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DEVELOPING A MODEL SYSTEM FOR ASSESSING THE EFFECTS OF CONVERSION TO SUSTAINABLE AGRICULTURAL PRACTICES IN A SENSITIVE ESTUARINE WATERSHED, ELKHORN SLOUGH, CALIFORNIA

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ABSTRACT

The Elkhorn Slough is located in the Central Monterey Bay area and is considered one of the most ecologically important estuarine systems in California. Over 1400 acres of the slough are in the National Estuarine Research Reserve System. Non-point source pollutants from farm use of chemical fertilizers and pesticides have been identified as a primary cause of water quality degradation in Elkhorn Slough. Erosion of sediments from cultivated slopes surrounding the slough is likewise a serious problem. In spite of this, there have been few studies addressing the relationship between cultivation practices, inputs to the estuary, and ecological effects of these inputs.

This paper reports preliminary, first-year results of a long term project to examine the effects of agricultural production on an adjacent wetland on a 137 acre ranch in the Elkhorn Slough. In two to four years, the organizations involved in the project intend to begin converting management of the land to more sustainable agricultural practices. Portions of the land will be restored to native habitat, while others will be used for implementing and testing sustainable agricultural practices. On the upland portions of the ranch we have documented land-use history and current management practices and inputs, and we have soil characteristics, movement of sediment and runoff water, leaching of nutrients in soil water, and deposition of sediment and nutrients. In the wetlands portion we mapped out marsh vegetation, assessed macroalgae and invertebrate populations, censused birds, and measured marsh water quality. These parameters will be used in the future to assess what changes occur after conversion of the land. This information will be used as an ecological baseline for designing low-input management systems in the future. An additional goal is working with the Elkhorn Slough National Estuarine Research Reserve and the Elkhorn Slough Foundation to develop a strong partnership between the public and private sectors for addressing watershed issues in the slough.

key words wetlands, erosion, sustainable agriculture, ecology, non-point source pollution, sediment, nitrogen

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INTRODUCTION

The Elkhorn Slough is located in the Central Monterey Bay area (Figure 1) and feeds into the head of the Monterey Submarine Canyon in the newly designated Monterey Bay National Marine Sanctuary. The slough is described by the Department of Fish and Game as "one of the most ecologically important estuarine systems in California" (ABA Consultants, 1988). Elkhorn Slough was designated as an environmentally sensitive habitat in the 1976 California Coastal Plan and over 1400 acres of the slough are in the National Estuarine Research Reserve System.

Water quality in the Elkhorn Slough is heavily influenced by both past and present human activities on the land surrounding the slough. This is especially true of agriculture. Non-point source (NPS) pollutants from farm use of chemical fertilizers and pesticides have been identified as a primary cause of water quality degradation in the Elkhorn Slough. Agriculture is one of the main land uses in the slough watershed with about 26% of the local watershed in agricultural production. Of this land, strawberry production accounts for the greatest area under production (Soil Conservation Service, 1984). Field testing and monitoring of alternative farming practices that decrease dependence on synthetic chemical inputs has been extremely limited. What is needed is the development of farming systems that are economically as well as environmentally sustainable.

The Azevedo Ranch site (Figure 2) encompasses 137 acres, approximately 120 of which are currently in strawberry cultivation. The land is jointly owned by The Nature Conservancy and the Monterey County Agricultural and Historical Land Conservancy, whose stated goal is to keep this property in open space in perpetuity. The property (Figure 3) will be divided into a wetlands buffer zone surrounding three "pocket marshes," and an upland agricultural zone. The marshes are separated from the main channel of the slough by a railroad berm. They are connected to tidal water by culverts through the berm, making each independent. The buffer zone, which is currently in cultivation, will be restored with native vegetative cover including native bunch grasses, Coast Live Oaks, and maritime chaparral. The upper agricultural zone will encompass 83 acres and will eventually be converted to low-input sustainable agriculture. The management of the agricultural lands will be guided by an advisory committee, but the overall goal is to develop models, for the greater watershed, of ecologically and economically sustainable methods for crop production.

An additional research site is located on the Elkhorn Slough National Estuarine Research Reserve. The site includes a small pond drained by sloping uplands. It is very similar to the three drainages on the Azevedo ranch, with the important exception that it has never been cultivated. Although the pond is larger than any of the Azevedo marshes and is subject to greater flushing, it provides the

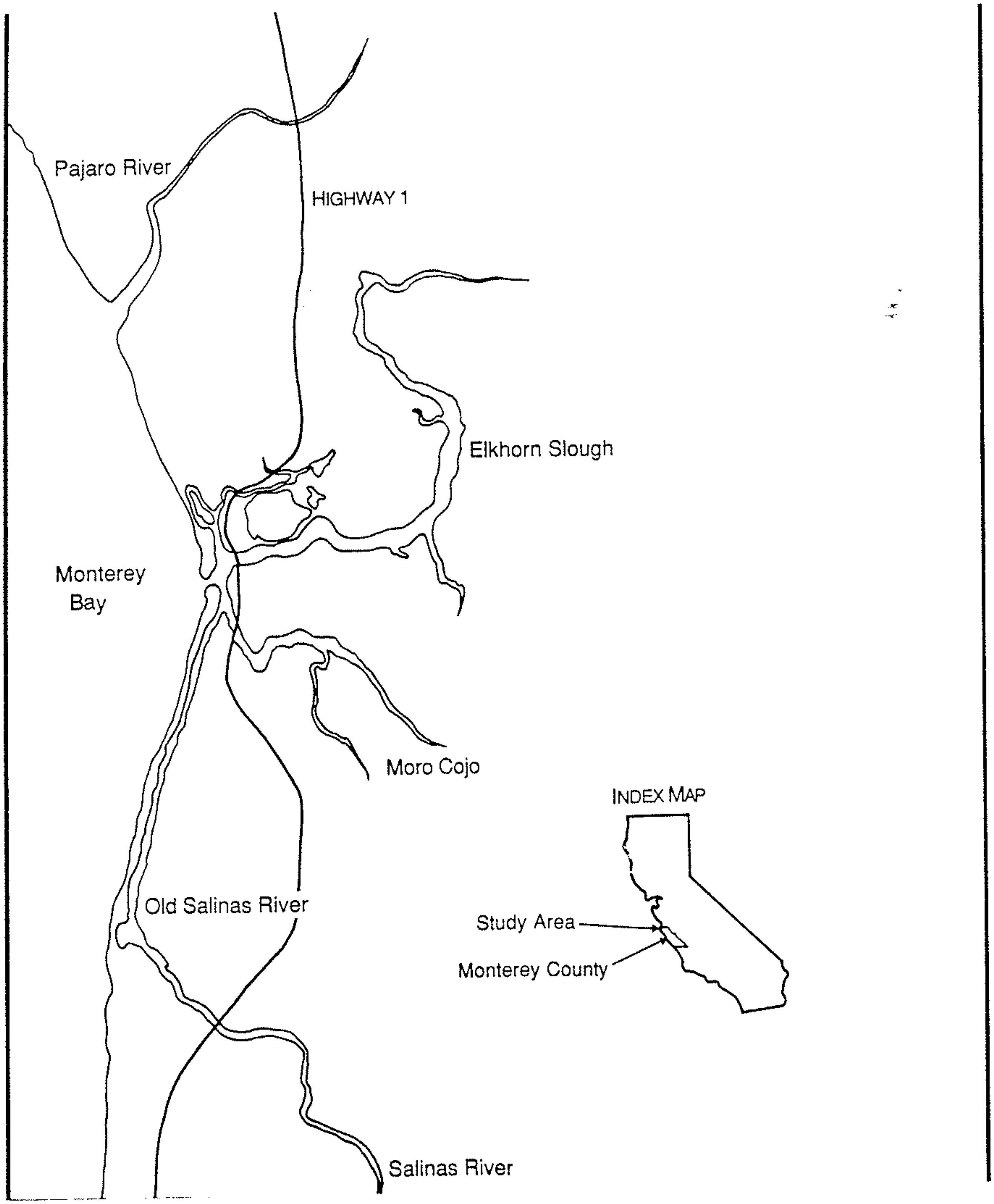


Figure 1. Location of Elkhorn SLough and adjacent wetlands.

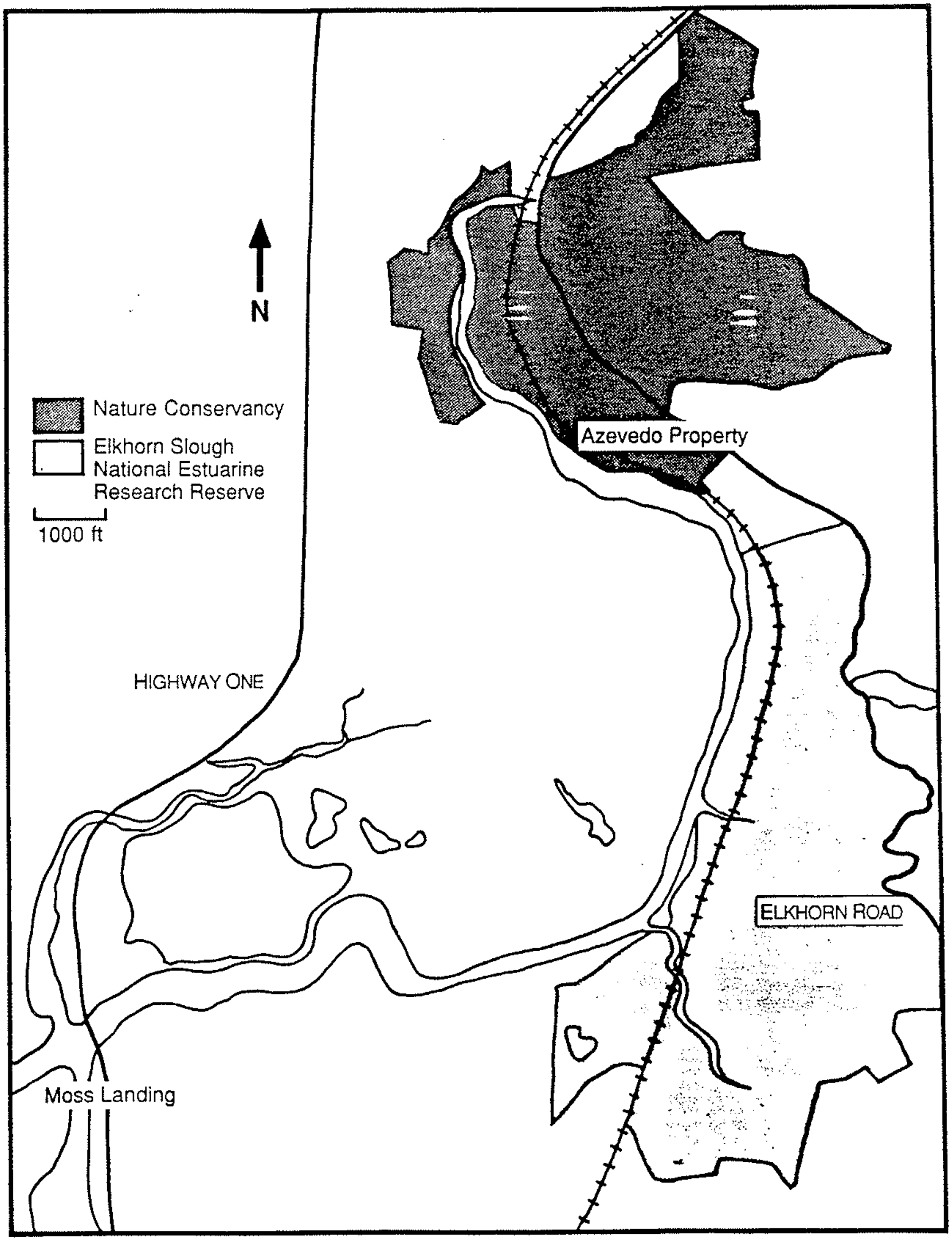


Figure 2. Map of Elkhorn Slough showing Azevedo property, Elkhorn Slough National Estuarine Research Reserve, and The Nature Conservancy holdings.

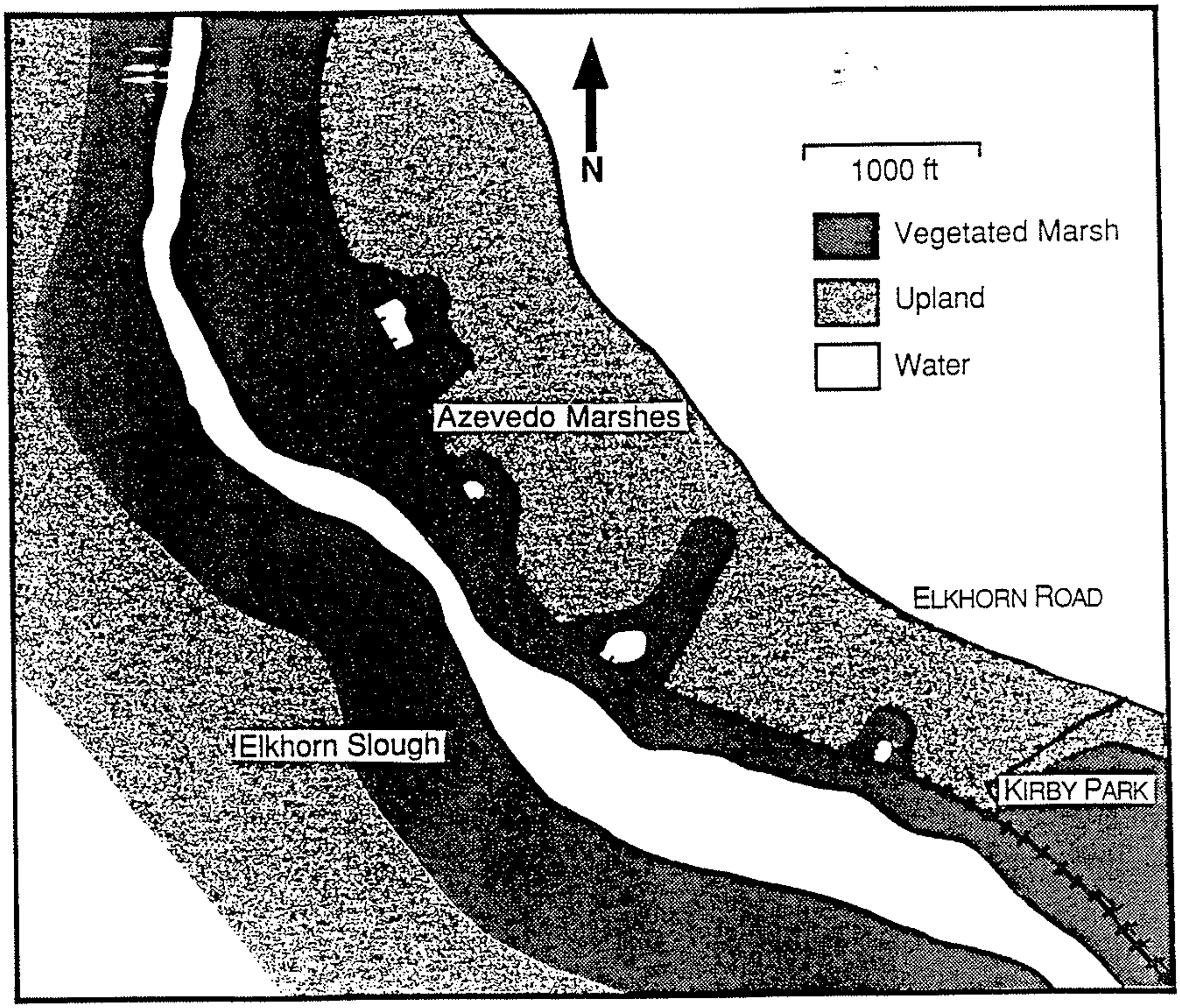


Figure 3. Detail of Azevedo property, showing pocket marshes.

opportunity to obtain background data on soils, sediments, and biota in the absence of agricultural disturbances.

During the first two years of the study we established critical measurements, protocols, and characterizations of these watersheds under standard cultivation practices. These data will serve as a baseline for comparison once the property is converted to low-input sustainable agricultural management and habitat restoration is completed in the wetland buffer. Conversion and restoration will occur in 2 to 4 years, once the land has been fully paid for. The project is guided by a Technical Advisory Committee which meets monthly.

Although this report marks the end of Project Number UCAL-WRC-W-801, the project is ongoing. Our long term goal is the investigation of linkages between different farm management practices and health of the adjacent slough, as monitored by sedimentation, input of anthropogenic chemicals, water quality, and the response of wetlands flora and fauna. In the future, we will implement and test alternative farming practices that lessen or eliminate the dependence on synthetic chemical inputs. We will also be able to assess the influence of border zones at the land-water margin as buffers between agricultural uplands and estuarine receiving waters. The lead author recently submitted a proposal to the UC Water Resources Center entitled, "Evaluating Vegetated Buffer Zones Between Commercial Strawberry Fields and the Elkhorn Slough Estuary."

Background

Monterey County is one of California's leading agricultural production areas. The marine-mediated climate in this region allows year-round production of a variety of fruit and vegetable crops, including lettuce, celery, broccoli, Brussels sprouts, artichokes, grapes, and strawberries. Strawberry farming is the major land-use practice effecting the Elkhorn Slough. Strawberry production in Monterey County in 1990 exceeded $181 million in gross production making strawberries the second most valuable crop grown in the region. Over three-quarters of this strawberry production occurs within the Elkhorn Slough watershed, on numerous production units averaging less than 40 acres in size, with many smaller, hillside operations of 10 acres or less. Conventional strawberry cropping is one of the most input-intensive production systems in California agriculture. Annual production costs may exceed $20,000 per acre, and considerable risk is taken due to potential variation in climatic and market factors. However, average gross income exceeds $26,000 per acre, and potential per acre profits for fresh market strawberries greatly exceed those of most other perennial crops grown in the area (Welch *et al.*, 1985). It is clear that strawberry production will be a major land-use in the watershed for some time to come. Identifying both the effects of current cultivation practices on the estuary, and practical ways of reducing inputs to the estuary from cultivated land are important goals for the long-term management of the area.

The region has a Mediterranean climate, characterized by mild, wet winters and cool, dry summers with frequent fog. Mean annual precipitation of 76 cm falls mainly between November and April, and mean monthly temperature ranges from about 8 to 18°C.

Erosion

Erosion of soils from strawberry fields is a major mechanism of transport of agricultural chemical residues into slough surface waters. About 75% of the anthropogenic erosion in the Elkhorn Slough watershed is attributed to strawberry production (128,900 tons/year). While a background rate of erosion for most soils is about 1 ton/acre/year, erosion from these strawberry lands ranges from 8 to 145 tons/acre/year, with the highest rates occurring during heavy rains. Costs of erosion and sediment damages are estimated at over $3 million/year, or $791/acre of strawberry land (Soil Conservation Service, 1984). These estimates do not include any factor for environmental damage to the estuary.

The Soil Conservation Service has recommended a variety of management practices designed specifically to address the problem of erosion from strawberry fields in the Elkhorn Slough watershed (Soil Conservation Service, 1984). Unfortunately, many local growers have not yet implemented these practices. Farmers need to know that they won't suffer economically to implement these measures. A demonstration project can test and report on these and other practices to convince reluctant growers that these techniques work. A recent report on farming practices in the Elkhorn Slough watershed showed that growing practices are strongly correlated with grower ethnicity, and that outreach programs must be targeted for specific underserved groups to be effective (Mountjoy, 1993).

Fertilizers

Growers apply synthetically and naturally compounded forms of nitrogen, potassium, phosphorous, and other plant nutrients to soils. Some portion of these minerals is taken up by the crop, some is retained in the soil, and some is subject to export from the system through downward leaching, surface runoff, or erosion. Nitrogen, in the form of nitrate, is especially prone to leaching and is a significant problem in groundwater in the Elkhorn Slough watershed. A significant percentage of wells in the Elkhorn Slough watershed are contaminated with unacceptable levels of nitrate (ABA Consultants, 1988). High levels of nitrate in groundwater are associated with agricultural activities, especially strawberry production around the slough. Other nutrients, such as phosphorous, tend to associate closely with soil colloids, and are prone to transport on eroded sediments.

There are little or no data to address the potential of fertilizer nutrients being transported into the slough. Research by Broenkow and Smith (1972) suggests that tidal water may be the major source of nitrogen in the slough, as local nitrogen concentrations seem to be controlled mainly by the tide. Strong pulses of nitrogen enter the slough after winter rains, but they are soon flushed by the tide. Past measurements have shown low nitrate (Jagger, 1981) and phosphate (Smith, 1973) levels in slough water, though no new measurements of slough channel surface water have been made since 1980.

MATERIALS AND METHODS

Land-Use History

Historical archives of aerial photographs beginning in 1931 were examined to assess changes in land use on the ranch. Two of the recent photographs, high resolution infrared aerials from 1987 and 1992, were enlarged and used to create base maps of the ranch and the marsh ponds.

Current Management Practices

Interviews with the farmers and other production personnel have provided information on growing practices used on these sites. Additional information on growing practices was provided by members of the Technical Advisory Committee that oversees the Azevedo property. Mapping of the Azevedo property, including identification of the ten foot contour line, was conducted by a surveyor under contract to the Monterey County Agricultural and Historical Land Conservancy.

General Site Characteristics

Site Description

A site description was made by observing soil characteristics in soil pits and during field preparation, and by consulting the Monterey County soil survey (USDA - SCS, 1978). Weather data, including temperature, irradiation, and rainfall, was collected from an established weather station located at the Elkhorn Slough National Estuarine Research Reserve. Only rainfall data is reported here.

Soil Transects

Because the uplands portions of the Azevedo property act as drainages corresponding to the three pocket marshes, we call the fields South Field, Central Field, and North Field. We collected baseline soil samples from the South Field and North Field in November 1992. Rainy weather and other delays prevented us from collecting soil samples from the Central Field until June, 1993. In November, our samples were collected along four transects in each field running from the upper slope of the cropped uplands, down to the center of each marsh. The transects were each divided into crop soil, border soil, and marsh sediment samples, the border zone being the area between the edge of the marsh and the edge of the strawberry field. Samples consisted of 30 pooled soil or sediment cores taken along the length of each transect section. Soils were sampled to 15 cm, sediments to 10 to 15 cm depth, using a 2.5 cm diameter corer. Crop soil samples were collected from within the strawberry row, mid-point between two plants. Soils for nutrient analysis were pooled in a plastic bucket, mixed, and transferred to paper bags for drying. Subsamples were stored in sealed plastic bags for gravimetric moisture analysis.

In November 1993 we sampled soils from all three fields for nutrient analysis. The upland portions of the transect were divided somewhat differently, based on advice from the Technical Advisory Committee on what upland areas are likely to stay in production, and what areas will be restored to native vegetation as buffer zones between the agriculture and the wetlands.

Soil organic matter content was determined by ashing at 450^{o}C for 16 hours (Nelson and Sommers, 1982). Soil pH was determined on a 1:1 soil:water slurry using a glass electrode and pH meter (McLean, 1982). Soil macro- and micro-nutrient content and cation exchange capacity was determined by the U.C. Division of Agriculture and Natural Resources (DANR) Analytical Lab in Davis, CA on samples oven dried at 105^{o}C to constant weight, then ground to pass a 2 mm sieve before shipping.

Soil nitrate and ammonium, nitrification potential, and soil microbial biomass were studied on a portion of the Central Field by a group of four E.S. Board intern students. Results are not included in this report.

Infiltration

Water infiltration rates measured in the field using a single-cylinder infiltrometer (Bouwer, 1986). A transect of 8 cylinders placed every 10 rows from the bottom to the top of the Central Field was sampled in August, 1992. A water depth of two to six inches was maintained in the cylinders during the measurements. Time for 1 cm of water to infiltrate was measured one hour and three hours after adding water. Preliminary measurements on these soils showed that infiltration rates reached a relatively constant rate one hour after adding water.

Nutrient Dynamics at the Uplands/Wetlands Interface

During the course of this study, we have come to see the uplands/wetlands interface as the place where we need to focus our research and monitoring efforts. This boundary between terrestrial and aquatic is the gate through which all interchanges between the two systems move.

Deposited Sediments

We were unable to install sediment ponds for collecting run-off during the first rainy season. Rainfall was above average during the 1992-1993 winter, and we noted that sediments were deposited in fans at the base of each road and path that ran downhill towards the marshes. As a rough first-estimate of sediment transport from these fields, we estimated the volume of sediment fans deposited around the Central Marsh. Surface area of sediment fans was calculated from the measured length of the three sides, using Heron's Formula, and surface area multiplied by average depth of sediment to give estimated volume.

During the second winter we collected soil cores from deposited sediment fans at the margins of the marsh. Samples were collected 21 Dec 93, after a rain, 21 Jan 94, after a period of no rain and several irrigations, 1 Feb and 23 Feb 94 after rain events. Cores were collected from 0 to 8 inch depth, with five cores pooled per sample. These samples were analyzed for nitrate, ammonium, labile-phosphorous, and water soluble-phosphorous content.

Runoff

In the second winter we installed one sediment pond, designed and constructed with assistance from the Soil Conservation Service. The sediment pond drains a hillside of about 4.2 acres that was planted with strawberries in November 1993. A data logger and pressure transducer were used to monitor height of water flowing over a V-notch weir, and volume of run-off was calculated. An ISCO water sampler was used to collect run-off samples during rainfall events. Water samples were analyzed for sediment, nitrate, ammonium, and phosphorous content.

Sub-Surface Flow

Soil water and nitrate movement through the surface soil were studied using porous cup lysimeters. In the first year, twelve lysimeters were installed in the Central Field and six in the grassland control site at the Elkhorn Slough NERR. Lysimeters were place in pairs at one foot and two foot depths to sample the root zone and below the principal root zone. In the crop field, three pairs were placed low on the slope, and three pairs higher up on the slope. In the grassland all three pairs were placed at a similar slope position.

First year results showed a great deal of variation in nitrate-nitrogen levels in strawberry bed soil-water. It was not possible to determine the direction of movement or any strong response to seasonality. Furthermore, we found that surface runoff was extremely significant in nutrient loading into the pocket marshes. We also became interested in focusing on the vegetated borders between the pocket marshes and the cropland as a potential means to reduce the soil-water nutrient content before it entered the marshes. Therefore, in year two, the lysimeters were moved to the uplands/wetlands interface, at the border of the cropped area. Stations consisting of four lysimeters placed at the two foot depth, one meter apart from one another, were placed at four locations in the field. Two stations were placed at the bottom of roadways, where surface flow is concentrated, and two stations were placed where there were no roads and surface flow was minimized.

During sampling times, vacuums were drawn using a hand pump and left overnight. Water samples were collected the next day and nitrate-N levels measured on the same day in the lab using a selective nitrate ion probe. Subsamples were frozen and later analyzed for nitrate-N using a spectrophotometer. (Keeney and Nelson, 1982). Samples were collected approximately monthly from January to June 1993, with a final sample in August. During 1994, samples were collected twice-monthly, from January to April. These 1994 samples were also analyzed for ammonium-nitrogen and phosphorous content. In 1993, grassland soils dried up by mid-June so no samples could be collected. Grassland samples were not collected in 1994.

Wetlands

The pocket marshes on the Azevedo property are separated from the slough by a railway dike (Figure 3), and water exchanges between the slough and the pocket marshes through culverts under the dike. We call the marshes South Marsh, Central Marsh, and North Marsh. The heights of the culverts varies and there is a gradient of flushing and size with the North Marsh being the largest and best flushed and the South Marsh being small and having little if any connection to the tidal waters. The Central Marsh is intermediate in size and flushing with some input from a perched freshwater pond at the upland end of the marsh. The pocket marshes were added as sample sites to a hydrological monitoring program that has been sampling surface water at 21 stations around the slough since 1988 (Frost, 1988). Once each month we monitored water temperature, salinity, oxygen, turbidity using a Nephelometer, pH, phosphate, nitrate, and ammonium. Water in the pocket marshes was sampled from the 0.5 m depth without disturbing sediments. Water chemistry analyses were conducted by the Monterey County Water Resources Agency (Monterey County, 1993). Hydrologists (Philip Williams and Associates) developed contour maps of the marshes which established limits of pickleweed and upper limits for the potential restoration of tidal action.

Characterization of the vegetation entailed the use of line intersect, point intersect, and quadrat methods. The sampling was stratified based on vegetation patterns. Vegetation was sampled in the upper mudflat zone, mid-Pickle Weed (*Salicornia virginica*) zone and along a gradient from the marsh to the strawberry fields in summer 1993. In the mudflat zone, five 30 x 30 cm quadrats were randomly positioned along a 10 m transect. In each quadrat, five randomly selected points in a 25 point grid system were chosen and the vegetation beneath them was identified. Two subsites were sampled in the North Marsh while only one site was sampled in each of the other marshes. In the Pickle weed zone, five transects 10 m long were laid end to end through the middle of the zone. At five random points along each transect, a pin was lowered and, at the point of first contact, the species and its height were recorded. Furthermore, 10 line transects were located in both the central and South Marsh along a gradient 20 meters in length from the *Salicornia virginica* vegetation to the strawberry fields.

Sampling stations for infaunal invertebrates were established in each of the pocket marshes. Three stations were sampled in the North Marsh, two in the Central Marsh and one in the South Marsh. Each station was sampled with five replicate cores randomly located on the bottom within a radius of three meters. Samples were taken in October, 1992 and July, 1993. The Reserve control pond was sampled within six weeks of the Azevedo marshes.

Infaunal samples were taken using cores 8.5 cm in diameter. Sediment was collected to a depth of 10 cm. Cores were screened over 0.5 mm mesh screens and the residue preserved in 10% formalin. Samples were washed and transferred to alcohol. Samples were sorted under dissecting microscopes and identified to the lowest possible taxon. Specimens are archived at the National Estuarine Research Reserve.

Birds using the three pocket marshes were censused on 19 high and 21 low tides between November 1992 and March 1993 (Neuman and Hickey, 1993). During one hour observation periods, all waterbirds present were counted using binoculars and a 10x spotting scope. Birds were observed from the railroad berm at five to eight feet above marsh level and 10 to 100 meters distant. Detailed results are reported in a senior thesis by Neuman and Hickey.

DISCUSSION OF RESULTS

Land-Use History

Over the past several decades, agricultural land-use in the Elkhorn Slough watershed has undergone a transition from orchards and grazing lands for dairy cattle, to row crops, especially strawberry production. Aerial photos of the Azevedo Ranch over this period show a similar trend. The presence of fences across the marshes indicates that they were drained in the past to increase grazing area on the property. Beginning in the 1960's, increasing portions of the land have been cultivated and planted with strawberries, starting with the more level terraces, and gradually encroaching on to the steeper slopes and down to the edges of the marshes. A series of drought years from 1988 to 1992 have allowed land to be cultivated that previously was under water. Heavier rainfall during the 1992-1993 winter caused flooding and crop loss in some areas bordering the marshes, and in seep areas that had been dry for several years.

Historically, the slough watershed was dominated by woodlands of Coast Live Oak, mixed with areas of Oak-brush and Oak-grassland. Riparian corridors supported sycamore, alder, box elder, and cottonwood. Hill tops with thin soils support maritime chaparral communities dominated by manzanita. Native perennial grasses throughout the watershed have largely been replaced by annual exotic species. The amount of Oak woodland has decreased over the centuries due to burning by native Americans, and cutting and clearing by Spanish, Mexican, and American settlers.

Current Management Practices

Although strawberries are a perennial plant, they are treated as an annual in most coastal California strawberry growing areas. Because of the marginal nature of Elkhorn Slough soils for farming, strawberry culture in the region is generally done on a two-year cycle in order to avoid the expense of replanting every year. Field preparation begins in September when irrigation systems are removed and fields are ripped and chiseled in preparation for whole-field fumigation with a mix of methyl-bromide and chloropicrin. Fumigation destroys soil pathogens, weed seeds, and most soil biota. After fumigation, beds and furrows are formed and planting in raised beds (using transplants from higher altitude sites in northern California) begins in mid-October or November. Varieties used were Selva and Seascape. Drip irrigation systems are installed and plants are irrigated as necessary. Harvest begins in March/April and continues until fall. Plants left in the ground for a second harvest season yield a berry that is smaller and softer, and these fruits are generally not fresh-marketed but used for processing.

The Azevedo Ranch is divided into two agricultural leases. Mr. C. directly leases the South Field, and Mr. S. subleases the central and North Fields from a shipping firm (Bay Fruit) which also functions as a lender. Both leases were planted in fall 1991, including fumigation, and again in fall 1993. Mr. C. leases 30 acres and has leased that plot for 7 years. Mr. S. farms a total of 64 acres, with 10 acres planted with cv. Seascape, and the remainder in cv. Selva. Mr. S. farms a total of 357 acres of strawberries in the Elkhorn Slough watershed, and this was his first crop on the Azevedo property.

Prior to and during the harvest season, applications of insecticides, miticides, and fungicides are made on a regular basis, in a cycle sometimes called pick-and-spray. Harvest crews work from one end of the field to the other, and sometimes they are still finishing up picking when the spray crew starts its work at the opposite end of the field. Mr. C. utilizes a tractor to apply pesticides, which is more typical of practices in the watershed, while Mr. S. uses farm laborers to apply pesticides by hand using hoses connected to a tank truck.

Plants are fertilized with controlled-release fertilizer applied at plant-out. The analysis of fertilizer applied on the north and Central Fields at plant-out in

1993 was 18% nitrogen (9.7% ammonium-nitrogen, 8.3% nitrate-nitrogen), 8% available phosphorous, and 13% soluble potassium. Mr. S. applies this material by hand to the surface of the beds, down the center, while Mr. C. drills the material into a slot in the center of the beds so that it is buried. In January 1993, Mr. S. applied granular 6-20-20 by hand to the top of the strawberry beds. In January 1994 he applied ammonium sulfate in the same fashion, at the rate of about 80 pounds per acre (21% ammonium-N, 24% sulfur). Both growers apply nitrogen through the drip irrigation system during the summer.

General Site Characteristics

Site Description - Geological Context

The Elkhorn Slough area is extremely active and has been subject to large scale changes over geologic time. Hydrologically, the area may have been a flood plain for one of the largest rivers in Pleistocene California. More recently, the area has been subject to continued changes in land-use patterns and vegetation cover due to human influences.

The Azevedo Ranch lies within the Salinian Composite Terrane, which is bound by the San Andreas Fault to the east and the Sur-Nacimiento Fault Zone to the west. It is unrelated to contiguous terranes, suggesting that it has migrated from its presumed origin 1500 km to the south (Vedder *et al.*, 1983). The basement rocks consist of quartz-diorite-ganodiorite rock which are Precambiam to late Mesozoic.

In the early Pleistocene the lower reaches of Elkhorn Slough and Elkhorn Valley appear to have been part of a large riverine system draining the Santa Clara Valley and/or the California Central Valley (see Schwartz *et al.*, 1986 for a review). In the late-Pleistocene the watershed area for the Elkhorn Valley was tectonically truncated, substantially reducing the volume of water moving through to the ocean and limiting the flushing and scouring of Elkhorn Valley.

During the most recent glaciation event 16,000-18,000 years B.P., a channel over 29 m below present day sea level was cut through the slough. As the earth's temperatures rose and sea-level began to rise, this channel was flooded. The sediments in the slough are characterized by a finer texture size as one approaches the top of the sediment layers from below where non-marine gravels dominate.

During the past 5,000 B.P. until 1946, salt marshes developed along landward margins of the slough. These marshes reduced the energy of the water, allowing further sedimentation and development of marsh vegetation toward the axis of the slough. This is the process by which the Azevedo Ranch pocket marshes were created. Until 1946 the slough was a shallow, quiet-water embayment with restricted tidal action. In 1947 Moss Landing Harbor was built, opening the Elkhorn Slough to direct tidal action. The effect was rapid and dramatic, and today erosion of wetland habitat in the slough continues to be a major concern (ABA Consultants, 1988).

Site Description - Soil Formation

There are three main land formations from which the major soil types have been derived: aeolian or colluvian Aromas Red Sands, wave cut terraces, and alluvial sand, silts, and clays. The mapped soils and their classifications are listed in Table 1. Several soil pits made in the terrace and Central Field suggest much greater diversity in soil types and origins on the Azevedo Ranch. Many seeps have been observed, where ground water surfaces through soil discontinuities or is forced to the surface by impermeable boundaries. Furthermore, a thick clay layer devoid of sands was found on the slopes of the marshes, suggesting lake deposited clays in a time of slower moving water. The discontinuity of the marine terrace sandstone indicates that it has been eroded by water draining from the uplands.

The Alviso series is alluvial consisting of fine texture sizes. The soils have a great deal of organic matter, and unless artificially drained can be almost completely anaerobic below the soil surface. These soils are dominated by wetland plants, *Salicornia virginica* and *Distichlis spicata*. This soil encompasses the pocket marshes and their margins, including the area presently farmed. These are considered to be relatively young soils.

The soil survey map for the Azevedo Ranch shows Arbuckle gravely loam on the terrace between the north and Central Field. The Arbuckle series contains gravel in banded patterns suggesting the edge of a flood plain subject to major high energy events alternating with low energy events. The soils are well drained, formed on terraces in semi-consolidated alluvium derived from igneous and sedimentary rocks. The soils are used for irrigated field crops, pasture, and dryfarmed grain.

The Elkhorn and Elkhorn variant series are among the oldest series in the entire slough. They are derived from the Aromas Red Sands and have a well developed argillic horizon. The soils are on marine terraces and dune-like hills, underlain by weakly consolidated sandy sediments or ferruginous sandstone. Permeability is moderately slow, although the Elkhorn Variant is slow. The argillic horizon has a low porosity, thus water tends to flow laterally in contact with this horizon. The soils are used for Brussels sprouts, strawberries, artichokes, broccoli, annual pasture, hay, or rangeland.

The Arnold series is also considered one of the older soils in the slough. It is formed on hill and uplands in old marine sand dunes or in material weathered from soft sandstone. These soils are somewhat excessively drained. There is no argillic horizon. They are most often used for range, wildlife habitat and watershed, with some orchard, row crops, and Christmas trees.

Table 1. Soil series and classifications for the Azevedo Ranch, Elkhorn Slough, CA.

series	*description*
• Alviso silty clay	Fine, mixed, nonacid, isomesic Tropic Fluvaquents
• Arbuckle gravely loam	Fine-loamy mixed, thermic Typic Haploxeralfs
• Arnold loamy sand	Mixed, thermic, Typic Xeropsamments
• Elkhorn fine sandy loam	Fine-loamy, mixed, thermic Pachic Argixerolls
• Elkhorn fine sandy loam, thin surface variant	Fine-loamy, mixed, thermic Typic Argixerolls
• Santa Ynez fine sandy loam	Fine, montmorillonite, thermic Ultic Palexerolls

Santa Ynez fine sandy loam on the central and South Fields is typically found on relatively distinct although hilly and dissected terraces with minimal tectonic distortion. These soils are well developed and have a mollic epipedon and high base saturation. This soil is formed on terraces in alluvium derived from sandstone and granite, although the sources vary, thus it is difficult to attribute any direct relationship between terrace deposits and soil formation. The soils are moderately well drained and runoff is categorized as slow to medium. There is an argillic horizon between 18-43 inches, with clay films and reduced water permeability. The soil descriptions do not note lithic contact within 60 inches; however, we observed lithic contact between 36-48 inches. This soil is often used as grazing lands, dry grain production, and irrigated row crop strawberries.

Soil Transects

Analysis of 1992 soil samples showed higher electrical conductivity and higher sodium levels in the border soils between the crop and the marsh, evidence of salt deposition from either high marsh levels or through irrigation. Calcium was highest in the Central Field and low in the South Field (Figure 4). This may be

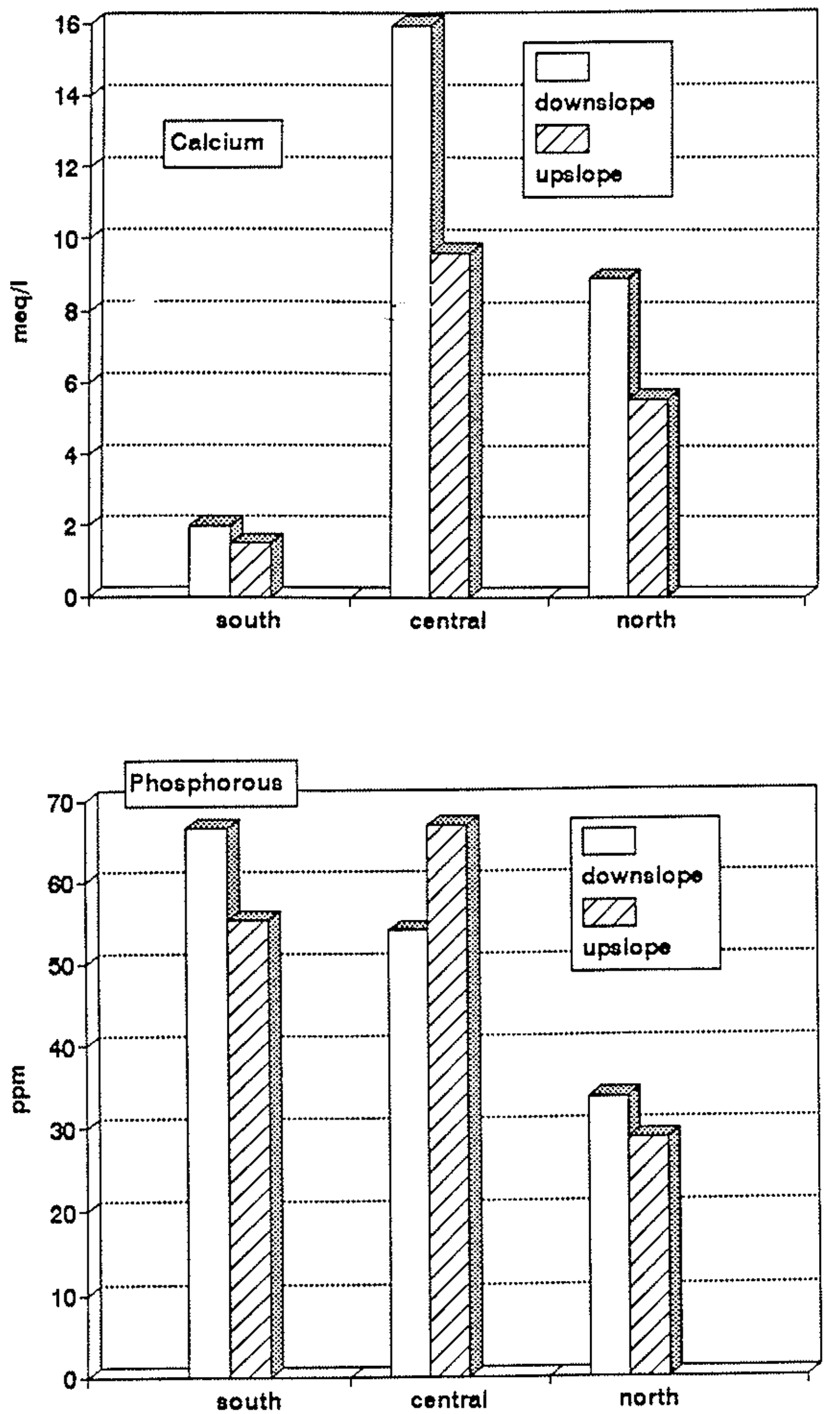


Figure 4. Calcium and phosphorous levels in soils collected in 1992 from Azevedo Ranch, Elkhorn Slough, CA.

related to timing or different fertilizer applications by the two growers. Phosphorous was lower in the North Field (Figure 4).

Soil samples from 1993 again showed higher levels of Na in the border soils, especially from the South Field (Figures 5 and 6). Iron concentration was higher in border soils, relative to crop soils, as was total N (Figure 5). Calcium, magnesium, and CEC levels were also highest in the South Field (Figure 6). Boron levels were elevated in the central and North Fields, both farmed by Mr. S, relative to other sample areas (Figure 6). The data (Table 2) will be used as a baseline from which to make comparisons with future soil characteristics as management practices on the site are altered.

Infiltration

Infiltration rates were highly variable (Figure 7). Sample 6 indicated less than 1 cm of infiltration during the four hours of measurements, so a rate of 7 hours/cm was estimated. The highly variable rates of infiltration in Central Field soils is probably a reflection of variations in the underlying soil profile. This factor will probably over-ride any influence of changing management patterns, so we decided not to pursue the measurement of infiltration rates for this project.

Nutrient Dynamics at the Uplands/Wetlands Interface

Deposited Sediments

We measured seven sediment fans at the base of strawberry roads and paths around the Central Marsh, and estimated they contained 3,745 ft^3 of deposited sediments. The Central Field is approximately 8.8 acres, for an average of 426 ft^3/acre, deposited sediments.

The sediment fans we measured consisted mostly of the heavier sand fraction. Any eroded clays and soil organic matter were not deposited in the fans and were likely carried into the marsh, possibly along with some portion of the heavier sand fraction.

We initiated sampling of deposited sediment fans during winter 1993-1994 as a survey technique to help us gain a better understanding of the contribution of surface run-off to nutrient loading in the marshes. Sediment transport from the strawberry fields occurs whenever there is rain or irrigation, and the amount of sediment carried depends on soil moisture content, time since last rain or irrigation event, rate and total amount of rainfall, time since cultivation, size of berry plants, plus the type and extent of erosion control practices implemented by the growers. While much of the run-off and the finer fractions of suspended sediments ultimately make their way to the marshes, a substantial portion of the coarser sediments are deposited in fans at the bases of field roads along the marsh margins. However, because of the relationships of N and P compounds

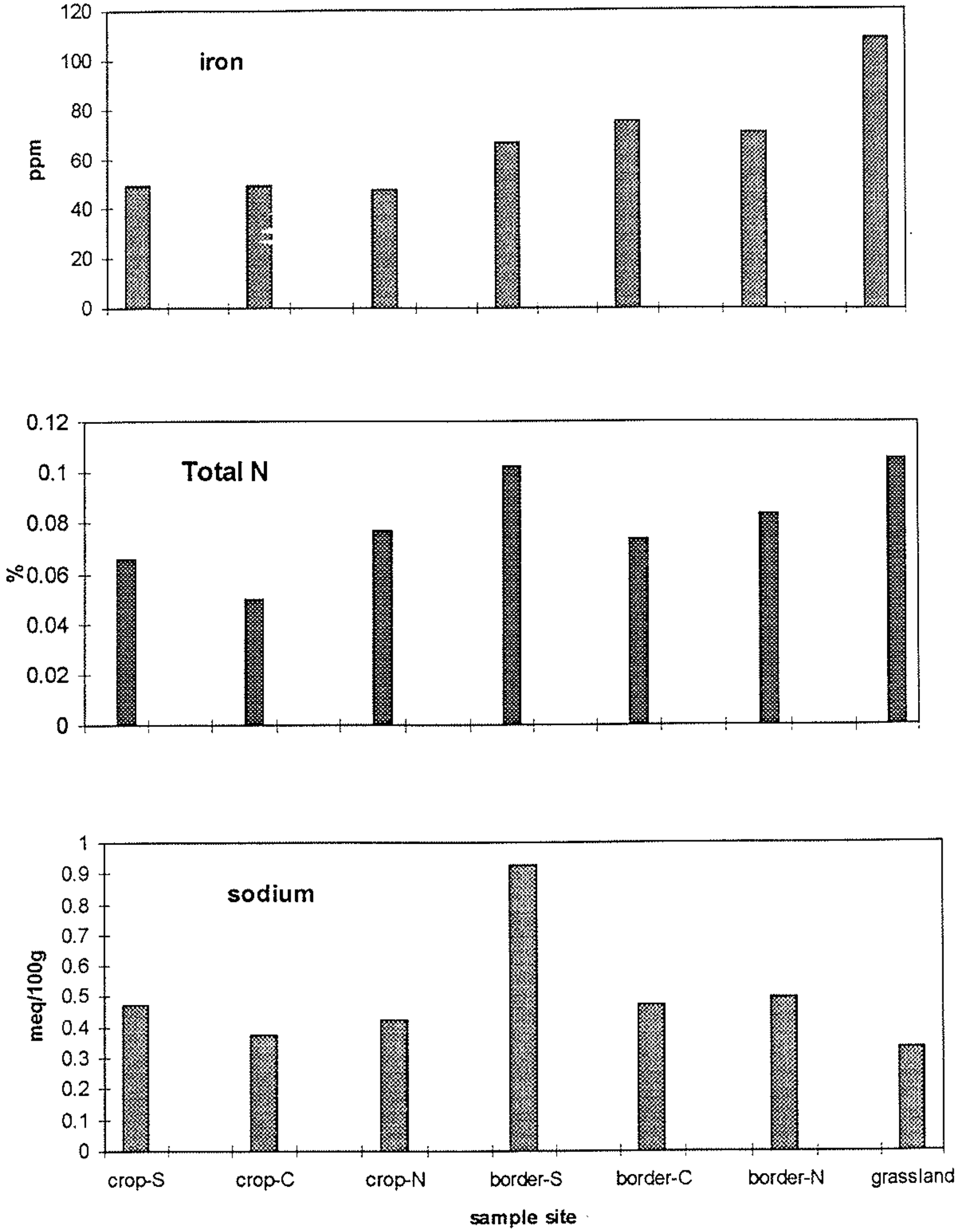
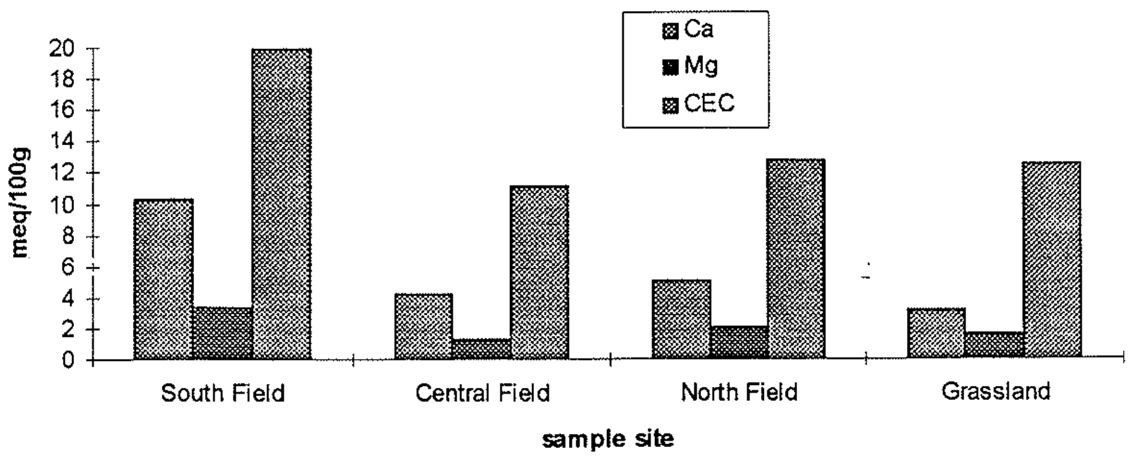


Figure 5. A comparison of soil characteristics in crop vs. border areas. ANOVA revealed significant differences for iron (< 0.0001), sodium (< 0.03), and nitrogen (< 0.003). Samples collected November 1993, N=12, S=South Field, C=Central Field, and N=North Field.

a).



b).

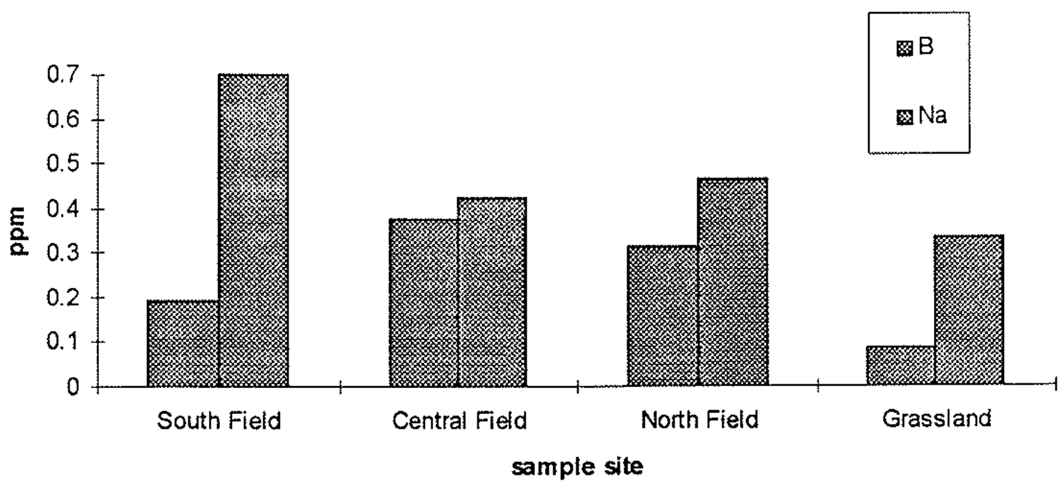


Figure 6. Comparison of soil characteristics based on November 1993 samples; N=8 for Azevedo sites, N=3 for Grassland site. a). Calcium, magnesium, and cation exchange capacity; b). Boron and sodium (Na).

Table 2. Analysis of soil samples collected from Azevedo Ranch, Elkhorn Slough, CA.

Sample Collection Date	Sample Site (mean of 4 transects)	pH	electrical conductivity millimhos/cm	Boron ppm	Nitrogen %	Phosphorous ppm	Bray-P 1 ppm	Potassium meq/100g	Calcium meq/100g	Magnesium meq/100g	Sodium meq/100g	Zinc ppm	Manganese ppm	Iron ppm	Copper ppm	cation exchange capacity meq/100g
Nov-92	crop-south	6.03	1.5	0.2	0.081	48.2		0.25	9.3	2.65	0.7	1.6	35.4	55	1.53	20.1
	crop-north	5.08	2.2	0.2	0.077	23.6		0.18	4	1.03	0.5	1.6	48	88	1.1	10.5
	border-south	6.7	16	0.4	0.1	41.1		0.4	9.4	4.85	4.75	2	30	52	1.33	19.2
	border-north	5.93	7.4	0.4	0.135	26		0.68	6	2.33	1.3	2.1	28.8	73	0.93	14.7
Jun-93	crop-south				0.069	55.3		127	1.5							
	crop-central				0.058	66.8		116	9.6							
	crop-north				0.082	28.5		105	5.6							
	border-south				0.093	66.5		171	2							
	border-central				0.08	54		90.3	16							
	border-north				0.095	33.5		111	8.9							
Nov-93	crop-south	5.98	1	0.2	0.066	57.3	74.5	0.35	8.2	2.63	0.48	1.6	51.4	49	1.5	17
	crop-central	6.13	1.8	0.4	0.05	61.3	126	0.43	3.7	0.95	0.38	1.7	20.8	49	1.13	11
	crop-north	6.53	2.5	0.3	0.077	33.8	48	0.4	4.4	1.75	0.43	1.4	28.4	48	0.78	12
	border-south	6.15	2.1	0.1	0.102	56	94	0.43	12	4.2	0.93	2.1	41.8	66	1.98	22.7
	border-central	6.05	3	0.4	0.074	45.5	80.8	0.33	4.7	1.63	0.48	1.4	22.4	75	0.98	11.2
	border-north	6.5	2.1	0.3	0.084	35.8	49.5	0.45	5.6	2.35	0.5	1.4	29.5	71	0.93	13.7
	grassland	5.2	1	0.1	0.106	11.3	9	0.33	3.1	1.6	0.33	1.2	44.4	108	1.37	12.5

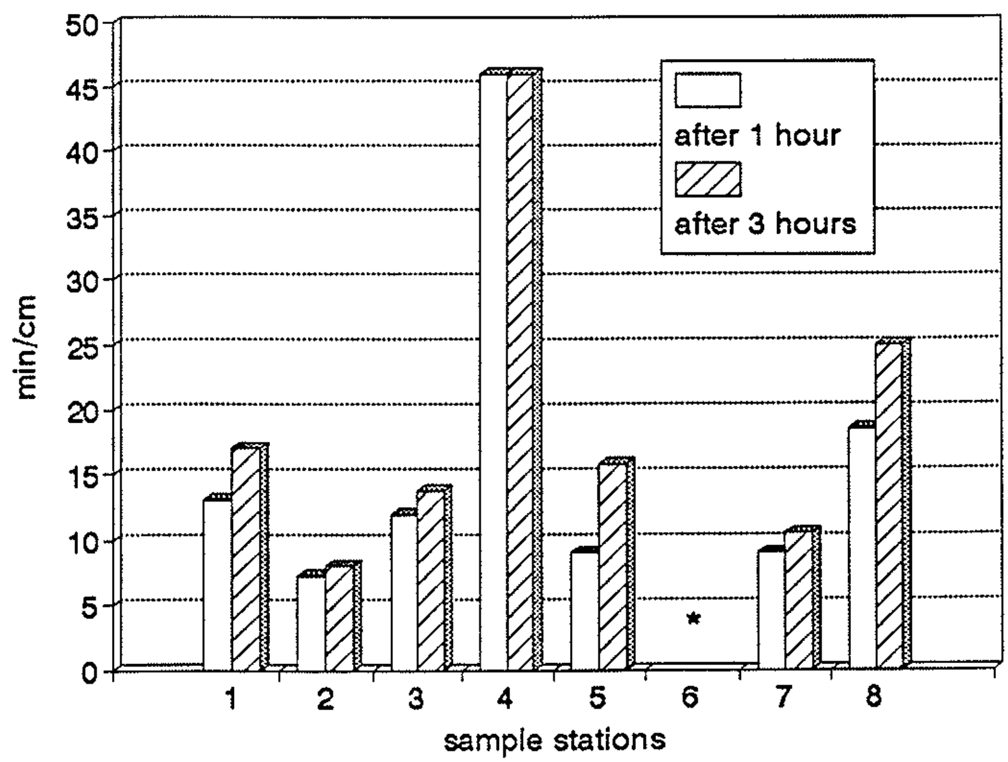


Figure 7. Rates of water infiltration at eight sites on the Central Field, Azevedo Ranch. Infiltration rate for station six was estimated at 7 hrs/cm.

to water and clay particles, our estimates of the nutrient load in deposited sediments are surely very low in relation to the total amounts of these nutrients entering the marshes.

Our results (Figure 8) show that nutrient loading in transported sediments is highest at the beginning of the winter rainy season for NO3, NH4, and labile P. We did not collect samples from sediment fans deposited after the initial rain events of the season (Figure 9). But based on these numbers from slightly later in the season, we hypothesize that nutrient loading is highest during the first rain events after planting.

There are several reasons for this. One is the presence of fertilizer nutrients in freshly cultivated and fumigated soils in the absence of plants with big enough root systems to take up those materials. Establishment of the plants and increased nutrient uptake later in the winter when the later samples were collected may account for decreased levels of N and P in sediments at those times. Enhanced levels of N and P in early winter run-off may also originate from a soil reservoir of fertilizer-applied nutrients applied in years past which are made available by the turning under of the crop and the intense cultivation of the soil prior to fumigation and planting. Lower levels of sediment N and P later in the rainy season may also reflect a net movement of these nutrients into the wetlands.

Runoff

From February to May 1994 there were seven storm events for which we captured complete data sets on runoff volume and nutrient loads (Figures 10 through 13). These storms varied widely in their intensity (Figure 9). Phosphorous loading in runoff was consistently low (<1 ppm) during these events (Figure 14). Nitrate and ammonium levels generally tracked flow rates (Figures 10 through 13), indicating that nutrient loading for these compounds was similar through the course of each storm event. Nitrate concentrations were generally below 10 ppm during the February runoff events, but were greatly elevated later in the season (Figure 14). This may have been caused by nitrate-based fertilizer applications, or perhaps to higher temperatures accelerating mineralization processes.

Sediment loading rates were positively correlated with runoff flow rates (Figure 15; $R^2 = 0.74$, p = 95%). Sediment load either matched the peak of flow during a storm event or closely followed it. When runoff rates were increasing, sediment rates tended to increase at a slightly faster rate, and when runoff rates were decreasing, sediment load tended to decrease more quickly.

Sub-Surface Flow

Lysimeter data for the first year are organized in three graphs (Figure 16) representing 3 stations at a lower elevation on the Central Field, 3 stations higher on the slope, and 3 stations at the grassland site. Each station consisted

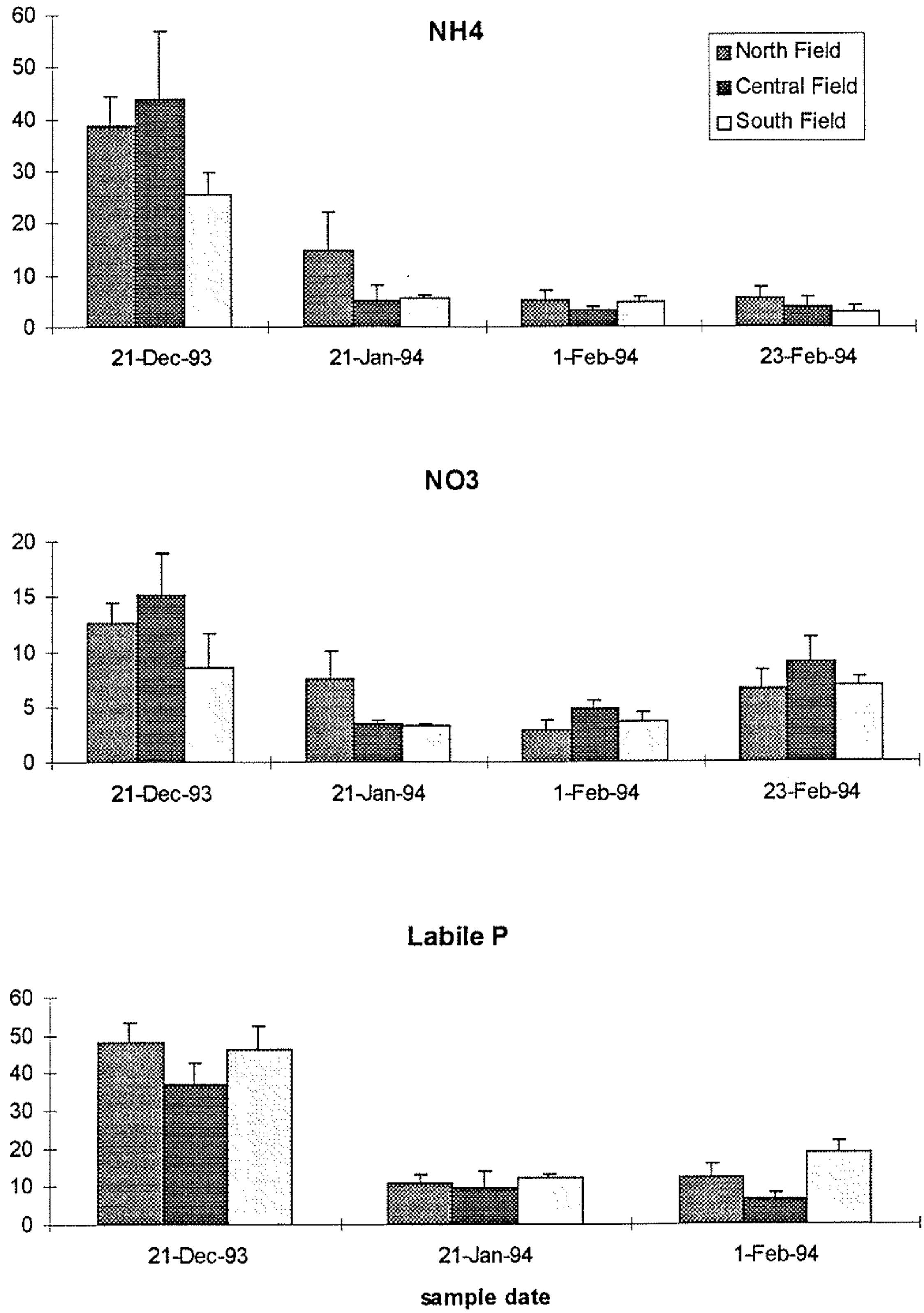


Figure 8. Nutrient concentrations in sediments deposited at the base of hillsides during the 1993-1994 winter rainy season.

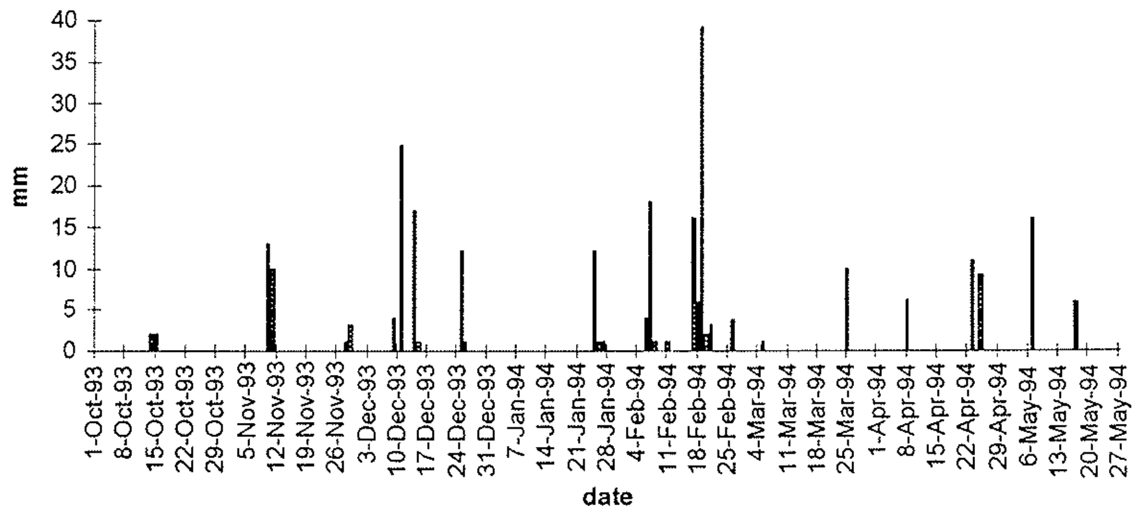


Figure 9. Daily rainfall totals for the 1993-1994 rainy season. Data collected at the Elkhorn Slough National Estuarine Research Reserve

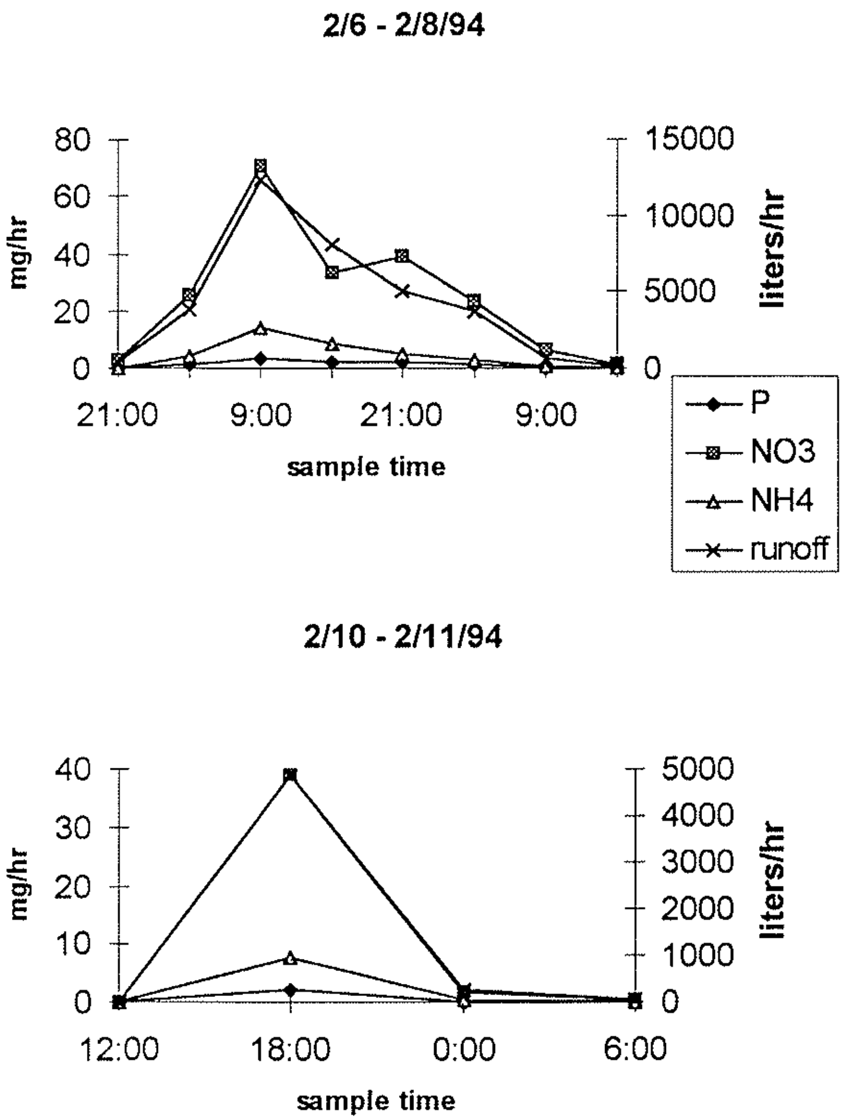
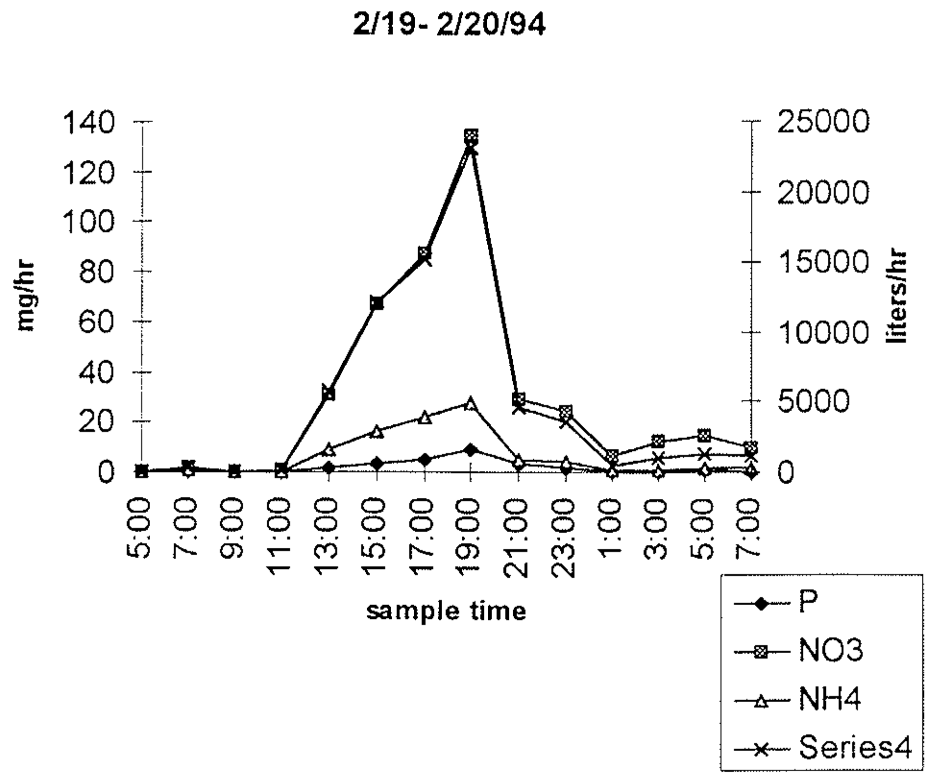


Figure 10. Runoff and nutrient loading from two storms during February 1994. Data measured from a sediment basin draining a 4.2 acre hillside planted with strawberries in November 1993.



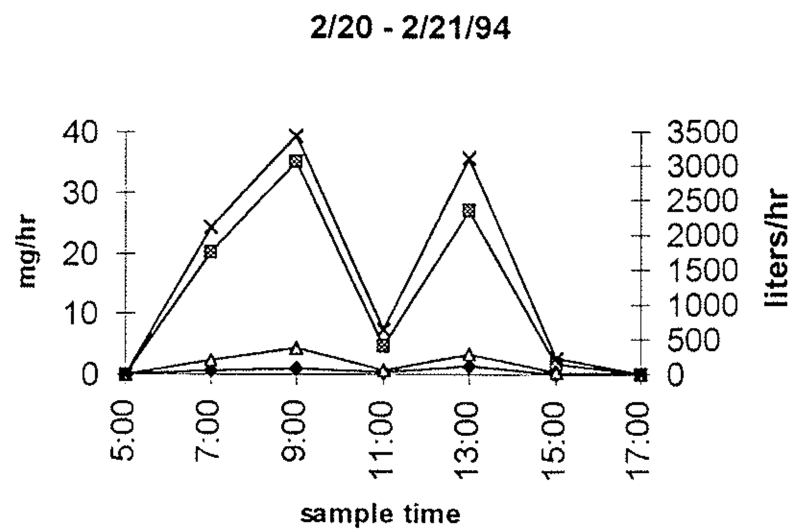


Figure 11. Runoff and nutrient loading from two storms during February 1994. Data measured from a sediment basin draining a 4.2 acre hillside planted with strawberries in November 1993.

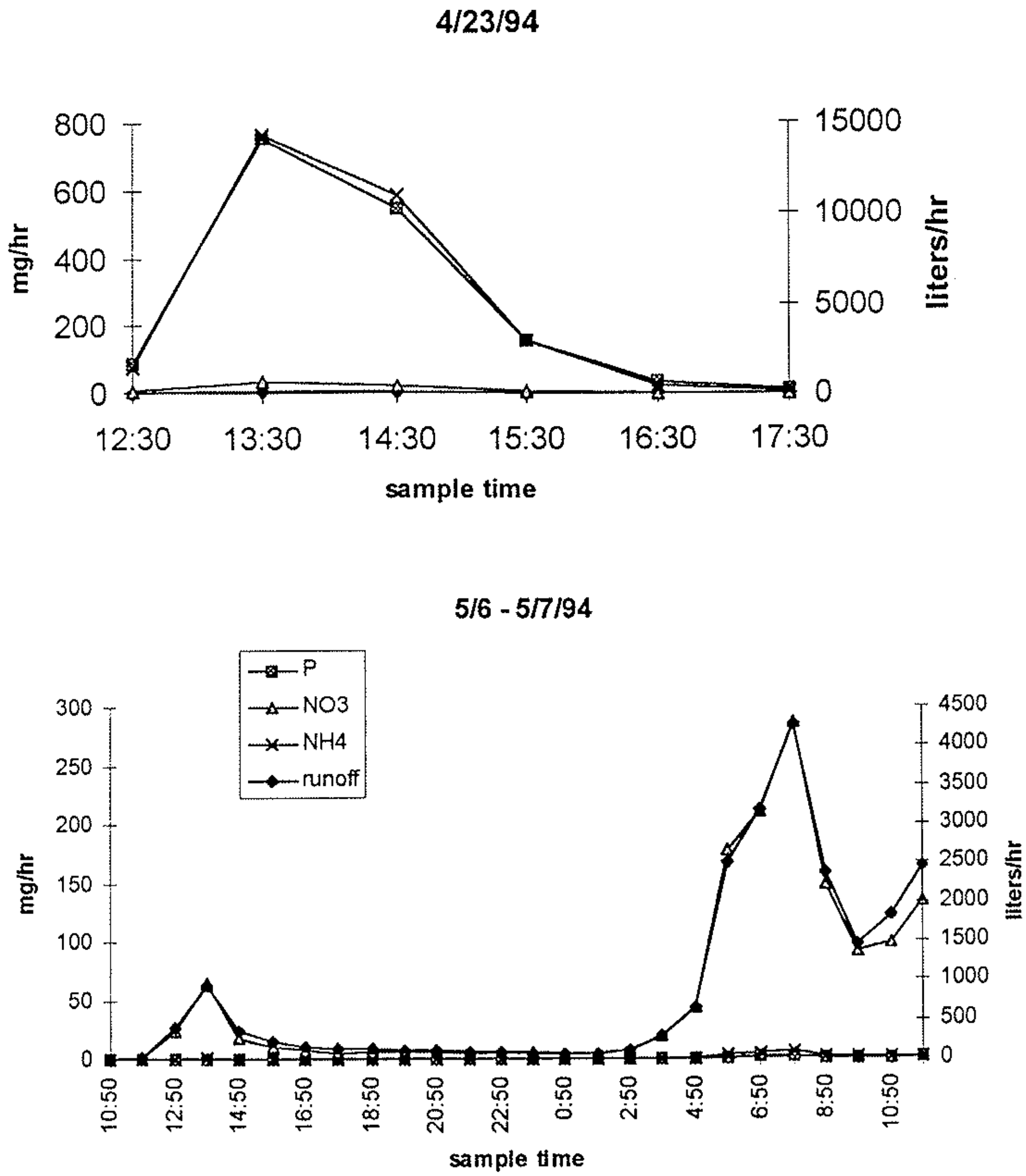


Figure 12. Runoff and nutrient loading from two storms during April-May 1994. Data measured from a sediment basin draining a 4.2 acre hillside planted with strawberries in November 1993.

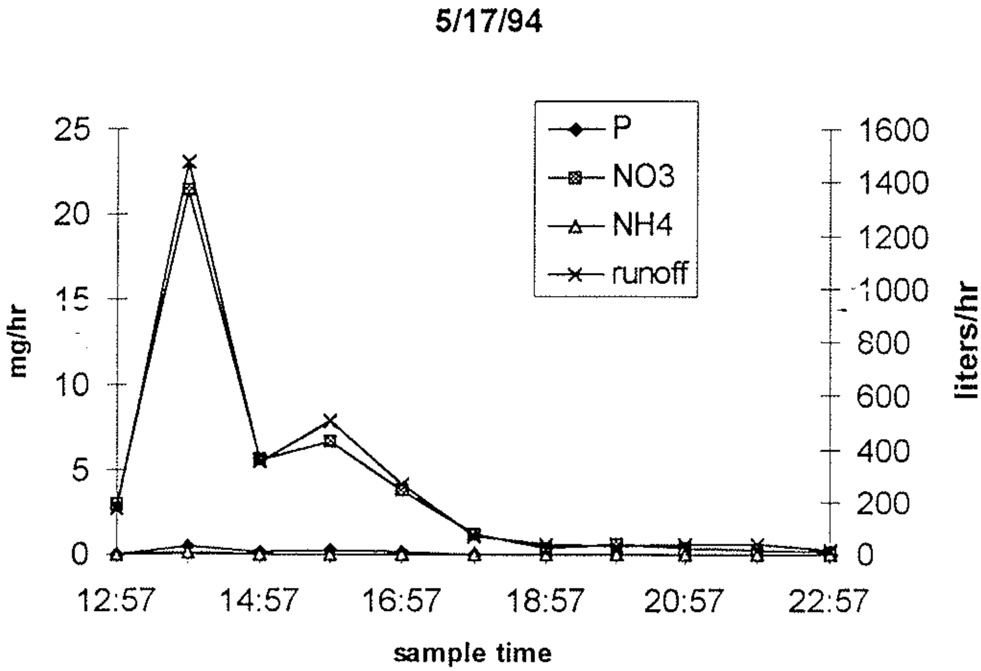


Figure 13. Runoff and nutrient loading from a storm on 17 May 1994. Data measured from a sediment basin draining a 4.2 acre hillside planted with strawberries in November 1993.

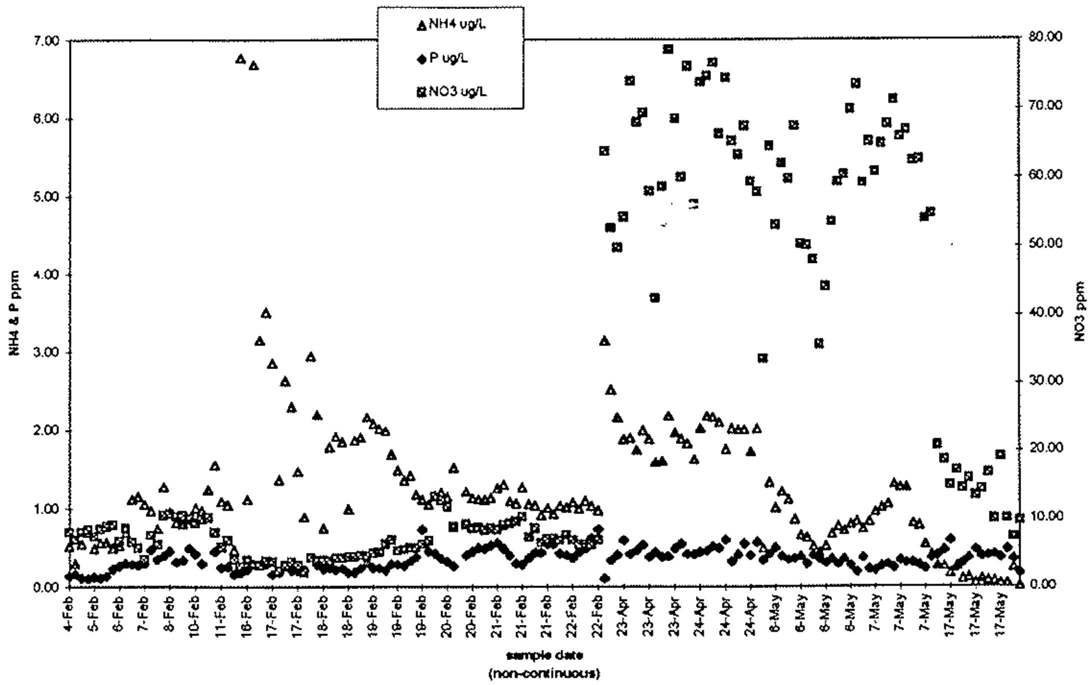


Figure 14. Nutrient concentrations in runoff collected in sediment basin.

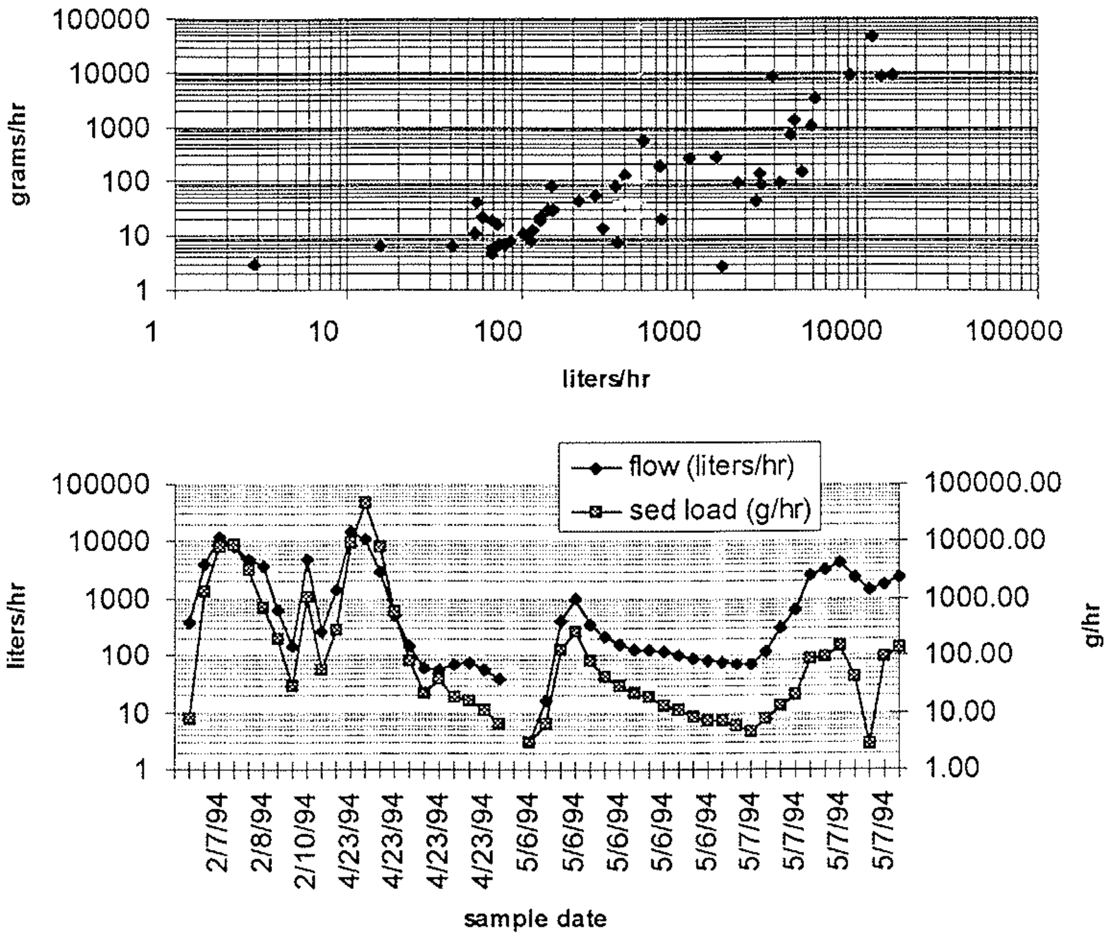


Figure 15. Relationship between sediment loading rates and runoff flow rates shown in a scatter diagram, and a line graph with two Y-axes.

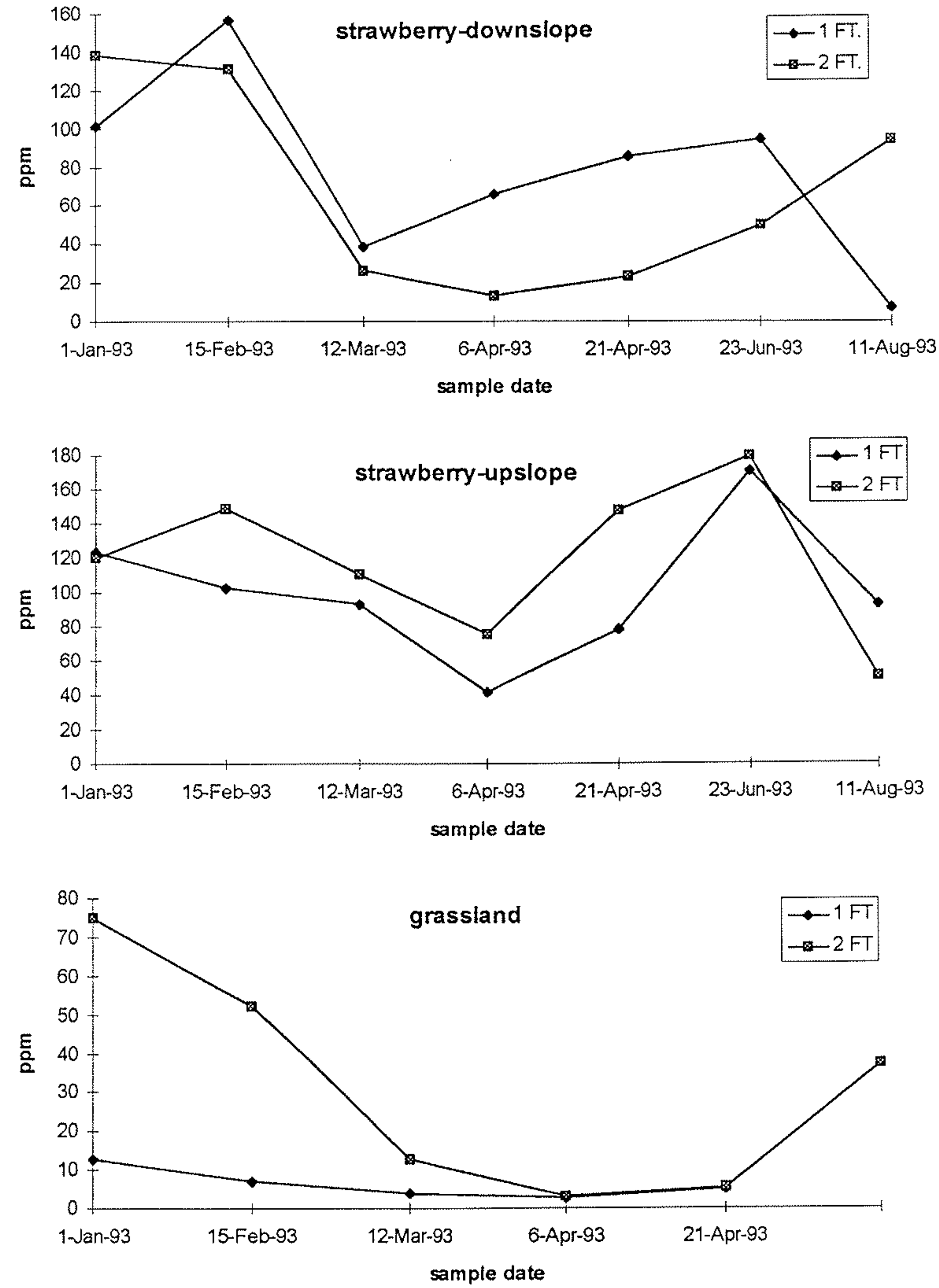


Figure 16. Nitrate-nitrogen levels in lysimeter samples (N=3) from the Azevedo Ranch (strawberries) and the National Estuarine Research Reserve (grassland) in Elkhorn Slough, CA during 1993.

of a one foot and a two foot deep lysimeter. Nitrate-N levels in soil water samples were generally higher in the cropped soils than in the grassland soils. Variability between samples was higher in the cropped soils, as reflected in larger error values.

Nitrate-N levels in the soil solution were much higher in the strawberry field than in the grassland, reflective of large nitrogen fertilizer inputs to the crop soil. Appearances in the crop field (soil homogenized by plowing, one dominant species planted in straight rows, water applied from a drip tape between the plant rows, uniform fertilizer application, etc.) suggest more uniform ecosystem processes than in the randomly structured grassland. However this is not the case, as shown by the greater degree of variability between crop samples than among grassland samples. This may be a product of extreme disturbance in the crop field, and a lack of consistent ecological processes for efficient N cycling within the system.

Lysimeter samples collected in 1994 showed no difference between the roadways and the non-roadway lysimeter nutrient content (ammonium-N, nitrate-N, and phosphorus). However, the nitrate-N concentrations averaged 4.98 mg/L (s.d. 7.4) for all samples from the vegetated border in 1994, while the nitrate-N in the strawberry fields averaged 89.19 mg/L (s.d. 85 mg/L) for the 1993 samples. Both measurements had a strongly tailed frequency distribution (Figure 17). Furthermore, it appear that the frequency distribution matches that of the grassland plots from the previous year very well. This suggests that the ground water in the vegetated border is not highly enriched in nutrients, although there are some temporally important times when water quality does seem highly enriched (Figure 18). Between January and the first week of February we found very high concentrations of nitrate (mean = 7.75 ppm, maximum value = 42.7 ppm).

There was no correlation ($R^2 < 0.1$) between nitrate-nitrogen concentrations, and the concentrations of ammonium-nitrogen or phosphorous (Figure 19). This suggests that the concentrations of these nutrients are independent of each other or that there is a lag time between their assimilation, release or movement in the vegetated border areas.

Wetlands

Wetlands Hydrology

Results of the monthly hydrological monitoring program are summarized in Figures 20 through 22. Water temperature varied seasonally and was lower in winter months. Salinity trends varied with season and the degree of isolation from the main slough channel. The south and Central Marshes have small culverts, so evaporation in the summer results in high salinity and rain in the winter results in fresh water. The North Marsh has free tidal exchange with the

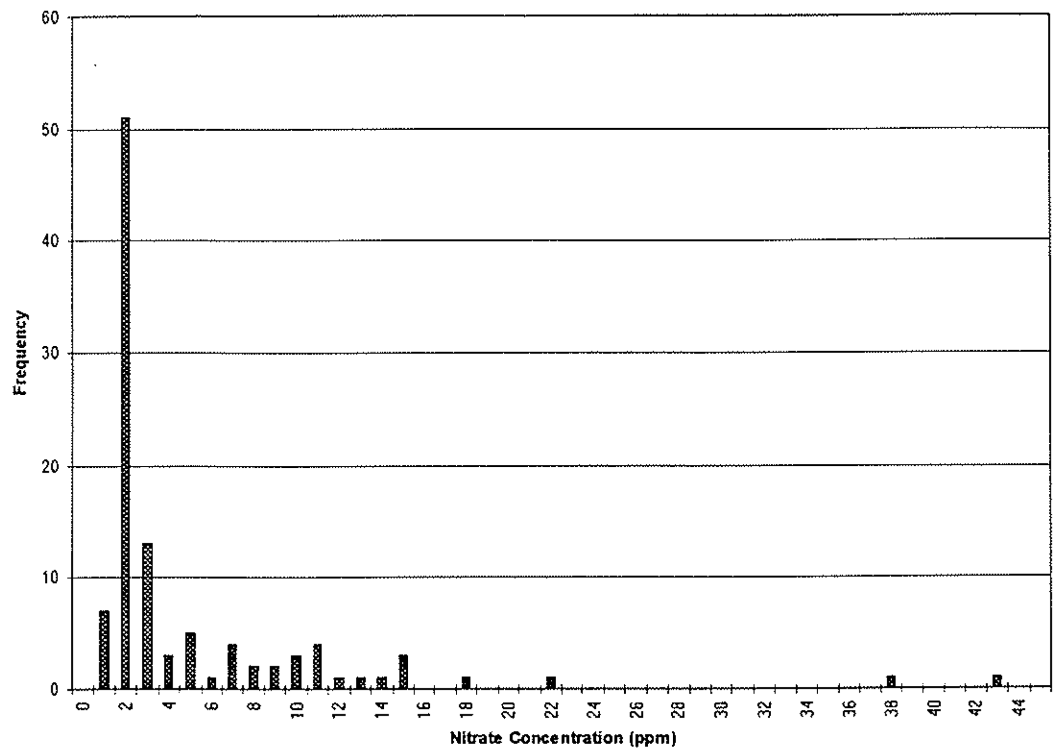
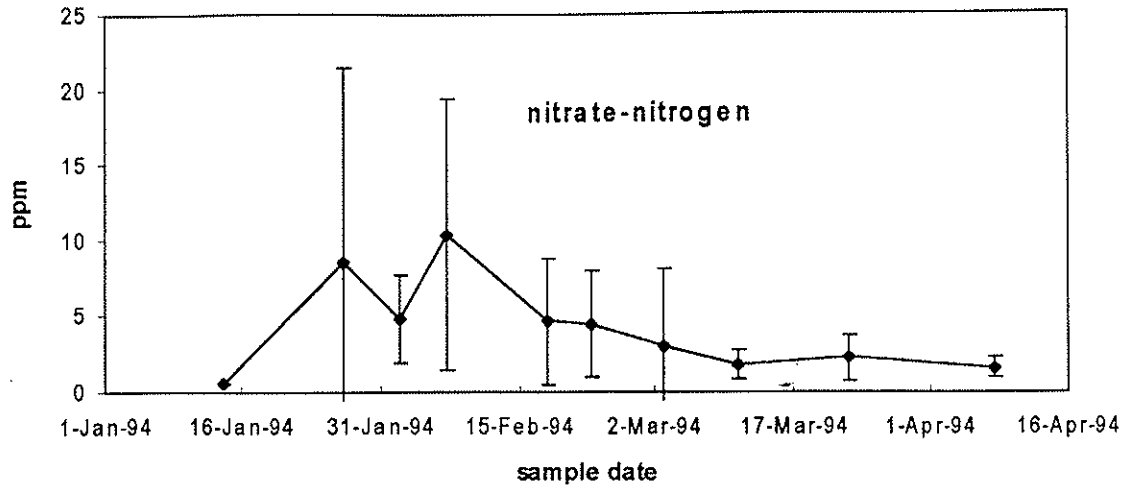
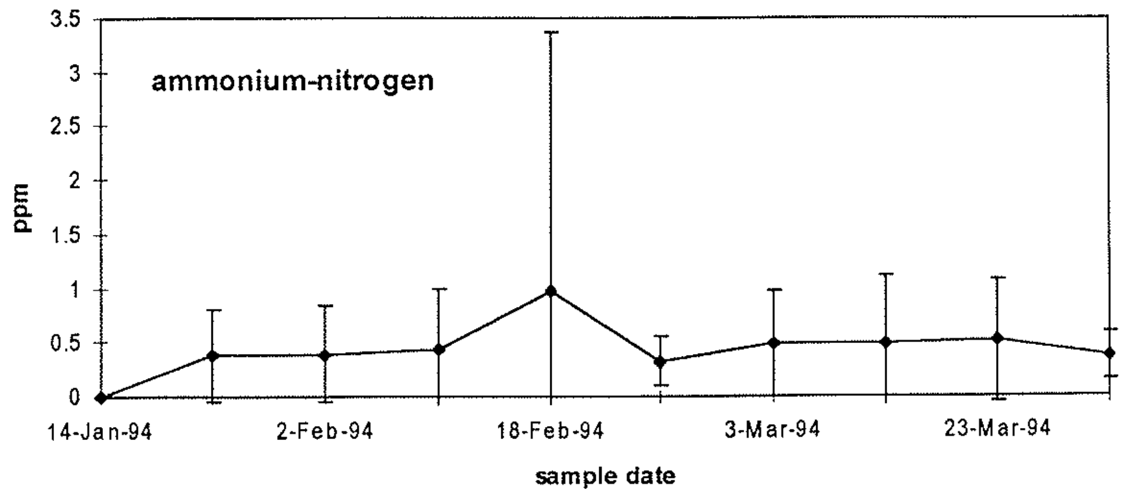


Figure 17. Frequency distribution of nitrate-nitrogen concentrations of soil-water sampled from lysimeters, Azevedo Ranch, Elkhorn Slough, CA.





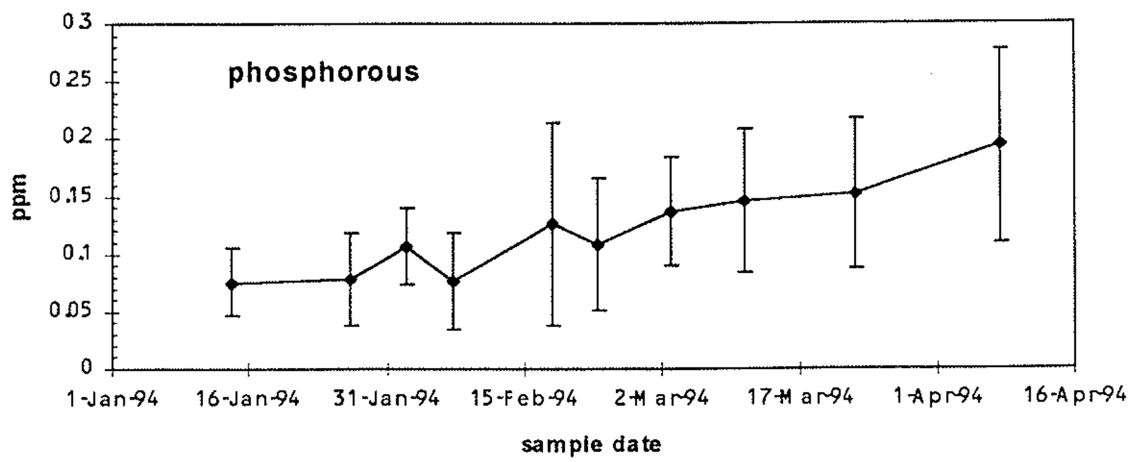
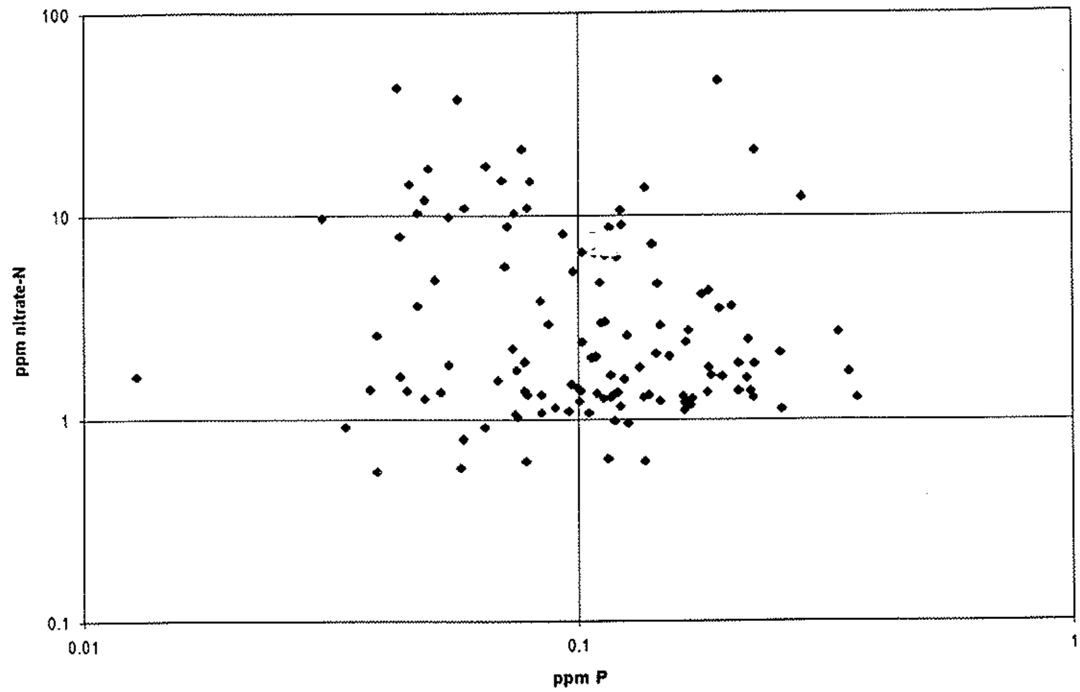


Figure 18. Nutrient levels in soil-water collected from lysimeters at 2 foot depth (N=16) in vegetated border between agricultural land and marsh at the Azevedo Ranch, Elkhorn Slough, CA during 1994.



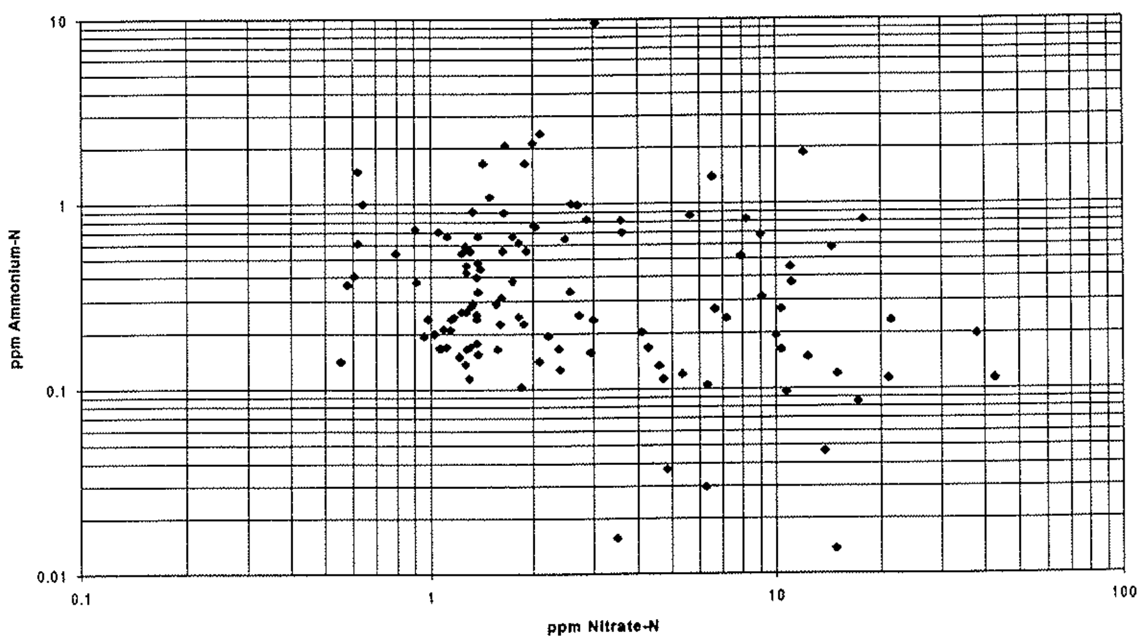


Figure 19. Scatter diagrams plotting nitrate-nitrogen concentration in lysimeter samples against ammonium-nitrogen (bottom), and against phosphorous (top).

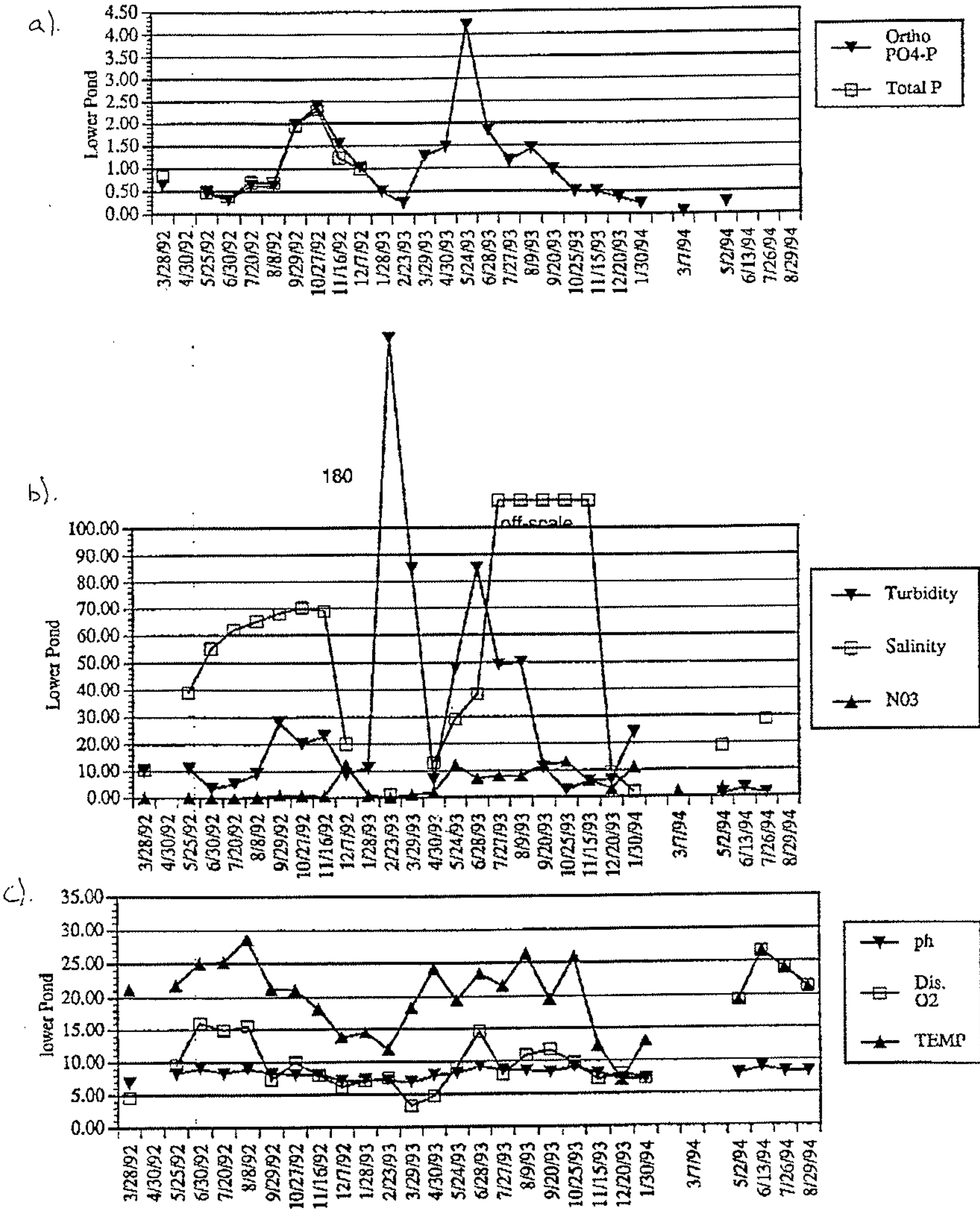


Figure 20. Results of monthly hydrological monitoring program from the South Marsh (Lower Pond) at the Azevedo Ranch in Elkhorn Slough, CA. a). Ortho-phosphate and total phosphorous. b). Turbidity, salinity, and nitrate-nitrogen. c). pH, dissolved oxygen, and water temperature.

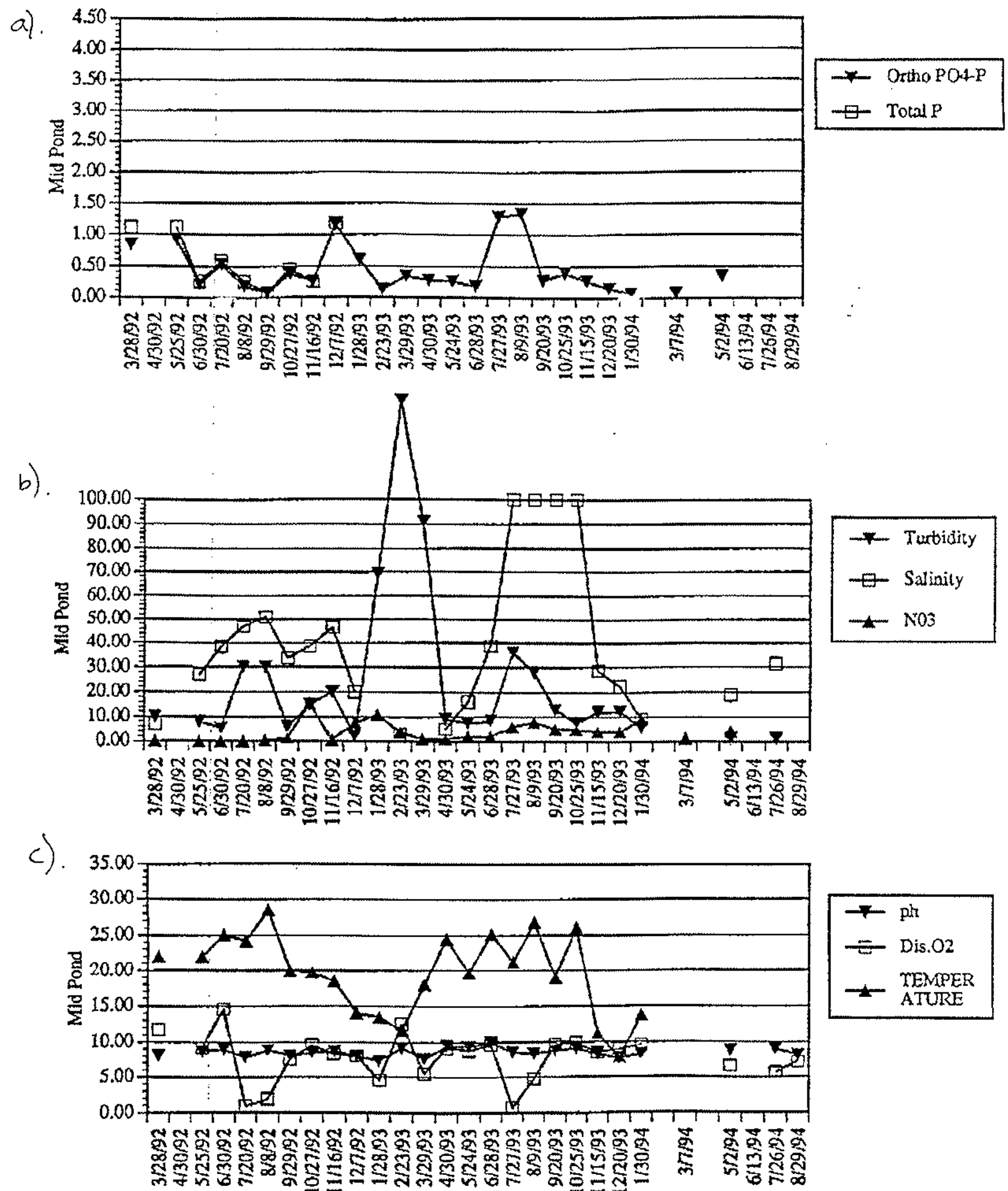


Figure 21. Results of monthly hydrological monitoring program from the Central Marsh (Mid Pond) at the Azevedo Ranch in Elkhorn Slough, CA. a). Ortho-phosphate and total phosphorous. b). Turbidity, salinity, and nitrate-nitrogen. c). pH, dissolved oxygen, and water temperature.

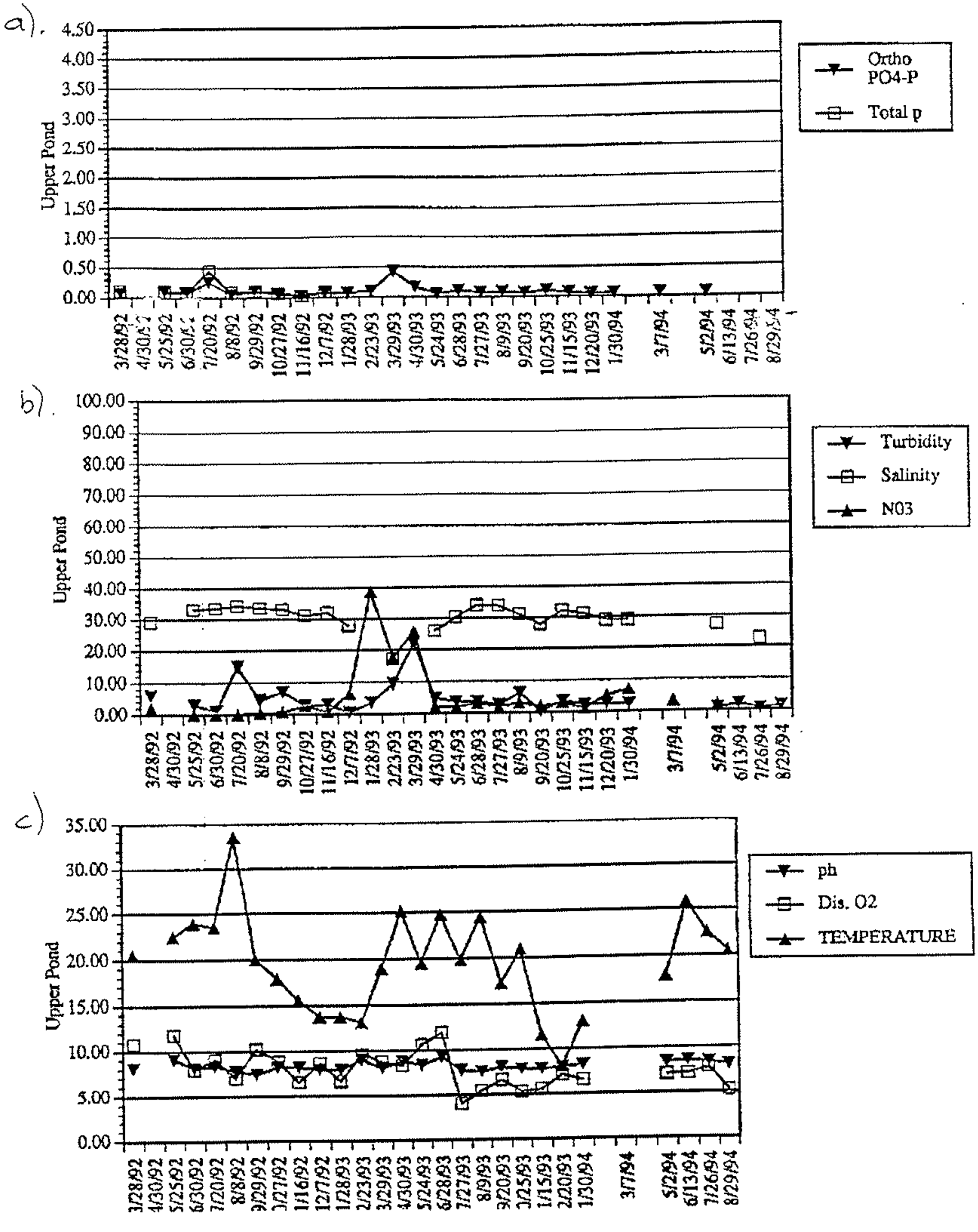


Figure 22. Results of monthly hydrological monitoring program from the North Marsh (Upper Pond) at the Azevedo Ranch in Elkhorn Slough, CA. a). Ortho-phosphate and total phosphorous. b). Turbidity, salinity, and nitrate-nitrogen. c). pH, dissolved oxygen, and water temperature.

slough, so its salinity remains roughly 33-34 ppt. Turbidity is generally constant at the North Marsh, but shows large seasonal peaks in the South and Central Marshes. Dissolved oxygen also appears to be more variable in the central and southern marshes. The pH fluctuates in the neutral to alkaline range at all sites. Ortho-phosphate levels were most variable in the South Marsh, and were consistently lowest in the North Marsh. Levels of total phosphorous closely followed ortho-phosphate levels early in the study and this measurement was discontinued in December 1992.

Levels of nitrate-nitrogen (Figure 23) and ammonium-nitrogen (Figure 24) were consistently lower in the Control Pond relative to the three Azevedo marshes. There were occasional spikes of both nitrogen forms in the Azevedo marshes, possibly related to runoff events carrying nutrient loads from the agricultural fields into the marshes. Both forms of nitrogen are added as fertilizers, at varying ratios and concentrations. Cultivation practices in October/November would also expose soil-held nitrogen to off-field transport during rain or heavy irrigation events, as is often practiced prior to fumigation to create proper soil moisture levels.

Wetlands Vegetation

The macro-vegetation of the mudflat zone consisted of bluegreen algae, *Enteromorpha* spp., and *Rupia maritima* (Figure 25). Blue green algae formed extensive floating mats at three of the four sites. *Enteromorpha*, not yet identified to species, also formed floating mats and was only absent at one site. *Ruppia*, an aquatic herb, was present in the Central Marsh but only abundant in the southern marsh.

Vegetation in the mid-Pickle Weed zone was dominated by *Salicornia*, but there were less common species present. The estimated cover in the transects was 100% *Salicornia*. There was some variability in the height of *Salicornia* between sites, but the color was consistently green (Figure 26). Other species noted in this zone included: *Atriplex leucophylla* (or possibly *A. triangularis*), *Cuscuta salina*, *Frankenia grandifolia*, *Jaumea carnosa*, *Distichlis spicata*, and *Elymus* sp.

The transects through the marsh-field border found a gradient from salt marsh species dominated by *Salicornia virginica*, *Distichlis spicata*, and *Cuscuta salina* to a more species-rich border flora with a maximum of 14 species. The species found are typical of wetland-upland transition zones along the central California coast.

The coast line of California contains several distinct vegetation types which are related to the topography, hydrology, soil type, latitude, historical land use patterns, and disturbance regimes. The Azevedo Ranch is in the midst of five vegetation communities: Coastal salt marsh, California annual grasslands, maritime chaparral, north coastal scrub and live oak woodland.

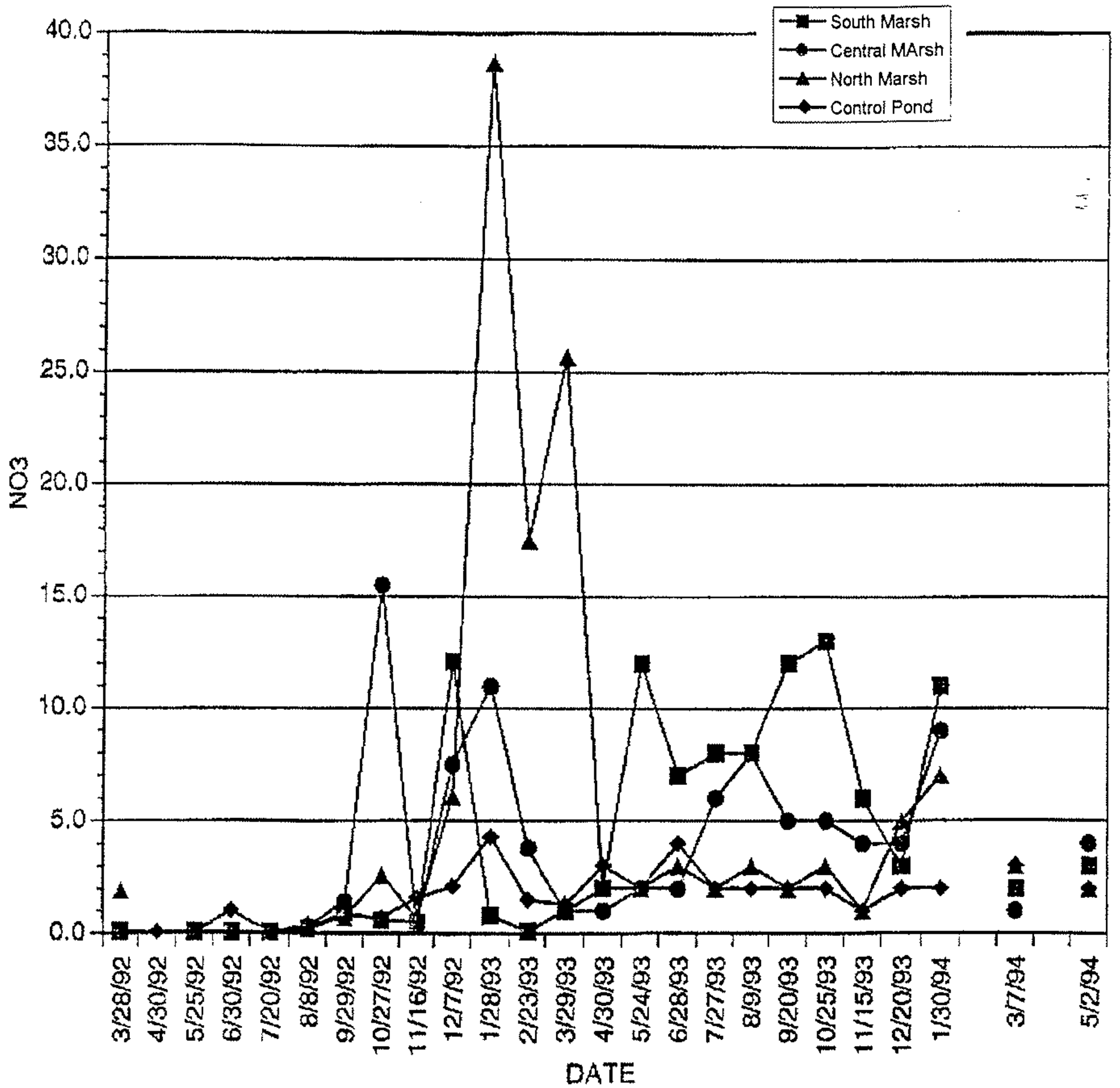


Figure 23. Nitrate-nitrogen concentrations (ppm) from monthly water samples collected from the three Azevedo pocket marshes, and a control pond at the Elkhorn Slough National Estuarine Research Reserve.

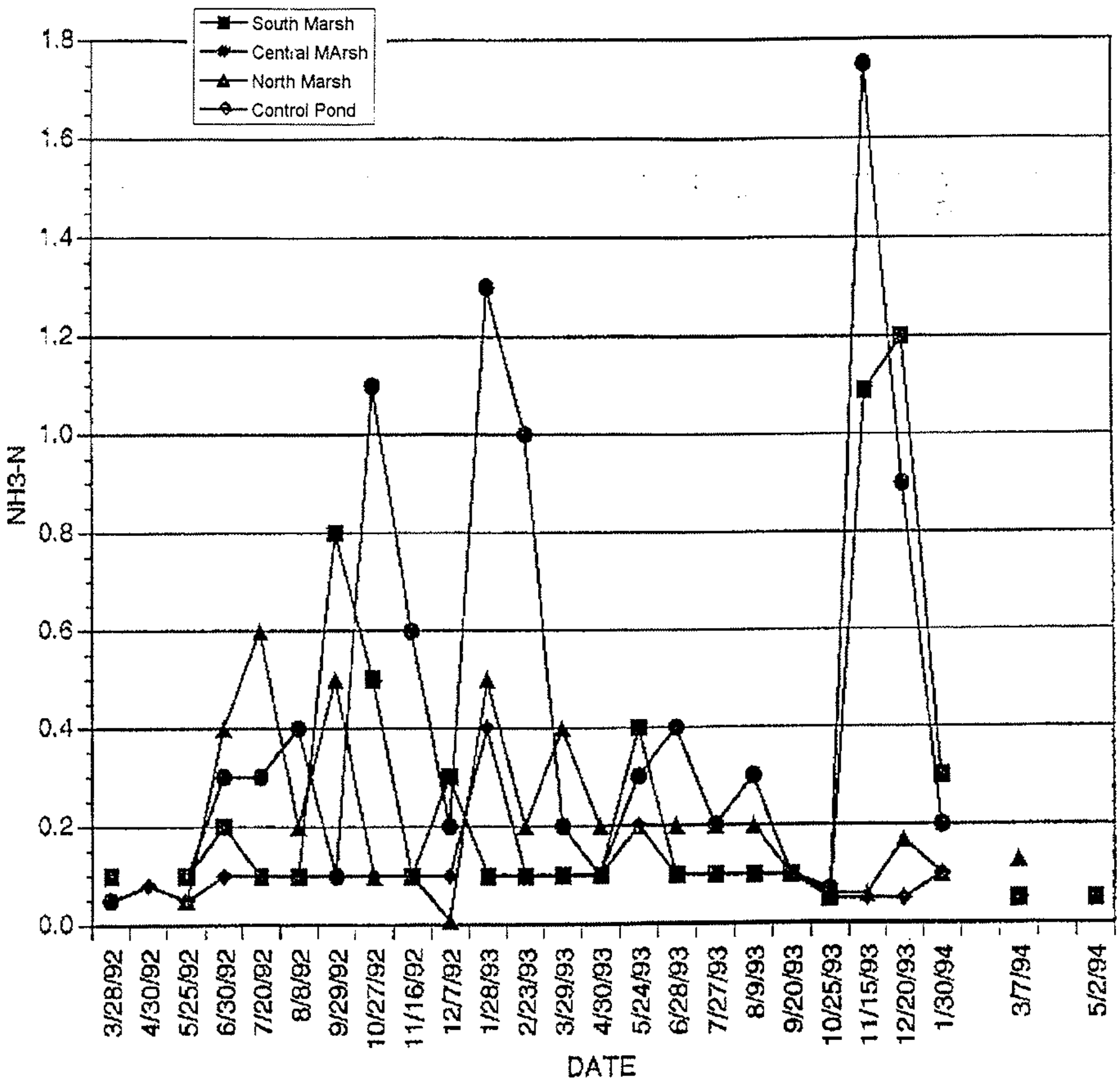


Figure 24. Ammonium-nitrogen concentrations (ppm) from monthly water samples collected from the three Azevedo pocket marshes, and a control pond at the Elkhorn Slough National Estuarine Research Reserve.

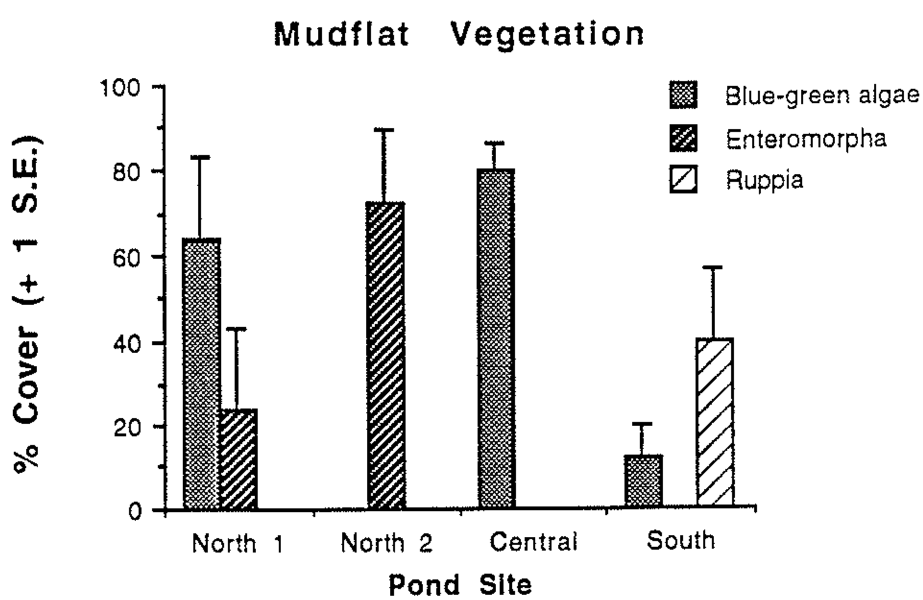
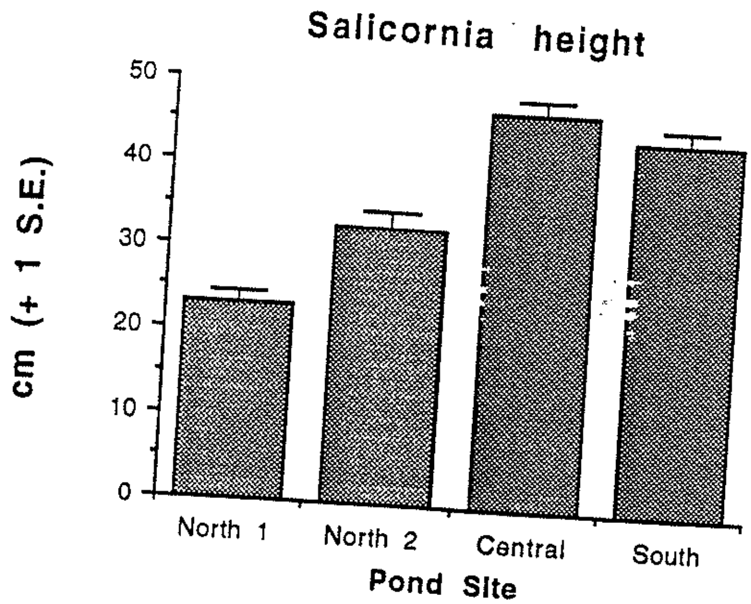


Figure 25. Vegetation of the mudflat zone in the Azevedo pocket marshes, Elkhorn Slough, CA.



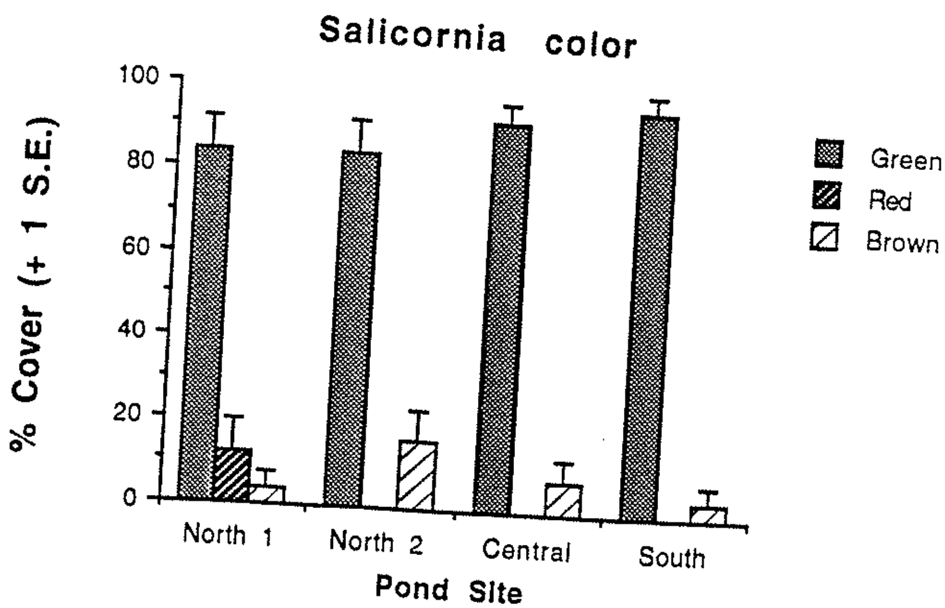


Figure 26. Height and color of *Salicornia virginica* in the Azevedo pocket marshes.

Wetlands Invertebrates

A minimum of sixteen infaunal invertebrate species, representing five phyla, were found in the benthic samples (Table 3). All of the organisms found in the cores are species known from other habitats in Elkhorn Slough. Most of the animals are typically found in rigorous or marginal environments.

Table 3. List of Benthic Invertebrate Species from Azevedo Marshes.

- Cnidaria
    - *Haliplanella luciae*
    - Unidentified burrowing Anemone
- Nemertea
    - Unidentified Nemertean
- Polychaetes
    - *Capitella capitata*
    - *Streblospio benedicti*
    - *Polydora* sp.
    - *Exogone lourei*
- Oligochaetes
    - Unidentified Oligochaeta
- Mollusca
    - *Assimnea* sp.
- Crustacea
    - *Corophium insidiosum*
    - *Corophium acherusicum*
    - *Grandidierella japonica*
    - *Leptochelia* sp.
    - *Sinelobus stanfordi*
- Ostracoda (Podocopida)
- Insecta
    - *Ephydra* sp.
    - Corixidae
- Algal species
    - *Enteromorpha intestinalis*
    - *Enteromorpha* sp.
    - *Gracilaria* sp.
    - *Ulva* sp.
    - *Blidingia minima*
    - Unidentified Bluegreen algae
- Other
    - Bacterial mats of several colors
    - *Ruppia maritima*

The marshes harbored a restricted fauna, relative to the fauna found in the adjoining slough (Nybakken *et al.*, 1977). The South Marsh showed the lowest abundance and diversity, with almost no living macrofauna collected from the benthos. This marsh undergoes the most dramatic changes in water chemistry during the year (see Figure 20). In addition, the sediment in the central portion of this marsh was completely anoxic. The Central Marsh likewise showed few infaunal invertebrates. This may also be a reflection of the changeable water quality and anoxic sediments. The North Marsh showed the greatest abundance and diversity of infaunal invertebrates of the three Azevedo marshes. This is consistent with the greater flushing of this marsh with tidal water.

The distribution of infaunal invertebrates within the three marshes tracks the relative degree of disturbance in each. The least flushed, most disturbed marsh showed no infauna while the largest, best flushed and least disturbed marsh showed the greatest diversity. All of these marshes exhibited a restricted fauna relative to the control pond on the Reserve. Future sampling will examine more of the seasonal changes associated with these ponds and will work to link land use practices with the health of the infauna.

The 1 acre South Marsh is the smallest of the three and is cut off from tidal exchange (Figure 27). It has experienced the greatest degree of filing from the adjoining agricultural operations and is surrounded by the smallest buffer of salt marsh. This pond had a growth of *Ruppia maritima* in July, 1992 that was heavily encrusted with consolidated sediment, perhaps cemented by a bacteria or protozoan. This mat of *Ruppia* formed a false bottom in the pond above which were pupae of the brine flies and corixid beetles. The underlying sediment was completely anoxic and no living infauna were retrieved from the cores in 1992. The summer 1993 samples contained one oligochaete and several corixid beetles. Again, the sediments were completely anoxic, although the *Ruppia* canopy was not present.

The Central Marsh is 4.1 acres in extent and is intermediate in size and disturbance (Figure 28). The central pond is blocked from tidal action by high culverts and by a low berm across the mouth of the marsh (between the marsh and the culvert). This marsh also receives direct freshwater input during the rainy season from a culvert draining an agricultural pond above the road. Sediments in this pond were oxidized on the surface, but anoxic a few millimeters below the surface. The infauna reflected these difficult conditions and few species were recovered from either station on either sampling date.

The North Marsh is the largest of the three at 10.1 acres (Figure 29). It is connected to the main channel of the slough through two culverts, one at either end of the marsh. This marsh receives the most tidal flushing, though the central portions of the marsh are not well flushed. In all cases, the North Marsh showed the greatest number and diversity of infaunal species of the three Azevedo marshes. Samples taken in July 1993 showed an absence of many of the soft-bodied species collected in October of 1992. In addition, the presence

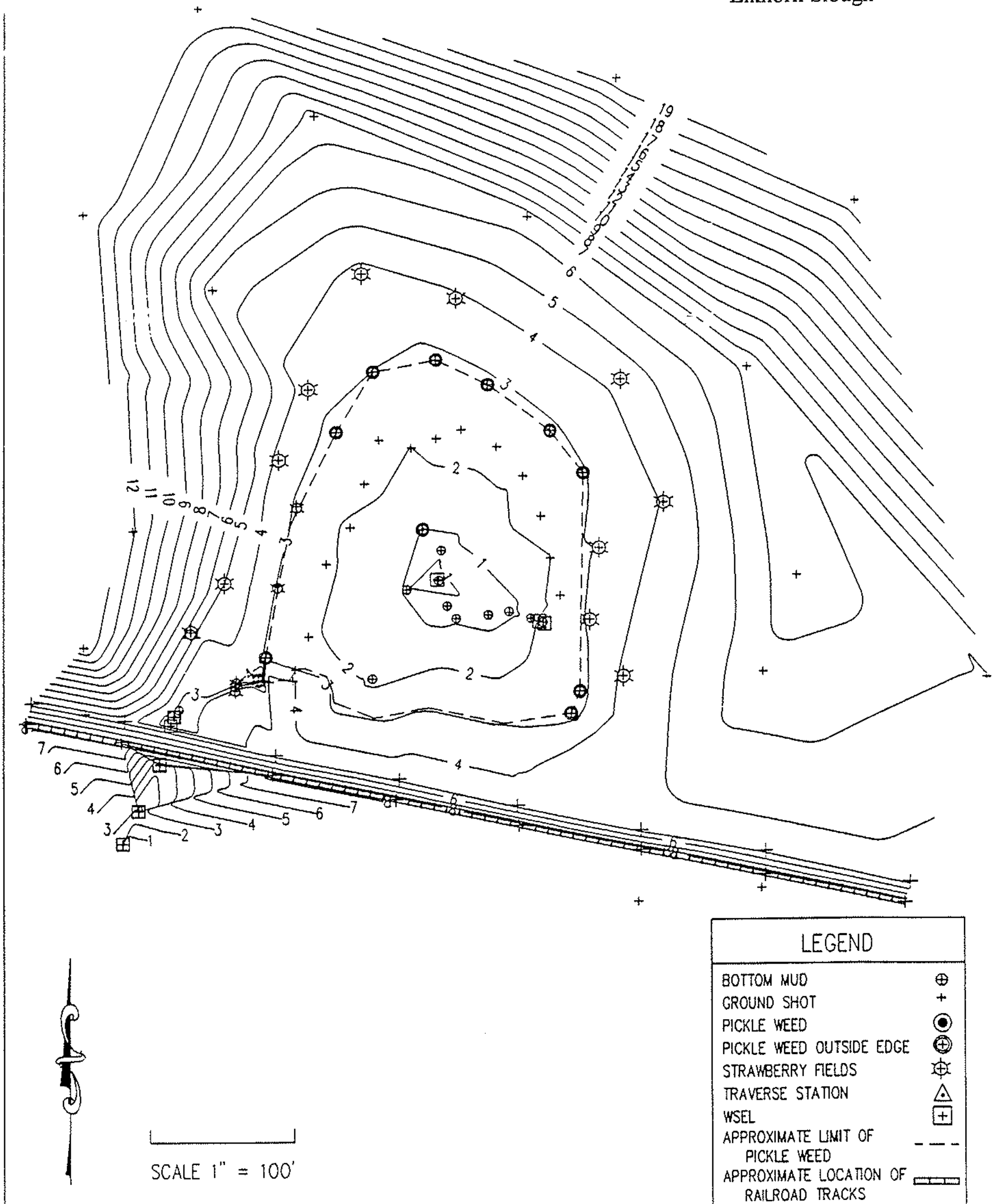


Figure 27. One-foot contour map of the South Marsh at Azevedo Ranch, Elkhorn Slough, CA.

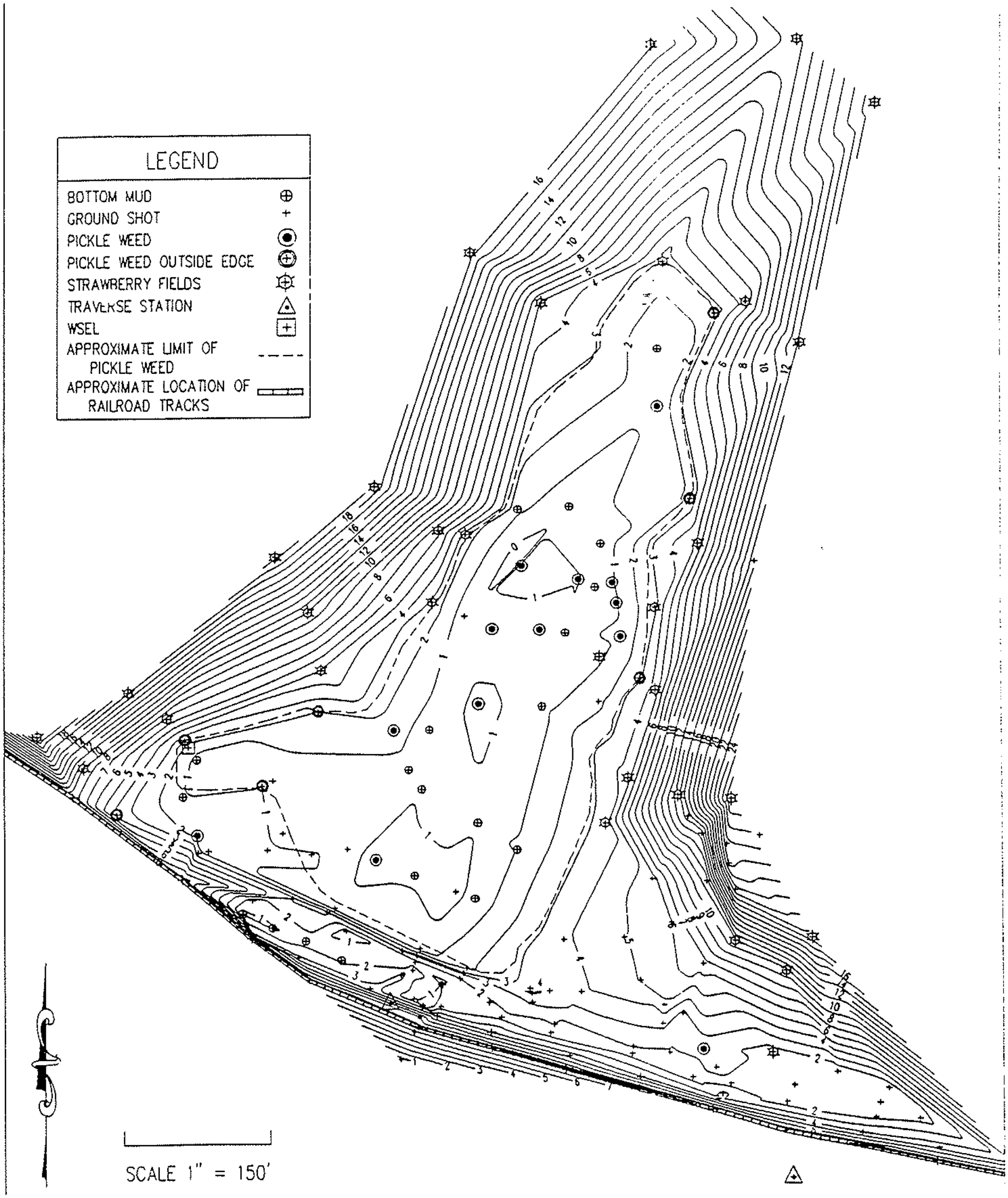


Figure 28. One-foot contour map of the Central Marsh at Azevedo Ranch, Elkhorn Slough, CA.

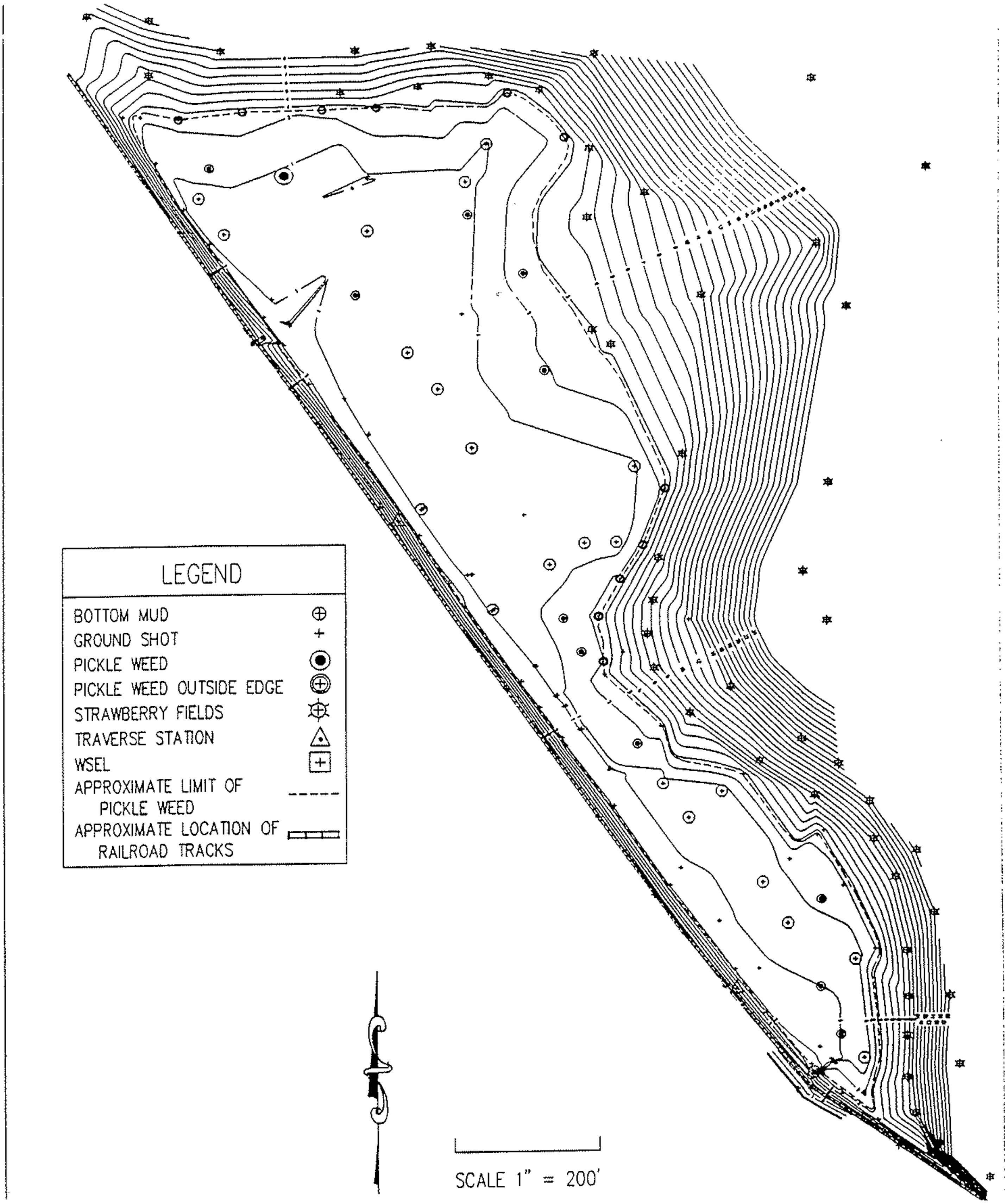


Figure 29. One-foot contour map of the North Marsh at Azevedo Ranch, Elkhorn Slough, CA.

of a podocopid ostracod in July was notable. Many dead ostracods and shells were recovered from these samples. In some areas, evidence of anoxic waters and sediments was observed, and dead ostracod shells found.

The control pond on the National Estuarine Research Reserve served as a contrast to the Azevedo marshes. It is more fully flushed, has never been cultivated, and is undisturbed relative to the Azevedo marshes. Infaunal samples showed greater species diversity in this pond relative to the Azevedo marshes. The invertebrate community in the control pond was more similar to that found in the main channel of the slough than the Azevedo marsh community.

CONCLUSION

We have begun the characterization of an agricultural site and an adjacent wetland area. These data will provide a baseline for comparison once the site is converted to low-input agriculture and habitat restoration. Over time, we will be able to assess the effects of sustainable agricultural management practices on inputs of sediment and anthropogenic chemicals to the wetland. Because agriculture is considered to be the main origin of NPS pollutants entering the Elkhorn Slough, this information will be invaluable in developing management practices and policies that are consistent with the goal of enhancing estuarine water quality.

If agriculture is to continue as an environmentally and economically sustainable land-use practice in the region, this information is essential. It is not enough to simply regulate against land-use practices that are suspected sources of pollutants. This project will yield and demonstrate alternative practices that can maintain a viable and important local industry, while protecting the estuarine habitat. An additional goal is working with the Elkhorn Slough National Estuarine Research Reserve and the Elkhorn Slough Foundation to develop a strong partnership between the public and private sectors for addressing watershed issues in the slough.

Negative impacts resulting from agricultural activities upstream from estuaries are a nearly universal problem, and development of alternative management approaches on the Elkhorn Slough watershed will have applicability to farms on other estuarine watersheds as well. In the future, we hope this project will demonstrate production alternatives that can reduce farmer dependence on synthetic fertilizers and pesticides. Successful alternative agricultural management practices will slow the spread of contaminants in the soils, waters, and air of the environment, produce quality food, and protect people that live and work in agricultural areas. Studies of the conversion of chemical intensive farming to more ecologically-based production practices have only begun to be systematically performed. Under current economic pressures and with little access to a tested and proven technology for conversion, farmers have little choice other than to continue their dependence on costly inputs.

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