generated by storms thousands of miles away across the Pacific. These waves tend to build up the beach and steepen its profile creating the "summer" beach.

As waves move from deep water to shallow water they change character and lose energy due to refraction and diffraction. Of most interest to this study is the power of waves breaking on the beach that will suspend beach sands that can then be deposited in the entrance channel. It was not within the scope of this study to carry out an analysis of the translation of waves in Bodega Bay. However, deep-water wave power can be used as a good index of shallow water wave power.

Deep-water wave power is defined as:

$$\phi_w = \frac{\gamma H_s^2 L}{16 T_w} = \frac{\gamma g H_s^2 T_w}{32\pi} \; ftlb/ft/sec$$

where

H_s	=	significant wave height in feet		
L	=	wave length in ft		
T_w	=	wave period in seconds		
γ	=	unit weight of sea water	=	64 lb/ft^3

Fortunately, a continuous wave recorder is maintained off Bodega Bay (see Figure 13). From data collected by the Bodega wave buoy, we can analyze the significant wave heights, steepness, energy, and wave power while the lagoon was tidal and during closure events. Appendix H shows plots of these parameters for 1992- 93. Figure 13 shows the running 6-hour average wave power during the period of closure in March and April 1993. It can be seen that this included a period of extreme wave conditions on March 24 with 19-ft swells occurring.

A beach profile was surveyed in June 1993 after the mouth had closed but while the beach was still building (see Appendix B). Extrapolation of the berm crest profile indicates an elevation at about +11 ft at the inlet, consistent with observations that the lagoon opens when the elevation reaches about +10 ft NGVD.

E. LAGOON CLOSURE

The process of closure of a coastal lagoon is complex and imperfectly described. O'Brien (1971), and Johnson (1973b) conceptually described the mechanics of closure as when the littoral transport of beach sand into the entrance channel by wave action was greater than the ability of the tidal current to scour the channel. O'Brien proposed an empirical closure relationship for Pacific Coast Lagoons as a ratio *C,* between wave power, which drives the littoral transport; and tidal power, which determines the scouring of the channel, to define when lagoon mouths are fully tidal and when they are closed.

$$C = \frac{\phi_w}{\phi'_T}$$

O'Brien defined tidal power as ϕ'_T :

$$\phi'_T = \frac{\gamma P h_r}{T_t b} \ ftlb/ft/sec$$

where

P	=	tidal prism in ft^3
h_r	=	tidal range in ft
T_t	=	tidal period in seconds
b	=	width of entrance channel in ft

For this analysis we have further defined these terms as

P	=	potential tidal prism
h_r	=	potential tidal range offshore
T_t	=	ebb tide period = 6.25 hours

Goodwin (PWA, 1993b) has refined the definition of the closure criteria to take into account the additional role of stream flow in scouring on the ebb tide. The stream power is added to give the total tidal power ϕ'_T :

$$\phi_T = \frac{\gamma h_r}{b}\left(\frac{P}{T_t} + Q\right)$$

where

Q = river flow in ft3/sec

for this analysis we have defined *C* $\frac{\phi_w}{\phi_T}$ as averaged over a 6-hour period.

For small lagoons, such as Estero de San Antonio, the closure mechanism can be complicated. It appears that closure may be more influenced by the onshore movement of beach sands during intrinsic high-energy wave conditions than longshore littoral transport. At this stage it is not clear whether there is any difference between the effects of swells or seas in mobilizing the movement of sand into the entrance channel. The magnitude of the effective tidal prism—the volume of water actually flooding and ebbing through the entrance channel—dictates the effectiveness of scouring by ebb tide flows removing sand deposited in the channel during the flood.

In addition, it is clear that the spring-neap variation in tidal amplitude has a significant role in closure. During the neap tides ebb tide scouring is weakest and it is more likely that any sand mobilized by wave action during the flood tide will settle out and remain in the entrance channel. Monitoring of the Estero during the spring of 1993 (Figure 10) shows two closure events, one initiated on April 1, and the other which permanently closed the entrance on April 16. Both of these occurred during neap tides. A period of extreme wave energy occurred on March 23 during a spring tide and higher runoff and failed to close the Estuary.

The closure conditions can also be greatly affected by streamflow. For Estero de San Antonio the actual mean tidal prism is 2.7 million ft^3 which means the average outflow over a 6.25 hour ebb tide is approximately 120 cfs. The minimum recorded neap tide fluctuation recorded at Franklin School Bridge is about 1.4 ft (between 2.2 and 0.8 ft NGVD on March 18, see Figure 10) which would account for an actual tidal prism of about 2.1 million ft^3 or an outflow of about 90 cfs. It can therefore be seen that streamflows of the order of 90 cfs would prevent flood tide currents during the neap period, significantly reducing deposition in the entrance channel. As can be seen from Figure 9 in an average year, the period December through February would typically have flows higher than 90 cfs.

The most critical conditions for closure occur in the spring when periods of high wave energy coincide with neap tides and low runoff. This is best shown by measurements taken during the study period 1992 to 1993. In January, 1992 the mouth was closed but had reopened by March. Water level readings taken by Ed Pozzi until June indicate the lagoon as tidal during this period, however he reports the mouth closed by July 4th. In January 1993 the lagoon was tidal. In the period until June it is noticeable that the summer was unusually calm (see Appendix H). Figure 10 shows that in 1993 the first closure event occurred during the neap tide period of April 1 when there was intense wave action (Figure 13). Estero Americano also closed permanently on April 1, 1993 (see Table 4). However it appears that there was still sufficient runoff at Estero de San Antonio to start eroding a channel through the beach when wave energy dropped on about April 7. Subsequently another period of high wave energy coincided with a neap tide on April 16 closing the entrance channel for the rest of the season. Average predicted flows had dropped from about 50 cfs on April 1 to about 11 cfs on April 16.

Table 5 shows wave and tidal characteristics for the extreme wave condition on March 24th and two closure events in April, and computes the closure criterion of wave power to tidal power. It can be seen that closure occurred when this ratio was greater than about 35. This ratio is useful for evaluating the impact of long-term changes in the Estero. For example it can be seen that even under the most extreme wave conditions occurring at neap tide, the 1862 tidal prism would have been large enough for the closure criterion to be well below 35 even with no inflow, indicating that the Estero mouth was always open under natural conditions.

It is useful to compare the closure conditions of Estero de San Antonio with other California Coastal lagoons. Figure 14 is a plot of average annual wave power against potential diurnal tidal prism which shows closure conditions for lagoons listed in Table 6. Although there is a considerable uncertainty in this plot, it is interesting to note that in 1862 Estero de San Antonio's tidal prism was large enough to place it very close to the "always open" line whereas, now with its reduced tidal prism, it falls well within the seasonally closed category.

VI. FUTURE CONDITIONS

Over the next 50 years two physical processes will continue to have a major affect on the Estero.

Sea level is projected to rise, which by itself will increase the tidal prism of the lagoon. There is an international scientific consensus that global warming will cause an accelerated rise in sea level even if drastic actions are taken to reduce greenhouse gases (NRC, 1987) There is considerable disagreement on the magnitude—or more precisely the timing of a given change. Predictions range from 1.5 ft to 5 ft over the next century with about 0.5 to 2 ft occurring in the next 50 years. Without the greenhouse effect sea level is projected to rise about 0.5 ft in the next century.

A 0.5 ft rise would increase the potential diurnal tidal prism by about 1.1 million ft^3 (to $8.2 \times 10^6 ft^3$) an increase of 4%.

If there were no changes in watershed management practices within the Stemple Creek watershed, such an increase in tidal prism would be more than counterbalanced by the effect of sedimentation in the Estero. Historic sedimentation has reduced the potential diurnal tidal prism at an average rate of 200,000 ft^3 per year over the last 131 years. This is about ten times the rate of increase in tidal prism due to historic sea level rise. Although most of the sedimentation would have occurred in the late 19th century it is likely that sediment delivery to the Estero continues to be considerably higher than natural conditions, resulting in net filling of the Estero.

The most significant affect of future sedimentation would be the deposition of sands within the channel gradually raising the bed. This might cause only a small reduction in potential tidal prism, but because it would reduce the hydraulic effectiveness of the channel it could cause a significant reduction in the actual tidal prism—particularly during the neap tides—thereby increasing the frequency of closure. It is conceivable that the reduction in tidal prism would allow sufficient shoaling at the entrance channel to practically eliminate tidal effects during neap tides.

With these conditions, higher streamflow would be required to keep the Estero tidal. For example, if a closure criterion value of 35 defines the critical conditions for closure of the lagoon, it means that a further 20% reduction in tidal prism would require an increase in streamflow of about 50 cfs to maintain the same tidal power. A closure event like that which occurred on April 1, 1993, would therefore require about 100 cfs instead of 50 cfs to keep the entrance channel open. Under these circumstances it can be seen (Appendix E) that the period of opening would diminish to typically the January-February period when there is high enough streamflow, and that the number and frequency of years when there would be no tidal action throughout the year would increase.

VII. ALTERNATIVE MANAGEMENT APPROACHES

A. WATERSHED MANAGEMENT

It is probable that extremely large floods will continue to deliver pulses of sediment to the Estero. However if sediment delivery from the smaller floods—the 2- to 10-year events, can be significantly reduced it is possible that scouring of the bed would take place. This would increase the hydraulic efficiency of the channel and allow some recovery of the effective tidal prism.

An indication that such scouring can take place was found somewhat fortuitously by measurements of the bed profile before and after the 1992-1993 winter floods. It appears that flood flows in 1993 were of the order of the 2- to 5-year event and occurred after 6 years of drought As can be seen in Figure 15, up to 5 ft of erosion occurred in areas of the lower estuary, due to these increase flows.

Measures can be undertaken to significantly reduce the delivery of sediments and particularly coarse sediment to the Estero. For example, gully control measures, riparian and flood plain restoration, rehabilitation of rangeland, and exclusion of livestock from stream banks would all cumulatively tend to reduce sediment delivery during flood events.

B. RESTORATION OF NATURAL TIDAL PRISM

The natural functioning of the Estero could be restored by recreating the tidal prism that existed in 1862. This would require the excavation of between 1 to 2 million cubic yards (cy) of sediment. Most of this material would be removed from floodplain meadows or wetlands that have filled the Estero over the last 130 years.

It is also possible to implement incremental increases in the tidal prism. Probably the most cost effective measure would be to deepen the Estero channel by removing about 2 feet of accumulated sediment. Assuming excavation of about 5,000 ft of channel 30 ft wide would require removal of about 10,000 cy. This would allow more effective tidal drainage, increasing the effective tidal prism. If this allowed the Estero to drain one foot lower at low tide, the effective tidal prism could be increased roughly 20%.

C. ARTIFICIAL BREACHING

The biologic assessment for the enhancement plan has recommended maintaining tidal action in the Estero if at all possible to improve fish habitat (Maron, 1992). It is feasible to extend the period of tidal action within the lagoon by artificially excavating an entrance channel across the beach after a closure event. During the period 1982 through 1991, the mouth of Estero Americano was maintained open in this fashion using a bulldozer equipped with low ground pressure tracks. It typically required up to 10 days of grading to create a new channel and final breaching was done at low tide (Peter Hain, November 22, 1993). The period for which data is available, 1985 to 1991, shows that usually the lagoon stays tidal once the mouth is breached (Table 4). However this appears to have been an unusually calm period and probably under-represents the frequency of closure at Estero Americano.

It is expected that Estero de San Antonio would behave similarly to Estero Americano but would be more likely to have repeated closures because of its smaller tidal prism. Assuming a closure criterion value of approximately 35 it can be determined that with virtually no inflow in the summer, the tidal prism will be insufficient to keep the entrance channel open whenever the deep-water wave power exceeds about 20,000 ftlb/ft/sec during neap tides. Inspection of the wave data (Appendix H) shows that during the summer and fall of 1992 wave power was less than this value and it is likely that had the entrance channel been excavated it would have stayed open. In 1993, however, it can be seen that had the entrance channel been excavated after closure on April 16 it almost certainly would have closed again at the beginning of June when a period of high wave power coincided again with the neap tide. Based on winter storm precipitation data, 1993 appears to be a more normal year than the calm period of 1992. It therefore appears that artificial breaching would be required several times in a typical year, most likely in the spring and fall.

The cost of each breaching would be similar to the cost of breaching Estero Americano and of the order of $10,000 including equipment rental (P. Hain, 1993).

D. MONITORING

A better definition of cost effective management measures could be obtained by analyzing some simple, monitoring data collected over the next 10 years. These should be carried out in coordination with ecologic and water quality studies in order to specifically define management goals for the Estero. The following information would enable us to better define the closure conditions and the physical evolution of the lagoon should it be considered desirable to reduce the frequency and period of closure:

1. Continuous water level recordings of the lagoon to identify opening and closure events as well as tidal fluctuations and summer water balance parameters. Preferably this would be a station close to the mouth, however for ease of access, the Franklin School Road Bridge site is satisfactory.

2. Establish a recording stream gage on Stemple Creek to determine flood peaks and summer inflow. This gage would have to be located where flood stages are not influenced by maximum level of the lagoon.

3. Carry out a detailed topographic and bathymetric survey at a scale of 1 inch = 50 ft with 1 ft contours for areas below about +15 ft NGVD to accurately determine the morphometric characteristics of the Estero. This survey should then be repeated after 10 years to analyze morphologic changes and net deposition. The mapping could also be used to provide input data for modeling tidal hydrodynamics and salinity distributions.

4. Carry out bed profile and cross-section transect surveys once a year to evaluate the impact of each winters flood flows.

5. Ensure that the Bodega wave station continues in operation over the next ten years.

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TABLES

TABLE 1

HISTORICAL CHANGE IN TIDAL PRISM AT ESTERO DE SAN ANTONIO

Date	1862 Tidal Prism ($x\ 10^6\ ft^3$)	1993 Tidal Prism ($x\ 10^6\ ft^3$)
Potential Mean Tidal Prism MHW — MLW	24	4.6
Potential Diurnal Tidal Prism MHHW — MLLW	33	7.1
Actual Mean Tidal Prism	24*	2.7**
Actual Diurnal Tidal Prism	32†	4.8‡

NOTES:

* Assumes tidal range is +2 to -2 ft NGVD

** Assumes tidal range is +2 to 0 NGVD

† Assumes tidal range is +3 to -2 NGVD

‡ Assumes tidal range is +3 to 0 NGVD

TABLE 2

HISTORIC CHANGES IN INLET CHANNEL DIMENSIONS

Year	Observed Channel Width (ft)		Calculated Channel Dimensions †			Potential Diurnal Tidal Prism (ft^3)
	MHW	MLLW	Area below MSL (ft)‡	Depth Below MSL (ft)‡	Width MSL (ft)‡	
1862	450	165	506	7	85	33
1930	337	84	—	—	—	—
1993	—	—	120	3.2	38	7.1

† Calculated based on Jarret's Equation (1976)

‡ Assuming width to depth ratio of 12:1

TABLE 3

TIDAL CHARACTERISTICS AT ESTERO de SAN ANTONIO
MEASURED MARCH 19th - llth, 1993

Tide	Tomales Bay[†] Entrance (ft NGVD)	Franklin School Bridge (FSB) (ft NGVD)	Middle Road Bridge (MRB) (ft NGVD)
Higher High Water	3.50	3.36	3.42
High Water	2.30	2.01	2.19
Low Water	-1.56	0.12	0.46
Lower Low Water	-2.40	0.08	0.46

[†] Adjusted from observed tides at Presidio Gage; corrections for Tomales Bay Entrance are as follows:

	High Tide	**Low Tide**
Tomales Bay Entrance	x 0.87 ft -12 min	x 0.91 ft +20 min

TABLE 4

CLOSURE EVENTS AT ESTERO de SAN ANTONIO AND AMERICANO 1984-1993

Year	Estero Americano[1]	Estero de San Antonio
1984	4/9	?
1985	?	?
1986	3/22	?
1986	4/18	?
1987	2/7	?
1988	none	?
1989	none	?
1990	none	?
1991	4/7	?
1992	none	between 6/9 and 7/4[‡]
1993	4/1	partial 4/1
1993	—	4/16

[†] Data provided by P. Hain, California Fish Growers

[‡] Reported by Ed Pozzi, Rancher

TABLE 5

CLOSURE CONDITIONS AT ESTERO de SAN ANTONIO

Date of Closure Event	H_s Signif. Wave Height (ft)	L Wave Length (ft)	T_w Wave Period (sec)	h_r Potential Tidal Range (ft)	P Potential Tidal Prism (ft^3)	Q Est. Stream Flow‡ (ft3/sec)	Est.* MSL Inlet Width (ft)	Φ_W Deep Water Wave Power† (ftlb/ft/sec)	Φ_T Potential Tidal Power (ftlb/ft/sec)	$\frac{\Phi_W}{\Phi_T}$
3/24/93	11	752	12	4.4 (-1.4 to 3)	$6.2X10^6$	75	38	3,373,716	99,216	34
4/1/93	17	576	11	4.3 (-1.9 to 2.4)	$5.3X10^6$	51	38	2,478,398	79,278	31
4/16/93	16	600	11	3.9 (-1.8 to 2.1)	$4.6X10^6$	11	38	2,034,330	54,104	38

Notes

* Cross-section area = 120 ft^2 below MSL and w/d ratio = 12:1 (from Bolinas Lagoon inlet cross-sectional plots)

† Averaged over 6 hours

‡ Estimate based on ratio of Redwood Creek (Marin County) daily flows to monthly average flows

TABLE 6.

TIDAL INLET CHARACTERISTICS FOR SOME CALIFORNIA COASTAL LAGOONS

Site Location		Potential Tidal Prism ($10^6 ft^3$)		Annual Deep-Water Wave Power (10^{11} ft-lb_F/ft/yr)	Closure Conditions
		Diurnal	Mean		
1	Smith River Estuary	35	24	303	(Infrequent)
2	Lake Earl	430	320	329	Frequent
3	Freshwater Lagoon	35	25	348	Always
4	Stone Lagoon	86	64	348	(Frequent)
5	Big Lagoon	240	180	348	(Frequent)
6	Eel River Delta	200	140	371	(Infrequent)
7	Russian River Estuary	76.2	56.6	(300)[a]	Frequent
9a	Estero de San Antonio, 1862	33	24	(200)	(Never)
9b	Estero de San Antonio, 1993	7.1	4.6	(200)	Frequent
10	Tomales Bay	1580	1070	209	Never
11	Abbotts Lagoon	17	11	307	Frequent
12	Drakes Estero	490	340	26	Never
13	Bolinas Lagoon, 1968	71.6	—	117	Never
14	Pescadero	6.8[b]	4.6[b]	(200)	(Frequent)
15a	Mugu, 1857	170	120	(100)	(Never)
15b	Mugu, 1976	27	19	(100)	Frequent
16	Carpinteria	4.8[b]	1.5[b]	(50)	Infrequent
17	Agua Hedionda, 1976	80	55[b]	28	Never
18	Batiquitos, 1976	0.33	0.23	(30)	Always
19a	San Dieguito, 1889	37	24	(30)	Never
19b	San Dieguito, 1976	0.2	0.14	(30)	Frequent
21	Los Penasquitos, 1976	2	0.75	(30)	Frequent
22a	Tijuana, 1852	67.5	47.9	(100)	Never
22b	Tijuana, 1928	34.4	20.0	(100)	Never
22c	Tijuana, 1977	14.8	8.3	(100)	Infrequent
22d	Tijuana, 1986	12.6[b]	4.8[b]	(100)	Infrequent
23	Bolsas Bay, 1874	—	38	(30)	Never
25a	San Lorenzo River, est. 1853	N/A	17.4	(200)	—
25b	San Lorenzo River, c. 1980's	N/A	3.69	(200)	Frequent

Sources: Johnson 1973, Williams 1984, Coats 1986, Williams & Swanson 1987, Goodwin & Lin 1992, Goodwin & Cuffe 1993, Rowntree 1973

[a] Parenthesis indicate an estimate of deep-water wave power.

[b] Indicates that tidal prism data based on a large-scale topographic map.

APPENDIX F

SUMMARY OF WATERSHED RESIDENT INTERVIEWS
Liza Prunuske, Prunuske Chatham, Inc.

Summary of Watershed Resident Interviews
Prepared by Liza Prunuske
July 1994

As part of developing the Enhancement Plan, I met with twenty-five Stemple watershed residents in nineteen households. The purpose of the interviews was twofold: first, to let people know about the project and discuss with them what we had learned so far; and second, to solicit information from them on historical changes, current conditions and concerns that they would like to see incorporated into the overall plan.

The following is a synopsis of the issues raised by the people interviewed.

Water Quality

Residents in seven of the 19 households had strong concerns over water quality. They lived from the very top to the downstream end of Stemple Creek. Most said that water quality had seriously declined within the last 10 to 15 years. Problems ranged from brown, smelly water coming out of faucets to a well that was condemned for household use because of dangerously high nitrate levels. Both dairy operators and downstream ranchers complained of problems. Most residents attributed the decline to the increase in dairy herd size over the past two decades. The Sonoma County Landfill and the Coast Guard facility were also named as possible causes.

Economic Viability

In six households, all but one of them dairies, residents had serious doubts as to whether their farms would survive into the next generation. Low prices for milk and meat, increasing regulation and technical demands, and high land costs contributed to the uncertainty. Some dairies increase herd size to try to cover the bills, and then face the difficulty of coping with increased waste and over-worked pastures. One dairyman said, "It just isn't fun anymore."

Two people interviewed cited the difficulty presented when property is jointly owned by several family members, many of whom have little or no stake in keeping the farm. The farming member is often faced with the choice of selling the entire operation, or buying out the other owners at some of the highest prices for grazing land anywhere in the country.

Economic hardship plays a direct role in natural resource conservation. As disposable farm income declines, ranchers are less likely to haul in rock to fix a washout, fence out a gully or reseed pastures. Many who are fortunate enough to own flat acreage along Stemple Creek are reluctant to take anything but a narrow strip out of production.

On the other hand, some dairy operations and ranches provide a good living in the Stemple Creek Watershed. Location, amount of good grazing land, whether the land was inherited or needed to be purchased, and the extent of facilities required to meet clean water regulations are factors in success.

Santa Rosa Wastewater

Nearly everyone had a strong opinion. Many downstream residents reiterated their fears about water quality, expressing alarm that both the treated water itself plus the potential additional increase in dairy herd size would further pollute their wells and surface water. On the other hand, many of the dairy operators interviewed and a of couple ranchers felt that the additional water could help them maintain or achieve economic stability.

Many people expressed a belief that they were not getting straight answers from the City of Santa Rosa's consultants and staff. Concerns included the long-term impacts on soil productivity from irrigation with the treated water and determining the areas where irrigation would be feasible. Several residents pointed out how this issue has divided the community.

Soil Erosion

Nine of the households had problems from erosion, either on-site or from upstream areas. The erosion sites included gullies, bank erosion along mainstem Stemple Creek, one massive landslide and the Sonoma County landfill. Many residents expressed interest in getting help from the RCDs on large erosion problems.

Flooding

Flood damage to crop and pasture lands was an issue for four of the households interviewed. One landowner has spent $40,000 - $50,000 dredging a reach of Stemple Creek that he remembers having deep holes 30 years ago. One landowner actively removes willows from his reach to increase the channel capacity. Another allows his cows into his fenced-off creek areas for brief periods as needed to clear willow growth from the channel. Three of the four residents interviewed live on Pepper Road.

Many residents recalled that Stemple Creek had deep holes when they were children. One woman told of an old-timer who remembered swimming parties on mainstem Stemple Creek near the Coast Guard Station. Now, the summer flow is only a couple of feet deep in that reach.

Rangeland Improvement

Eight of the households expressed interest in rangeland improvement. Many already have active programs of fertilization and reseeding. One rancher is experimenting with high-density grazing in small paddocks combined with frequent rotation.

Several landowners said they would welcome assistance with fencing costs, seeding and fertilization, and/or monitoring programs to help them modify practices as needed.

Red Tape and Regulation

Five of the residents expressed frustration with the number of agencies involved in approving a given project, the amount of time each requires and the apparent lack of coordination among them.   The agencies that are involved in issuing permits for streambank repair within the watershed, for example, include (and are probably not limited to) the California Department of Fish and Game, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, the Marin County Public Works Department and the Sonoma County Water Agency. County building inspectors, milk inspectors, the State Division of Water Rights and both counties' Public Health Departments regulate other agricultural practices.

Other public agency-related concerns include frequent changes in regulations and inconsistency, particularly regarding dairy waste discharges. One dairyman suggested that the Department of Fish and Game should visit every dairy in the watershed at the same time, immediately following the same storm, for example. Some people expressed frustration with Department of Fish and Game wardens who, they claim, give dairymen little or no opportunity to correct a problem before issuing a citation. The Regional Water Quality Control Board staff and Department of Fish and Game biologists seem to have a better track record among residents for cooperation.

Habitat Improvement

Ten of the households interviewed were very interested in general improvement or protection of wildlife habitat on their ranches. At least six households had sections of riparian corridor fenced and five wanted to add riparian fencing. Residents were particularly interested in attracting quail, deer and waterfowl. Many people noted the decline in waterfowl since their childhoods in the watershed.

Coyote Predation

Three of the sheep ranchers interviewed identified coyotes as a major problem for them or their neighbors. One rancher was considering cutting some of his riparian habitat because it provided cover for foxes and coyote that were regularly killing his lambs. The lack of public understanding of the impacts of coyotes on the lambs and the rancher was particularly frustrating to one landowner.

Residents Interviewed

Simon and Marilyn Azevedo
Margaret Bradley (extended telephone interview)
David Burbank
Linda Burbank
Alvin Hansen (brief telephone interview)
Ray Jacobsen
Bill Jensen
Garry and Gillian Mahrt
Bill McCall
Neil McIsaac, Jr.
Ken Martin
Paul and Jill Martin
Ken and Nancy Mazzetta
Al and Loren Poncia
Ed Pozzi
Francis Righetti
Julie Titus
Joe and Kathy Tresch
Terry Zimmerman