CLEAR LAKE

DIAGNOSTIC & FEASIBILITY STUDY

IOWA DEPARTMENT OF NATURAL RESOURCES

NOVEMBER 2001

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This study was carried out by Iowa State University with funding from
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Executive Summary – Diagnostic & Feasibility Study

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The purpose of this 2-year project was to study multiple aspects of Clear Lake, its watershed and community to determine water-quality related problems and their likely causes, and suggest a list of potential remedial measures. The project was funded primarily by the Iowa Department of Natural Resources (IDNR), the City of Clear Lake, Cerro Gordo County, Hancock County and the Hancock and Cerro Gordo County offices of the Natural Resources Conservation Services (NRCS). Iowa State University (ISU) also provided substantial cost-share. The first part of this project, the diagnostic study, is a description of the principal findings of the analysis of the lake, its watershed, and the social landscape.

The study was performed by a large team of scientists and students with the help of dozens of citizen volunteers. The work could not have been done without the generous contribution of time and effort by hundreds of willing citizens and the volunteer work of several ISU professors. Over the course of the project, hundreds of thousands of meticulous measurements and analyses were made to study the lake, the watershed and the importance of Clear Lake to the regional social structure.

Lake and Watershed Characteristics

Clear Lake is third largest of 34 natural, glacial lakes in Iowa, and is managed for water-based recreation and fishing. It is shallow, with a maximum depth of 5.9 meters (19 ft) and an average depth of 2.9 meters (9.6 ft). Water is supplied to the lake by small tributaries, rainfall, groundwater, and many areas of direct surface runoff. Forty-seven percent of the water supply flows in from a large wetland complex (Ventura Marsh). The lake's watershed to lake-area ratio is only 2.3:1 and the watershed is composed of 59% cropland, 10% urban areas, 9% wetlands, 8% grasslands, 5% wooded lands, 5% roadways, 2% farmsteads, 1% pasture and 1% State Parks.

Clear Lake has a long history as a focal point for recreation in Iowa, and is currently intensively used. Use is 44% camping, picnicking and other passive uses, 28% pleasure boating, 19% swimming, 7% fishing, 2% winter activities, and 0.2% hunting. Total use of the two State parks on the lake (Clear Lake State Park, McIntosh Woods State Park) totals more than 660,000 person-days per year and is growing substantially. In addition to the State Parks, the cities of Clear Lake and Ventura maintain recreational facilities on the lake. There are 24 public access points on the lake and 15 of these have public docks. Clear Lake is currently managed by the Iowa Department of Natural Resources for recreation and gamefish production.

Clear Lake is intensively used both by residents and by visitors from across Iowa and the region. Clear Lake is located in Cerro Gordo and Hancock Counties, which have combined populations of around 60,000. Much of the population of Cerro Gordo County is located quite near the lake (Mason City: population=29,000), and this population has a higher than average income for the State. Agriculture and related industries are also important sources of income in this region (82%-91% of total land area in these counties). Economic activity associated with the lake is intense. Data on hotel/motel tax receipts indicate that Clear Lake has enjoyed an annual tourism impact of $30-$40 million annually for several years. Estimates of willingness to pay for lake water quality maintenance or improvement suggest that citizens value the lake at between $20 and $40 million over a 5-year period, respectively. Much of the valuation of the lake is expressed by local residents, although even visitors expressed a willingness to personally support water quality maintenance and improvement with substantial financial contributions. Hunting revenues are quite small, but play an important social role.

Valuing Preservation and Improvements of Water Quality

One important indicator of social importance of a resource such as Clear Lake is the willingness that citizens have to pay for maintenance or improvement of the resource. This is distinct from the amount that they pay to use a resource (an amount that is very large indeed, and approaches the GNP of the region associated with the resource), and indicates the unique economic value of the resource. As part of this study, economists performed surveys to provide information on recreational usage of the lake, attitudes of recreators and local residents toward possible watershed management changes, as well as estimates of visitors' and residents' willingness to pay for water quality improvements. Clear Lake is very important as a recreational resource, with visitors reporting high, persistent usage of the lake (an average of over 6 trips per annum). Both visitors and residents report a high willingness to pay to avoid further deterioration of the lake, about $100 for visitors and about $550 for residents. When asked about their willingness to pay for improvement from the current conditions, respondents indicate that they are willing to pay only moderate amounts for a low quality improvement, but substantial amounts for a more significant quality improvement, $215 and $600, respectively for visitors and residents.

Attitudes and Perceptions Regarding Water Quality and Community

Because substantial improvements to lake water quality often require social change to take place, the beliefs, attitudes and values of residents are an important part of planned landscape change in communities. A critical goal of this study was to propose feasible restoration alternatives toward the improvement of water quality in Clear Lake. Therefore, part of this study summarized interviews with residents reflecting a broad range of experiences and connections with the lake and community, while balancing income, gender, education, occupation and years lived in the area. Interviews were conducted individually using photographs as discussion points. Analyses focused on (1) residents' relationship to the lake, (2) organizational and social aspects of the community, (3) perceptions of water quality, and (4) perceived community needs as they relate to water quality.

Clear Lake is the focal point of the community and the region. Visual changes are watched in detail, including water clarity, water level, fish populations, etc.
The lake has a strong personal importance to the community but is also important as part of the community's link with the external world through tourism. Although residents expressed concern about Iowa's water quality in general, specific views about Clear Lake are optimistic, although there is concern for the cost of remediation. Residents expressed interest in additional lake-centered facilities including a bike trail around the lake, more public docks, additional boat trailer and vehicle parking, and small pocket parks on the lakeshore. The community is extremely well educated about water quality and communicates very well within itself and without. There is a large degree of tolerance for the visual aspects of water-quality enhancing structures (e.g., wetlands, filter strips). Considerations for future community action indirectly related to water quality emerged from this part of the study: community sense of place, interpretation of local history and perceptions of public/private ownership.

Historical Changes in the Waterscape

Dr. Ken Carlander, a well-known emeritus scientist at Iowa State University and a long-time analyst of the Clear Lake ecosystem, began to chronicle changes in the Clear Lake shoreline in the early 1950s by establishing a photographic record. One part of this study was to repeat his photographs from the same vantage points to see how Clear Lake has changed. Comparisons show striking changes in the extent and density of emergent and submergent rooted plants in Clear Lake. Reduced water clarity has resulted in a reduction in the extent and biodiversity of rooted plants. These plants are important as fish and wildlife habitat as well as the stabilization of bottom sediments and shorelines.

Limnology and Ecology of Clear Lake

Clear Lake is a formerly oligotrophic to mesotrophic lake that has increased in total phosphorus concentration from around 60 ppb in the early 1970s to around 190 ppb in 2000. Total phosphorus appears to be increasing in Clear Lake at an average rate of about 4 ppb/year. At this rate, Clear Lake would move from a eutrophic/hyper-eutrophic lake to a hyper-eutrophic lake, attaining 340 ppb by 2040. Total phosphorus has therefore already tripled in the last 30 years and appears to be climbing under current watershed management scenarios. Concurrently, water clarity has been cut to nearly a third of what it was in the early 1970s, and probably around 10% of the clarity the lake had near the turn of the century. Water clarity in 1974 was about 0.9 meters (nearly 3 ft.), but is now around 0.35 meters (about 1 ft.).

Clear Lake is typical of large, shallow, corn-belt kettle lakes. Clear Lake receives a very elevated rate of supply of nutrients (most notably phosphorus) from its watershed, rainfall and groundwater, resulting in a volume-weighted average spring phosphorus concentration of 186 ppb. Much of the watershed is at the western end of the lake, thus nutrient supply and concentrations are higher in the west end than the east end of the lake. The very shallow depth (maximum 5.9 m or 19 ft) means that wind mixing returns nutrients from the sediments into the water column during the warm, summer season. This large input of nutrients from the watershed and the remobilization of sediment nutrients gives Clear Lake a very high concentration of nutrients such as nitrogen and phosphorus. The mixed agricultural and urban watershed furnishes very high nutrient loads to the lake, some of which has been deposited into the sediment layers. These high nutrient inputs, coupled with the fish-, boat- and wind-induced mixing of sediments, are significant impediments to water quality, since they have now turned Clear Lake into a eutrophic to hyper-eutrophic lake. The impact of these nutrient loads is exacerbated by a greater-than-average concentration of suspended silt that likely arises due to wind resuspending watershed-derived silt, carp and other benthic fish digging in sediment deposits, and power-boat wakes disturbing sediments in shallow waters. Further exacerbating water quality problems is a declining population and biodiversity of rooted water plants which formerly held bottom sediments and protected shores and shallow waters from wave erosion.

Very high nutrient concentrations in Clear Lake have fueled over-abundant growth of algae, resulting in green water and frequent algae blooms. Phytoplankton in Clear Lake follow a seasonal pattern that is typical of temperate, shallow, hypereutrophic lakes. Algal biomass is generally highest in mid-summer when it forms conspicuous "blooms" of algae coloring water an intense green color. Cyanobacteria ("bluegreen algae") and diatoms make up the majority of the algae. Cyanobacteria usually dominate the algae and make up >80% of the algae in mid- to late-summer. As is frequently the case for eutrophic lakes, the types of Cyanobacteria present in blooms include some of the groups that can produce toxins under certain conditions. These groups compose an average of 35% of the algae. Because such toxins could become harmful to invertebrates, fish, wildlife, livestock, and humans, reduction of nutrient levels to eliminate Cyanobacterial dominance would be welcome.

Declines in water quality have reduced fish and wildlife habitat substantially in Clear Lake. The number of species of aquatic plant species found in Clear Lake has declined from 35 species in 1952 to 21 species in 1981 to 12 species in 1999. More than 80% of the species currently present in Clear Lake have declined significantly since 1981. Aquatic plants cover about half the area of the lake that they covered in 1981. Rooted aquatic plants are important wildlife and fish habitat and stabilize bottom sediments and shore zones.

Bacteria were studied intensively in Clear Lake and were usually found at low levels, especially in the open waters away from shore. Concentrations of fecal coliforms, *E. coli*, and fecal enterococci were highest near shore and showed patterns that should allow remedial measures to trace bacteria sources and eliminate or reduce these inputs. Bacteria were found to enter the lake around much of the shore. Since much of the shore is in residential development, significant amounts of bacteria likely result from urban activities. In spite of this, parkland and agricultural lands also appear to contribute substantial bacterial inputs. Concentrations of bacteria were found to be highest during the warmth of mid-summer, especially following rainfall events.

Sedimentation has resulted in substantial changes in the bottom of Clear Lake. During the first 10,000 years of its life, we calculate that the lake filled-in about 38% of its original basin. Almost ¼ of this volume was filled-in since 1935. Agricultural, urban and construction activities around the basin have reduced the average depth of the lake by one foot since 1935. Around 85,000 tons of sediment are added to the lake each year causing the lake to lose depth at a rate of about 4 mm/year. Assuming a constant rate of sediment addition to the lake, Clear Lake would be completely filled-in in 700-800 years. Normally, however, these processes usually accelerate as lakes become shallower, so this life-time may be over-estimated.

Internal nutrient loading via the resuspension of benthic sediments by wind-induced waves and recreational boat traffic is a common problem facing the managers of shallow lakes like Clear Lake. Benthic sediment resuspension may contribute to the suppression of fish and macrophyte communities, domination of the phytoplankton community by potentially toxic cyanobacteria, suspension of toxic ammonia and increased restoration time-scales. In Clear Lake, resuspension by wind-induced waves and recreational boat traffic may contribute to daily, often substantial, nutrient flux with total phosphorus concentrations increasing by over 100% and ammonia concentrations reaching levels toxic to fish. When wind speeds exceed 10 $m \cdot s^{-1}$ (22 mph), a large proportion of the lake's sediments may become mobile. Sediments in Clear Lake are most susceptible to turbulence by wind waves and boats in the lake's shallow western basin and around the lake's margins. Here, it is likely that violations of the lake's no wake zones may exacerbate wind-induced resuspension and may slow the resettlement of resuspended sediments. Additionally, the frequently observed sediment plumes passing from the western basin into the larger basins to the east suggest that prevailing currents may transport large loads of sediments and nutrients throughout the lake. Unless measures are taken to suppress the impacts of wind and boats on the lake's sediments, we may expect problems associated with sediment resuspension, including increased restoration time-scales, may become more severe as the lake's depth continues to decline, exposing more sediments to turbulence.

Increased phosphorus concentrations in Clear Lake have resulted in decreases in many aspects of the quality of the Clear Lake ecosystem. Judging from trends in water clarity, Clear Lake was likely oligotrophic-mesotrophic at the turn of the century, mesotrophic until the mid 1970s, then moving from eutrophic in the mid-1970s to near hyper-eutrophic in the late 1990s. Phosphorus concentrations of the magnitude seen in Clear Lake during this study are very poor for continued quality of recreational use. If trends continue in this vein, users of Clear Lake should expect further degradation of water clarity, reduced oxygen levels, frequent blooms of toxic algae, increased survival and persistence of fecal and potentially pathogenic bacteria, accelerated filling and siltation, mobile toxins, increased impacts of ammonia on the quality of fish and other aquatic organisms, continued declines in biodiversity and year-to-year stability, degraded fish and wildlife habitat, decreased fish production and a fish community more highly dominated by rough fish.

The increase in total phosphorus concentration in the lake has yielded a profound increase in algal abundance. The dense algae that have bloomed in Clear Lake have decreased water clarity to the point that rooted aquatic vegetation has declined substantially. Turbid waters with toxic algae favor the growth of resistant fishes like carp and bullhead that perturb sediments and uproot vegetation. Sediment resuspended by fish and increased wind mixing in the absence of rooted vegetation further decreases water clarity, further reducing the ability of aquatic plants to cleanse waters and stabilize sediments. Resuspended sediments lead to increased phosphorus concentrations that have favored even more algae growth. Projected increases in phosphorus concentrations indicate that, in the absence of remedial measures, Clear Lake will continue to decline in quality and utility as a recreational resource.

In order to improve the limnological aspects of Clear Lake, three fundamental changes would need to take place:

- Reductions in phosphorus loading to the lake.
- Reductions in silt input and resuspension by fish, wind and boat action.
- Reductions in inputs of bacteria from the watershed surrounding the lake.

Such changes would give rise to gradual improvements in the lake, the course of which is likely to span 5-30 years before substantial improvements would be achieved.

Knowledge of the hydraulic and nutrient budgets as well as various limnological details allow computation of future water quality under various scenarios of improved watershed characteristics. One can thus calculate the expected change in water quality (i.e., phosphorus concentration) by calculating the impact of a reduction in phosphorus input. We examined the fit of more than a dozen such models and found that current phosphorus concentration at spring circulation could be predicted within 2% of the actual phosphorus concentration. This model is thus likely to predict the phosphorus concentration under future remedial states. Application of these equations indicates that it would take around a 60% reduction in total phosphorus inputs to bring the lake back to the total phosphorus concentrations that were seen in the late 1970s and early 1980s. This analysis suggests that a 60% reduction in total phosphorus loading to Clear Lake should bring water clarity to the 0.8-1.2 m. level, once lake conditions equilibrate. This water clarity level is somewhat conservative because increased water clarity and carp management taken together would greatly reduce suspended solids in the water column, affording even greater increases in water clarity. It is likely, therefore, that such a management scenario could bring water clarity in Clear Lake back to pre-1970 levels, allowing marked increases in the entire lake as an ecosystem and recreational resource.

Groundwater Hydrology

A potentially important part of the nutrient budget of Clear Lake is groundwater inflow and outflow. An understanding of the geology and hydrogeology of the Clear Lake region is thus needed to understand lake-groundwater interactions. The following objectives were investigated:

- determine the thickness of Quaternary units underlying the lake and overlying the regional bedrock aquifer;
- estimate hydraulic heads in the regional aquifer and their relationship to the lake elevation and shallow groundwater flow;
- determine the nature and types geologic units affecting flow to and from the lake.

Estimation of groundwater discharge (or seepage) to lakes is necessary to determine nutrient load, but it is difficult task and generally involves the extrapolation of small-scale measurements to a much larger lake area. In cases where the geology beneath the lake is not well known and where discharge may vary, large errors are involved in the measurement and extrapolation steps.

A geochemical investigation of groundwater was undertaken in order to understand the presence and absence of nutrients and contaminants in groundwater and their potential to enter Clear Lake. Groundwater samples from the 32 out of 33 piezometers were analyzed for total P, total N, Si, alkalinity, electrical conductivity and pH. Additional parameters (major cations and anions, trace elements, dissolved O_2, dissolved organic carbon) were measured in order to understand the geochemical environment in which the nutrients occur. Geochemical speciation models and soil P measurements were used to determine potential sources of P. Selected samples were analyzed for fecal coliform bacteria and caffeine, in order to determine potential sources of nutrients and Cl. A radioactive isotope of hydrogen, tritium (^3H), was used to determine the relative age of the groundwater. Nutrient and contaminant loads from groundwater to Clear Lake were calculated from estimates of groundwater inflow and outflow and estimates of the concentrations of nutrients (primarily P, N and Si) and Cl in groundwater. Nutrient load per time was calculated by multiplying discharge (L^3/T) times concentration (M/L^3). Because of Clear Lake's nature as a flow-through lake, nutrients will be added to the lake in areas of inflow and lost from the lake in areas of outflow.

Ventura Marsh Biology, Ecology and Biomanipulation

Early in the study, we found that Ventura Marsh (a large wetland that processes 49% of the water budget) was not removing nutrients from the water but was a significant source of nutrients. Experience in other shallow water bodies in Iowa and elsewhere indicated that this was due to impact of non-native fish (carp) on the sediments and vegetation, creating a nutrient supply rather than a sink. We therefore evaluated the effects of a benthivorous fish reduction. After a substantial fish removal was obtained, water clarity increased as a result of decreased suspended sediment and phytoplankton biomass. Water column total phosphorus declined by about 25% from 147 ppb to 115 ppb. Prior to the clear water phase, phytoplankton was phosphorus limited. Zooplankton grazing reduced phytoplankton biomass during the clear-water phase. The biomass of *Daphnia* and *Ceriodaphnia* increased following fish removal. During this period, grazing pressure was high and standing phytoplankton biomass remained low. Phytoplankton appeared to be regulated by top-down control for approximately two months before reverting back to bottom-up control. Changes in water quality due to wind and/or return of juvenile carp may account for the switch back to bottom up control. Macrophyte diversity and density increased after the initiation of the clear water phase. We therefore concluded that restoration of Ventura Marsh and carp control could be one potentially viable remedial measure for decreasing nutrient flux into Clear Lake.

Watershed Loads, Tributaries and Nutrient Budgets

Various tributaries to Clear Lake were sampled to identify areas contributing greatest nutrient loads. A total of 37 sampling stations were established across the watershed. Inputs of various elements were calculated multiplying concentrations by the water (hydraulic) loading rate at each point. The study spanned one very wet year and one very dry year. The amount of precipitation has a large impact on the overall nutrient loading rate as well as the distribution of the nutrient loads among the many potential sources.

Much of the watershed lies in the agricultural region to the west of the lake, thus much of the phosphorus entering the lake comes from agricultural lands. The average phosphorus budget for the lake indicates that 43% derives from the agricultural watershed, 7% from groundwater, 6% from the City of Clear Lake, 2% from the City of Ventura, and 2% from unconsolidated county urban lands. An average of 31% of the phosphorus budget derives from direct rainfall on the lake, since Iowa's rainfall phosphorus has been enriched 10-fold with airborne phosphorus over the past 30 years. The large amount of phosphorus deriving from direct rainfall was somewhat surprising and ironically makes remediation more difficult because of the small watershed to lake area ratio. Another surprise is the high phosphorus concentration of groundwater. Groundwater concentrations were quite high, suggesting that phosphorus has moved down through the soil profile enriching the groundwater. Another surprising result was that 9% of the lake's overall phosphorus budget derives from internal loading from Ventura Marsh. Ventura Marsh provides much of the water flowing into Clear Lake and concentrations of major nutrients in this water are very high (average 350-400 ppb of phosphorus). Because of carp activities and poor aquatic plant development in the marsh, however, somewhat more phosphorus leaves the marsh than enters, indicating that the marsh is a net source of sediments and does not cleanse water as large wetlands usually do. Nutrient loading to the lake should generally be much higher in wet years than dry ones, and the fraction of the nutrient budget derived from rain and groundwater declines substantially under wet conditions.

Although the predominance of agricultural lands in the watershed makes them a major overall nutrient source, nutrient losses per unit land area indicate areas where nutrient losses are most severe. In general, phosphorus losses were somewhat higher (per unit area) from urban lands than agricultural lands. This indicates that substantial reductions in phosphorus input could be achieved by both urban and agricultural communities. Sediment losses from lands varied markedly, indicating broad differences in land use management. Sediments tend to cause water quality impairment on their own, but also carry large amounts of phosphorus with them. Not surprisingly, agricultural areas supply the largest amounts of nitrogen per unit area, likely owing to the prevalent use of pure N fertilizer in Iowa agriculture. Nitrogen is not a large problem for Clear Lake, since phosphorus is generally the production-limiting element.

Because of the importance of agriculture in the watershed, extensive analyses of soil phosphorus and management practices were performed. Eighty-nine percent of the agricultural watershed was planted in corn and soybean rotation, while 7% was planted in continuous corn and the remaining land was under CRP, alfalfa or pasture. Forty-eight percent of the land was managed with chisel plowing in combination with disking and/or field cultivation. Twenty-one percent of the remaining land was in no-till, 18% in ridge-till, 7% moldboard plow and 6% was V-ripped. Forty-four percent of the fertilizer application is incorporated by fall plowing, disking or injecting, which is the environmentally preferred method. On average, P fertilizer was applied to fields 2.2 times over the last 5 years. P fertilizer was typically applied at 65 lb P_2O_5/acre which is a rate that is lower than the recommendation of Iowa State University. Eleven percent of the farmland had received manure in the previous five years. Manured fields in the watershed were very similar in P concentration to those receiving high and/or frequent applications of inorganic fertilizer.

Soil phosphorus was tested using 3 commonly used agronomic soil P tests and two environmental P tests. Although these methods measured different amounts of P, most yielded similar overall results concerning identifying high-testing areas. The survey of soil P status and P management practices of the Clear Lake agricultural watershed was useful to identify areas that may be sources of large P loads to the lake and to identify priority areas where changes in P management practices would be desirable. Approximately one third of the area of the watershed had soil-test P values that were twice to five times higher than levels needed to maximize crop production. Soil test summaries since the 1960s for the two counties surrounding the lake and our survey data from the lake watershed shows that P management practices have markedly increased soil P tests over time. The highest soil-test P values were found in a very small number of fields that received either P fertilizer or manure, which likely are the source of the major proportion of the P being transported to the lake.

Analysis of Clear Lake Fisheries

The fisheries of Clear Lake are an important component of recreation as well as an important indicator of water quality. Because of their importance, fish have been studied in Clear Lake since the early 1940s. The most striking change in the fishery has been the near disappearance of the sunfish family (bluegill, crappie & largemouth bass). These fish are still present but are only occasionally caught. The loss of these important fish is probably due to water-quality mediated declines in aquatic vegetation which are necessary as spawning and nursery cover. Although bullhead and carp have been common in the lake for 50 years, they are now the dominant fish, existing at densities of 150-300 lb/acre and 100-200 lb/acre, respectively. They have probably filled the void left by the bass, crappie and bluegill because of their great tolerance of degraded water quality conditions (e.g., sediment, Cyanobacteria, low oxygen, ammonia). Since resistant fish like carp degrade water quality, successful improvements will need to include management of fish populations to reduce carp dominance. This can be accomplished by (1) improving water quality to enhance vegetation and decrease substances degrading fish habitat, and (2) managing bottom-feeding fish (primarily carp and bullhead) to reduce their abundance.

Point Sources and Potential Pollutants

Part of the diagnostic study examined the point-source input of materials to Clear Lake and the potential for toxic substances to be concentrated in lake sediments. The latter was done in case sediment dredging should be employed as a restoration option. There are currently no permitted point-source dischargers of effluents into Clear Lake. On three occasions over the past five years, however, past exigencies have resulted in the discharge of some pre-treatment sewage effluent into the lake. The largest of these was the discharge of 250,000 gallons of diluted pre-treatment sewage into the lake on June 20, 1998. Total P in this sewage was probably about 1.5 mg/L, meaning that sewage bypasses such as this, although certainly to be avoided, only would supply about 0.02% of the lake's phosphorus budget. This is surprising, but the sheer magnitude of watershed inputs and rainfall are of massive proportions. Sediments contain some materials of concern, notably cadmium, chromium, copper, lead and zinc. Potential sources of these elements are batteries not properly disposed of, leaching from chrome-plated metals, trace sources in agricultural fertilizers, building materials, leaded fuels, lead shot, fishing weights, and leaching from plated steel.

Summary of Diagnostic Study

The diagnostic portion of this study shows that Clear Lake has water quality problems, due to historic and present phosphorus and sediment loading, internal resuspension of sediment and nutrients, and inputs of fecal-derived bacteria. These problems derive from the agricultural and urban watersheds and from the lake bottom. Deep lakes (i.e. >13 ft. (4 m) average depth) generally have better water clarity, lower densities of algae, lower concentrations of suspended particles in the water, and are more likely to lack winter fishkills or other oxygen depletion problems. Shallow lakes like Clear Lake (mean depth=9.6 ft (2.9 m)) have less volume for the dilution of nutrient and sediment inputs. Accumulated sediments also decompose and resuspend and can exacerbate oxygen and nutrient problems. Further, even these nutrient-rich sediments derive from watershed impacts since sedimentation rates increase sharply when eutrophication and deposition of eroded material lead to increased plankton production and carbon-rich detritus.

Anthropogenically eutrophied lakes like Clear Lake suffer many undesirable ecological characteristics (Table 9, Chapter 5 of the Diagnostic Report) most of which can be remediated through better watershed management.

Sediment from watershed runoff has had a major impact on this lake over its lifetime. Sediment flux has reduced the volume of Clear Lake to 38% of its original post-glacial volume, and nearly 25% of that sediment was deposited since 1935. The rate of sediment deposition in the lake may have been reduced in the last few decades due to improved erosion management. Sediment deposition still occurs, however, so Clear Lake is becoming shallower and smaller with the passing years.

Runoff from the watershed contributes bacteria, nutrients, and turbidity to the water and leads to algal blooms, reduced transparency, and great concentrations of suspended solids. In the long term, sediments accumulate in the lake basin and cause water quality problems that are common to shallow lakes. Eventually, lake basins can fill to the point that they are no longer useful for recreation. Nutrients in the excess quantities found in Clear Lake impair many aspects of water quality.

Feasibility of Lake Restoration

Clear Lake is an excellent lake of outstanding potential for recreation and is of very great economic importance. Improvement of water quality could benefit from the activities of many at all levels, including citizens and municipal, county, state and federal government agencies. The following restoration alternative suggestions are designed to reverse the eutrophication and sedimentation processes by improving the nutrient retention of the watershed and by deepening parts of the lake. Preventative measures in the watershed are necessary to slow the input of new nutrients and sediments into the lake, so that the restored lake can have an enhanced lifetime and improved water quality.

Principle restoration measures suggested are:

- reduction in phosphorus inputs to the lake,
- reduction in bacteria inputs to the lake,
- improved management of bottom sediments, siltation, erosion, and fish populations to reduce turbidity and nutrients due to sediment.

We project that phosphorus loading to the lake can be reduced by 50-60% by implementing practices designed to address these issues. This will lead to a substantial increase in water clarity and improved biological function.

Improving watershed management and increasing the depth of certain parts of the lake by dredging are two important aspects of this lake restoration plan. These management approaches compliment each other; dredging helps to restore the basin by increasing water depths and watershed restoration helps improve water quality and decelerate the rate at which the lake will degrade in the future. We suggest that both approaches would be most effective if adopted together; for it will do little good to remove the sediments from the lake if soil erosion and nutrient loads rapidly return sediment and phosphorus to the lake, while watershed restoration would only restore the water quality of the supply to a lake of short life and dubious aquatic potential.

Watershed management activities identified that would benefit Clear Lake include: land conservation by planting permanent vegetation, pond and wetland installation, Ventura Marsh renovations, water control structure renovations, dredging, fish barrier construction, and post-restoration lake monitoring. The total estimated cost for these activities is $15,555,300. Respondents to the Clear Lake survey indicated a willingness to pay of $19.5 million to avoid the deterioration of Clear Lake. Alternatively, respondents are willing to pay about $40 million for quality improvements at the lake. These numbers represent the value to visitors and residents of water quality improvements. In considering whether investments to clean up the lake are worth the costs, these value estimates provide the appropriate baseline for comparison. These large values associated with water quality improvements at the lake are consistent with the lack of good substitutes and the potential quality of this unique resource.

If no restoration options are employed, the lake will become more and more eutrophic, and thus become a less attractive recreation resource. Additionally, in time ,the lake will fill to the point that its value as a recreational lake declines dramatically. Long before that time, however, severe water quality problems will be encountered. The combination of watershed improvements and lake dredging will enhance the recreational value of the lake and greatly prolong its useful life. Watershed restoration and lake deepening will act to reduce nutrient inputs and dilute their effect in the lake, however, the lake is still likely to have some water quality problems due to algae blooms and low transparency. This is due to the limits on restoration imposed by phosphorus-rich precipitation and groundwater.

How long will it take? It should be noted that the time-course of response to nutrient abatement is likely to be quite long. Researchers have analyzed a number of cases in which external nutrient loads were reduced substantially. They found that short-term (<5 years) improvements were only noted in about half the lakes and that most lakes take more than 5 years for changes to begin to be detected. In shallow lakes, the problem is exacerbated by internal loading, so changes may be very slow. Lakes may improve over a decade or two before the equilibrium level is approached. The time-course of restoration should therefore be expected to be 5-30 years depending upon the speed and degree to which restoration activities are undertaken.

CHAPTER 1

An Introduction to Clear Lake, Iowa

An Introduction to Clear Lake, Iowa

John A. Downing, Jeff Kopaska, Rebecca Cordes, and David Knoll

A. Identification and location.

Clear Lake is one of Iowa's 34 natural, glacial lakes, and it is one of 27 that are managed for water-based recreation and fishing. It discharges into Clear Creek at Clear Lake, Iowa. The lake is located in Sections 13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26 and 28 of Township 96 North, Range 22 West of Cerro Gordo County, Iowa. The location of the lake within the state and Cerro Gordo County is shown in Figures 1 and 2. The surface area of the lake is 1,468 hectares (3,625 acres) when the water elevation is at 373.9 meters (1226.8 feet) above mean sea level (MSL). The surface area of the watershed is 4,888 hectares (12,079 acres), with nearly level to steeply sloping topography. Prairie-derived soils in this area were developed from Wisconsin glacial till. The major soil association in the watershed is Canisteo-Nicollet-Clarion. A spillway is located along the eastern shore of the lake and drains the lake at an elevation of 373.9 meters (1226.8 feet) MSL into Clear Creek.

Lake Name:	Clear Lake
State:	Iowa
County:	Cerro Gordo
Nearest Municipalities:	Clear Lake, Ventura
Latitude:	43° 08′ 01"N (gauging station)
Longitude:	93° 22′ 57" W (gauging station)
EPA Region:	7
USGS Major Basin Name:	Upper Mississippi
USGS Minor Basin Name:	Iowa-Skunk-Wapsipinicon
USGS Hydrologic Unit Code:	07080203
Major Tributaries:	Ventura Marsh
Receiving Water Body:	Clear Creek

B. Geological description of the basin.

Clear Lake is Iowa's third largest natural lake, and the lake measures 8 km (5 miles) long and has a maximum width of 3 km (2 miles) in the eastern portion. Clear Lake is rather shallow with a maximum depth of 5.8 meters (19 feet) and a mean depth of 2.9 meters (9.5 feet). The watershed is drained by many small tributaries, and the greatest portion (47%) of surface flow passes through Ventura Marsh on its way to the lake. The watershed to lake ratio of 2.3:1 is very small compared to most Iowa lakes. Land use in the watershed consists primarily of cropland (59%), urban areas and roads (14%), and marsh (9%). Watershed land use practices are discussed in detail in Chapter 10 (pages 233-259).

Clear Lake and its watershed lie in the Algona-Altamont moraine complex of the Des Moines Lobe. The watershed has a varying topography with slopes from 0 to 25 percent. The soils of the watershed are prairie- and forest-derived (Fig. 3), and the dominant soil associations are Canisteo-Nicollet-Clarion and Clarion-Webster-Nicollet. The most common soil series found in the watershed are Clarion (25%), Webster (14%), and Canisteo (10%), and the distribution of these series is shown in Figure 4.

Hydrologic soils groups are used to help estimate runoff from precipitation. Soils are grouped according to their ability to absorb water when the soils are wet and receive precipitation from storms of long duration. Combinations of groups are used for heterogeneous soil complexes.

Group A soils have a high infiltration rate (low runoff potential) when thoroughly wet. These soils consist mainly of deep, well drained to excessively drained sands or gravely sands. They have a high rate of water transmission.

Group B soils have a moderate infiltration rate when thoroughly wet. These soils consist chiefly of moderately deep or deep, moderately well drained or well-drained soils that have moderately fine texture to moderately coarse texture. They have a moderate rate of water transmission.

Group C soils have a slow infiltration rate when thoroughly wet. These soils consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. They have a slow rate of water transmission.

Group D soils have a very slow infiltration rate (high runoff potential) when thoroughly wet. These soils consist chiefly of clays that have a high shrink-swell potential, soils that have a permanent high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. They have a very slow rate of water transmission.

Most soils in the watershed (90%) are classified hydrologically as Group B as shown in Figure 5. Group A soils are found in a few locations in the watershed, and Group C and D soils are present, but very rare (Fig. 5).

C. History of Clear Lake and of lake use.

Clear Lake has a long and interesting history as a focal point for recreation in Iowa. This history has been well documented locally and in print. Two of the primary historical documents are "A pictorial history of Clear Lake, Iowa" (Clear Lake Mirror-Reporter 1993) and "Sesquicentennial history book of Clear Lake, Iowa" (Clear Lake Mirror-Reporter 2001). One other historical book about Clear Lake is "White clouds, blue water: the story of Clear Lake" (Herker 1976). These publications provide excellent historical views of the lake and community at Clear Lake. In addition to these locally-produced historical documents, graduate students from Iowa State University have thus far produced over 40 theses and dissertations describing the fish, water, and plankton of Clear Lake (Appendix 1).

Recreationally, Clear Lake has been, and continues to be, intensively used for several reasons. Although there are 7 other lakes within 80 km (50 miles) of Clear Lake, there are no other large water bodies within 30 km (20 miles). Within that 30 km radius are located the cities of Mason City, Clear Lake, Ventura and Garner. Historically, the lake and its surroundings have been intensively developed for public recreational use by the state IDNR.

Estimates of lake use were reported by Bachmann et al. (1994) in A Classification of Iowa's Lakes for Restoration (IDNR, Final Report). These estimates were made by IDNR district fisheries biologists for this report, and are based on a combination of existing reports and professional judgment (Table 1). Estimates were made of the annual total visits to Clear Lake. From these data, the areas adjacent to Clear Lake, such as Clear Lake State Park, Clear Lake City Park, and McIntosh Woods State Park are used extensively for camping and picnicking forms of recreation. Camping and picnicking account for almost 50% of the use of Clear Lake and its surrounding areas while multiple types of fishing and pleasure boating account for another 35%.

Additionally, records have been kept of park use by IDNR park rangers. Total visitation of the lake has increased by more than 50% since 1996 while the number of campers using the lake has increased more than 20% during the same period (Table 2).

D. Comparison of use with other lakes.

Recreation use surveys have been done for major public lakes in Iowa. Estimates of the number of recreational visits per year for lakes within an 80 km radius show that Clear Lake has a great number of visitors and high use intensity, according to IDNR data (Tables 3 and 4). Clear Lake is intensively used for recreational purposes for several reasons, one of which is that Clear Lake and Mason City constitute the regional population center for north-central Iowa (Bachmann et al. 1994). Although there are 7 lakes within 80 km (50 miles) of Clear Lake, none of them are within 30 km (20 miles). Factors that influence the high visitation rate and use intensity include the relatively high local population, the ease of transportation access to the lake, and the size of Clear Lake. Additionally, the lake and its surroundings have been intensively developed for public recreational use by the IDNR.

E. Description of public access.

Clear Lake lies in the western part of Cerro Gordo County in north-central Iowa, and has the cities of Clear Lake and Ventura lying along its shores. The 3,625-acre lake and two bordering state parks, Clear Lake State Park and McIntosh Woods State Park, are managed by the IDNR. Additionally, the cities of Clear Lake and Ventura have city parks that lie along the shores of Clear Lake. Approximately ten percent of the lake's shoreline is in public ownership (Bachmann 1994). There are also 24 public access points to the lake in the city of Clear Lake, and 15 of these have public docks. Clear Lake is one of Iowa's 34 natural, glacial lakes, and is currently managed for recreation and gamefish production.

Clear Lake State Park has one of the most popular campgrounds in the Iowa state park system. The campground contains 215 camping sites, 95 with electric hookups, and modern restrooms. The park also contains more than 10 acres of picnic grounds, an open picnic shelter, a lodge, a 900 foot sandy swimming beach, and playground equipment. A concrete path runs the length of the beach for use by the mobility impaired. The fees assessed at the parks are $20 per day for open picnic shelters, $80 per day for the lodge, $16 per night for an electric hook-up campsite, and $11 for a primitive campsite. (Source: http://www.state.ia.us/parks/brochure.htm)

McIntosh State Park has 50 camping sites, 45 with electricity, modern restrooms, and an open picnic shelter. The park also boasts the only 2 "yurts" (round tent-like structures on a platform containing a futon, bunk bed, and table and chairs) in Iowa parks. The park is also one of the major boat access points for Clear Lake. A modern boat ramp with an extensive area for vehicle and trailer parking is present. The fees assessed at the parks are $30 per day for yurt rental, $20 per day for open picnic shelters, $16 per night for an electric hook-up campsite, and $11 for a primitive campsite. (Source: http://www.state.ia.us/parks/brochure.htm) Ventura Access is located a mile west of McIntosh Woods and features a boat ramp, an open picnic area, a ball field and a new fishing dock designed for handicap access.

There are a number of lakes available for recreation in this part of Iowa, yet Clear Lake is used extensively for water-based outdoor recreation. Like other rural areas in Iowa, there is no public transportation to the lake; however, there is ample access for private transportation. The lake is close to one state highway (107), several federal highways (18, 65, 69), and one interstate highway (35). There are also several paved city and county roads providing immediate access to the lake and parks. The cities of Clear Lake (pop. 8,161) and Ventura (pop. 670) are located on the shores of Clear Lake, and the lake is also 10 miles east of Mason City (pop. 29,172). (Source: http://www.soc.iastate.edu/census/2000.html)

Public transportation is not available for most individuals, however mobility impaired individuals are provided with access to the lake at the public's expense to ensure that all individuals who wish to enjoy Clear Lake can do so. CART (Clear Lake Area Responsive Transit) offers transportation to the lake for mobility impaired Clear Lake residents. Cerro Gordo county residents who are mobility impaired can access the lake through the Cerro Gordo County Public Transit. Public transportation from Opportunity Village in Clear Lake to the lake is also provided for mobility-impaired individuals. Other forms of publicly funded transportation to Clear Lake include student groups from local schools traveling in school buses to the lake for interpretive programs, and to the IDNR fish hatchery for walleye spawning programs. Also, interpretive programs are held at the lake for local Boy and Girl Scout groups.

F. Population and economic characteristics.

The use of Clear Lake is divided between local residents and people from other regions. Local use includes individuals from both Cerro Gordo and Hancock counties, while regional use includes use by people from all of central and north-central Iowa, as well as south-central Minnesota.

Based on the most recent information available from the Iowa State University Sociology World Wide Web page located at http://www.soc.iastate.edu/census/ and 2000 data from Iowa PROfiles (Public Resources Online) World Wide Web page, located at at http://ia.profiles.iastate.edu/, the population of Cerro Gordo County is 46,447 and the population of Hancock County is 12,100. The major population center is Mason City (Cerro Gordo Co.), with a 2000 population of 29,172.

According to the 1998 data, Cerro Gordo County has an average per capita income of $24,902 and Hancock County has an average per capita income of $21,716. Comparatively, the statewide 1998 average per capita income was $24,745. Services, retail trade, and manufacturing are the chief sources of employment in Cerro Gordo County, while manufacturing, services, and farming are the chief sources of employment in Hancock County. According to 1997 statistics, 9.5% of the families in Cerro Gordo County and 8.0% of the families in Hancock County were living below the federal poverty level. The average of families falling below the poverty level for the state of Iowa falls in between these values at 9.1%. On the basis of these comparisons the income levels of the local users of Clear Lake are similar to those of the state, while Cerro Gordo County residents have a higher income than Hancock County residents and residents of the state as a whole. The above data were obtained from the state of Iowa libraries at http://www.silo.lib.ia.us/datacenter/, the sociology server at Iowa State University at http://www.soc.iastate.edu/census/, and from the Iowa PROfiles (Public Resources Online) World Wide Web page, located at http://ia.profiles.iastate.edu/.

Agriculture and related industries are also important sources of income in Cerro Gordo (area = 367,670 acres) and Hancock Counties (area = 366,539 acres). In 1997 there were 822 farms in Cerro Gordo County encompassing 300,851 acres and averaging 366 acres in size. Thus, farmland occupies 82% of the county. During 1997; 138,810 acres of corn and 120,639 acres of soybeans were harvested. In all, 264,004 acres were harvested for grain and forage, which is 88% of the total farmland or 72% of the total land in the county. Also, in 1997 there were 126,766 hogs and 9,418 cattle on farms in Cerro Gordo County. The above data were obtained from the Iowa PROfiles (Public Resources Online) World Wide Web page, located at at http://ia.profiles.iastate.edu/.

The same data source indicates that in 1997 there were 849 farms in Hancock County encompassing 334,050 acres and averaging 393 acres in size. Thus, farmland occupies 91% of the county. During 1997, 165,437 acres of corn and 136,208 acres of soybeans were harvested. In all, 304,229 acres were harvested for grain and forage, which is 91% of the total farmland or 83% of the total land in the county. Also, in 1997 there were 174,621 hogs and 11,616 cattle on farms in Hancock County.

The Clear Lake Chamber of Commerce indicates that Clear Lake has enjoyed an annual impact of tourism worth over $30 million locally every year since 1995. Data for the 1995-1996 fiscal year (April 1995 – March 1996) show this was the first year Clear Lake generated over $30 million (Table 5). Tourism expenditures increased annually and topped out at just over $39 million in 1998-1999, but dropped to around $35 million in 1999-2000. These figures are based upon hotel/motel tax receipts collected annually in Clear Lake, and applied to statistics from U.S. travel expense data for Iowa.

G. **Valuation of Clear Lake Water Quality**. (Written by Cathy Kling, Joe Herriges, and Chris Azevedo, Department of Economics, ISU).

One factor that often determines the value of a lake is its water quality. While it is difficult to establish a monetary value for clean water, it is possible to determine the "willingness to pay" of lake users for maintenance of or improvement upon the present water quality of a lake. This was the goal of the survey reported upon in Chapter 2, Valuing Preservation and Improvements of Water Quality in Clear Lake. This section uses information from the survey, and extrapolates them to get a measure of the total value of water quality maintenance or improvement at Clear Lake.

To determine the total value associated with avoiding deterioration of the lake, it was necessary to add up the reported value of the lake to residents and visitors, appropriately weighted by the numbers of residents and visitors, respectively. The value of the lake to residents and visitors was determined using survey methods, and is described in the following chapter. This method of determining value actually provides a lower bound on the value of avoiding water quality deterioration, as it omits the value placed on water quality improvements by people that neither visit the lake nor live near the lake. This latter type of value is referred to as "nonuse" or "existence" value. It is likely that there are some Iowans who would be willing to pay for water quality improvements despite never visiting of living near the lake.

There are about 2965 residences in the towns of Clear Lake and Ventura, as reported by Survey Sampling Inc. The survey results find respondents report an average willingness to pay of $550 to avoid the deterioration as described in Plan A (Chapter 2). Thus, an estimate of the total willingness to pay of residents to avoid the water quality reduction is about $1,630,000. The estimate of the average value a visitor places on this water quality improvement is about $100. Note that this is a value per visitor household, not per trip. Thus, to arrive at a total value for all visitors, we need an estimate of the number of visitors (households) who visit the lake annually.

The 1999 Clear Lake Creel Survey conducted by Jim Wahl, Bruce Ellison and Gary Vonderohe indicated that 34,800 anglers used Clear Lake in 1999. Of that number, about 77% were from outside the towns of Clear Lake or Ventura; thus, 26,796 (rounded to 26,800) visitors are from outside of the two towns (it is important not to double count residents here as their values are incorporated above). However, this number represents an estimate of anglers only. To estimate the total number of households that use the lake, it is assumed that each angler represents a separate household. The survey asked visitors to indicate the percentage of their time they spent at various activities. On average, visitors report spending 15% of their time at Clear Lake fishing. That is,

0.15(Total time) = Fishing time, or
Total time = Fishing time/(0.15).

The angler data collected in the 1999 Creel Survey assumes that fishing trips are the sole purpose of the trip. If so, or if the relationship between fishing time and total time can be extended to fishing trips and total trips, then an estimate of the total number of visitors engaged in all activities at the lake is provided by

Total number of households visiting the lake = 26,800/(0.15) = 178,650.

Multiplying this estimate of the number of households visiting the lake by an average value of about $100, yields a total value to visitors of avoiding the water quality deterioration of about $17, 865,000. The total value of avoiding the deterioration to both residents and visitors is about $19,500,000 over a 5-year period.

The previous estimate is, of course, very dependent on the estimate of the number of households who visit the lake (178,650). If more accurate estimates of the number of visitors are available, the total value could easily be recomputed. Finally, it is important to note that there is statistical uncertainty associated with these estimates since they are based on a sample of the population. Although it is difficult to precisely compute confidence intervals due to combining data from various sources (survey data and angling visitors), it is suspected that confidence intervals of plus or minus 40% are not unreasonable.

The survey also provides information on a substantive improvement in the conditions of the lake. Performing the same set of calculations as described above, and using the same estimates of household numbers, generates a total value estimate of about $40,200,000 over 5-years.

Finally, we have attempted to estimate a total value for the current users of Ventura Marsh. Guy Zenner (IDNR waterfoul biologist, pers. comm.) has estimated that there are about 1330 hunter days at the Marsh. Using data from previous wetland research conducted by the authors (Iowa Wetlands: Perceptions and Values by Azevedo, Herriges, and Kling. Available online at http://www.card.iastate.edu/publications/texts/00sr91.pdf), it was estimated that hunters made up 32% of the users of Iowa wetlands. Therefore, an estimate of the total number of users of Ventura Marsh is 4156. From the same wetlands research, the value of a visitor day to a wetland was estimated to be about $8 - $17 per day. Therefore, a rough estimate of the annual value of the marsh in its current condition is somewhere between $33,250 and $70,650.

In addition, it is important to emphasize that this represents one year's benefits in a continuing stream, as opposed to the values reported above that represent the total value associated with a project to improve or prevent degradation of the water quality.

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TABLE 1. Itemized summary of 1991-1992 recreational activities at Clear Lake, from Bachmann et al. (1994). Data reflect estimates made by IDNR district fisheries biologists, and were based on a combination of existing reports and professional judgment.

Activity	Total Visits	Use/Hectare	Use/Acre	% of Total Use
Fishing				
From boats	16000	10.7	4.3	3
Shore or ice fishing	24000	16.1	6.5	4
Swimming	105000	70.4	28.5	19
Pleasure boating	160000	107.3	43.3	28
Hunting	1200	0.8	0.3	0.2
Picnicking, camping, other activities prompted by the lake's presence	250000	167.7	67.9	44
Snowmobiling	8000	5.4	2.2	1.3
Ice-skating and cross-country skiing	3000	2.0	0.8	0.5
Total	567200	380.4	154.0	

TABLE 2. Total visits and camping activities at Clear Lake State Park and McIntosh Woods State Park, 1996-2000. Data from Jim Scheffler, IDNR (pers. comm.) as reported to him by local IDNR park staff.

	Clear Lake State Park		McIntosh Woods State Park	
Year	Total Visits	Individual Campers	Total Visits	Individual Campers
1996	197,600	25,941	269,700	10,577
1997	206,275	16,489	301,800	11,230
1998	176,250	23,982	307,000	9,953
1999	201,100	25,588	349,000	8,038
2000	300,300	31,935	361,500	9,225

TABLE 3. Comparison of 2000 recreational use of Clear Lake's state parks with other state parks within an 80 km radius (Jim Scheffler, IDNR, pers. comm.).

Lake	County	Total use	Individual Campers
A.A. Call	Kossuth	71,900	370
Beeds Lake	Franklin	275,000	19,092
Clear Lake	Cerro Gordo	300,300	31,935
McIntosh Woods	Cerro Gordo	361,500	9,225
Pilot Knob	Hancock	128,500	4,275

TABLE 4. Comparison of 1991-1992 recreational use of Clear Lake with other lakes within an 80 km radius. Data are from Bachmann et al. (1994) reflecting estimates made by IDNR district fisheries biologists, and were based on a combination of existing reports and professional judgment.

Lake	County	Lake Size (ha.)	1991-1992 Total Use	1991-1992 Visits/ha. of Lake
Beeds Lake	Franklin	41.0	231,700	5651.2
Clear Lake	Cerro Gordo	1491.0	567,200	380.4
Lake Cornelia	Wright	98.0	87,500	892.9
Crystal Lake	Hancock	108.6	13,979	128.7
Eldred Sherwood Lake	Hancock	8.0	8,063	1007.9
Lake Hendricks	Howard	16.0	30,534	1908.4
Silver Lake	Worth	128.0	3,475	27.1
Lake Smith	Kossuth	24.0	12,690	528.8

TABLE 5. Itemized summary of 1994-2001 hotel/motel tax receipts and calculated annual impact of tourism for Clear Lake. Data were provided by the Clear Lake Area Chamber of Commerce.

Fiscal Year	Hotel/Motel Tax Receipts	Annual Impact of Tourism
1994-1995	$147,732.21	$27,357,816
1995-1996	$163,041.92	$30,192,947
1996-1997	$177,169.69	$34,071,094
1997-1998	$199,007.04	$36,183,098
1998-1999	$214,758.04	$39,046,916
1999-2000	$205,124.65	$35,366,319
2000-2001	$203,681.72	not available

FIGURE 1. Location of Clear Lake within Cerro Gordo and Hancock counties and the state of Iowa.

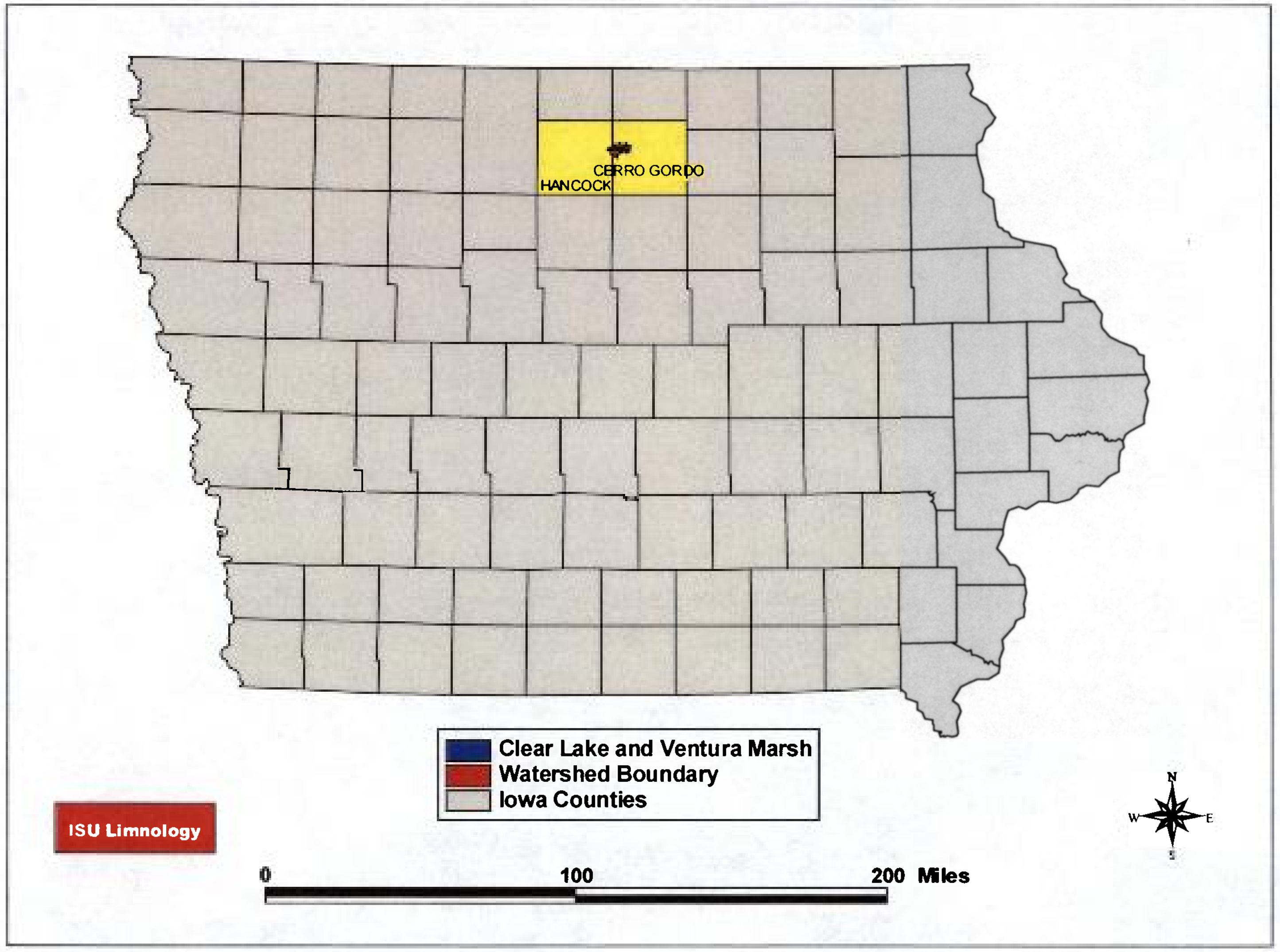


FIGURE 2. Location of Clear Lake within Cerro Gordo and Hancock counties.

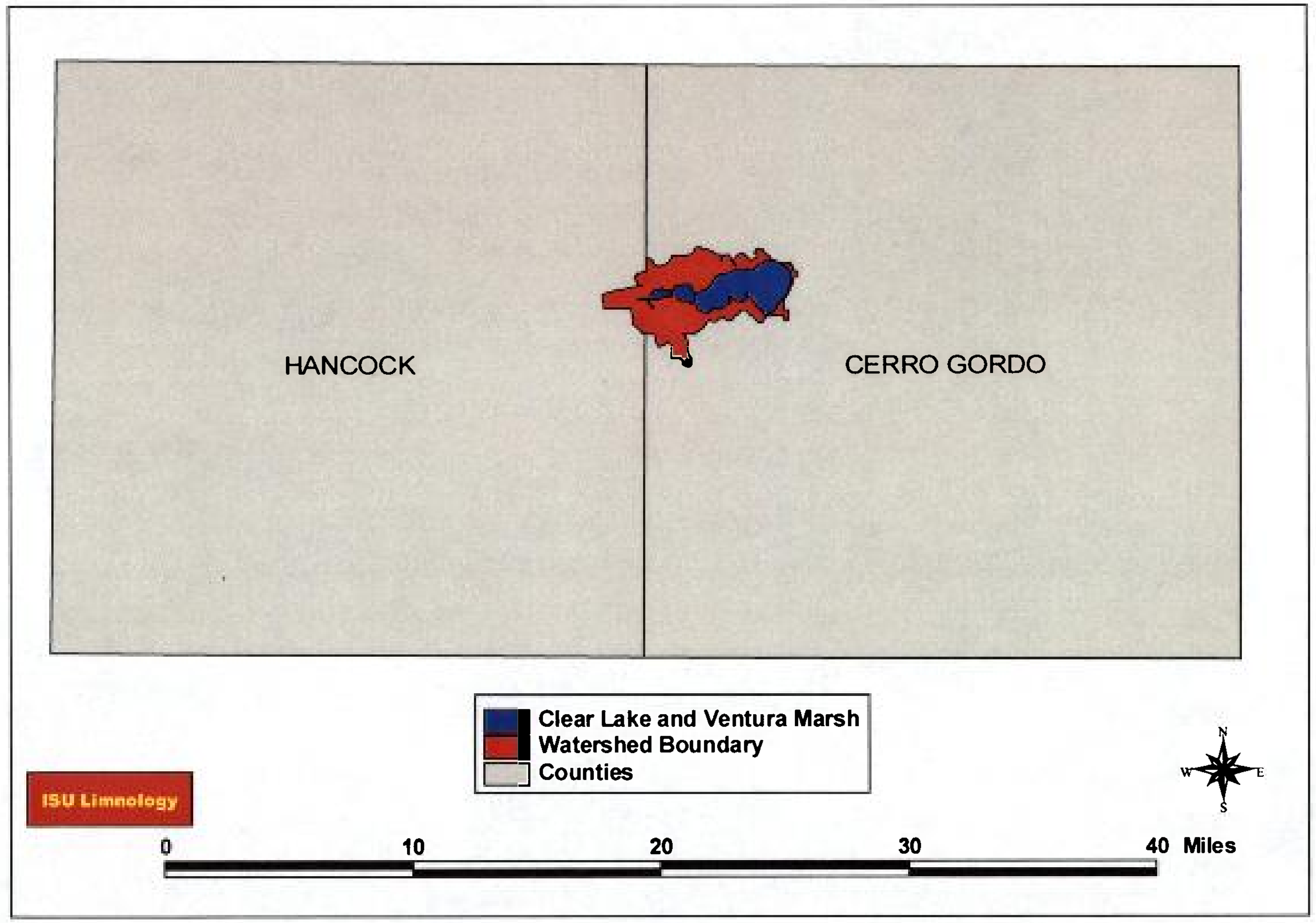


FIGURE 3. Map of Clear Lake watershed representing prairie and forest derived soils.

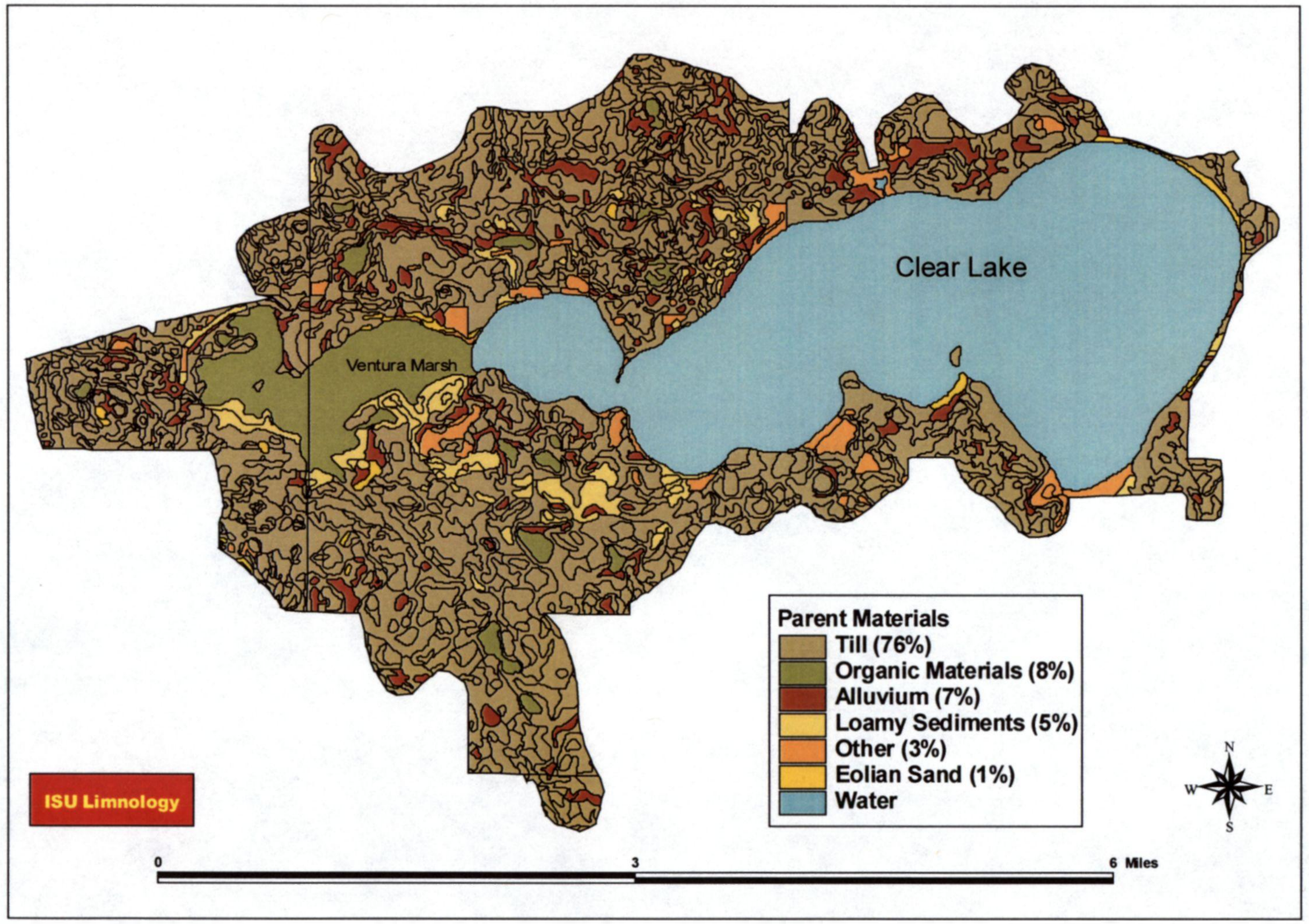


FIGURE 4. Distribution of common soil series in the Clear Lake watershed.

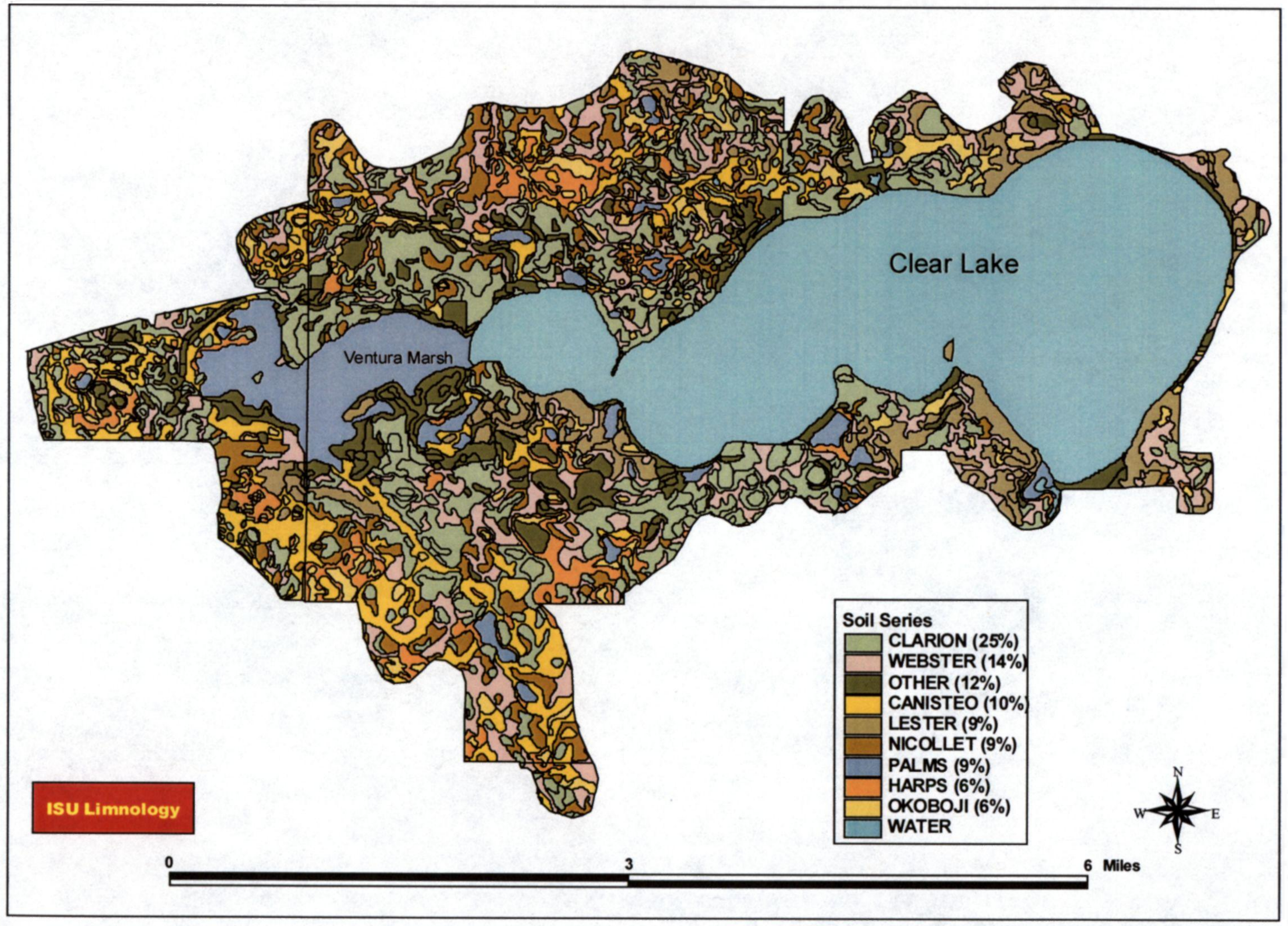
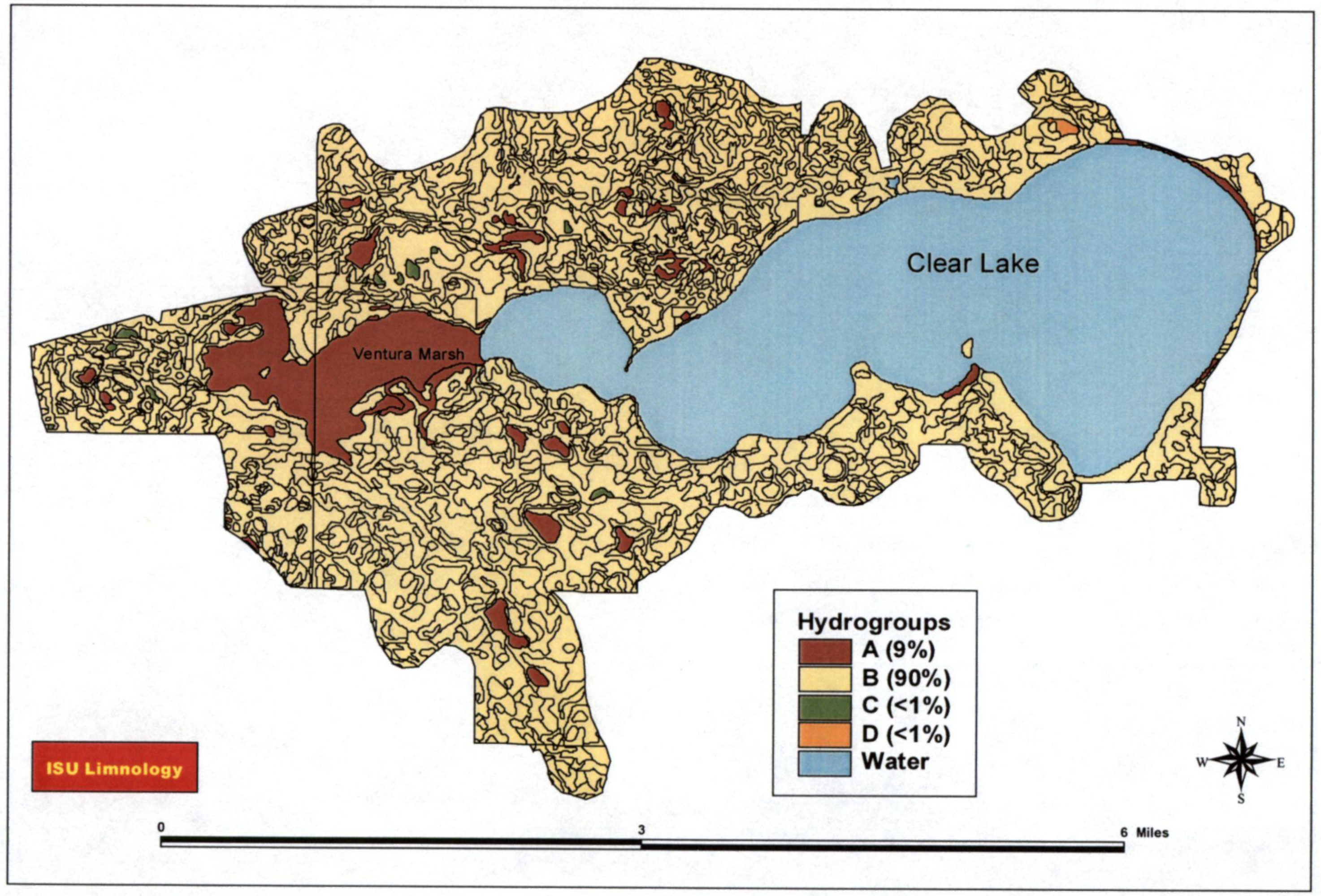


FIGURE 5. Distribution and percentage of soil hydrogroups in the Clear Lake watershed.



CHAPTER 2

Valuing Preservation and Improvements of Water Quality in Clear Lake

Valuing Preservation and Improvements of Water Quality in Clear Lake

Christopher Azevedo, Joseph Herriges, and Catherine Kling

A. Abstract

This report presents summary statistics and other results of a survey of Clear Lake visitors and residents. The purpose of the survey was to collect information concerning use and value of water quality improvements at Clear Lake. Support for the survey was provided by the Iowa Department of Natural Resources.

B. Introduction

This report describes the results of a study on Clear Lake as a recreational resource. It is intended to provide information on recreational usage of the lake, attitudes of recreators and local residents toward possible watershed management changes, as well as estimates of visitor's and resident's willingness to pay for water quality improvements at the lake.

C. Survey Design and Implementation

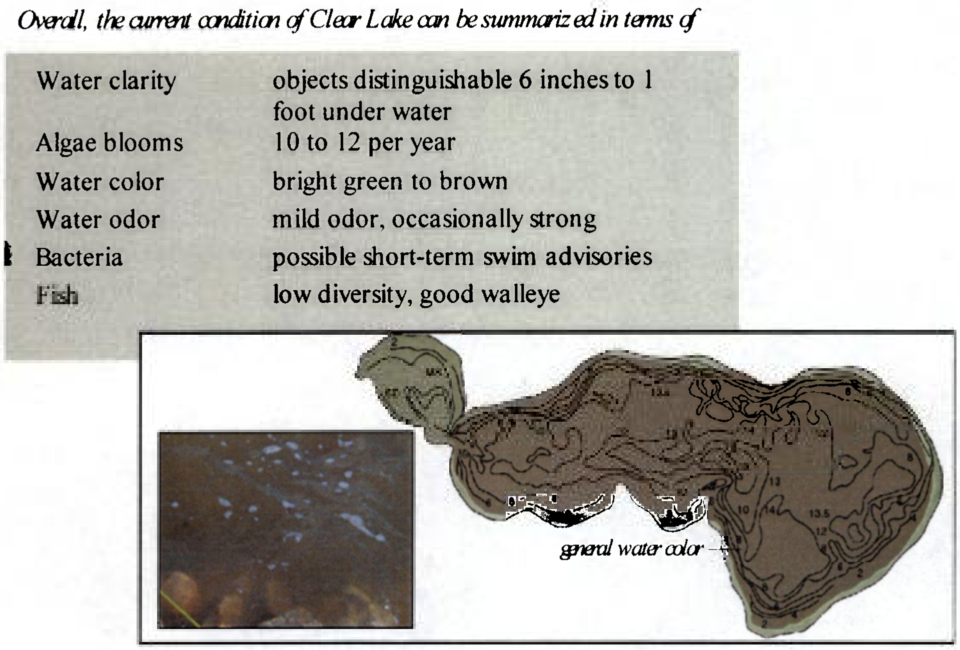
In this section of the report, we provide an overview of the procedures used in selecting the samples and designing the Clear Lake Survey, the implementation procedures used to administer the survey, and the final survey response rates.

1. Sample Selection. Two groups of respondents were targeted to receive the survey: recreational users (visitors) of the lake and local residents. Although other population segments may value water quality improvements at Clear Lake, for example to protect the wildlife habitat the lake provides to migratory birds, we believed that the largest values would be associated with those who actually visit the lake or live in its vicinity. However, it is important to note that all of the information provided in this report relates only to those two population segments: those who have visited the lake at least once, and those who have residences in the cities of Clear Lake or Ventura, Iowa.

To obtain addresses of visitors to the lake, potential respondents were intercepted while engaging in recreational activities at the lake. This occurred during the months of May, June, July, August, and September of 2000. A total of 1,024 recreators agreed to participate in a mail survey that was scheduled for October of that year. They were informed that everyone who returned a completed survey would receive five dollars. The sample of local residents was provided by Survey Sampling, Inc., a sampling firm located in Connecticut. The sample of 900 names was randomly drawn from the white page listings for the cities of Clear Lake and Ventura, Iowa.

It is important to note that the sampling of visitors on site, as was done here, will produce a sample that does not accurately represent the true population of visitors. This is because individuals who take more than the average number of trips have a higher chance of being intercepted and interviewed than their true representation in the population. Likewise, individuals who take fewer than the mean number of trips will be under-represented in the sample. It is thus necessary to adjust the data by re-weighting the observations so that they appropriately represent the actual population. All summary statistics reported here have already been appropriately adjusted.

2. Structure of the Survey. The surveys mailed to the two groups (visitors and residents) were very similar. The survey was designed to focus on how the respondent values different levels of water quality at Clear Lake. In order to provide a baseline level of quality for the respondent, current conditions at Clear Lake were described. This description was developed in consultation with limnologists John Downing and Jeff Kopaska of the Department of Animal Ecology at Iowa State University, both of whom have studied the water quality conditions at Clear Lake. Both versions of the survey contained the following description of the current conditions at the lake.



Overall, the current condition of Clear Lake can be summarized in terms of

Water clarity	objects distinguishable 6 inches to 1 foot under water
Algae blooms	10 to 12 per year
Water color	bright green to brown
Water odor	mild odor, occasionally strong
Bacteria	possible short-term swim advisories
Fish	low diversity, good walleye

Respondents were then presented with various plans, each describing a different overall condition of the lake (as defined by the above attributes), and were asked about their willingness to pay for the plan. Plan A described a decrease in water quality, and Plan B described an increase in water quality. Data pertaining to both of these plans will be summarized below.

In addition to the valuation questions, both versions of the survey also contained questions pertaining to the respondents' support for various projects for improving water quality, their opinion concerning various land use changes, and the water quality attributes most important to them. Finally, socioeconomic information was gathered from all respondents.

The visitor's and resident's versions of the survey differed in that the visitor's version collected information on the number of recreation trips the respondent took to the lake in the past year, as well as information on the number of trips the respondent planned to make in the coming year under various scenarios. The visitor's and resident's versions of the survey are contained in Appendices 2 and 3.

3. Response Rates. The visitor's version of the survey was mailed in mid October while the resident's version was mailed in early December. For both versions, respondents who did not return the survey were sent a reminder postcard approximately two weeks after the initial survey was mailed. After approximately two more weeks, survey recipients who still had not returned the survey were sent a second copy of the survey. Of the 1,024 surveys mailed to the group of visitors, 26 were returned by the post office as undeliverable. Of the deliverable surveys, 662 were returned, resulting in a 66 percent response rate. Of the 900 surveys mailed to the group of local residents, 132 were returned as undeliverable. Of the deliverable surveys, 443 were returned, resulting in a 58 percent response rate.

D. Survey Results

In this section of the report we provide summary statistics from the Clear Lake survey, focusing on (*1*) reported visitation, (*2*) spending patterns, (*3*) attitudes toward various watershed and land use changes and (*4*) implied valuations.

1. Visitation. On average, visitors reported a high usage of Clear Lake between November 1999 and October 2000. The average total number of trips taken was 6.6. Of those trips, an average of 2.67 were multiple day visits (i.e. the respondents spent at least one night in or around Clear Lake). Respondents indicated that they expected to make an average of 6.63 trips to Clear Lake over the next year. Respondents reported having visited Clear Lake an average of 3.63 times over the past five years. Table 1 shows the average number of trips (both multi-day and single-day) reported by time period, while Figure 1 shows the average percentage of time devoted to various activities reported by respondents. As expected, a majority of trips were taken during the summer months. The most popular recreation activity engaged in by visitors was recreational boating.

Table 2 shows the average number of trips taken from November 1999 through October 2000 to other lakes and reservoirs. Minnesota lakes, Saylorville Lake, the Mississippi River, and other unlisted lakes appear to be the main alternatives to Clear Lake.

TABLE 1. Average number of trips by time period

Time Period	Number of Visits
November 1999 through February 2000	0.62
March 2000 through May 2000	1.13
June 2000 through August 2000	3.70
September 2000 through October 2000	1.13

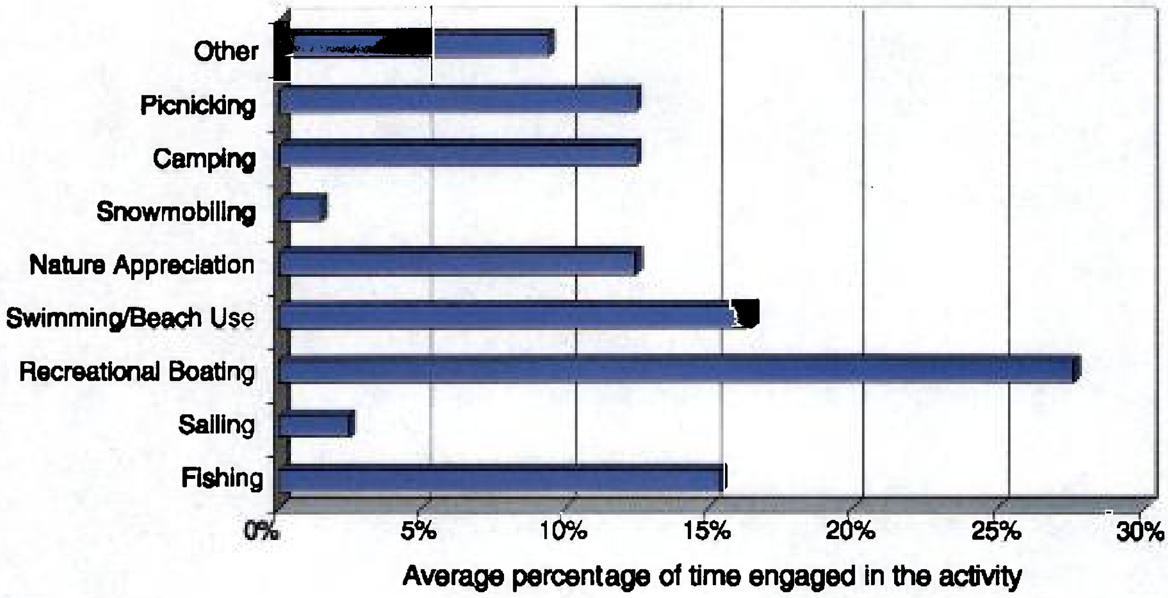


FIGURE 1. Clear Lake activities

TABLE 2. Average number of trips taken to other lakes and reservoirs

Lake or Reservoir	Number of Visits	Lake or Reservoir	Number of Visits
Lake Okoboji-East and West	0.98	Lake Odessa	0.05
Lost Island Lake	0.03	Rathbun Reservoir	0.97
Rice Lake	0.36	Mississippi River	0.77
Spirit Lake	0.23	Minnesota Lakes	1.76
Storm Lake	0.10	Wisconsin Lakes	0.19
Tuttle Lake	0.04	Lake Red Rock	0.40
Saylorville Lake	1.96	Other	2.78
Coralville Reservoir	0.12		

2. Spending. Respondents reported spending an average of $51 in or near the town of Clear Lake on a typical visit. Respondents from Iowa reported spending an average of $48 per trip, while out-of-state respondents reported spending an average of $93 per trip.

Spending can also be categorized by the type of trip taken. Respondents who took only single-day visits reported spending an average of $26 per trip, while respondents who took only multi-day visits reported spending an average of $98 per trip.

3. Opinions. Respondents were asked to allocate 100 importance points to the lake characteristics listed in Figure 2. The average point allocation is shown for both visitors and residents. Safety from bacterial contamination is the most important characteristic for both visitors and local residents. As expected, those characteristics associated with water recreation are slightly more important to visitors, while water clarity and lack of water odor are slightly more important to local residents.

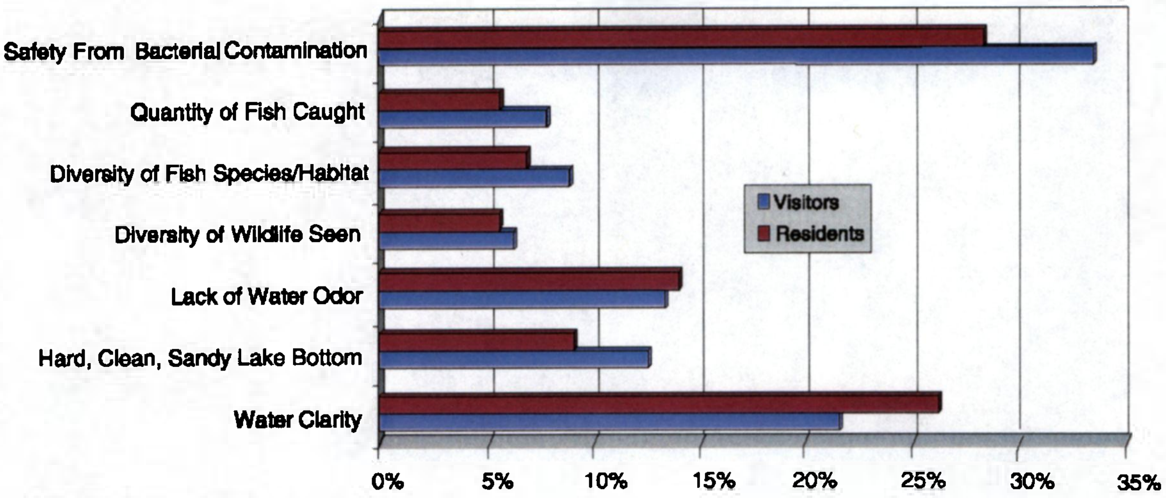


FIGURE 2. Importance points

Figures 3, 4, 5, and 6 show respondent's opinions toward various water quality projects and land use changes. In general, both visitors and local residents appear to either support, or are indifferent to, most projects and land use changes. Very few respondents in either group oppose repair of storm drains or restoration to Ventura Marsh. Restrictions on residential development are supported by roughly 75 percent of local residents surveyed, with fewer than 10 percent opposing restrictions.

The issue that generated the most opposition among respondents was the institution of non-motor boat days. Roughly 40 percent of visitors oppose non-motor boat days, with about 34 percent supporting them. In the case of local residents, roughly 30 percent oppose non-motor boat days, while about 45 percent support them. Increased no-wake zones are supported by about 60 percent of local residents and about 43 percent of visitors. Roughly 70 percent of local residents and only about 37 percent of visitors support limiting motor horsepower. There appears to be wide support for restoration of woodlands, prairies, and wetlands in both groups.

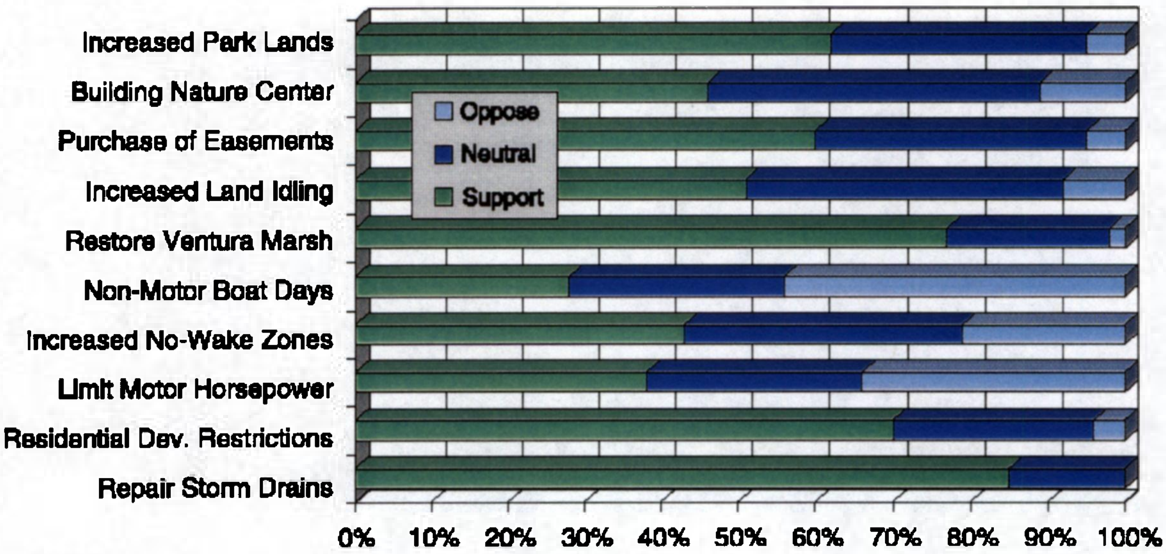


FIGURE 3. Projects: visitors

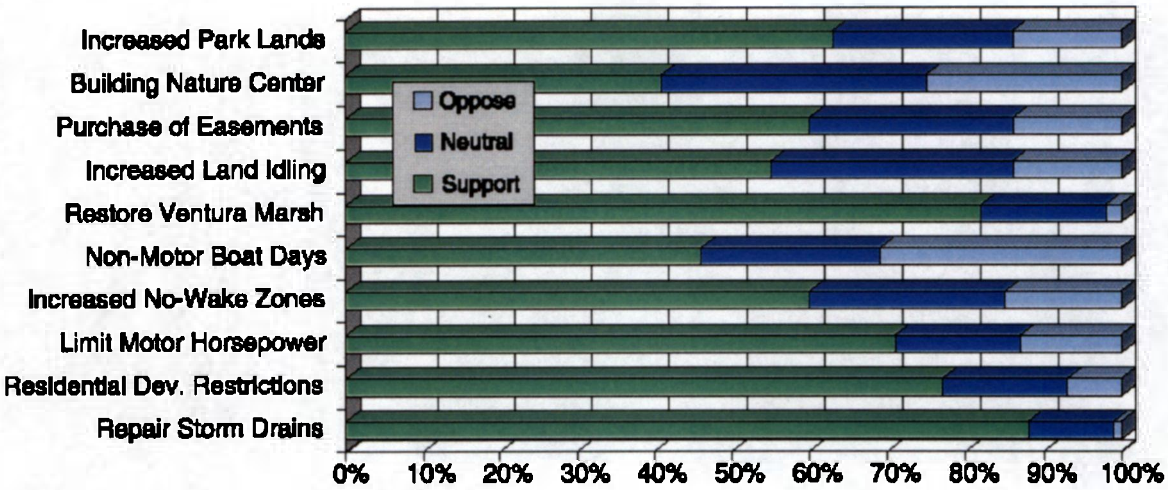


FIGURE 4. Projects: local residents

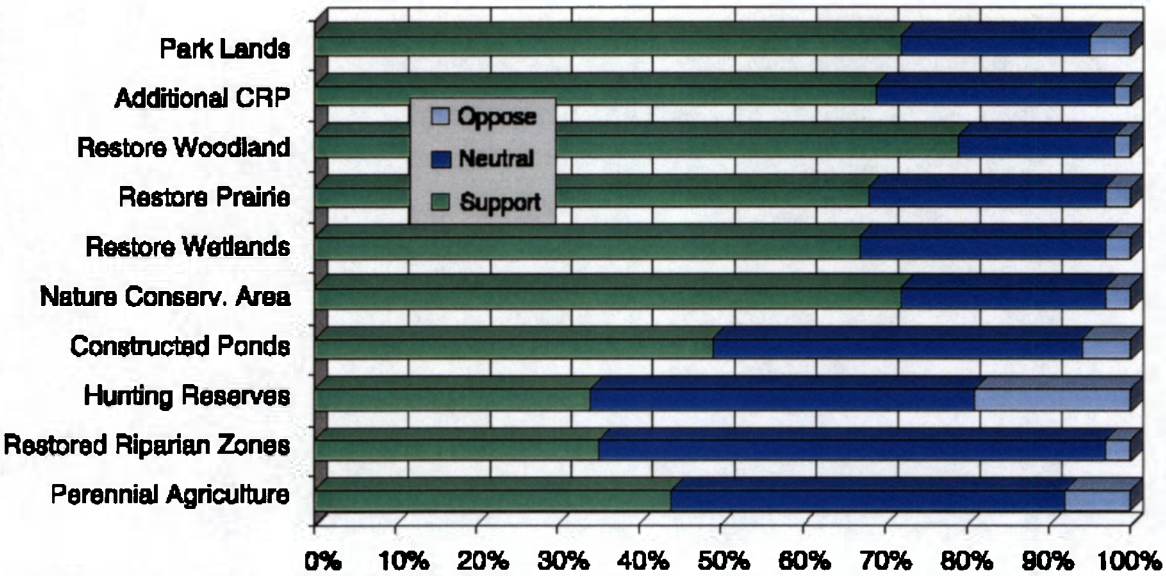


FIGURE 5. Land use changes: visitors

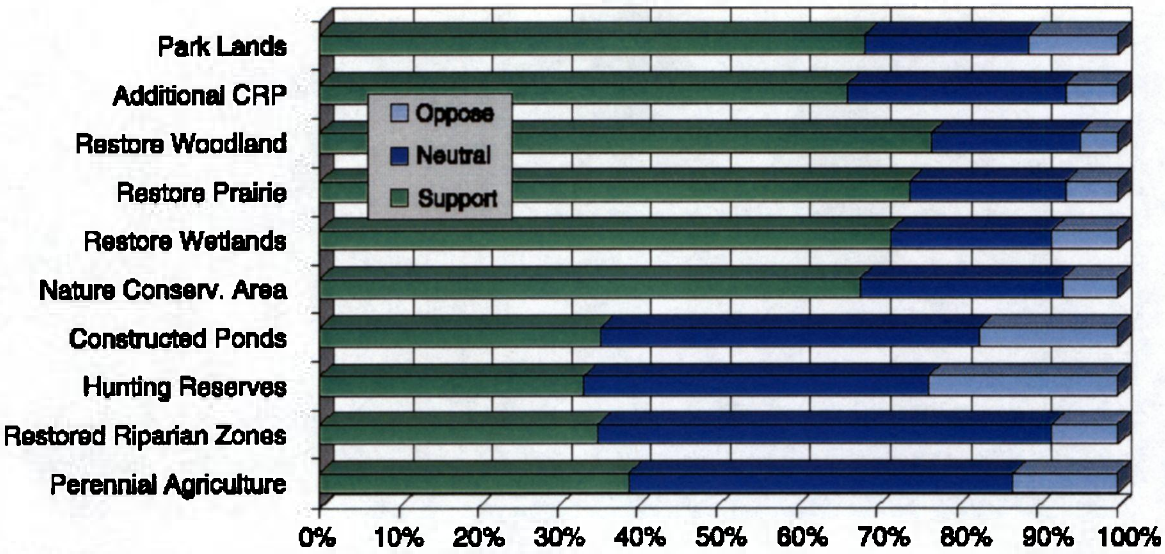


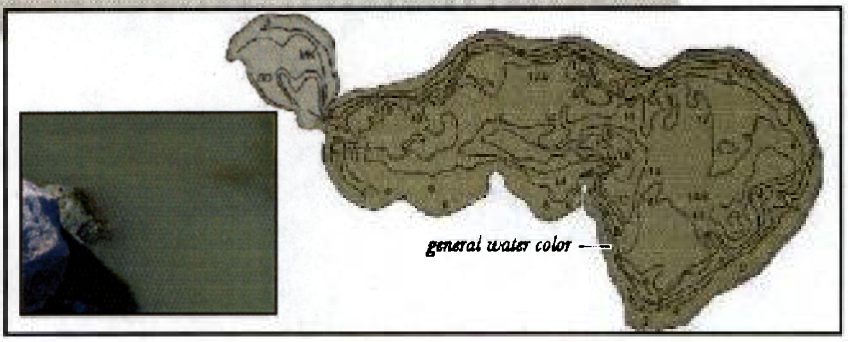
FIGURE 6. Land use changes: local residents

4. Valuation. One important goal of the survey was to estimate the value that both visitors and local residents place on the preservation and/or restoration of Clear Lake. Conservation budgets are tight and there are more projects than there is money to fund them. Thus, society must decide where to focus the available resources, both private and public sources. To help with these decisions, economists have devised methods to measure the value people place on environmental goods as measured by their willingness to pay for the goods. Two of these techniques are employed in this study. The first method is based on observing the public use of a natural resource (visits to the lake) and inferring visitors' willingness to pay for the resource from their behavior. The second method is based on directly asking whether people are willing to pay various sums of money to support a particular project.

The first value estimated in this study is the willingness to pay for the existing level of Clear Lake visits. This can be thought of as providing a baseline of the value visitors place on preserving the existing level of the resource in terms of how much enjoyment they get from Clear Lake at its current level of water quality. Based only on the reported single-day trips data, the average recreational value per season of Clear Lake is $28 per visitor. Analysis of multiple-day trips has not been completed to date and is not represented in this value. Since 25 percent of the reported trips to the lake were multiple-day trips, they represent a potentially significant source of value.

Next, the value of various water quality changes was estimated. Both the visitor's and resident's version of the survey contained a scenario entitled Plan A. The description of the plan stated that if nothing is done to improve the water quality of the lake, it is likely to deteriorate over the next decade. Specifically, respondents were told to suppose that the conditions at Clear Lake were as follows:

Water clarity	**objects distinguishable 1 inch to 5 inches under water**
Algae blooms	**constant**
Water color	**fluorescent green**
Water odor	**always strong**
Bacteria	**frequent swim advisories and/or beach closings**
Fish	**low diversity, mostly rough fish**



They were then asked the following question, "Would you vote yes on a referendum to maintain the current water quality of Clear Lake and avoid the deteriorated water quality as described under Plan A? The proposed project would cost you $B (payable in five [$B/5] installments over a five-year period). In this question, the value of "B" was varied so that different respondents were faced with different project costs.[1] Figure 7 plots the relationship between the percentage of visitors indicating they would be willing to pay the stated amount along the horizontal axis. Roughly 85 percent would be willing to pay $30 toward this plan ($6 annually for five years), but only about 20 percent would be willing to pay $150. Based on these data, the average willingness to pay is approximately $104 per visitor in support of Plan A.[2]

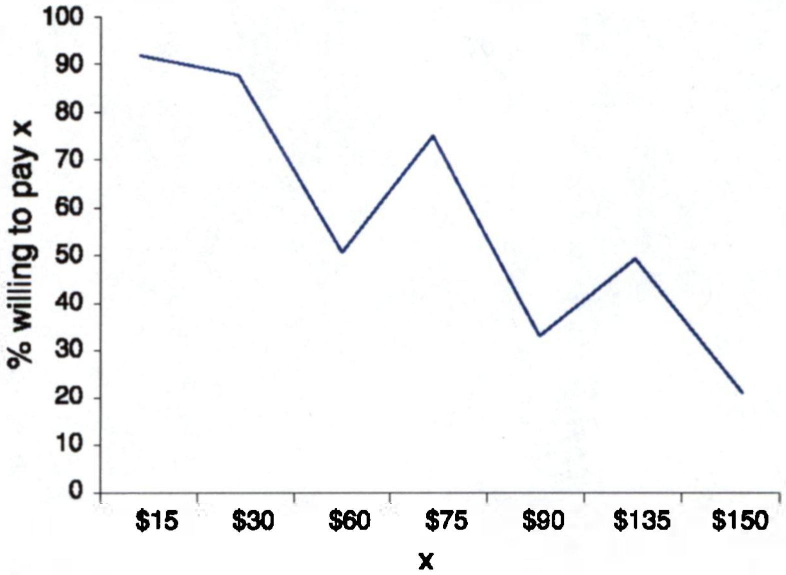


FIGURE 7. Willingness to pay for Plan A: visitors

Figure 8 plots the relationship between the percentage of local residents indicating they would be willing to pay the stated amount along the horizontal axis. Though the trend is somewhat less pronounced for the local residents, statistical analysis clearly indicates that fewer people are willing to contribute at the higher bid levels. On average, local residents would be willing to pay approximately $568 in support of Plan A. This significantly higher value for residents is not surprising given their continuous exposure to the lake and its attributes.

While Plan A focused on the respondent's willingness to pay to avoid a deterioration in water quality, Plan B focused on willingness to pay for improvements in water quality. Two versions of Plan B were created: the first described a program that would result in a moderate improvement in water quality over the next five to ten years, while the second described a program that would result in a substantial improvement in water quality over the next ten to twenty years. Both versions are shown below.

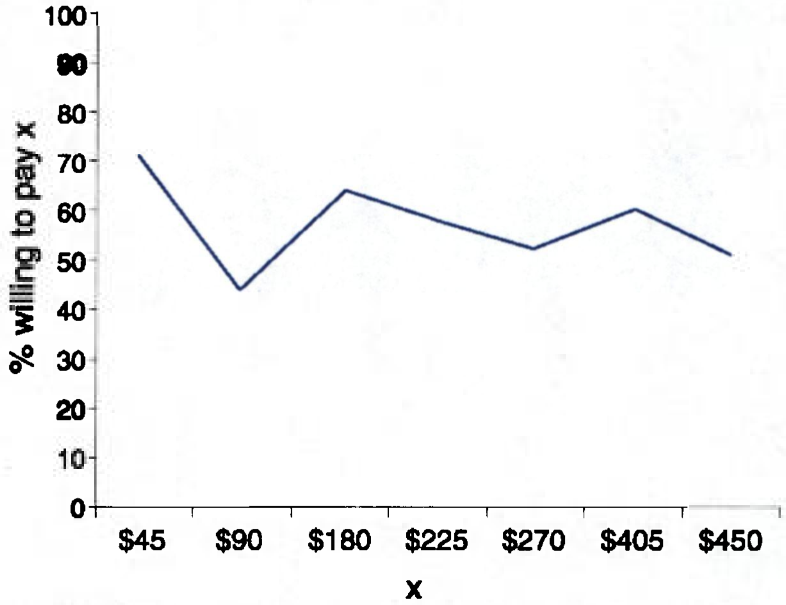
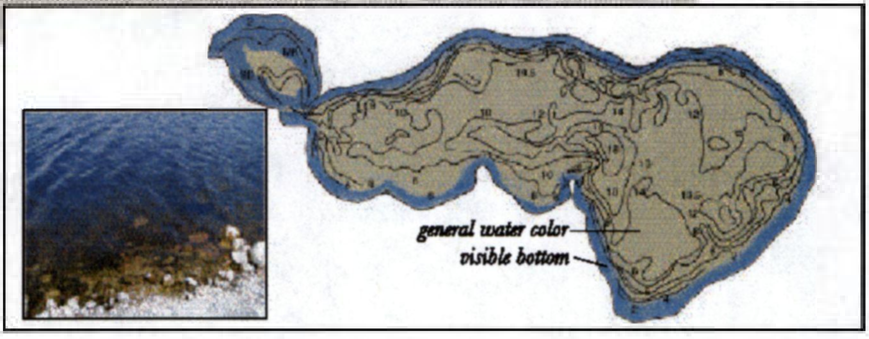


FIGURE 8. Willingness to pay for Plan A: Local residents

Water clarity	objects distinguishable 2 to 4 feet under water
Algae blooms	6 to 8 per year
Water color	green to brown
Water odor	occasional mild
Bacteria	occasional swim advisories
Fish	low diversity, good walleye



Water clarity	objects distinguishable 10 to 12 feet under water
Algae blooms	0 to 1 per year
Water color	blue
Water odor	none
Bacteria	none
Fish	high diversity

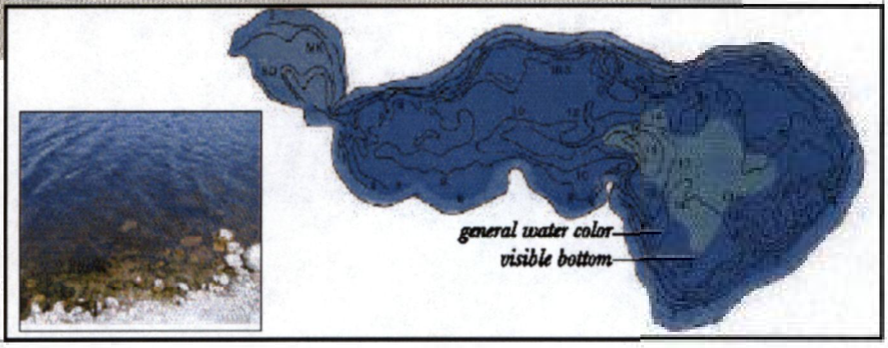


Figure 9 shows the data from the visitor's survey for the low quality improvement. As before, the relationship between the percentage of respondents indicating they would be willing to pay the stated amount of the horizontal axis is plotted. Based on these data, visitors would, on average, be willing to pay approximately $85 in support of the low quality improvement described in Plan B.

This value is actually less than the $104 visitors were willing to pay for Plan A, which simply maintained the current lake conditions. However, the two results are not statistically different, suggesting that visitors are willing to pay roughly $100 to maintain the lake, but little, if any, for modest improvements.

Figure 10 shows the data from the local resident's survey for the low quality improvement. Based on these data, local residents would, on average, be willing to pay approximately $550 in support of the low quality improvement described in Plan B. Again, this value is slightly lower than the $568 local residents were willing to pay for Plan A, though the two are not statistically different. This indicates that local residents are willing to pay roughly $550 to maintain the lake, but little, in any, for modest improvements.

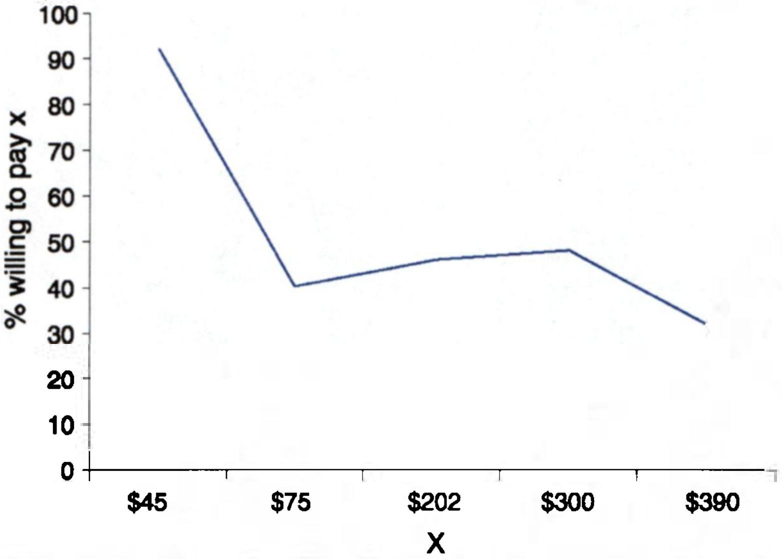


FIGURE 9. Willingness to pay for Plan B, low improvement: visitors

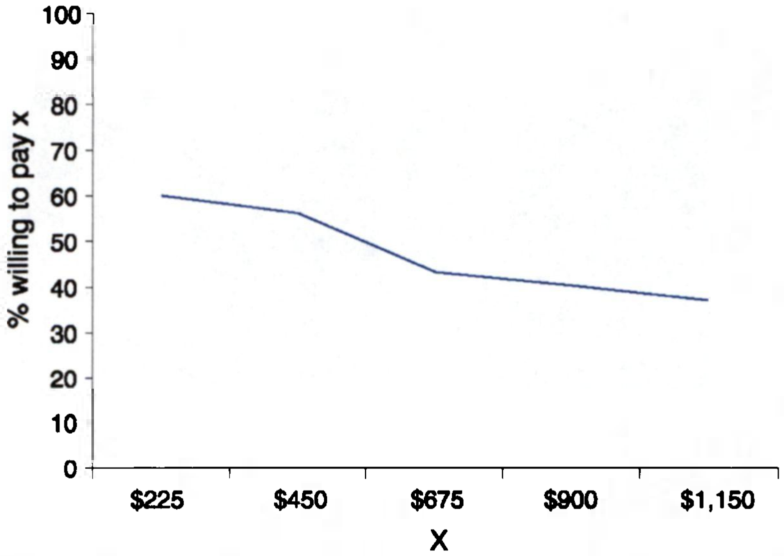


FIGURE 10. Willingness to pay for Plan B, low improvement: local residents

Figure 11 shows the data from the visitor's survey for the high quality improvement. Based on these data, visitors would, on average, be willing to pay approximately $425 in support of the high quality improvement described in Plan B.

In addition to the values described above, visitors indicated that the quality changes described in the survey would affect the number of trips they would expect to take. As described above, visitors indicated that they took an average of 6.60 trips between November 1999 and October 2000. They also reported that over the course of the next year they expected to make 6.63 trips to Clear Lake. After each quality change plan was described, the respondent was asked to consider all the recreation trips they made to Clear Lake in the past year, and report the number of trips they would have made if conditions were as described in the plan. This information is summarized in Figure 12.

The response to the decreased water quality described in Plan A is dramatic. With the decrease in water quality, visitors would take an average of about two trips. Visitors also responded to the higher water quality scenarios by indicating that they would increase the number of trips they would take. With the low quality improvement, respondents would take an average of 7.03 trips, while with the high quality improvement, respondents would take an average of 10.32 trips.

The average income level reported for the visitor's survey was $45,000. Average household size was about 3 people, and about 61 percent of the respondents were male.

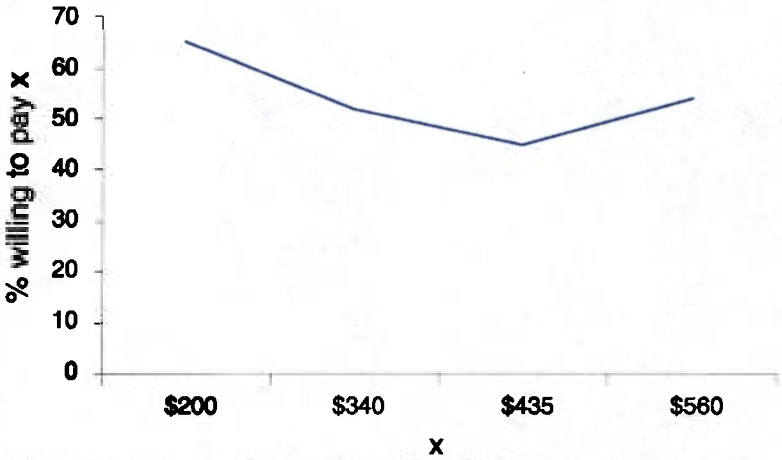


FIGURE 11. Willingness to pay for Plan B, high improvement: visitors

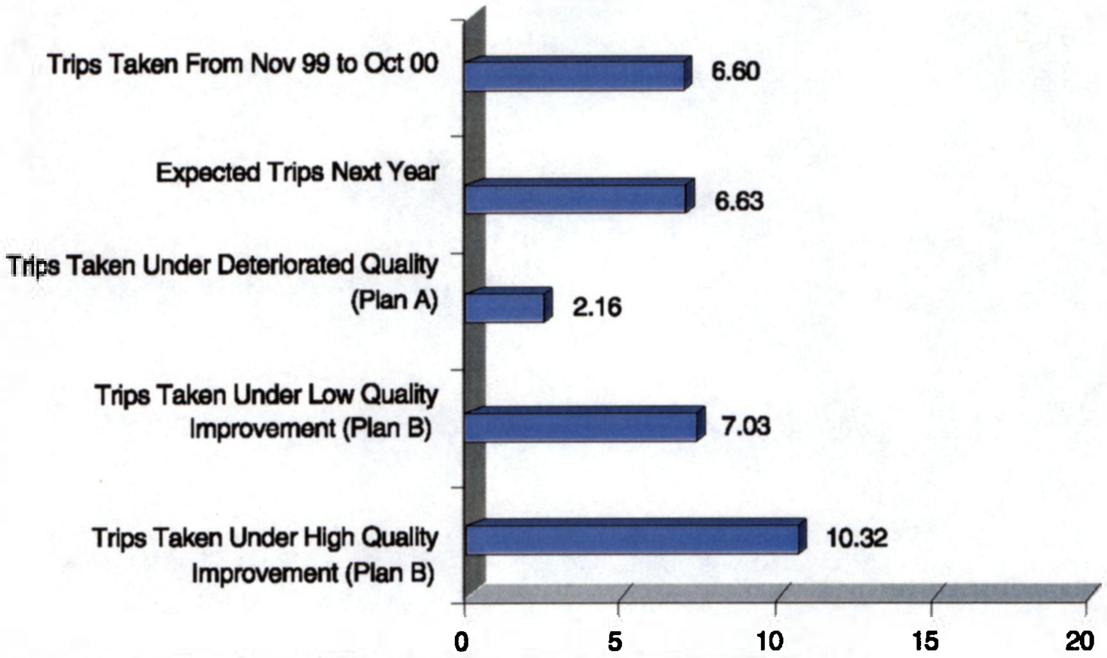


FIGURE 12. Number of trips taken at varying quality levels

The average income level reported for the local resident's survey was $40,000. Average household size was about 2.5 people, and about 67 percent of the respondents were male.

E. Conclusions

Clear Lake is very important as a recreational resource, with visitors reporting high, persistent usage of the lake. Both visitors and residents indicated a high willingness to pay to avoid further deterioration of the lake. When asked about their willingness to pay for improvement, respondents indicated that they are willing to pay only moderate amounts for a low quality improvement to the lake, but they are willing to pay substantially more for a significant quality improvement to the conditions at the lake.

This strong preference for the high quality improvement over the low quality improvement is also borne out by the number of trips visitors expect to take under each scenario. With the current conditions, visitors reported that they expect to take 6.63 trips next year. The expected number of trips falls to about 2 trips under Plan A (deteriorated quality). With the low quality improvement, the expected number of trips is 7.03, not much different than the expected number of trips under current conditions, which is consistent with the relatively low values reported for Plan A. However, with the high quality improvement, the expected number of trips jumps significantly to about 10. Thus, respondents appear to value highly avoiding further deterioration to the lake, and if quality is to be improved at the lake, they indicate a strong preference for a high quality improvement.

Finally, it is important to remember that the value estimates presented in this paper are point estimates. That is, though they are not reported in this paper, there is a sampling error associated with each estimate. For example, the point estimate for the local resident's willingness to pay for Plan B is $550 with a margin of error of ± $226.[3]

Endnotes

1. The value of "B" varied between $15 and $150 for visitors and between $45 and $450 for local residents.
2. The value of $104 was generated via a formal statistical model.
3. This margin of error represents a 90 percent confidence interval.

CHAPTER 3

Attitudes and Perceptions Regarding Water Quality and Community

Attitudes and Perceptions Regarding Water Quality and Community

Mimi Wagner, Iowa State University--Department of Landscape Architecture

A. Introduction

The beliefs, attitudes and values of residents are accepted as an informal part of planned change in any community—whether it be locating a new soccer field or proposing changes for a longtime city park. Designers and resource planners also seek this information when contemplating landscape change—particularly when the changes may directly or indirectly affect people.

A critical goal of the **Clear Lake Diagnostic / Feasibility Study** was to develop both an understanding of water quality conditions in the lake as well as strategies for enhancing water quality conditions. This research contributed to that goal by identifying the broad range of beliefs, attitudes and values as they relate to water quality and the community of Clear Lake. Water quality researchers then used this understanding of community values to assemble alternative strategies for water quality enhancement.

The goal of this research was not to quantify the number of residents who hold various beliefs and values. This study gave an indication of what residents value socially and behaviorally about the lake and how these values are structured. The study also indicated what elements they believe enrich their lives and how change in the landscape has affected them.

B. Methods

This report serves as a summary of interviews conducted during the 2000-2001 winter in and near Clear Lake. The land immediately surrounding the lake edge was the primary focus of discussions. This research included residents from Clear Lake's urban area as well as its agricultural watershed; it did not include significant representation from Ventura. As such, the conditions described are limited to Clear Lake and its agricultural watershed.

Residents were selected to reflect a broad range of experiences and connections with the lake and community. Income, gender, education, occupation and years lived in the area were balanced. Interviews were conducted individually using photographs of the area as discussion points. The names of residents interviewed, as well as interview transcripts, are confidential. Occasional excerpts from statements are included in this report and are intended to serve as examples.

This research focused on four aspects: (1) residents relationship to Clear Lake as a central element of the community, (2) organizational and social aspects of Clear Lake, (3) perceptions of water quality and (4) a summary of community needs, as they relate to the lake and water quality. Several suggestions for community action are included in the section, "Appropriate Considerations for Future Action." These suggestions were developed in response to needs, attitudes and perceptions found in this investigation that are beyond the scope of the Diagnostic / Feasibility Study.

C. The Lake as a Central Element in the Community

Clear Lake is clearly the focal point of the community and the region. It is an active element—changing and responding to climate, season and management in very dynamic ways. Residents are watchful of the lake and are very connected to its condition. Visual changes are watched in great detail including water clarity, water level fluctuations, fish population (size, diversity and quantity) and fish kills.

The lake is perceived as having shifted from being a 'public' lake in the past to being more 'private' today. Although public accesses and lands are available for use, local residents sense a change in the lake's availability for those other than shoreline property owners. Fewer open, unbuilt sections of shoreline have contributed to this perception.

1. Attachment to the Lake. The term 'attachment' describes the relationship between people (or a person) and a place. Attachments to a place or object can be strong or weak, positive or negative. Understanding attachments to landscape elements, such as Clear Lake, illustrates a great deal about what the community values and why they make the decisions they do.

Understanding local attachments was important in this project because it can guide researchers and decision-makers in creating alternatives to enhance water quality. This guidance is important to consider so valuable elements of the place or community aren't unnecessarily disrupted or destroyed to meet water quality objectives.

This research identified two types of attachment in the Clear Lake community. The first type, 'Internal,' relates to the quiet respect and admiration people have for the lake. The second type, 'External,' is the connection residents make between the lake and the outside—visitors, for example. Both are described in more detail below.

a. Internal Attachment to the Lake. Clear Lake has strong personal importance to the community. Residents had a consistently solid understanding of the geologic uniqueness of the lake and its watershed. They have a deep sense of pride for the natural elements of the lake including the shoreline, the forested vegetation surrounding the lake, its marshes and the watershed topography. There is a strong sense of reverence and respect in maintaining the character of these elements—although many changes have occurred over time.

This internal attachment represents a strong emotional bond between people and the lake. It is present among residents who use the lake regularly as well as those that enjoy the lake only from a visual standpoint. The following anecdotes illustrate this bond:
- The same public beaches and parks have been used for successive generations in their family. Also, land—agricultural and nonagricultural—and homes have remained in the same families for multiple generations.
- Sunrises and sunsets across the lake are a valued event.

- Residents enjoy driving around the lake just to see the water. The visual 'availability' of the lake from surrounding roads is a aspect that has changed greatly over the years as larger homes continue to replace cottage-style homes.
- Physical closeness to the lake is highly valued—this is separate from wanting to use the lake for a functional purpose such as fishing, swimming and boating.
- Many value the quiet, isolated public areas on the lake—particularly at times when the visitor population isn't high.

The respect and reverence observed for the visual aspects of the lake are also present for cultural landmarks in the community. These landmarks include longtime businesses (such as the Ritz), the cottage-style of housing common in the early to mid 1900's and older specimen trees such as those in the city park. When change occurs to landmarks—either intentionally such as the replacement of cottages with new homes, or unintentionally such as the fire at the Ritz—the community senses a loss in its physical character. Residents expressed a desire for the lake and the community to "be as in their memory,"—realizing also that some changes are necessary, inevitable and uncontrollable.

The lake is a sacred element internally to many people. Residents find value in both active use and a passive closeness. This internal form of attachment was found consistently through most interviews, however it is often a quietly held, personal reflection and value. This contrasts with the second form of attachment identified, External Attachment.

b. External Attachment to the Lake. Above and beyond the internal or personal importance of the lake, residents also maintain a separate form of attachment or relationship to the lake via the 'external' world—visitors and tourists to the lake and community.

The Clear Lake community is largely organized around tourism. Events and opportunities are created to attract people to the water for purposes of economic development. The elements of attraction are often related to direct contact with the lake / water, such as boating, fishing, snowmobiling, hunting and swimming. The revenue generated by outside visitors to the lake region is substantial, and the community realizes that they are able to maintain the "physical-ness" and infrastructure they have as a result of these revenues. As such, they have a strong attachment to sustaining the attraction of visitors to the lake. Decisions about change and development in the community include strong consideration of the needs and desires of visitors and other active-users of the lake.

2. Attachment Summary. Residents value both their internal and external attachments to the lake. A combination of these values guides decision-making about changes in the community and the lake edge. External attachments sometimes override the quieter, more personally held internal attachments. The following examples illustrate the difficulty in balancing the two.

- Agricultural land in the watershed has been converted to subdivisions to allow population growth. This change compromises the rural character of the land residents value.
- It's more difficult to see the lake when driving around it, because the new houses are so much larger than those they replace and views are more restricted. One resident remarked,

"Local people, like me, like to drive around the lake and look at it. It needs to be accessible for the people of Iowa."

- Fewer lots and areas left undeveloped in the watershed.
- The sense that access to the lake is restricted for those not living on it—even the boat launches at the street dead ends are rented out as boat slips.
- Replacement trees in the city park are trees that grow more quickly rather than the slow-growing native species they replace.
- Emergent vegetation is removed for aesthetic reasons and boat access, even though residents realize it is important for fish habitat.

D. Organizational and Social aspects of the Clear Lake community

Residents discussed many aspects of the community and how decisions are made. Over and over, they described it as a great place to live and work. Many residents of the community choose to live in Clear Lake because it is where they want to be—rather than because it is where their job is, for example. This strong connection to 'place' included descriptions of the community as 'a special place,' and as having a 'sense of magic.'

1. Aspects of the Community. As commonly observed in Midwest communities, residents perceive change in the social connection between the agricultural and urban communities. The presence of agriculture in the lake's watershed is perceived as diminished as compared to fifty years ago. Urban growth—residential, commercial and industrial—has likely contributed to this change in perception.

There is a sense of satisfaction with the community. As one resident indicated, "People are pretty happy with the physical-ness of Clear Lake." Clear Lake has long favored continued growth and development as a means to stabilize this physical infrastructure. Some factions within the community are beginning to question the long-standing belief that continued growth will always lead to prosperity. There is concern that the community may reach a point where its size may actually be detrimental to the elements of the community they value—such as a lack of traffic congestion, well-maintained streets and infrastructure and the tight-knit social connections between residents.

2. Working Relationships Inside and Outside the Community. The community leadership structure was described as fair and trustworthy, with a history of making decisions that take into account many situations and individuals. Changes undertaken in the community were described as being from the "bottom-up," rather than "top-down."

Clear Lake is a great example of a community that takes action on its own when there is a need—rather than relying on organizations outside of the community to do something for them. This long history of self-initiative is evident at both the individual level and within organizations.

Residents perceive well-established and strong working relationships with other communities, agencies and outside organizations. There has not been a strong history of dialogue with the community of Ventura—but residents indicated they believe communication channels with Ventura are open and that past joint efforts between the two communities have been successful.

The IDNR is seen as the overall decision-maker for the lake. The community also believes that is has the ability to help shape decisions made by IDNR regarding the lake. Residents interviewed perceived that IDNR has been fair in their decisions and actions regarding the lake.

3. Communications. All communities have the ability to communicate information within them, although this ability ranges in effectiveness. The structure for these communications is both formal (newspaper and radio stations, for example) and informal (coffee shop discussions, public meetings and working committees, for example). The communication structure within Clear Lake appears incredibly well functioning. The local press was credited for communicating current issues and information about the lake. There is also a very functional informal communications network, enabling information to be passed between different groups of residents and neighborhoods. An example of this informal communication structure is most obvious in the consistency of local knowledge pertaining to the lake.

4. Local Knowledge of the Lake. There is a high level of awareness about the lake system in a general sense. For example, there is a strong understanding of the importance of emergent vegetation for fish habitat and wetlands—even though residents report that less of it remaining today than in previous years.

Residents acknowledge the somewhat large amount of 'natural' vegetation occurring in the watershed—marshes, unmanaged woodlands and prairies. Most interviewed accepted the aesthetic qualities of these landscapes—even though they wouldn't want it in their own yard—because they recognize its importance for wildlife habitat. These 'natural' areas were also valued for the primitive, quiet experience they offer people.

5. Physical Change in the Community. Residents indicated that a large amount of change has occurred in the physical nature of the landscape over the past fifty years. Individual property owners along the lakeshore have made a majority of the changes discussed in the interviews. Examples of these changes include the following,

- Demolition of cottage-style homes and replacement with large homes with a different architectural style,
- Land around the edge of the lake is completely built up—there are no vacant lots,
- Disappearance of rental cottages and boat rental facilities on the lake,
- Conversion of farmland to condominiums and single family housing, and
- Loss of local businesses, such as the Ritz, and their failure to rebuild in the same location.

Public perceptions of these changes range from broad acceptance to alarm at their fast pace. These changes have contributed to a significant amount of visual change over time—in some cases very quickly.

The community as a whole tends to make decisions about visual or physical change on public property slowly and deliberately. There is a high value on new features or elements looking like they have always been there. The new seawall is an excellent example of this from a materials and construction standpoint. It also illustrates the cautious, "bottom-up" decision making processes employed by the community.

E. Water Quality Perceptions

The Clear Lake community, particularly the urban residents, holds the **Clear Lake Diagnostic / Feasibility Study** in high regard. They helped sponsor this study to clarify the existing water quality conditions and recommend future management strategies. This study has been incredibly visible to residents of both the urban and agricultural communities. Residents have observed and interacted with field personnel conducting sampling and met personally with Dr. Downing at public events. This high level of contact with the project has given residents a sense of confidence about the study, the personnel conducting it and the outcomes.

Residents expressed concern with the quality of Iowa's water in general--they realize that clean water is a critically important to human health. There is a wider range of beliefs about water quality conditions in Clear Lake itself. Some residents interviewed were deeply concerned about water quality conditions in the lake and believe there is a real problem. Others were less sure there is a real problem, stating they believe the lake "has always been this way" and that "it can take care of itself." There was also confidence expressed that the lake will "always be here" and available to them.

A similar range of beliefs exists regarding their hope for improvement in water quality conditions in the lake. Many residents have a high sense of optimism that conditions can be improved through changes in behavior and land management. For example one resident stated, "All is not lost here, but we need answers—our future is promising." Others believe that people have significantly less control over water quality conditions. When responding to their beliefs about human ability to impact water quality in the lake, responses included, "it's tough to make change" and "our hands are tied."

The amount of money that may be required to enhance water quality conditions is a concern locally. Some view that the necessary changes will likely be expensive and not effective—"a lot of money will be spent and not much will be accomplished." Others are certain that improvements can be affordably made, citing the construction of stormwater filtration boxes, reduced lawn chemicals and sanitary sewer improvements already undertaken.

There is a high level of knowledge about the steps the Clear Lake urban area has taken to improve water quality conditions. The Clear Lake Enhancement And Restoration Project directed water quality education and improved public awareness in a role of lake water quality representative to the urban watershed. Because the scope of the CLEAR Project was limited to the urban landscape, community understanding about the role of the agricultural watershed is not clearly defined.

F. Community Needs As Related to the Lake

Residents were questioned about additional community needs specifically related to use of the lake and water quality conditions. All responses centered on recreation and use of the lake. Four distinct needs were communicated.

1. A bike trail around the lake—this was the most frequently mentioned need,
2. More public docks for day visitors,
3. Additional parking for boat trailers and vehicles while boating, and
4. Small pocket parks on lakeshore land suitable for picnics, viewing the lake and general relaxing.

Some individuals indicated that there are no needs stating, "I can't think of anything we don't already have, besides there's no land left."

G. Opportunities for the Diagnostic / Feasibility Study

The Clear Lake community and watershed are positioned well to respond to the challenges and needs identified by the Diagnostic / Feasibility Study. This research concludes that there is an enormous potential within the community to make and adjust to the changes necessary to enhance water quality conditions. Several conditions presently exist in Clear Lake that support this conclusion:

- Residents care about Clear Lake very deeply. They have both a personal attachment to the lake as well as an economic need to maintain its integrity.
- Clear Lake, on an individual and a community scale, has a long local history of taking action locally to facilitate changes they believe are important.
- Most community members already acknowledge a water quality problem in Clear Lake and they wanted this study to identify contributing factors to the conditions and suggest alternatives.
- The community already has a high understanding of water quality basics and has taken action locally in response. They have also responded positively to past awareness and education efforts regarding water quality.
- The level of communication within the community is very high—supporting the effective dispersal of study results and alternatives.
- Although some residents question the community's ability to impact water quality conditions in the lake, many residents and decision makers are convinced that conditions can be improved and are willing to support IDNR's efforts to enhance water quality conditions.
- The community is largely tolerant of the visual aspects of landscape elements contributing to enhanced water quality—wetlands, prairies, grassed waterways, filter strips and riparian buffers. Residents will be able to rationalize the importance of these elements if they are included in the final solutions selected by IDNR and the community.
- The youth and future generations of the community possess an enormous opportunity to bring new energy and momentum to the issues present in the community.

H. Appropriate Considerations for Future Action

Three opportunities emerged as a result of this portion of the Diagnostic / Feasibility Study. They are presented here as considerations for future community action that are unrelated to water quality. Each is connected with strengthening the relationship between people and the 'place' of Clear Lake—in different ways. These considerations include (1) Community 'Sense of Place,' (2) Interpretation of Local History and (3) Perceptions of Public / Private Ownership.

1. Community Sense of Place. Close relationships between a place or landscape element foster a high sense of satisfaction for residents. These relationships include deliberate attempts to identify the often-intrinsic features that give a place its specific identity. Once identified, these elements or features can be protected and even strengthened. The elements and features then become the trademarks or characteristics that set the community and watershed apart from others in the state. Articulating and enhancing a community or region's sense of place has benefits for both residents and visitors.

Community responses to the loss of long-time physical features in Clear Lake illustrate the appropriateness of sense of place studies. Although some choices and changes related to physical elements of a community are inevitable and uncontrollable, others can be planned for. An example would include the visual appearance of City Beach and the adjacent city park. Residents have significant internal attachment to both of these landscapes and value the fact that they have changed little over generations. The identification of other specific characteristics or places in the community would allow the community to make active decisions about their management rather than react to change after it occurs.

2. Interpretation of Local History. There is an enormous amount of local history in and adjacent to the lake. Local residents value this history but often don't articulate its importance. A legible interpretation of the past 200+ years in Clear Lake would be a benefit to residents, including youth, who enjoy remembering the past and learning more about their home. Visitors would have an additional type of experience to choose from. The interpretation could also be linked with a bike trail around the lake, adding value to both experiences.

A sample of potential elements that could be interpreted include:

- The geologic history of Clear Lake and its watershed,
- Pre-history, European settlement and recent history,
- History of agriculture in the region, and
- Water quality topics relating to the lake: changes over time and efforts to enhance water quality.

3. Perceptions of Public / Private Ownership. The perception that the lake is becoming more privatized is an important concern. More research is needed to identify the factors contributing to the perception. Community elements, such as pocket parks on the lakeshore, are a beginning step in shifting this perception.

Pocket parks are small, neighborhood-scale places that are set aside for everyday types of passive activity, including picnics, relaxing in the shade, people watching and looking at the lake. These types of activities occurred in informal ways more frequently before the lakeshore was built up. Pocket parks, and other similar efforts offering residents and visitors more opportunities to experience the lakeshore, would be a positive contribution to the community's concern with change from a "public" lake to a "private lake."

CHAPTER 4

Historical Changes in the Clear Lake Waterscape

Historical Changes in the Clear Lake Waterscape

Kenneth Carlander, David Knoll, Carol Elsberry and John A. Downing

Special Acknowledgment. *Dr. Ken Carlander, a well-known emeritus scientist at Iowa State University and long-time analyst of the Clear Lake ecosystem, began to chronicle changes in the Clear Lake shoreline in the early 1950s by establishing a photographic record. We re-discovered Dr. Carlander's photographs in the Carlander Library of the Department of Animal Ecology at Iowa State University, and repeated as many as possible in late 2000. David Knoll took the 2000 photographs and Carol Elsberry selected views that offer the most coherent look at the changed landscape. The 2000 photos were taken in autumn so the vegetation is somewhat different, but aquatic plants would still be quite visible if present. This series of photos offers a unique view of ways in which the shoreline, landscape and waterscape of Clear Lake have changed over the last half-century. Notes are offered below to highlight some of the changes.*

Plates #1.	Although emergent rushes are still visible in 2000, their extent is much smaller. In the foreground, note the current complete lack of shallow water vegetation.
Plates #2.	This wave-swept beach has changed little since 1965 although background shore development is greatly increased.
Plate #3.	No current image available.
Plate #4.	No current image available.
Plates #5.	The 1961 photo shows widespread emergent plants in the foreground and across the bay. The dark patches on the lake surface to the left and right show very dense submerged macrophytes growth. The current photograph shows that low water clarity has eradicated all emergent and submergent macrophytes.
Plate #6.	No current image available.
Plates #7.	This open water series does not show enough detail to allow comparison of water quality, but one can note a large amount of new shore development in the background.
Plate #8.	No current image available.
Plates #9.	The 1952 image shows dark patches on the water surface that indicate extensive submergent macrophytes growth. Further, although trees in Ventura are smaller, shore vegetation was allowed to grow. Riparian vegetation is important for protecting the shore. The current photograph shows no submergent or emergent macrophytes and a lawn-like shore. These indicate poor shore management and greatly reduced water clarity.
Plates #10.	The 1954 image shows completely wooded shores, while the current image shows a great deal of shore clearing. Wooded riparian zones are important for the protection of water quality and provide good buffer zones.

Plates #11.	The 1966 photograph shows well-developed shore vegetation that is quite diverse and abundant. The 2000 photograph shows no shore vegetation at the same site. Riparian vegetation is essential for the protection of water quality.
Plate #12.	No current photograph available but the 1952 photograph shows extensive, dense and diverse patches of submerged macrophytic vegetation. This vegetation can no longer grow in Clear Lake due to reduced water clarity. Submerged vegetation keeps sediments from resuspending and provides excellent fish habitat.
Plates #13.	The current photograph shows that McIntosh Point currently has more vegetation and is a more substantial geographical feature than it was in 1955.
Plates #14.	The striking difference in emergent and submergent vegetation shows a radical degradation in water clarity since 1958. This is a profound change that decreases the quality of the habitat for aquatic and terrestrial organisms and increases the nutrient loading through resuspension of nutrient-rich sediments.
Plates #15.	Although there is still some emergent vegetation at left in the current photograph, submerged vegetation has completely disappeared and the entire bed of rushes at right has been eradicated.
Plates #16.	Shore disturbance has removed near-shore vegetation. Short macrophytes near shore at left in 1962 indicate that plant biodiversity has changed considerably since this time.
Plates #17.	Although some of the rushes that existed in 1966 are still present, the density and extent of the plants is now greatly reduced. Note also the current poor condition of riparian vegetation.
Plates #18.	Near-shore vegetation has been eradicated (likely due to reduced cover from wave-action) and the density and extent of emergent plants is now greatly reduced over 1960 conditions. Note also the nearly complete removal of riparian vegetation.
Plates #19.	The 1966 photograph shows well-developed cattail and bulrushes. The current photograph shows complete eradication of this important riparian vegetation.
Plates #20.	The 1960 photograph shows extremely dense beneficial emergent plant growth and wide and well-developed riparian plants along the grade. The current photograph shows a complete lack of aquatic vegetation and a very thin riparian buffer.
Plates #21.	The band of bulrushes in 1956 was wide and quite dense in the deep waters. This vegetation shielded the shallow waters from extreme wave-action, allowing emergent plants to remain rooted near shore. The current photograph shows a narrower band of bulrushes and a denuded band near shore due to reduced offshore plant density and extent.

Plates #22. The 1962 photograph shows dense and diverse riparian, emergent and submerged vegetation, which supported abundant wildlife (note muskrat houses). The current photograph shows that vegetation has been reduced to patches of the most resistant emergent plants. No submergent macrophytes are currently visible in photographs of this site.

Plates #23. The shore zone in 1956 was stabilized by a dense band of beneficial rushes and other emergent plants at this site. Nearly all of these plants have now been eradicated.

Plates #24. This very exposed site had a dense band of emergent macrophytes beyond the surf zone in 1962, but nearly all of these stabilizing plants are now gone.

Plates #25. This is the sole site that seems to indicate more extensive aquatic vegetation now than in 1962. This is perhaps due to the denser and more developed riparian woodland.

Plates #26. This site still shows some of the extensive emergent macrophytes beds that were present in 1962, but it is important to note that whereas many plants grew close to shore in 1962, the reduced plant density has apparently allowed wave-action to uproot macrophytes in the surf-zone near shore.

Plates #27. Although it is somewhat difficult to discern beyond the unwise piles of soil near shore in 1958, one can discern beds of submerged aquatic plants among the docks. Little of this vegetation now remains.

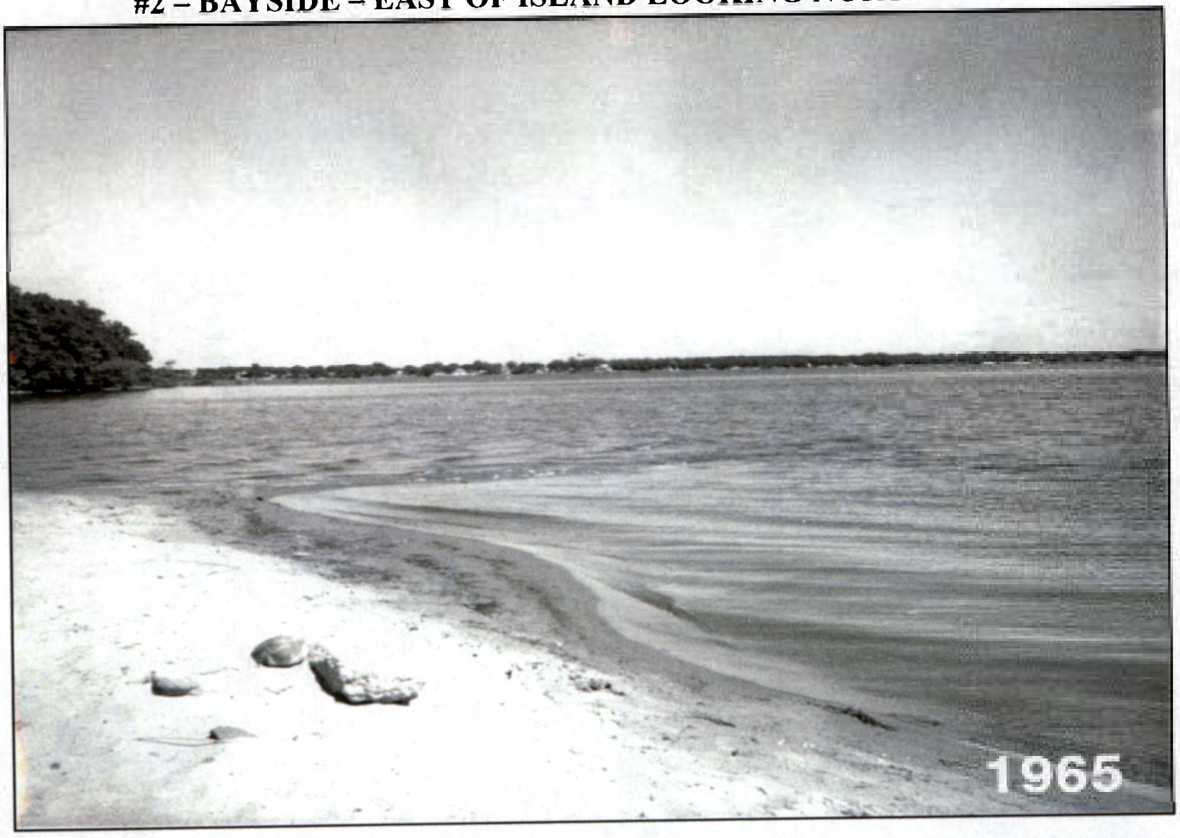
Plates #28. In 1956, this site showed dense and well-developed emergent macrophytes beds reaching a great distance from shore. These shore- and bottom-stabilizing macrophytes beds have been completely eradicated.

Plates #29. These plates show the current poor condition of the carp-control structure in Ventura Marsh.

Plates #30. This wave-swept shoreline near the island has changed little since 1962.

#1 – FROM FARMER'S BEACH, CLAUSEN'S COVER, LOOKING TOWARD LONE TREE POINT

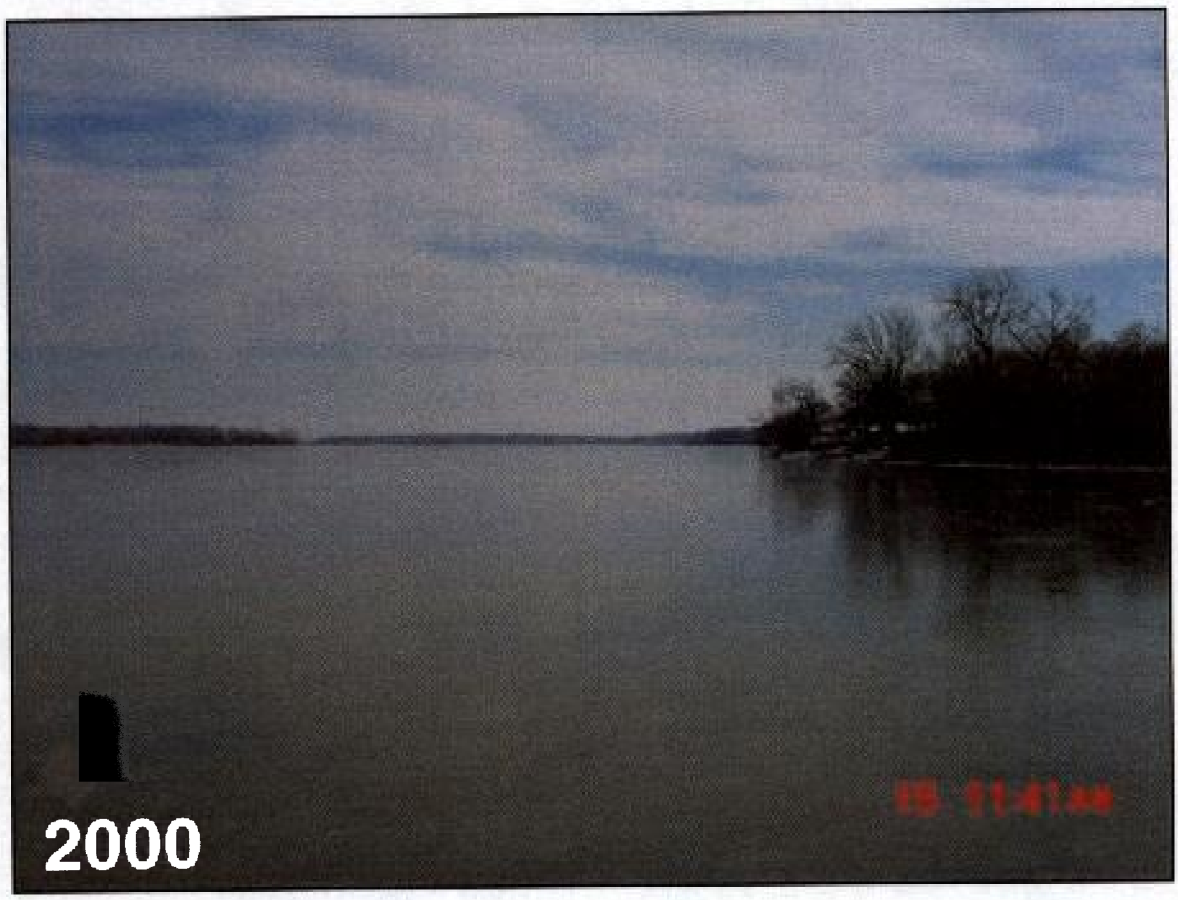
#2 – BAYSIDE – EAST OF ISLAND LOOKING NORTH



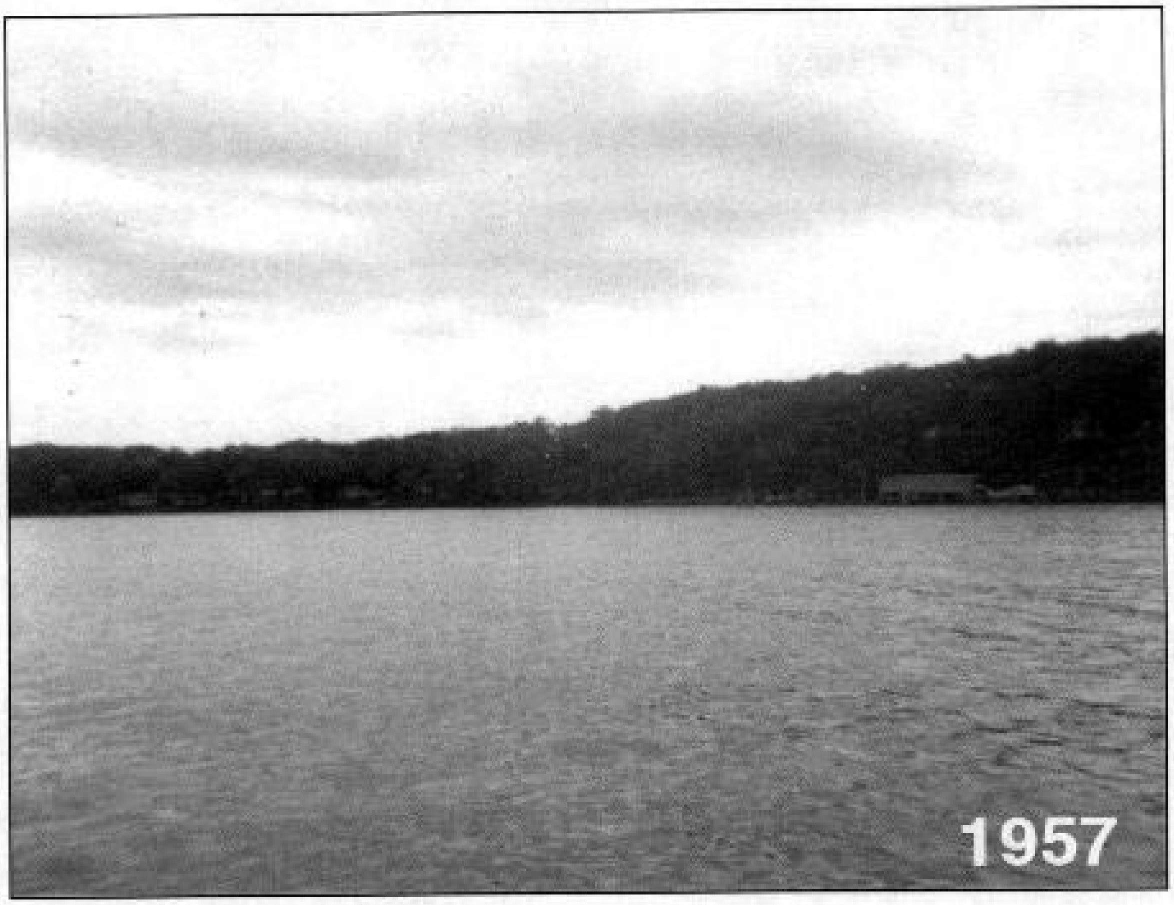
#3 – McINTOSH WOODS – MAMMOTH BRIDGE IN CENTER BACKGROUND (TAKEN FROM BOAT)

#4 – LONE TREE POINT FROM WEST END (TAKEN FROM BOAT)

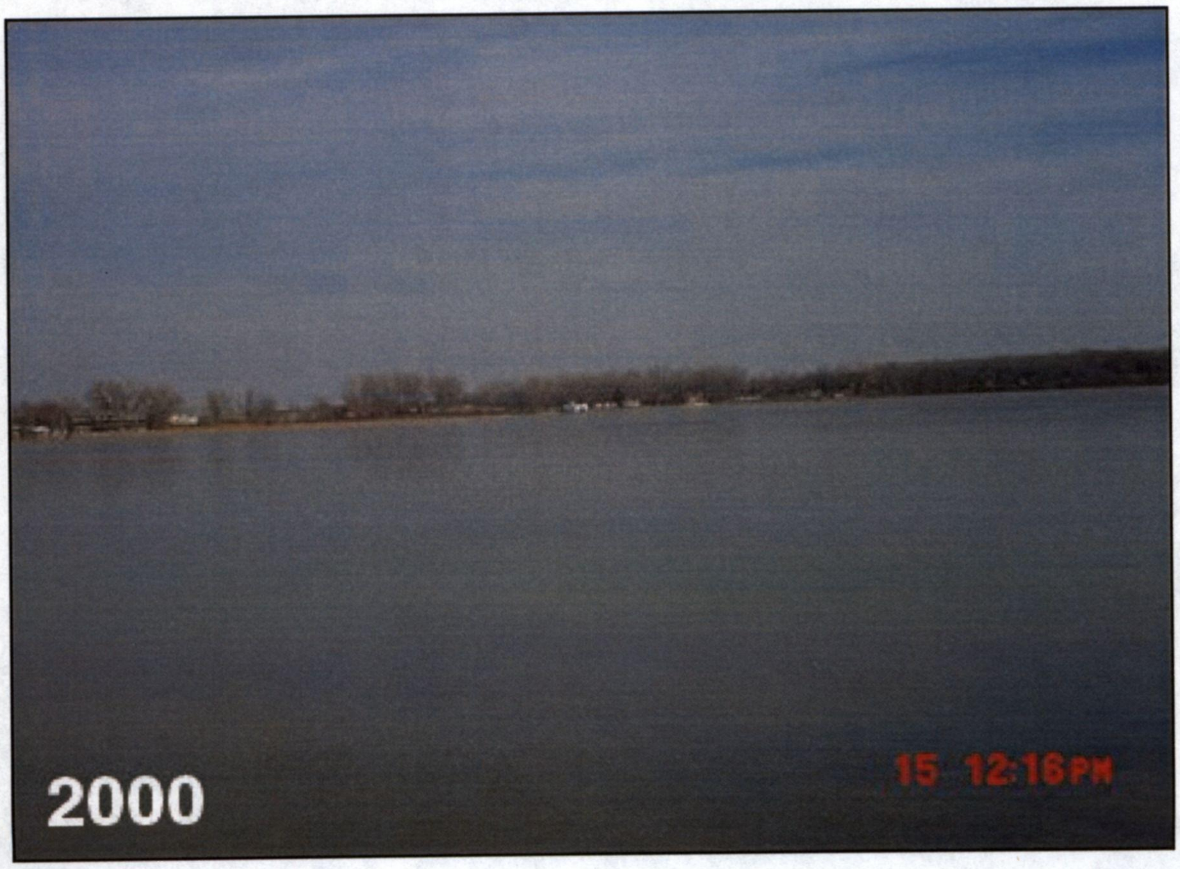
#5 – LOOKING EAST TOWARD McINTOSH ON LEFT AND LONE TREE ON RIGHT FROM GRADE


[redacted]

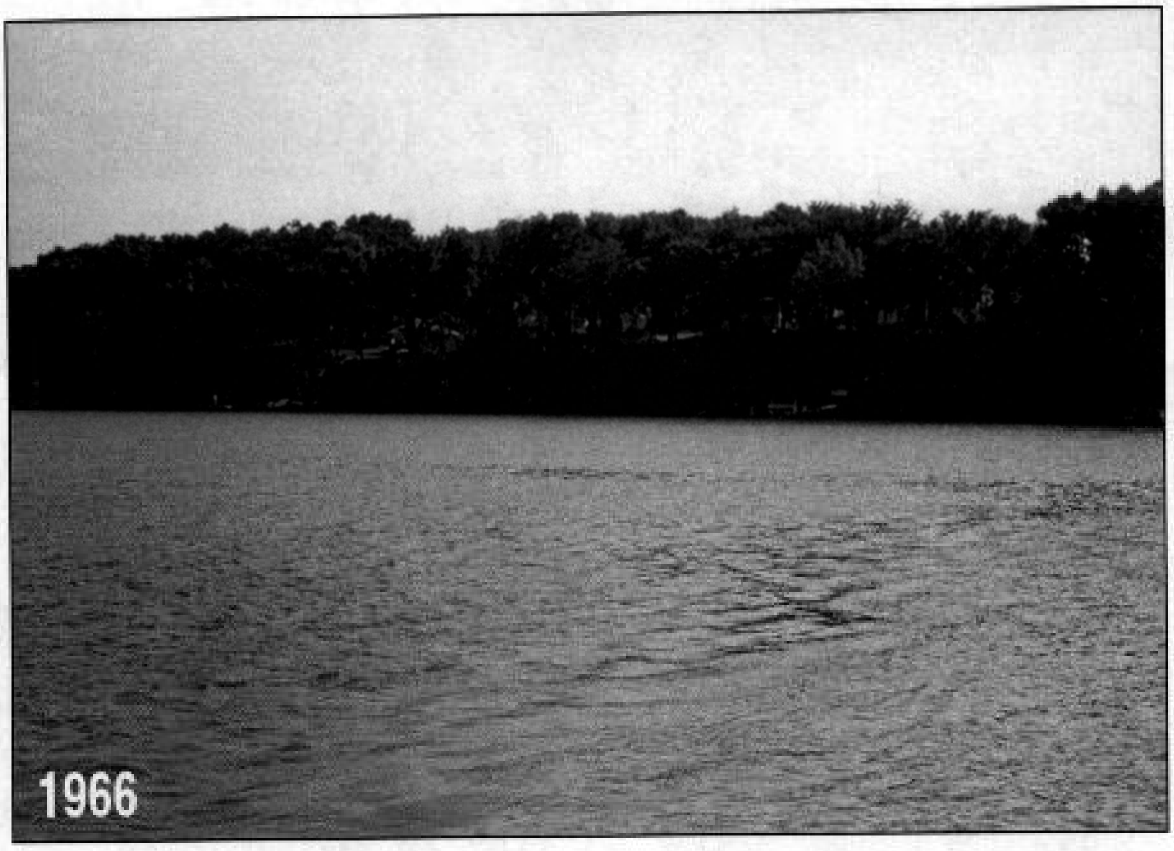
#6 – BOY SCOUT CAMP TAKEN FROM BOAT



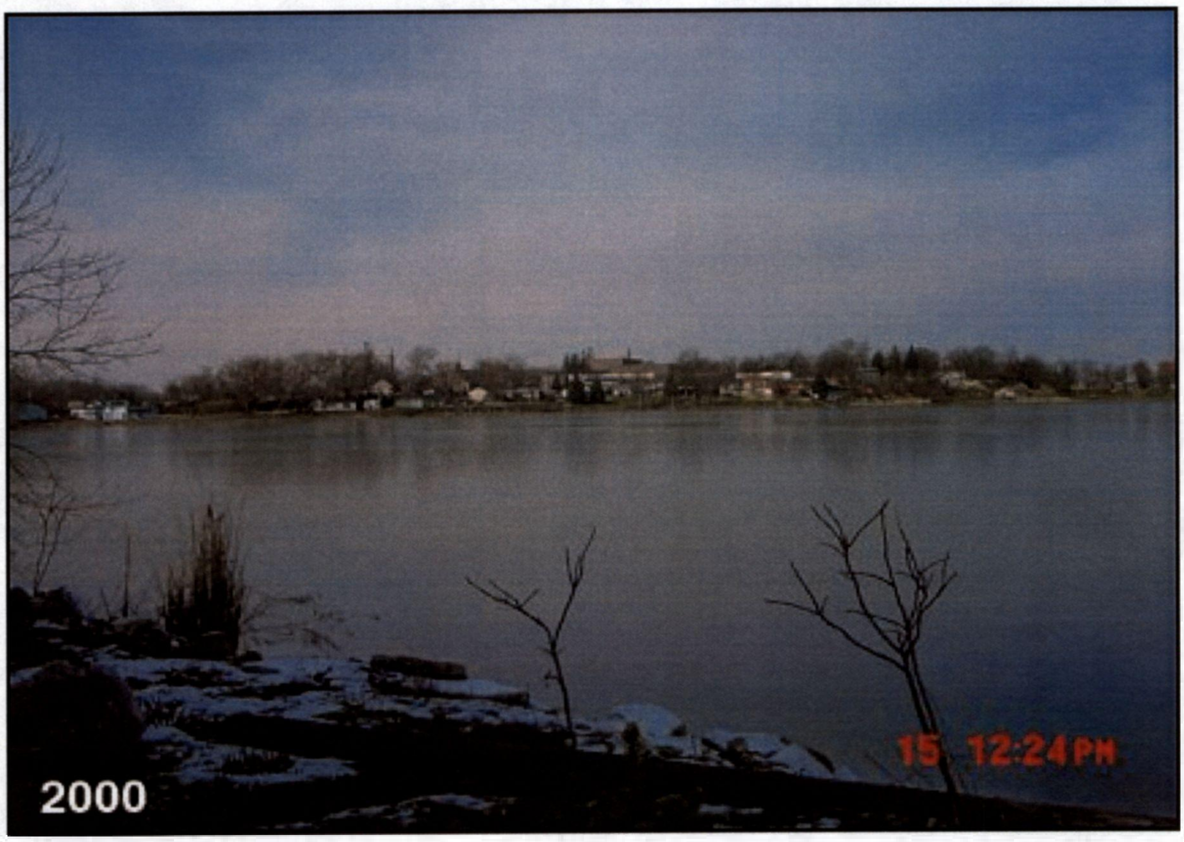
#7 – KASTER'S KOVE IN CENTER BACKGROUND FROM HESSER'S DOCK



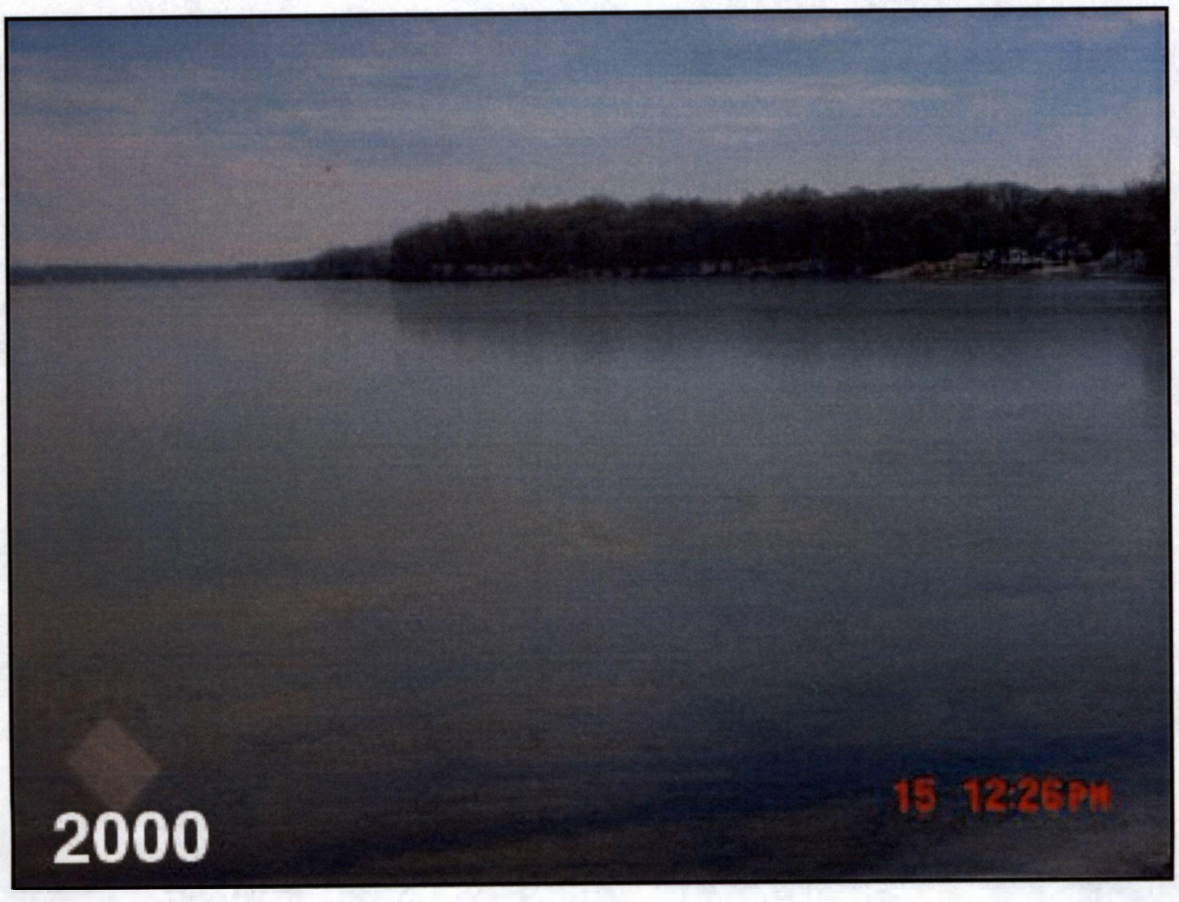
#8 – WEST OF BOY SCOUT CAMP TAKEN FROM BOAT


1966

#9 – VENTURA FROM ACROSS LAKE (FROM HESSER'S DOCK)

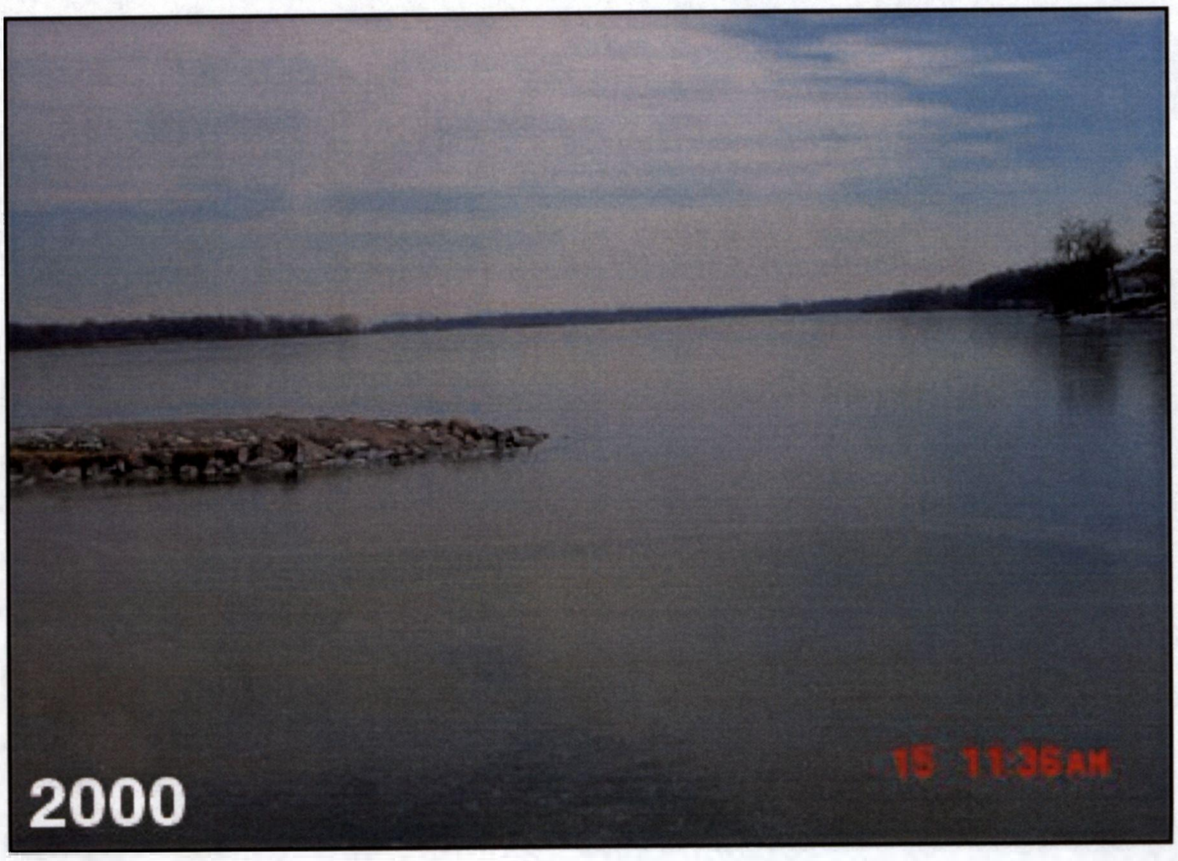


#10 – FROM VENTURA HEIGHTS BANK TOWARD LONE TREE POINT



#11 – FIN AND FEATHER BOAT DOCK NEAR GRADE

1966



2000

15 11:35AM

#12 – KASTER'S IN RIGHT BACKGROUND (TAKEN FROM BOAT)

#13 - McINTOSH POINT WEST SIDE OF SANDBAR
(TAKEN FROM BOAT)

#14 – LOOKING SOUTHEAST ALONG WEST SIDE OF McINTOSH

#15 – GRADE IN RIGHT BACKGROUND FROM McINTOSH BLUFF NEAR POINT

#16 – SOUTH BAY LOOKING TOWARD ISLAND

#17 – SOUTHEAST TOWARD CLAUSEN'S COVE FROM McINTOSH BLUFF NEAR POINT

#18 – DEAD MAN'S CURVE LOOKING TOWARD ISLAND

#19 – FROM HESSER'S LOOKING TOWARD SANDBAR

1966

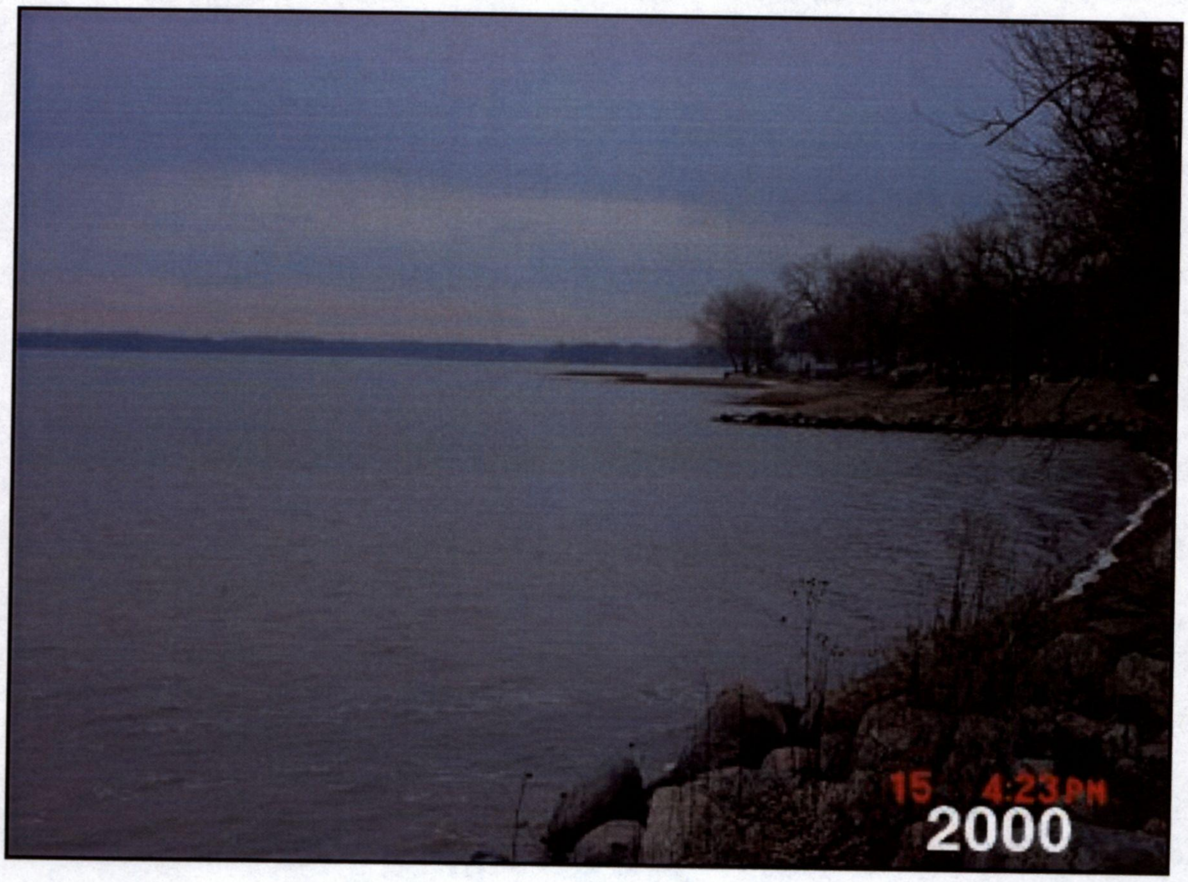
15 12:21 PM
2000

#20 – SOUTHWEST CORNER OF WEST END. HESSER'S DOCK IN BACKGROUND – TAKEN FROM GRADE

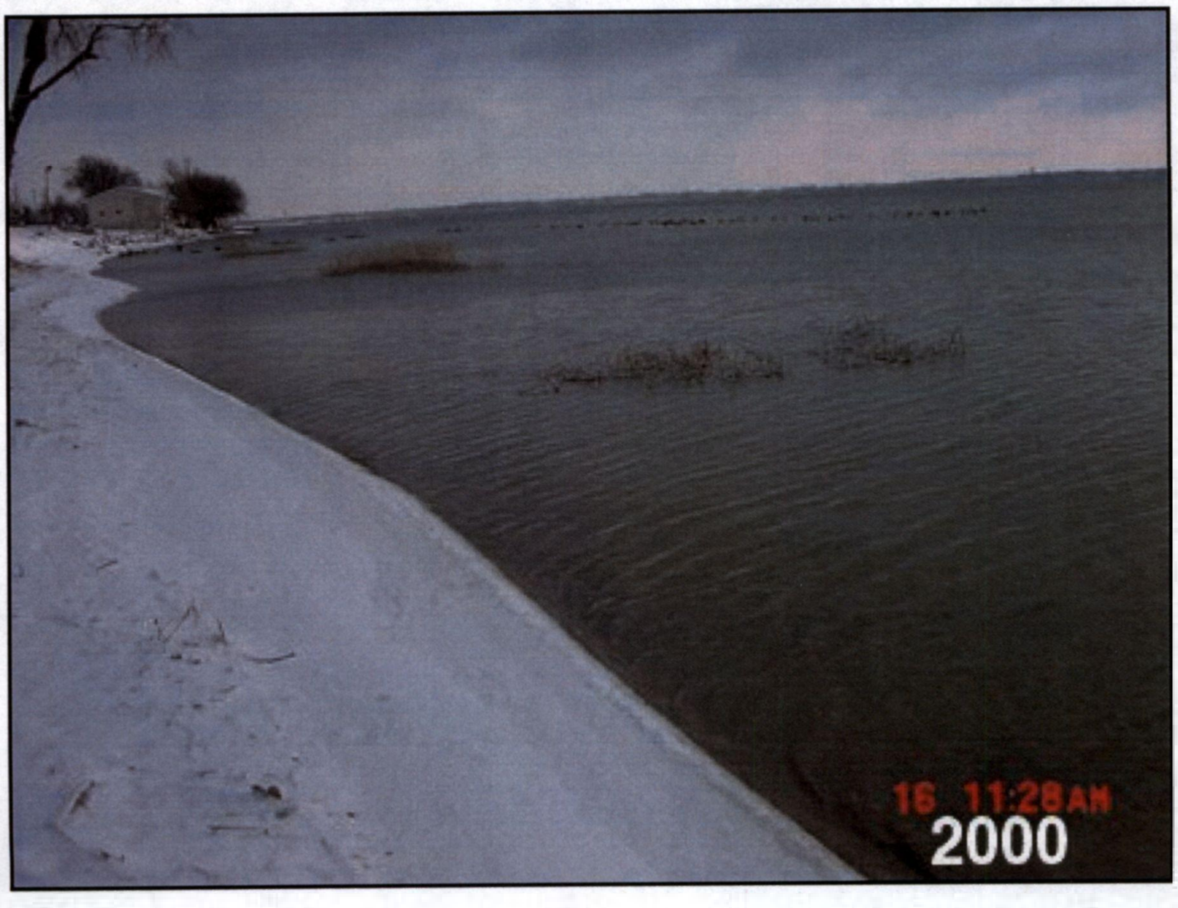
#21 – FROM EAST END OF BLACK RUSHES LOOKING TOWARD CLAUSEN'S COVE

#22 – LOOKING SOUTH FROM BRIDGE CULVERT BETWEEN WILLOW INN AND ELM BEND

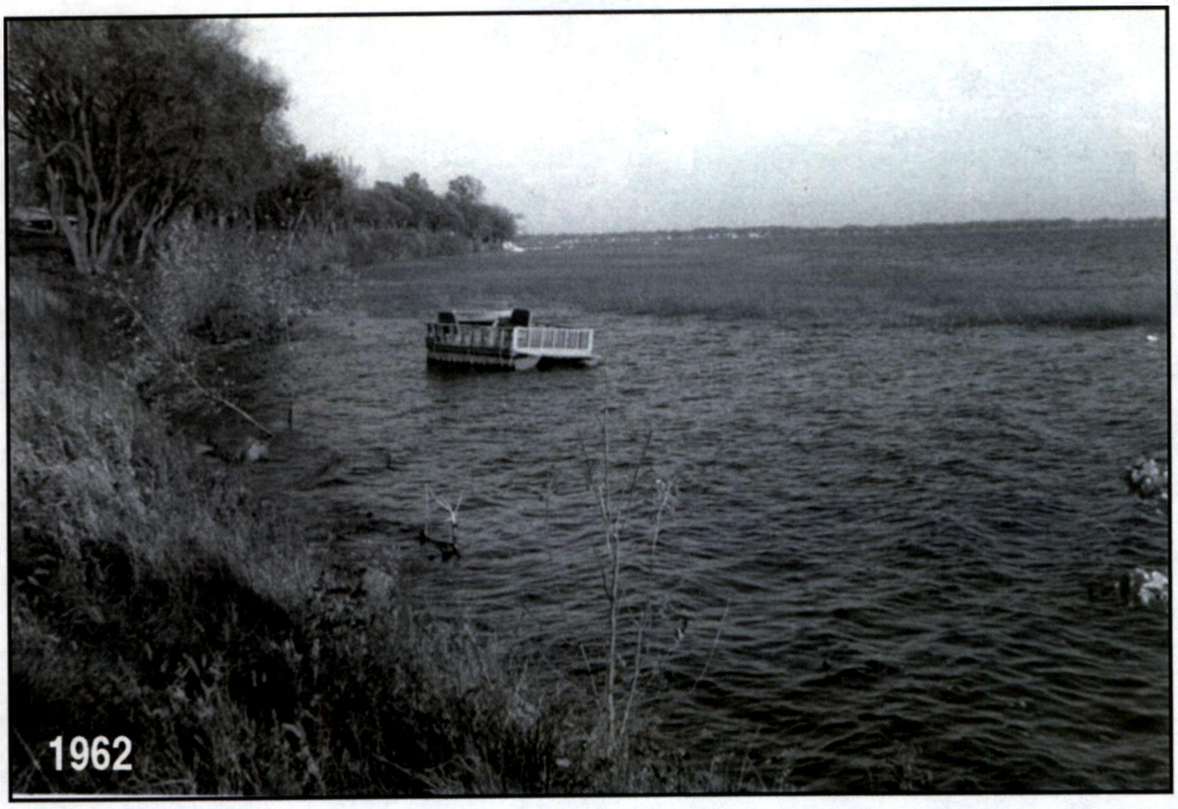
#23 – STATE DOCK LOOKING WEST



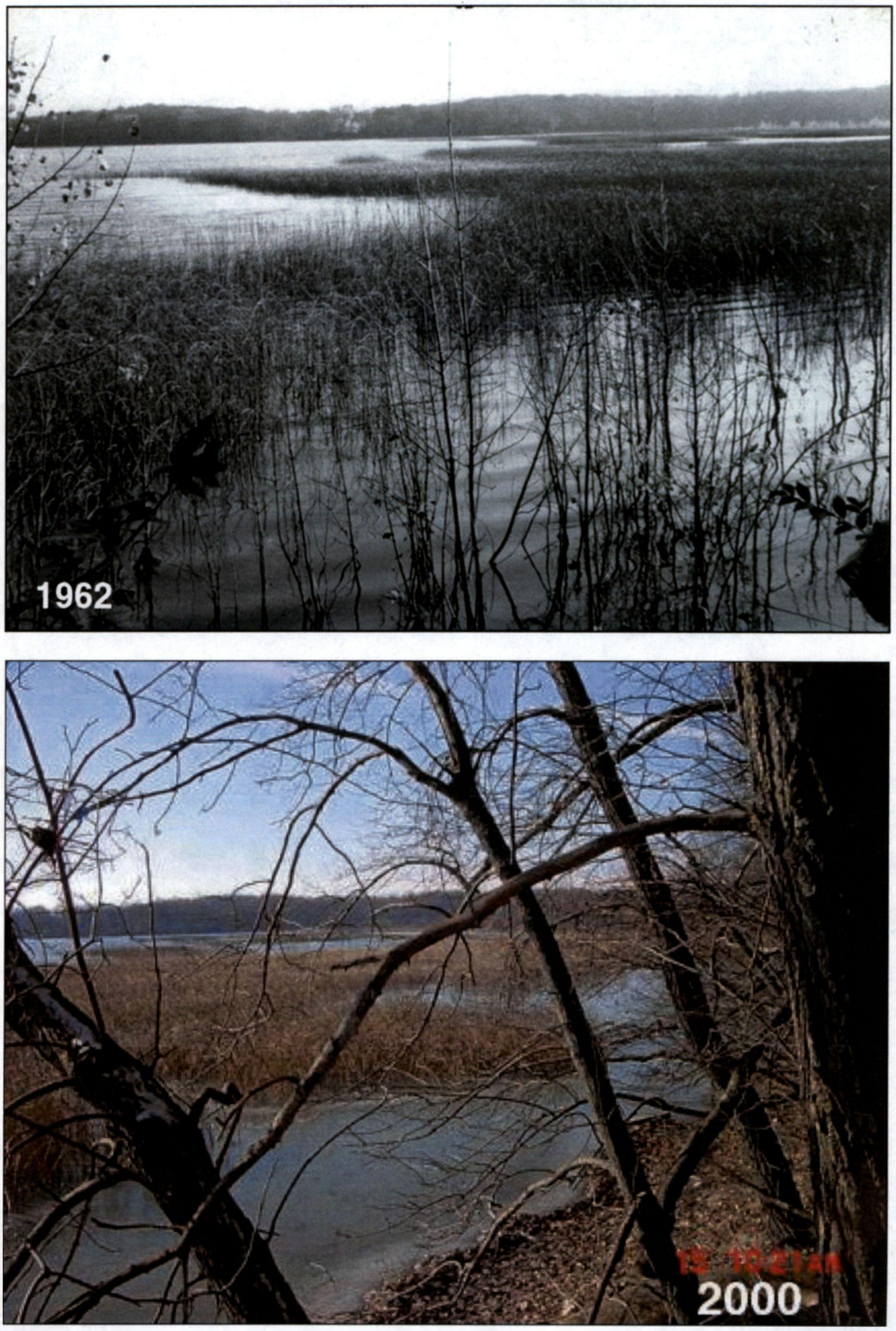
#24 – GARNER BEACH LOOKING SOUTHEAST



#25 – FROM STATE DOCK TOWARD BUEHLER'S



#26 – LOOKING FROM EAST CORNER (FENCE) OF McINTOSH WEST TOWARD SANDBAR

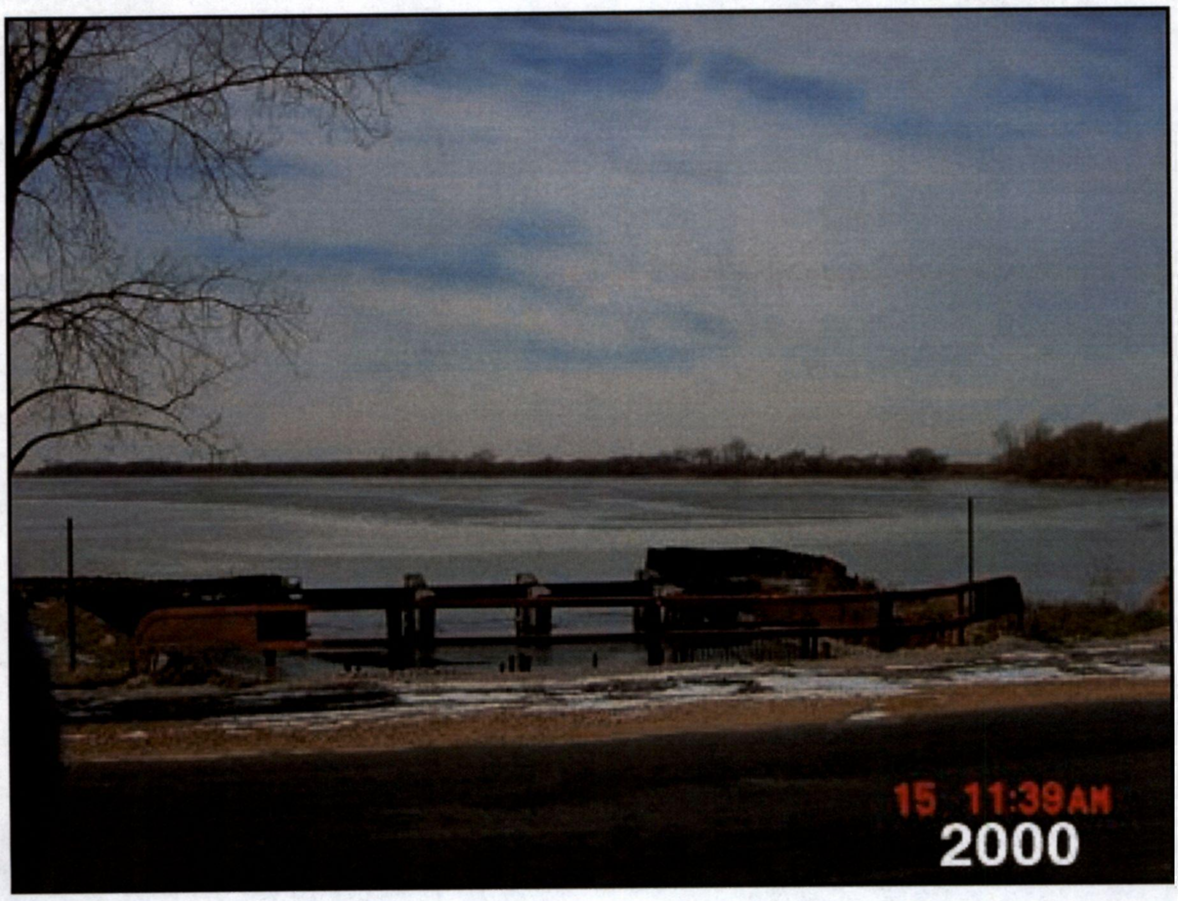


#27 – LOOKING SOUTHWEST FROM HATCHERY (ISLAND CENTER BACKGROUND)

#28 – WEST SIDE OF McINTOSH LOOKING FROM BANK AT SOUTH END OF McINTOSH WOODS TOWARD

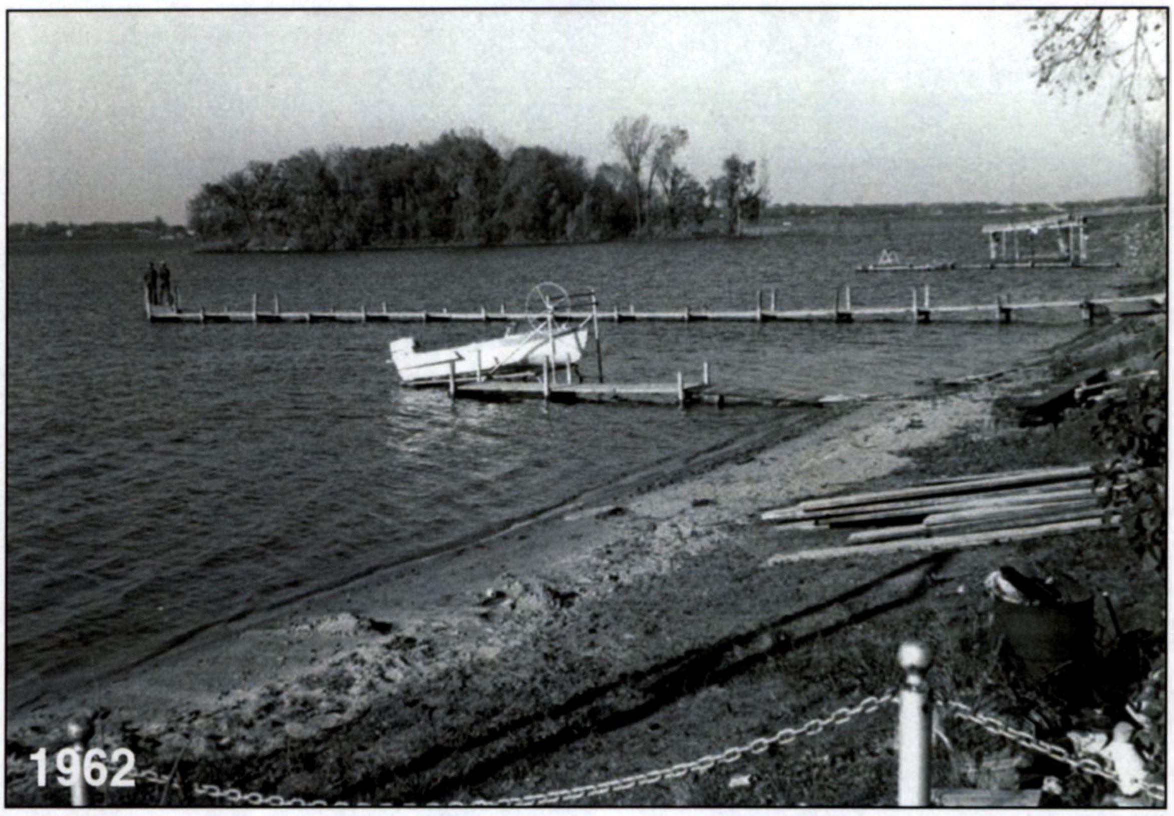
#29 – VENTURA MARSH – CARP TRAP

1962



15 11:39AM
2000

#30 – WEST SIDE OF ISLAND FROM PRINCESS DOCK DRIVE DOWN BY RITZ CLUB



CHAPTER 5

Limnology of Clear Lake

Limnology of Clear Lake

John A. Downing, Jeff Kopaska, Rebecca Cordes, and Nicole Eckles

A. Introduction.

Clear Lake is typical of a large, shallow, corn-belt, kettle lake. The very shallow depth (maximum about 5.9 m or 19 ft) means that wind mixing and fish activities return nutrients from the sediments into the water column during the warm, summer season. This large input of nutrients from the watershed and the remobilization of sediment nutrients give Clear Lake a very high concentration of nutrients such as nitrogen and phosphorus. The mixed agricultural and urban watershed furnishes very high nutrient loads to the lake, some of which has been deposited into the sediment layers. These high nutrient inputs, coupled with the fish- and wind-induced mixing of sediments, are significant impediments to restoration efforts, since they have turned Clear Lake into a hypereutrophic ecosystem.

B. Physical Characteristics.

Lake surface area:	1,468 hectares	(3625 Ac)
Maximum depth:	5.9 meters	(19.2 ft)
Mean depth:	2.9 meters	(9.6 ft)
Volume:	42,054,656 m^3	(34,080 Ac-ft)
Length of shoreline:	22.7 kilometers	(14.1 mi)
Shoreline development index:	1.60	
Watershed area:	4,888 hectares	(12,079 Ac)
Watershed area/Lake area ratio:	2.3	
Hydraulic residence time:	1.6 years	

C. Historical Data.

Clear Lake was one of fifteen Iowa lakes and reservoirs studied in the National Eutrophication Survey performed by U.S. EPA in 1974-1975. This survey indicated that Clear Lake was eutrophic, based on a combination of the following parameters: total phosphorus, dissolved ortho-phosphorus, inorganic nitrogen, Secchi disk measured water clarity, chlorophyll *a* and dissolved oxygen. Water samples were collected April 18, July 3, and September 23, 1974 from one or more depths at three locations in Clear Lake. From those samples, mean total phosphorus was 59 µg/L (N=13), mean inorganic nitrogen was 0.19 mg/L (N=13) and mean Secchi disk depth was 0.89 m (N=8). This survey ranked Clear Lake fourth out of fifteen lakes on a least to most eutrophic gradient according to measured in-lake parameters.

From data collected in Iowa's 1979 lake classification survey, Clear Lake was classified as a eutrophic lake. The mean total phosphorus concentration was 110.5 µg/L (N=8), mean total Kjeldahl nitrogen was 1.3 mg/L (N=2), and mean Secchi disk depth was 0.7 m (N=5). Summer fishkills were estimated to be rare, but winter fishkills were estimated to occur in one year out of 100. An extensive winter fishkill occurred in 1978, and this was the first large-scale fishkill that had occurred in recorded history. A water quality index was calculated for the 106 Iowa lakes sampled in the 1979 lake classification study based upon Secchi disk depth, total phosphorus concentration, algal chlorophyll concentration, total suspended solids and winter fishkill frequency. The index ranked Clear Lake as the 28th poorest water quality of all lakes in the survey. Clear Lake's major problems were water level maintenance, water removal by the city of Clear Lake and nonpoint source pollution from soil erosion and agricultural chemicals. This was suggested to be due to soil erosion from agricultural land in the watershed, considering that 76.9% of the watershed was under row crop production.

From data collected for Iowa's 1994 lake classification survey (field collections occurred in 1990 and 1992), Clear Lake was classified as a eutrophic lake. The mean total phosphorus concentration was 155 µg/L (N=9), mean total nitrogen was 4.1 mg/L (N=9) and mean Secchi depth was 0.4 m (N=3). Winter and summer fishkills were estimated to be rare. A numerical system was developed to rank all Iowa lakes with mean depths of less than 4 m. It was based on a point system to rank Iowa lakes based on public benefit, need for restoration and restoration effectiveness. This system gave Clear Lake a ranking of 18th in terms of priority for restoration projects. A summary of lake nutrient changes over time is shown in Table 1.

Additional monitoring studies have occurred in recent years. In the summer of 1992, ISU was involved in a study on Clear Lake. Roger Bachmann, along with several Clear Lake residents, took samples on a weekly basis from May 1992 until August 1992. Average Secchi depths typically ranged from 0.305 m to 0.45 m. Chlorophyll concentrations were typically high at 84 µg/L relative to the Iowa average of 47 µg/L. The average summer phosphorus concentration was 100 µg/L, while the average total nitrogen and nitrate concentrations were 2.1 mg/L and 0.17 mg/L, respectively. In addition to the 1992 study, monitoring of Clear Lake was carried out by Dr. William Crumpton's laboratory at ISU in both 1995 and 1996 (Appendix 4). Average chlorophyll concentration was 52 µg/L and average summer phosphorus concentration was 153 µg/L. As a result of these and other previous studies, long-term lake monitoring was recommended.

These data, taken together with the recent diagnostic work, show that Clear Lake has increased in nutrient concentration by nearly 3-fold since the early 1970's, and has decreased in water clarity by nearly 3-fold during the same period (see Fig. 1). The most rapid drop in water clarity arose around 100-120 ppb (between 1980-1985). Currently, Clear Lake is increasing in total phosphorus concentration at a rate of 4 ppb/year. At the current rate of increase in total phosphorus, the concentration in Clear Lake would likely be 216 ppb by 2010, and 340 ppb by 2040. Projections such as this make many assumptions but are only meant to indicate the very rapid rate of change being seen in the water quality in this important lake.

D. Limnological data from diagnostic study.

a. Sampling Scheme. Clear Lake limnology was analyzed by sampling at three points, distributed from west to east across the lake (Fig. 2). This approach was used because Clear Lake has three somewhat distinct basins that function slightly differently. For example, the Little Lake can be considered a nearly separate waterbody. Analyses were, therefore, performed separately for each basin and the aggregate trends in water quality were examined by calculating volume-weighted averages for the entire lake. The baseline survey was conducted from July 1998 to September 2000. Previously established methods for diagnostic surveys were followed in regard to sampling frequency, and analytical techniques outlined in Standard Methods for the Analysis of Water and Wastewater (APHA 1994) were used. Average values of the measurements made in this study are presented in Tables 2-5. Additional tables of raw data are presented in Appendix 5.

b. Physics and Chemistry. Clear Lake is polymictic, meaning that it is nearly continuously mixed to the bottom by wind and wave action. The relative lack of stratification compared to other Iowa lakes is due to a somewhat shallow basin and broad expanse of water over which the wind can create turbulence due to wave and current energy. Relatively homogeneous water column temperatures are indicated by the nearly vertical lines on the isotherm graphs in Figure 3. Temperature decreases sharply and transparency increases in the autumn as the lake is cooled rapidly by wind mixing. Generally, temperatures are quite extreme in the lake, varying from >25°C in mid-summer to <4°C in winter. These extremes in heating and cooling result from the shallow depth and extreme degree of wind mixing of the water column, and are instrumental in the weathering and breakdown of sediments. In general, water clarity during the summer season averages between 0.3-0.4m (ca. 1 foot, Fig. 4).

Because of the intense mixing of the water column, surface oxygen concentrations are generally adequate throughout the year (Fig. 5). Because of intense sedimentary decomposition during warm weather and very weak stratification of water layers near the bottom, bottom waters are frequently somewhat low in dissolved oxygen during the summer and winter months. Concentrations of dissolved oxygen near the bottom rarely fall beneath the minima required to safely sustain sport fish.

Clear Lake is well buffered, containing an average of about 150 mg/L of calcium carbonate alkalinity (range of averages 130-180). Alkalinity generally increases throughout the summer in the Little Lake, likely owing to evaporative loss of water and resultant concentration of dissolved salts in Ventura Marsh and this shallow basin (Fig. 6), but declines somewhat in the main lake due to extremely high rates of primary production during late summer. Lake pH becomes quite high in mid-summer as the phosphorus-driven primary production uses CO_2 more rapidly than the alkalinity buffering system can supply it (Fig. 7). Maximum summer pH approaches 9.0. Some low pHs are observed in the bottom waters during mid-summer, due to intense decomposition of organic materials and bottom sediments, and declines rapidly throughout the autumn. Total dissolved solids peak in the spring as runoff dissolves terrestrial salts (Fig. 8), declining through dilution after spring rains, then declining further as alkalinity is depleted in late summer. Silicon (a dissolved mineral essential to the growth of beneficial algae) was highest near the beginning of the study and generally declined over the analysis period (Figs. 9-10). The silicon concentration declined fairly steadily over the study period, probably in response to intense inputs from heavy rains at the beginning of the study followed by steady sedimentation of algae.

In spite of the relatively small size of the watershed, Clear Lake has a very high concentration of suspended solids. The average for Iowa lakes (including natural and artificial lakes) is about 20-30 mg/L (0.02-0.03 g/L), with natural lakes usually containing less suspended solids than artificial impoundments (Fig. 11). Clear Lake averages much greater than this, with frequent lake-wide averages of >30 mg/L (0.03 g/L) (Fig.s 11-12). Highest suspended solids concentrations were found in mid-summer, indicative of the resuspension of lake sediments by wind and fish action. The lake sediments and watershed erosion are almost certainly the source of suspended solids during the summer months. This is indicated by the tendency for highest concentrations to be near the bottom (Fig.s 13-14) and the fact that one can observe the movement of sediment loads associated with high rainfall in June-July 1999 sequentially along the lakes axis from the Little Lake in June to the eastern-most sampling station in August (Figs. 12, 15).

c. Nutrient Concentrations. Nitrogen and phosphorus are the most important essential nutrients to the growth of algae and other organisms in lakes. Although Clear Lake is far from the most nutrient-rich lake in the state, it is extremely rich in nutrients when compared to some of Iowa's other lakes (Fig. 16, Table 6) and lakes elsewhere in the world (Fig. 17). The rich nutrient environment is likely due to significant nutrient inputs from the agricultural watershed, as well as the regeneration of sedimentary nutrients throughout the summer season. Total nitrogen trends are characterized by large peaks of nutrient concentrations during periods of high run-off with concentrations highest in the Little Lake where most of the hydraulic load is received (Fig. 18). Late summer nitrogen concentrations generally decline, probably due to denitrification loss to the atmosphere under warm conditions at the oxic/anoxic interface near the sediment surface. Generally, however, the source of nitrogen is clearly indicated by the fact that total nitrogen concentrations decrease as water masses move from west to east. A paired t-test shows that total nitrogen concentrations in the Little Lake are an average of 0.7-0.8 mg/L higher than those in the central or eastern basins, respectively ($p<0.0001$). Total nitrogen levels decrease through autumn and winter as cool conditions slow nitrogen inputs from the watershed. Because the lake is large with respect to its watershed, algae growth is quite high and only a small fraction of the nitrogen occurs in the form of nitrate (Fig. 19), except in spring and early summer when watershed efflux is high. Generally, however, dissolved nitrogen is dominated by ammonium, because it is liberated from decomposing sediments (Fig. 20) and is mixed into the water by wind and fish. Under the current nutrient scenario, ammonia is likely to have adverse impacts on fish and other organisms in Clear Lake because unionized ammonia concentrations peak beyond the levels normally responsible for severe fish damage (Fig. 21). Unionized ammonia levels in Clear Lake are much higher than would be desirable for sustaining optimal sport fisheries. The prevalence of ammonia as a nitrogen form imply a constant supply of reduced nitrogen from decomposition or from other nutrient-rich, low oxygen sources.

Trends in total phosphorus are dominated by inputs from the watershed and the regeneration of phosphorus from decomposing sediments, summer wind mixing and fish activities. Normally a lake will show maximum phosphorus levels near ice-out, decreasing throughout the summer until a second phosphorus peak is observed in autumn. In Clear Lake, however, phosphorus concentrations are lowest in winter and early spring, reaching high levels during the warm-water season, then declining when cold weather begins (Figs. 22, 23). Unlike many other lakes, there is no marked trend in phosphorus concentration across the season, but lake-wide total phosphorus hovers between 150-200 ppb. These levels now place Clear Lake within the hyper-eutrophic category. It is likely that much of the supply of phosphorus originates in the watershed, since much of the watershed is at the western end of the lake and a paired t-test of inter-station differences in total phosphorus shows that concentrations in the Little Lake are generally around an average of 33 ppb higher than that in the central basin ($p<0.0001$). Nutrient concentrations generally decline as the water masses move from west to east across the lake.

The concomitant decrease in total nitrogen in mid-summer and increase in total phosphorus from summer sediment mixing means that conditions favor the excess growth of nuisance algae. Ratios of total nitrogen to total phosphorus (N:P) are most frequently below the acceptably high range (>30 as mass units) that would favor the growth of most useful forms of phytoplankton. N:P falls to very low levels by the end of summer (Figs. 24, 25). This is due to the excessively high rate of input of phosphorus that keeps N:P quite low. This favors the growth of nitrogen fixing forms such as the cyanobacteria (formerly "blue-green algae") that can be a nuisance and health hazard when they grow in excess.

d. Phytoplankton Community Structure and Biomass. Phytoplankton in Clear Lake follow a seasonal pattern that is typical of temperate, shallow, hypereutrophic lakes (Fig. 26). Algal biomass is generally highest in mid-summer when it forms conspicuous "blooms" of algae coloring water an intense green color. Cyanobacteria ("blue-green algae") and diatoms (Bacillariophyceae) make up the majority of the phytoplankton biomass for much of the active growing season (Figs. 27-31). Cyanobacteria dominance is especially acute in mid- to late-summer, when cyanobacteria make up >80% of the algal biomass. The dominance of Cyanobacteria gives Clear Lake a sometimes fluorescent green color. The taxa of Cyanobacteria involved in summer blooms are *Anabaena, Spirulina* and *Oscillatoria* (Figs. 29-31). These are taxa that are known to be able to produce some toxic materials, and these potentially toxic taxa compose between 27% of the phytoplankton in the Little Lake to 47% of the phytoplankton biomass at the central sampling station (overall average during the summer season: 35%). It is likely that the Cyanobacteria in Clear Lake exude some degree of toxin during growth, senescence or decay (Falconer 1999). Because such toxins can be harmful to invertebrates, fish, wildlife, livestock and humans, reduction of nutrient levels to eliminate Cyanobacterial dominance would be welcome. Cyanobacteria dominance in mid-summer arises due to very high nutrient concentrations and very low N:P ratios. Overall, about 38% of the phytoplankton in the lake is composed of Cyanobacteria on an annual basis (Table 7). Figure 32 shows that, when compared to world lakes in general, Clear Lake develops somewhat less Cyanobacteria than would normally occur at this high a level of total phosphorus concentration.

E. Trophic condition of lake.

Based on both the historical data and the data collected during this study, Clear Lake is classified as hypereutrophic. This is reflected in the relatively high values for total phosphorus and total nitrogen, and low Secchi disk transparencies.

F. Algae.

The ratio of mean total nitrogen to mean total phosphorus concentration on the lake is 13:1. This indicates that Clear Lake algae are phosphorus limited throughout much of the ice-free season, but potentially nitrogen limited at the height of summer stagnation.

G. Macrophytes.

Aquatic macrophytes were surveyed during the summers of 1999 and 2000. Transects perpendicular from the shoreline to the outer edge of macrophyte beds were established at 20 m intervals. Macrophytes were then quantified at 20 m intervals along each transect using a $1m^2$ quadrat. From this survey, we were able to determine species present and abundance of each species. These data were then compared to historical data collected from Clear Lake over the past 100 years.

Results for Clear Lake show that there exists a total of 12 different species of aquatic macrophytes in the lake. Species frequency of occurrence in quadrats show that *Scirpus* (Rush) is the most common 68%, followed by *Typha* (Cattail) 21%, *Nuphar a.* (Yellow Lily) 4.2%, *P. nodosus* (Floating Leaf Pond Weed) 3.4%, *Nymphaea t.* (White Lily) 2.2%, *P. pectinatus* (Sago Pond Weed) 0.4%. The rest were <1%.

To see changes in macrophyte distributions over the years, these results were compared to results from seven other surveys conducted on Clear Lake dating back to 1896. Results show that species abundance has steadily decreased from a maximum of 35 species surveyed in 1952, to 21 species in 1981, and is now 12 species. Frequency of occurrence of species in each quadrat was compared to data from 1981, which was the last time an aquatic survey was completed on Clear Lake. Results show a decrease in all of the species listed above except *P. nodosus* and *Nuphar a.*, which show increases. The areal extent of macrophyte beds was measured by digitizing aerial photographs of Clear Lake from 1979 to 1999. Results show that there has been an overall decrease in macrophyte bed size by 49%.

We compared these data to historical Secchi disk readings and found a dramatic decrease in water clarity from 2.4 m in 1896 to 0.4 m in 2000 (Fig. 33). An increase in water clarity would lead to an increase in macrophyte species diversity and abundance in Clear Lake. If water clarity continues to degrade, macrophyte species diversity and abundance will continue to decrease. Macrophytes help stabilize sediments and create very useful fish and wildlife habitat.

H. Hydraulic budget for lake.

The method used in the analysis is based on the equation of continuity.

Fundamental Equation: $\Delta S = \text{Inflow} - \text{Outflow}$
The equation in more detail is: $\Delta S = P + R - O - E + GW$
Where:
S = change in storage (m^3)
P = the precipitation falling directly onto the lake (m^3)
R = the surface runoff from the watershed (m^3)
E = the evaporation from the lake surface (m^3)
O = the outflow over the spillway (m^3)
GW = the groundwater seepage (m^3)

P and R are positive quantities, E and O are negative quantities, GW and S may be either positive or negative. Precipitation records from the Mason City Municipal Airport (July 1998-September 2000, source: http://nndc.noaa.gov/?home.shtml). Evaporation records are from the National Weather Service, Climatological Data (May 1998-April 1999) for Ames. A pan coefficient of 0.74 was used (Kohler et al., 1959).

Runoff was determined using a rainfall volume and runoff coefficient method. Runoff coefficients were derived from measurement of rainfall and runoff in two subbasins (one agricultural, one urban) that were continuously monitored using flow meters. These runoff coefficients were directly assigned, or combined to determine, a runoff coefficient for the other subbasins in the watershed based upon percentages of agricultural or urban land use in the other subbasins. The entire study length was broken down into different time periods that had similar runoff coefficients. Water flux from each subbasin was determined by multiplying rainfall volume, drainage area and runoff coefficient for each time period. Periodic water fluxes (m^3) were summed to determine total annual runoff.

Outflow was determined using discharges measured on the outflow stream. Outflow was measured in the field periodically (two times per month in April-September, once per month in October-March). Instantaneous outflow (m^3/s) were multiplied by 86,400 to determine daily outflow (m^3/day). These results were compared to lake stage data from the USGS gauging station at Clear Lake. From these results, a stage-discharge relationship was built for lake stage data for Clear Lake.

Groundwater seepage and other groundwater information are discussed in detail in Chapter 8 (page 180) of this report.

Table 8 summarizes the hydraulic budget for Clear Lake for a period of two years, ending July 31, 2000. The lake derives 49% of its water from rainfall onto the lakes surface and 43% of its water from runoff. Clear Lake loses 61% of its water through evaporation and 28% of its water through outflow. The lake flushes 0.69 times per year for a hydraulic retention time of 1.45 years. These data indicate that the lake overall has a positive water budget. The period that this budget covers is short due to the lack of inflow and outflow data other than that which was collected during the course of this study.

I. Lake bathymetry

A bathymetric survey of Clear Lake was conducted in July 2000. The survey was performed using digital, discriminating sonar and differentially corrected Global Positioning Systems (GPS). Lake elevation at the spillway crest was used as the baseline for lake depth, and over 77,000 distinct locations with their associated depths were used to create the new bathymetric map seen in Figure 34. These data were imported into SURFER™, a commercial geostatistical mapping package, to calculate the lake volume and generate bathymetric maps. The volume of the lake at spillway height in 2000 was found to be 42,054,656 m^3 (34,108 ac-ft), and the surface area was 1,468 hectares (3,625 ac). The maximum depth of the lake was 5.9 m (19 ft), and the mean depth was 2.9 m (9.6 ft).

A bathymetric survey of Clear Lake was also completed in 1935. This map is shown in Figure 35. This earlier survey was digitized using ArcView and the data was exported for use in SURFER™. Using this data set, SURFER™ determined the volume of the lake in 1935 to be 45,669,742 m^3 (37,010 ac-ft) with a mean depth of 3.1 m (10.3 ft). An original lake volume was calculated using sediment depths from borings taken in 1935. The depths of soft sediments were added to the water depths recorded for the 1935 bathymetric survey to calculate original lake water depths. This map is shown in Figure 36. The original lake volume was determined to be 68,121,176 m^3 (55,248 ac-ft) with a mean depth of 4.7 m (15.5 ft).

Sediment deposition in Clear Lake from 1935 to 2000 is shown in Figure 37. This figure was created by subtracting the 2000 depth map from the 1935 depth map. The change in depth between the two years is the result of sediment deposition. Sediment deposition from the original lake to 2000 was also calculated in the same manner and shown in Figure 38. Between 1935 and 2000, 3,537,706 m^3 (2869 ac-ft) of lake volume was filled with sediment. Between the original lake and 2000, 25,990,520 m^3 (21,079 ac-ft) of sediment was deposited with 2,731,853 m^3 (2,216 ac-ft) of that sediment accumulating in the Little Lake (Fig. 39). This indicates an annual sediment deposition of 54,426 m^3 (44 ac-ft) into Clear Lake between 1935 and 2000. The present volume represents an 8% reduction in lake volume from 1935 to 2000. From the original lake to 2000, Clear Lake has lost 38% of its volume. It is expected that sediment deposition rates will decrease with time, as trap efficiency of the lake declines. However, assuming constant rates of sediment delivery and deposition in the future, Clear Lake would completely fill with sediment in approximately 775 years.

Sediment deposition has resulted in the loss of one foot of mean depth since 1935. Considering that annual sediment deposition has been 54,426 m^3 (44 ac-ft), and the surface area of the lake is 1,468 hectares (3,625 ac), the lake has been losing 3.7 mm/yr (0.94 in) of depth if this sediment were evenly distributed. This sediment has a density of 1440 kg/m^3, which when multiplied by annual sediment deposition rate gives a result of just over 78 million kg/yr (>85,000 tons/yr) of sediment added to the lake. Thus, the Clear Lake watershed has lost 22,910 kg/ha/yr (10 tons/acre/yr) of sediment on average. This figure represents, of course, the aggregate of all erosional transport in the watershed (e.g., gully, sheet, rill, streambank, etc.), exclusive of shoreline erosion, less the sediment retransported down stream. It also does not account for erosional losses redeposited within the basin that were not yet transported into the lake. This figure thus represents a minimal estimate of erosional soil loss in the watershed. During the course of this study, tributary monitoring showed the sediment transport to the lake to be somewhat more than 1.1 million kg/yr (see Chapter 10), which equates to 327 kg/ha/yr (0.2 ton/acre/yr). Because these sediment loss flux rates are less than the overall average sediment accumulation rate, it seems that the rates we measured during 1998-2000 are lower than those over the lifetime of the lake. The decrease in watershed sediment loss rates may result from climatic variability and improved agricultural conservation practices implemented throughout the watershed.

J. Impact of Lake Degradation and Outlook for Lake Improvement

Drastically increased phosphorus concentrations in Clear Lake have resulted in decreases in many aspects of the quality of the Clear Lake ecosystem. Judging from trends in water clarity, Clear Lake was likely oligotrophic-mesotrophic at the turn of the century, mesotrophic until the mid 1970s, then moving from eutrophic in the mid-1970s to near hyper-eutrophic in the late 1990s. The implications of this change for many aspects of the Clear Lake ecosystem are listed in Table 9. Phosphorus concentrations of the magnitude seen in Clear Lake during this study are very poor for continued quality of recreational use. If trends continue in this vein, users of Clear Lake should expect further degradation of water clarity, reduced oxygen levels, frequent blooms of toxic algae, increased survival and persistence of fecal and potentially pathogenic bacteria, accelerated filling and siltation, mobile toxins, increased impacts of ammonia on the quality of fish and other aquatic organisms, continued declines in biodiversity and year-to-year stability, degraded fish and wildlife habitat, decreased fish production and a fish community highly dominated by rough fish.

The increase in total phosphorus concentration in the lake has yielded a profound increase in algal abundance. The dense algae that have bloomed in Clear Lake have decreased water clarity to the point that rooted aquatic vegetation has declined substantially. Turbid waters with toxic algae favor the growth of resistant fishes like carp and bullhead that perturb sediments and uproot vegetation. Sediment resuspended by fish and increased wind mixing in the absence of rooted vegetation further decreases water clarity further reducing the ability of aquatic plants to cleanse waters and stabilize sediments. Resuspended sediments lead to increased phosphorus concentrations that have favored even more algae growth. Projected increases in phosphorus concentrations indicate that, in the absence of remedial measures, Clear Lake will continue to decline in quality and utility as a recreational resource.

In order to improve Clear Lake, three fundamental changes would need to take place:

- Reductions in phosphorus loading to the lake from all parts of the watershed.
- Reductions in silt input and resuspension by fish, wind and boat action.
- Reductions in inputs of bacteria from the watershed surrounding the lake.

Such changes would give rise to gradual improvements in the lake, the course of which is likely to span 5-30 years before substantial improvements would be achieved.

Knowledge of the hydraulic and nutrient budgets as well as various limnological details allow computation of future water quality under various scenarios of improved watershed characteristics. First, it is important to understand that the phosphorus concentration in the lake is principally a function of the rate of phosphorus input and the rate of flushing of the lake, and secondarily a function of return of sedimentary phosphorus to the water column. One can thus calculate the expected change in water quality (i.e., phosphorus concentration) by calculating the impact of a reduction in phosphorus input. There are many models that enable these calculations but normally it is wise to fit several of them to find which yields the best prediction of the current total phosphorus concentration from calculated inputs and hydrology. We examined the fit of more than a dozen such models and found that the Canfield/Bachmann (Canfield & Bachmann 1981) yields a prediction of current phosphorus concentration at spring circulation that is the best, and is within 2% of the actual phosphorus concentration. This model is thus likely to predict the phosphorus concentration under future remedial states.

Next, it is possible to alter the parameters of the equations to examine the predicted change in total phosphorus concentration that would result from various levels of decrease in phosphorus inputs (Fig. 40). Apparently, it would take around a 60% reduction in total phosphorus inputs to bring the lake back to the total phosphorus concentrations that were seen in the late 1970s and early 1980s. Using the normal relationship between water clarity and total phosphorus seen in other Iowa lakes (Bachmann et al. 1994), we can predict changes in water clarity that would be expected following these scenarios (Fig. 41). This analysis suggests that a 60% reduction in total phosphorus loading to Clear Lake should bring water clarity to the 0.8-1.2 m level, once lake conditions equilibrate. This water clarity level is somewhat conservation because increased water clarity and carp management taken together would greatly reduce suspended solids in the water column, affording even greater increases in water clarity. It is likely, therefore, that such a management scenario could bring water clarity in Clear Lake back to pre-1970 levels, allowing marked increases in the entire lake as an ecosystem and recreational resource.

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Good things are happening in clear lake

- Who's responsible ?
- How are things Changing ?
- How has your work helped other lakes ?
- What does the future hold ?

TABLE 1. Summary of historical nutrient data collected on Clear Lake.

Parameter	1974 Study	1979 Survey	1990 Survey
Total Phosphorus	59 μg/L	110.5 μg/L	155 μg/L
Nitrogen	0.19 mg/L (inorganic N)	1.3 mg/L (TKN)	4.1 mg/L (TN)
Secchi depth	0.89 m	0.7 m	0.4 m

TABLE 2. Summary table of measurements made on all Clear Lake sampling stations during the diagnostic study between July 1998 and September 2000. All dates, depths and stations combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	μg/L as P	188	4	659
Total Nitrogen	mg/L as N	2.39	0.06	659
Nitrate-Nitrogen	mg/L as N	0.29	0.01	475
Ammonia-Nitrogen	mg/L as N	0.20	0.02	475
Chlorophyll *a*	μg/L	42	6	111
Secchi depth	m	0.41	0.01	111
Alkalinity	mg/L as $CaCO_3$	143	2	390
Dissolved Oxygen	mg/L	9.2	0.4	611
Specific Conductance	μmhos/cm	331	5	636
Total Suspended Solids	mg/L	60	13	579
pH	neg. log H^+ conc.	8.40	0.02	636

TABLE 3. Summary table of measurements made on the Little Lake Site in Clear Lake during the diagnostic study between July 1998 and September 2000. All dates and depths combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	μg/L as P	210	10	156
Total Nitrogen	mg/L as N	2.9	0.2	156
Nitrate-Nitrogen	mg/L as N	0.41	0.05	110
Ammonia-Nitrogen	mg/L as N	0.23	0.05	110
Chlorophyll *a*	μg/L	49	11	39
Secchi depth	m	0.34	0.02	37
Alkalinity	mg/L as $CaCO_3$	143	4	94
Dissolved Oxygen	mg/L	12	2	145
Specific Conductance	μmhos/cm	308	7	149
Total Suspended Solids	mg/L	62	10	137
pH	neg. log H^+ conc.	8.54	0.03	149

TABLE 4. Summary table of measurements made on the Central Lake Site in Clear Lake during the diagnostic study between July 1998 and September 2000. All dates and depths combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	μg/L as P	184	7	252
Total Nitrogen	mg/L as N	2.25	0.07	252
Nitrate-Nitrogen	mg/L as N	0.26	0.01	183
Ammonia-Nitrogen	mg/L as N	0.21	0.03	183
Chlorophyll *a*	μg/L	33	9	36
Secchi depth	m	0.45	0.03	37
Alkalinity	mg/L as $CaCO_3$	144	3	147
Dissolved Oxygen	mg/L	8.37	0.18	234
Specific Conductance	μmhos/cm	341	11	243
Total Suspended Solids	mg/L	66	27	219
pH	neg. log H^+ conc.	8.38	0.02	243

TABLE 5. Summary table of measurements made on the East Lake Site in Clear Lake during the diagnostic study between July 1998 and September 2000. All dates and depths combined.

Parameter	**Units**	**Mean**	**Standard Error**	***n***
Total Phosphorus	μg/L as P	180	6	251
Total Nitrogen	mg/L as N	2.19	0.06	251
Nitrate-Nitrogen	mg/L as N	0.26	0.01	182
Ammonia-Nitrogen	mg/L as N	0.19	0.03	182
Chlorophyll *a*	μg/L	45	12	36
Secchi depth	m	0.43	0.02	37
Alkalinity	mg/L as $CaCO_3$	142	3	149
Dissolved Oxygen	mg/L	8.31	0.19	232
Specific Conductance	μmhos/cm	336	3	244
Total Suspended Solids	mg/L	53	2	223
pH	neg. log H^+ conc.	8.32	0.03	244

TABLE 6. Summary table of summer measurements made on Clear Lake during study period (1998-2000), during the 1990 and 2000 state lake surveys and on all Iowa lakes during the 1990 and 2000 state lake surveys.

Parameter	**Units**	**Clear Lake 1998-2000**	**Clear Lake 1990**	**Iowa lakes average 1990**	**Clear Lake 2000**	**Iowa lakes average 2000**
Total Phosphorus	μg/L as P	188	155	163	129	187
Total Nitrogen	mg/L as N	2.39	4.1	3.4	1.97	2.15
Chlorophyll a	μg/L	42	53.4	48.1	31	28
Secchi depth	m	0.41	0.4	1.1	0.4	1.0

TABLE 7. Fraction of total biomass composed of different algae taxa in Clear Lake, Iowa during 1999 and 2000. Total biomass data were calculated directly from volumetric approximations of algae counts. The data represent the average for all stations and all dates sampled.

Taxon	**Overall Average**
% Bacillariophyceae	44
% Cyanobacteria	38
% Chlorophyceae	12
% Chrysophyceae	4
% Cryptophyceae	1
% Dinophyceae	<1
Total Biomass (mg/L)	47.0

TABLE 8. Hydraulic budget for Clear Lake.

Month	**Precip.**	**Pan Evap.**	**Change in Storage**	**Precip.**	**Runoff**	**Evap.**	**Groundwater**	**Outflow**
	(cm)	(cm)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
Aug-98	14.0	16.2	1985720	2060273	2460529	-1758944	-48050	-728088
Sep-98	4.6	17.9	-547569	674339	805345	-1943661	-46500	-37092
Oct-98	8.8	8.2	1895531	1289068	1539499	-884986	-48050	0
Nov-98	2.8	0.0	860611	413545	493886	0	-46500	-319
Dec-98	1.0	0.0	410277	152751	305576	0	-48050	0
Jan-99	3.6	0.0	1516969	521588	1043431	0	-48050	0
Feb-99	4.1	0.0	1756372	599826	1199946	0	-43400	0
Mar-99	3.2	0.0	1166813	473155	946541	0	-48050	-204833
Apr-99	20.8	10.9	2769206	3043839	3591777	-1179981	-46500	-2639928
May-99	19.2	18.7	350207	2820301	3327999	-2029126	-48050	-3720916
Jun-99	13.1	18.2	-898881	1914973	2259698	-1976744	-46500	-3050308
Jul-99	28.3	22.0	1249376	4154076	1629469	-2393046	-48050	-2093073
Aug-99	5.5	17.8	-1701496	808461	224886	-1927119	-48050	-759675
Sep-99	5.5	14.8	-799738	804736	52094	-1610068	-46500	0
Oct-99	2.8	16.7	-1423028	409819	26529	-1811326	-48050	0
Nov-99	1.9	0.0	254977	283148	18329	0	-46500	0
Dec-99	1.9	0.0	778713	271971	554792	0	-48050	0
Jan-00	2.7	0.0	1175107	402368	820789	0	-48050	0
Feb-00	4.1	0.0	1801111	607277	1238783	0	-44950	0
Mar-00	3.1	0.0	725231	450801	322480	0	-48050	0
Apr-00	4.3	17.7	-1021026	633357	310965	-1918848	-46500	0
May-00	12.1	23.9	7303	1777125	872532	-2594304	-48050	0
Jun-00	13.2	21.2	95663	1929876	517110	-2304823	-46500	0
Jul-00	14.3	42.2	-2069334	2093803	561035	-4582076	-48050	-94046
Total	194.9	266	10338116	57180951	25124021	-28915052	-1133050	-13328278

TABLE 9. Tabular representation of the usual changes in aquatic ecosystems corresponding with alterations in the phosphorus concentrations of freshwater lakes.

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
Total P (ppb)	0-20	20-70	70-200	>200
Clarity	Excellent	Good	Poor	Very Poor
Oxygen	Abundant	Adequate	Hypoxic	Anoxic
Toxic Algae	Absent	Absent	Frequent	Constant
Bacteria	Rare	Rare	Abundant	Very Abundant
Silt / Filling	Very Slow	Slow	Rapid	Very Rapid
Toxin Mobility	Bound	Bound	Mobile	Very Mobile
NH3 Toxicity	Improbable	Infrequent	Frequent	Constant
Biodiversity & Stability	High	Good	Poor	Very Poor
Fish Habitat	Good	Excellent	Poor	Very Poor
Wildlife Habitat	Good	Excellent	Poor	Very Poor
Fish Production	Low	Moderate	High	Moderate
Fish Community	High Quality	Good Quality	Poor Quality	Rough Fish

FIGURE 1. Trend in total phosphorus and Secchi disk transparency since the early 1970's. Data are from EPA and State of Iowa surveys. The dashed line is a linear regression analysis (r^2=0.70) showing a slope of around 4 ppb/year.

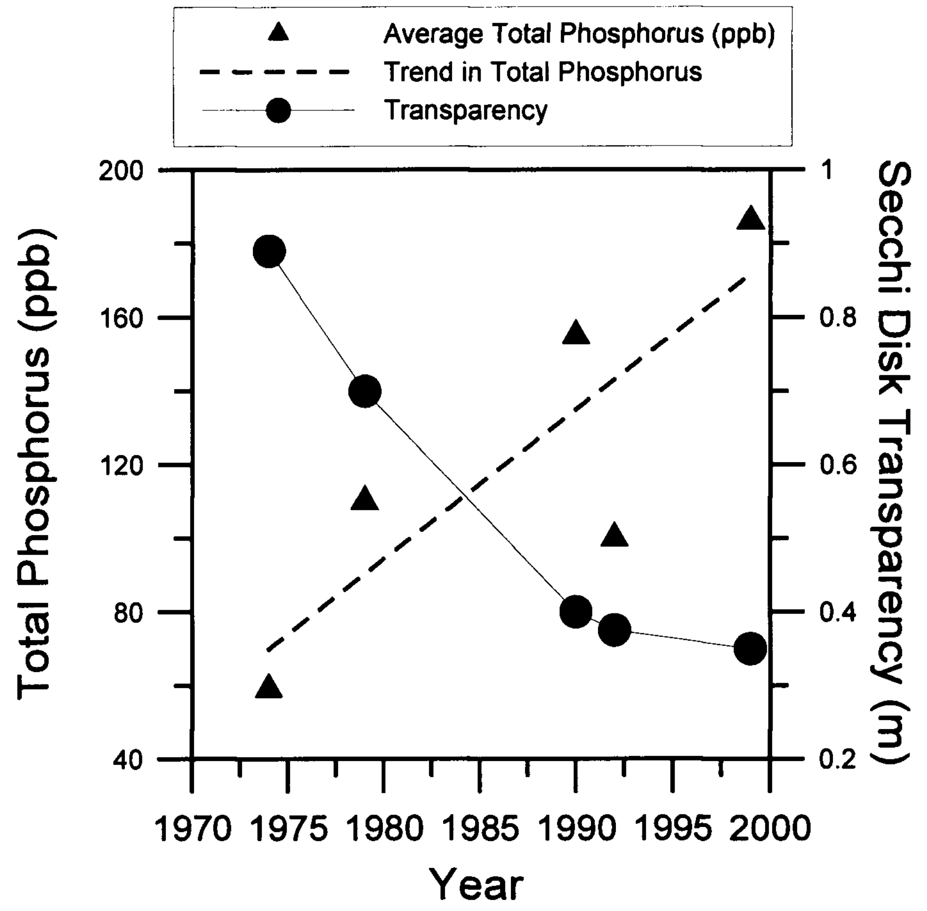


FIGURE 2. Open water sampling points in Clear Lake, Iowa.

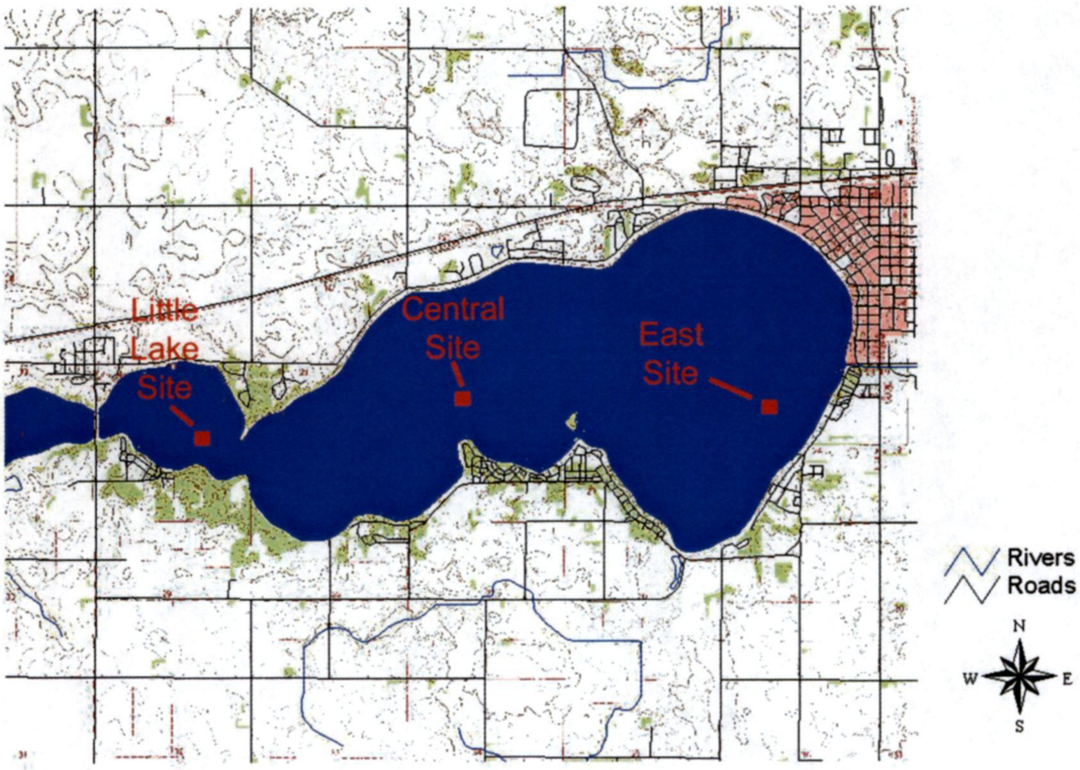
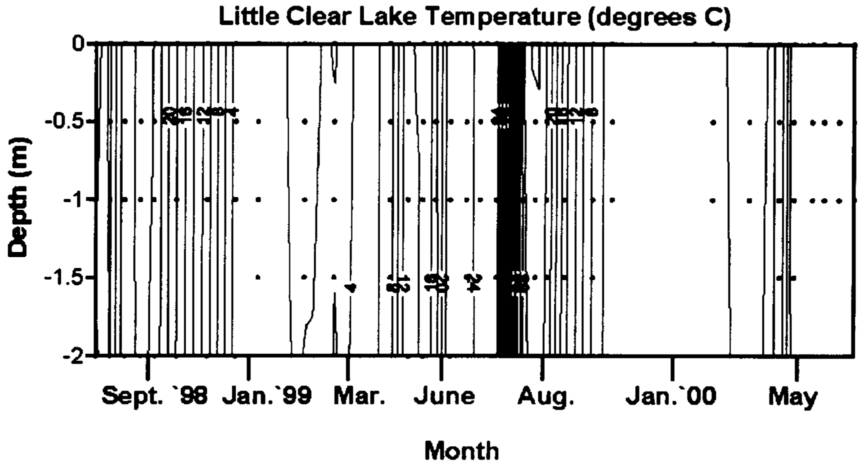
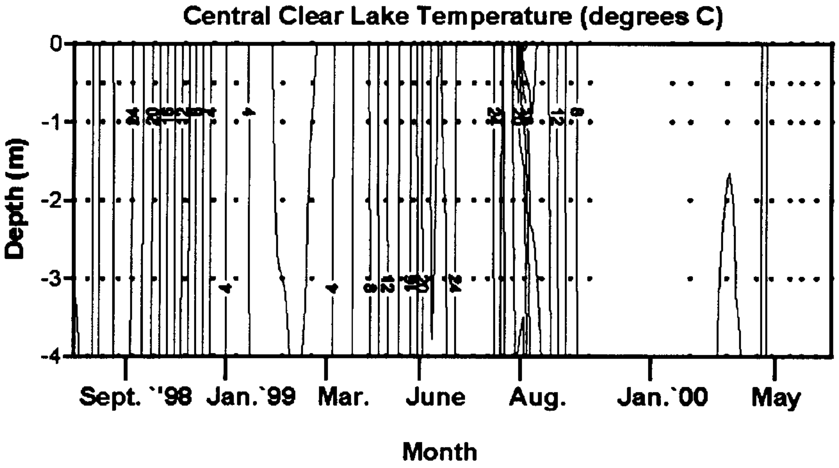


FIGURE 3. Trends in water temperature in Clear Lake, Iowa during 1998-2000. Temperature data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.





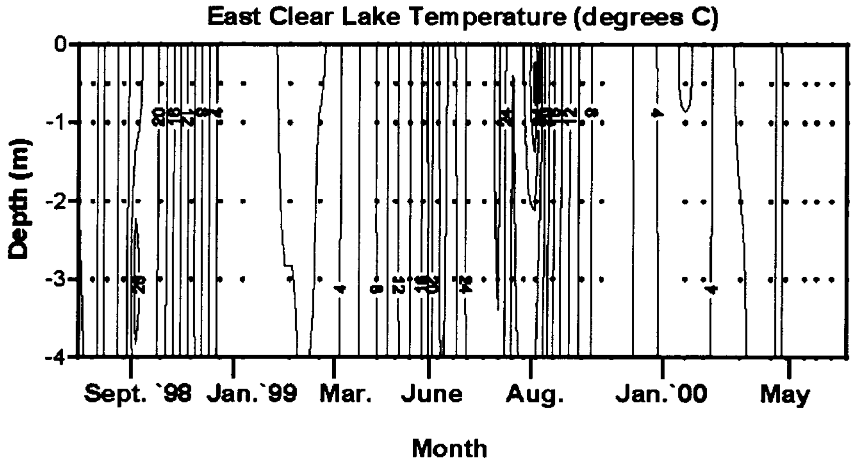


FIGURE 4. Trends in water clarity in Clear Lake, Iowa from 1998-2000. Larger numbers indicate greater water clarity.

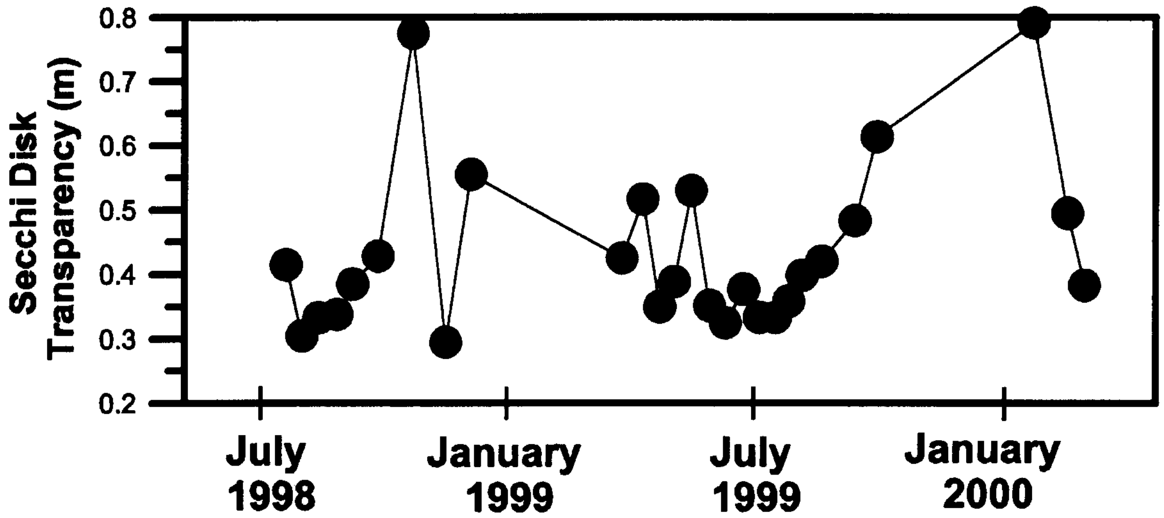


FIGURE 5. Trends in oxygen concentrations in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

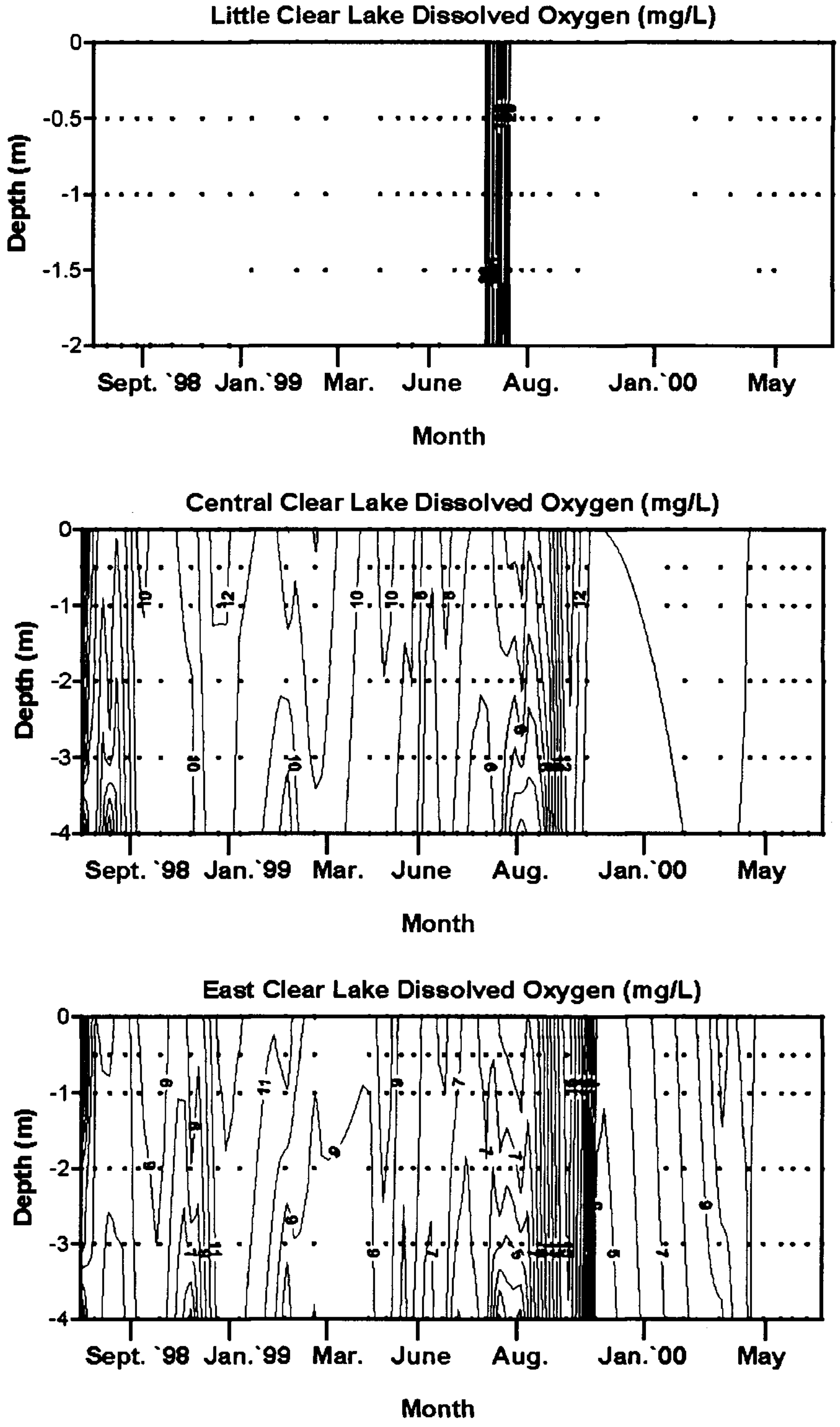
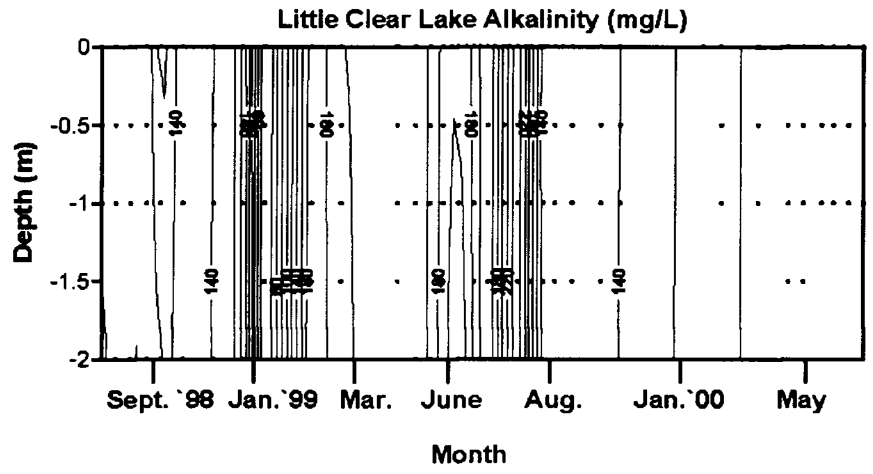
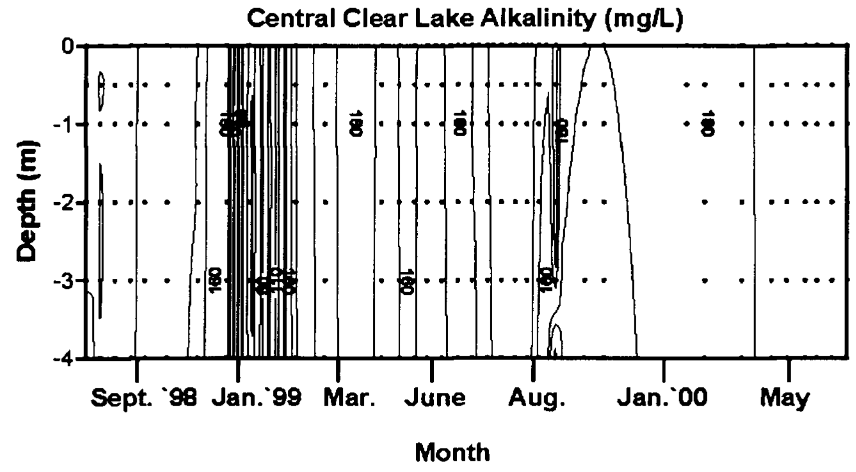


FIGURE 6. Trends in alkalinity concentrations in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.


Little Clear Lake Alkalinity (mg/L)


Central Clear Lake Alkalinity (mg/L)

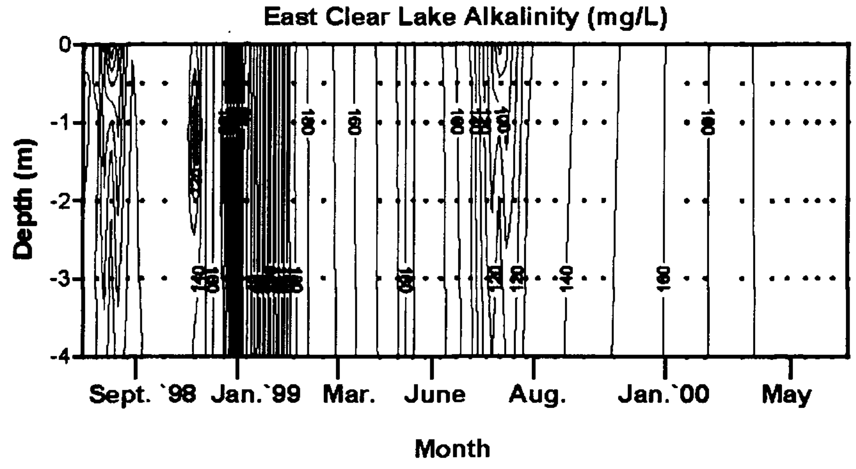

East Clear Lake Alkalinity (mg/L)

FIGURE 7. Trends in pH of Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification. Numbers below 7 indicate acid conditions.

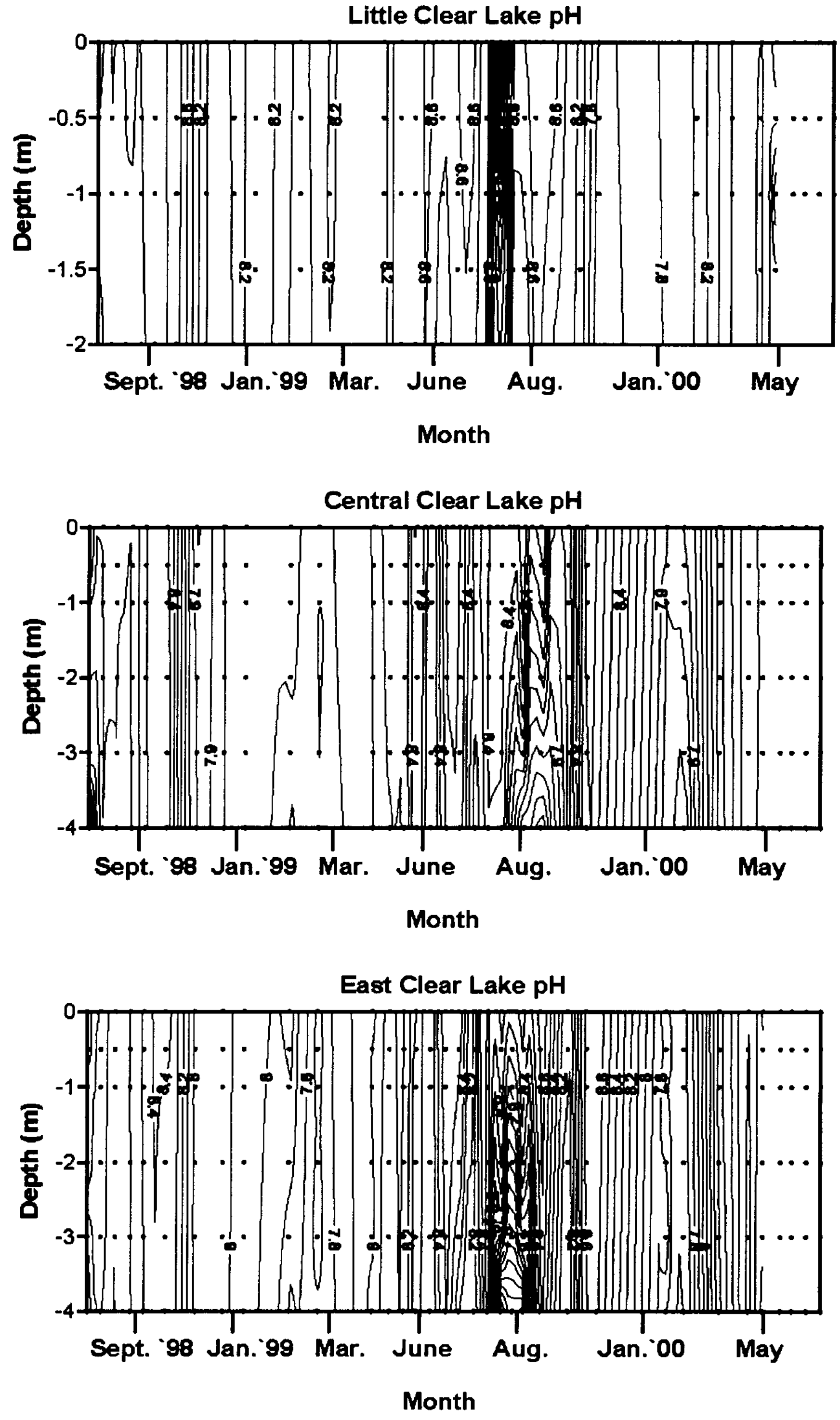
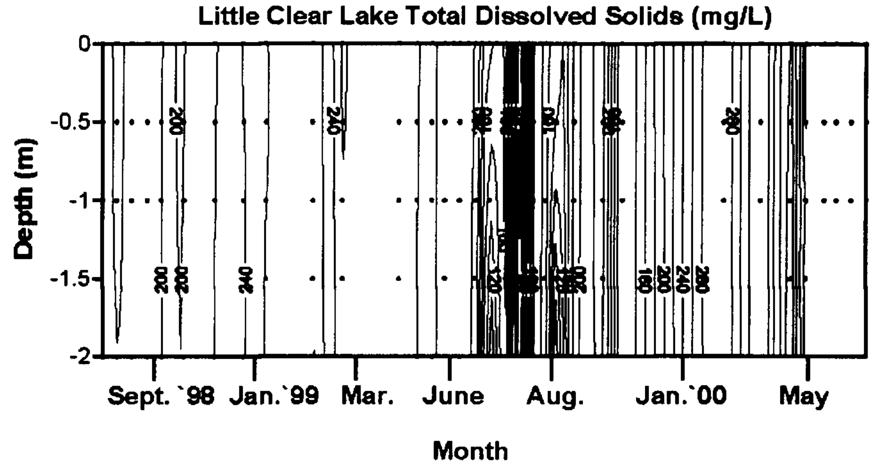
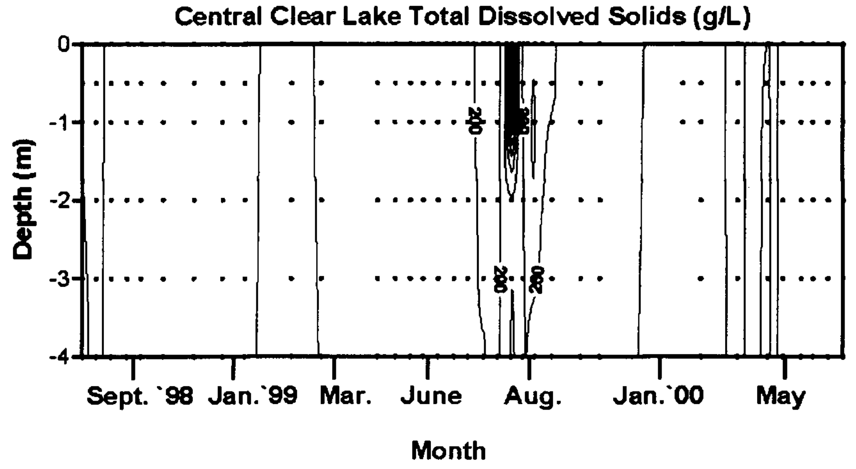


FIGURE 8. Trends in total dissolved solids (TDS) in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.


Little Clear Lake Total Dissolved Solids (mg/L)


Central Clear Lake Total Dissolved Solids (g/L)

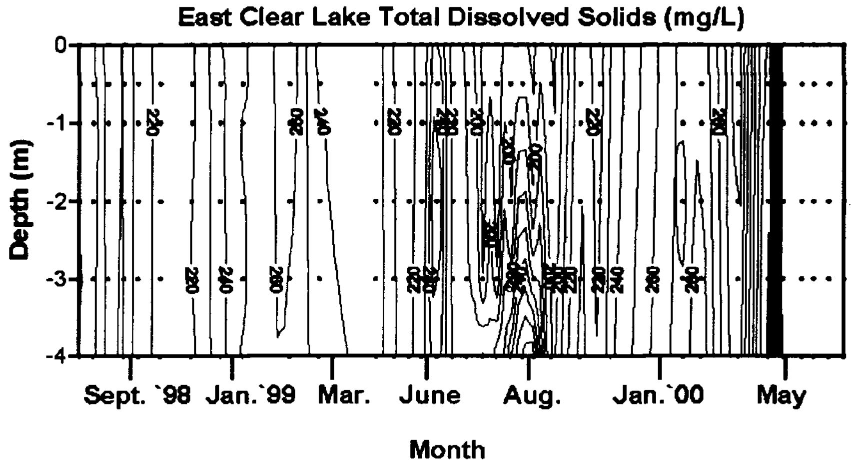

East Clear Lake Total Dissolved Solids (mg/L)

FIGURE 9. Trends in silicon in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

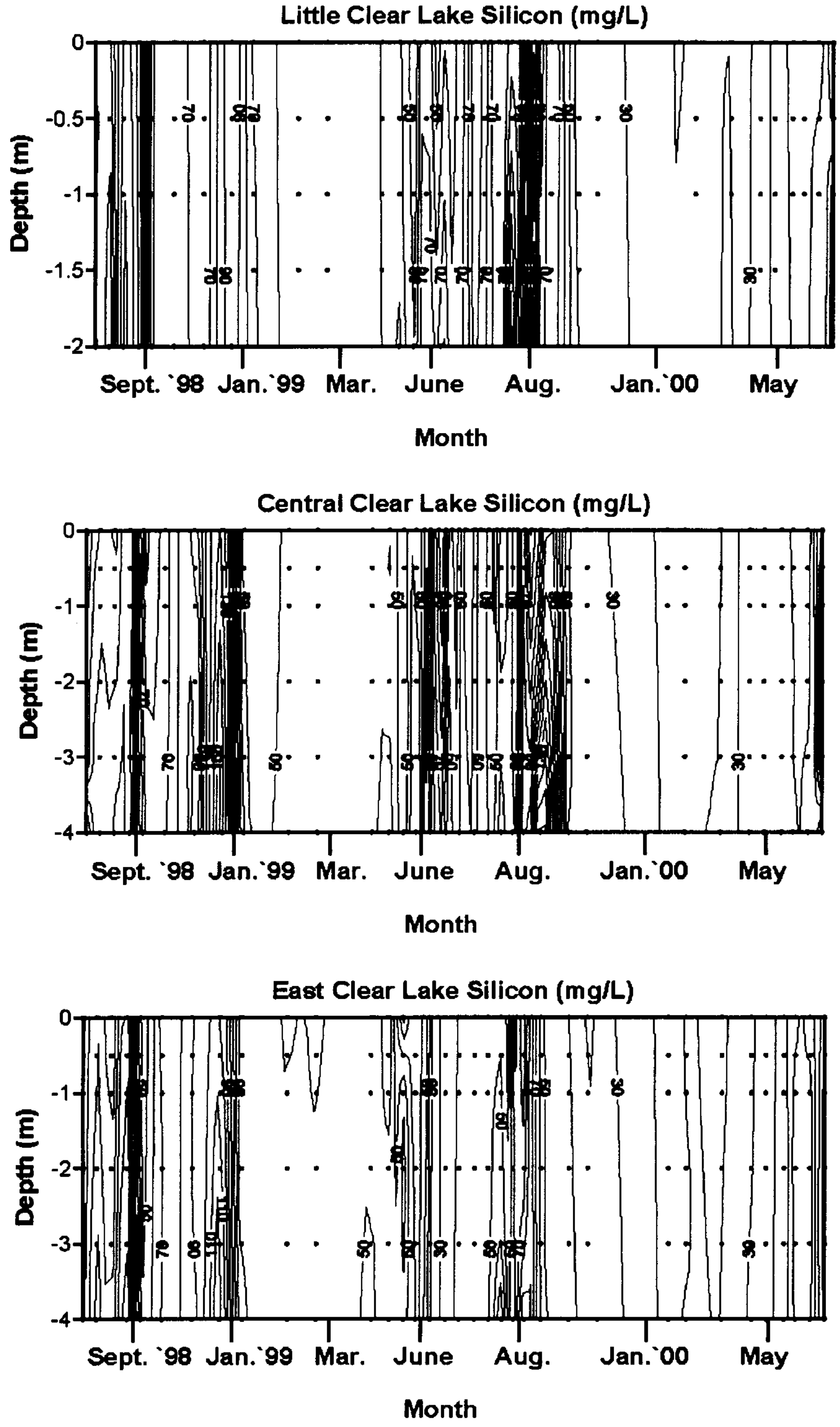


FIGURE 10. Trends in whole-lake, volume weighted concentrations of silica in Clear Lake, Iowa during 1998-2000.

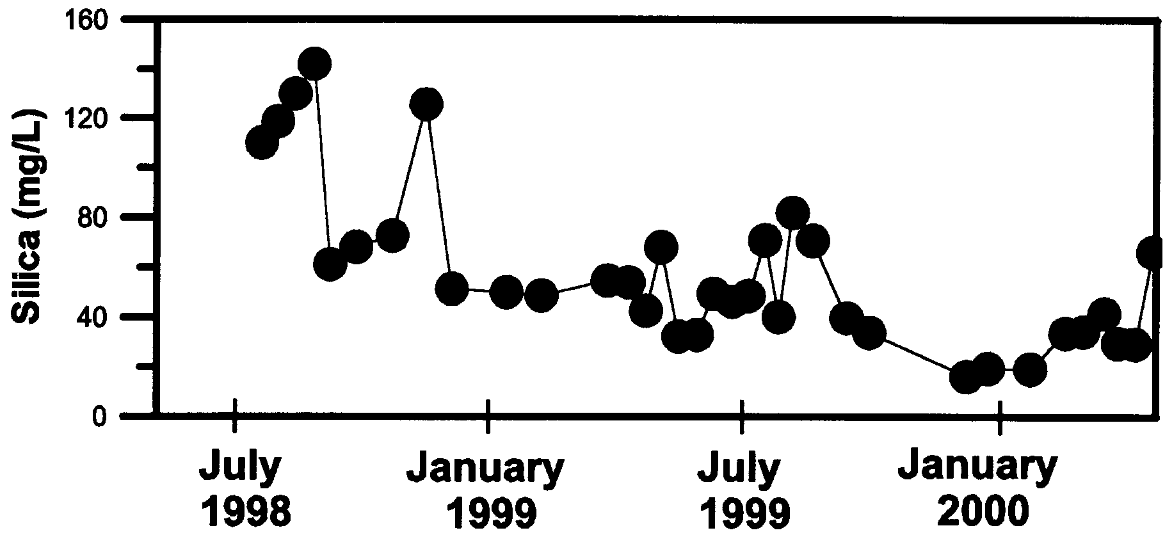


FIGURE 11. Comparison of total suspended solids concentrations in Clear Lake with those found in the 2000 Iowa Lake Water Quality Survey (Downing & Ramstack 2001).

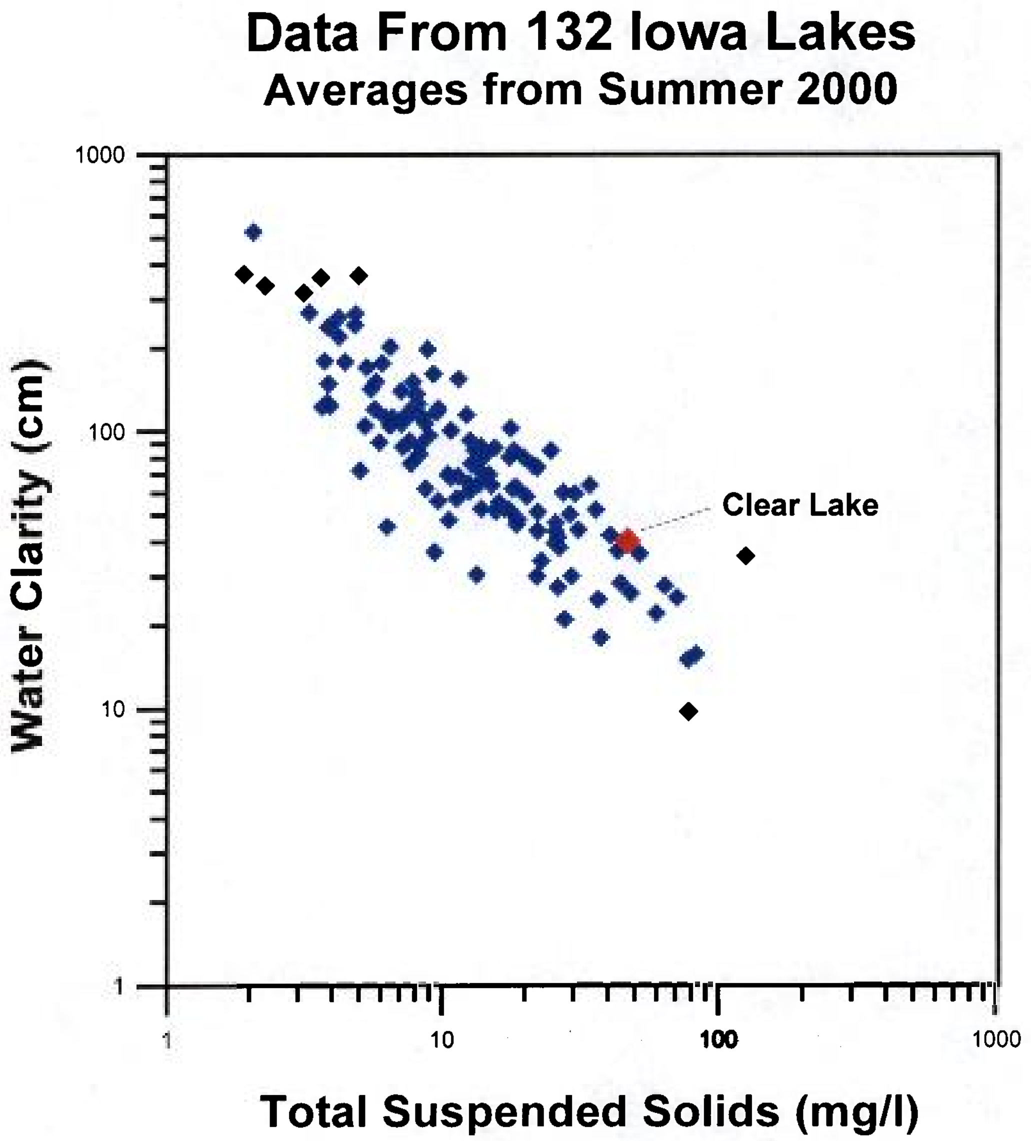


FIGURE 12. Trends in total suspended solids (TSS) in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

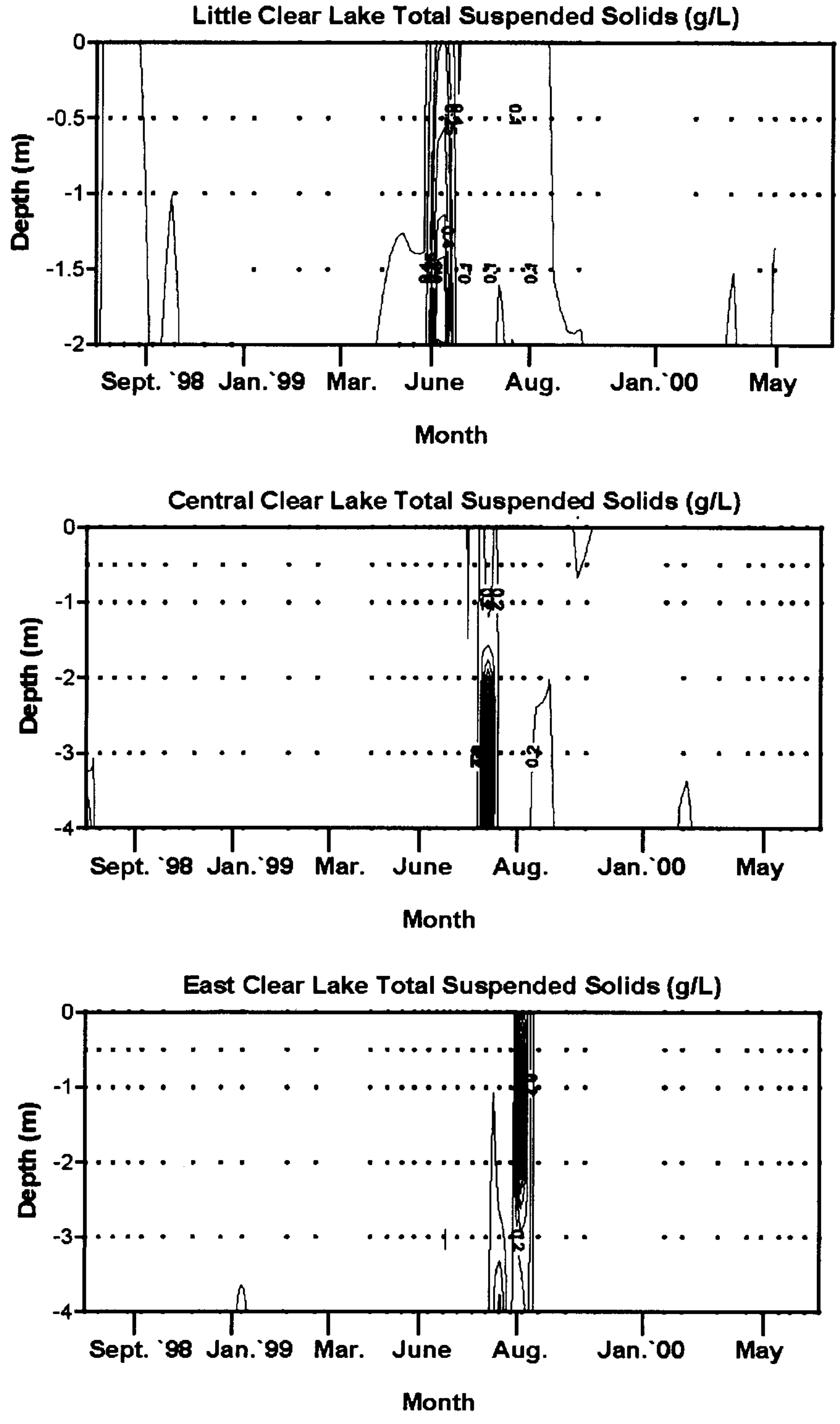


FIGURE 13. Volume weighted trends in suspended solids in Clear Lake, Iowa during 1998-2000.

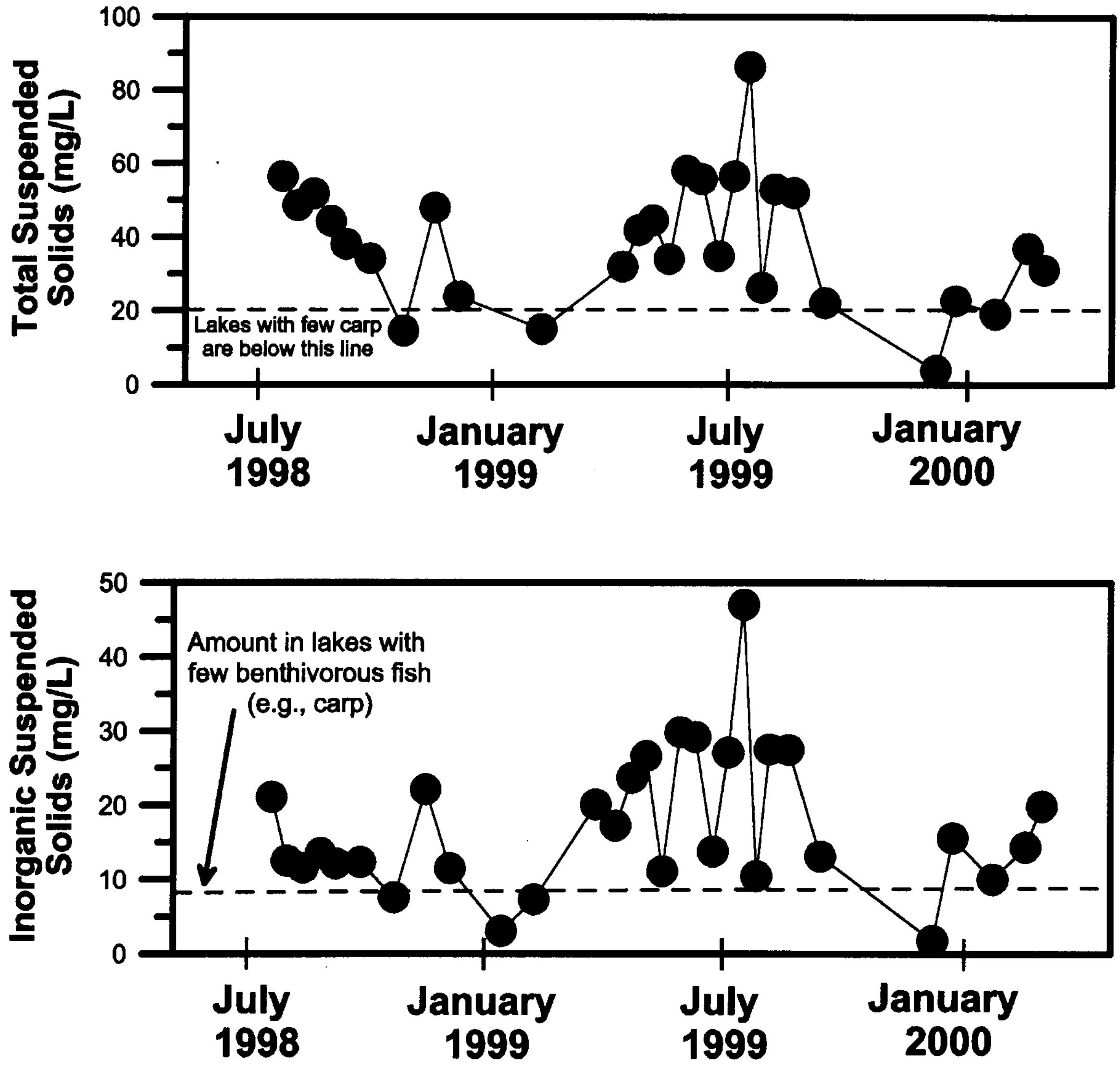


FIGURE 14. Trends in inorganic suspended solids (ISS) in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

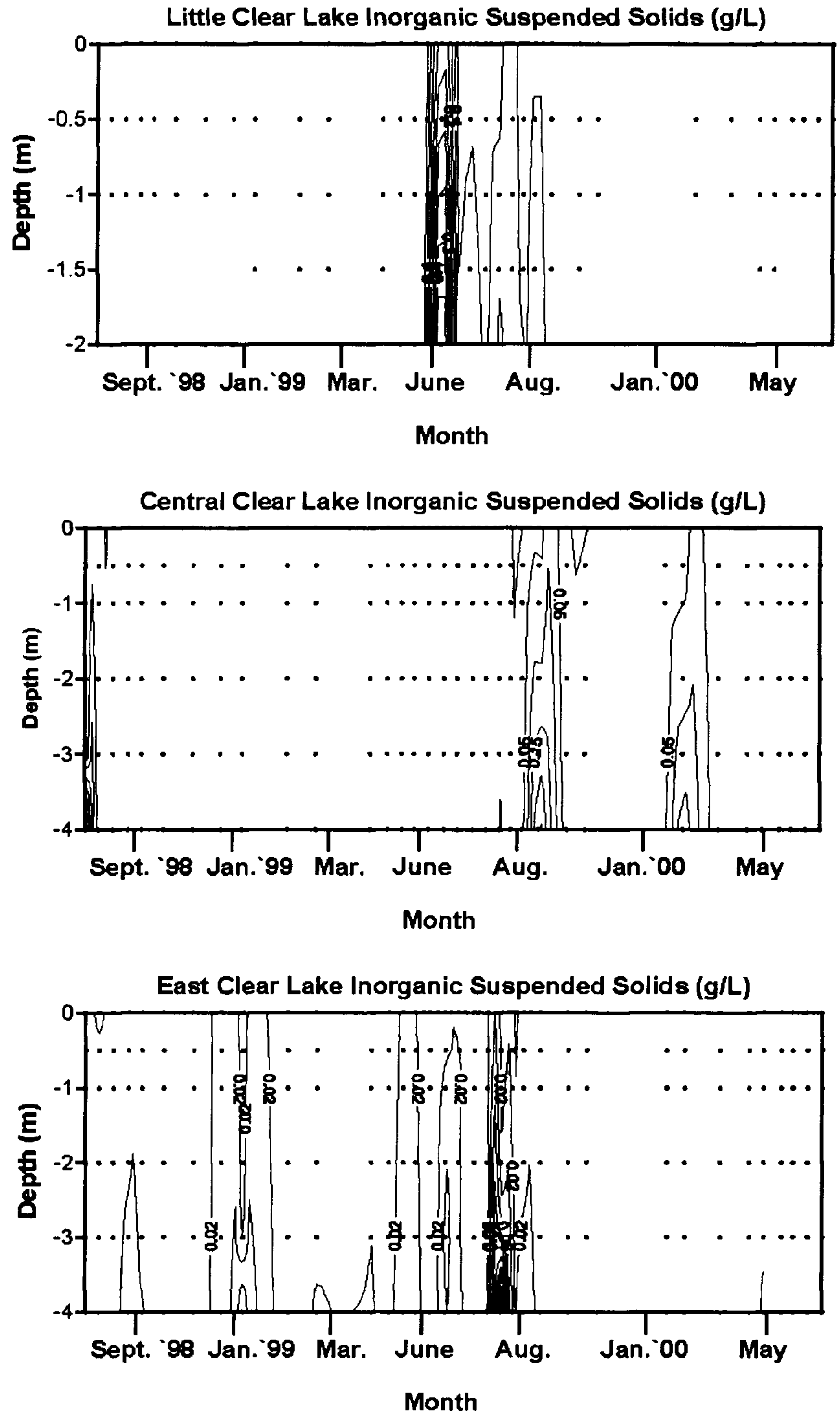


FIGURE 15. Trends in volatile suspended solids (VSS) in Clear Lake, Iowa during 1998-2000. Volatile suspended solids represent the organic fraction of the suspended sediment and therefore contain algae, detritus and soil particles. Data are averages of measures taken at each sampling point in the lake.

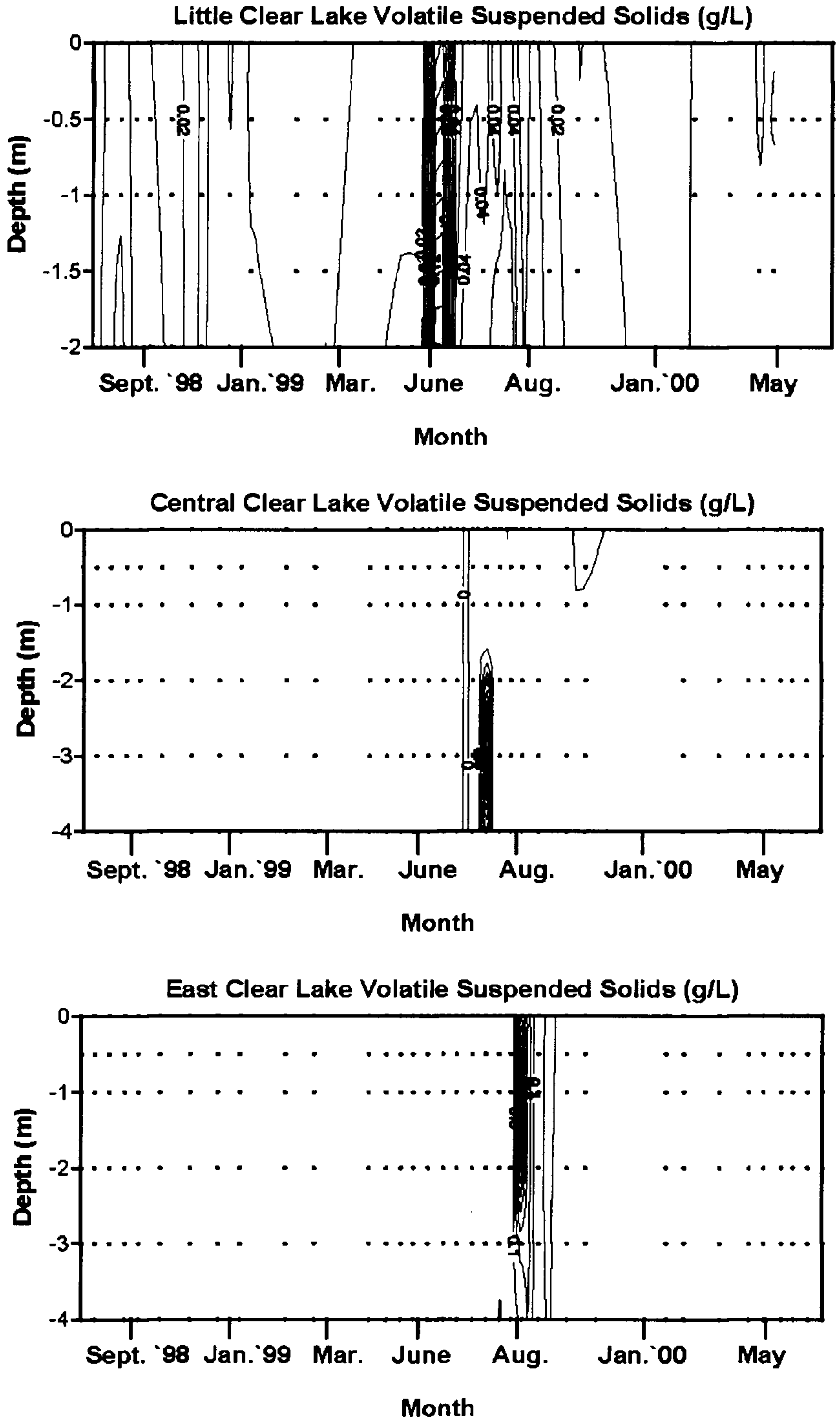


FIGURE 16. Comparison of total phosphorus concentrations in Clear Lake with those found in the 2000 Iowa Lake Water Quality Survey (Downing & Ramstack 2001).

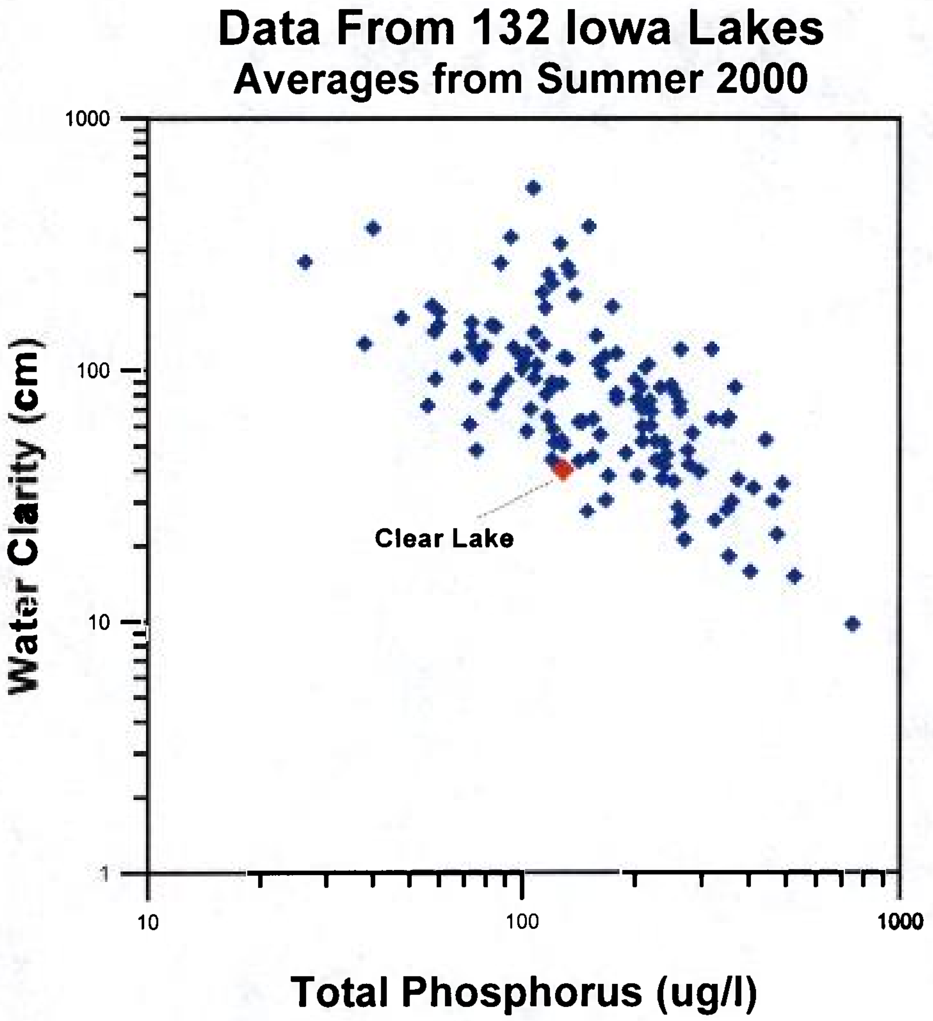
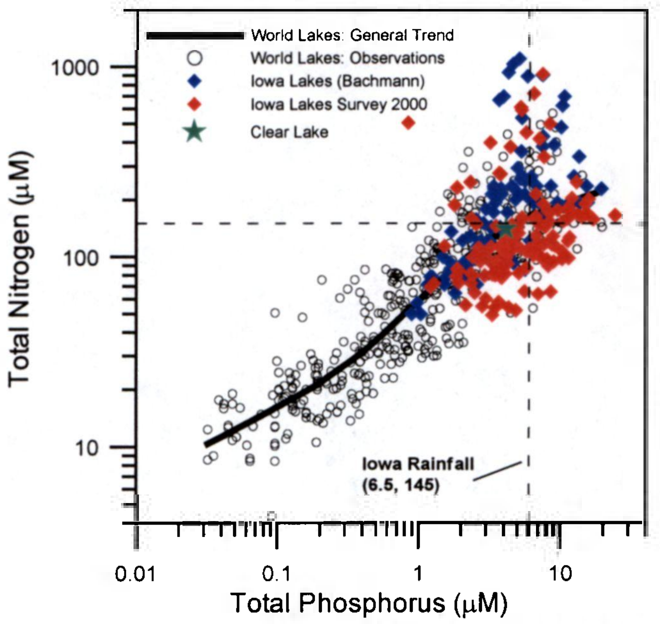


FIGURE 17. Comparison of total phosphorus and total nitrogen concentrations in Clear Lake with those found in the 1990 (Bachmann et al 1992) and 2000 Iowa Lake Water Quality Surveys (Downing & Ramstack 2001), as well as world lake data (Downing and McCauley 1993).



(data from Hatch 1992 [IA]; McCauley & Downing 1993 [WORLD])

FIGURE 18. Trends in total nitrogen in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

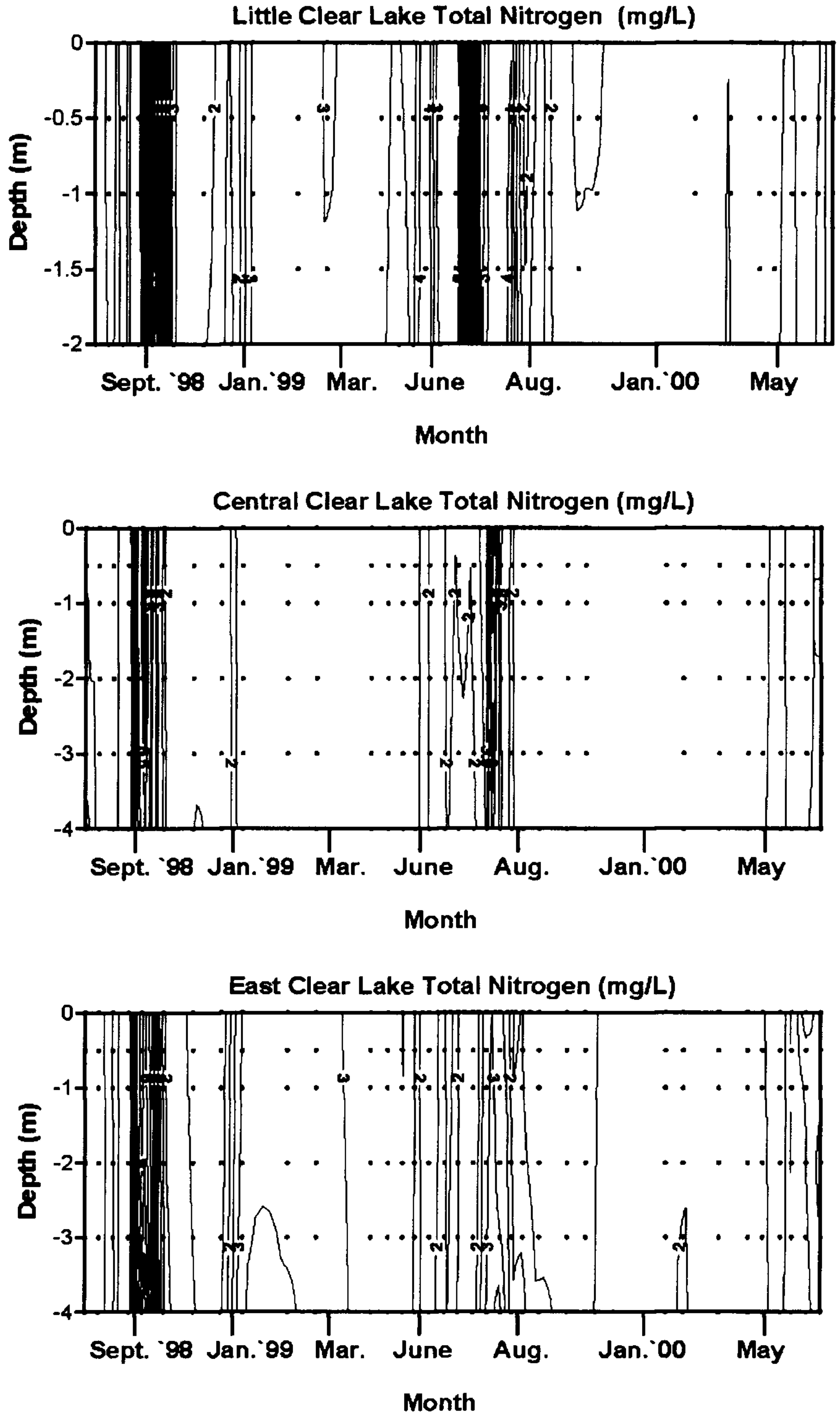


FIGURE 19. Trends in nitrate in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

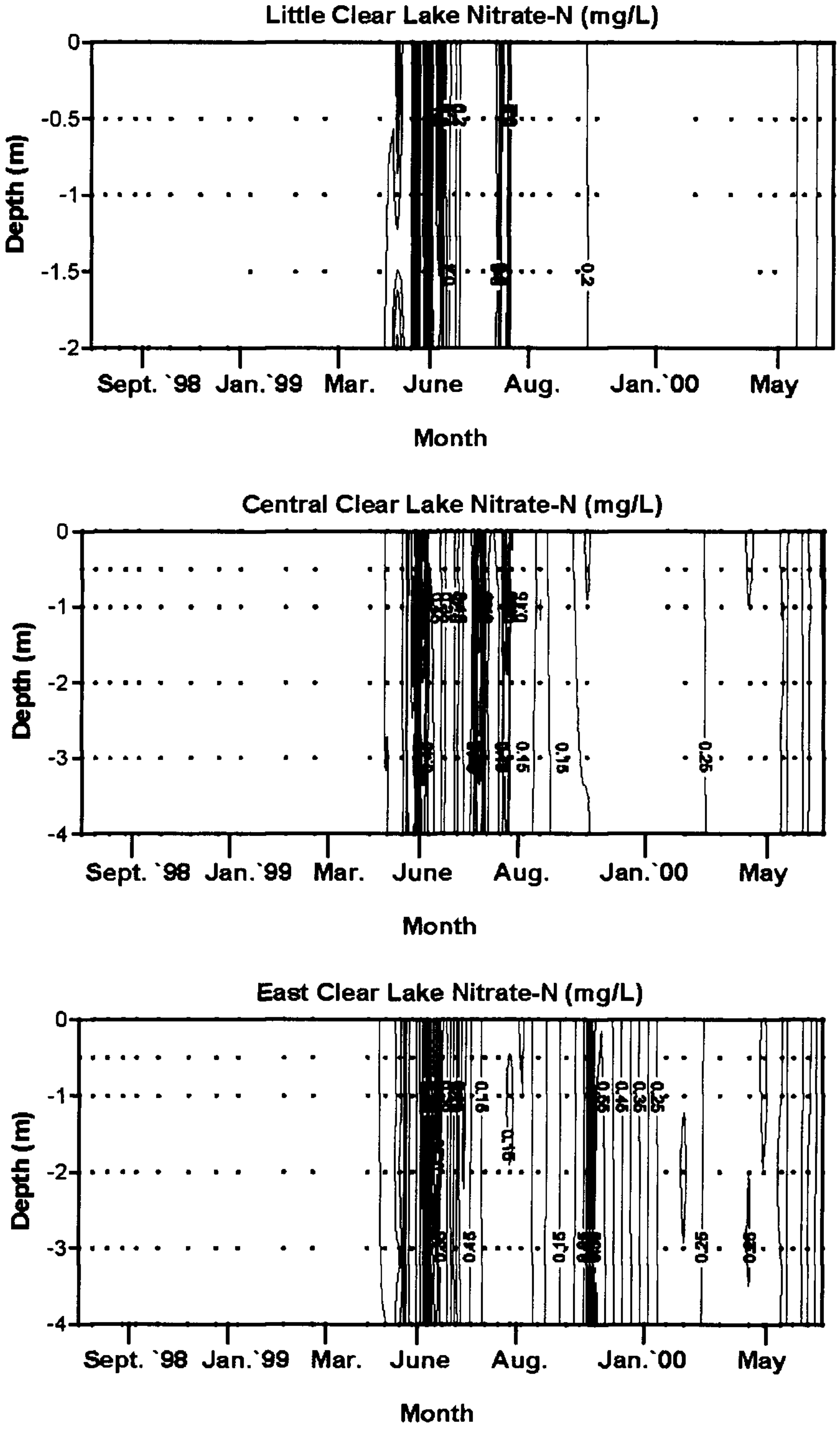
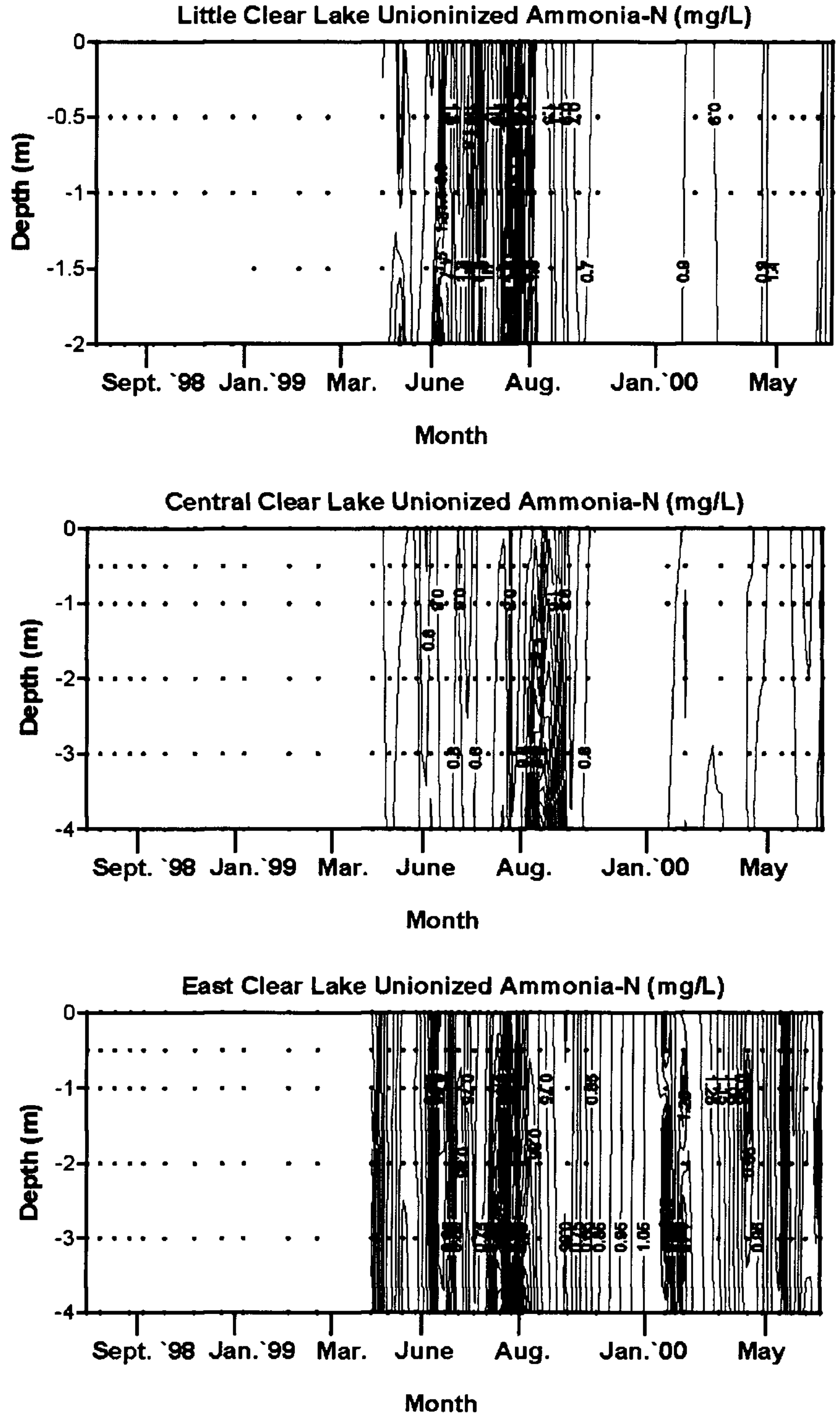


FIGURE 20. Trends in ammonia nitrogen in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.



Little Clear Lake Unioninized Ammonia-N (mg/L)

Central Clear Lake Unionized Ammonia-N (mg/L)

East Clear Lake Unionized Ammonia-N (mg/L)

FIGURE 21. Trends in volume weighted concentrations of various forms of nitrogen in Clear Lake, Iowa during 1998-2000.

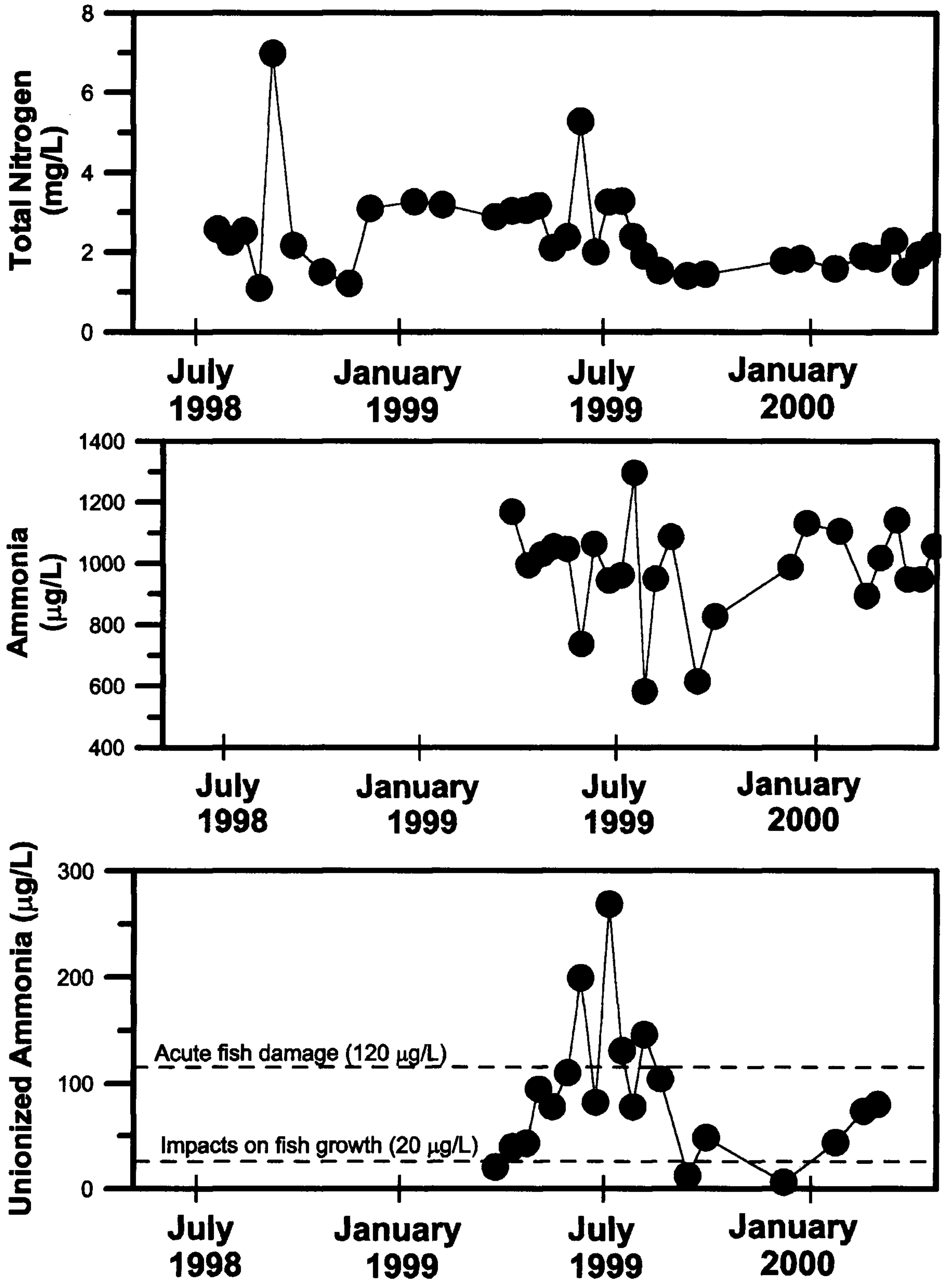


FIGURE 22. Trends in total phosphorus concentration in Clear Lake, Iowa during 1998-2000. Data are averages of measures taken at each sampling point in the lake. The dots indicate dates and depths of sampling. Vertical lines indicate that the lake is mixed from top to bottom, while the more horizontal lines indicate periods of relative stratification.

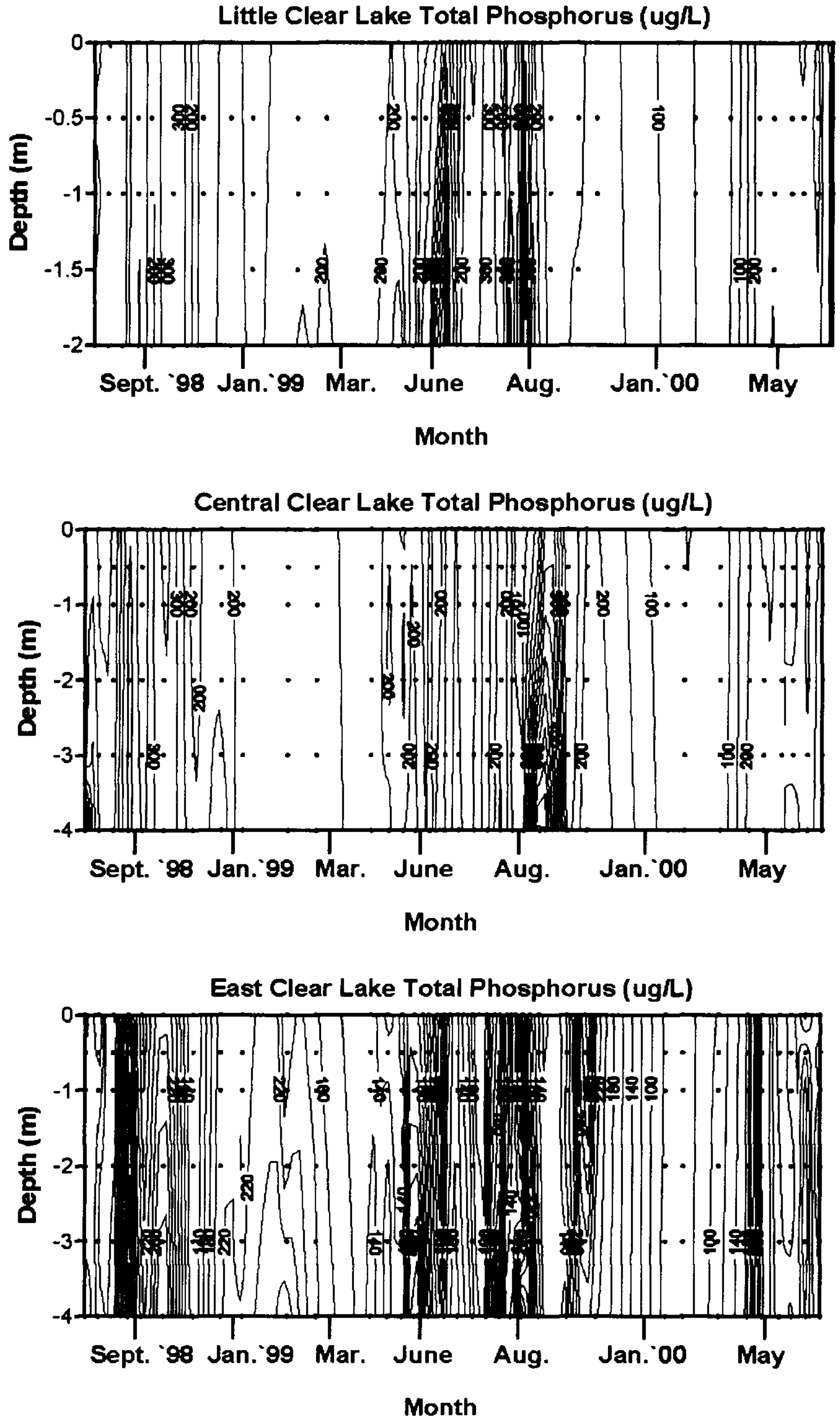


FIGURE 23. Trend in volume weighted concentrations of total phosphorus in Clear Lake, Iowa during 1998-2000.

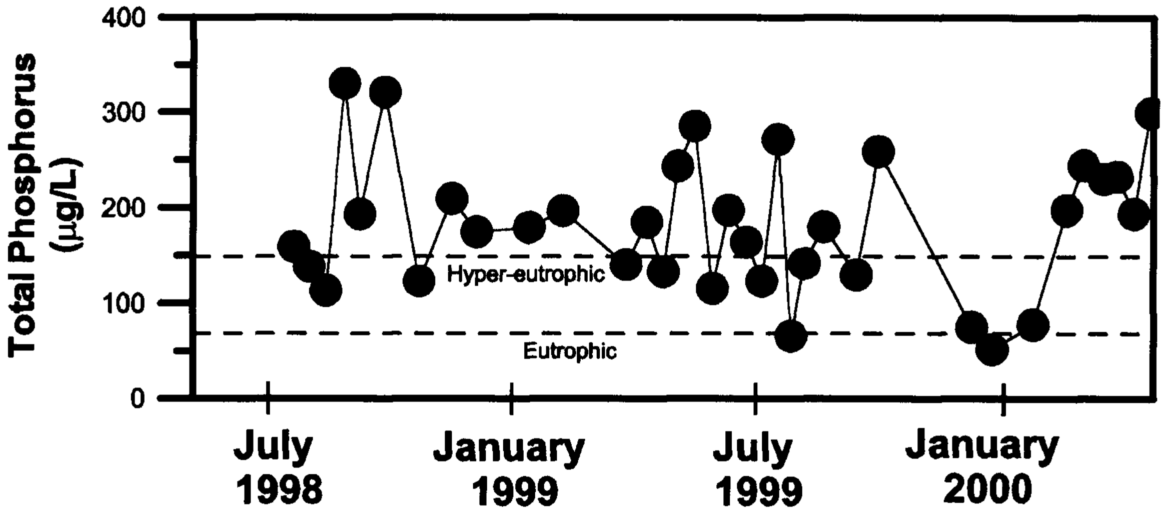


FIGURE 24. Trends in the volume weighted ratio of total nitrogen to total phosphorus concentration in Clear Lake, Iowa during 1998-2000.

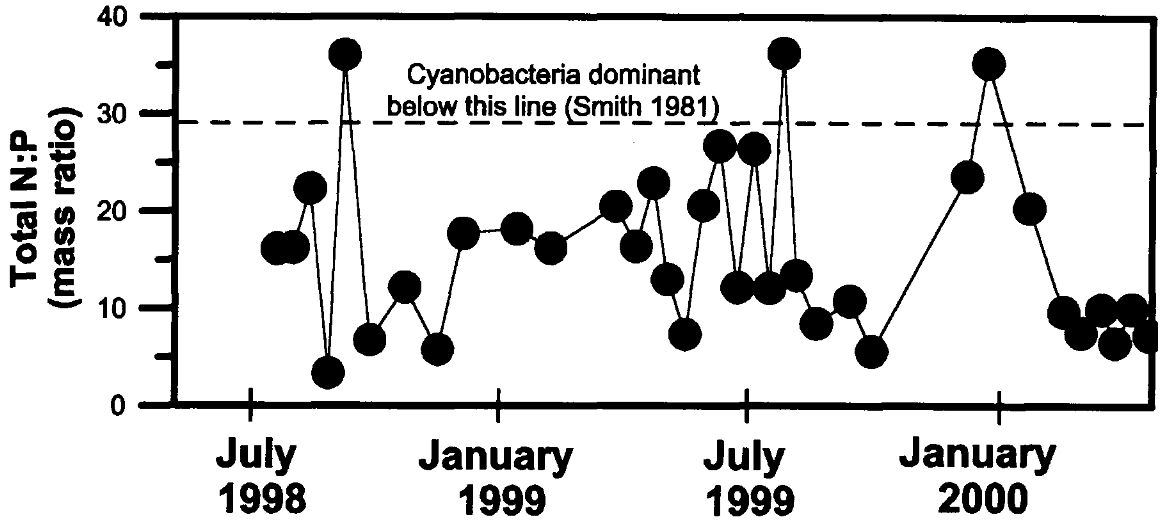


FIGURE 25. Trends in the volume weighted chlorophyll a concentrations in Clear Lake, Iowa during 1998-2000.

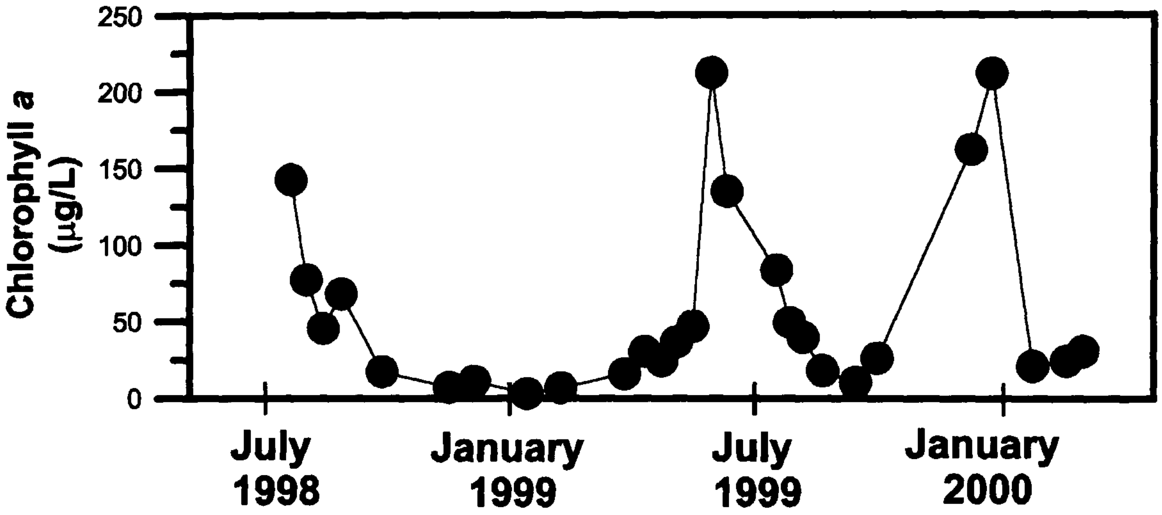
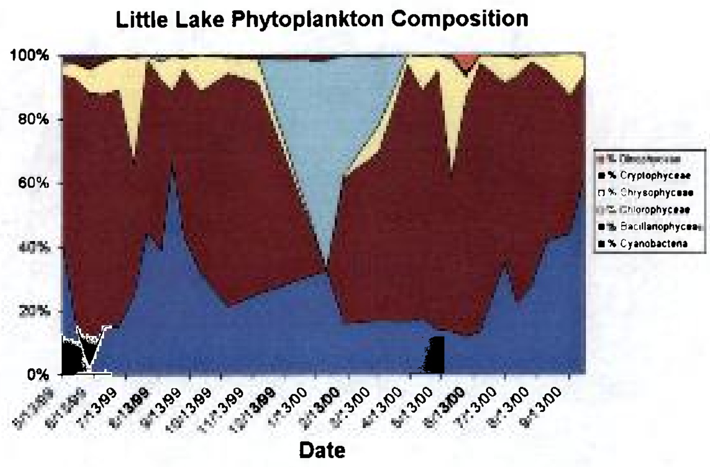
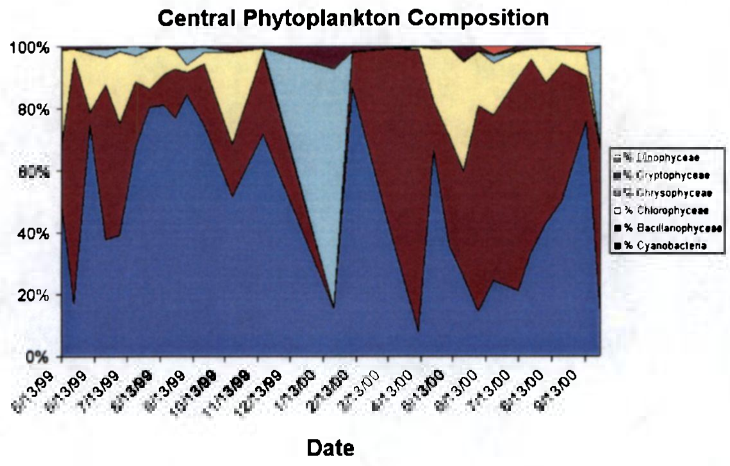


FIGURE 26. Trends in percentage taxonomic composition of phytoplankton in Clear Lake, Iowa during 1998-2000 (by biomass).





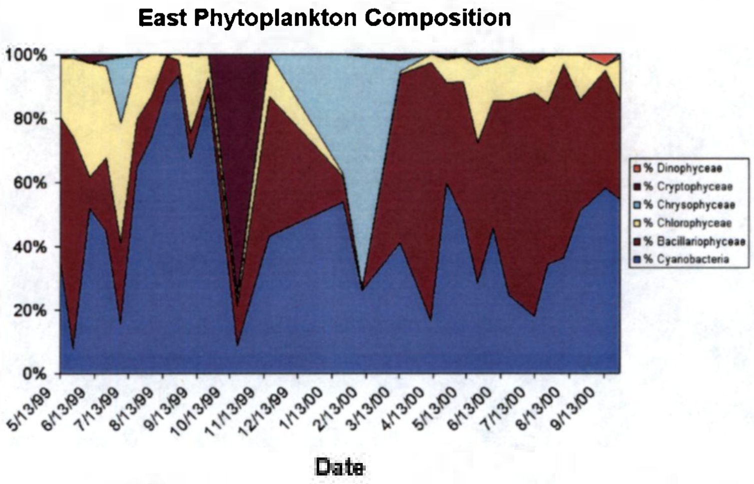


FIGURE 27. Photograph of Bacillariophycaea (*Melosira sp.*) from Clear Lake.

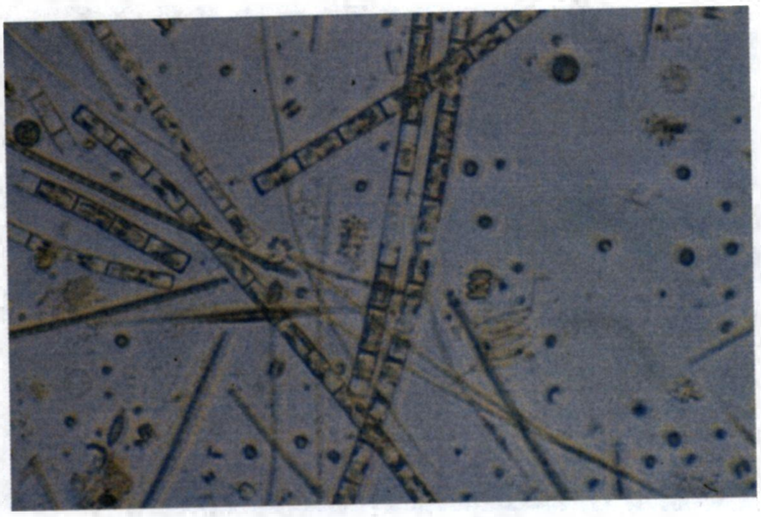


FIGURE 28. Photograph of Bacillariophycaea (*Asterionella sp.*) from Clear Lake.

FIGURE 29. Photograph of Cyanobacteria (*Spirulina sp.*) from Clear Lake.

FIGURE 30. Photograph of Cyanobacteria (*Oscillatoria sp.*) from Clear Lake.

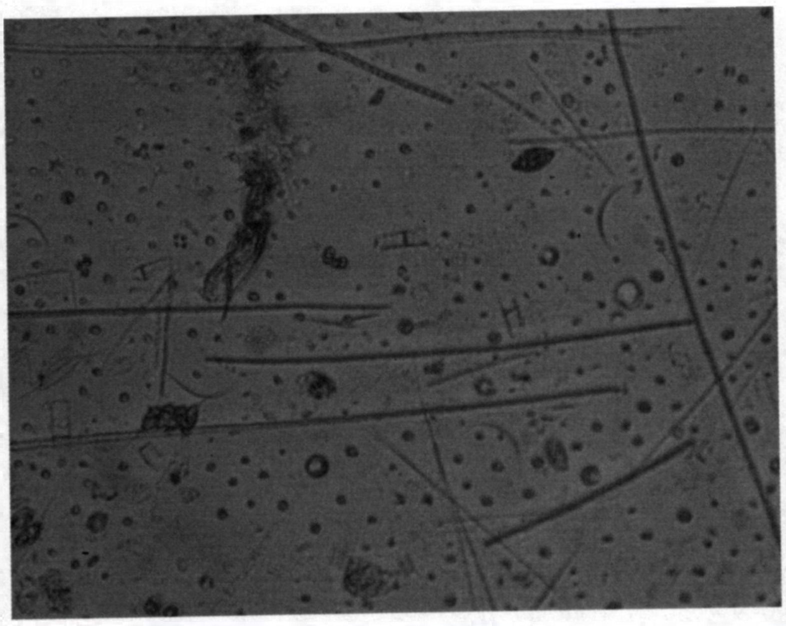


FIGURE 31. Photographs of Cyanobacteria (*Anabaena sp.*) from Clear Lake.

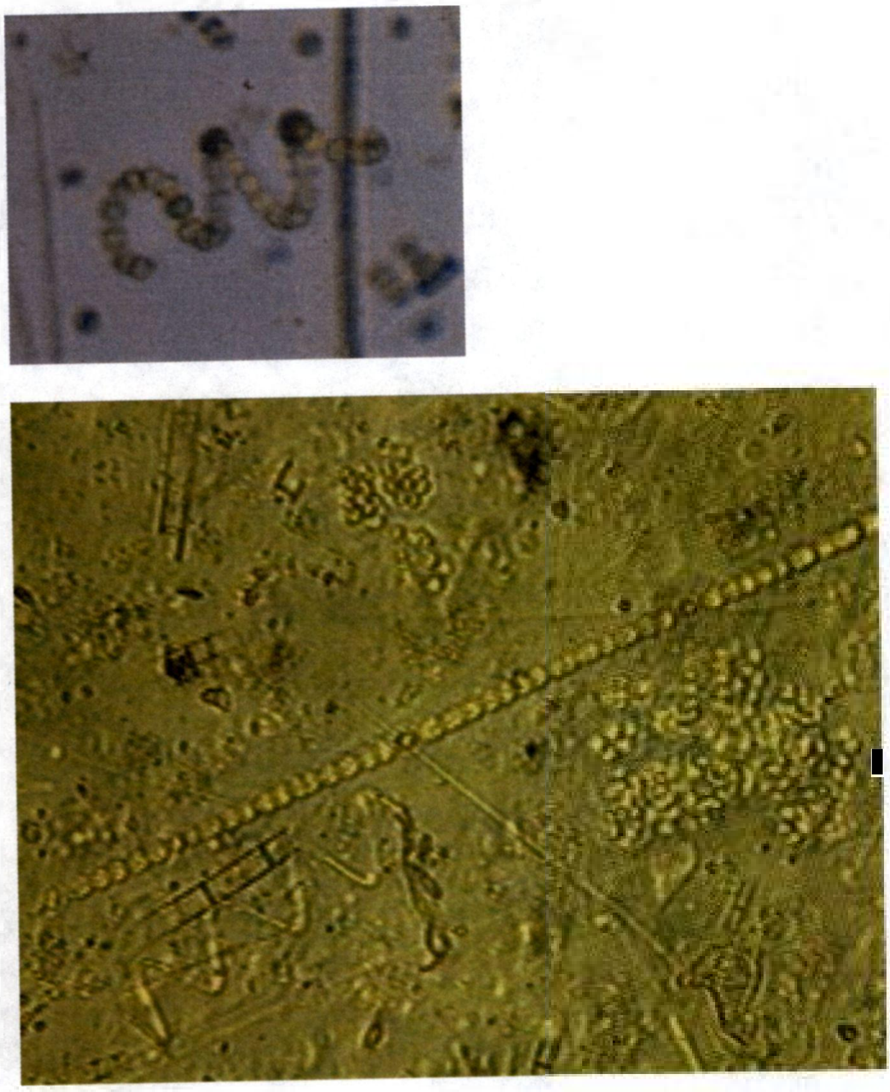


FIGURE 32. World trend in Cyanobacteria abundance as related to the total phosphorus concentrations in lakes. The percentage Cyanobacteria composition of phytoplankton in Clear Lake, Iowa during 1998-2000 (by biomass) is shown as a star.

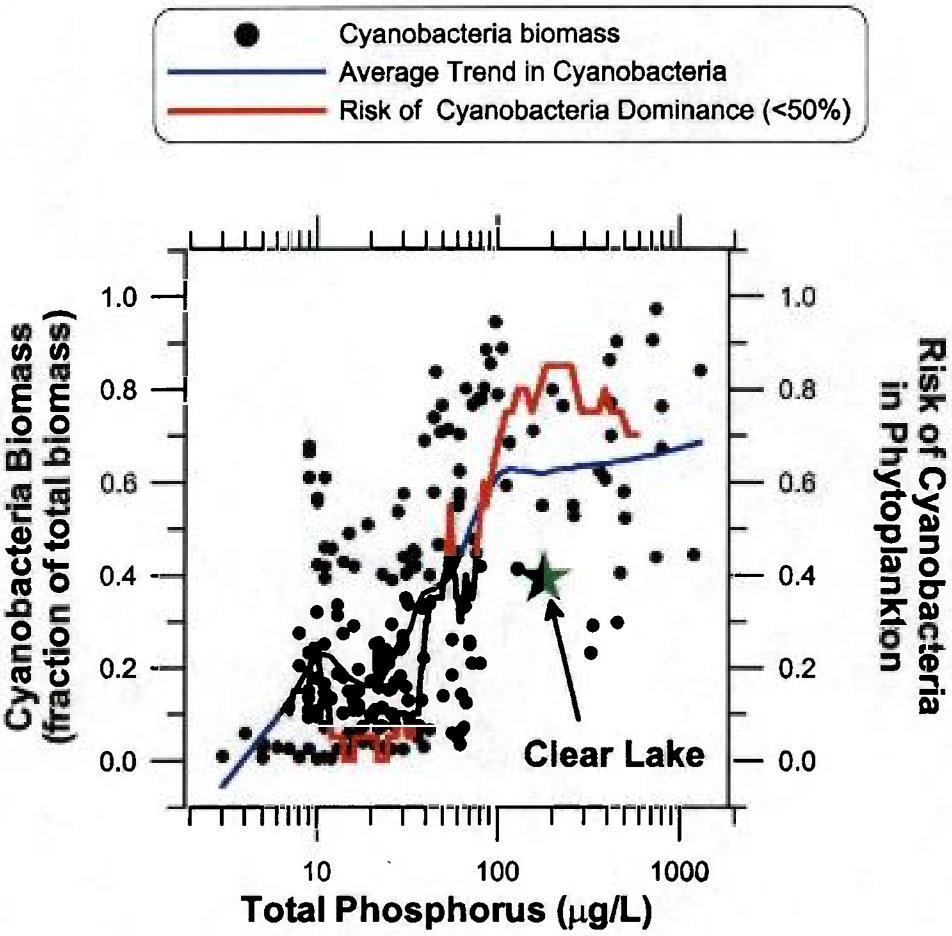


FIGURE 33. Secchi disk measurements and macrophyte abundance in Clear Lake from 1896 to 2000.

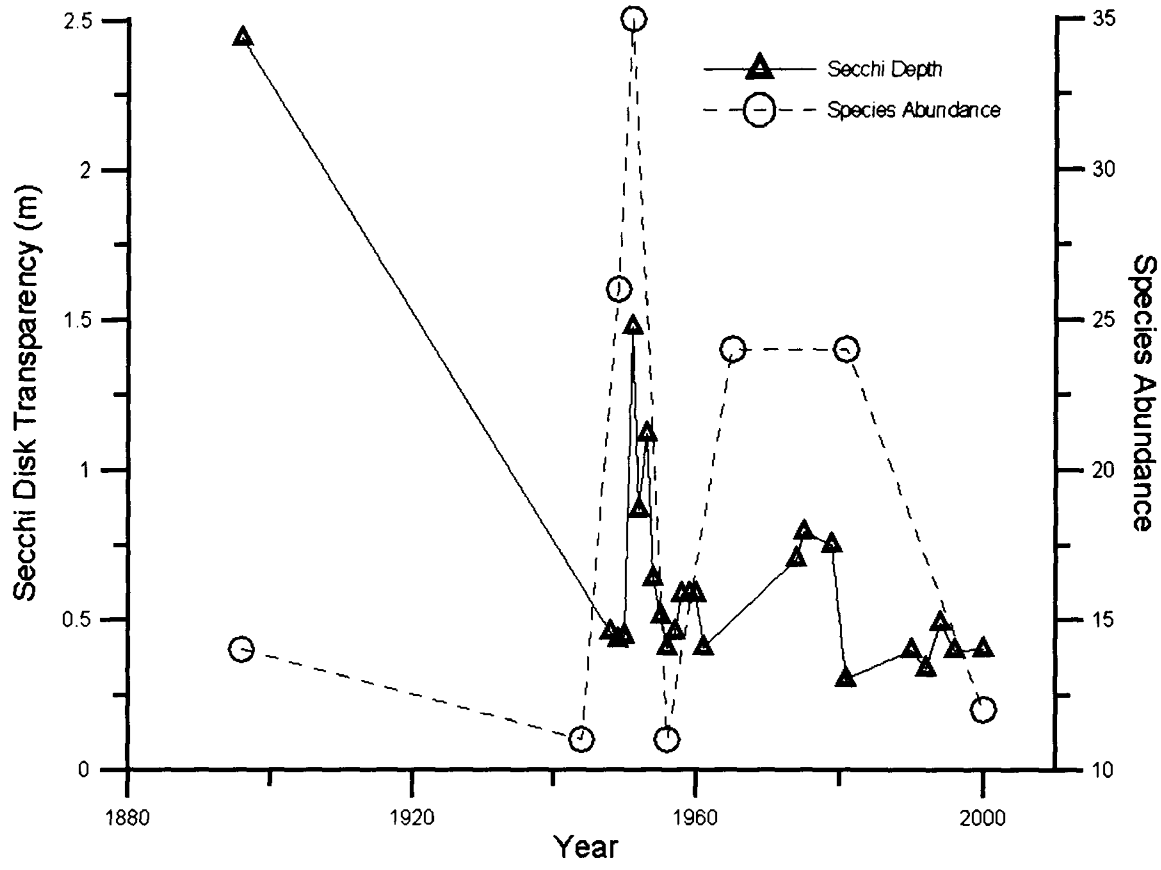


FIGURE 34. Clear Lake bathymetric map, 2000.

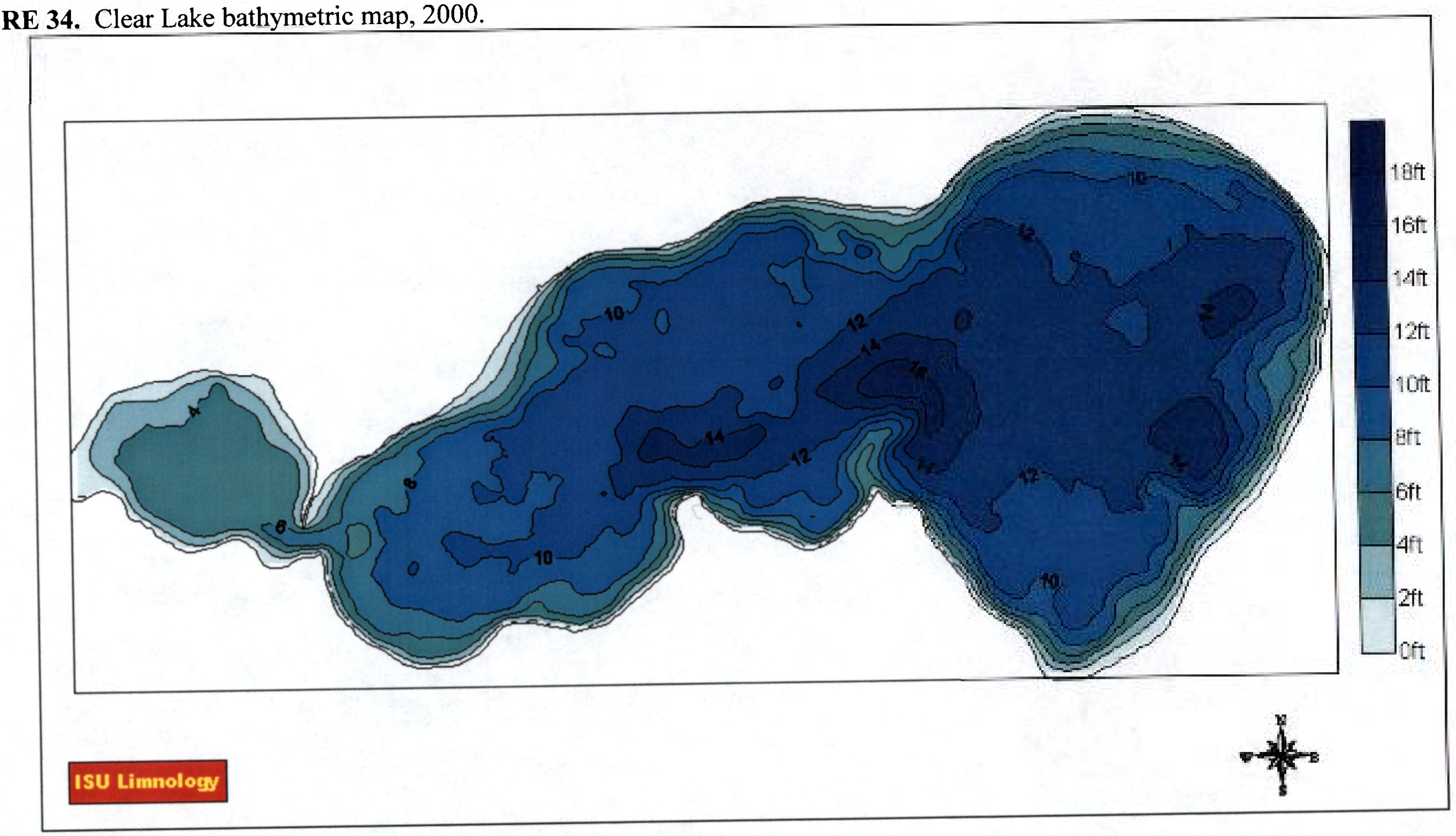


FIGURE 35. Clear Lake bathymetric map, 1935.

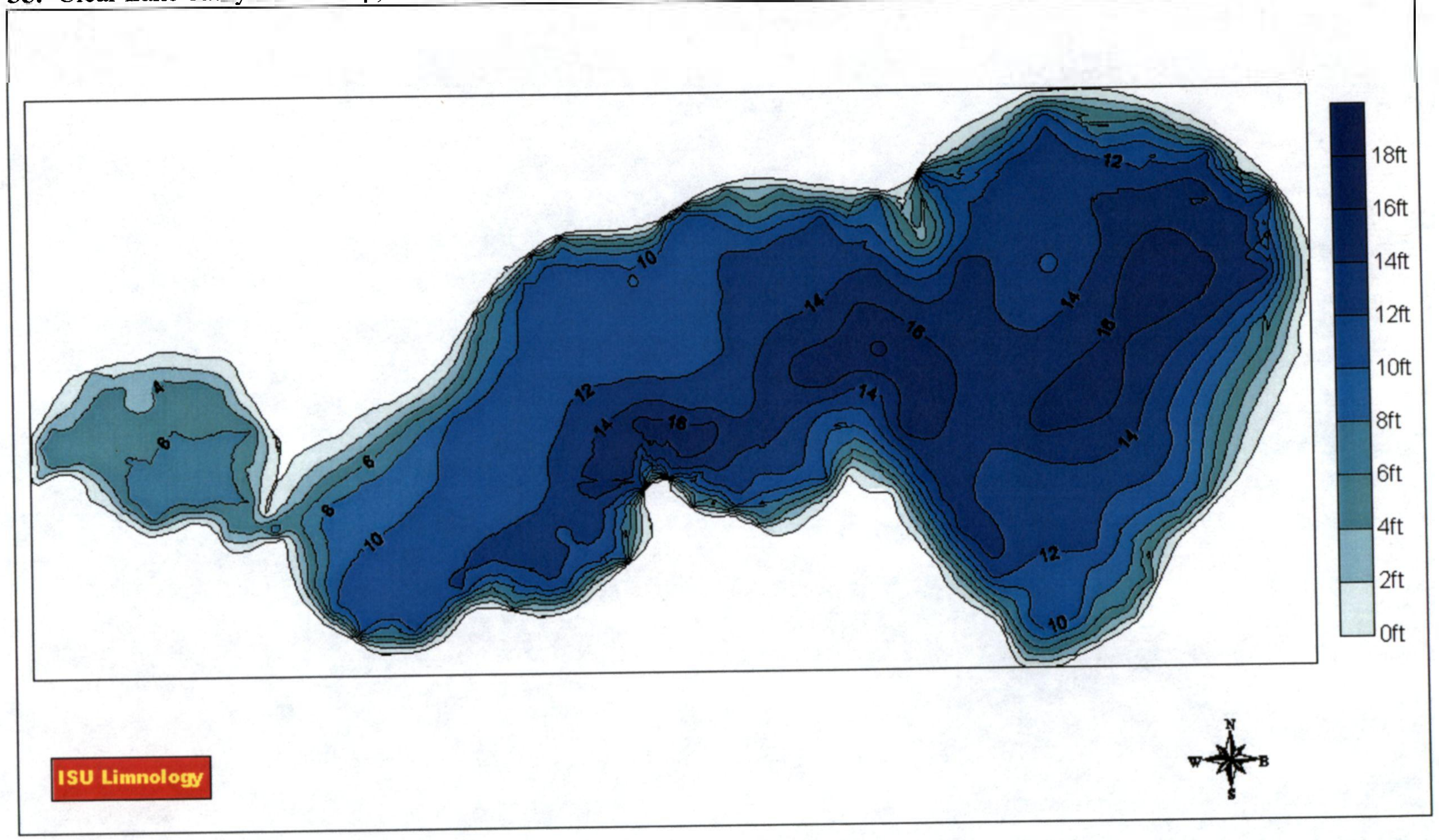


FIGURE 36. Clear Lake bathymetric map, original post-glaciation estimate.

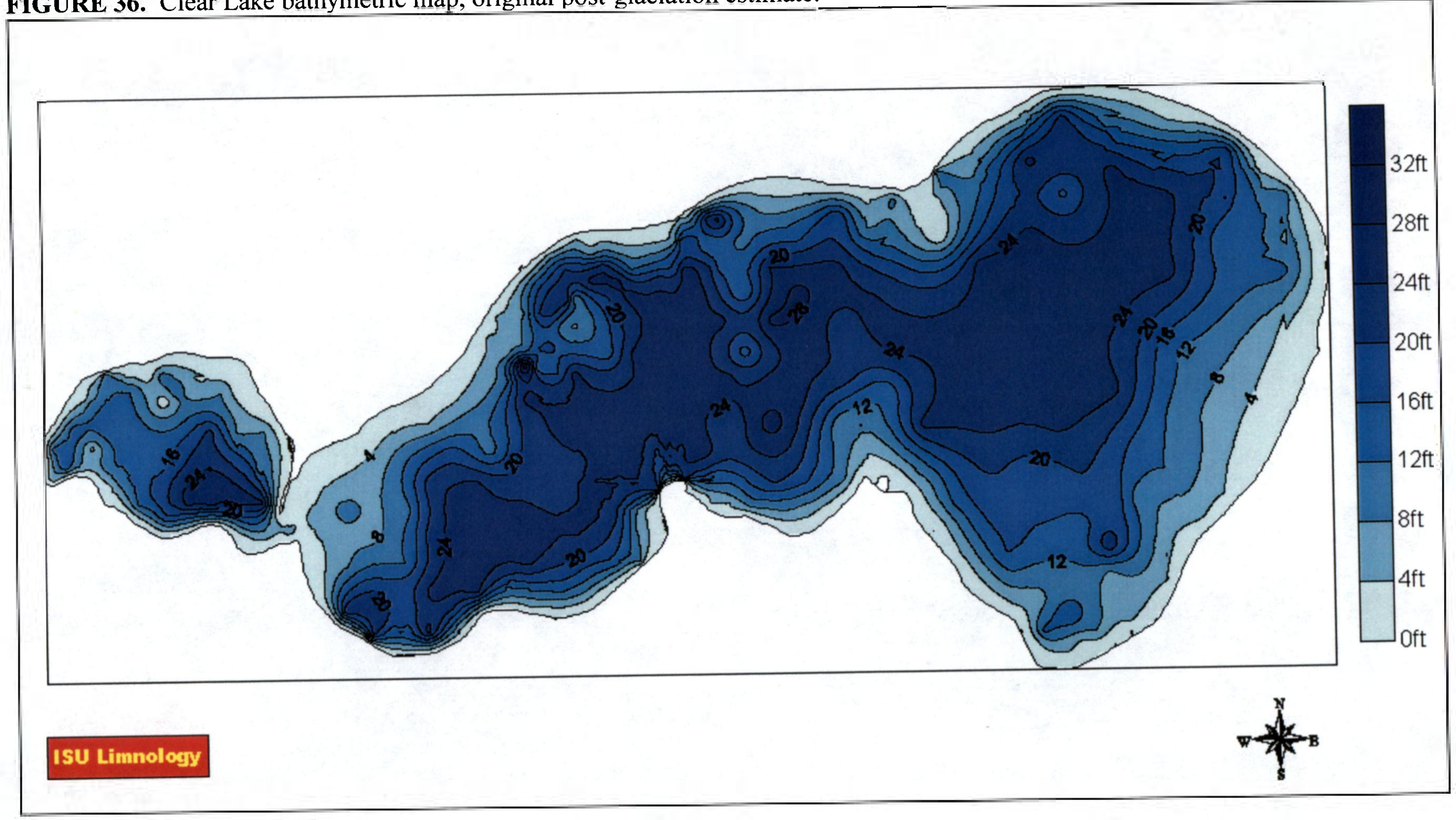


FIGURE 37. Clear Lake sediment deposition map, 1935-2000.

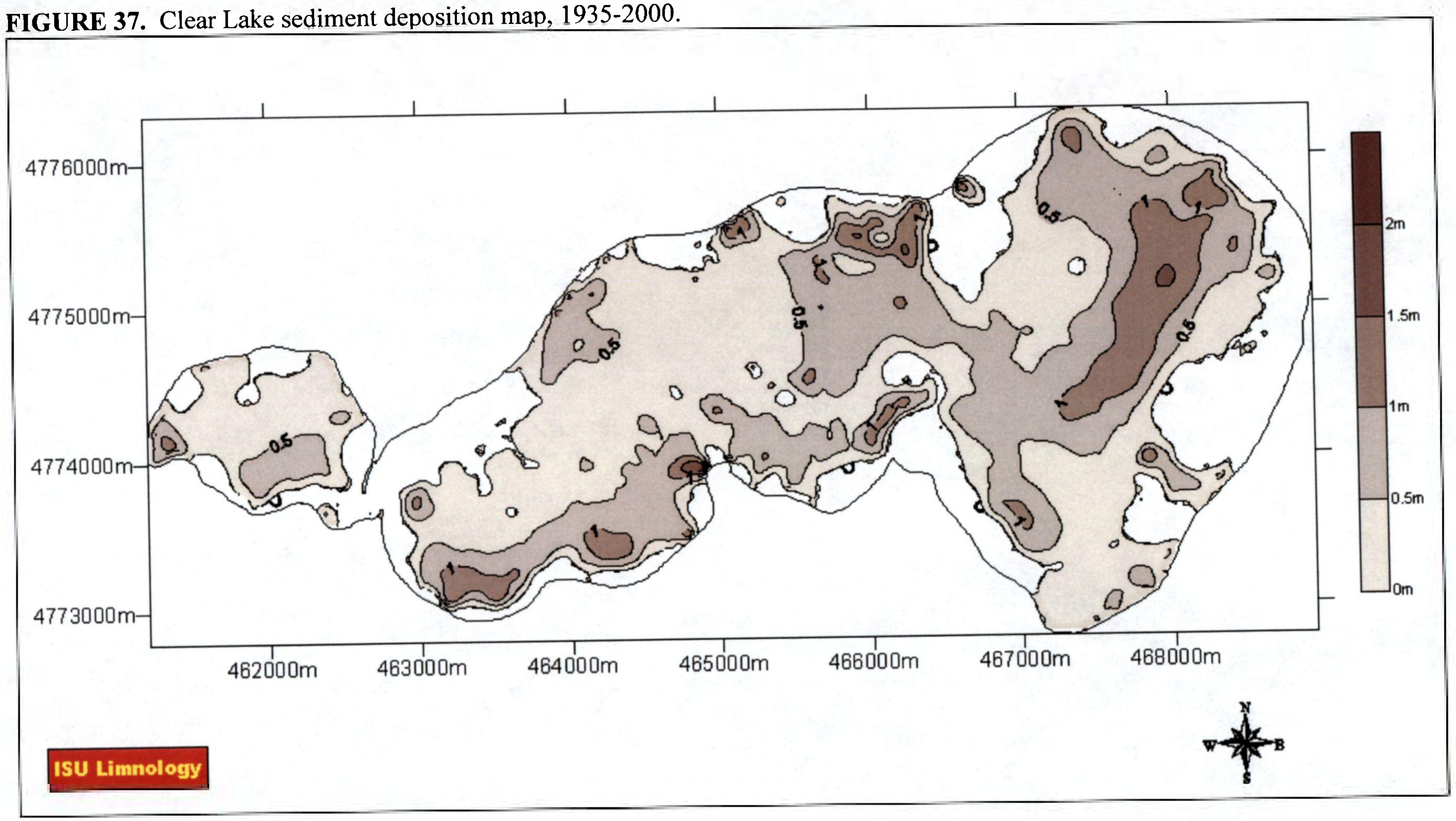


FIGURE 38. Clear Lake sediment deposition map, original lake basin estimate-2000.

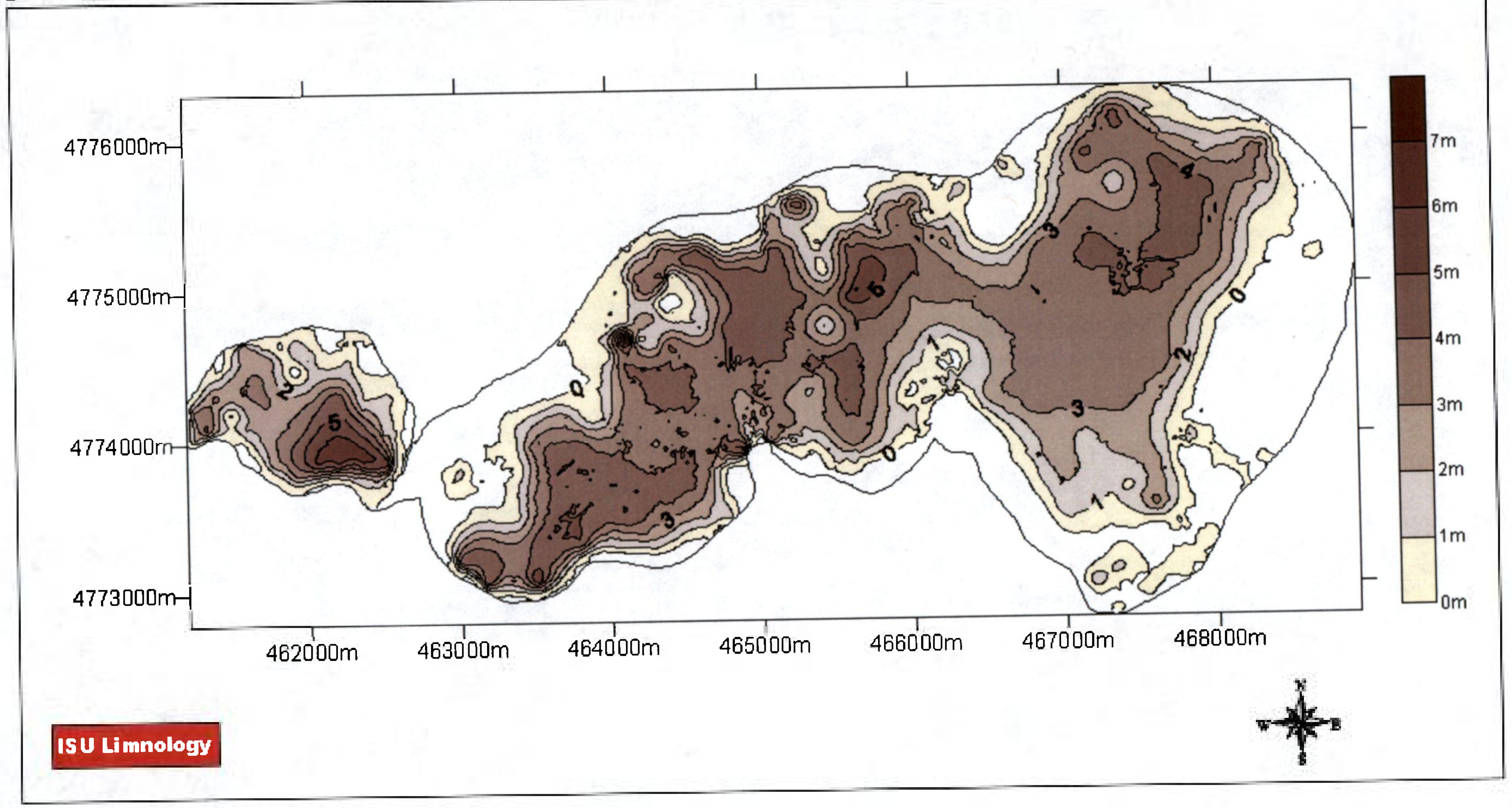


FIGURE 39. Little lake section of Clear Lake sediment deposition map, original lake basin estimate-2000.

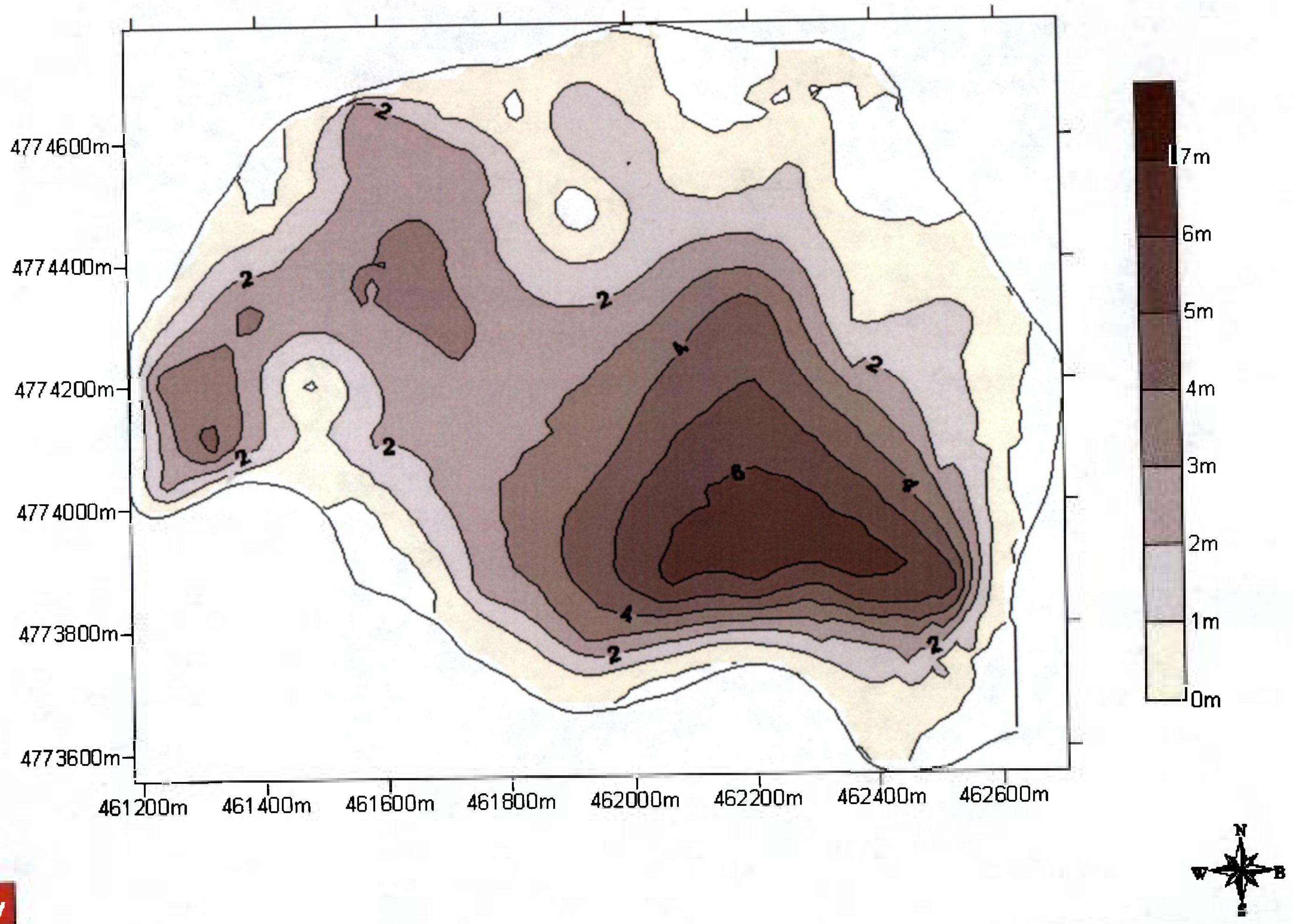


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FIGURE 40. Changes in ambient total phosphorus concentration in Clear Lake predicted from the Canfield/Bachmann model for various levels of reduction in phosphorus input from the watershed. The upper (red) line is an approximately upper 70th percentile of predictions, while the lower (green) line is an approximately lower 70th percentile of predictions. The black line indicates the approximate expected phosphorus concentration in an average year, given a certain level of decrease in phosphorus input.

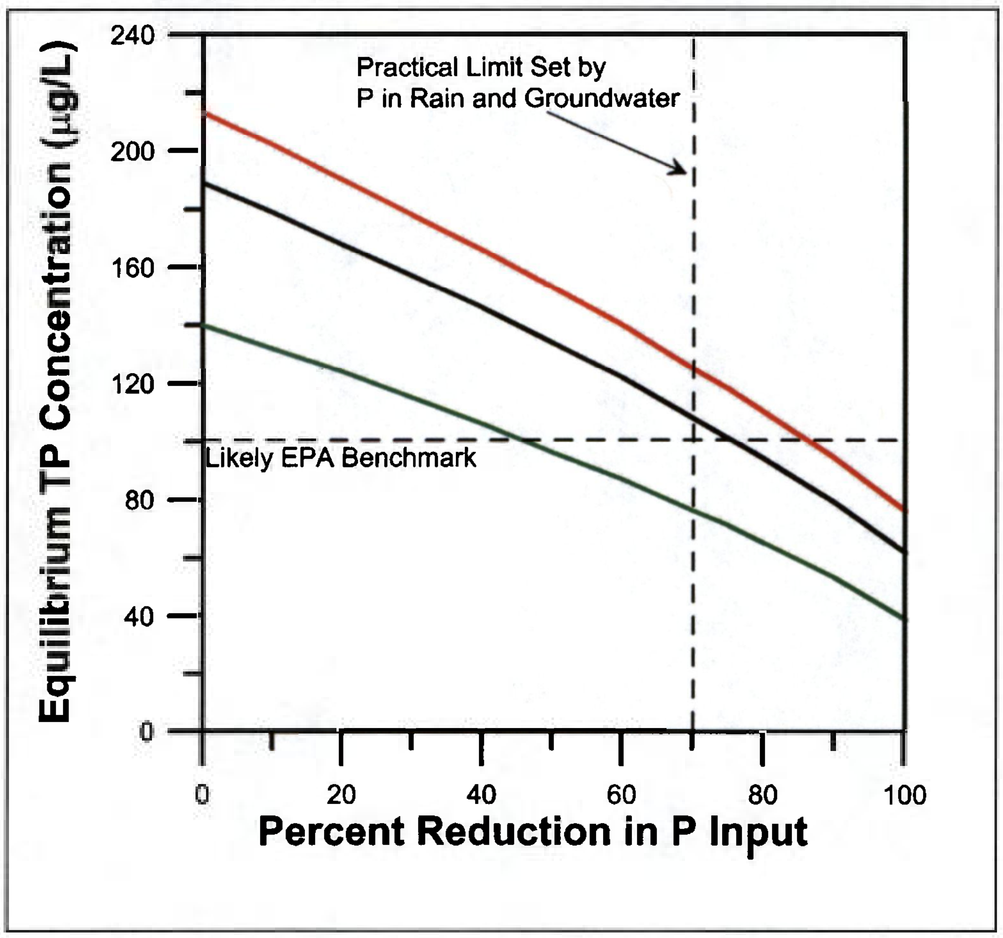
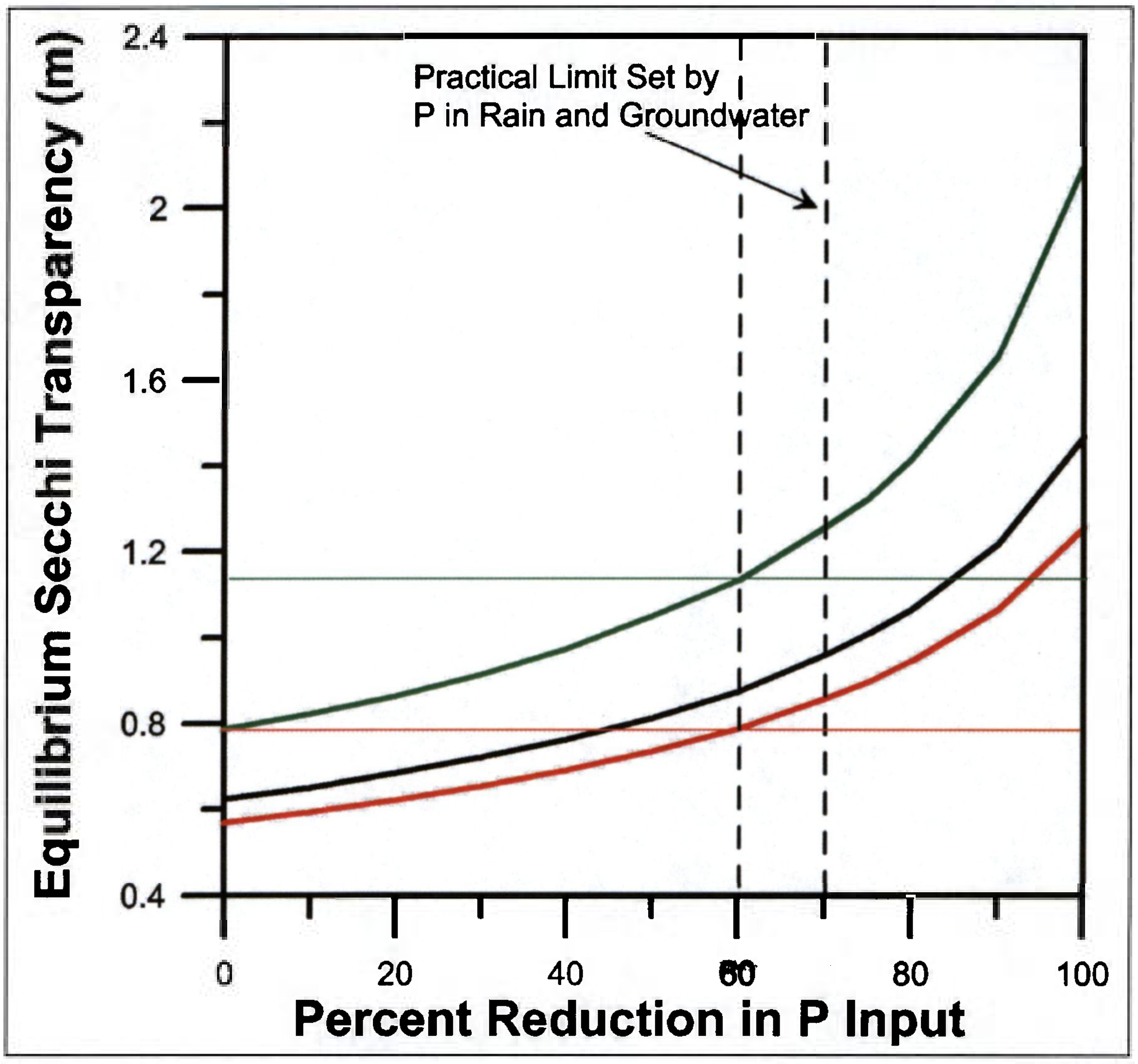


FIGURE 41. Changes in ambient water clarity in Clear Lake predicted from the Canfield/Bachmann model for various levels of reduction in phosphorus input from the watershed. The upper (red) line is an approximately upper 70th percentile of predictions, while the lower (green) line is an approximately lower 70th percentile of predictions. The black line indicates the approximate expected water clarity in an average year, given a certain level of decrease in phosphorus input. Water clarity is predicted for Clear Lake based on relationships between total phosphorus and water clarity observed in other Iowa Lakes (Bachmann et al. 1994).



CHAPTER 6

Environmental Microbiology and Bacteriology of Clear Lake, Iowa

Environmental Microbiology and Bacteriology of Clear Lake, Iowa

John A. Downing and Nicholas Schlesser

Special Acknowledgment. *We would like to acknowledge the special financial assistance of the City of Clear Lake for portions of this analysis, as well as the willing help of many volunteers and city employees who collected samples for preliminary analyses leading to these microbiological studies. Special action taken by the Mayor Kirk Kraft, City Manager Tom Lincoln and the entire City Council in August and September of 1998 was instrumental in stimulating this work.*

A. History.

Bacteria are essential to the function of aquatic ecosystems and a natural part of the biota of all environments. Certain bacteria, usually called "enteric bacteria" or "coliforms" enter aquatic systems from fecal matter produced by humans and other warm-blooded animals, and are thus used as indicators of potential disease-causing organisms in freshwaters. Shallow, warm-water systems such as Clear Lake frequently receive coliform bacteria from the surrounding watershed during rain events, and the very rich nutrient and sediment environments found in eutrophic and hypereutrophic lakes allows these bacteria and probably the pathogenic bacteria to survive for relatively long periods.

It is quite likely that coliform bacteria have been found in Clear Lake and other Iowa lakes for quite a long time. Analyses performed routinely by the University Hygienic Laboratory (UHL) on the intake water of the old Clear Lake city water system show frequent detections of coliform bacteria dating from as far back as records are available (i.e., early 1960s). Therefore, fecal coliform bacteria have been a part of the Clear Lake environment for decades.

In the summer of 1998, however, a health incident precipitated the testing of the beaches of Clear Lake for coliform bacteria, and some high readings were detected. Prior to this time there had been little routine beach testing by IDNR so beach closings were attempted as a reaction to these high levels. Some of the samples were taken just following rain events, so some high values would normally have been expected. As agencies acquired more information on fecal bacteria levels and testing protocols, however, it became clear that fecal bacteria levels were quite variable but that averaged measurements in Clear Lake were not consistently high.

Because of their concern for the well-being of Clear Lake and its safety as a recreational resource, Clear Lake City Council contracted intensive bacterial analyses of the lake, other lakes, and storm drain effluents to gauge the best route to efficient and effective remediation. The sought to answer three questions: (1) How do coliform levels in Clear Lake compare to those found in other recreational lakes in the region? (2) Are storm drains a potential source of bacteria? (3) Do spatial analyses of bacteria in the lake indicate the greatest potential sources? The City of Clear Lake has commendably already taken action toward using these data to reduce the City's contribution of fecal bacteria to the lake.

The first question was approached by testing several Iowa beaches immediately following Labor Day weekend. All showed levels of fecal coliform bacteria within the acceptable norms for recreational waters. Clear Lake beaches were all in the high 25% of tested beaches, but were all within the acceptable range. Sampling was performed following the standard protocols indicated in *Standard Methods for the Examination of Water and Wastewater.* Samples were taken in a way that represents the exposure of swimmers and other recreational users to lake water. Five sets of samples were taken at each site, halfway between the surface and bottom in approximately three feet of water. Samples were all taken on September 8, 1998, immediately following Labor Day weekend. The results below show the average level of fecal coliform bacteria found at each site. It should be noted that fecal coliform levels can vary greatly with time and are especially sensitive to rainfall events.

		Concentrations (CFUs/100ml)					
Lake	Site	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	**Average***
Clear Lake	***McIntosh Woods***	*50*	*70*	*20*	*50*	*<10*	***38***
Rathbun Lake	**Island View**	10	<10	10	18	50	**18**
Clear Lake	***City Beach***	*<10*	*<10*	*50*	*10*	*<10*	***12***
Big Creek	**beach**	20	10	10	<10	<10	**8**
Clear Lake	***State Park***	*20*	*10*	*<10*	*10*	*<10*	***8***
West Okoboji	**Gull Point**	<10	<10	<10	30	<10	**6**
Rathbun Lake	**dam beach**	20	<10	<10	<10	<10	**4**
Storm Lake	**beach**	<10	<10	10	10	<10	**4**
West Okoboji	**Terrace Park**	10	<10	<10	10	<10	**4**
Spirit Lake	**Marble Beach**	<10	<10	<10	10	<10	**2**
Big Blue Quarry	**Mason City**	<10	9	<10	<10	<10	**2**
Spirit Lake	**Crandall Park**	<10	<10	9	<10	<10	**2**
Crystal Lake	**beach**	<10	<10	<10	<10	<10	**0**
Saylorville Lake	**Sandpiper**	<10	<10	<10	<10	<10	**0**
Spirit Lake	**Orleans Beach**	<10	<10	<10	<10	<10	**0**
Spirit Lake	**Waterworks Beach**	<10	<10	<10	<10	<10	**0**
West Okoboji	**Arnolds Park**	<10	<10	<10	<10	<10	**0**
West Okoboji	**Emerson Bay**	<10	<10	<10	<10	<10	**0**
West Okoboji	**Pikes Point**	<10	<10	<10	<10	<10	**0**
West Okoboji	**Triboji Beach**	<10	<10	<10	<10	<10	**0**

Federal standards for bacteria are exceeded when fecal coliform counts are greater than 200 colony forming units (CFU) per 100 mL of water.

The *Ambient Water Quality Criteria for Bacteria - 1986* (USEPA, 1986) had the following recommendations for recreational bathing waters:

> Based on a statistically sufficient number of samples (generally not less than five samples equally spaced over a 30-day period), the geometric mean of the *E. coli* concentrations should not exceed `126 per 100 mL`.

Therefore, all Iowa beaches tested following a period of high use and low rainfall had acceptable levels of coliforms. Clear Lake's beaches had among the highest levels, but were comparable to those found in Rathbun Lake, Big Creek Lake, and at West Okoboji's Gull Point Beach.

The second question (storm drain contributions of bacteria) was examined by applying a battery of diagnostic tests assess bacteria levels and attempt to discriminate animal fecal from human sewage bacteria. Most input of fecal bacteria from storm drains would potentially occur shortly after runoff events. Storm drain effluents were analyzed immediately after a storm-event on September 23, 1998. Water samples were analyzed for bacterial constituents including fecal coliforms, *Escherichia coli*, and enterococcal bacteria. The indicator-ratios of fecal coliforms/enterococci and *E. coli*/enterococci were calculated since higher ratios indicate that coliforms are likely of human origin. Indicator chemical species including caffeine, nitrogen and phosphorus were also measured. Data indicate that significant amounts of bacteria derive from storm drains and that materials of human origin are most abundant in lakeside storm drains between 7th Avenue South and 4th Avenue North near downtown Clear Lake, and along the north shore between Fareway Drive and Clark Road. Isolated strong indicators were also present near the 2100 block of North Shore Drive. Fecal coliforms of animal origin apparently dominate along much of the north shore between 5th Avenue North and Reely Point. Notably, similar batteries of tests were not performed on county storm drains or those of the City of Ventura. Based on storm drain nutrient data, it is quite likely that storm drains from other residential and commercial areas around the lake would yield similar conclusions.

1. Methods

a. Field collections. Storm drain grab samples were collected by employees of the City of Clear Lake, and each storm drain outlet to the lake proper was sampled. Employees were asked to catch the first flush of water through these systems for analysis. Five samples were taken for microbiological analysis, and one sample for chemical analysis. Microbiological samples were collected directly into glass bottles provided by the University of Iowa Hygienic Laboratory (UHL). These five samples were spaced at one-minute intervals. A time-integrated sample was taken between filling the glass bottles, using a 20-liter chemically clean water container. Some situations did not allow placement of the water container under the storm drain outfall, so a cleaned and modified one-gallon milk jug was used to collect the water sample and transfer it to the water container. Care was taken to avoid contamination of the water samples with anything other than the effluent flowing from the outfall.

b. Analytical methods. We used standard protocols (APHA 1995, Hach Company 1992) to perform sample bottle and glassware preparation, sample preservation and laboratory procedures. Steps taken for quality assurance and quality control included taking replicate water samples in the field and analyzing triplicate samples in the laboratory. Assays using these protocols included pH, conductivity, chloride, total alkalinity, total-, volatile-, and inorganic-suspended solids and total phosphorus. Specifically, pH and conductivity were measured directly using digital meters, chloride was measured by use of an ion-selective electrode, and total alkalinity was measured by titration. Total, volatile and inorganic suspended solids were measured by mass difference after filtration, evaporation and combustion of the sample. Total nitrogen assays were performed using the second derivative spectroscopy technique of Crumpton et al. (1992). Microbiological determinations of fecal coliform bacteria, *E. coli* and enterococci were conducted by UHL and followed the membrane filtration procedure with confirmation. Total phosphorus was determined by spectrophotometry using the acid persulfate digestion, ammonium molybdate method, and all samples were run in triplicate for quality asurance/quality control purposes. Caffeine analyses were performed by methylene chloride extraction and concentration followed by detection using a gas chromatograph / mass spectrometer.

2. Results. The analytical results of the storm drain samples are shown in Table 1. Normally, storm drain water should be mostly composed of rainwater and the nutrient materials picked up as the water runs off of streets and lawns. Most water therefore should be of neutral pH (ca. 7.0) or slightly lower; alkalinity and conductivity should both be low. Clear Lake's storm drain water is extremely heterogeneous, reflecting diverse sources, including some higher alkalinity measurements that suggest that storm waters are mixed with ground water or pass through soils before they are discharged.

a. Microbial Analyses. Fecal coliform concentrations in storm drain effluent were high across the board. No sample yielded concentrations lower than 2700 colony forming organisms per 100 mL of water sample (safe lake water must consistently have <200 colony-formers per 100 mL). Highest concentrations of fecal coliforms were found in drains along the north shore, especially toward the western extreme of the city limits (Fig. 1). A very similar pattern was seen in the concentrations of *E. coli* (Fig. 1). Most of the fecal coliforms were probably natural enteric forms of *E. coli*. Another group of bacteria derived from the digestive systems of all warm-blooded animals, the enterococci, also showed a very similar distribution among the storm drains along the north shore of the lake (Fig. 1).

Because enterococci are less abundant in human sewage than in animal excrement, the ratios of fecal coliforms or *E. coli* to enterococci can be used to indicate human inputs. Higher values of these ratios are typical of human sewage while most other animals would show lower ratios. These ratios both show that human inputs are most likely in storm drains numbered 5-14 and 25-30 in Table 1. These drains were located along the downtown waterfront and at the extreme west of the city, west of the Harborage. Thus, bacterial inputs from storm drains were considerable, but downtown and extreme western drains were likely to have a human component. Much of the bacteria between these areas probably derives from yard, animal and pet waste. Concentrations of bacteria from all these drains are likely to contribute substantially to the bacterial concentrations seen in tests of lake water.

b. Chemical Analyses. Alkalinity measures the buffering capacity of water and is therefore a good indicator of how much contact there has been between drainage water and soil. Several of the drains showed significant alkalinities (>20 mg/L; lakewater measures 130-150 mg/L). Storm drains showing higher bacterial ratios had higher alkalinities indicating that these waters had been in contact with soil or have a groundwater or surface water component of 10-50%. This could result from overflow of rivers, streams or holding tanks, or from the discharge of saturated groundwaters. Chloride (Cl) is a conservative tracer of human sewage because salt (NaCl) is common in the human diet, relatively rare in the environment, and is not broken down or absorbed once it is dissolved. Chloride measurements show probable human inputs around downtown Clear Lake, in drainage water near 33rd Street West, as well as near Reely's Point and near the Fish Hatchery (Fig. 2).

Caffeine was analyzed because it is a reliable indicator of human sewage inputs. Urinary caffeine levels in caffeinated soda drinkers (2 per day) are about 1500 μg/L (Bernardot 1996). Considering that normal urine volume is an average 1400 mL/day, adult urinatation frequency is an average five times/day (Berkow 1977), and normal flush volume is about 2.6 gallons (9.8 liters), raw urinary sewage should contain about 41,000 ng/L of caffeine. Our minimum analytical level for caffeine (40 ng/L) therefore can reliably detect raw sewage diluted up to 1000-fold. The Mississippi River below the Twin Cities' sewage outfall contains about 70 ng/L of caffeine (Meade 1995) and therefore corresponds to about a 600-fold dilution of raw urinary sewage.

Caffeine was detected in all of the Clear Lake storm drains (Fig. 2). Concentrations ranged from 24 to 780 ng/L (Table 1). These concentrations correspond to sewage dilution rates of 50- to 1700-fold. Highest caffeine concentrations were found clustered around downtown Clear Lake between 7th Street South and 1st Avenue North, and at the western extremity of Clear Lake's storm drain system between 33rd Street West 3800 block of North Shore Drive (Fig. 2). An isolated high concentration was found in the 2100 block of North Shore Drive near Reely Point. These areas of concentration correspond well to the areas with high coliform/enterococcus ratios, indicative of human inputs (Fig. 1).

Nitrogen and phosphorus concentrations in storm drain inputs show similar patterns to those indicated by bacterial ratios, alkalinity and caffeine. Phosphorus averaged 2.5-times the concentration found in lake water and was most concentrated at the south and north ends of downtown, near the fish hatchery, at the tip of Reely Point, and at the extreme west end of Clear Lake (Fig. 2). This pattern was repeated for nitrogen concentrations in storm drains as well as total suspended solids (an indicator of erosion). N:P ratios in storm drain water were generally in the range seen for sewage, manure and other excretory products (Downing and McCauley 1992), but greatly below those that would result from drainage of agricultural fields.

Several of the storm drains show signatures that make them likely to supply substances like bacteria and nutrients derived from human activities. These substances can enter storm drains due to line breaks yielding cross contamination through soil percolation, through overflows of sanitary systems or fields during rain storms, through saturation of relict septic systems within the city, through backups of sanitary systems by indirect connections (e.g., leakage of domestic sewage through sump systems), through accidental direct connection of sanitary drains to the storm drain system, or through other pathways. All of the storm drains showed high fecal coliform concentrations, so other avenues, such as pet waste control and elimination of potential livestock inputs might also serve to decrease fecal coliform concentrations at routine lake monitoring stations. Again, it should be stressed that these analyses concerned only City of Clear Lake storm drains, but all other storm drains around the lake are likely to show very similar signatures.

A third bacterial analysis was undertaken in 1998 to determine whether all parts of the lake had equal bacterial concentrations of bacteria, to use bacterial patterns to indicate probable sources, to examine sediments as a source or sink for bacteria and to examine depth profiles of bacteria. A regular grid of sampling sites, five series of water-column profiles and 20 sediment grid samples were used to determine spatial patterns in fecal coliform bacteria, *E. coli*, enterococci, chloride and nutrients. Maps were made to indicate spatial patterns and directions of concentration gradients. Spatial trends in bacteria concentrations echo the results of storm drain analyses along city shores, but suggest several other potential bacteria sources outside of city limits. Bacteria were most concentrated along the north shore of the lake, but also near the City of Ventura and in South Bay. Bacterial ratios suggest that downtown Clear Lake, city lands west of Reely Point, the City of Ventura and developed property in South Bay and along the south shore of Clear Lake constitute potential sources of human input. Depth profiles of bacteria and nutrients show that bacteria are mixed throughout the water column. Sediment bacterial numbers are sometimes high, and are most concentrated near shore, near the cities of Clear Lake and Ventura, and in the center of the lake north of the Island. Spatial patterns across the lake point to the same areas of the City indicated by storm drain analyses, but suggest several other areas of significant potential input. These analyses were expanded in the Diagnostic / Feasibility Study in 1999 to examine the spatial pattern of bacteria at monthly intervals across the open-water season.

3. Methods.

a. Sampling Design and Field Collections. The perimeter of Clear Lake was measured to determine an appropriate spacing for sampling sites. The shoreline length of Clear Lake is approximately 22 kilometers, and one hundred sampling sites around the perimeter were desired. Thus, sampling sites were located approximately 220 meters apart, and samples were taken at a distance of 20 m from shore. An arbitrary point on the western end of Clear Lake was chosen as the starting point, and two teams moved around the perimeter in opposite directions to complete the perimeter sampling. Location of sampling points were determined and recorded using differentially-correcting GPS. In addition to the perimeter sites, samples were taken from sites across the body of the lake. A grid with 500 m by 500 m blocks was overlain on the lake, and one sample was taken from each. Fifty samples were taken from this grid, with sampling sites again being located and recorded using differential GPS. All samples were taken at a depth of 0.25 meters below the lake surface. All perimeter samples were taken on October 14, 1998, while the grid samples were taken on October 15, 1998.

Water profile and sediment samples were also taken on October 15, 1998. Depth profiles of bacteria and nutrients were determined by sampling at the surface and one-meter depth intervals with a 5-liter Van Dorn bottle rinsed continuously with ambient lake water. Nutrient samples were collected into chemically clean, opaque bottles and were transported cold to the laboratory for analysis. Bacterial samples were collected into sterile bottles and refrigerated until analyzed. Sediments were collected with a clean Ponar grab at 20 different sites and bacterial analyses were performed on elutriates and by the most probable number (MPN) method on solid sediment samples.

b. Analytical methods. We used standard protocols (APHA 1995, Hach Company 1992) to perform sample bottle and glassware preparation, sample preservation, and laboratory procedures. Steps taken for quality assurance and quality control included taking replicate water samples in the field and analyzing triplicate samples in the laboratory. Assays using these protocols included chloride, total nitrogen and total phosphorus. Chemical analyses were performed as discussed above. Microbiological determinations of fecal coliform bacteria, *E. coli* and enterococci were conducted by UHL and followed the membrane filtration procedure with confirmation.

c. Mapping methods. Surface concentration contour maps of the different constituents analyzed were created by interpolating the data collected at the different sampling sites by standard geostatistical techniques. These maps were created using Surfer™ (Golden Software, Golden, Colorado). The interpolation method used was a geostatistical procedure called kriging, which allows data trends to be accurately approximated. This procedure assigned values to 10 m by 10 m blocks of the lake, which allowed fine details of trends to be estimated. These lake surface maps were then overlain on topographic maps to allow visualization of the relationship between in-lake trends in concentrations and watershed characteristics.

4. Results.

a. Microbial Analyses. Fecal coliform concentrations varied significantly across the lake (Fig. 3) with low concentrations in open waters, and higher concentrations along the shore. Very strong concentrations were found near the City of Ventura and plume-like concentration gradients occurred along the north shore from the extreme west of Clear Lake city limits to the southern side of downtown Clear Lake. Other significant concentrations were found just west of the Clear Lake State Park near Lekwa Marsh, and northwest of the Park toward Grand View Point. *E. coli* concentrations echoed the distribution of fecal coliforms with very similar levels of concentration (Fig. 3). This suggests that much of the fecal coliform bacteria found in Clear Lake is *E. coli*. Enterococci were most concentrated near Ventura, but also showed points of concentration along the north shore. Along city shores, bacterial abundances are strongly correlated with the points of concentration seen in the storm drain effluents measured in September.

b. Water Column Profiles of Bacteria and Nutrients. Bacteria were distributed throughout the water column, probably because high wind and wave exposure can mix bacteria to the bottom of a lake the depth of Clear Lake. The profiles echo the general west to east gradient in bacterial numbers seen in Figure 2. Some of the highest fecal coliform and *E. coli* concentrations were found at 4 meters depth (13 feet). The mixed nature of Clear Lake does not allow water column profiles to shed further light on the potential sources of bacteria.

c. Sediment Bacteria Distributions. Under certain conditions, enteric bacteria can survive and even reproduce in warm, nutrient rich sedimentary environments. We therefore sampled twenty random sites to estimate the degree of coliform concentration in sediments. Virtually all sediment elutriate samples showed very low concentrations of fecal coliforms, *E. coli* and enterococci, but direct test of sediments for fecal coliforms (using the "most probable number" method) showed very high, often extreme concentrations of fecal coliforms. Nine out of the fourteen nearshore stations showed fecal coliform concentrations >100 colonies per 100 ml. All of the stations showing >1000 colonies per 100 ml were in the eastern basin of Clear Lake, toward the City of Clear Lake. The highest sediment concentration (>10,000 colonies per

100 ml) was found in the deepest part of the lake, off the island near Grand View Point. The source of sediment fecal coliforms is not known but high concentrations near shore near areas such as downtown, the west end of the City of Clear Lake, and Ventura (areas showing high surface water fecal coliforms and/or high fecal coliform concentrations in storm drain effluent) suggest human origins, while the very high concentration found in the center of the lake could indicate avian or human origins.

B. Seasonal Variation in the Spatial Distribution of Enteric Bacteria.

Initial work in 1998 stimulated an analysis within the Diagnostic / Feasibility study of the seasonal variation of spatial distributions of bacteria. Therefore, using similar methods to the spatial analyses discussed above, maps of fecal coliforms, *E. coli*, and fecal enterococci were created during May, June, July, August, September and October of 1999.

1. Fecal Coliforms. The maps of bacteria in Fig. 4 indicate several important points. First, the fact that concentrations are high near shore and low in the center of the lake indicates that bacteria originate on shores, moving into water. It is unlikely, therefore, that aquatic animals such as water birds are a significant source of bacteria to Clear Lake. Second, concentrations across the lake become quite elevated in mid-summer, especially after periods of protracted rainfall, such as July 1999. Third, source areas along shores are quite consistent in where bacteria are concentrated, suggesting that there are source areas that could be localized for remediation. Fourth, bacteria seem most concentrated in the Little Lake. This is quite reasonable since much of the water load arises in the west and the periods of intense rainfall apparently bring in substantial watershed bacteria. Finally, although some concentration is found in the west of the basin, much of the residential and commercial shoreline appears to be a bacteria source. Therefore, remedial measures taken in the urban area of the shoreline could have a substantial impact on decreasing bacteria concentrations in Clear Lake.

2. E. coli. Patterns of spatial distribution of *E. coli* were similar to those seen for fecal coliforms (Fig. 5). Concentrations were, however, substantially lower and rarely increased above the limits suggested by EPA for long-term average concentrations. Even during mid-summer when some very high, very localized concentrations were observed, lake-wide concentration of *E. coli* were quite low. One surprising result is that these bacteria can spread completely across the lake (e.g., August, Fig. 5). This is counter-intuitive, since they are supposed to have a very short survival time in freshwater. The warm temperatures and rich nutrient and organic matter environment is likely to prolong their survival and potentially those of other enteric bacteria.

3. Fecal Enterococci. Fecal enterococci are more abundant in the excrement of non-human animals so concentrations of it may indicate higher animal inputs. Fecal enterococci distributions are generally similar to those seen for *E. coli*, except that strong concentrations are seen around North Beach and in the Little Lake (Fig. 6). Some of the fecal bacteria especially in the west end may therefore be of animal origin. Again, these organisms spread out to fairly uniform distributions across the lake in August and September when temperatures are fairly warm and organic matter abundant.

4. General Comments on Spatial Analyses of Bacteria. Although the aggregate from these maps (Fig. 7) suggests that much of the shoreline is a source of bacteria to the lake, darkest areas are quite consistent in their placement. This suggests that remediation might be achieved by seeking out and pinpointing the sources of bacteria and correcting a series of localized problems. It is important to note that *E. coli* concentrations are very localized within the lake and that few very high levels were observed throughout the study. The water is generally quite safe from a bacteriological point of view, but most caution should be exercised at specific high-risk areas during very warm weather.

C. Beach Analyses.

During 2000, the IDNR monitored fecal bacteria weekly at the two state beaches on Clear Lake. Fecal coliforms only exceeded the suggested 200 CFU/100 ml limit at one of the beaches (McIntosh Woods) on one occasion. E. coli was only monitored for five weeks, but never exceeded the EPA suggested limit at either beach, while fecal enterococcal abundance exceeded the limit (26 CFU/100 ml) three times out of 18 weeks at State Park Beach, and six times out of 18 weeks at McIntosh Woods Beach. State monitoring indicated that bacteria concentrations were routinely higher at McIntosh Woods than at State Park Beach. The reason for this is clear from Figs. 4-6.

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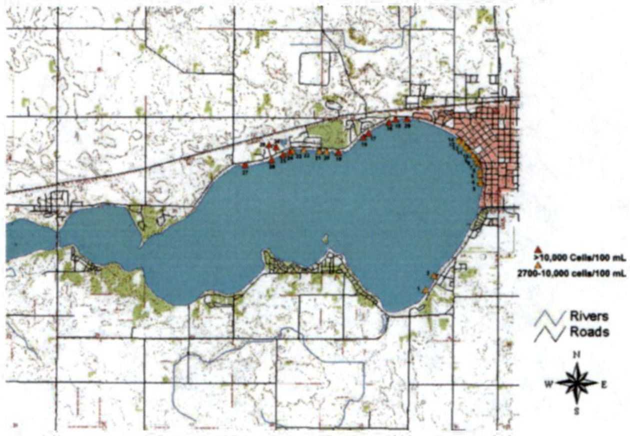
TABLE 1. Analytical results from tests of water collected from thirty storm drain sites in the City of Clear Lake, Iowa on September 23, 1998. Data highlighted in red indicate high values indicating human and/or animal input.

Site	Location	Fecal Coliforms (colonies/ 100 mL)	*E. coli* (colonies/ 100 mL)	Enterococci (colonies/ 100 mL)	FC/ent	*Ec*/ent	Total Nitrogen (TN; mg/L)	Total Phosphorus (TP; µg/L)	TN:TP	Alkalinity mg/L	Conductivity (µmho/ cm)	pH	Caffeine (ng/L)	Chloride (mg/L)	Total Suspended Solids (g/L)
1	2700 block, S. Lakeview Drive	5726	3630	32474	0.18	0.11	1.75	316	5.6	0	68	2.6	120	4.2	0.02468
2	2200 block, S. Lakeview Drive	3659	4185	21646	0.17	0.19	1.27	277	4.6	0	50	2.3	76	1.4	0.04209
3	7th Ave. S., south side of public approach	2736	2924	16074	0.17	0.18	2.20	480	4.6	37	104	6.8	780	3.6	0.02970
4	7th Ave. S., north side of public approach	3903	5487	11846	0.33	0.46	2.37	628	3.8	35	99	6.8	220	8.3	0.20188
5	6th Ave. S., south side of public approach	4127	4878	8640	0.48	0.56	3.88	696	5.6	28	92	6.8	85	8.9	0.12054
6	6th Ave. S., north side of public approach	4199	5624	4967	0.85	1.13	2.06	571	3.6	23	58	7.5	100	3.8	0.09750
7	4th Ave. S. and S. Lakeview Drive	6902	6874	6680	1.03	1.03	1.28	291	4.4	0	56	3.7	240	2.8	0.05877
8	1st Ave. S. and S. Lakeview Drive, south side	8290	10144	7441	1.11	1.36	2.51	326	7.7	21	63	7.1	550	9.5	0.09489
9	1st Ave. S. and S. Lakeview Drive, north side	5578	5407	8712	0.64	0.62	1.61	420	3.8	34	57	8.2	240	8.3	0.06744
10	Main St. Boat Ramp	5785	4707	6010	0.96	0.78	1.09	72	15.2	0	53	3.8	430	8.7	0.01078
11	1st Ave. N. and N. Lakeview Dr., south side	5650	4852	7341	0.77	0.66	1.17	228	5.1	0	44	3.2	190	8.7	0.03278
12	1st Ave. N. and N. Lakeview Dr., north side	5346	4039	5092	1.05	0.79	1.21	250	4.8	0	38	3.5	99	1.8	0.03086
13	2nd Ave. N. and N. Lakeview Dr.	6569	2884	3317	1.98	0.87	0.86	396	2.2	0	35	3.4	86	1.4	0.01044
14	4th Ave. N. and N. Lakeview Dr.	9063	3330	4123	2.20	0.81	1.48	413	3.6	0	57	3.2	84	3.3	0.07766

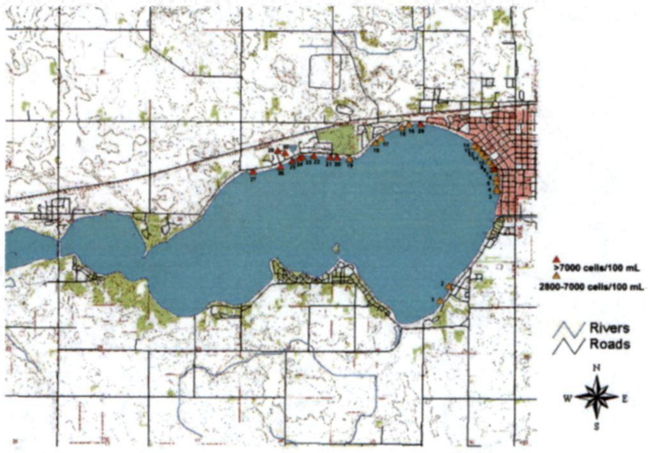
Site	Location	Fecal Coliforms (colonies/ 100 mL)	*E. coli* (colonies/ 100 mL)	Enterococci (colonies/ 100 mL)	FC/ent	*Ec*/ent	Total Nitrogen (TN; mg/L)	Total Phosphorus (TP; μg/L)	TN:TP	Alkalinity mg/L	Conductivity (μmho/cm)	pH	Caffeine (ng/L)	Chloride (mg/L)	Total Suspended Solids (g/L)
15	1101 N. Shore Drive	10411	4302	19774	0.53	0.22	1.94	809	2.4	29	84	7.6	24	10.2	0.07308
16	IDNR Fish Hatchery	14065	4174	15754	0.89	0.26	1.49	359	4.2	0	54	3.0	100	2.6	0.04078
17	1615 N. Shore Drive	13775	4304	19234	0.72	0.22	1.17	160	7.3	0	37	2.6	37	1.0	0.01758
18	18th St. W. Public Approach	13357	6714	18301	0.73	0.37	1.14	273	4.2	0	38	2.6	40	3.7	0.01216
19	2100 block N. Shore Drive	10122	6504	20769	0.49	0.31	2.82	409	6.9	82.5	335	7.5	440	15.1	0.10245
20	2300 block N. Shore Drive	7511	7813	20769	0.36	0.38	1.15	276	4.2	0	63	3.4	58	3.2	0.03592
21	West 2401 N. Shore Drive	7747	8640	26370	0.29	0.33	1.18	195	6.1	0	32	2.2	57	1.4	0.01113
22	2510 North Shore Drive	7910	9106	14877	0.53	0.61	1.22	175	7.0	0	44	2.2	67	1.7	0.01053
23	North Shore Drive and Orchard Lane	8271	9521	16732	0.49	0.57	0.90	135	6.7	0	32	2.3	37	2.1	0.01117
24	2700 block N. Shore Drive	10012	10776	15524	0.64	0.69	1.91	241	7.9	26	74	7.3	83	2.8	0.03365
25	2906 N. Shore Drive	15090	11599	14057	1.07	0.83	1.33	252	5.3	30	77	7.7	130	2.4	0.03137
26	3308 N. Shore Drive	15499	12985	12842	1.21	1.01	1.88	317	5.9	24	61	6.7	190	1.2	0.01953
27	3805 N. Shore Drive	21791	17281	18059	1.21	0.96	1.01	186	5.4	0	32	3.9	190	0.7	0.20974
28	34th St. W	27146	20701	19536	1.39	1.06	2.17	863	2.5	21	60	6.9	380	2.9	0.05205
29	N. Shore Drive and N. 9th St. SW	36860	22334	12094	3.05	1.85	0.65	101	6.5	0	34	2.3	30	1.7	0.00520
30	33rd St. W	38468	26742	20787	1.85	1.29	1.96	675	2.9	34	75	8.1	37	9.4	0.06977

FIGURE 1. Color-coded bacterial concentrations in storm drains around the City of Clear Lake. Note that storm drain analyses were funded directly by the City of Clear Lake so dozens of storm drains from other residential and commercial areas were not tested but would likely yield similar values.

Fecal Coliforms in Clear Lake Storm Drains, Sept. 23, 1998



E. coli **in Clear Lake Storm Drains, Sept. 23, 1998**



Enterococci in Clear Lake Strom Drains, Sept. 23, 1998

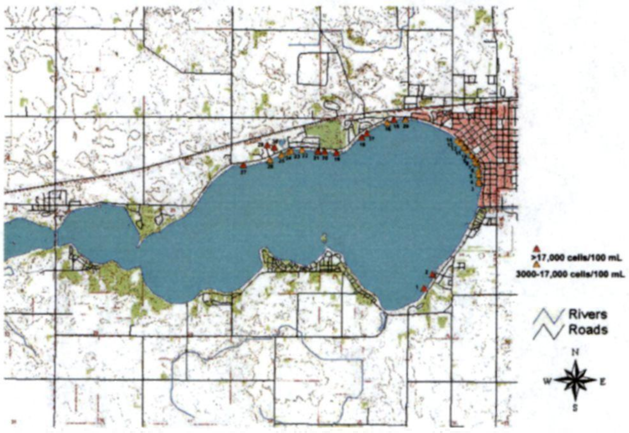
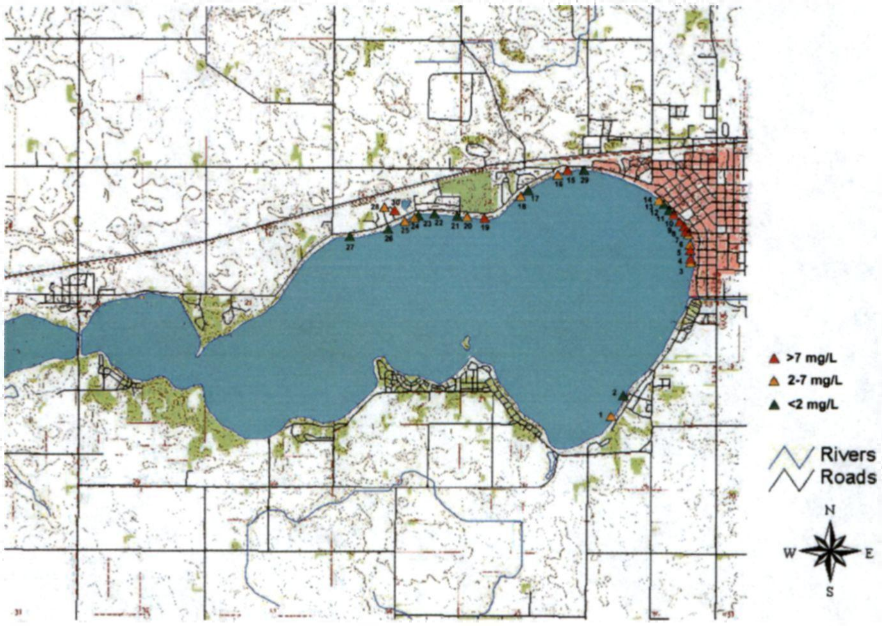
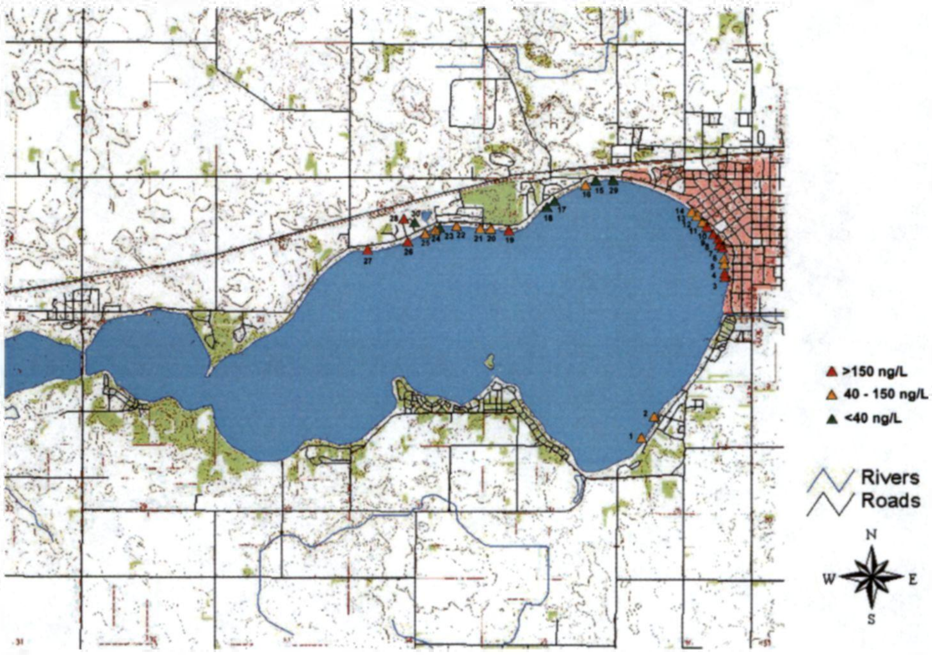


FIGURE 2. Color-coded chemical concentrations in storm drains around the City of Clear Lake. Note that storm drain analyses were funded directly by the City of Clear Lake so dozens of storm drains from other residential and commercial areas were not tested but would likely yield similar values.



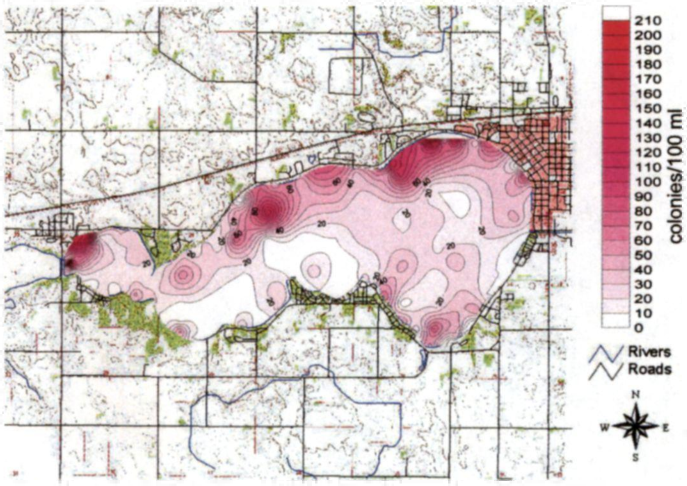
Chloride in Clear Lake Storm Drains; September 23, 1998



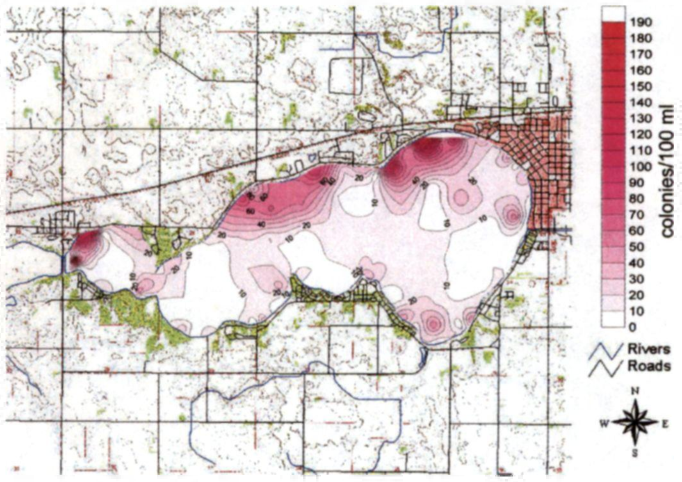
Caffeine in Clear Lake Storm Drains; September 23, 1998

FIGURE 3. Spatial patterns of bacterial concentrations in Clear Lake, Iowa. These analyses were funded directly by the City of Clear Lake.

Clear Lake Fecal Coliform Concentrations (October 1998)



Clear Lake E. coli Concentrations (October 1998)



Clear Lake Enterococci Concentrations (October 1998)

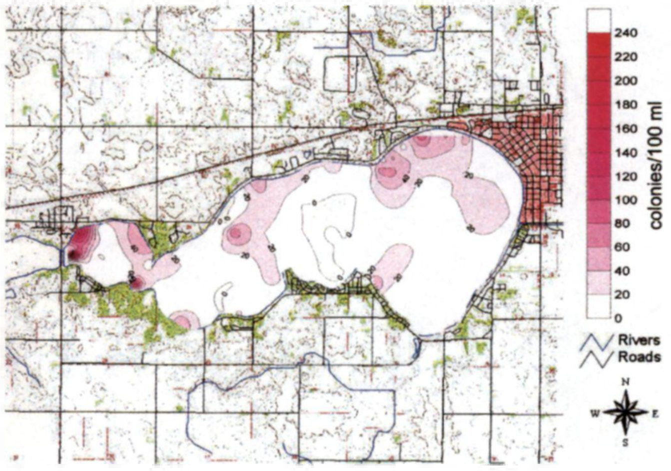


FIGURE 4. Spatial patterns of fecal coliform concentrations in Clear Lake, Iowa across the open water season of 1999. The arrows point up-gradient in bacteria concentration so point toward the likely source of the bacteria. The larger and darker arrows indicate a steeper gradient.

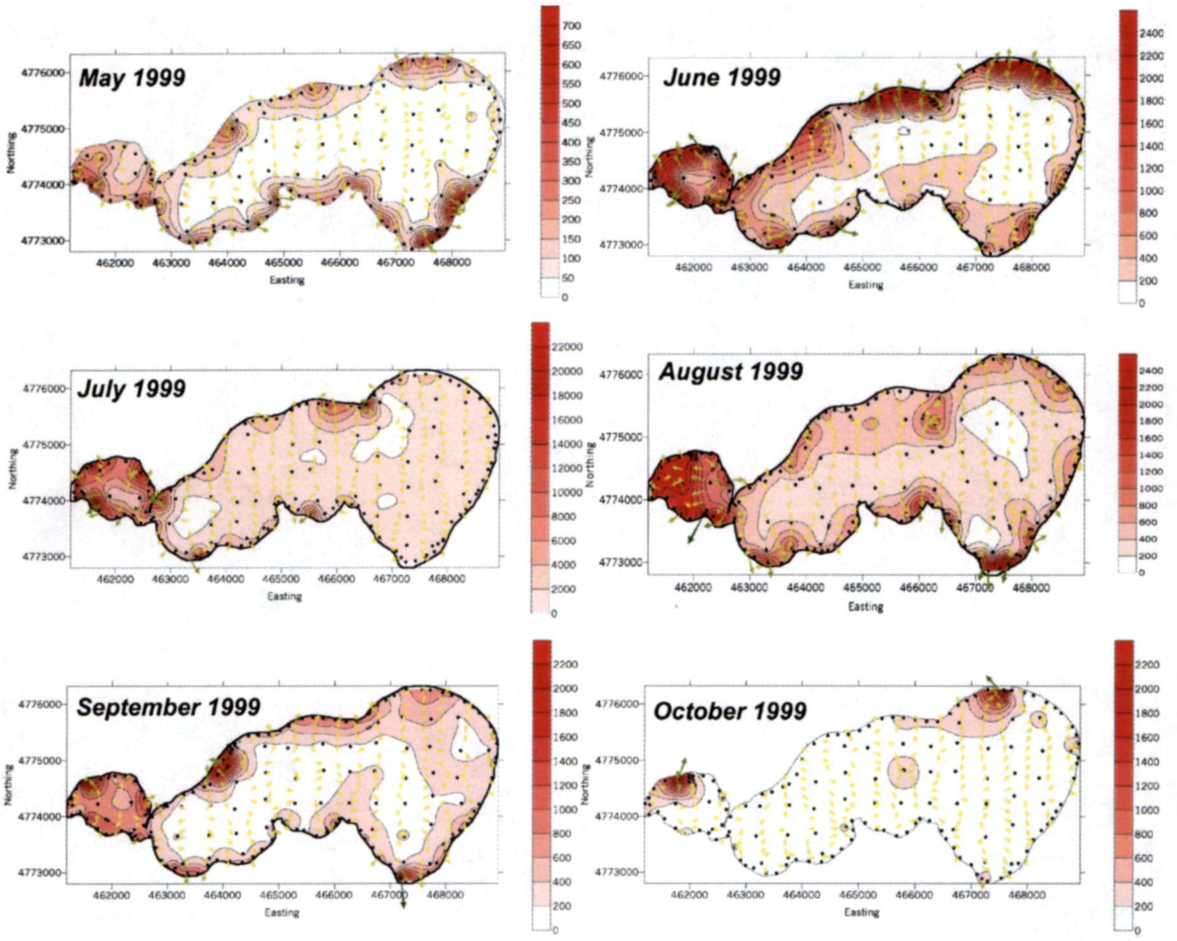


FIGURE 5. Spatial patterns of *E. coli* bacteria concentrations in Clear Lake, Iowa across the open water season of 1999. The arrows point up-gradient in bacteria concentration so point toward the likely source of the bacteria. The larger and darker arrows indicate a steeper gradient.

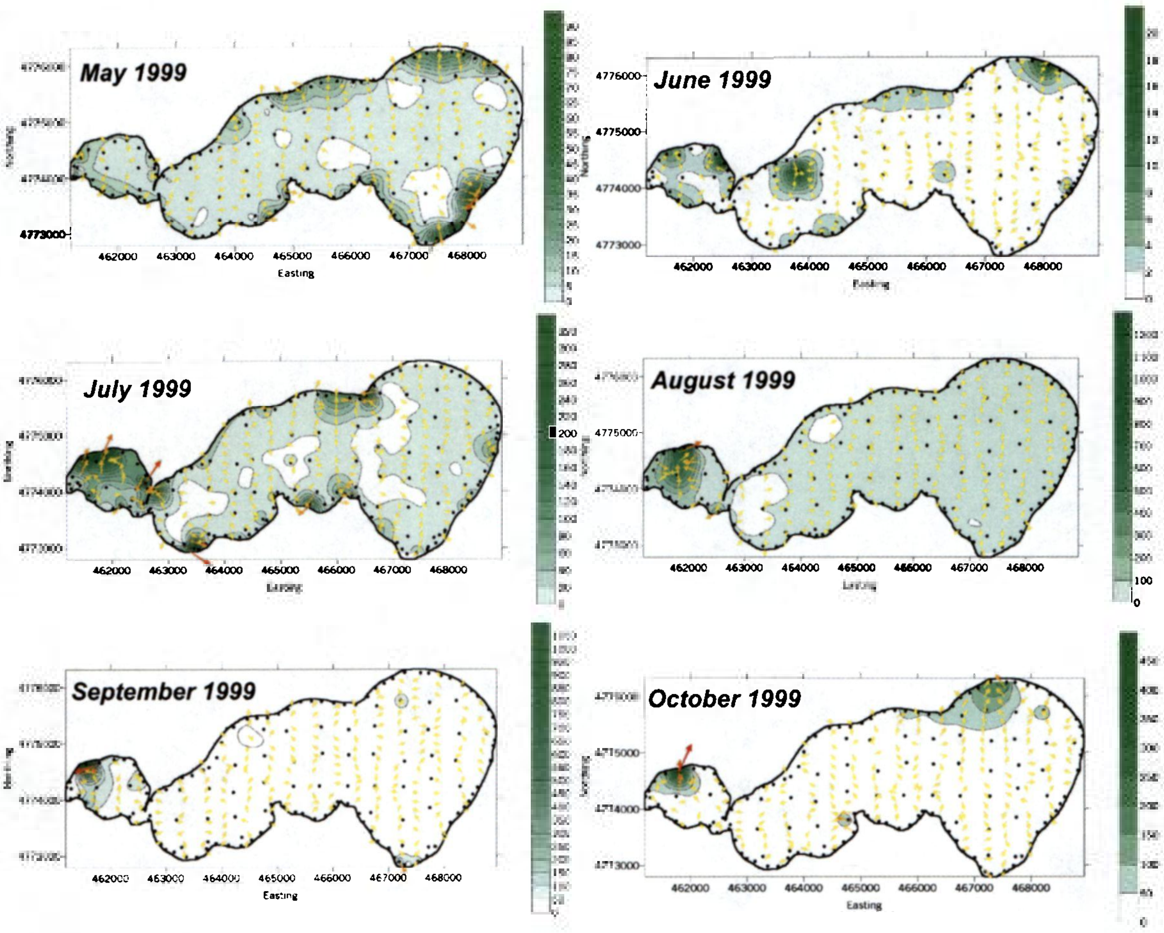


FIGURE 6. Spatial patterns of fecal enterococcal bacteria concentrations in Clear Lake, Iowa across the open water season of 1999. The arrows point up-gradient in bacteria concentration so point toward the likely source of the bacteria. The larger and darker arrows indicate a steeper gradient.

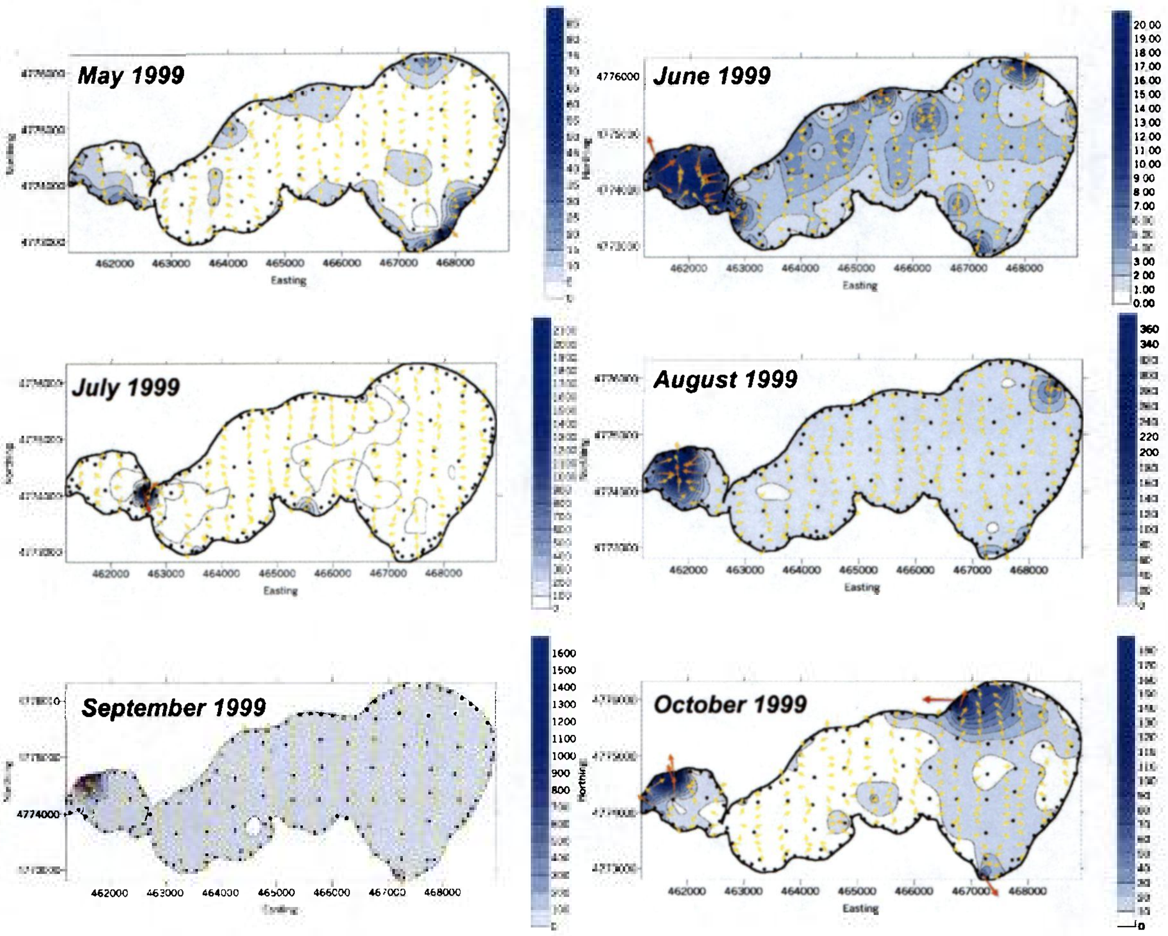
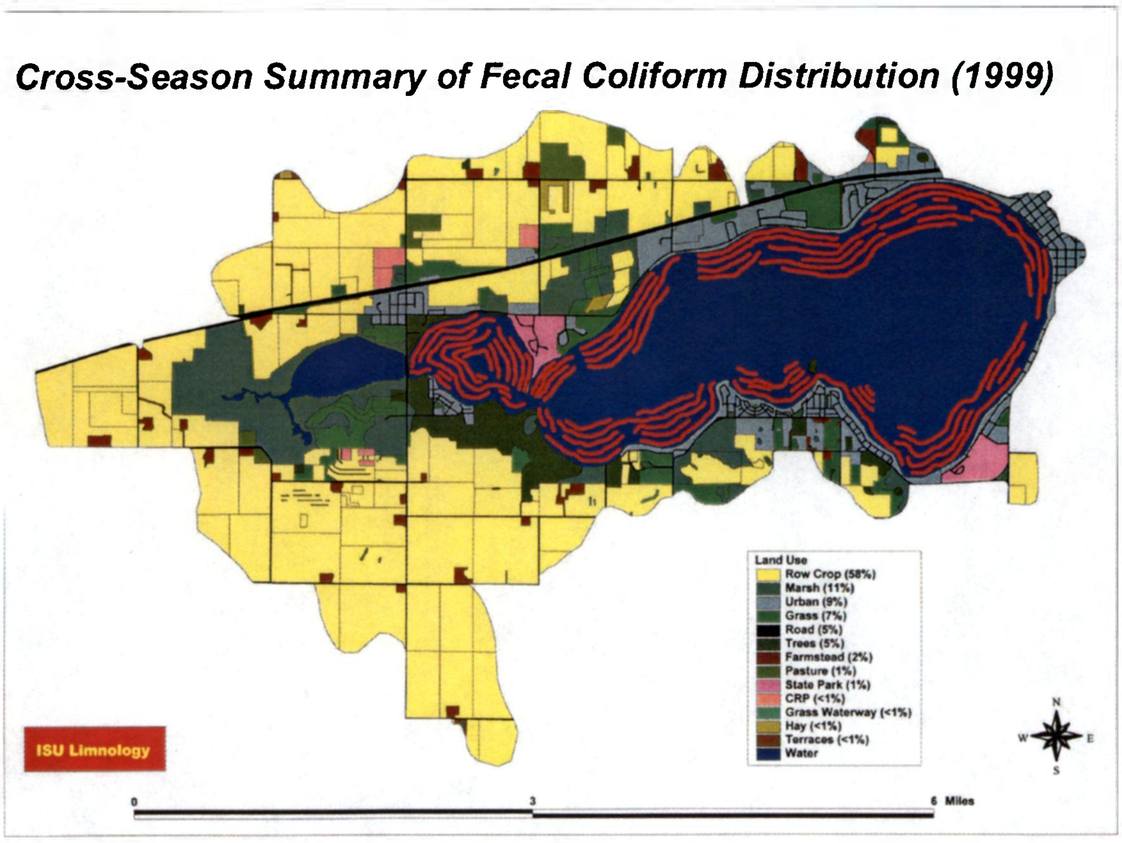


FIGURE 7. Aggregate patterns of fecal coliforms across the season. Red lines are drawn along shore in areas where the vectors in Figure 4 indicate shore origin of fecal coliforms. A new stripe was drawn for every month when the shore appeared to be a source. Six stripes offshore indicate that the shore is a likely source in all of May-October.



Cross-Season Summary of Fecal Coliform Distribution (1999)

CHAPTER 7

Physical Limnology of Clear Lake

Physical Limnology of Clear Lake

James Anthony, Jordi Morell Farre, and John Downing

A. Introduction

Although analyses of external nutrient loads dominate lake restoration research, internal nutrient loads (nutrient loads arising from sources within the lake), have received comparatively little attention (Hamilton and Mitchell 1997). In shallow aquatic systems, however, internal nutrient loading may contribute significant proportions of the total nutrient load by diffusive flux of nutrients through the sediment-water interface (Søndergaard et al. 1999) as well as through the mobilization of nutrients by turbulent resuspension of sediments and nutrient-rich pore water (Kristensen et al. 1992; Reddy et al.1996; Nõges and Kisand 1999). Large-scale resuspension of sediments in shallow, lacustrine systems may be driven by wind-induced waves (Kristensen et al. 1992; Reddy et al.1996; Nõges and Kisand 1999) and recreational boat traffic (Yousef et al. 1980; Garrad and Hey 1987). The resuspension of benthic sediments may contribute to increased nutrient concentrations in the water column (Kristensen et al. 1992; Reddy et al.1996; Nõges and Kisand 1999), increased algal growth (Galicka 1992; Hawley and Lesht 1992; Søndergaard et al. 1992) and degradation of the light climate (Somlyódy 1982). Turbulent resuspension of sediments may also negatively impact macrophyte and fish communities (Jeppesen et al. 1990; McQueen 1990; Meijer et al. 1990) and sediment-mediated light limitation may facilitate domination of the phytoplankton community by potentially toxic cyanobacteria (Søndergaard et al. 1992).

In addition to negatively impacting aquatic communities, frequent resuspension of sediments may also maintain elevated trophic status long after external nutrient loads have been drastically reduced. This is due to the substantial concentrations of nutrients stored in lake sediments from periods of high external loading (Søndergaard et al. 1999). For example, total phosphorus concentrations in eutrophic Lake Søbygaard, Denmark remained unaltered 15 years after 80-90% reductions in external nutrient loads (Søndergaard et al. 1999). This persistence of elevated trophic status by diffusive flux and turbulent resuspension has been noted in other shallow, eutrophic lakes and is likely to be a common, although often overlooked, problem facing the management of these systems (Kristensen et al. 1992, Reddy et al. 1996; Nõges and Kisand 1999; Søndergaard et al. 1999).

Unfortunately, the mechanisms of diffusive flux and, especially, of turbulent resuspension of nutrients in shallow lakes are poorly understood (Phillips et al. 1994; Welch and Cooke 1995), making identification and quantification of internal nutrient loading quite difficult (Hamilton and Mitchell 1997; Søndergaard et al. 1999). Still, those studies that have been conducted on wind-induced resuspension indicate that rapid mobilization of phosphorus (P) and ammonium nitrogen (NH_4-N), enhanced by photosynthetically-elevated pH levels (Bouldin et al. 1974), may be a common occurrence in shallow, eutrophic systems (Søndergaard et al. 1999). In fact, substantial wind-induced resuspension of sediments and nutrients may occur over 50% of the time in some shallow systems and may lead to variable nutrient and light limitation (Hamilton and Mitchell 1988).

Just as wind-induced waves may contribute to sediment resuspension, turbulence induced by recreational boat traffic may resuspend sediments and interstial water in some shallow lakes and rivers (Yousef et al. 1980; Garrad and Hey 1987). Boat-induced turbulence has been correlated to rapid increases in total dissolved solids, soluble reactive phosphorus, total phosphorus (Yousef et al. 1980), and turbidity (Yousef et al. 1980; Garrad and Hey 1987). It is therefore probable that, like wind, recreational boat traffic may lead to persistence of elevated trophic status, suppression of macrophyte and fish communities, and domination of the phytoplankton community by harmful cyanobacteria.

Because of their importance to internal nutrient loading, lake restoration time-scales, water quality, phytoplankton community structure, macrophyte suppression and fish community dynamics, we have examined the contributions of wind and recreational boat traffic to sediment resuspension in shallow, eutrophic Clear Lake, Iowa. These analyses not only elucidate potential means for sediment and nutrient resuspension in Clear Lake, but also provide insight into the degree of resuspension present. Our objectives are (1) to determine the influence, if any, of wind and recreational boat traffic on sediment resuspension, (2) to establish the frequency and degree of resuspension occurring in the lake and (3) to provide estimates of nutrient flux via sediment resuspension.

B. Methods

1. Long-term field data collection. A submersed YSI 6500 multiparameter sonde was used to measure chlorophyll *a* ($\mu g \cdot L^{-1}$) and turbidity (NTU) at 5 minute intervals in Clear Lake, Iowa between July 25, 2000 and October 19, 2000. The data logging sonde, located approximately 80 meters from the northeast shore of the lake (UTM coordinates: 4-68-778, 4-77-5537; Fig. 1) was suspended from a buoy at a depth of approximately 1.5 meters. The lake depth at the site was approximately 3.3 meters. Weather data consisting of wind speed and direction were gathered at ten-minute intervals between August 25, 2000 and October 19, 2000 using a Young Wind Sentry anemometer and vane with a Campbell Scientific CR10 data logger. The wind unit was located at a height of approximately ten meters atop the Clear Lake Municipal Water Treatment Facility on the immediate shore of the lake (Fig. 1). Data were downloaded at weekly intervals from both the sonde and the CR10 data logger. Additional weather data including resultant wind direction and average daily wind speed were obtained from the National Climactic Data Center (NCDC) for the National Weather Service meteorological station number 135235 at the Mason City, Iowa Airport, located approximately 4.5 km from Clear Lake.

2. Wind event data collection. Weather forecasts for September 27, 2000 indicated high winds were expected at Clear Lake. Consequently, water samples were gathered from the lake throughout the day in order to ascertain the impact of wind on nutrient flux from resuspended sediments. Beginning at 7:30am, water samples were gathered at 30-minute intervals from a depth of approximately 1.5 meters in the immediate vicinity of the primary data collection sonde described above (Fig. 1). To avoid disturbing this sonde, however, we used an additional sonde suspended from a boat at a depth of 1.5 meters to measure turbidity.

3. Laboratory water quality analyses. Water samples collected on September 27, 2000 were analyzed in the laboratory for total phosphorus (TP) and ammonium-nitrogen (NH_4^+). Triplicate samples were analyzed for TP using a persulfate digestion followed by an ascorbic acid colorimetric analysis. Analyses for NH_4^+ were performed in triplicate using the Nessler Method.

In addition to analyses of lake water samples for ammonium and total phosphorus concentrations, we wished to establish a relationship between total phosphorus and turbidity as measured by the YSI 6500 sonde. Three superficial sediment samples were taken at the site of the submersed sonde (See Fig. 1) using a 0.0225 m^2 Ekman grab. These sediment samples were mixed and homogenized. Sediments were then added in increasing amounts to samples of water from Clear Lake in order to create a gradient of turbidity that might be representative of increasing degrees of resuspension in the lake. These samples were subsequently analyzed for total phosphorus as described above and for turbidity using a YSI 6500 sonde in order to establish a predictive relationship between turbidity and TP in Clear Lake. This relationship was used to provide estimates of total phosphorus flux that may be attributed to resuspended benthic sediments in the lake.

4. Calculations of wave and wind parameters. We evaluated the ability of wind-induced waves to resuspend benthic sediments near the data logging sonde as well as at a lake-level scale. Records of wind speed and direction were used to calculate several wave parameters, including wave height, period, celerity (or rate of advancement of wave crests), wavelength, and maximum orbital velocity, as well as the maximum effective fetch (L_f), at the site of the sonde and at 3700 points throughout the lake for which for which latitudinal (X), longitudinal (Y), and depth (Z) coordinates were known (Fig. 1). In addition to calculations pertaining to the recorded wind speeds and directions, we calculated wave and wind parameters (described in detail below) for hypothetical wind speeds of 5, 10, 15, 20 and 25 $m \cdot s^{-1}$ along the prevailing Northwest-Southeast wind axis (330°-170°) and for commonly occurring wind events (10 and 15 $m \cdot s^{-1}$) along North-South (0°-180°), East-West (270°-90°), and Northeast-Southwest (45°-225°) axes. These calculations allowed us to directly compare characteristics of wind-induced waves to water quality parameters measured by the submerged sonde as well as to explore the potential for wind resuspension throughout the lake for a variety of hypothetical wind speeds and directions.

In order to ascertain the impact of wind direction on the prevalence of sediment resuspension, we calculated the maximum effective fetch (L_f), a measure of the water surface that may be acted upon by wave action, following Håkanson and Jansson (1983). We measured the distance to the lakeshore from the sonde and the 3700 points throughout the lake along a radial of each recorded and hypothetical wind direction (discussed above) as well as along 14 additional radials deviating from the selected wind direction by ±6°, ±12°, ±18°, ±24°, ±30°, ±36°, and ±42°. The maximum effective fetch was then calculated as:

$$L_f = (\Sigma x_i \cdot \cos \gamma_i)/(\Sigma \cos \gamma_i) \qquad (1),$$

where L_f is the maximum effective fetch in meters, γ_i is each ith deviation angle, where $\gamma_i = \pm 6°, \pm 12°, \ldots \pm 42°$, and x_i is the distance in meters of the γ_ith radial from the given site to land.

Characteristics of wind-induced waves including wave height, period, wavelength, celerity and the maximum orbital velocity at the lake bottom were calculated according to Airy wave theory for irotational waves traveling over a horizontal bottom at any water depth. The assumption of irrotationality simply requires that the individual particles comprising the water retain their orientation in space rather than spinning. Therefore, in the open water, there is no net transport of water particles but, rather, a transfer of energy (i.e. energy, not water, is actually displaced). It is this transfer of energy that becomes important in the translocation of sediments and erosion of shorelines (Komar 1972).

The wave heights, the distance from trough to crest, induced by a given wind speed and direction were calculated according to Airy wave theory as:

$$H = w\cdot[0.0026\cdot(g\cdot L_f / w^2)^{0.47}]/g \qquad (2),$$

where H is the wave height in meters, w is the wind speed in $m\cdot s^{-1}$, g is the acceleration due to gravity (9.8 $m\cdot s^{-1}$), L_f is the maximum effective fetch in meters, and 0.0026 and 0.47 are constants (Håkanson and Jansson 1983). Wave heights were calculated at the position of the sonde for all recorded wind speeds and at the 3700 points throughout the lake for the hypothetical wind speeds described above.

Estimates of wave period, the time interval between successive wave troughs or crests, induced by a given wind speed and direction were calculated as:

$$T = w\cdot[0.46\cdot(g\cdot L_f / w^2)^{0.28}]/g \qquad (3),$$

where T is the wave period in seconds, w is the wind speed in $m\cdot s^{-1}$, g is the acceleration due to gravity (9.8 $m\cdot s^{-1}$), L_f is the maximum effective fetch in meters, and 0.46 and 0.28 are constants (Håkanson and Jansson 1983). Wave period calculations were performed for waves at the sonde and for the 3700 points throughout the lake as discussed above for wave height.

The wavelengths for wave groups passing the sonde and the 3700 lake-wide points were calculated as:

$$\lambda = 1.56\cdot T \qquad (4),$$

where λ is the wavelength in meters, 1.56 is a constant, and T is the wave period in seconds (Håkanson and Jansson 1983). Estimates of wave celerity, or rate of advancement of wave crests were then calculated as:

$$c = \lambda / T \qquad (5),$$

where c is the celerity in $m\cdot s^{-1}$, λ is the wavelength in meters and T is the wave period in seconds (Håkanson and Jansson 1983).

The orbital diameter of surface waves decline exponentially with depth. Since we were interesting in benthic sediment resuspension, we needed to calculate the orbital velocity of these waves near the lake bottom. The maximum orbital velocity of waves near the lake bottom at the sonde and at the 3700 points throughout the lake were therefore calculated as:

$$v = \pi \cdot H / T \cdot e^{-2\pi d/\lambda} \qquad (6),$$

where v is the maximum orbital velocity in $m \cdot s^{-1}$, π is pi (3.1416), H is the wave height in meters, T is the wave period in seconds, d is the water depth in meters and λ is the wavelength in meters (Smith and Sinclair 1973).

5. Boat Traffic Monitoring. Boat traffic near the submerged sonde was monitored between August 25, 2000 through September 3, 2000 using time-lapse videography. A video camera and a 960-hour time-lapse videocassette recorder were mounted inside the Clear Lake Municipal Water Treatment Facility (See Fig. 1) facing the sonde's position in the lake. The videocassette recorder recorded camera images every 1.4 seconds. We then documented the approximate size, speed (i.e. wake vs. no wake), and location of each vessel passing the buoy from which the sonde was suspended. Trends in parameters measured by the sonde (discussed above) were then analysed with trends observed in boat traffic to evaluate the role of boat traffic in the resuspension of benthic sediments.

C. Results

During the course of our examination of sediment resuspension in Clear Lake, Iowa, measurements of turbidity varied from a maximum of 1202.1 NTU to a minimum of 9.4 NTU around a mean of 33.9 NTU. It is likely, however, that the 1202.1 NTU maximum is an aberrant observation due to interference in the measurement instrument's path. Chlorophyll concentrations over the same period varied from a maximum of 49 $\mu g \cdot L^{-1}$to a minimum of 14 $\mu g \cdot L^{-1}$around a mean of 25 $\mu g \cdot L^{-1}$. Time-trends in both variables show considerable variability (Fig. 2). It is important to note, however, that measurements of turbidity are inextricably tied to those of chlorophyll *a* because the algal cells containing chlorophyll *a* are themselves a component of turbidity. Additionally, if resuspension is occurring, it is likely that a large proportion of the chlorophyll *a* indicated by the sonde is actually comprised of recently sedimented, rather than planktonic, algae. This close relationship is evident in the similarities in time-trends, or spectra, of both variables (Fig. 2).

Although variability in chlorophyll and turbidity measurements may superficially appear somewhat random (Fig. 2), closer examination of both time-trends reveals that, superimposed upon larger fluctuations, are notable diel patterns in both variables, with low values generally present during the evening and early morning and rising to daily maxima by early afternoon (Fig. 2). Although some of these diel patterns in turbidity may be strongly influenced by daily production of algae, the confounding of chlorophyll and turbidity measurements prevents a definitive diagnosis and it is possible that the rapid increases in chlorophyll concentrations are indicative of sedimented algal cells resuspended by wind or boat traffic. Variable and generally high values of turbidity early in the study may have been the result of the use of a turbidity probe that was subject to fouling. This probe was subsequently replaced with one that employs a cleaning mechanism to avoid such variability. Also notable is that the sonde ran out of battery power between September 9, 2000 and September 15, 2000 and all data for this period were lost.

Wind was variable with a mean of 6.8 $m \cdot s^{-1}$, a minimum recorded speed of 0.2 $m \cdot s^{-1}$, and a maximum record of 27.8 $m \cdot s^{-1}$. Wind direction was generally unstable at Clear Lake.

Although the mean observed wind direction was 169.5°, sustained winds were observed from throughout a range from 0° to 360°. These values are representative of wind speed and direction records measured by our wind station atop the Clear Lake Municipal Water Treatment Facility (See Fig. 1). When daily mean wind speed data from the National Climactic Data Center were examined for the period of April – October in 1998, 1999, and 2000, the mean wind speed near Clear Lake was found to be 4.6 $m \cdot s^{-1}$with a maximum record of 11.3 $m \cdot s^{-1}$ and a minimum daily average wind speed of 0.6 $m \cdot s^{-1}$. The period between April and October was chosen to provide information representative of the seasonal no-ice state of the lake. It is only during this period that wind may influence the lake's benthic sediments. Just as observed with chlorophyll and turbidity measurements, wind speed generally showed similar diel patterns superimposed upon larger, more long-term fluctuations (Fig. 3). Again, wind speeds tended to rise through the morning hours, before declining in late afternoon and evening (Fig. 3).

Unfortunately, the characteristics of the water quality and meterological variables measured do not lend themselves to straightforward statistical analyses. For example, the lack of independence between turbidity and chlorophyll is likely to mask a clearly defined and repeatable predictive relationship between wind and turbidity, even if one exists, since we cannot distinguish turbidity peaks caused by algal blooms from those induced by wind events. Variable and, likely, very slow settling velocities of small, unconsolidated particles as well as varying algal composition in the lake may also contribute to a varying background turbidity level that prevents the application of most statistical analyses. It is therefore not surprising that no significant relationships were observed among wind or estimated wave parameters and turbidity in the lake.

Despite the inadequacy of conventional statistical measures to treat these complex data, examination of spectral trends makes it increasingly plausible that wind may influence sediment resuspension in Clear Lake (Fig. 3). The locations of peaks and troughs in wind speed are, in many cases, remarkably similar to those of turbidity, indicating that much of the diel and long-term variability in turbidity in Clear Lake may be related to wind events (Fig. 3). Calculations of wave orbital velocities near the bottom of the lake for the 3700 lake-wide points corroborate the implications of spectral analyses by indicating that large proportions of the lake bottom may become prone to wave velocities strong enough resuspend sediments ranging in size from silts to pebbles (Table 1; Figs. 4 – 12).

Maps of wave velocities near the bottom of Clear Lake indicate that large portions of the lake bottom may become prone to wave velocities capable of substantial resuspension. At wind speeds near the mean daily wind speed indicated by NCDC data (~5 $m \cdot s^{-1}$), little wind-driven resuspension is likely to occur in Clear Lake when winds are along the prevailing wind axis (Fig. 4) or along the other wind axes examined. Bottom velocities capable of resuspending sediments become prevalent along the lake margins and in the shallow, western basin of the lake when wind speeds along the prevailing wind axis reach 10 $m \cdot s^{-1}$ (Fig. 5). Dramatic increases in bottom velocities and the area of the bottom involved in sediment resuspension (Table 1) are notable, however, when wind speed along the prevailing wind axis climbs to 15 $m \cdot s^{-1}$, 20 $m \cdot s^{-1}$ and 25 $m \cdot s^{-1}$ (Figs. 6-8). At these wind speeds, a majority of the lake bottom becomes mobile, and wind-induced sediment resuspension may become a lake-wide phenomenon. The same dramatic increase in the potential for sediment entrainment is notable for 10 $m \cdot s^{-1}$ and 15 $m \cdot s^{-1}$ winds along

North-South, East-West, and Northeast-Southwest axes (Figs. 9-11). The potential for sediment resuspension is particularly notable in areas where fetch becomes large or where depth becomes shallow. This is especially true for the shallow margins of the lake as well as for the small western basin of the lake, which is exposed to strong potential for resuspension even at relatively low wind velocities.

The rate of occurrence of substantial resuspension events such as those described above is difficult to quantify. Our wind data, however, indicate that winds during our study period ranged from 5 - 10 $m{\cdot}s^{-1}$, 10 - 15 $m{\cdot}s^{-1}$, 15 - 20 $m{\cdot}s^{-1}$, and 20 – 25 $m{\cdot}s^{-1}$, 43.4%, 14.9%, 5.8% and 1.1% of the study period, respectively. This implies some degree of resuspension occurring over 60% of the time at Clear Lake. These estimates may be slightly biased, however, as our data may include substantial wind gusts which, if present only in short duration, may not lead to large-scale wind resuspension. Data from the NCDC suggest mean daily wind speeds from 5 – 10 $m{\cdot}s^{-1}$may occur 45.1 % of the time while winds exceeding 10 $m{\cdot}s^{-1}$ occur only 2.3 % of the time. This may, however, lead to a large underestimate of the frequency and magnitude of resuspension occurring at the lake, however, as these daily mean wind data, may mask the presence of some high wind periods.

During September 27, 2000, wind speeds at Clear Lake ranged from a minimum of 14 $m{\cdot}s^{-1}$ at 7:30 AM to maximum of 24 $m{\cdot}s^{-1}$at 3:00 PM (Fig. 12a). Winds increased throughout the day before beginning to diminish after the 3:00 PM maximum (Fig. 12a). Sonde measured turbidity ranged from a minimum of 30 NTU at 7:30 AM to a maximum of 48 NTU at 3:00 PM, before declining thereafter (Fig. 12a). Similar patterns were observed in ammonium-nitrogen concentrations, which increased from a minimum of 739 $\mu g{\cdot}L^{-1}$at 7:30 AM to a maximum of 1052 $\mu g{\cdot}L^{-1}$at 2:00 PM (Fig. 12b). Concentrations of unionized ammonia (NH_3) increased from 61 to 115 $\mu g{\cdot}L^{-1}$. Although these concentrations are just below those necessary for acute fish damage (120 ug/L) they are low only due to the low temperatures in the lake in September (~13°C). Had the water temperature been closer to that observed in the summer months (~25°C), unionized ammonia would have increased from 126 to 221 $\mu g{\cdot}L^{-1}$, reaching concentrations far beyond those necessary for acute fish damage. Concentrations of total phosphorus in the lake increased from a minimum of 82 $\mu g{\cdot}L^{-1}$ at 7:30 AM to a maximum of 186 $\mu g{\cdot}L^{-1}$at 2:00 PM before declining (Fig. 12c). The similarity in trends of the 71% increase in wind speed and the 60% increase in turbidity, 42% increase in ammonium and 126% increase in total phosphorus support the role of wind in sediment resuspension and substantial increases in water column nutrient concentrations. In fact, on September 27, 2000, statistical analyses of the data reveal positive correlations between wind speed and turbidity ($r^2 = 0.65$), ammonium ($r^2 = 0.27$), and total phosphorus ($r^2 = 0.51$).

Concentrations of total phosphorus increased rapidly when benthic sediments were added to water taken from Clear Lake. The turbidity gradient created ranged from 32 to 160 NTU, while TP concentrations ranged from 143 to 876 $\mu g{\cdot}L^{-1}$. The relationship between the two variables, with TP as the independent variable ($y = 3.975x + 55.4$) was used to estimate TP concentrations in the water from turbidity measurements provided by the sonde. These predictions are, however, based upon turbidity comprised primarily of sediment and are unlikely to account for variability of background phosphorus from other sources. The slope of the laboratory-derived relationship between turbidity and TP (4.0), however, is very similar to that derived *in situ* (3.9) on September 27, 2000. It is therefore likely that the magnitude of change in phosphorus (ΔTP) predicted by the laboratory-derived relationship is an accurate depiction of the change in TP in the lake, while predictions of the actual TP concentrations may be slight overestimates. Total phosphorus concentrations predicted from turbidity in Clear Lake through our study period are quite variable with a daily phosphorus flux often surpassing 100 $\mu g{\cdot}L^{-1}$ (Fig. 12d). Some very rapid fluctuations and very high concentrations of TP are likely related to turbidity spikes that may have been erroneously high due to bubbles or other obstructions in the instrument's path.

Although substantial evidence seems to support the role of wind in the resuspension of sediments and nutrients in Clear Lake, not all of the flux of turbidity and TP may be attributed to wind-induced wave energy. Through the analysis of the passage near the buoy (generally within 100 meters) of 2287 boats, it appears as though recreational boat traffic may play an important role in the entrainment of benthic sediments. Most of the 2287 boats observed were traveling at a sufficient velocity to produce wakes. Violations of the no wake zone (91.5 meters from shore) were frequent (Fig. 13a and b) and many boats traveled at high speeds along the margin of the no wake zone (Fig. 13c). Although the same problems that plague statistical analyses of wind-induced resuspension preclude a direct statistical analyses of boat traffic (no significant correlations exist), spectral trends in mean hourly turbidity do appear to be closely related to those of the mean number of boats passing the sonde per 10 minute interval (Fig. 14a). While spectral trends in wind over the same period seem to follow those of turbidity with some correspondence, it is important to note that wind speeds during the period are generally low and, over time, wind generally decreased while turbidity and boat traffic show overall increases through time. The role of boat-induced turbulence in the resuspension of sediments in Clear Lake is also anecdotally supported by observations of sediment plumes following the passage of boats (Fig. 14b).

D. Discussion

Although the nature of the time-series data we collected prevents direct statistical analyses among wind, recreational boat traffic, and turbidity, spectral analyses of these data support the potential for wind and boat traffic to influence sediment resuspension in Clear Lake. Downing and Ramstack (2001) have also shown turbidity maxima near the lake's bottom indicating that resuspension of sediment may be prevalent. Maps of wave velocity near the lake's bottom also indicate that, during strong wind events, sufficient energy may exist to lift even relatively large sediment particles from a large proportion of the lake bottom. Turbulent resuspension of benthic sediments and nutrients may therefore be frequent occurrences that, without remediation, may lead to increased restoration time-scales as resuspended nutrients maintain the lake's elevated trophic status.

The degree of nutrient flux evident during wind resuspension events is of substantial magnitude. Concentrations of total phosphorus may more than double, increasing by over 100 $\mu g{\cdot}L^{-1}$, in less than 12 hours, leading to rapid reductions in N:P ratios. Fortunately, as observed in other shallow, eutrophic lakes (Kristensen et al. 1992), resuspended total phosphorus seems to drop out of the water column with turbidity during times of low wind, implying that suppression of wind-induced waves could suppress phosphorus flux from the sediments. The resuspension of unionized ammonia, however, represents perhaps a more insidious threat to the aquatic community as concentrations may frequently exceed levels dangerous to fish and wildlife. During the summer months, when water temperature and pH are high, turbulent resuspension of high concentrations of unionized ammonia could lead to ammonia-, rather than oxygen-mediated fish kills.

Areas of the lake characterized by shallow depths and long fetch may be particularly sensitive to resuspension from wind-induced waves, especially as wind speeds surpass 10 $m \cdot s^{-1}$. This is perhaps most evident in the lake's small, shallow, western basin. Resuspension here is likely to be a common occurrence even at relatively low wind velocities due to the basin's shallow depth and fine, unconsolidated sediments. In fact, the frequent brown hue of the water in this smaller basin suggests sediments are often in suspension. Nutrient flux from resuspended sediments and phosphorus- and ammonia-rich pore water is likely to be high here and it is probable that prevailing currents transport large sediment and nutrient loads from the smaller western basin into the lake's larger basins to the east. This is, in fact, observable in the sediment plumes that may often be observed passing through the narrow strait between basins.

Shallow areas of Clear Lake may also be quite susceptible to sediment resuspension induced by recreational boat traffic. It is important to note, however, that increased resuspension due to boat traffic was evident even in relatively deep water (over three meters) at the site of the sonde. Because maps of bottom velocity also indicate that wind-driven sediment resuspension may be most prevalent in the shallow areas around the lake's margin and in the small western basin, it is plausible that the frequent violation of the no wake zones in these areas may enhance and contribute to resuspension or may prevent resuspended particles from resettling. Through this mechanism, wind and boat traffic may act together to resuspend benthic sediments and maintain their suspension in shallow water.

Internal nutrient loading through turbulent resuspension of sediments is a substantial problem in Clear Lake and, without change, will likely lead to further degradation of the lake's water quality, recreational value, and its fish and wildlife communities. Potentially hazardous blooms of cyanobacteria may become more common as resuspended sediments degrade the light climate, suppress macrophyte growth, and lower N:P ratios. As sediments continue to fill the lake, reducing water depth, more of the lake's bottom will become susceptible to resuspension, thereby increasing water column nutrients including total phophorus, ammonium, and toxic ammonia. Lake restoration time-scales may also be prolonged if sediment resuspension continues to occur unabated in the lake.

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TABLE 1. The area (m^2) of the bottom subject to wave velocities capable of resuspension and the total % of the bottom capable of resuspension and, for the prevailing wind axis (*), the % bottom capable of resuspending particles of increasing diameters. Estimates of the area and % of the bottom prone to mobility during wind events are based upon lake surface area and are therefore slight underestimates.

Wind Axis	Wind Speed	Total Mobile Area (m^2)	Total Mobile Area (% of surface area)	Silt (<0.063mm)	Fine Sand (0.063 – 0.5mm)	Coarse Sand (0.5 – 1.0mm)	Very Coarse Sand (1.0 – 2.0mm)	Granules (2.0 – 4.0mm)	Pebbles (4.0 – 64mm)
NW-SE* (330°-170°)	5 $m \cdot s^{-1}$	28825	0.2	0.2	-	-	-	-	-
NW-SE* (330°-170°)	10 $m \cdot s^{-1}$	1804562	17.2	12.5	4.6	-	-	-	-
NW-SE* (330°-170°)	15 $m \cdot s^{-1}$	8370631	58	33.8	19.7	4.2	0.3	-	-
NW-SE* (330°-170°)	20 $m \cdot s^{-1}$	13420174	93.0	33.7	42.1	12.5	4.1	0.8	-
NW-SE* (330°-170°)	25 $m \cdot s^{-1}$	14284528	99.0	9.7	45.7	28.9	9.9	3.9	1.0
NE-SW (45°-225°)	10 $m \cdot s^{-1}$	3964036	27.5						
NE-SW (45°-225°)	15 $m \cdot s^{-1}$	12183123	84.5						
N-S (0°-180°)	10 $m \cdot s^{-1}$	3736538	25.9						
N-S (0°-180°)	15 $m \cdot s^{-1}$	12324986	85.4						
E-W (270-90°)	10 $m \cdot s^{-1}$	2568821	17.9						
E-W (270°-90°)	15 $m \cdot s^{-1}$	8638721	59.9						

FIGURE 1. Locations of the sonde (•), Clear Lake Municipal Water Treatment Facility (•), and 3700 points used for calculation of physical wave characteristics (•).

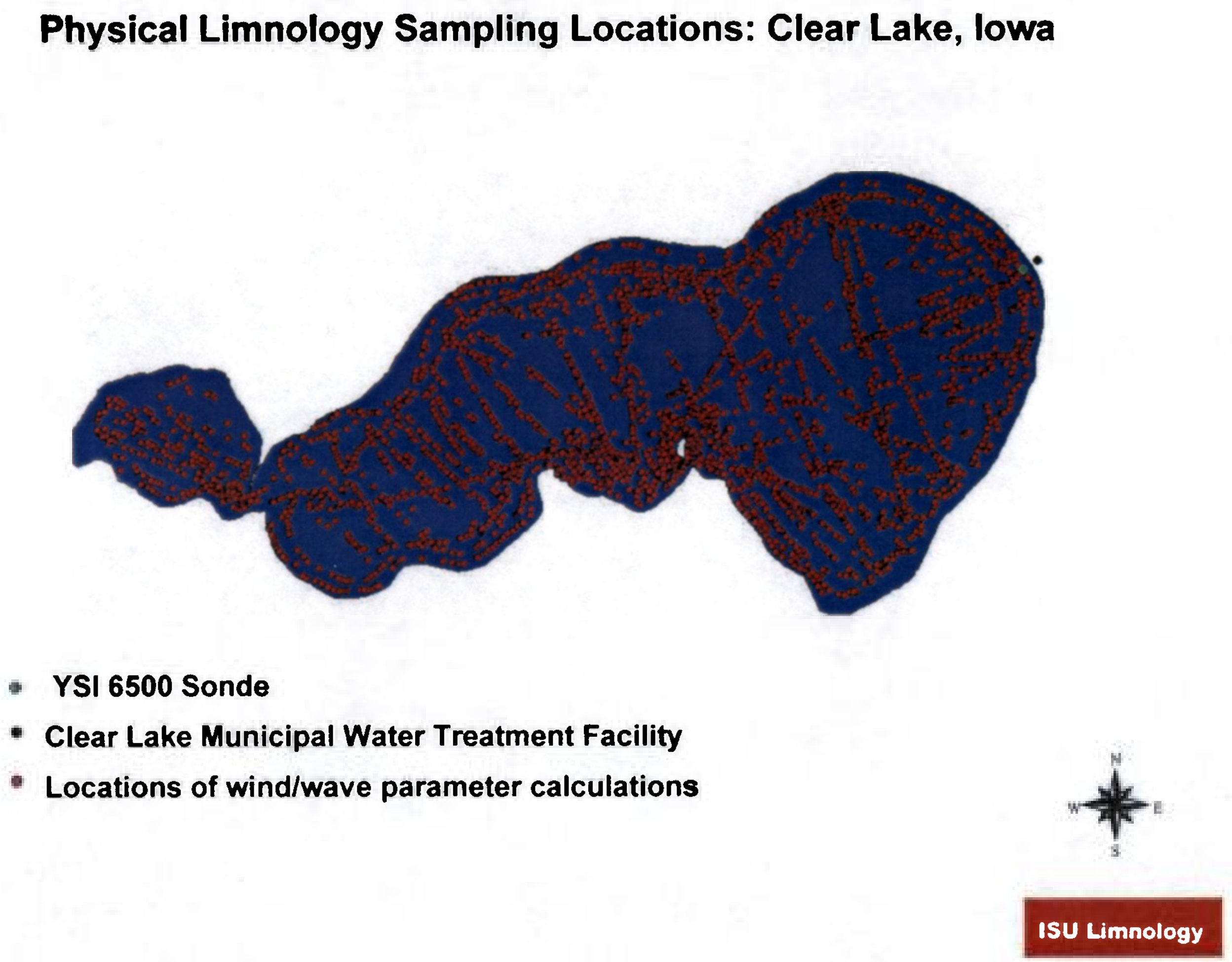


FIGURE 2. Turbidity (NTU) (•), chlorophyll *a* concentrations (μg·L^{-1}) (•), and wind speed (m·s^{-1}) (•) observed at Clear Lake between July 25, 2000 and October 19, 2000. The data logging sonde ran out of battery power between September 9, 2000 and September 15, 2000 leading to data loss for that period. Although data are variable, closer examination (cut away) reveals diel fluctuations in all three variables are superimposed on larger-scale trends.

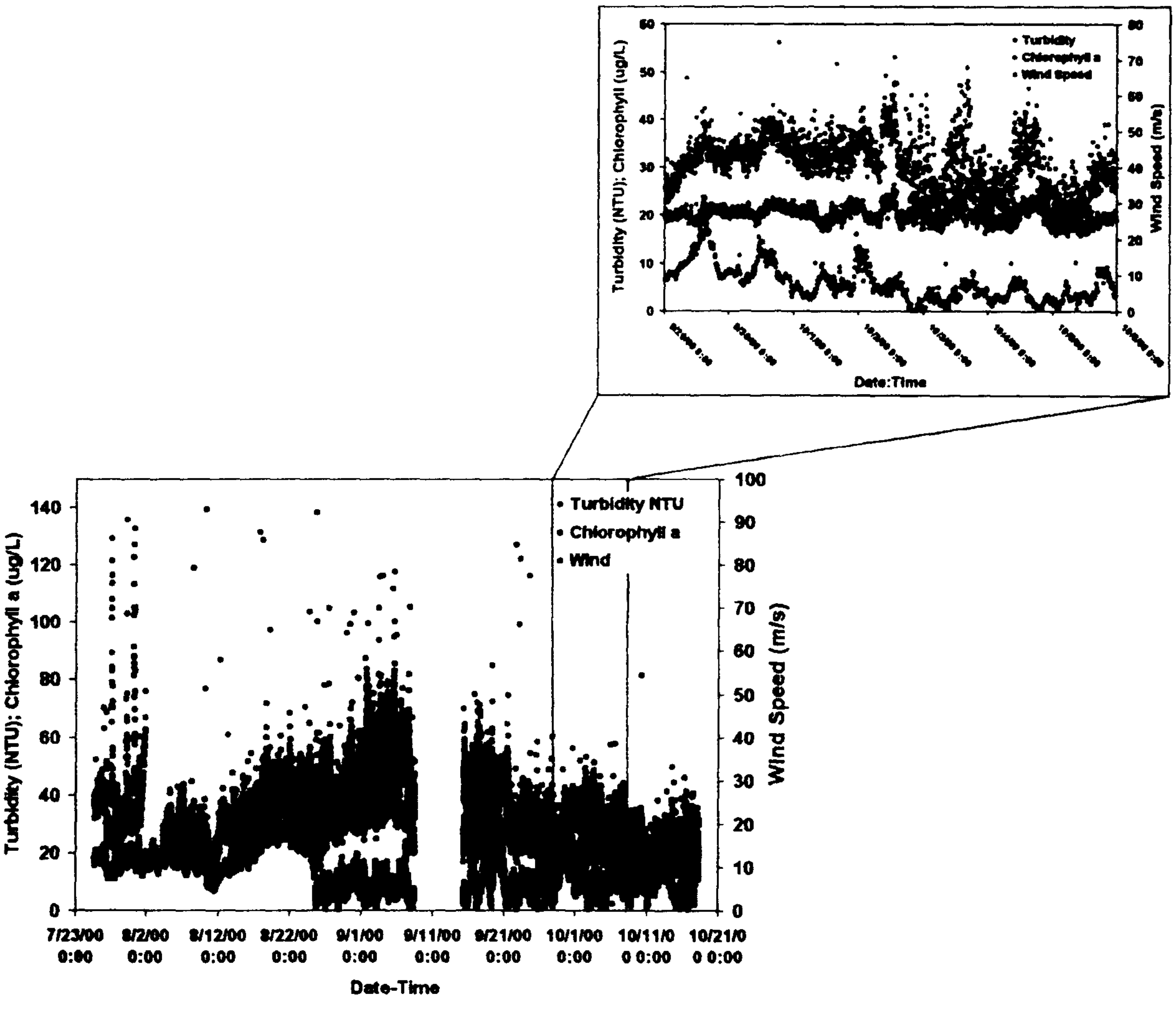
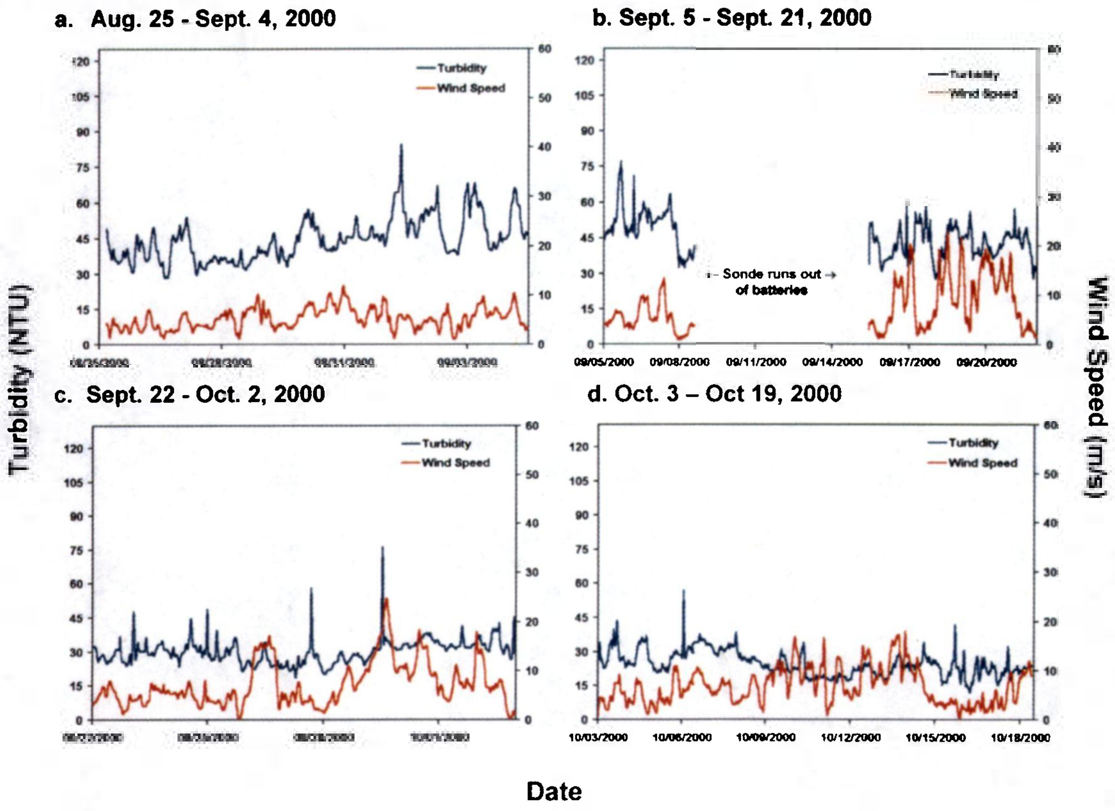


FIGURE 3. Peaks and troughs in spectral trends in Turbidity (NTU) (—) and wind speed ($m{\cdot}s^{-1}$) (—), both averaged over one hour intervals, are similar, implying a role of wind–induced turbulence in sediment resuspension at Clear Lake.



a. Aug. 25 - Sept. 4, 2000

b. Sept. 5 - Sept. 21, 2000

c. Sept. 22 - Oct. 2, 2000

d. Oct. 3 – Oct 19, 2000

FIGURE 4. Wave velocities (cm•s^{-1}) at the lake bottom during a 5 m•s^{-1}wind event along the prevailing Northwest-Southeast (330°-170°) wind axis.

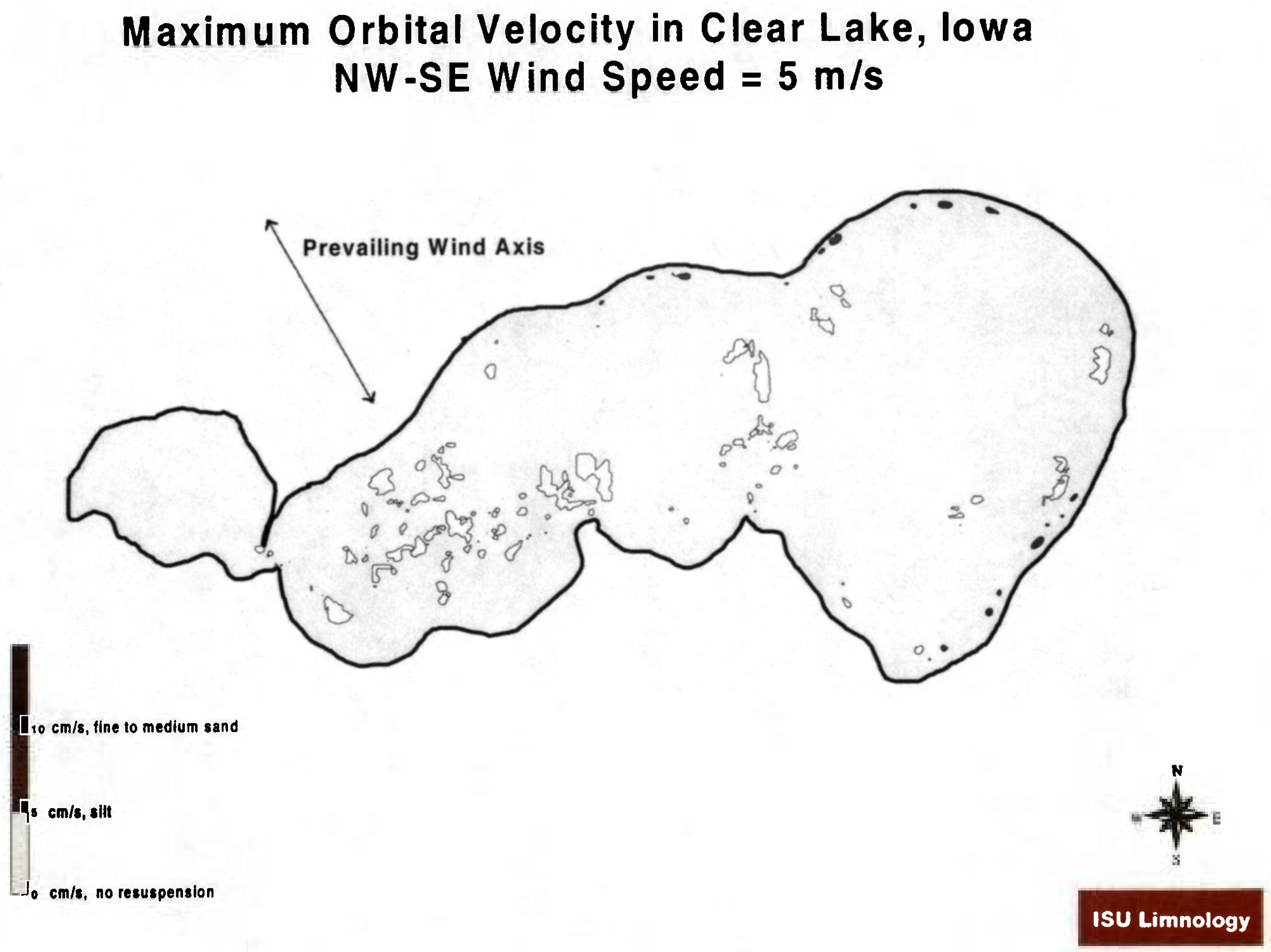


FIGURE 5. Wave velocities ($cm{\cdot}s^{-1}$) at the lake bottom during a 10 $m{\cdot}s^{-1}$ wind event along the prevailing Northwest-Southeast (330°-170°) wind axis.

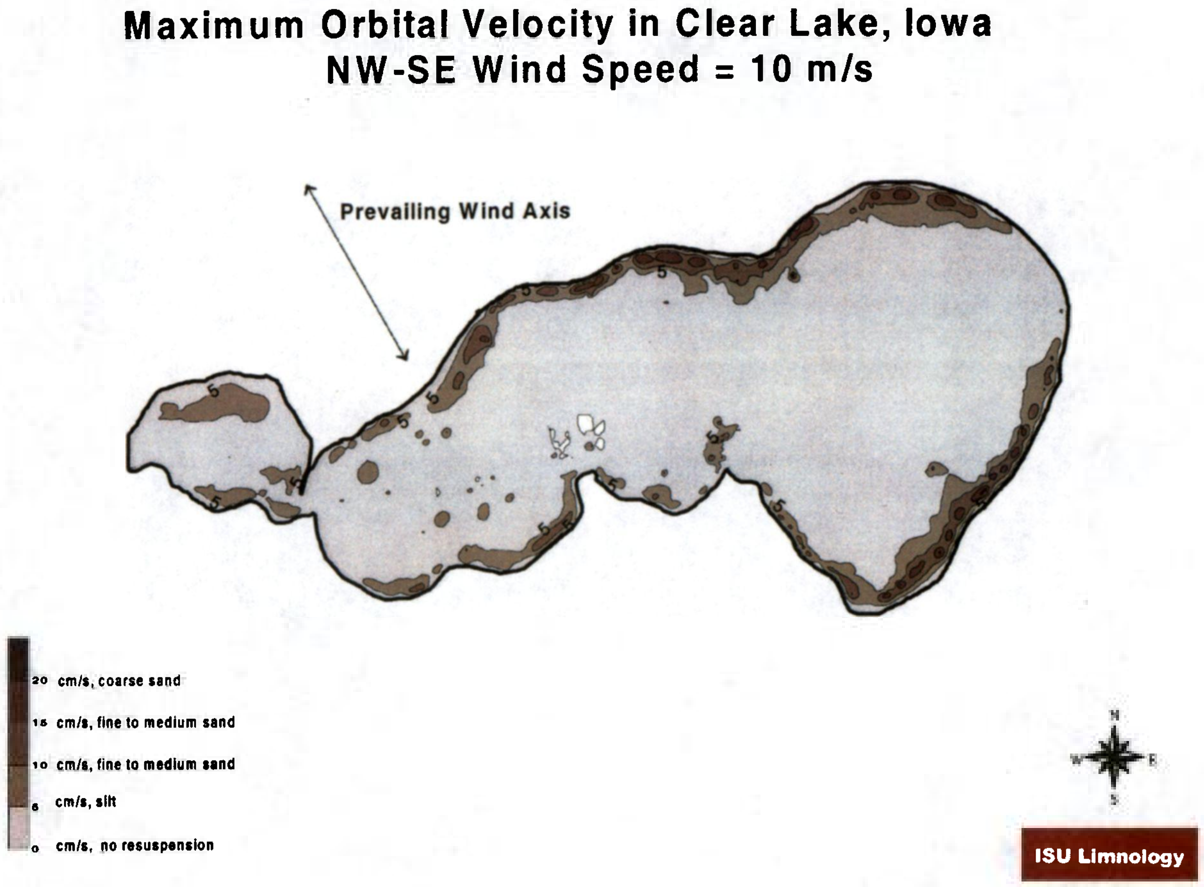


FIGURE 6. Wave velocities ($cm\cdot s^{-1}$) at the lake bottom during a 15 $m\cdot s^{-1}$ wind event along the prevailing Northwest-Southeast (330°-170°) wind axis.

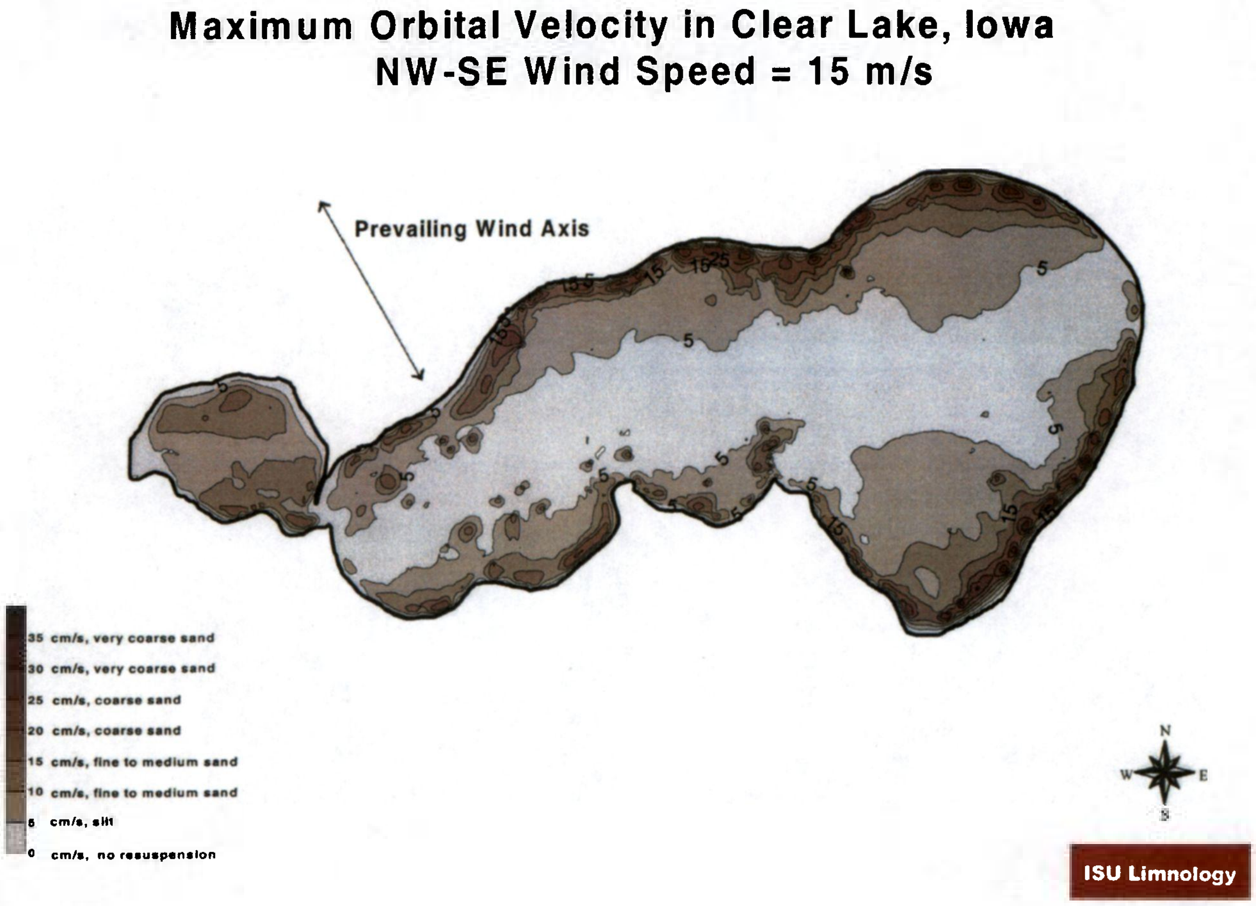


FIGURE 7. Wave velocities (cm•s^{-1}) at the lake bottom during a 20 m•s^{-1}wind event along the prevailing Northwest-Southeast (330°-170°) wind axis.

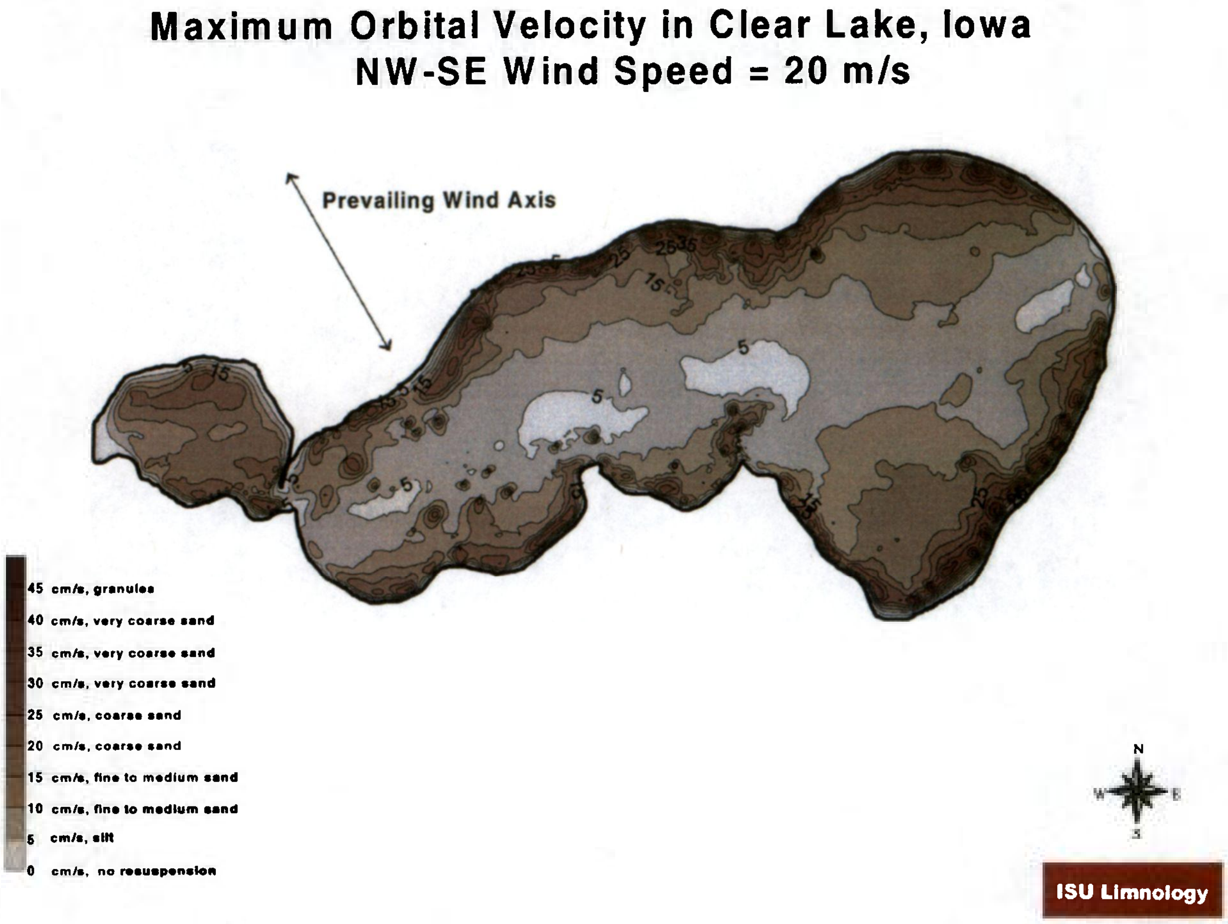


FIGURE 8. Wave velocities (cm•s^{-1}) at the lake bottom during a 25 m•s^{-1}wind event along the prevailing Northwest-Southeast (330°-170°) wind axis.

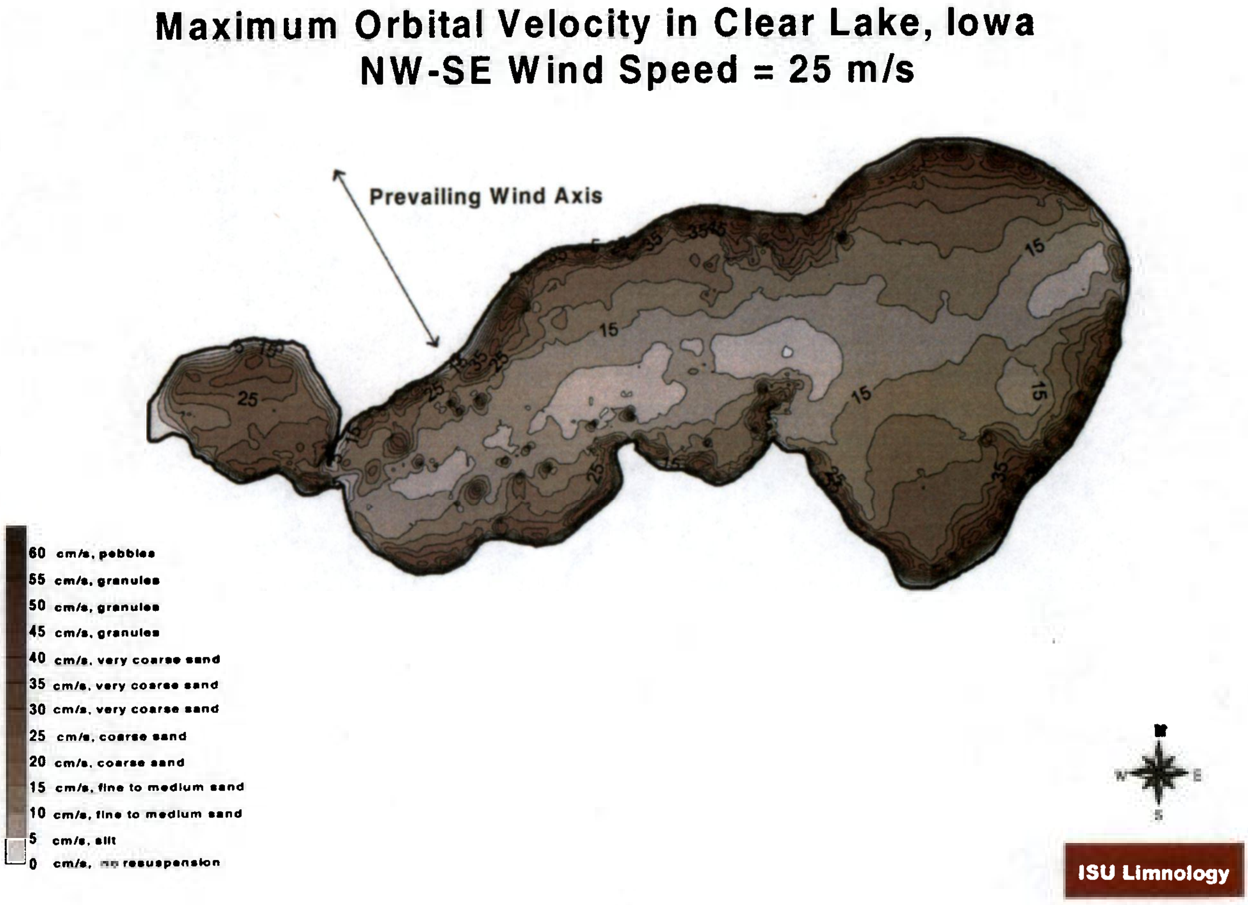


FIGURE 9. Wave velocities (cm·s^{-1}) at the lake bottom during 10 m·s^{-1} and 15 m·s^{-1} wind events along a North-South (0°-180°) wind axis.

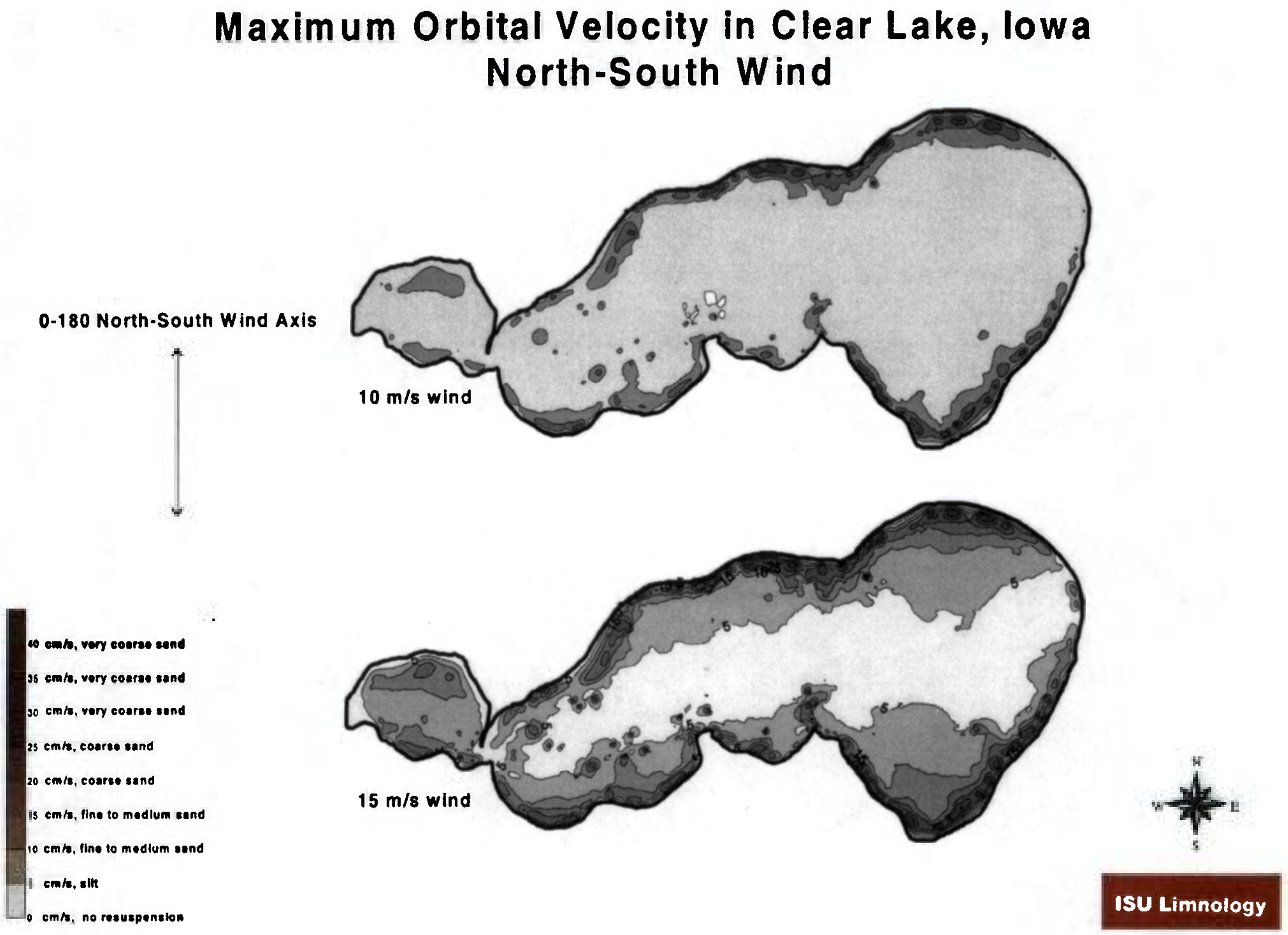


FIGURE 10. Wave velocities (cm•s^{-1}) at the lake bottom during 10 m•s^{-1}and 15 m•s^{-1}wind events along an East-West (270°-90°) wind axis.

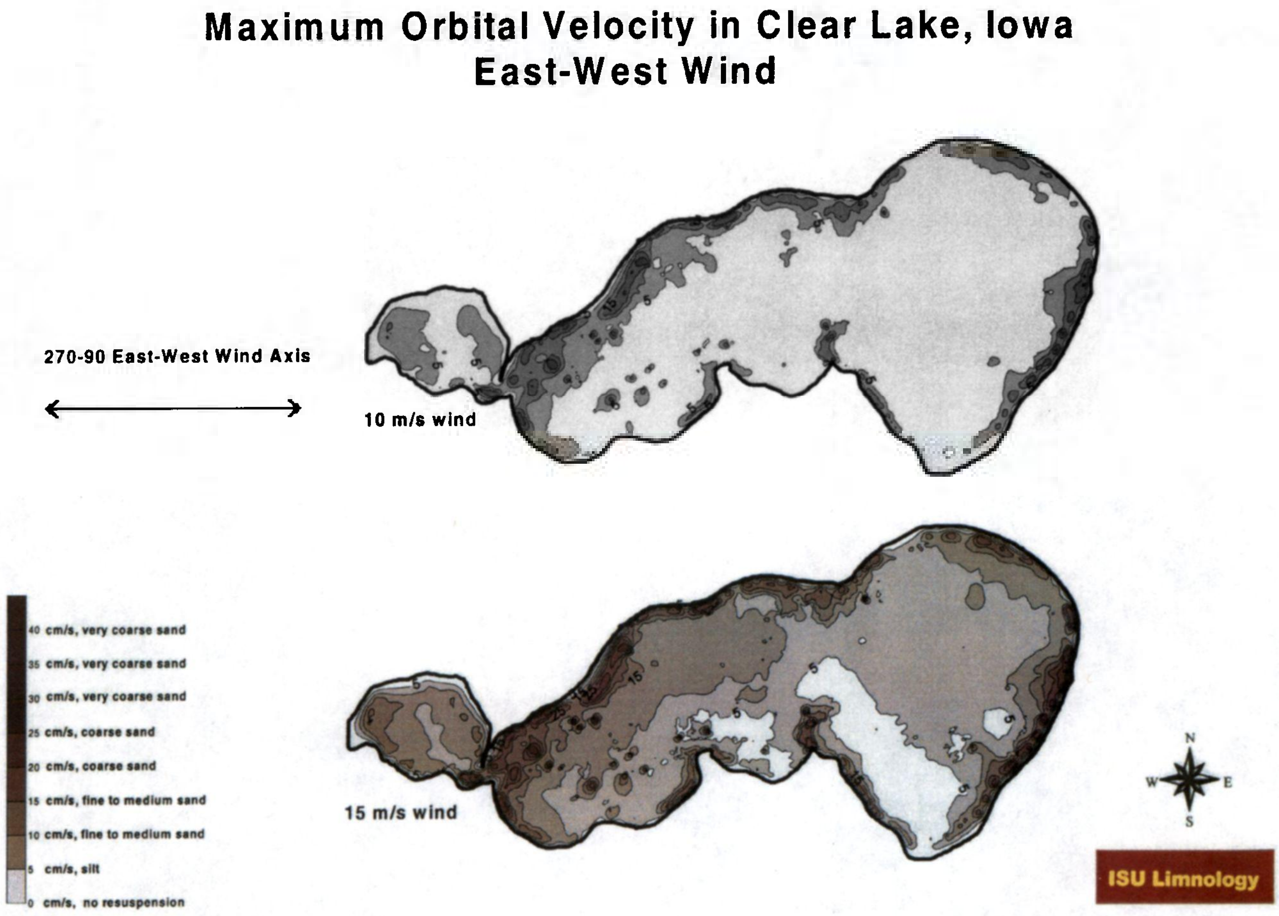


FIGURE 11. Wave velocities (cm•s^{-1}) at the lake bottom during 10 m•s^{-1}and 15 m•s^{-1}wind events along a Northeast-Southwest (225°-45°) wind axis.

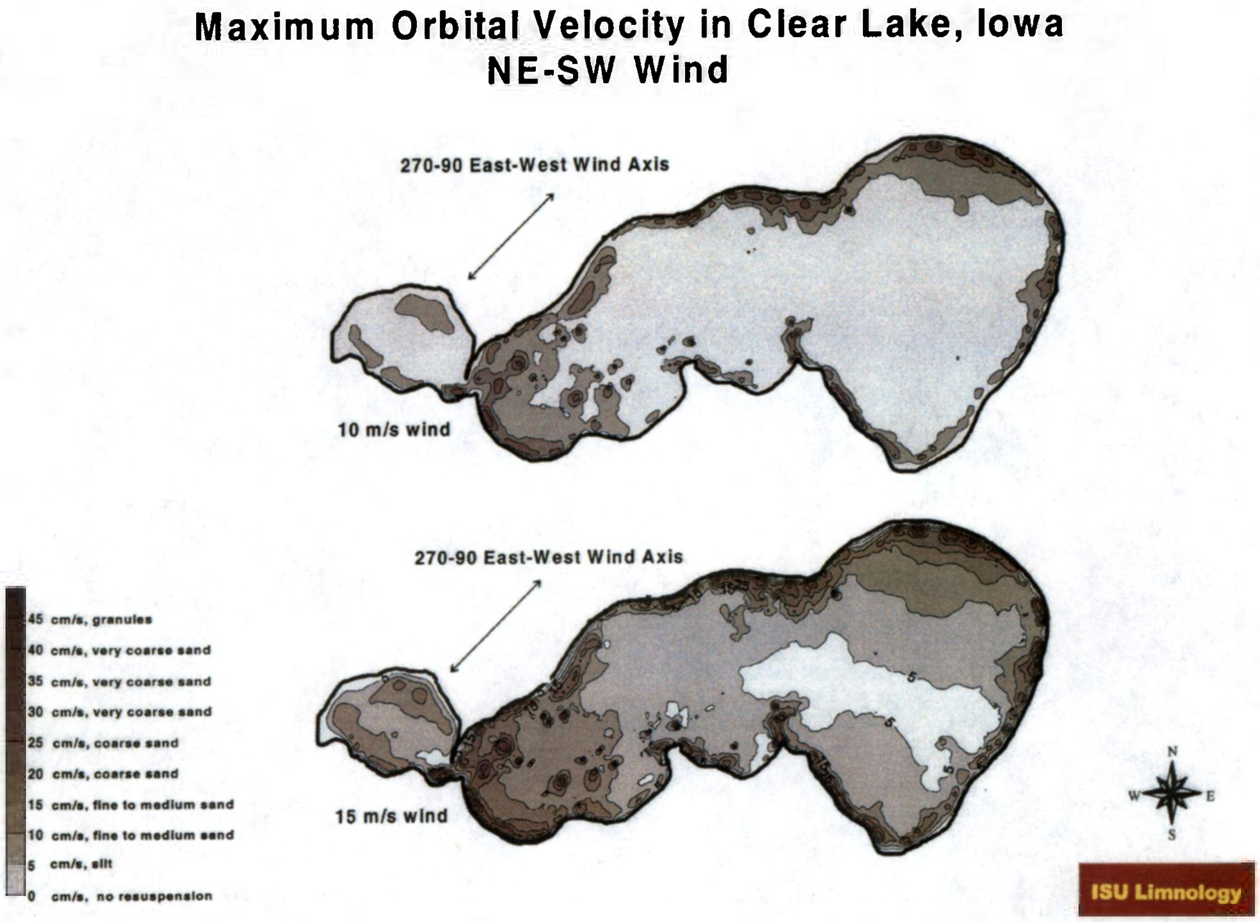
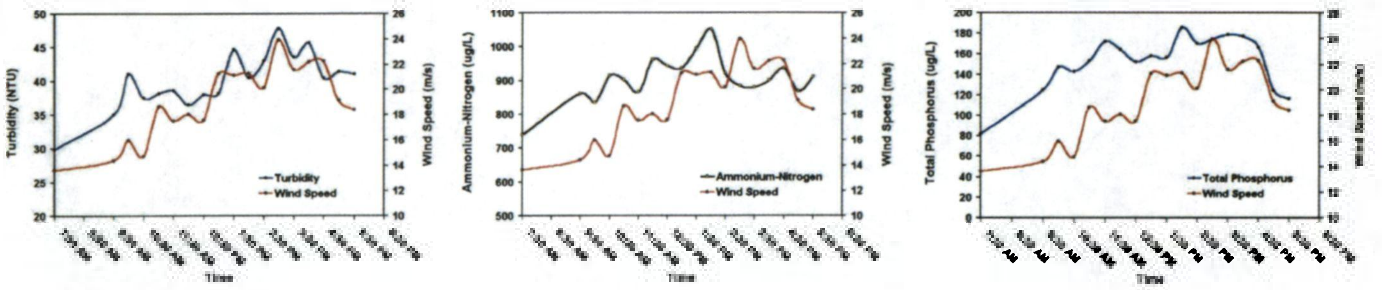


FIGURE 12. Flux of (a) turbidity (NTU) (—), (b) ammonium ($\mu g \cdot L^{-1}$) (—), and (c) total phosphorus ($\mu g \cdot L^{-1}$) (—) during a significant wind event (10 $m \cdot s^{-1}$) (—) on September 27, 2000. Total Phosphorus (d) flux (—) between August 4, 2000 and October 19, 2000 was estimated from a laboratory-derived relationship between water and sediments from Clear Lake. These predictions of total phosphorus are likely to be overestimates since they do not account for variable background phosphorus from external sources. The change in predicted TP concentrations over time is, however, likely to be accurate.



a. Wind Speed and Turbidity **b. Wind Speed and NH_4^+** **c. Wind Speed and TP**

d. Predicted TP Flux

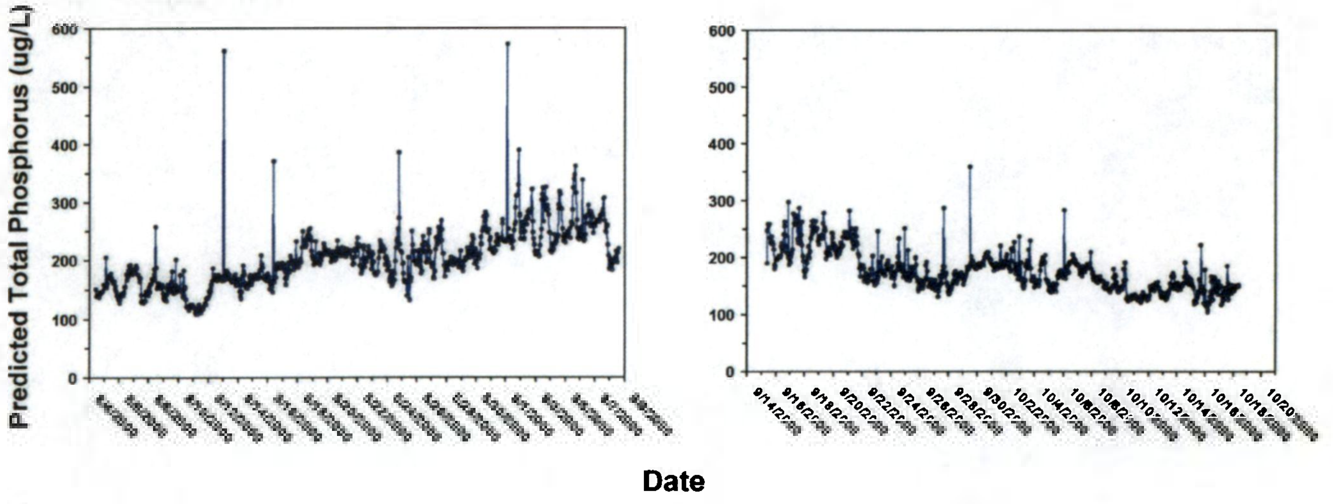
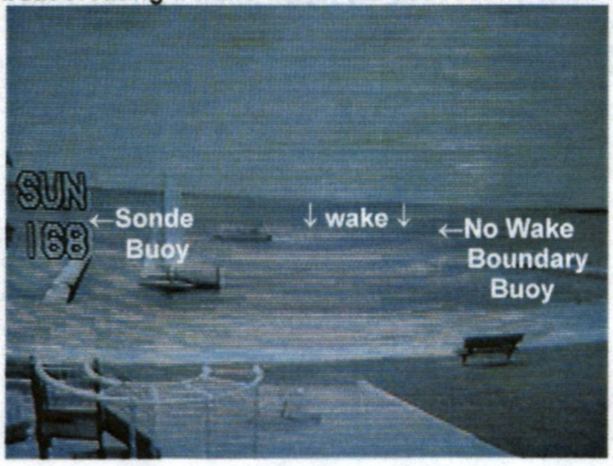


FIGURE 13. Violations of the no wake zone on Clear Lake, Iowa.

a. A boat leaving the beach creating a wake within the 300 foot no wake zone

b. A boat creating a wake within the 300 foot no wake zone



c. Boats creating wakes near the outer limit of the 300 foot no wake zone

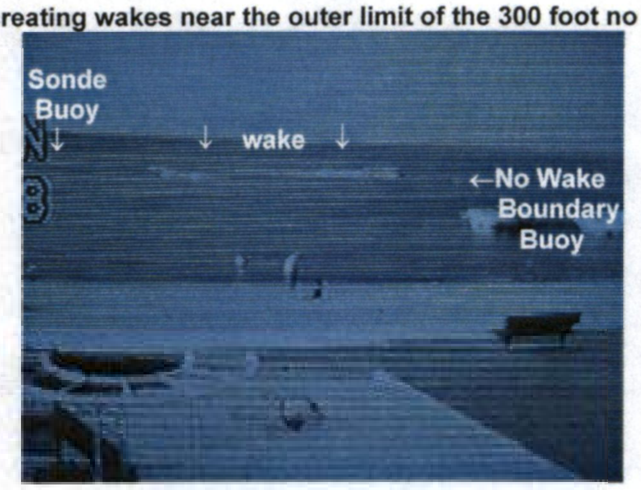
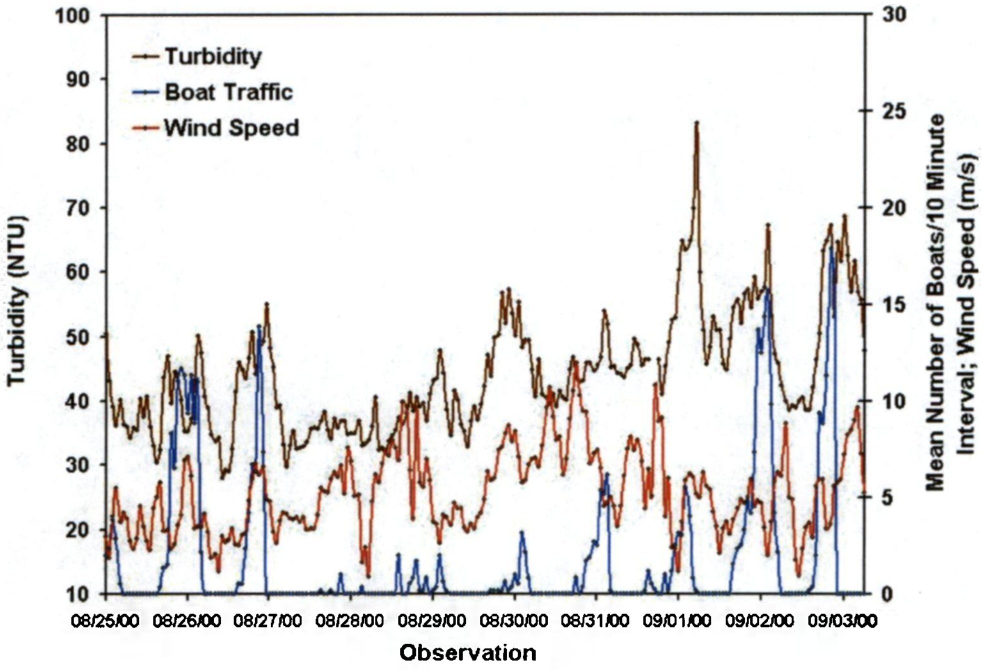


FIGURE 14.

a. Trends in the mean number of boats passing the sonde per 10 minute interval (—), turbidity (NTU) (—), and wind speed ($10 m \cdot s^{-1}$) (—) between August 25, 2000 and September 3, 2000.



b. A plume of resuspended sediment behind a motorboat in the western basin

CHAPTER 8

An Analysis of Hydrogeology, Groundwater Discharge, and Nutrient Input to Clear Lake

An Analysis Of Hydrogeology, Groundwater Discharge, And Nutrient Input To Clear Lake

Dr. William W. Simpkins, Keri B. Drenner, and Sarah Bocchi

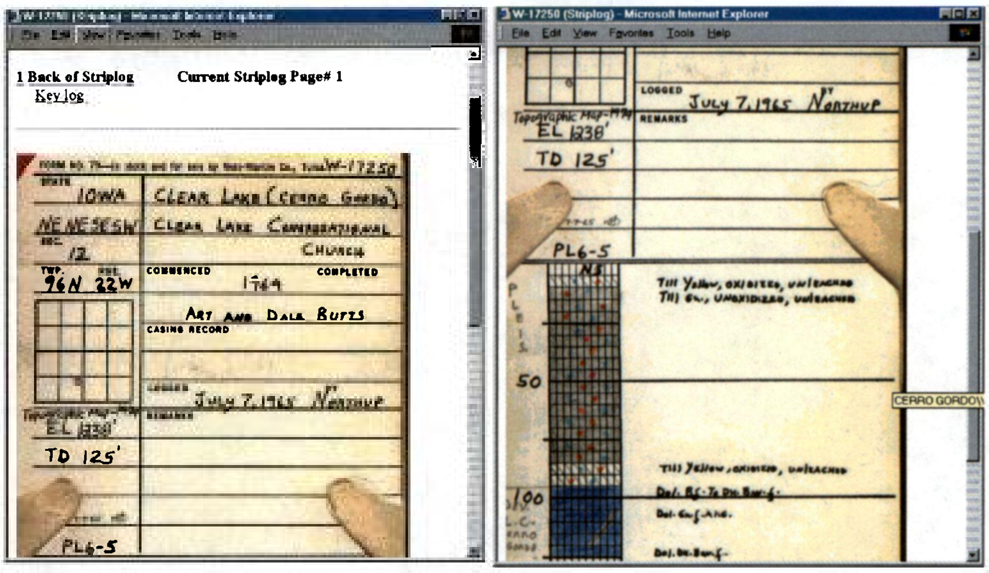
A. Geology And Hydrogeology Of The Clear Lake Region

1. Introduction. An understanding of the geology and hydrogeology of the Clear Lake region is needed to understand lake-groundwater interactions. The following objectives were investigated:

- determine the thickness of Quaternary units underlying the lake and overlying the regional bedrock aquifer;
- estimate hydraulic heads in the regional aquifer and their relationship to the lake elevation and shallow groundwater flow;
- determine the nature and types geologic units affecting flow to and from the lake.

The discussion below provides a summary of the work to date.

2. Methods. We examined nearly 300 well logs from private wells in the region during summer 2000 to determine thickness of Quaternary units below the lake and to estimate hydraulic head (Fig. 1). The well logs were available on-line at the Iowa Geological Survey Bureau (IGSB) Virtual Geologic Sample Database (GEOSAM) **http://gsbdata.igsb.uiowa.edu/geosam/** . Based on the logs, we identified the aquifer for each well and estimated hydraulic head from ground-surface elevation and static water level data. In some cases, ground surface elevation had been estimated by the IGSB. In others, we estimated the elevation from topographic maps, because field location proved impractical. In addition to well logs, core was examined from 11 coreholes taken as part of piezometer installations during summer 2000. Descriptions are given in Appendix 6. We also examined preliminary maps of the glacial geology of the region provided by IGSB.



W-17250 (Striplog) - Microsoft Internet Explorer

1 Back of Striplog Current Striplog Page# 1
Key log

W-17250
STATE IOWA
CLEAR LAKE (CERRO GORDO)
NE NE SE SW
CLEAR LAKE CONGREGATIONAL CHURCH
SEC. 12
TWP. 96N RGE. 22W
COMMENCED 1964 COMPLETED
ART AND DALE BURTS
CASING RECORD
LOGGED JULY 7, 1965 BY NORTHUP
REMARKS
Topographic Map-1970
EL 1238'
TD 125'
PL6-5
NS
Till Yellow, oxidized, unleached
Till Gr., unoxidized, unleached
50
Till Yellow, oxidized, unleached
100
CERRO GORDO

FIGURE 1. Private well log downloaded from the IGSB's Virtual GEOSAM database.

3. Results and Discussion. Clear Lake lies within the Algona-Altamont end moraine complex of the Des Moines Lobe (D. Quade, IGSB, verbal communication, 2000). This is a stagnation moraine built by at least 2 ice advances and characterized by hummocky topography. The eastern edge of the end moraine is about 1 mile (1.6 km) east of the lake. East of the end moraine, a late Wisconsinan till plain or Pre-Illinoian surface is encountered. A large outwash deposit follows the axis of Clear Creek northeast from the lake and merges into an outwash fan complex west of Mason City. This outwash deposit is important hydrogically, because it provides an effective groundwater drain for the east side of the lake (see Part II under Analytic Element Modeling). Bettis (1998) speculated that Clear Lake occupies a former subglacial tunnel channel that fed the outwash streams of Clear and Willow Creeks.

Coring of the east side of the lake basin indicates about 33 ft (10 m) of lake sediment on top of till or outwash (Baker et al., 1992). Below that Clear Lake is underlain by about 70 ft (21 m) of Quaternary sediment, including till of Wisconsin age and earlier glacial advances, Peoria loess, and paleosol units. In the uplands on the west, south, and north sides of the lake, till of the Dows Formation, which here consists mostly the supraglacial Morgan Member, is about 66 ft (20 m) thick. This unit houses the local groundwater flow system that interacts with the lake. Units directly below the lake (paleosols and older till units) are probably effective confining units with considerably lower hydraulic conductivities that restrict vertical flow in or out of the lake. Coring at the 11 piezometer sites indicated that there are areas of lake sediment (silt and sand) and coarse outwash adjacent to the lake, suggesting that the lake may have been larger in the past. Peoria loess (Site C) and older till units (Site J) were also encountered during piezometer installation.

Major aquifers beneath the lake are Devonian in age, and include the Shell Rock (upper Devonian) and Cedar Valley (middle Devonian) Formations (aquifers), which are among the most prolific karst aquifers in Iowa (Appendix 6). Wells in these units are generally anywhere from 100 to 600 ft (30 to 183 m) in depth. The city wells of both Ventura and Clear Lake are finished in the Cedar Valley aquifer. Some wells in the region are finished in the Ordovician, presumably in the St. Peter sandstone. Approximately 187 wells both within and outside the watershed contained enough information to be able to discern hydraulic head information. Based on an average lake stage of 1226.2 ft (374 m) during the study, most aquifers show hydraulic heads that are below lake stage (Fig. 2), suggesting a potential for flow out of the lake to underlying aquifers. Seventeen private wells show heads at or above lake stage, which would suggest a potential for flow from aquifers up into the lake.

4. Conclusions. Clear Lake sits within a large end moraine complex of the Des Moines Lobe. Till and associated sediment in the moraine provide the media for local groundwater flow systems that interact with the lake. Hydraulic head relationships suggest that bedrock aquifers in the region are not hydraulically connected to the lake. Studies on the geology and hydrogeology surrounding Clear Lake are continuing.

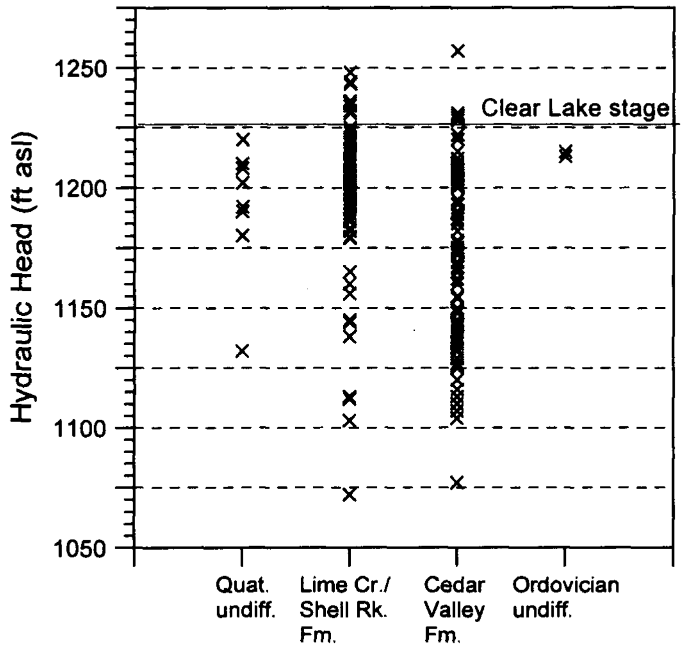


FIGURE 2. Hydraulic heads in major aquifers in relation to Clear Lake stage.

B. Estimation Of Groundwater Discharge To Clear Lake

1. Introduction. Estimation of groundwater discharge (or seepage) to lakes is necessary to determine nutrient load, but it is a difficult task and generally involves the extrapolation of small-scale measurements to a much larger lake area. In cases where the geology beneath the lake is not well known and where discharge may vary, large errors are involved in the measurement and extrapolation steps. A review of literature on the subject indicates that a number of methods have been used. In this study, groundwater discharge was estimated by three separate and independent methods:

- Direct measurements using seepage meters (Lee, 1977);
- Application of Darcy's Law using hydraulic head gradient and hydraulic conductivity data (Pennequin and Anderson, 1983; Shaw et al., 1990);

- Use of an analytic element groundwater model (Hunt and Krohelski, 1999).

Appliation of the three methods and their respective results are presented below.

2. Methods: Seepage Meters. Lee (1977) developed the seepage meter for groundwater discharge estimation in lakes. "Meters" consist of cut-off 55-gallon (204 L) metal barrel that is advanced into the lake bottom. As groundwater moves into the barrel, lake water is displaced into a plastic bag on the top of the barrel and a volume per time (discharge) can be recorded. A Darcy flux (L/T) is calculated by dividing discharge by the cross-sectional area of the meter. Lee (1977) also terms this, albeit incorrectly, a "macroscopic seepage velocity." Along with hydraulic head measurements, seepage meters can also be used to estimate hydraulic conductivity of lakebed sediments using Darcy's Law relationships. Total discharge to the lake is estimated by then applying individual flux measurements to the area of the lake. Lee (1977) envisioned these meters to have their greatest use in "high to moderately permeable material" presumably where groundwater discharge would be uniformly distributed. He suggested that measurements in fine-grained, low permeability sediments may be difficult to obtain because of lower discharge and preferential flow out of or into the lake bottom. Studies have corroborated problems with using meters in fine-grained lake sediments (Pennequin and Anderson, 1983).

Measurements (N=341) were made in July-August and November 1999 and again in May-June 2000 at 21 sites in the lake (Fig. 3). Ventura Marsh was excluded from seepage measurements because of the extremely mucky bottom and the difficulty encountered emplacing the meters. Original plans called for more or less permanent emplacement of some meters at some sites close to the piezometer nests around the lake, so that repeated measurements could be made at the same place. This plan was abandoned primarily because of vandalism and heavy boat and beach traffic. As a result, seepage meters were generally emplaced just prior to use, removed and then moved to another measurement site. Most measurements made within 3 to 4 m of shore, although some were made at 100 m offshore. Time and personnel constraints limited our attempt to emplace seepage meters in deep water. Measurements of volume were done in a 4-L, thin polyethylene bag approximately one hour after emplacement. All bags were filled with an initial 200 mL of lake water to preclude problems with bag infilling or induced flow (see Shaw and Prepas, 1989). Sites 1 to 4, 6 to 9, and 12 to 21 were visited in 1999, with sites 7, 9, 12, and 13 visited twice (171 measurements). Sites 3 to 5, 7 to 10, 14, 15, and 22 were visited in 2000, with sites 3 to 5, 7, and 8 visited twice (170 measurements). Included in that total are multiple sequential measurements at sites 8, 9, 10 and 13 in 2000. These were done to estimate the intrasite variabilty. Sites 3, 4, 7, 8, 9, 14 and 15 were visited both in 1999 and 2000 to estimate interannual variation. Discharge estimates were computed in units of mL/min and converted to flux measurements of µm/s for this report. Hydraulic head gradient measurements were also made adjacent to many seepage meters using a potentiomanometer device as described by Winter et al. (1988).

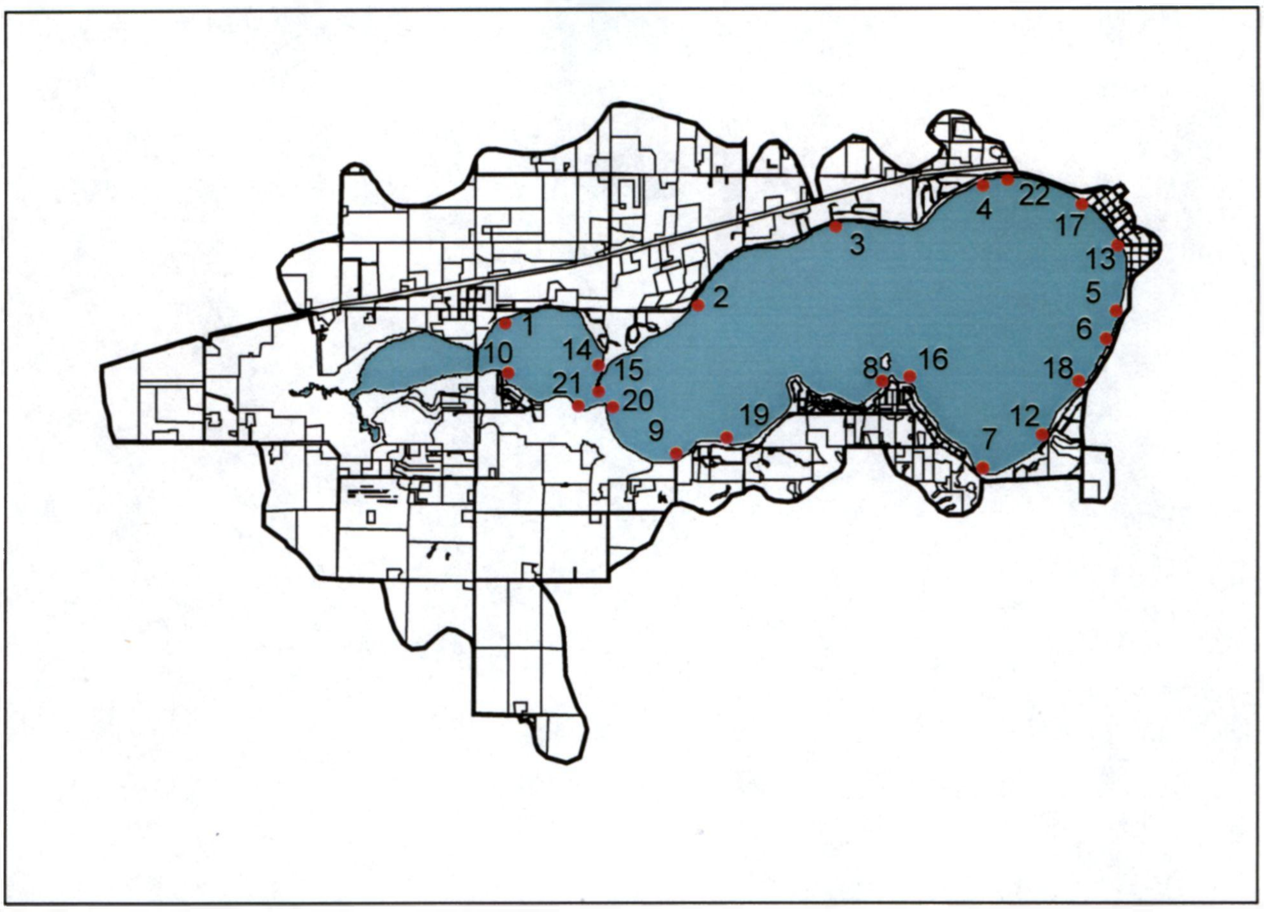


FIGURE 3. Map of Clear Lake watershed showing location of seepage meter measurements in 1999 and 2000. North is to the top of the map.

3. Results: Seepage Meters. The mean flux value for all 341 measurements during the 2-year sampling period is 0.45 µm/s (Table 1)(note: 1 µm/s is equal to 1 $cm^3\ m^{-2}\ s^{-1}$ or 1 $ml\ m^{-2}\ s^{-1}$). The range of values is similar to those observed by Lee (1977) for Lake Sallie in Minnesota, Krabbenhoft and Anderson (1986) for Trout Lake in Wisconsin, and Shaw et al. (1990) for Narrow Lake in Alberta. Most measurements at Clear Lake indicate inflow to the lake. Anecdotal evidence, based on influx of significantly colder water on our feet during emplacement, corroborates inflow at Sites 3, 9 and 10. Out of the 341 measurements, four showed zero net flux and four showed negative values. The lack of many negative values is at odds with hydraulic head data that indicates definite zones of outflow on the east side of the lake (see later discussion). Histograms indicate a positive skewness in the total data set and in 1999 (0.9) and 2000 (1.9) individually. Transformations of the data did not improve the normality of the distribution. Because the data did not appear to meet assumptions of normality, nonparametric statistical techniques are relied on in this analysis. Boxplots indicate that many of the very large values are outliers.

Data from the seepage meters appear to be repeatable at an individual site. Repeat measurements made in consecutive 1-hour readings at sites 8, 9, and 10 in 2000 indicate no significant difference ($p = 0.05$) in median seepage rates. At site 13 (City Beach), however, median seepage rates increased from 0.13 to 0.60 to 0.88 µm/s in consecutive 1-hr measurements. The reason for this phenomenon, particularly at what is probably a groundwater outflow zone, is unknown.

Individual sites show interesting differences among them. There are no general trends of seepage around the lake, except that many of the higher flux values occur on the eastern side of the lake. For example, sites 5 and 6 show high flux values into the lake, despite the fact that these areas are likely ones where groundwater is flowing out of the lake (see later discussion). This anomaly suggests that other factors may cause the seepage bags to fill at these locations. Site 10 at Ventura Heights and Site 14 at the beach at McIntosh Woods State Park both show very low fluxes into the lake. Both of these sites are on very sandy points or spits. This would appear to be consistent with studies that suggest that groundwater flow is concentrated in embayments and not at points between embayments in lakes.

TABLE 1. Statistics for original flux measurements. Values in µm/s.

	N	**Mean**	**Median**	**Std. Dev.**	**Std. Error**	**CV%**	**Max.**	**Min.**	**95% C.I. of Mean**
All	341	0.45	0.32	0.416	0.023	92.4	2.04	-0.02	± 0.044
1999	171	0.59	0.51	0.455	0.035	77.1	2.04	-0.01	± 0.069
2000	170	0.28	0.17	0.304	0.023	108.6	1.72	-0.02	± 0.046

Significant differences, as measured by a Mann-Whitney test, exist in fluxes measured in 1999 and 2000, with 1999 showing larger median fluxes. This could simply be due to the fact that we did not visit the same sites in the two-year period and that only the most permeable sites were visited in 1999. However, at sites duplicated in 1999 and 2000, four out of seven sites showed significant differences in their median flux values ($p = 0.05$) between the two years. Precipitation totals in nearby Mason City were significantly different in 1999 (44.19 in; 1122 mm) and 2000 (30.59 in; 777 mm) and this likely explains the difference in measurements. The mean annual precipitation is about 33 in (838 mm). Higher hydraulic heads in the upland areas in 1999 would have steepened the hydraulic gradient and induced more flow to the lake. A 12.08-inch (307 mm) rainfall in July 1999 unfortunately occurred during and after many of the measurements. Downing and Peterka (1978) and Boyle (1994) have shown the effects of rainfall on seepage meter flux in lakes. Accordingly, the 1999 seepage data were reduced by 31 percent so that data from both years could be used in one data set (Table 2). Even with these adjustments, there are significant differences between the medians calculated for each site (Fig. 4), as shown by a Kruskal-Wallis test of significant differences.

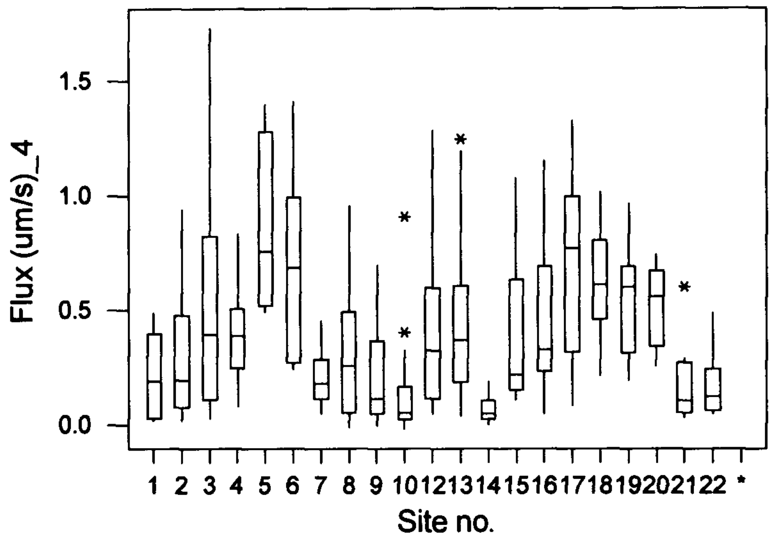


FIGURE 4. Boxplots showing seepage measurements at the 21 sites (see Fig. 3).

TABLE 2. Descriptive statistics using adjusted 1999 flux measurements. Values in μm/s.

	N	Mean	Median	Std. Dev.	Std. Error	CV%	Max.	Min.	95% C.I. of Mean
All(adj.)	341	0.34	0.25	0.314	0.017	92.4	1.72	-0.02	± 0.034
1999(adj.)	171	0.41	0.35	0.313	0.024	76.3	1.41	-0.01	± 0.047
2000	170	0.28	0.17	0.304	0.023	108.6	1.72	-0.02	± 0.046

4. Calculation of Whole-Lake Discharge. Extrapolation of individual seepage meter measurements to an entire lake is difficult. Methods have generally concentrated on defining a relationship between flux and either distance from shore or water depth. Early studies on lake-groundwater interaction by McBride and Pfannkuch (1975) indicated that the log of discharge decreased away from the shoreline. Subsequent flow net analysis by Lee (1977) in his original paper also suggested this relationship. His flow net analysis suggested that most flow would occur within 15 m of shore, although he found that that substantial influx was still occurring at 60 to 80 m offshore. He presented the relationship:

$$\text{Flux} = 0.381 * (969)^{\text{distance}}$$

with an $r^2 = 0.56$ (significant at $p=0.05$). Brock et al. (1982) also suggested a relationship between water depth and flux, such that ($r^2 = 0.96$).

$$\ln \text{Flux} = 1.0719 - 1.5797 * (\text{water depth})$$

These relationships suggested that fluxes should approach zero at some distance from shore or at some water depth. Hence, whole-lake estimates of groundwater discharge could be derived from seepage meter measurements made only in the near shore or littoral zone environment. Cherkauer and Zager (1989) and Boyle (1994) have noted similar relationships. In contrast, other studies have indicated that flux may increase from shore (Woessner and Sullivan, 1984) or show variability due to the geology under the lakebed (Krabbenhoft and Anderson, 1986). Studies have also shown that groundwater flux in or out of the lake does occur outside the nearshore littoral zone in non-littoral zone (Belanger and Mikutel, 1985), although fluxes in the latter may be one to two orders of magnitude less (Boyle, 1994).

Data in this study showed no statistically significant relationship between seepage flux and distance from shore or water depth. Thus, it was not possible to delineate a zone in the lake where seepage was zero or could be ignored. In addition, there are significant differences in fluxes at different locations and, in some cases, the highest values are at documented outflow areas. Thus, the reliability of the seepage measurements is questionable at those sites. Rather than try to extrapolate data from each location to some distance into the lake, we chose a more simplified approach. Groundwater discharge to the entire lake was calculated using the adjusted median flux value and applying it to the percentage of the lake area to which that applies (Table 3). The maximum discharge based on seepage meter data is 5.4 x 10^5 m^3/d, a value that is disturbingly large given the volume of water in the lake. It could be less if smaller percentages of the lake, such as nearshore zones where we measured, contribute all the discharge.

TABLE 3. Estimates of groundwater discharge to Clear Lake based on seepage meter data.

Area of lake (m^2)	Adjusted median flux (μm/s)	95% CI of median	GW discharge (m^3/d)	1% area (m^3/d)	25% area (m^3/d)	50% area (m^3/d)
1.46E+07	0.25	±0.05	5.4E+05	5.4E+03	1.4E+05	2.7E+05

5. Methods: Darcy's Law. An alternative method for estimating groundwater discharge involves the use of the familiar Darcy's Law equation:

$$Q = -K I A$$

where Q is discharge, K is hydraulic conductivity, I is hydraulic gradient (negative because it decreases in the direction of flow) and A is the cross-sectional area through which flow occurs. The method has been used by Pennequin and Anderson (1983) for Lake Wingra in Wisconsin and by Shaw et al. (1990) for Narrow Lake in Alberta.

For this analysis, piezometer nests were installed at 11 sites on the perimeter of the lake in 2000 (Figs. 5 and 6) to intercept groundwater flowlines just prior to entering the lake. Piezometers consisted of 1.25 in (3.2-cm) id, PVC standpipes with 20-slot, factory slotted screens of 2 to 3 ft (0.61 to 0.91 m) in length. They were installed at depths between 3 and 31 ft (0.9 and 9.5 m) using hollow-stem augers. Coordinates (X-Y) and absolute elevation of the standpipes (and the USGS lake stage gage) to within 1 cm were obtained from a professional surveyor using GPS and total station equipment. Cores were taken from the boreholes and described using standard methods. Geologic materials encountered include till (Dows Formation, Morgan and Alden Members), outwash, lake sediment, Peoria loess, and fill (see Appendix A). The variety of materials encountered attest to the heterogeneity present at the lake interface. Falling and rising-head slug tests were performed in the shallowest piezometers at each nest in January 2001 and analyzed using the Hvorslev (1951) method to determine K. These piezometers, which are at or near the water table, were used to provide a maximum K value for flow into the lake.

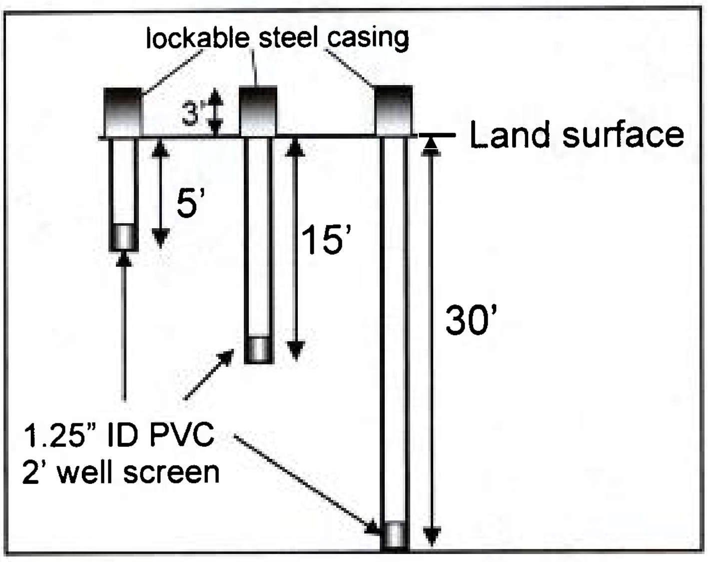


FIGURE 5. Cross-sectional diagram showing piezometers in a nested configuration.

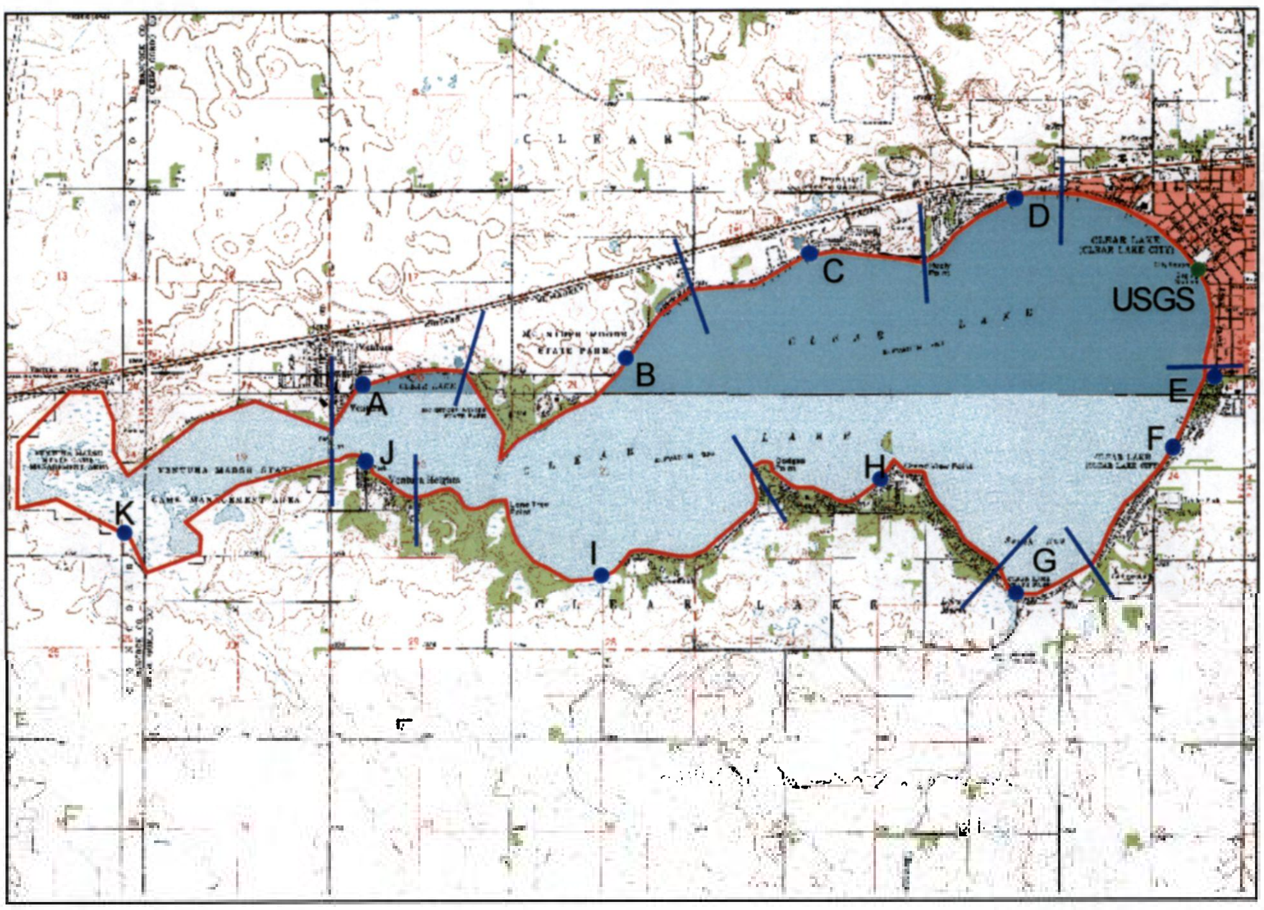


FIGURE 6. Topographic map showing location of piezometer nests (blue dots) and boundaries of cross-sections (lines) for discharge calculations by Darcy's Law. USGS gaging station is shown by the green dot. North is to the top of the map. Sections are 1 mi (1.6 km) square.

Hydraulic heads in the piezometers were measured from September 2000 through February 2001. Vertical hydraulic gradients were analyzed for the January 5, 2001, measurements. A mean horizontal hydraulic gradient was calculated by averaging the difference between lake stage and the water table from the shallow well at each measurement time between September 2000 and February 2001. Finally, Clear Lake was divided into 11 groundwater discharge sections, based on K and I values from the nearest piezometer nest and the expected geology along the section (Fig. 3). Distances along these sections were calculated using ArcView. A uniform depth of 10 m was used for each section to complete the cross-sectional area of flow. This value is generally greater than the depth of the lake; however, because upward hydraulic gradients are shown by the piezometers at 10 m, the potential exists for groundwater flow into the lake from these depths.

6. Results: Darcy's Law. Vertical and horizontal hydraulic gradients provide evidence for groundwater discharge in and out of Clear Lake. Sites A, B, C, I, J, and K suggested groundwater inflow at all times. Sites E, F, and G, showed groundwater outflow at all times. Sites D and H show both groundwater inflow and outflow during the monitoring period and may change on a seasonal basis. Vertical hydraulic gradients are present, but they are very small. Hence, gradients at the water table were used to calculate discharge. Values of K varied from 1.6 x 10^{-6} m/s in till to 1 x 10^{-4} m/s in outwash sand. These values are similar to those seen in the lake from potentiomanometer measurements. Values for groundwater discharge show variability among sites due to the differences in K values and hydraulic gradients. However, there is roughly a balance between inflow and outflow, although outflow is the larger of the two values. Presumably, precipitation and surface water inflow will comprise the difference and raise inflow to equal the outflow values.

TABLE 4. Values of groundwater discharge estimated from Darcy's Law.

Segment	Length (m)	K (m/s)	grad h	Depth (m)	Discharge (m^3/d)
A	1411.18	9.1E-06	4.292E-03	10	4.78E+01
B	3170.15	1.6E-06	1.278E-03	10	5.67E+00
C	2082.48	8.6E-06	5.562E-03	10	8.63E+01
D1	1400.71	8.4E-06	5.176E-05	10	5.28E-01
H	2930.58	9.1E-05	3.643E-03	10	8.37E+02
I	4088.48	1.0E-05	5.598E-03	10	2.04E+02
J	940.06	4.8E-05	1.022E-02	10	3.48E+02
K	7994.85	6.3E-06	7.267E-02	10	3.16E+03
				Inflow	**4.69E+03**
D2	2299.29	8.43E-06	-2.973E-02	10	-4.98E+02
E+F	2043.41	1.07E-04	-2.973E-02	10	-5.62E+03
G	1015.36	9.20E-06	-6.910E-03	10	-5.58E+01
				Outflow	**-6.17E+03**

7. Methods: Analytic Element Model. Groundwater modeling has proven to be a valuable tool in understanding groundwater-lake interaction (Anderson and Munter, 1981; Krabbenhoft, et al. 1990a; Hunt et al., 1998). In the past, grid-based, finite-difference models such as MODFLOW (McDonald and Harbaugh, 1988) have been used. Recent research has shown that the Analytic Element (AE) method (Haitjema, 1995) is applicable to groundwater-lake systems (Hunt and Krohelski, 1996; Hunt et al., 2000). The AE method can be used as a screening tool at the regional scale to identify boundary conditions, which can improve solutions generated later by smaller-scale and more complex finite-difference simulations (Hunt et al., 1998).

A Windows-based, AE model, GFLOW 2000, was used to simulate the groundwater flow system and to calculate groundwater discharge into the lake. This modeling approach is two dimensional, steady state (hydraulic head does not vary with time), and utilizes Dupuit-Forcheimer approximations that assume that groundwater flow is mostly horizontal. AE methods are relatively new in their application and are based on superposition (i.e., addition or subtraction) of analytic functions, each representing a feature of the aquifer (Strack, 1989; Haitjema, 1995). Wells, line sinks (streams and tile drains) and inhomogeneities (areas with differing K, porosity, or recharge values) can be addressed in the model. AE assumes that the aquifer is infinite in extent, with boundaries consisting of rivers, creeks, and lakes that can be easily seen on topographic maps. A unique feature of the model, the "flux inspector," allows flux (i.e., discharge) to be calculated across any line drawn in the problem domain. Hence, discharge to a lake can be estimated by drawing "flux inspection" lines around the lake.

An analytic element model was constructed for Clear Lake and its surrounding watersheds. Input data included elevations of stream and drainage tiles, K values and groundwater recharge. Because the model does not explicitly incorporate lakes, Clear Lake was given a very high K value to simulate that effect, as suggested by Hunt et al. (2000). Both Ventura and Lekwa Marsh were included in the area of the lake, because early model simulations indicated problems with closely spaced line sinks. An unpublished glacial geologic map (based on digital soil survey data) from the IGSB was used to identify geological units that could affect flow in the vicinity of the lake. Although Clear Lake is set within the Algona-Altamont Moraine Complex, a large outwash deposit occurs on the eastern edge of the lake. It is approximately aligned with the Clear Creek outlet and leads into what appears to be an outwash fan east of the City of Clear Lake. This deposit and the elevation drop east of the City of Clear Lake provide an effective drive for eastward groundwater flow out of Clear Lake.

8. Results: Analytic Element Model. The model was run multiple times until reasonable agreement was reached with the hydraulic heads measured in the piezometers around the lake. Early model runs omitted the outwash deposit at the east end of the lake. As a result, the K values for till in the model were 2×10^{-4} m/s. In later runs, the addition of a more conductive zone on the east end allowed K values to be reduced in the watershed (Fig. 7). Thus, assigning a K value of 3.5×10^{-3} m/s to the outwash allowed K values in the till to be lowered 5.3×10^{-5} m/s. Although this is still a high value for till, it is in keeping with K values estimated from slug tests at the lake. Using a recharge value of 81.3 mm/yr (3.2 in/yr or 10 percent of mean annual precipitation), the final model produced heads similar to those observed in the field (Fig. 8) and produced inflow and outflow in the areas indicated by field data. The maximum departure from the field data was 0.55 m and the mean absolute difference was 0.27 m (Fig. 8).

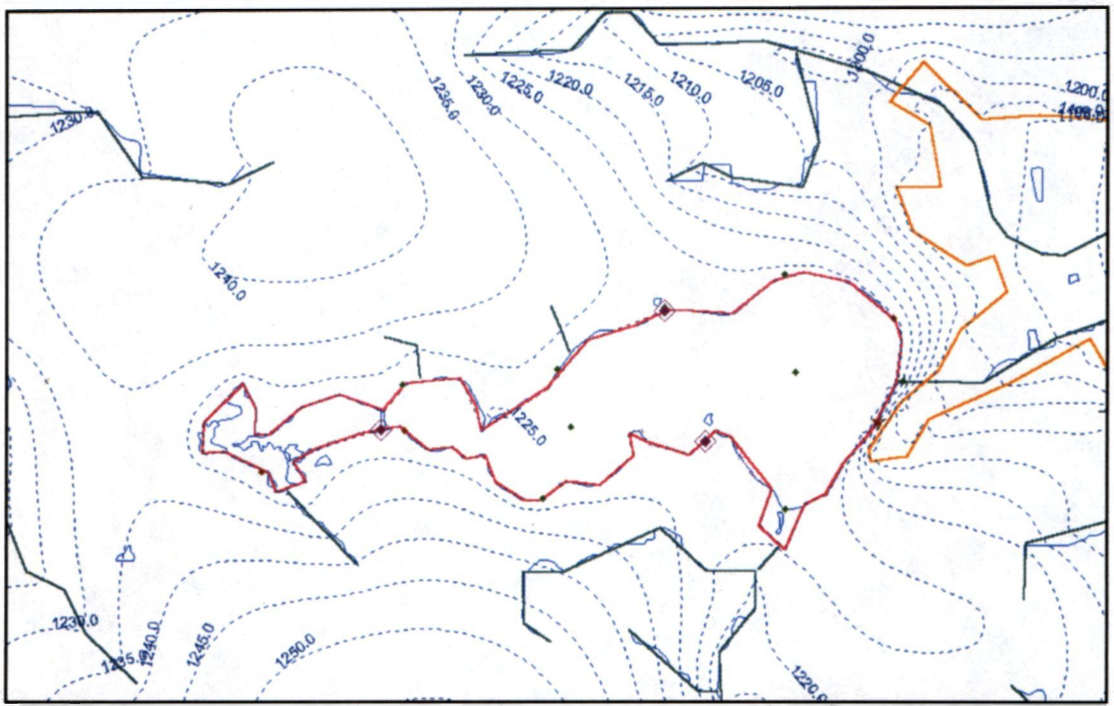


FIGURE 7. Simulation of groundwater flow in the vicinity of Clear Lake using the AE model GFLOW 2000. Contour interval is 5 ft. Outwash deposit is outlined in orange. Calibration points (piezometers) are shown with green diamonds (see Fig. 6 for locations).

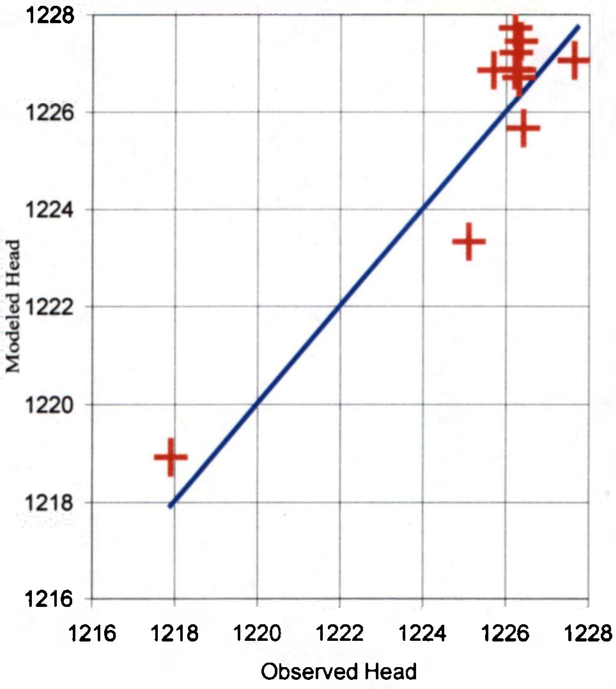


FIGURE 8. Calibration curve for the AE simulation shown in Figure 7.

Perhaps the most unique aspect of this AE model is its ability to calculate fluxes across any line sink, and, in this case, to Clear Lake. Flux inspection lines were drawn along areas that the model shows to be inflow and outflow zones. The results suggest that groundwater inflow (discharge) to Clear Lake is approximately 7.9 x 10^3 m^3/d, while the groundwater outflow is approximately –8.9 x 10^3 m^3/d. Although these values are higher than those suggested by the Darcy's Law analysis, they are within the same order of magnitude. Of that total, Ventura Marsh (including areas outside the present water surface on Fig. 6) accounts for about 3.3 x 10^3 m^3/d of groundwater discharge to the lake.

TABLE 5. Comparison of groundwater discharge values estimated by the three methods.

Method	**GW Inflow (m^3/d)**	**GW outflow (m^3/d)**	**Net (m^3/d)**
Seepage meters	5.4E+05	None	5.4E+05
Darcy's Law	4.7E+03	-6.2E+03	-1.5E+03
AE GW Model	7.9E+03	-8.9E+03	-1.0E+03

9. Conclusions. Estimation of groundwater discharge to Clear Lake was investigated by three independent methods. The Darcy's Law and analytic element model methods both recognized areas of inflow to and outflow from the lake and corroborated field measurements of hydraulic head. They produced values within the same order of magnitude (Table 5). In contrast, seepage meters failed to indicate any areas of groundwater outflow, even though these areas must occur to balance the input of water to the lake. In addition, values of inflow estimated by the seepage meters were nearly 2 orders of magnitude larger than values calculated by the other two methods and were comparable to the volume occupied by the entire lake. The large discrepancy could be due to measurements taken in years of different rainfall, heterogeneity in the lake bottom, and/or the inability of these devices to work at Clear Lake. Assuming some relationship of discharge vs. distance from shore exists, the discharge overestimate could be due to the applying one median flux value over the entire lake. A more reasonable value might be obtained if the seepage meter data were valid for a smaller portion of the littoral zone, say 1 percent of the area of the lake. The determination of such an "effective" discharge zone could not be made in this study, however, and may be the subject of future work. Because of the number of assumptions involved in the Darcy's Law calculation and the size of the lake, the value from the AE model is probably the best estimate of groundwater discharge to Clear Lake.

C. Estimation Of Nutrient Load From Groundwater

1. Introduction. A geochemical investigation of groundwater was undertaken in order to understand the presence and absence of nutrients and contaminants in groundwater and their potential to enter Clear Lake. Groundwater samples from the 32 out of 33 piezometers were analyzed for Total P, Total N, Si, alkalinity, electrical conductivity, and pH. Additional parameters (major cations and anions, trace elements, dissolved O_2, dissolved organic carbon) were measured in order to understand the geochemical environment in which the nutrients occur. Geochemical speciation models and soil P measurements were used to determine potential sources of P. Selected samples were analyzed for fecal coliform bacteria and caffeine, in order to determine potential sources of nutrients and Cl. A radioactive isotope of hydrogen, tritium (^3H), was used to determine the relative age of the groundwater. Nutrient and contaminant loads from groundwater to Clear Lake were calculated from estimates of groundwater inflow and outflow and estimates of the concentrations of nutrients (primarily P, N, and Si) and Cl in groundwater. Nutrient load per time was calculated by multiplying discharge (L^3/T) times concentration (M/L^3). Because of Clear Lake's nature as a flow-through lake, nutrients will be added to the lake in areas of inflow and lost from the lake in areas of outflow.

2. Methods. Groundwater samples were taken from the 32 piezometers on 7 dates between September 2000 and February 2001 (9/15/00, 9/30/00, 10/31/00, 11/14/00, 1/5/01, 1/15/01, and 2/24/01). Samples of lake water and sediment porewater (groundwater?) were also taken from the potentiomanometer device on various dates from May through October. These samples were analyzed primarily for Total P, Total N, Si, alkalinity, pH, and electrical conductivity (results will be reported at a later date). Samples for total geochemistry (cations, anions, trace metals), organic carbon, NO_3-N, and NH_4-N were taken on 10/31/00. Samples for tritium (^3H), fecal coliform, and caffeine were taken on 1/15/01. Although the piezometers installations were completed in July, sufficient time was allowed to develop them and clean out non-formation water that may have been introduced during the drilling and installation process. This is particularly critical for sampling of P, because turbid water, which is often produced by the type of material encountered in this investigation, may contain sorbed P. Sampling was accomplished using a peristaltic pump and dedicated polyethylene sampling tube in each piezometer. The sampling tube was pulled up from the bottom during sampling to avoid introduction of sediment into the sample. Some samples, however, always contained sediment, due in part to less than ideal completions. One well volume was purged at an interval of one to several days prior to sampling.

Samples for cations, anions, trace metals, and dissolved organic carbon (DOC), were filtered with a 0.45 μm filter prior to entering the sample bottle. Cation and trace metal samples were preserved with 1 mL of 4.5 N HNO_3. Samples for NO_3-N and NH_4-N were preserved with 1 mL of 8N H_2SO_4. Samples for DOC were preserved with 1N HCL. All samples were kept at nearly 4 °C prior to analysis.

Samples for Total P, Total N, Si, alkalinity, electrical conductivity, and pH in groundwater were analyzed in the Limnology Laboratory in the Department of Animal Ecology. Total P, Total N, and Si samples were run in triplicate and the mean is reported here. Total P was determined using persulfate digestion and ascorbic acid using Hach PhosVer3 powder pillows (EPA 365.2/Standard Method 4500-P-E). Total N was determined using second derivative spectroscopy (Crumpton et al., 1992). Silica (SiO_2) was determined using the molybdate-reactive method. Major cations, anions, and trace metals (including P) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) at the Soil and Plant Analysis Laboratory, University of Wisconsin-Madison. Alkalinity and pH were determined using a Hach digital titrator and pH meter, respectively, in the Hydrogeology Laboratory within 2 days of collection. Cl, SO_4, F and NO_3-N were analyzed by ion chromatography in the Department of Geological and Atmospheric Sciences. Analyses were speciated and charge balances checked to within 10 percent with the geochemical model NETPATH v. 2.0 (Plummer et al., 1994). DOC was analyzed using persulfate oxidation in the Department of Agronomy. Dissolved O_2 was measured in the field by the modified Winkler-azide method. Tritium (^3H) was analyzed using a scintillation counter at the Environmental Isotope Laboratory at the University of Waterloo (Ontario, Canada). The National Soil Tilth Laboratory analyzed samples for NO_3-N and NH_4-N using copper cadmium reduction on a Lachat apparatus. Caffeine (EPA 3510) and fecal coliform bacteria (SM18-9222D) were analyzed at the University of Iowa Hygienic Laboratory. Bacteria were analyzed within 1 day of sample collection. Samples from continuous core at Sites B, F and J (Fig. 6) were analyzed for pH, organic carbon and soil P at the Soil Analysis Laboratory in the Department of Agronomy at Iowa State University. Soil P was analyzed using both the Bray and Olsen methods.

3. Results and Discussion.

a. Geochemical Environment in Groundwater. The geochemical environment in groundwater is one dominated by Ca and HCO_3 ions and pH values between 7 and 8 – a typical system in carbonate terrain (Appendix 7). In addition, the system is reducing and alternate electron acceptors are clearly being used to oxidize organic carbon (Appendix 7). Samples taken in October 2000 show that dissolved O_2 is largely absent and NO_3-N concentrations are < 1 mg/L. Nitrogen, when present, occurs as NH_4-N, and dissolved Fe concentrations reach 15 mg/L. In addition, most groundwater samples smell of H_2S and some may produce CH_4 gas. Dissolved organic carbon (DOC) was present in all samples. Mean and median values were 4.5 and 4.3 mg/L, respectively and the highest concentration of 11.7 mg/L was shown at Site G (Appendix 7). As such, the system is similar to that described by Simpkins and Parkin (1993) for till in central Iowa; however, wetlands surrounding the lake may also contribute DOC. Fe^{2+} will be the dominant Fe species; thus, limiting the role of ferric oxides and sesquioxides to sorb P and immobilize it, as is commonly the case in lake sediments (Nriagu and Dell, 1974; Williams et al., 1976). While the P contribution to Clear Lake under these redox conditions may be large, the contribution of NO_3-N is probably negligible. Silica is generally conservative at near-neutral pH and is relatively unaffected by low redox conditions.

TABLE 6. Statistics for Total P, Total N and SiO_2 concentrations in groundwater from 32 piezometers. Total P concentrations in μg/L. Total N and SiO_2 concentrations in mg/L.

Analyte	N	Mean	Median	Std. Dev.	SE Mean	Min.	Max.	CV%
Total P	219	237.7	172.9	232.9	15.7	< 0.01	1783.1	100
Total N	219	1.1	0.8	1.57	0.11	0.001	11.54	10
SiO_2	219	40.4	37.3	14.3	0.96	17.6	131.3	35

b. Phosphorus (P) in Groundwater. Total P concentrations in the 32 wells (219 samples) showed a mean value of 237.7 μg/L, with a standard deviation of 232.9 μg/L (Table 6). Because some very high concentrations skew the distribution, the median value of 172.9 μg/L may be a better measure of the central tendency. Although there are some differences in the concentrations during the 7 sampling periods, they are generally not significant (Fig. 9). Low concentrations reported on 10/31/00 were due to insufficient shaking of the samples (and dislodging P from the bottles and sediment) prior to analysis. Consequently, we used the ICP-MS value of Total P in the statistical analysis. Some differences are apparent among samples taken from the different piezometers (Fig. 10), most noticeably in samples taken from shallow piezometers. A trend exists for higher concentrations at shallow depths, which suggests a near-surface source for P (Fig. 11). Preliminary geochemical modeling suggests that the system is still undersaturated with respect to vivianite, a ferrous phosphate ($Fe_3(PO_4)_2 \bullet 8H_2O$) mineral known to control P concentrations in groundwater. Clear Lake wells #2 and #3 showed Total P concentrations of 8.4 and 10.5 μg/L, respectively.

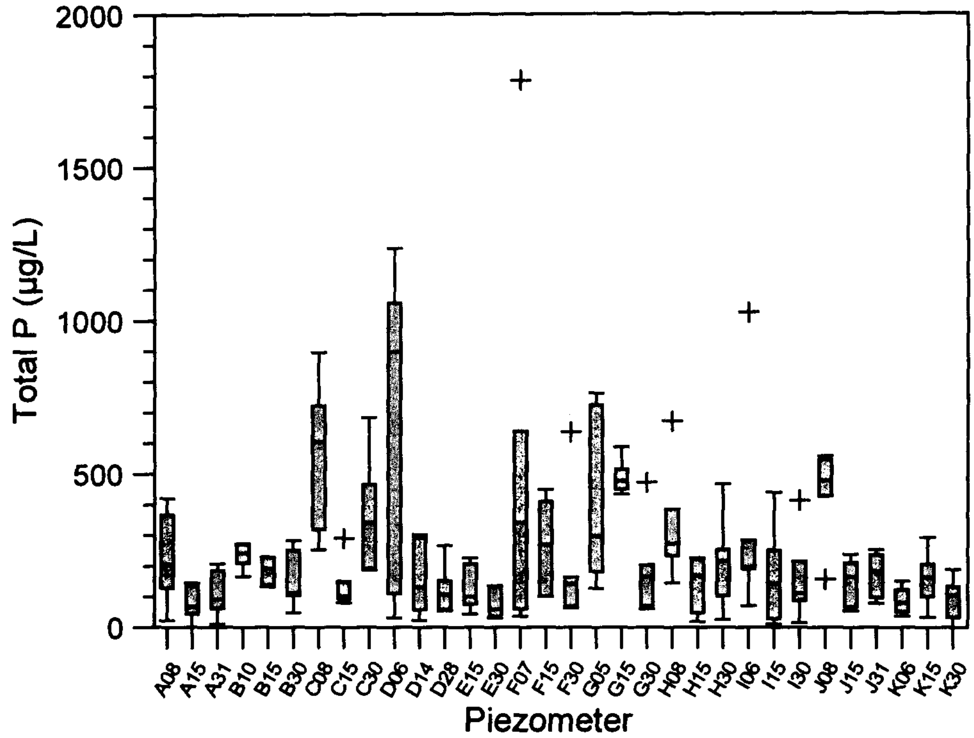


FIGURE 9. Boxplots showing Total P concentrations in groundwater.

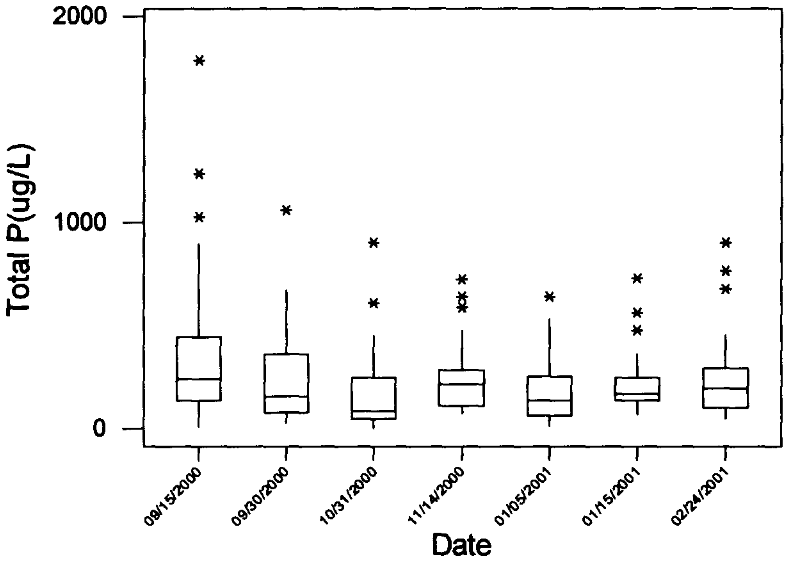


FIGURE 10. Boxplots showing concentrations of Total P at each piezometer. Differences in concentrations exist between piezometers.

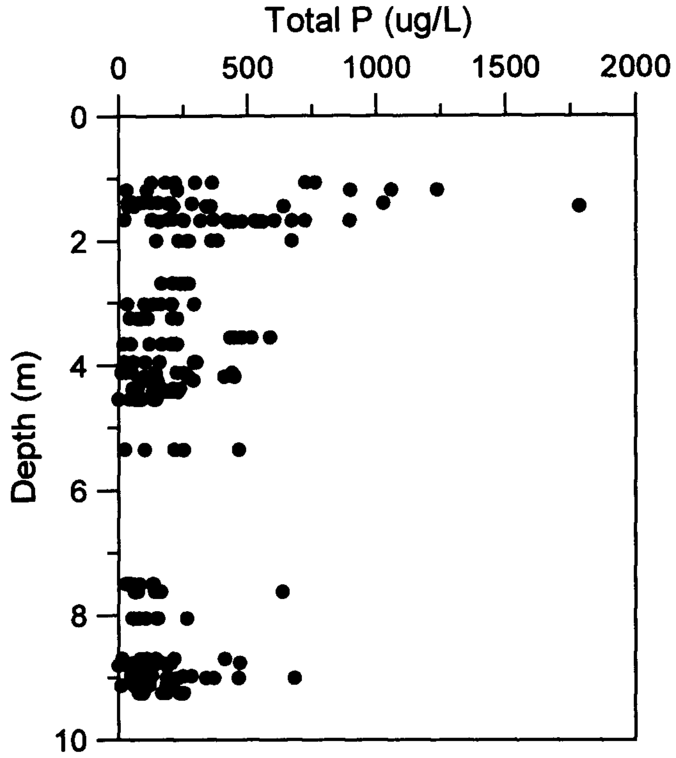


FIGURE 11. Vertical profile of Total P concentration in groundwater at all sites. Highest values occur at shallow depths, but there is no consistent trend with depth.

Most of these P concentrations would be considered high in comparison to previous studies of P in groundwater (i.e. Robertson et al., 1998). However, concentrations of P in drainage tile water have been shown to range from 7 to 900 µg/L in Canada (Bolton et al., 1980) and the midwestern United States (Baker et al., 1975; Schwab et al., 1980; Bottcher et al., 1981). Macropore flow at shallow depths has been shown to promote leaching of particulate P in similar soils and presumably geologic units containing fractures (Beauchemin et al., 1998). In any case, these P values are within the concentration range to contribute to lake eutrophication.

c. ***Phosphorus (P) in Geologic Materials.*** Till, lake and outwash sediments that surround Clear Lake also contain extractable (soil) P in the core (Fig. 12). Whether that P occurs naturally in these materials or is the result of anthropogenic activity cannot be determined at this time. Highest concentrations occur in the solum and decrease below, where concentrations appear similar despite different materials. This suggests that P is either released at shallow depth or the presence of anthropogenic P.

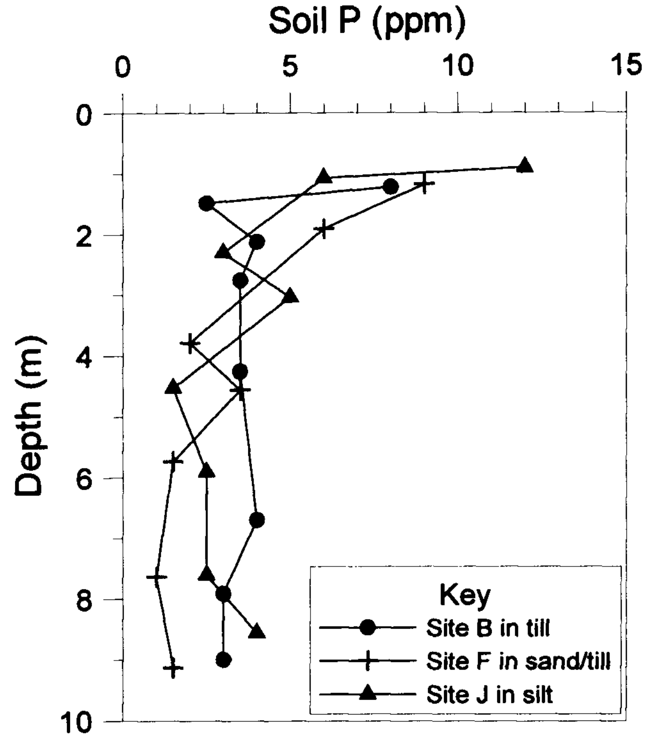


FIGURE 12. Variation of Soil P (Olsen method) with depth in core. Soil pH > 7.5.

d. Nitrogen (N) in Groundwater. In contrast to P, concentrations of Total N are more consistent (Fig. 13) and considerably less (Table 6). The mean, standard deviation and median values are 1.1, 1.57 and 0.8 mg/L, respectively. Data from Total N analyses are corroborated by the individual NO_3-N and NH_4-N concentrations (Appendix 7). The lack of NO_3-N in these samples is consistent with the lack of dissolved O_2 and use of alternate electron acceptors in the system. Interestingly, many Total N concentrations >1 mg/L at shallow depths may be due to NH_4-N. Samples taken from piezometer C-30, consistently show high NH_4-N concentrations, which are responsible for the outliers in Figure 13. Production of NH_4-N in loess is consistent with earlier studies in central Iowa (Simpkins and Parkin, 1993). It is unclear at this time whether groundwater supplies much N as NH_4-N to Clear Lake. Groundwater at Sites F and G, in lake-outflow areas, show NH_4-N concentrations that may reflect concentrations in the lake itself (Appendix 7).

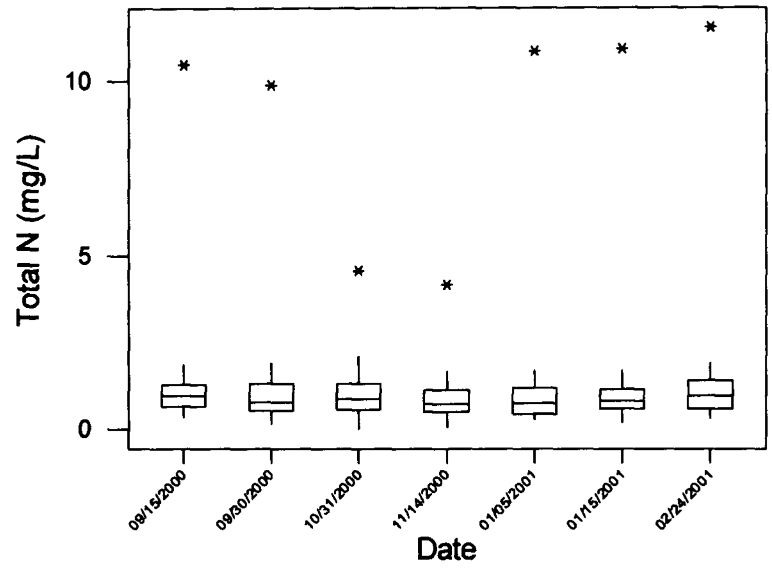


FIGURE 13. Total N concentrations in groundwater. Outliers are due to high NH_4-N concentrations in piezometer C-30 finished in loess.

e. Silica (SiO_2) in Groundwater. Concentrations of SiO_2 were generally consistent among the 7 sampling dates and are within the range common for groundwater systems at near-neutral pH in these materials (Table 6; Fig. 14). Mean, standard deviation and median concentrations were 40.4, 14.3 and 37.3 mg/L, respectively. There is some variability in samples from different piezometers; however, the differences are not significantly different (Fig. 15). Some of the higher concentrations are found in the shallowest piezometers.

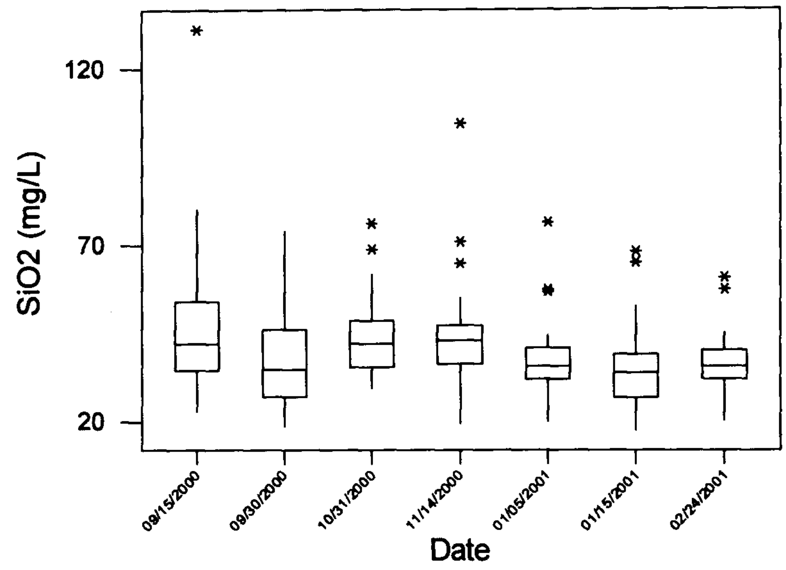


FIGURE 14. SiO_2 concentrations in groundwater.

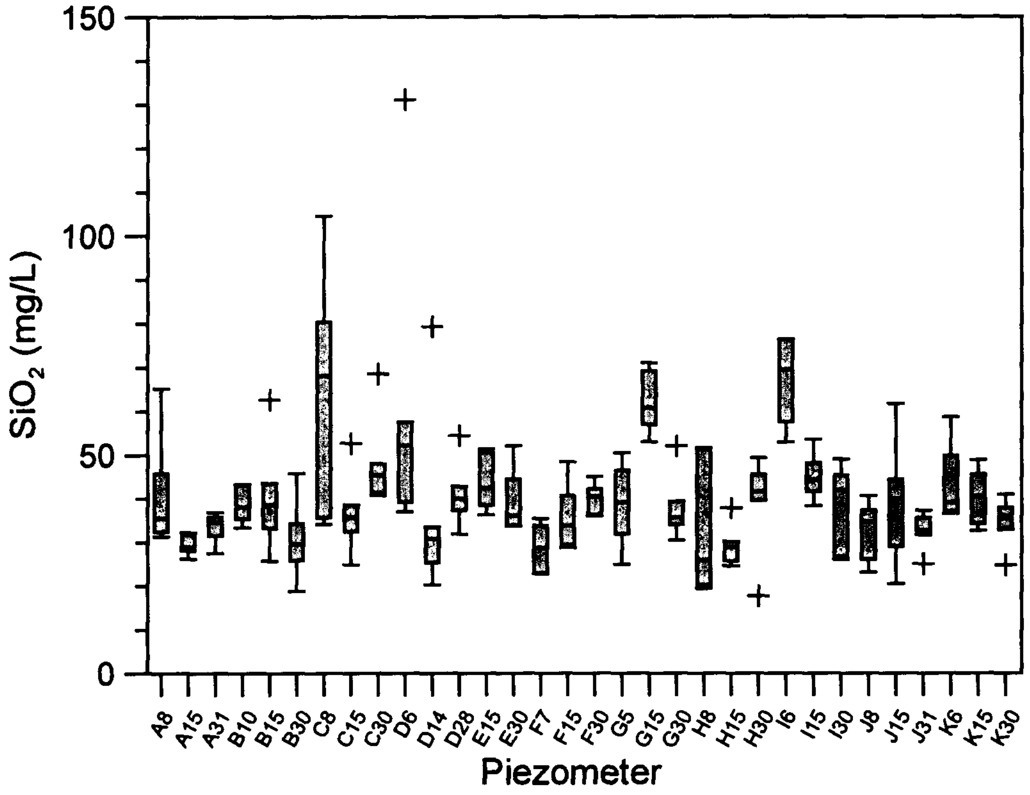


FIGURE 15. SiO_2 concentrations in groundwater among the piezometers. Many shallow piezometers (e.g., C8, D6, I6) show the highest concentrations.

f. Chloride (Cl) in Groundwater. Chloride concentrations in groundwater ranged from 1.0 to 73.1 mg/L, with a mean of 17.1 mg/L. The mean Cl concentration in Clear Lake is about 16 mg/L. Because there is no known natural source of Cl in the glacial sediment, its origin must be anthropogenic. Potential sources include agricultural fertilizers, septic systems and road de-icing salts and solutions. Data from this study indicate that concentrations generally decrease with depth, which suggests that activities near the surface are adding Cl to the groundwater. It is common to find Cl concentrations of this magnitude in agricultural areas based on other studies in similar materials (Simpkins and Parkin, 1993). However, concentrations of 73.1 mg/L are unusual. We tested the hypothesis that septic system effluent was influencing shallow groundwater by analyzing samples for fecal coliform bacteria and caffeine. Tests of groundwater in all the shallow piezometers were negative (<10 CFU/100 mL). Caffeine was analyzed in groundwater samples from B10, C8, and D6, and was found to be less than the 40 ng/L quantitation limit. Thus, high Cl concentrations are not directly influenced by septic tank effluent at these sites. However, plots of Na versus Cl revealed that many higher concentrations found in shallow piezometers help define a 1:1 meq relationship with an $r^2=0.59$ (Fig. 16). This suggests that road de-icing activities around the perimeter of the lake may be adding Cl to the groundwater.

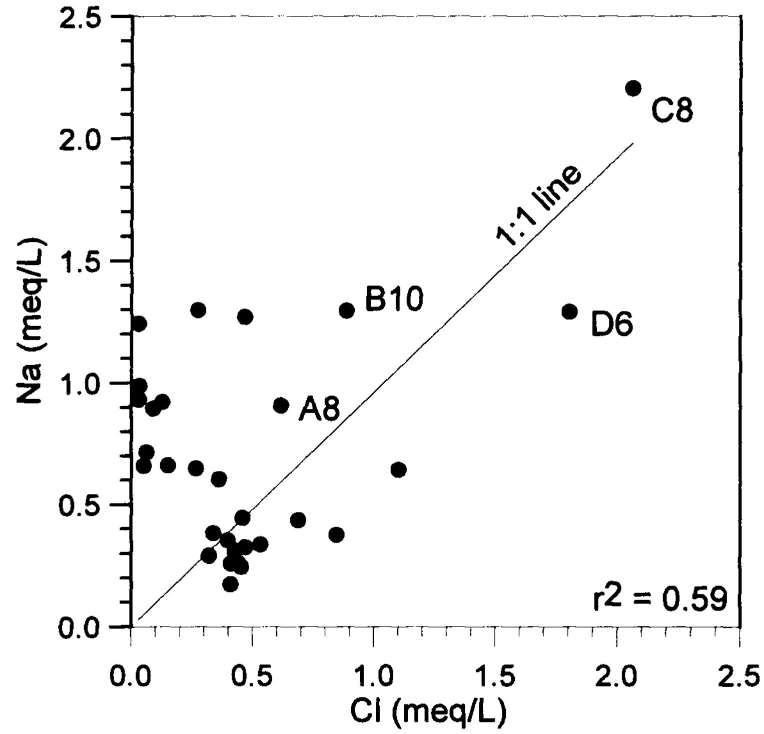


FIGURE 16. Relationship of Na and Cl concentrations (meq/L) in groundwater. Alignment along a 1:1 line suggests that the source of Cl is NaCl.

g. Tritium (^3H) in Groundwater. The radioactive isotope of hydrogen, tritium (^{3}H), was analyzed in groundwater samples taken from each piezometer (see Appendix 7). The profile of ^{3}H with depth is shown in Figure 17. Interpretation of the data is somewhat clouded by the precision of ±8 TU; however, cost considerations precluded use of higher precision analyses.

Nevertheless, there is an interesting lack of a trend with depth. Piezometers B-30 and C-30 showed no ^{3}H activity, suggesting groundwater recharge prior to 1953. Many samples throughout the profile down to 30 ft (10 m) show essentially modern ^{3}H activities, indicating recent recharge. However, a majority of the samples show ^{3}H activities in the 20 TU range that would indicate groundwater that was recharged during the 1970s. Alternatively, these higher than modern ^{3}H activities could be associated with Gulf moisture sources in summer thunderstorms when most groundwater recharge occurs in Iowa (Simpkins, 1995). The ^{3}H composition of the lake water is also not known. Interpretation of the data may be helped by the analysis of stable isotopes δ^{18}O and δ^2H in lake water, precipitation, and groundwater, which will hopefully occur in summer 2001.

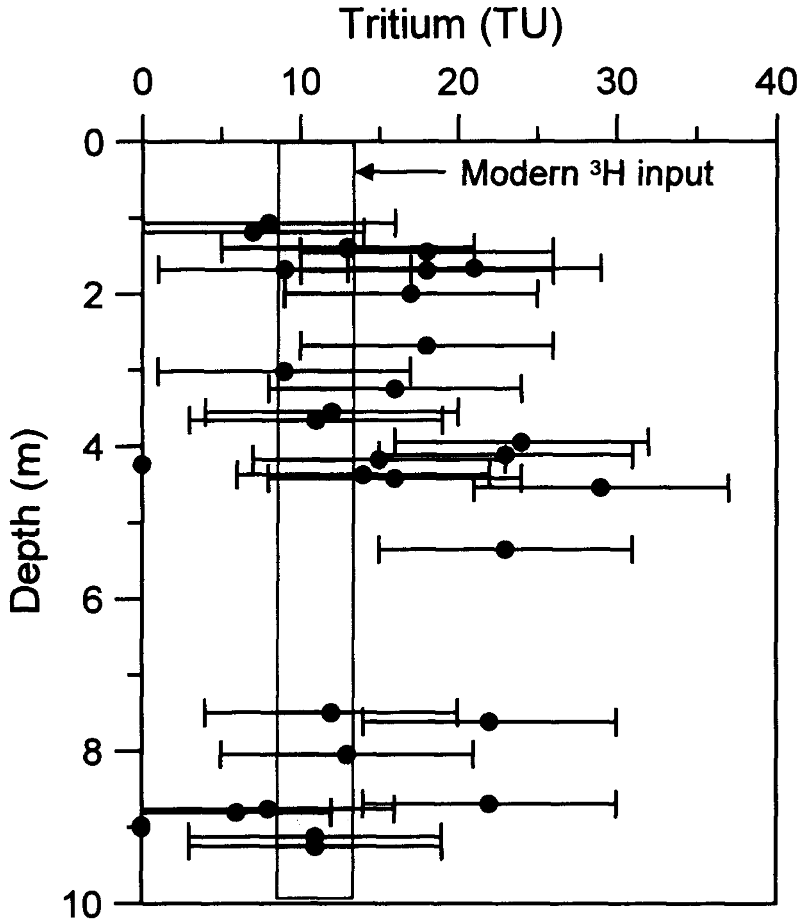


FIGURE 17. Profile of ^{3}H (TU) in groundwater in the piezometers. Shaded area is the approximate modern ^{3}H input in Iowa (after Simpkins, 1995).

TABLE 7. Summary calculations of nutrient and contaminant load to Clear Lake.

Flow direction	**Q (m^3/d) from Part I**	**Nutrient or contaminant**	**Median conc. (mg/L)**	**Load (kg/d)**
In	7.9E+03	Total P	0.173	1.37
	"	Total N	0.8	6.32
	"	Silica (SiO_2)	37.3	294.70
	"	Cl	14.3	112.98
Out	-8.9E+3	Total P	0.174	-1.54
	"	Total N	1.31	-11.66
	"	Silica (SiO_2)	38.7	-344.47
	"	Cl	15.4	-137.08
Ventura	3.30E+03	Total P	0.173	0.57
Marsh	"	Total N	0.8	2.64
(in)	"	Silica (SiO_2)	37.3	123.1

h. Nutrient and Contaminant Load to Clear Lake. Given an understanding of nutrient and Cl concentrations in groundwater adjacent to the lake, and assuming that these concentrations represent what would be likely be transported by groundwater to the lake, a calculation of the nutrient/contaminant load may be made. For this simplified analysis, we will use the model-calculated discharges (Table 5) and use the median concentrations separated by inflow and outflow areas. Estimates indicate that about 1.37 and 6.32 kg/d of Total P and N, respectively, are added to the lake via groundwater (Table 7). The form of P (e.g., sorbed, dissolved, organic) entering the lake is not known at this time, but it is likely that N enters the lake as either NH_4-N or organic N. Calculations indicate that nearly 300 kg/d of SiO_2 enter the entire lake via groundwater. Estimates of Total P, Total N, and SiO_2 to Ventura Marsh alone are 0.57, 2.64, and 123.1 kg/d, respectively, using the total median values. Losses of these components from the lake in Table 7 are generally higher because additions to the lake from other sources are not included in the analysis.

Chloride in groundwater, probably from road de-icing activity, adds about 113 kg/d to the lake. It is interesting to note that the mean outflow concentration of Cl (15.4 mg/L) is similar to the mean Cl concentration of the lake of about 16 mg/L.

4. Conclusions. The geochemical environment of groundwater near Clear Lake was investigated and found to contain reducing conditions that may suppress NO_3-N concentrations while liberating P. Using analyses from 7 separate sampling dates, we found that groundwater adds about 1.37, 6.32, and 294.7 kg/d of P, N, and SiO_2 to the lake. Road de-icing activity, and undoubtedly some septic systems and fertilizers, adds about 113 kg/d of Cl to the lake. Clear Lake itself loses nutrients and Cl via groundwater outflow. The long-term future and health of Clear Lake may depend on identifying the sources and reducing inputs of these components to groundwater.

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CHAPTER 9

Pathways Leading to Water Clarity Restoration in Ventura Marsh Following Benthivorous Fish Removal

Pathways Leading To Water Clarity Restoration In Ventura Marsh Following Benthivorous Fish Removal

Laura J. Schrage and John A. Downing

A. Abstract

We evaluated the effects of a benthivorous fish reduction in a large, shallow, eutrophic wetland in a predominately agricultural watershed in Iowa, USA. After a substantial fish removal was obtained, water clarity increased as a result of decreased suspended sediment and phytoplankton biomass. Prior to the clear water phase, phytoplankton was phosphorus limited. Zooplankton grazing reduced phytoplankton biomass during the clear-water phase. The biomass of *Dapnia* and *Ceriodaphnia* increased following fish removal. During this period, grazing pressure was high and standing phytoplankton biomass remained low. Phytoplankton appeared to be regulated by top-down control for approximately two months before reverting back to bottom-up control. Changes in water quality and/or return of juvenile carp may account for the switch back to bottom up control. Macrophyte diversity and density increased after the initiation of the clear water phase.

B. Introduction

Exotic, benthivorous fish are among the major determinates of water quality in shallow, nutrient rich lakes. Of the exotic benthivores, perhaps the most widely distributed is the common carp (*Cyprinus carpio*). Common carp are native to Eurasia but have become established in North America, Europe, India, South Africa and Australia (Roberts et al. 1995). Populations of common carp are found throughout the continental United States with the lakes and rivers of the Midwest having the greatest densities (Courtney et al. 1984).

Common carp have been implicated in eutrophication of water bodies. The impact of common carp is largely attributed to its benthic feeding activities (Welcomme 1984). Potentially, carp may enhance phosphorus concentration (Breukelaar et al. 1994, Havens 1991, Brabrand et al. 1990, Lamarra 1975, Vanni and Findlay 1990), increase phytoplankton biomass, increase turbidity (Scheffer 1998) and reduce the abundance of submerged macrophytes (Crivelli 1983, Roberts et al. 1995, Barko and Smart 1981, Skubinna et al. 1995).

One important technique used to restore water quality in freshwaters is biomanipulation. Biomanipulation is a lake management tool aimed at increasing water clarity by manipulating the biomass of fish (Perrow 1997). Biomanipuations have been conducted throughout Europe and North America during the past fifty years, many of which have been successful in improving water clarity and/or lowering phytoplankton biomass (Drenner and Hambright 1999).

Despite the many studies there are still discrepancies as to the mechanism through which water clarity increases following fish biomanipulation. Benthivores structure aquatic systems through many processes and it is not completely certain which processes are involved in the increase in water clarity following biomanipulation.

Following benthivorous fish removal, water clarity may increase due to a reduction in suspended sediment. Benthivores feed on invertebrates, such as chironomids, oligochaeta, and mollusca, inhabiting the sediment by sucking in sediment and catching the invertebrates in their gill rackers. This feeding process forms small pits in the lake bottom and resuspends sediment (Scheffer 1998). In Lake Bleiswijkse and Lake Noorddiep benthivorous fish had a substantial effect on turbidity due to bioturbation of the sediment (Meijer et al. 1990). Experimental ponds stocked with common carp (*Cyprinus carpio)* showed a positive relationship between fish biomass and suspended solids (Breukelaar et al. 1994, Lougheed et al. 1998). A benthivorous fish density of 600 kg/ha in a shallow lake may reduce Secchi disk transparency to 0.4 m solely due to sediment resuspension (Meijer et al. 1990). Changes in water clarity following benthivorous fish removal may be due to reduced bioturbation of the sediment during foraging.

Reduction of phytoplankton biomass as a result of phosphorus limitation may be an alternate pathway through which water clarity increases following removal of benthivorous fish (Boers et al. 1991). Benthivores may increase phosphorus concentrations due to recycling of nutrients from the sediment and fish excretion (Breukelaar et al. 1994, Havens 1991, Brabrand et al. 1990, Lamarra 1975, Vanni and Findlay 1990). Phosphorus concentrations decreased in some biomanipulations involving a reduction of benthivores (Meijer et al. 1989, Hanson and Butler 1994, Meijer and Hosper 1997), although, other manipulations observed no change in nutrient concentrations (VanDonk et al. 1990, Lougheed 2000, Bonneau 1999).

Increased water clarity, due to a reduction in phytoplankton biomass, may be a result of trophic cascading. The idea being that a reduction in fish biomass will shift the zooplankton community from smaller-bodied to larger-bodied zooplankters, such as *Daphnia.* An increase in larger-bodied zooplankton may reduce phytoplankton biomass, leading to increased water clarity since larger-bodied zooplankton are more efficient grazers than smaller-bodied zooplankters (Brooks and Dodson 1965, Shapiro and Wright 1984, Carpenter et al. 1985). A shift from smaller-bodied to larger-bodied zooplankters may be expected for two reasons following removal of benthivores. First, removal of benthivores may reduce the predation pressure on larger-bodied zooplankton since juvenile benthivores selectively feed on the larger zooplankters (Drenner and Hambright 1999) and many adult benthivores switch between benthic and pelagic feeding (Lammens and Hoogenboezem 1991). Secondly, turbity may also structure the zooplankton community (Bonneau 1999, Lougheed and Chow-Fraser 1998). It has been shown that under conditions of high suspended sediment grazing by large cladocerans is hindered, leading to a zooplankton community consisting of smaller-bodied individuals (Kirk 1991, Hart 1988). If predation and/or suspended sediment decreases following removal of benthivores, the zooplankton community may shift towards larger-bodied zooplankton. Therefore, the reduction in fish biomass may have a cascading effect down through the aquatic trophic levels and eventually reduce the phytoplankton biomass leading to increased water clarity.

Expansion of macrophyte beds has been observed following biomanipulations involving removal of benthivores (Meijer et al. 1990, Ozimek et al. 1990, Hanson and Butler 1994, Meijer and Hosper 1997). This may occur since the higher water clarity allows for macrophytes to establish at greater depths (Barko and Smart 1981, Skubinna et al. 1995) and the uprooting of vegetation by foraging benthivores, such as carp, is reduced (Crivelli 1983).

Macrophytes growth during the clear water phase following fish removal can provide positive feedbacks, which help stabilize the clear water phase. Macrophytes help maintain high water clarity by competing with algae for nutrients and light (Perrow et al. 1997, Van Donk et al. 1993), providing refugia for zooplankton (Timms and Moss 1984, Schriver et al. 1995), increasing sedimentation of suspended particles (James and Barko 1990), and perhaps suppressing algal growth by allelopathy (Wium-Anderson et al. 1982).

The purpose of this study was to examine the impacts of fish removal, primarily benthivorous, from the temperate, eutrophic Ventura Marsh. Venture Marsh is unique in that it is a large, shallow, windy system located in a predominately agricultural watershed. This paper will describe the effectiveness of benthivorous fish removal in increasing water clarity of Ventura Marsh and attempt to elucidate the pathway by which water clarity is affected.

C. Methods

Ventura Marsh is a shallow (mean depth 0.79 m), 76 ha marsh located in Cerro Gordo County, Iowa, USA (Fig. 1). Ventura Marsh is fed by surface drainage that forms three concentrated points of entrance into the marsh from the west, southwest, and south. The outlet is located on the eastern end of the marsh and enters into a channelized culvert that flows into Clear Lake. The water level in the marsh can be regulated by placing boards to the desired level across this culvert. This structure also reduces the movement of fish between Clear Lake and Ventura Marsh. Prior to treatment, the fish fauna of Ventura Marsh was primarily common carp (*Cyprinus carpio)* and black bullhead (*Ameiurus melas)*.

The western bay of Clear Lake (Little Lake), to which Ventura Marsh is a tributary, was monitored as reference site for this study (Fig. 1). The Little Lake was chosen because it is similar to Ventura Marsh in nutrient regime, size (127 ha), depth (mean depth 1.13 m), and is exposed to the same seasonal variability.

To determine the mechanism(s) by which benthivorous fish removal influenced Ventura Marsh, we studied water quality, plankton, benthos, and macrophytes before and after a series of fish kills. Initially, the fish removal was planned to occur at the end of the summer of 1999 sampling season, so that we could obtain a year of pre- and post-biomanipulation data. Difficulties in obtaining a substantial fish removal resulted in three attempts at rotenone application before a large removal was attained. The IDNR applied rotenone aerially to Ventura Marsh on August 17, 1999 and June 7, 2000. In addition, rotenone was applied under the ice on February 13, 2000. Water quality, plankton, and benthic communities were sampled every two weeks from April through October of 1999 and every two weeks from March through September of 2000 with a higher frequency of sampling employed following summer fish removals. Water quality and phytoplankton samples were collected from the Little Lake every two weeks on the same days as Ventura Marsh.

We assessed water quality variables at three sites on Ventura Marsh (Fig. 2) and at one site on the Little Lake. Dissolved oxygen, temperature, pH, and conductivity were measured at each half-meter interval in the water column. At each half-meter interval, we also collected water samples for analysis of total nitrogen, nitrate, ammonia, total phosphorus, silica and total, inorganic and volatile suspended solids. Total nitrogen and nitrate were analyzed using the second derivative method (Crumpton et al. 1992). The remaining analyses were conducted according to standard methods (American Public Health Association 1998). Secchi disk readings were also taken at these three sites.

Plankton and benthos samples were collected in excess. In August of 1999 we expanded our sampling of plankton and benthos from three samples to 13 planktons samples and 7 benthic samples (Fig. 2). Fewer benthic samples were taken because we felt that the distribution of benthos was more homogeneous than that of the plankton community. We counted a number of randomly chosen samples that was sufficient to yield an inter-replicate standard error of ≤ 20% of the mean (Downing 1979). After counting many of the 1999 plankton samples it was noticed that only 4 phytoplankton and 3 zooplankton samples were counted for most dates. We therefore reduced the number of samples collected in 2000 to 6 phytoplankton and 5 zooplankton samples. We continued to collect 7 benthic samples in 2000.

The phytoplankton samples were comprised of equal volumes of water taken from each half-meter interval, and were preserved with Lugol's solution (APHA 1998). Samples were concentrated and sub-sampled with a Hensen-Stempel pipette. The volume of the sub-sample varied between 2 – 5 ml depending on density of cells. Using an inverted microscope, we identified, counted, and measured phytoplankton. Samples were counted until the most abundant species reached 125 except when *Oscillatoria* was most abundant. When *Oscillatoria* was most abundant, samples were counted until *Oscillatoria* reached 1000. Fifty cells of each taxa were measured from each sample except *Oscillatoria,* for which 250 cells were measured. Phytoplankton was identified to genus, with the exception of small cyanophyceae, using the keys of Ward and Whipple (1959) and Whitford and Schumacher (1984). Phytoplankton cells were measured and biomass estimated by applying basic geometric formulas (Findenegg 1974). From this information we calculated the biomass of edible (<30 μm) and inedible (≥30 μm) phytoplankton (Watson et al. 1992).

We used a 30 L Shindler-Patalus trap with a 61μm mesh net to collect zooplankton samples from the onset of the study until May 23, 2000, at which time we began sampling using a 61μm mesh Wisconsin net. We switched to a Wisconsin net because we were unable to submerge the Shindler-Patalus trap without disturbing the sediment during periods of low water in 2000. To determine the difference in efficiency between these two sampling devices, both collection methods were used simultaneously on three sampling dates. In terms of biomass, the Schindler-Patalus trap was found to be approximately 5% more efficient than the Wisconsin net. Therefore, zooplankton values from Wisconsin net samples were corrected such that they express the expected biomass, had the Schindler-Patalus trap been used. Zooplankton samples were preserved in 5% Formalin solution with 20 g/L of sucrose, and were later transferred to 70% ethanol. Samples were sub-sampled using a Hensen-Stempel pipette to obtain a volume with a minimum of 60 organisms (McCauley 1984). Using a stereomicroscope with 50X magnification, we identified, counted, and measured zooplankton. Twenty-five individuals of each taxa were measured. Rotifera and Cladocera were identified to genus and Copepoda to suborder using the key of Pennak (1989). We estimated zooplankton biomass by applying length-weight equations (Rosen 1981, Dumont et al. 1975) with the exception of *Keratella spp.*

The biomass of *Keratella spp.* was estimated from biovolume (Ruttner-Kolisko 1977) assuming a specific gravity of 1.0 and a wet to dry weight ratio of 0.05 (Schindler and Noven 1971).

Grazing rate of cladocerans and rotifers was approximated using abundance data and estimated filtering rates from the literature (Grosselain et al. 1996, Haney 1973, Mourelatos and Lacroix 1990, Bogdan and Gilbert 1982). Copepods were not included in the estimation of grazing rates. Only harpacticoid and cyclopoid copepods were present in this study. Harpacticoids feed from the bottom (Pennack 1989) so they would not contribute to the grazing of the phytoplankton in suspension. Cyclopoid grazing on phytoplankton is not well understood (Adrian 1991) and therefore were not included in the estimated grazing rate.

The sediment of Ventura Marsh is organic mud so we were able to obtain 1 L benthic samples with an Ekman grab. We filtered the sediment samples through a 600 μm sieve, and the portion remaining in the sieve was preserved in 5% Formalin solution with 20 g/L sucrose and 100 mg/L of rose bengal (Mason and Yevich 1967). We counted and identified all benthic organisms in the sample using the keys of Pennak (1989) and Merritt and Cummins (1996). The first 25 Chironomids and 30 oligochates in each were sample measured. Dry masses of Diptera and Gastropoda were estimated using length-weight equations (Benke et al. 1999, Eckblad 1970). We estimated oligochaete dry mass based on biovolume (Smit et al. 1993). The density of benthos was determined by dividing biomass by the volume of the sediment sample.

In order to evaluate the impact of fish manipulation on submerged macrophytes, we conducted macrophyte surveys in July 1999 and August 2000. Twelve north south transects evenly spread throughout the open water were surveyed in 1999. We recorded the species present along these transects. In 2000 the open water of the marsh was surveyed for submerged macrophytes with 27 north south transects approximately 20 m apart. A one-meter square quadrat was placed every 20 meters along these transects. We identified the species in the quadrats and estimated the percent cover of each species.

To gauge the success of the rotenone treatments, the Iowa Department of Natural Resources conducted gill netting surveys. Three gill nets, measuring 160 feet long with 2½ in bar mesh, were placed for 24 hours in Ventura Marsh on four occasions (8/3/99, 9/10/99, 4/12/00, and 6/21/00). The fish captured were identified and enumerated. During the last three gill net surveys carp were categorized as either small (< 1.8 kg) or large (≥ 1.8 kg). There was reason to believe that the carp population was becoming re-established in late summer of 2000, so electroshocking was conducted on September 1, 2000. Two transects were shocked for 7 minutes each. The fish captured during electroshocking were identified and the lengths of the first 50 fish of each species were measured.

Direct comparisons of water quality values between the four time periods (pre-manipulation, postmanipulation 1, postmanipulation 2 and postmanipulation 3) could be confounded by seasonal variability. To reduce this, the before-after-control-impact (BACI) method of analysis (Smith et al. 1993) was used to determine whether differences in nutrient concentrations, suspended solids, Secchi disk transparency and phytoplankton biomass were statistically significant among the four time periods. The Little Lake was used as the reference system in this analysis.

D. Results

Prior to rotenone applications, gill nets placed overnight in Ventura Marsh collected 170 common carp (*Cyprinus carpio*) (Table 1). After the first and second rotenone applications 113 and 84 common carp were collected respectively. Of the carp captured following the first rotenone application 54% were large fish (1.8 kg), while only 11% of the carp captured following the second rotenone application were large. Only 2 common carp, less than 1.8 kg in weight, were collected following the third application in June of 2000, indicating that the majority of the carp population had been eradicated by the three rotenone applications. Thirty-one bullheads (*Ameiurus melas)* were collected after the first rotenone application but none were captured on the other collection dates. On September 1, 2000 two transects in the marsh were electroshocked. A total of 73 fishes (68 common carp, 4 buffalo, and 1 bullhead) were captured in transect one. Only seven fishes (6 common carp and 1 buffalo) were captured in transect 2. The carp were primarily juveniles with an average length of 15.7 cm (6.2 in) and a range of 11.9 - 26.7 cm (4.7 – 10.5 in).

Secchi disk transparency was generally quite low in the marsh (~0.35 m) but was significantly higher following the third rotenone application (BACI, $p < 0.05$). The highest Secchi disk transparency of 1.0 m was recorded on July 13, 2000 (Fig. 3), 6 weeks following the final rotenone treatment. The Secchi disk transparencies from May 10, 2000 to July 19, 2000 were slightly underestimated since the Secchi disk reached the marsh bottom at one or more of the sites without disappearing from view. The period following the third rotenone application is therefore referred to the clear water phase and the period prior as the turbid phase.

There was weak evidence that total phosphorus concentrations were reduced in the period following the third fish removal compared to the premanipulation period (BACI, $p < 0.058$). In the turbid phase the total phosphorus of Ventura Marsh was on average 147 μg/L higher than the total phosphorus concentration of the Little Lake, whereas in the clear water phase the difference was an average of 32 μg/L. In the turbid phase total phosphorus and phytoplankton biomass were strongly correlated ($r^2 = 0.73$) but were less so in the clear water phase ($r^2 = 0.21$) (Fig. 4).

Ammonia concentrations following the third rotenone application were significantly different from the premanipulation and postmanipulation 1 period (BACI, $p < 0.05$). Total nitrogen, nitrate, and silica showed no significant change in concentrations among the four treatment periods (BACI, $p < 0.05$).

Inorganic suspended solids (ISS) concentrations in the water column did not differ significantly among the four treatment periods (BACI, $p < 0.05$), although the lowest concentration of ISS occurred during the clear water phase (Fig. 3). Linear regression of Secchi disk depth and inorganic suspended solids showed a negative correlation ($r^2 = 0.51$) (Fig. 5).

Volatile suspended solids following the third rotenone application were significantly lower than during the other three treatment periods (BACI, $p < 0.05$). Volatile suspended solids include both phytoplankton and organic detritus. No significant difference in phytoplankton biomass was detected between the four periods (BACI, $p = 0.05$). A sizeable decrease in phytoplankton biomass occurred between May 23, 2000 and June 27, 2000 (Fig. 6). Secchi disk transparency showed a strong negative linear relationship with phytoplankton biomass across the turbid and clear phases ($r^2 = 0.55, 0.74$).

Phytoplankton biomass steadily increased throughout 1999 and a similar trend began in 2000 (Fig. 6). However, after the third fish removal the phytoplankton biomass decreased. Total phytoplankton biomass and cyanophycea biomass appeared to be higher in 1999. Cyanophycea, *Oscillatoria*, and *Actinastrum* were more prominent in 1999, while *Closterium, Mersimopedia* and *Synedra* were more predominant in 2000.

Changes were observed in the zooplankton community across the fish manipulations (Fig. 7). The zooplankton biomass composition during the premanipulation period (4/12/99 – 8/16/99) was variable. There was a peak of *Bosmina* in early June and an increase in biomass of *Chydorus* during August that remained high until the first rotenone application. Cyclopoid copepods and *Keratella* biomass were fairly constant during this period. Following the first rotenone application, zooplankton biomass was low. There was a small peak of *Brachionus* followed by a steady biomass of *Keratella, Chydorus,* Cyclopoid copepods and nauplii. *Chydorus* was very abundant during this period. The biomass composition of zooplankton remained fairly similar throughout the postmanipulation 2 period (8/17/99 – 10/15/99). The zooplankton biomass in postmanipulation 2 was primarily cyclopoida copepods. In the spring, cyclopoid nauplii and *Daphnia* were present but remained very low throughout the rest of the postmanipulation 2 period. The zooplankton biomass composition underwent substantial changes following the third biomanipulation. The first zooplankter to increase following the third fish removal was *Brachionus*. *Brachionus* began to decrease in late June 2000, at which time the biomass of *Daphnia, Ceriodaphnia,* cyclopoid copepods, and nauplii began to increase. Approximately one month later the biomass of *Bosmina* increased. In early August *Daphnia* and *Ceriodaphnia* populations began to decline. By mid-August and September of 2000 the zooplankton community consisted mainly of *Brachionus, Bosmina,* cyclopoid copepods and nauplii.

Changes in the size distribution of cladocerans during this study reflect changes in the prominent cladoceran (Fig. 8). In 1999, the length of most cladocerans was between 0.2 – 0.3 mm, whereas, in 2000, a larger range of cladoceran lengths was observed. In 1999, *Chydorus* was the primary cladoceran while larger cladocerans, such as *Daphnia* and *Ceriodaphnia,* were more prominent in 2000. The distribution of copepod lengths remained similar throughout the study with a median length of approximately 0.6 mm (Fig. 8).

Estimated grazing rates of cladocerans and rotifers peaked in September 1999, June 2000, and July 2000 (Fig. 9). The 1999 peak corresponded to a high biomass of *Chydorus*. The June 2000 peak was due primarily to rotifers, while the July 2000 peak corresponds to high abundance of *Daphnia* and *Ceriodaphnia*. The July 2000 peak in grazing was the highest, with nearly 140% of the marsh water being filtered each day. There was little correlation between grazing rate and phytoplankton biomass when viewed across both the turbid and clear phase ($r^2 = 0.16, 0.23$).

Oligochaetes and chironomids were the primary benthic organisms in Ventura Marsh (Fig. 10). The composition of the benthic community was similar throughout the study but the biomass changed considerably. In the premanipulation and postmanipulation 1 periods the average biomass of benthos was 22 and 32 mg/L respectively, whereas in postmanipulation 2 and 3 the average biomass was 95 and 116 mg/L. The distribution of oligochaete length remained similar throughout the study while the median length of Chironomids increased in the postmanipulation 3 period (Fig. 11).

Throughout this study cattails, *Typha,* surrounded the shoreline of Ventura Marsh and clumps of *Lemna* were present throughout the open water. In 1999, only six of the twelve transects were found to contain submerged macrophytes. Three species of submerged macrophytes were observed: sago pondweed (*Potamogeton pectinatus*), coontail (*Ceratophyllum*) and water lily (*Nymphaea sp.*). Sago pondweed and coontail were the primary submerged macrophytes with only one occurance of water lily. All submerged macrophytes in 1999 were found within 5 m of the shoreline. In the 2000 survey, macrophytes were present along all 27 transects with over 80% of transects having submerged macrophytes extending 60 m from shore. Of the quadrats sampled within 60 m of shore, nearly half had 40% or more cover from submerged macrophytes. A total of 6 species of submerged macrophytes were found (*Potamogeton pectinatus, Elodea, Ceratophyllum, Vallisneria americana, Zannichellia palustris* and *Sagittaria*) with *Potamogeton pectinatus* and *Elodea* being the most prevalent species.

E. Discussion

A short-term clear water phase was obtained following the third rotenone application involving elements of trophic cascading and changes in physical disturbance. One factor involved in determining water clarity in Ventura Marsh was suspended sediment as indicated by the negative correlation of inorganic suspended solids (ISS) and Secchi disk transparency (r^2 = 0.51). Patterns in ISS and Secchi disk transparency tend to mirror one another (Fig. 3). Overall, ISS were not significantly lower during the clear water phase (BACI, $p = 0.05$), however, extremely low ISS values were recorded for approximately two months after the third fish removal. The low ISS values recorded in July and August of 2000 indicate a reduced amount of sediment in the water column. The benthic biomass during the clear water phase was approximately 5X greater than a similar time period during the turbid phase, suggesting that fish foraging was very low during the clear water phase. The high water clarity following the third fish removal may be partially due to lower amounts of suspended sediment as a consequence of reduced fish foraging. Similarly, Meijers et al. (1990) attributed increased water clarity in Lake Bleiswijkse Zoom and Lake Noorddiep following fish removal partially to decreased suspended sediment due to reduced bioturbation by fish.

Phosphorus concentrations appeared to be somewhat reduced during the clear water phase compared to the premanipulation period (BACI, $p < 0.058$). Sediment resuspension was low during portions of the clear water phase perhaps leading to reduced nutrient recycling and thus lower phosphorus concentrations. In addition, the reduced fish biomass may have led to lower total phosphorus concentrations due to reduced fish excretion.

The increased water clarity of Ventura Marsh appeared to also result from reduced phytoplankton biomass in the water column. Secchi disk transparency showed a strong negative relationship with phytoplankton biomass both in the turbid and clear water phases (r^2 = 0.55, 0.74), indicating that water clarity increased as phytoplankton biomass declined. Phytoplankton biomass showed large fluctuations in 1999 but overall steadily increased throughout the summer (Fig. 6). A similar trend began to develop in 2000 with a ten-fold increase in phytoplankton biomass from March to early June. However, following fish removal in June phytoplankton biomass decreased to low biomasses, similar to those observed in 2000 following ice out, for approximately one month.

The reduction in phytoplankton biomass following the third fish removal appears to be due to zooplankton grazing. Shortly after the third fish removal, zooplankton grazing rates peaked at 55% of the marsh water per day, followed a month later by another peak of 139% of the marsh water per day (Fig. 9). The first peak was due solely to rotifers since cladocerans had not yet become established. During the second peak in grazing zooplankton biomass was not notably higher, but approximately half of the zooplankton biomass was comprised of *Daphnia* and *Ceriodaphnia,* which were rarely observed on other occasions (Fig. 7). Of the cladocerans and rotifers identified in this study, *Daphnia* and *Ceriodaphnia* were the genera with the highest filtration rates. Phytoplankton biomass remained low during these peaks in grazing suggesting that the control of phytoplankton was by zooplankton grazing.

The factor limiting phytoplankton biomass in Ventura Marsh switched between nutrients and zooplankton grazing. The amount of phytoplankton seemed to be determined by phosphorus concentration in the turbid phase (Fig. 4). Following the third fish removal *Daphnia* and *Ceriodaphnia* became abundant and phytoplankton was limited by zooplankton grazing. Zooplankton grazing rate quickly decreased from the high peak of 139% in July 2000 to less than 25% per day. The standing phytoplankton biomass may not have been sufficient to support the zooplankton community, thus resulting in a population decline. After the decline in grazing in late July 2000, phytoplankton biomass began to increase again. Grazing rate remained low ($\leq$35% per day) during August and September while phytoplankton continued to grow until constrained by another factor. The trend in standing phytoplankton biomass in August and September are similar to the trend in total phosphorus suggesting the phytoplankton was once again limited by phosphorus. Overall, phytoplankton in Ventura Marsh were phosphorus limited until after the third fish removal when it switched to top-down control. Two months later the system had reverted back to bottom-up control.

The maintenance of top-down control is essential to a successful fish biomanipulation. It is therefore important to discern the factors limiting the abundance of large-bodied filter feeding cladocerans. Top-down control occurred following the third fish manipulation for approximately two months when there was a substantial biomass of *Daphnia* and *Ceriodaphnia.* The reduction in fish predation and lower suspended sediment in the clear water phase may all account for the increase in biomass of these larger-bodied cladocerans. Biomass of *Daphnia* and *Ceriodaphnia* began to decline in late July, probably due to insufficient standing phytoplankton biomass. In August when the phytoplankton biomass began to increase again the cladoceran population did not respond with a subsequent increase in biomass and grazing rate, but remained low for the remainder of the study. An increase in juvenile carp and ISS, perhaps due to wind, may help explain why larger-bodied cladocernas did not become abundant again once their food source returned.

The increase in water clarity was sufficient to promote a dramatic increase in macrophyte diversity and abundance. The higher water clarity and the reduced fish foraging allowed macrophytes to establish at greater depths and in higher densities. The presence of macrophytes is essential to the maintenance of high water clarity. Macrophytes may help maintain lower suspended sediment and biomass of phytoplankton (James and Barko 1990, Perrow et al. 1997, Van Donk et al. 1993).

F. Conclusions

The increased water clarity following the third fish removal can be partly explained by reduced physical disturbance and trophic cascading. A reduction in suspended sediment occurred due to lower fish foraging activity leading to increased water clarity. Reduction in phytoplankton biomass was also partially responsible for the increased water clarity. The low phytoplankton biomasses observed following the third fish manipulation can be explained by zooplankton grazing. The high grazing can be attributed mainly to the abundance of *Daphnia* and *Ceriodaphnia.* The reason for the increased abundance of these larger-bodied cladocerans is difficult to discern but likely contains elements of predation and turbidity.

Turbidity appears to be an important factor structuring Ventura Marsh. Water clarity, zooplankton composition, and macrophyte distribution may all be impacted by suspended sediment. A portion of the suspended sediment in the water column of Ventura Marsh can be attributed to the feeding activities of the benthivorous fish. Other factors, such as wind, may also contribute to the resuspension of sediment. The expansion of macrophyte beds following the clear water phase may help maintain lower turbidity in Ventura Marsh during subsequent years.

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TABLE 1. Results of gill netting surveys on Ventura Marsh. Carp were categorized as either small (< 1.8 kg) or large (≥ 1.8 kg).

	Date	Common carp	Size class	Bullhead	Channel catfish
Premanipulation	August 3, 1999	170		0	2
Postmanipulation 1	September 10, 1999	113	61 large 52 small	31	1
Postmanipulation 2	April 12, 2000	84	9 large 75 small	0	0
Postmanipulation 3	June 21, 2000	2	0 large 2 small	0	0

FIGURE 1. Map of Clear Lake watershed showing land use and the location of Ventura Marsh and the reference system (Little Lake).

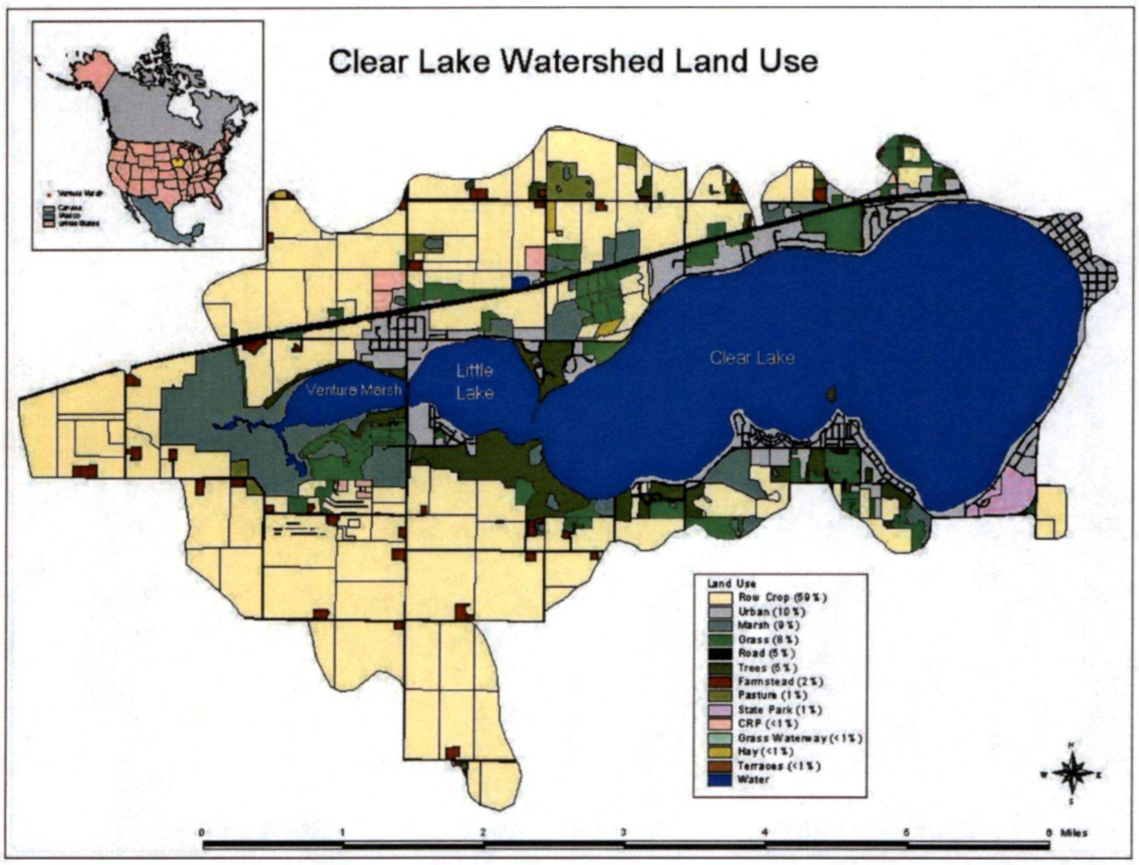


FIGURE 2. Map of Ventura Marsh showing the water quality, plankton, and benthic sampling sites

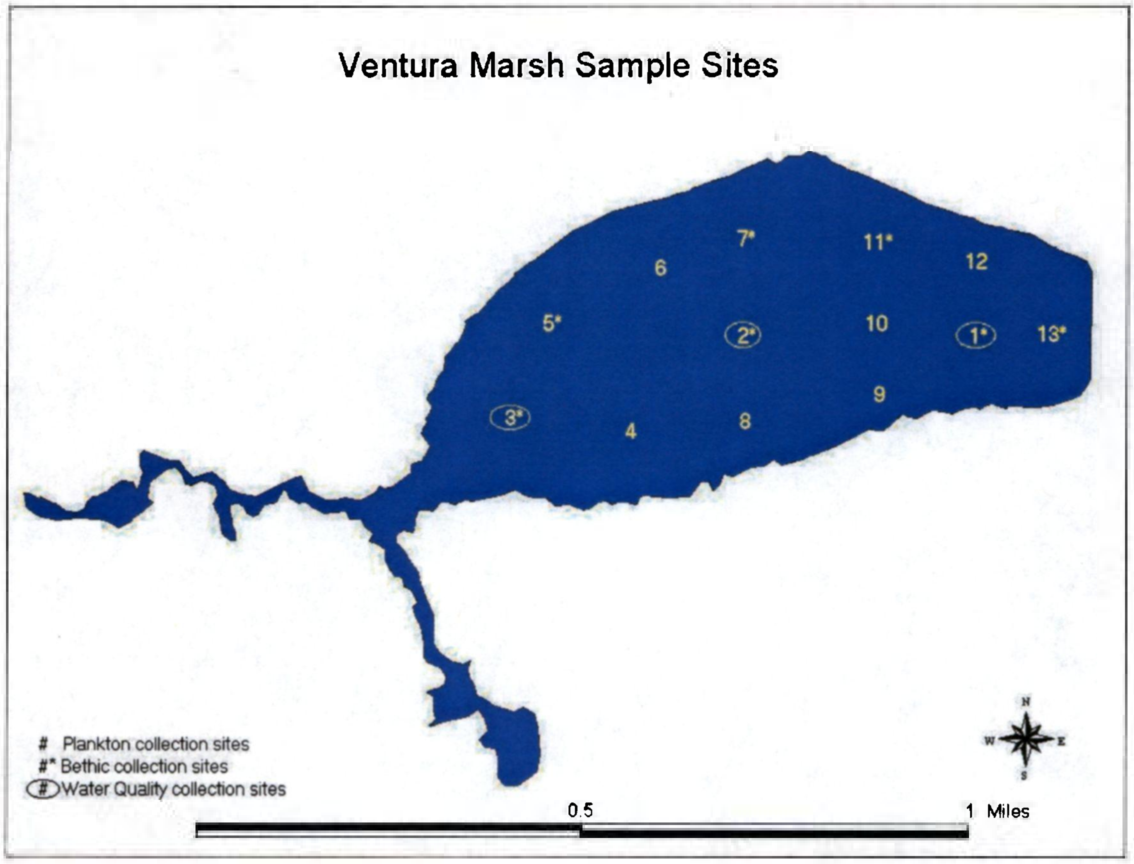


FIGURE 3. Inorganic suspended solids and Secchi disk transparency for Ventura Marsh from April 14, 1999 to September 27, 2000. Arrows indicate rotenone applications.

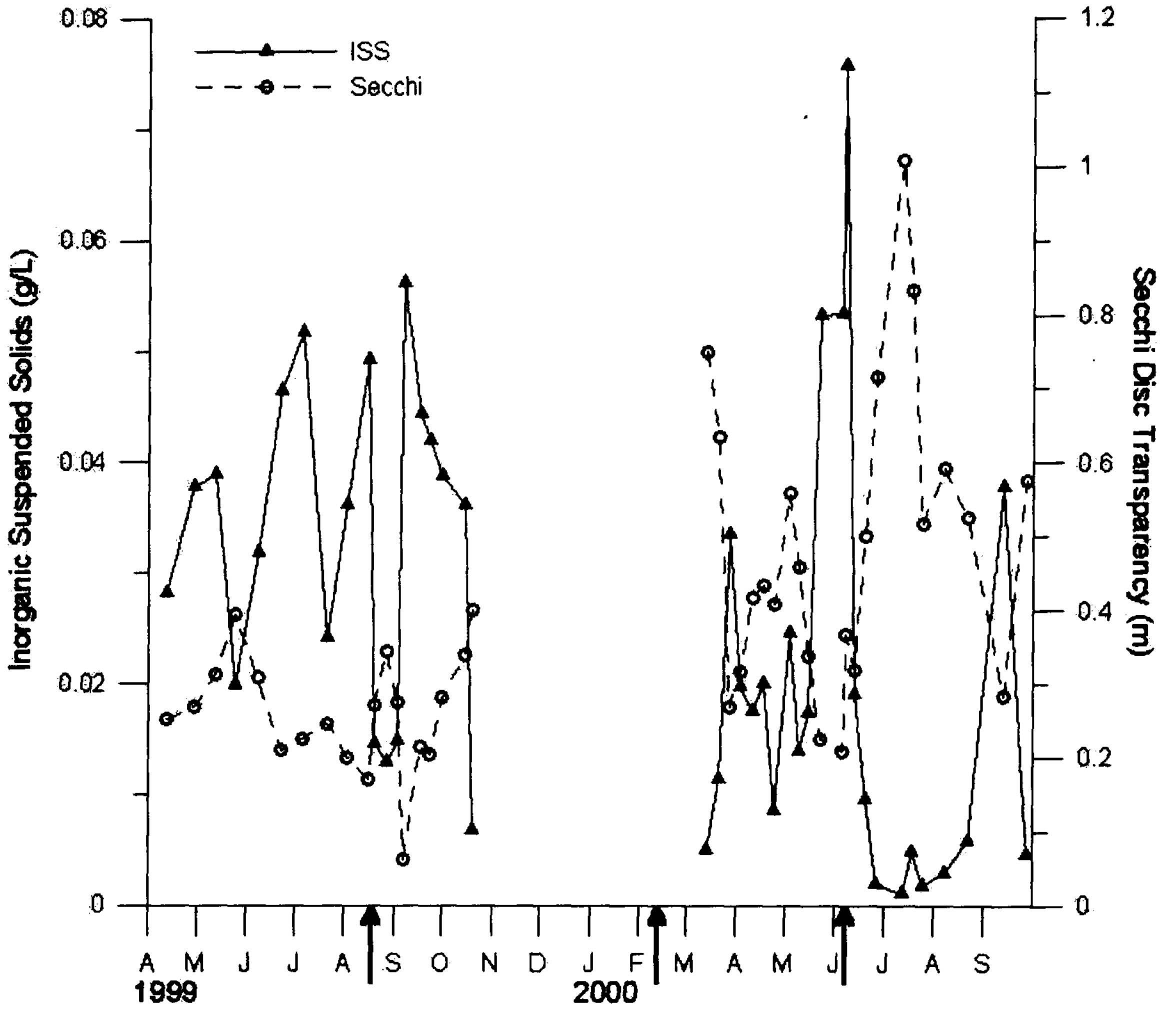


FIGURE 4 A & B. The relationship between total phosphorus and phytoplankton biomass was examined. Figure 4A is of the turbid phase (4/12/99 –6/6/00) and Figure 4B is of the clear water phase (6/7/00 – 9/27/00).

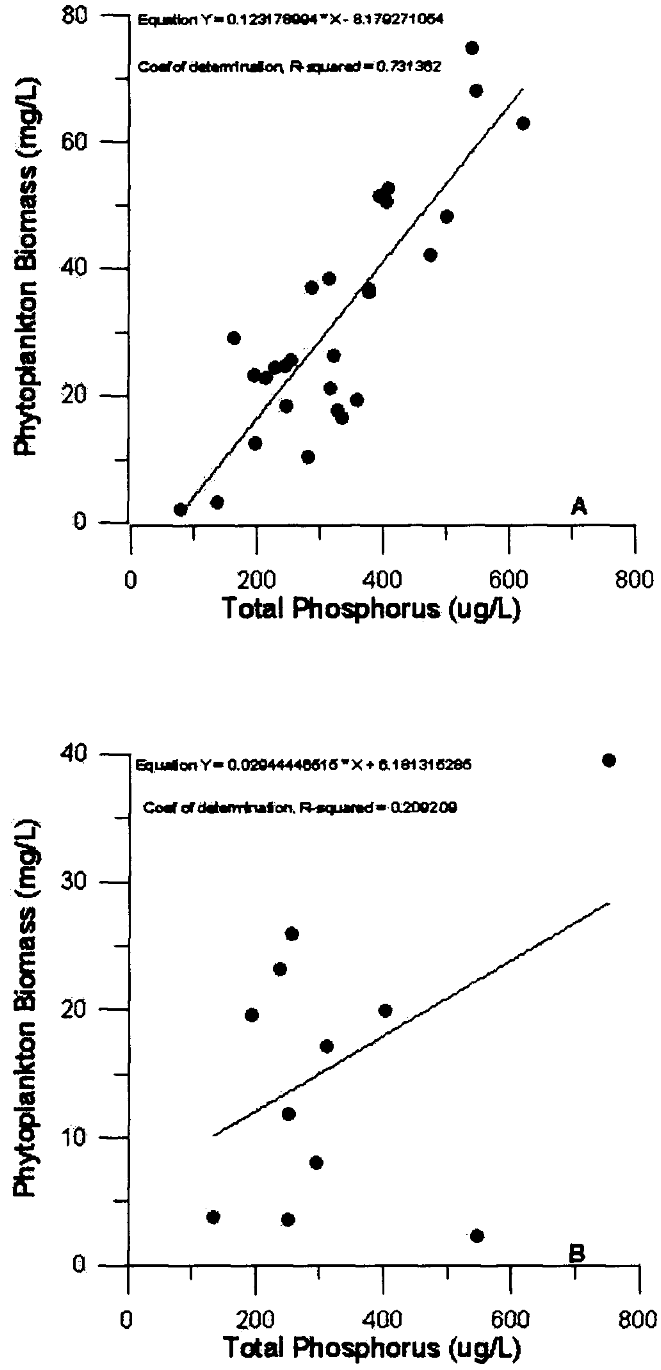


FIGURE 5. The relationship between inorganic suspended solids and Secchi disk transparency was examined. Solid circles indicate data from the turbid phase (4/12/99 –6/6/00) and open circle indicate data from the clear water phase (6/7/00 – 9/27/00).

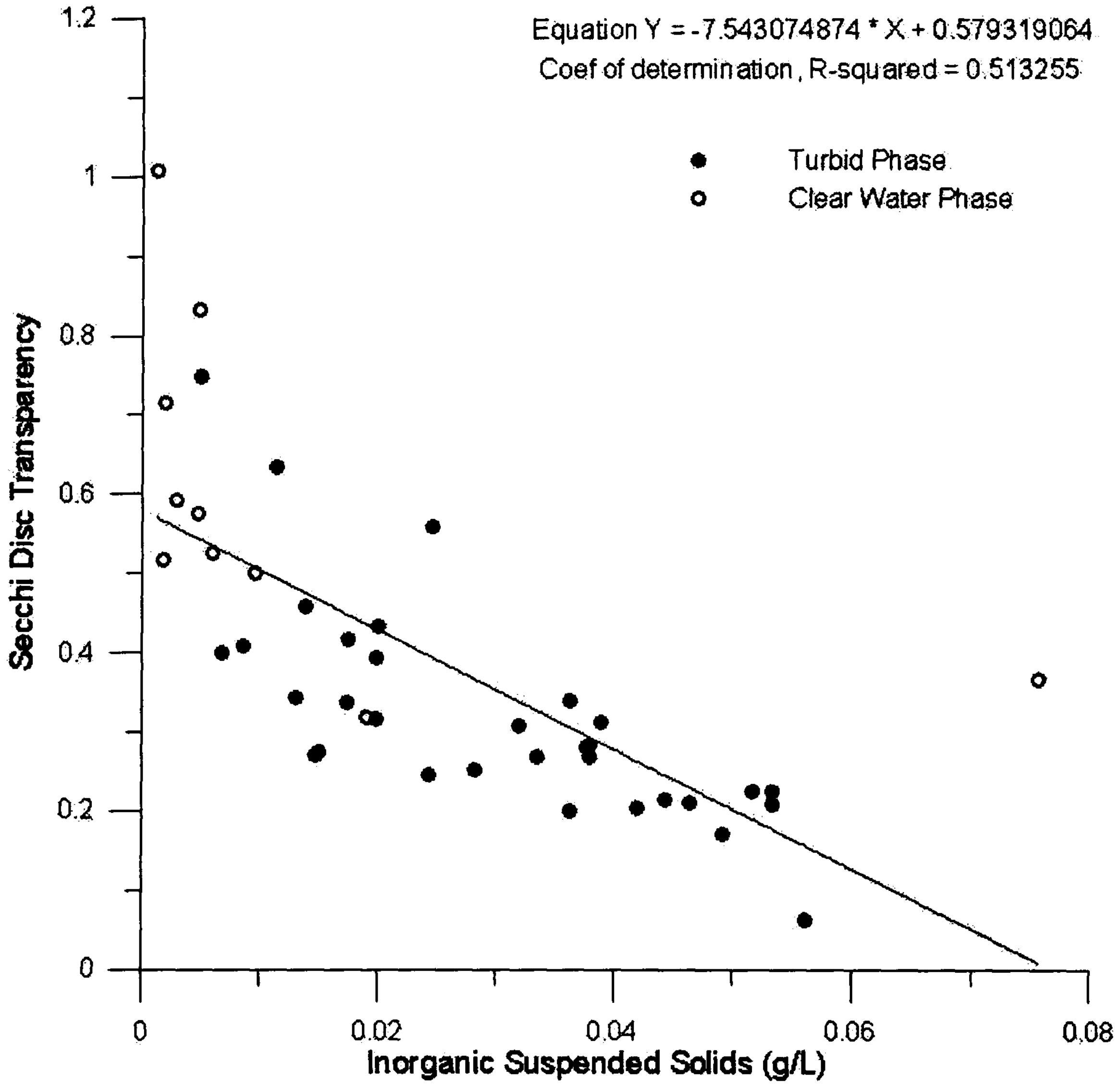


FIGURE 6. Phytoplankton biomass and percent composition for Ventura Marsh from May 13, 1999 to September 27, 2000. Arrows indicate rotenone applications.

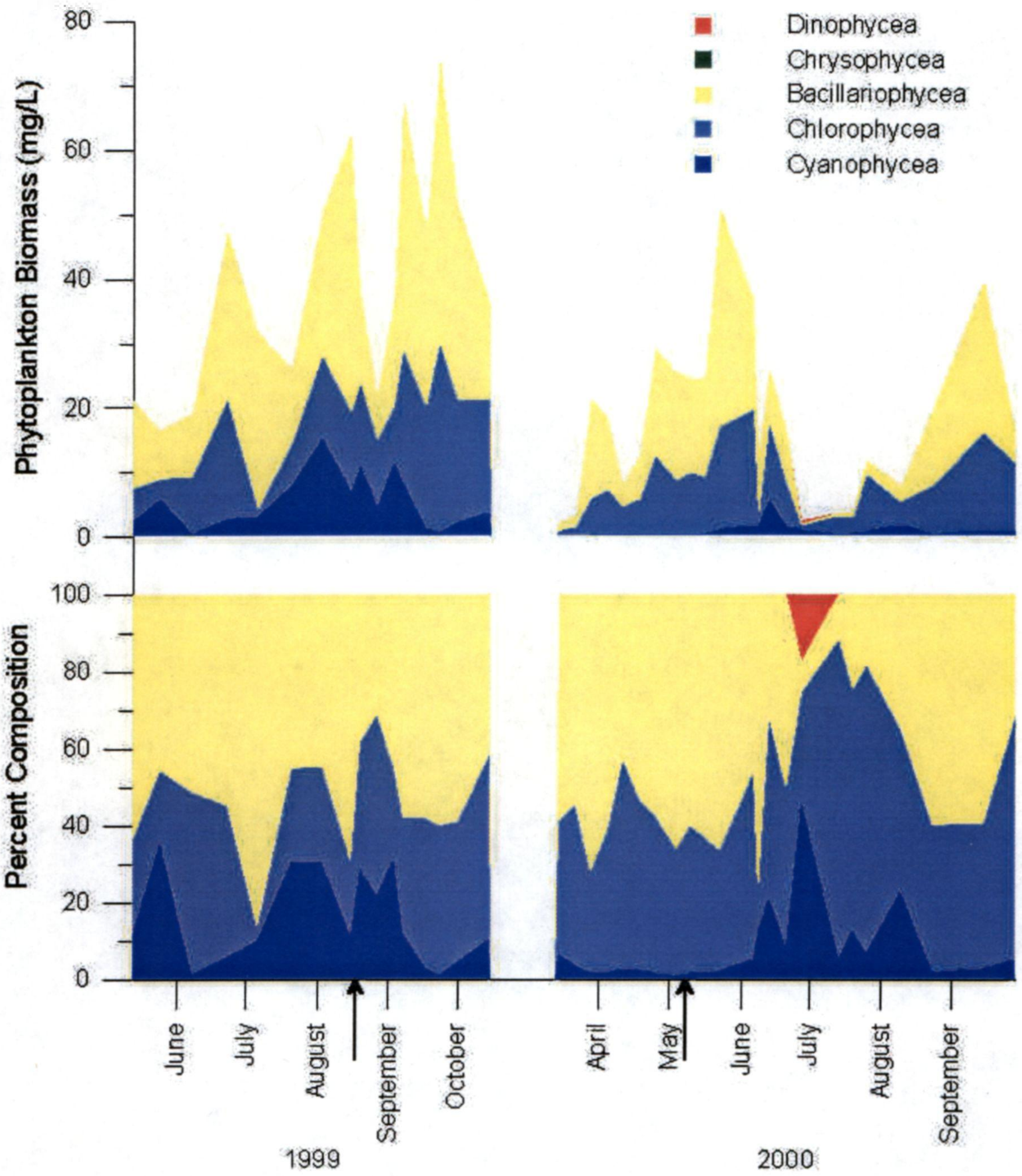


FIGURE 7. Zooplankton biomass and percent composition for Ventura Marsh from April 12, 1999 to September 27, 2000. Arrows indicate rotenone applications

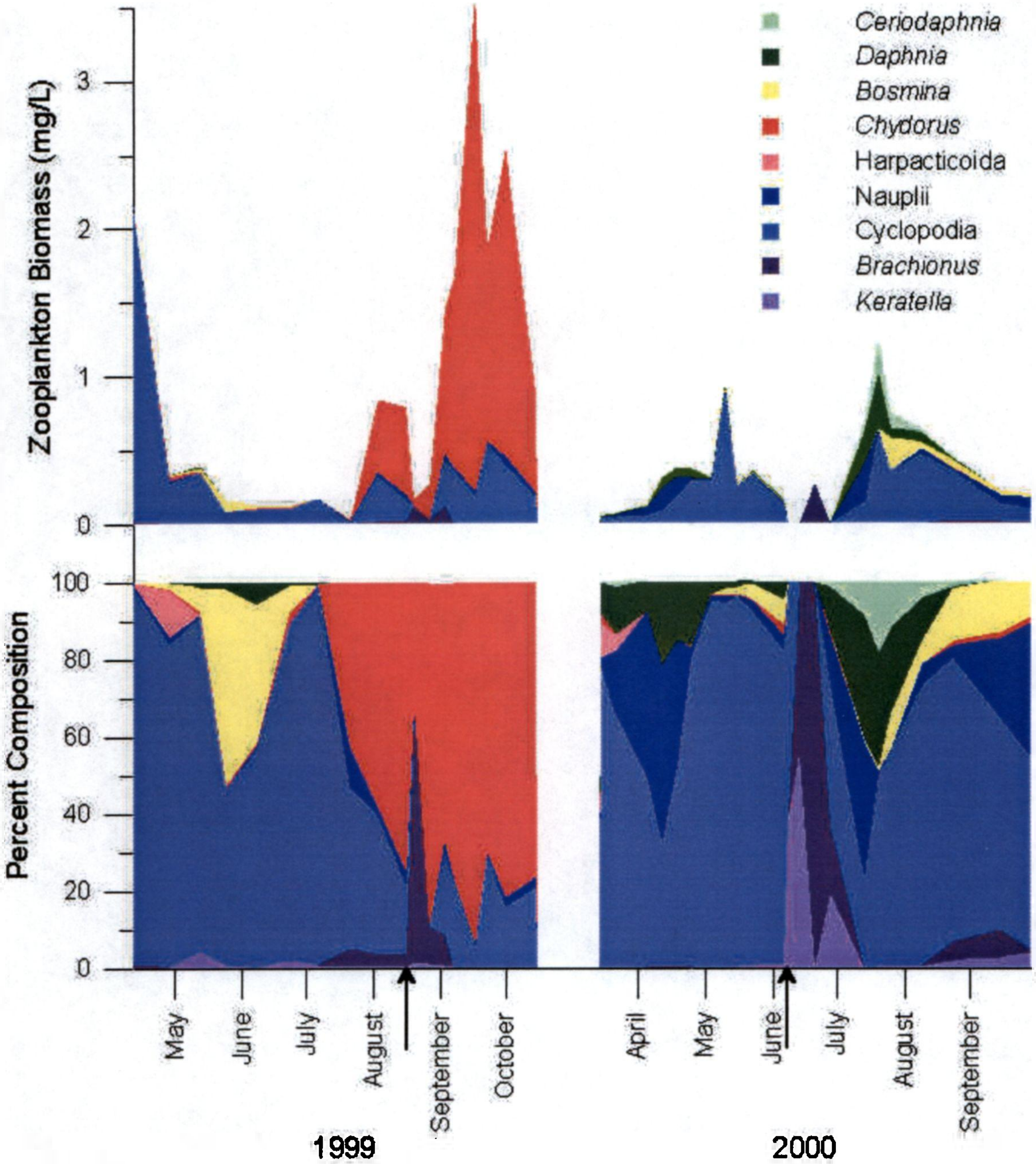


FIGURE 8. Box-whisker plot of cladoceran and copepod lengths during premanipulation (4/12/99 – 8/16/99), postmanipulation 1 (8/17/99 – 10/15/99), postmanipulation 2 (3/14/99 – 6/6/00), and postmanipulation 3 (6/7/00 – 9/27/00). Copepod nauplii were not included in these plots.

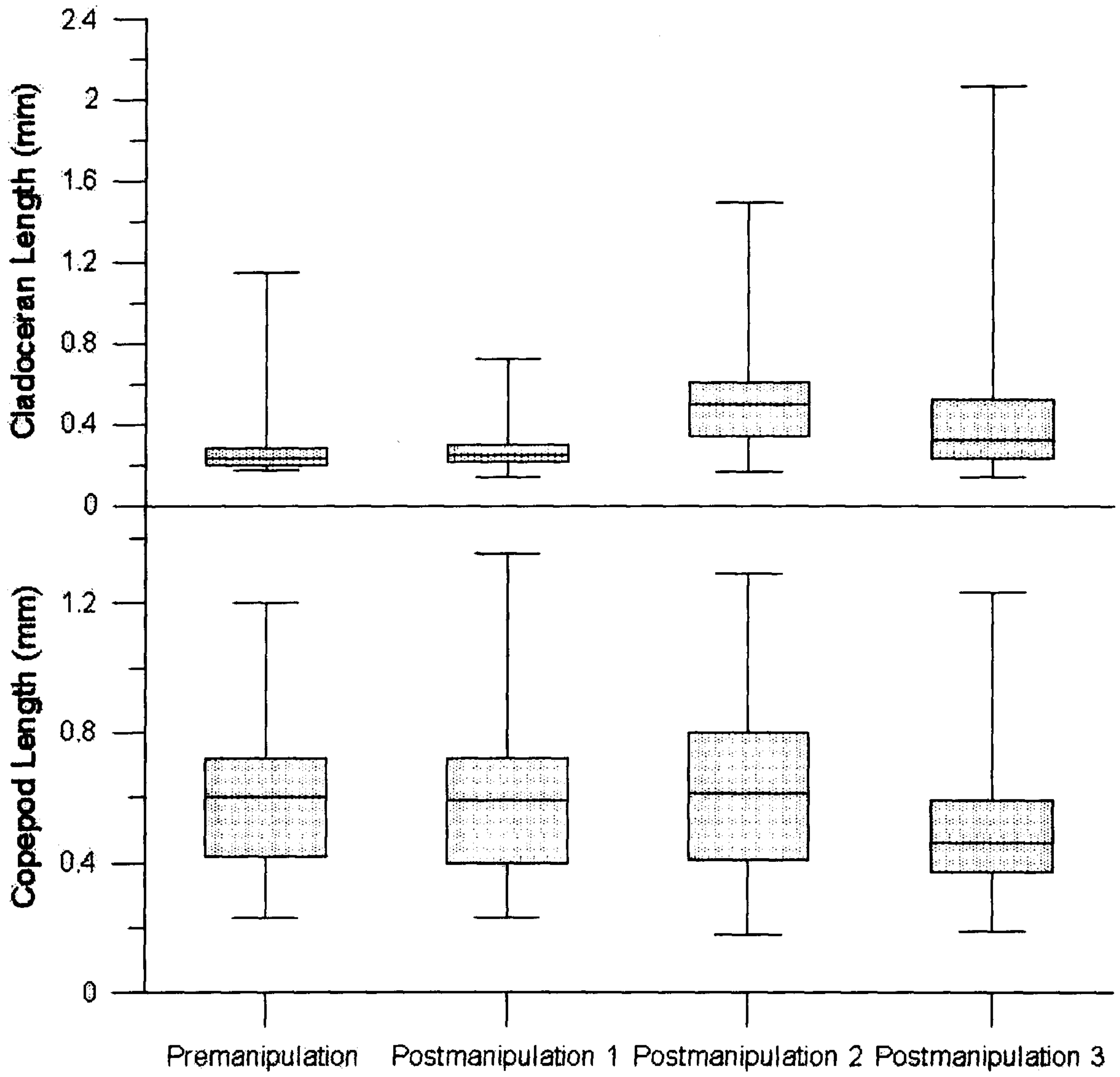


FIGURE 9. Grazing rate and phytoplankton biomass for Ventura Marsh from May 13, 1999 to September 27, 2000. Arrows indicate rotenone applications.

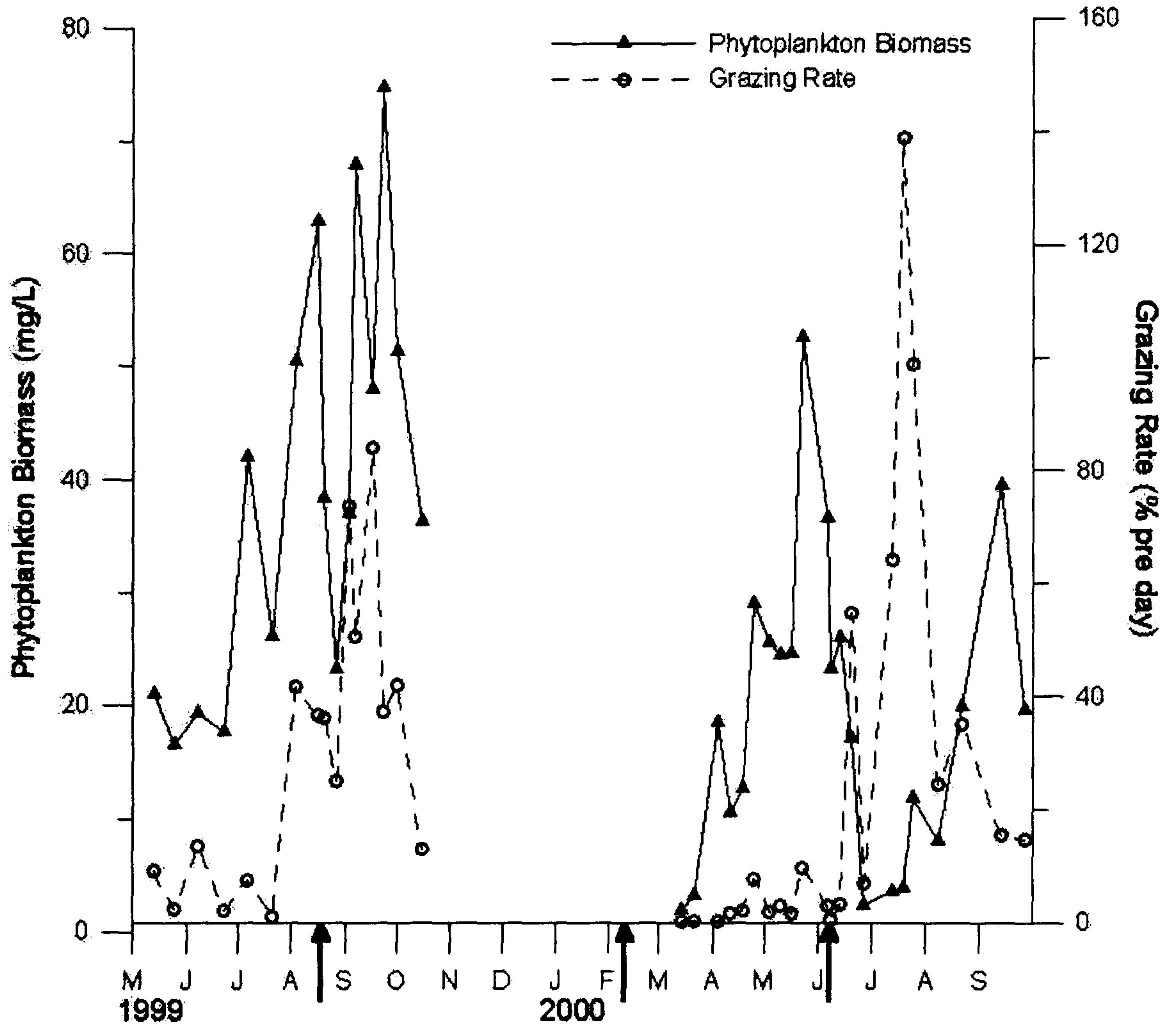


FIGURE 10. Benthic biomass and percent composition for Ventura Marsh from April 12, 1999 to September 27, 2000. Arrows indicate rotenone applications

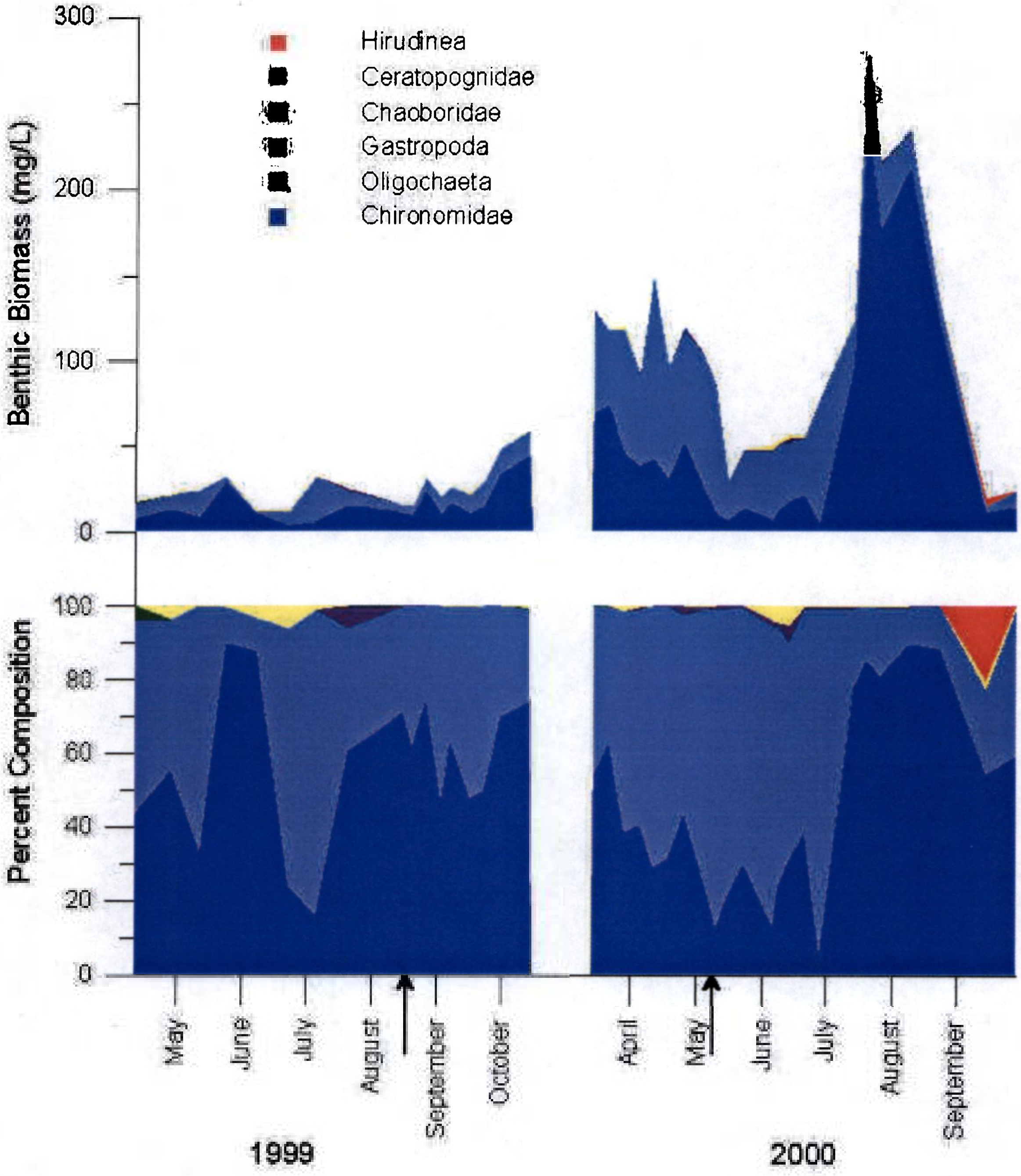
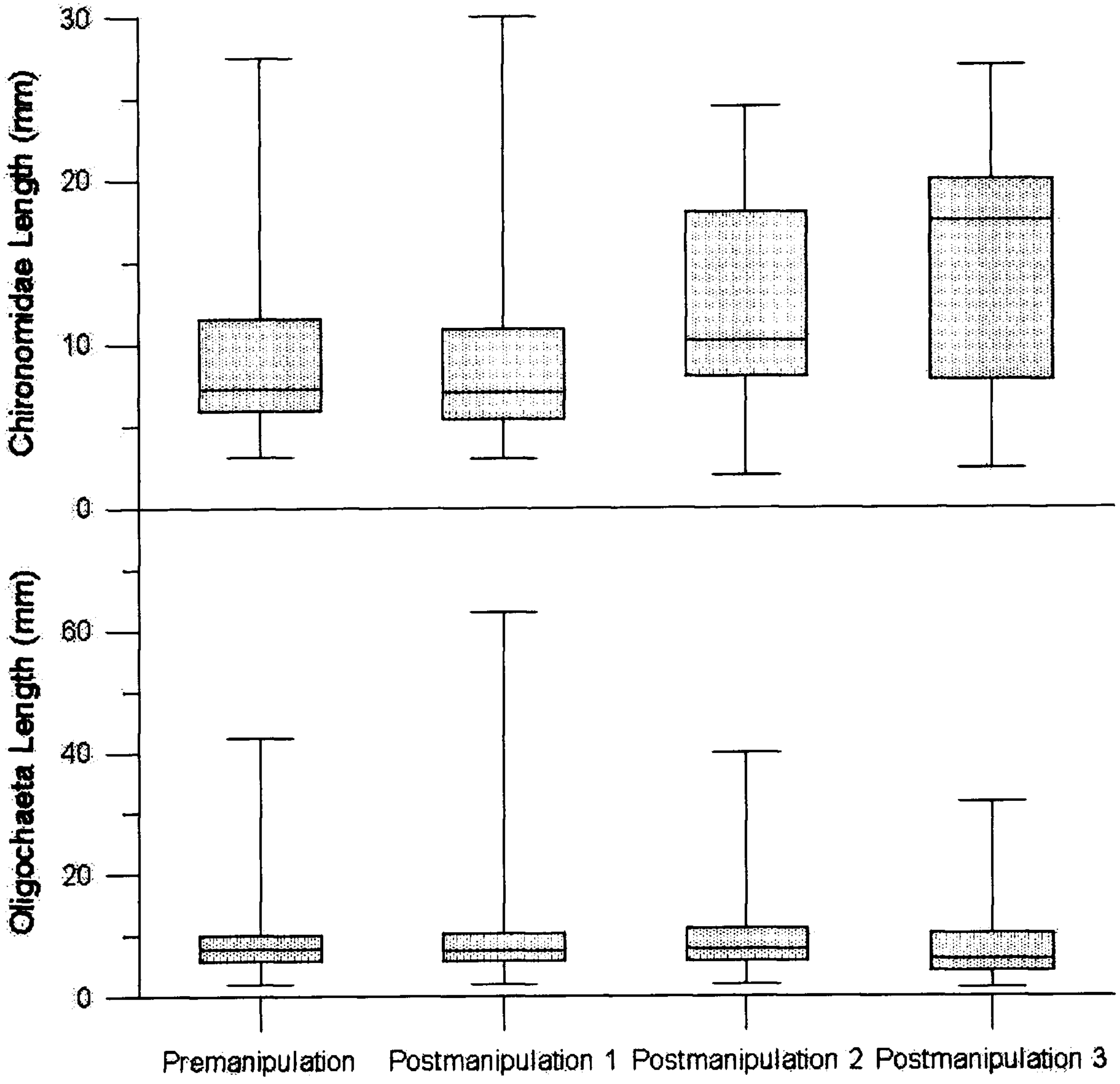


FIGURE 11. Box-whisker plot of chironomid and oligochaete lengths during premanipulation (4/12/99 – 8/16/99), postmanipulation 1 (8/17/99 – 10/15/99), postmanipulation 2 (3/14/99 – 6/6/00), and postmanipulation 3 (6/7/00 – 9/27/00).



CHAPTER 10

Watershed Analyses

Watershed Analyses

Jeff Kopaska and David Knoll

A. Introduction

A lake's watershed is an important feature, which partially determines the structure of the lake. The size, topography, geology, and climate of the drainage basin influence the types and quantities of materials that are transported to the lake. Fertile agricultural landscapes, of which Iowa is a prime example, have large amounts of available nutrients that can be moved off of the landscape and into lakes. Therefore, fertile landscapes tend to have fertile lakes. Different types of land uses within a watershed may also impact lakes in multitude of different ways. Thus, it is important to look at a lake's watershed to determine the ways in which the watershed is influencing the lake.

B. Tributary analyses

1. Introduction. Streams, drainage ditches, storm drains, and marsh outlets all carry water off of different areas of the Clear Lake watershed. That water moves through the landscape, picking up and carrying with it nutrients and sediment, all of which ultimately ends up in the lake. Sampling the different tributaries to Clear Lake allows the determination of how much water, nutrient, and sediment is carried to the lake. It also facilitates the determination of the total nutrient and sediment contributions of different areas of the watershed to the lake.

2. Methods. A network of stream sampling stations were established throughout the watershed to identify areas contributing greatest nonpoint source nutrient and sediment loads to Clear Lake. This network was comprised of thirty-seven sampling stations spatially distributed across the watershed (Fig. 1). Previously established methods for diagnostic surveys were followed in regard to sampling frequency. Grab samples of water were collected from each site (when they were flowing) during each sampling event, and nutrients were analyzed in the laboratory. Laboratory analytical techniques used are outlined in Standard Methods for the Analysis of Water and Wastewater (APHA 1994). Mean values for nutrient and sediment concentrations for all sites from the period of study are shown in Tables 1 and 2. Additional tables of raw data are presented in Appendix 8.

3. Results and Conclusions. Clear Lake is provided most of its surface water from Ventura Marsh. One additional area is an important supply of surface water in the Clear Lake watershed. This area lies to the north and west of Clear Lake, and drains into the western basin of the lake. Each of these areas had multiple sampling sites. The differences in nutrient and sediment concentrations in tributary water for these areas are shown in Tables 3, 4, and 5. These data show that the flows into the lake from the northwest tributary and Ventura Marsh have similarly high concentrations of phosphorus. The inflows to Ventura Marsh and the northwestern tributaries have similar concentrations of nitrogen, as well. Comparing Tables 4 and 5, it can be seen that Ventura Marsh acts to decrease the concentration of nitrogen in water leaving the marsh, but it increases the concentrations of total phosphorus and total suspended solids exiting the marsh.

Urban and residential areas are common in the Clear Lake watershed, and multiple sampling sites were located at the outlets of the storm drains that remove water from these areas. The storm drains from the rural residential area along the south shore of Clear Lake contained the highest concentrations of phosphorus (Table 6). Storm drains from Clear Lake and Ventura contained similar levels of phosphorus. Storm drains from Ventura and the south shore had the highest concentrations of suspended solids.

Public concern about potential human sewage inputs to Clear Lake led to the testing of selected tributaries for caffeine. The results of these tests are found in Table 7 and Appendix 10. Six of the twelve sampling sites tested for caffeine showed detectable, quantifiable level of caffeine at least once during the period of study. Site 20 (Fig. 1) was the most consistent, having quantifiable detections in four of the five tests. Site 26 had the highest concentration in any detection, at 500 nanograms/liter. Additional information concerning caffeine in storm drains is discussed in Chapter 6.

C. Nutrient and sediment loads

1. Introduction. It is important to know where the highest concentrations of pollutants occur, but knowledge of the mass or volume delivered through that point is of even greater utility. The nutrient load that a lake receives determines many of the chemical characteristics of that lake. The common human saying "you are what you eat" also applies to lakes, because lakes reflect their inputs. Nutrient and sediment loading to a lake includes inputs of nutrients (e.g. phosphorus and nitrogen) and sediments from sources such as surface runoff, precipitation and groundwater. Other sources of nutrients and sediments that are part of the lake's nutrient budget but are not included in this chapter are dryfall (aeolian inputs) and nitrogen fixation by cyanobacteria.

2. Methods. The annual input of phosphorus and nitrogen to the lake from surface runoff was estimated by summation of the inputs of all tributary streams to the lake. Surface runoff was calculated from discharges measured on tributary streams in the watershed. Grab samples of water were collected from each site at the time that discharges were measured, and nutrients were analyzed in the laboratory. Discharge was measured and samples were collected in the field periodically (two times per month in April-September, once per month in October-March). Measured flux was multiplied by 86,400 (the number of seconds in one day) to determine daily flux (m^3/day). The average of daily fluxes from two consecutive sampling dates was applied to the period between the two measurement dates to calculate periodic flux (m^3). Periodic fluxes were summed to estimate total annual water flux. Additionally, discharge was continuously monitored at two locations in the watershed, one agricultural and one urban tributary (Appendix 10). Flow data from continuously monitored sites were combined with basin areas and rainfall volumes to determine runoff coefficients for these basins. Annual runoff volumes derived from rainfall and runoff coefficients were compared to estimated water fluxes calculated from measured discharges for regularly sampled tributaries. Excellent agreement ($r^2 = 0.96$) was found between these two methods of determining water flux. Many tributaries in this watershed are ephemeral channels and do not flow regularly, thus it was difficult to accurately measure discharge from them. It was determined that using water flux calculated from drainage area, rainfall volume and runoff coefficient would be the most accurate method of estimating water flux, and this method was applied to all areas of the watershed. Periodic water fluxes (m^3) were multiplied by average nutrient concentrations (mg/L) for that period to determine periodic nutrient flux (raw data can be found in Appendix 8). Periodic fluxes were summed to determine total annual nutrient flux.

Annual nutrient flux is reported in this section for the period August 1998 – July 1999, referred to as 1999, and August 1999 – July 2000, referred to as 2000. The 1999 period of study was much wetter than an average year, with 48.63 inches of precipitation. The 2000 period of study was significantly drier than an average year, with 28.11 inches of precipitation. In an average year, 32.57 inches of precipitation fall at Clear Lake. (Source: http://www.agron.iastate.edu/climodat/table.html)

Calculation of nutrient loading from precipitation requires quantification of rainfall volumes and nutrient concentrations in rainfall. Estimation of these nutrient inputs requires accurate measures of local nutrient deposition, but no data collection station is located near Clear Lake. To address this problem, local volunteers were solicited to collect rainwater samples for analysis by ISU. Local samples revealed higher than expected rainwater nutrient concentrations. On average, rainwater contained 0.169 mg/L of phosphorus, 2.03 mg/L of nitrogen, and 26 mg/L of silica (raw data in Appendix 11). These average values were multiplied by periodic precipitation on the lake surface, and summed to attain annual precipitation nutrient inputs. A summarization of annual nutrient and sediment influx and efflux is shown in Tables 8 and 9, and the raw data can be found in Appendix 8. A summarization of nutrient and sediment influx from different areas of the watershed is shown in Tables 10 and 11, with site and sub-basin locations shown in Figure 2. Graphic illustrations of data combined from Tables 8-11 are shown in Figures 3 - 5.

3. Results and Conclusions. Nutrient (phosphorus and nitrogen) and sediment fluxes are greatest through the agricultural areas of the watershed in 1999 and 2000. The city of Clear Lake is also a significant contributor of nutrients and sediment to the lake. Additionally, Ventura Marsh acts as a sink for nitrogen, but it exported more phosphorus, silica, and sediment than flowed into it during the course of this study.

External phosphorus loading was very high for Clear Lake, and was well above the state average for both lake loading and watershed loss rate (Tables 12 and 13). Previous studies of Iowa lakes produced phosphorus budgets by multiplying mean annual tributary total phosphorus concentration by annual runoff. This method underestimates the impact of episodic high flow events on nutrient budgets, and did not include rainfall and groundwater phosphorus contributions. Using the old method, annual phosphorus input into Clear Lake would have been estimated at 4,390 kg, while this studies' calculation was 10,470 kg for 1999 and 4,968 kg for 2000. This could partially explain why phosphorus loading to Clear Lake seems to be much higher than phosphorus loadings calculated for other Iowa lakes (Table 3).

External nitrogen loading, found to be 11.0 g/m^2 in 1999 and 3.2 g/m^2 in 2000, was also high for this lake (Table 3). Clear Lake's surface inputs are similar to other Iowa natural lakes located in agricultural landscapes, as seen in Table 4. Watershed loss of 33.1 kg/ha in 1999 and 9.5 kg/ha in 2000 of nitrogen is high. With 59% of the watershed in row crop production, and inputs of over 200 kg/ha of nitrogen fertilizer to the watershed's cornfields, high nitrogen loss rates from the watershed are expected.

Viewing nutrient and sediment flux from the perspective of loss per hectare highlights problem areas. Tables 13 and 14 show yields of nutrients and sediment from different areas of the watershed. The south shore residential area loses the most phosphorus per unit area, but the entire watershed is remarkably similar in terms of areal phosphorus loss. Nitrogen losses are greatest from the north shore agricultural areas and the agricultural areas that flow into Ventura Marsh. Nitrogen amendment to crop fields in this area is generally 220-240 kg/ha, so these fields lost approximately 25% of the applied fertilizer during the wet period of 1998-1999. Sediment losses were relatively large from the city of Ventura in both time periods of the study. All agricultural areas (north shore, south shore, Ventura Marsh inflows) experienced high sediment losses in the wet period of 1998-1999, while the south shore agricultural and residential areas showed highest sediment losses in the drier 1999-2000 period.

Phosphorus and sediment loading to this lake during the course of this study seemed to be driven by three major factors. The first was major storm events that result in high fluxes of phosphorus and sediment to the lake. The second was high flows from Ventura Marsh in the wet portion of 1998-1999, which occurred prior to the fishery renovation. Water flowing from the marsh to the lake carried large amounts of phosphorus and sediment, probably due to the actions of wind and benthic fish in the marsh. The third factor driving phosphorus loading to the lake is rainfall (Tables 1 and 2). Rainfall in the Clear Lake area has an average phosphorus concentration of 0.169 mg/L, and the lake derived 53% of its water from direct precipitation onto the surface of the lake during the course of this study. Rainfall phosphorus accounted for around 20% of the lake's phosphorus budget in the wet period (1998-1999), and 40% of the lake's phosphorus budget in the drier period (1999-2000).

D. Basin characteristics and sources of impact (nonpoint source)

1. Introduction. Watershed models are useful tools in the process of watershed management planning. They aid in the process of identifying areas which may be contributing large amounts of nutrients or sediment to a waterbody, and they are helpful in pointing our problem areas or "hotspots" in a watershed. This model is not intended to exactly predict nutrient loads from particular areas, but instead to determine areas with relatively lesser and greater nutrient export potential. Additionally, the model can be used as an index of the types of changes we might expect from land use manipulation.

2. Methods. Records from NRCS offices, aerial photography and field surveys were used to determine the land use within the drainage basin of Clear Lake. Figure 6 is a map showing the distribution of land use patterns in the watershed. The acreages and percentages of each land use in the Clear Lake drainage basin are shown in Table 16. From these data, it can be seen that the majority of the watershed is in row crops (corn and soybeans), with 59% of the area in this land use. Nearly 21% of the basin is in permanent herbaceous vegetation (pasture, grass, grassed waterways, hay, marsh), while 5% is in timber. Urban land use comprises 10% of the watershed, while roads cover 5% of the land area. The remainder of the watershed is in other uses such as farmsteads.

The data on land use combined with previously described information on soils and topography provided some of the input into a watershed analysis tool called the Agricultural Non-Point-Source Pollution Model (AGNPS). The AGNPS model was developed by the Agricultural Research Service (ARS) in cooperation with the Soil Conservation Service (now NRCS) and the Minnesota Pollution Control Agency. The model estimates runoff, sediment and nutrient transport from agricultural watersheds for specified rainfall events. The nutrients analyzed are nitrogen (N) and phosphorus (P), which are both common fertilizers and major sources of surface water pollution (USEPA 1994).

In order to perform a GIS analysis of AGNPS modeling results, the watershed is divided into cells, and inputs are made for each cell. These inputs include soil type, land slope, cropping practices, and curve number. Whether designated officially as "CRP" land or not, fields being grazed were designated as "pastureland", hayland was designated as "grassland" and cropland designations were based on their actual use during the period of study. Our estimates of "CRP" and other land uses may therefore differ somewhat from official tallies. Such discrepancies would have little impact on the predictions made here as AGNPS input parameters for several of these non-cropped categories are substantially similar. Wetlands, ponds and tile-inlet terraces are considered as depositional areas of sediment and sediment-related nutrients.

Our modeling effort started by dividing the Clear Lake watershed into eleven distinct sub-basins that were modeled separately from each other. In total 24,875 0.22-acre (900 m^2) cells were used in the modeling effort. This area comprised the majority of the agricultural areas in the watershed. Data for the model were obtained from USGS topographic maps, Digital Elevation Models (DEMs), Iowa Cooperative Soil Survey soil maps and their associated attributes from the Iowa Soil Properties and Interpretations Database (ISPAID), visual inspections, the AGNPS User's Guide (Young et al. 1994), soil nutrient data obtained during the course of this study, water quality data obtained during the course of this study and USDA Agricultural Handbook 537 (1978). General model input data found in the AGNPS User's Guide included runoff curve numbers, overland Manning's coefficients, surface condition constants and chemical oxygen demand factors. Input data from the USDA Agricultural Handbook 537 included soil erodability factors, cropping management factors, and conservation practice factors.

3. Results and Conclusions. The AGNPS model was applied according to present land use practices, verified through field observations of actual field uses in 2000 and was then modified to simulate future land use scenarios designed to reduce inputs to the lake from the watershed. We modeled one storm event to simulate the typical rain event-driven loading seen in Iowa watersheds. This event was a 2-inch, 24-hour storm, which climatic records show to occur at least once annually. Some model input parameters are shown in Table 17. The results of the present conditions modeling are shown in Table 18 and Figure 7. This table shows sediment yields are relatively low for the entire watershed. Sub-basins 2, 3, 4, 5 and 10 (Fig. 1) export the greatest masses of nitrogen and phosphorus to the lake. The model also predicts that sub-basin 11 loses the most nitrogen and phosphorus on a per unit area basis.

The results from modeling nutrient and sediment loss under current conditions seem to reflect the general trend of field observations. Field observations also show subbasins 2, 3, 4, 5 and 10 losing the largest masses of nutrients. Model calibration was not possible because no comparable rain events were sampled by the continuous monitoring stations. Results from a prior study, Rock Creek, indicate that AGNPS model output comes close to accurately modeling soluble nutrient transport and water movement in the watershed.

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TABLE 1. Summary table of measurements made on all tributaries to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates and sites combined.

Parameter	**Units**	**Mean**	**Standard Error**	***n***
Total Phosphorus	µg/L as P	500	20	868
Total Nitrogen	mg/L as N	6.7	0.4	868
Nitrate-Nitrogen	mg/L as N	5.4	0.2	755
Silica	mg/L as N	67	7	796
Total Suspended Solids	mg/L	80	10	836

TABLE 2a. Summary table of measurements made on individual tributaries to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates combined.

Site	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	
1	540	2.0	0.08	Mean
	70	0.1	0.05	Standard Error
	18	18	17	*n*
2	666	2.0	0.05	Mean
	102	0.2	0.03	Standard Error
	18	18	17	*n*
3	460	5.9	0.11	Mean
	84	1.0	0.09	Standard Error
	19	19	18	*n*
4	445	3.6	0.014	Mean
	80	0.4	0.003	Standard Error
	19	19	18	*n*
5	671	2.2	0.05	Mean
	97	0.2	0.01	Standard Error
	18	18	17	*n*
6	508	1.8	0.05	Mean
	104	0.2	0.01	Standard Error
	17	17	16	*n*
7	522	2.1	0.07	Mean
	92	0.3	0.03	Standard Error
	12	12	12	*n*
8	971	8	0.09	Mean
	416	1	0.03	Standard Error
	19	19	16	*n*
9	649	2.3	0.20	Mean
	147	0.3	0.08	Standard Error
	7	7	7	*n*
10	465	3.4	0.08	Mean
	69	0.5	0.04	Standard Error
	15	15	12	*n*
11	260	13.2	0.02	Mean
	40	0.7	0.01	Standard Error
	57	57	54	*n*
12	508	0.8	0.1	Mean
	216	0.2	0.1	Standard Error
	2	2	2	*n*
13	1310	2	0.02	Mean
	590	2	0.01	Standard Error
	2	2	2	*n*
14	390	9.3	0.020	Mean
	36	0.6	0.007	Standard Error
	52	52	50	*n*
15	330	9.8	0.014	Mean
	41	0.5	0.004	Standard Error
	53	53	52	*n*
16	449	11.5	0.03	Mean
	60	0.6	0.02	Standard Error
	55	55	54	*n*
17	411	14	0.017	Mean
	54	6	0.005	Standard Error
	57	57	56	*n*

TABLE 2b. Summary table of measurements made on individual tributaries to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates combined.

Site	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	
18	403	3.5	0.061	Mean
	23	0.3	0.006	Standard Error
	49	49	47	*n*
19	328	8.5	0.028	Mean
	40	0.4	0.009	Standard Error
	56	56	55	*n*
20	412	12.1	0.05	Mean
	54	0.5	0.03	Standard Error
	59	59	57	*n*
21	1539	3	1	Mean
	658	2	1	Standard Error
	5	5	5	*n*
22	1463	2.4	0.2	Mean
	541	1.0	0.1	Standard Error
	7	7	7	*n*
23	536	2.6	0.4	Mean
	55	0.4	0.2	Standard Error
	37	37	36	*n*
24	569	1.6	0.09	Mean
	114	0.2	0.03	Standard Error
	37	37	36	*n*
25	489	1.9	0.03	Mean
	59	0.2	0.01	Standard Error
	32	32	31	*n*
26	499	2.1	0.12	Mean
	82	0.2	0.06	Standard Error
	48	48	47	*n*
27	458	5.5	0.07	Mean
	66	0.3	0.02	Standard Error
	43	43	42	*n*
28	4077	1.4	0.48	Mean
	1675	0.6	0.06	Standard Error
	3	3	3	*n*
29	896	1.8	0.4	Mean
	170	0.3	0.2	Standard Error
	4	4	4	*n*
30	927	2.3	0.16	Mean
	101	0.2	0.04	Standard Error
	17	17	16	*n*
31	797	2.0	0.08	Mean
	173	0.2	0.02	Standard Error
	16	16	15	*n*
32	470	2.3	0.019	Mean
	104	0.4	0.004	Standard Error
	16	16	16	*n*
33	719	3.0	0.06	Mean
	96	0.3	0.01	Standard Error
	17	17	17	*n*
34	774	2.3	0.021	Mean
	276	0.3	0.007	Standard Error
	13	13	12	*n*

TABLE 2c. Summary table of measurements made on all tributaries to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates combined.

Site	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	
35	437	5	0.007	Mean
	46	2	0.002	Standard Error
	3	3	3	*n*
36	150	2	0.011	Mean
	30	1	0.004	Standard Error
	2	2	2	*n*
37	544	2.7	0.027	Mean
	77	0.4	0.009	Standard Error
	13	13	13	*n*

TABLE 3. Summary table of measurements made on the northwestern tributary (sites 12-17), during the diagnostic study, July 1998 - September 2000. All dates and sites combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	µg/L as P	400	50	221
Total Nitrogen	mg/L as N	11	1	221
Nitrate-Nitrogen	mg/L as N	8.8	0.5	201
Silica	mg/L as N	47	2	210
Total Suspended Solids	mg/L	21	5	216

TABLE 4. Summary table of measurements made on tributaries to Ventura Marsh (sites 19, 20) during the diagnostic study, July 1998 - September 2000. All dates and sites combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	µg/L as P	370	30	115
Total Nitrogen	mg/L as N	10.3	0.4	115
Nitrate-Nitrogen	mg/L as N	9.2	0.4	105
Silica	mg/L as N	54	5	109
Total Suspended Solids	mg/L	38	7	112

TABLE 5. Summary table of measurements made at the outfall of Ventura Marsh (site 18) to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates and sites combined.

Parameter	Units	Mean	Standard Error	*n*
Total Phosphorus	µg/L as P	400	20	49
Total Nitrogen	mg/L as N	3.5	0.3	49
Nitrate-Nitrogen	mg/L as N	0.7	0.1	44
Silica	mg/L as N	64	5	46
Total Suspended Solids	mg/L	61	6	47

TABLE 6. Summary table of measurements made on urban storm drains to Clear Lake during the diagnostic study, July 1998 - September 2000. All dates combined.

Town (Sites)	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	
Clear Lake (1, 2, 4-7)	560	2.3	50	Mean
	40	0.1	10	Standard Error
	102	102	97	*n*
Ventura (9, 10)	520	3.1	120	Mean
	70	0.4	40	Standard Error
	22	22	19	*n*
South Shore (28-37)	900	2.2	110	Mean
	150	0.2	25	Standard Error
	55	55	53	*n*

TABLE 7. Results of tributary caffeine analyses during the diagnostic study, July 1998 - September 2000. Values are in nanograms/liter. N/A indicates the station was dry at the time of sampling, or no sample was taken; ** indicates an estimated value, because the value is below the 40 ng/l minimum detection limit; * indicates no detection of caffeine in the sample.

	Sampling Date				
Sampling Site	**08/19/98**	**08/24/99**	**02/08/00**	**08/22/00**	**09/27/00**
11	<40*	18**	12**	14**	N/A
14	N/A	N/A	N/A	62	26**
15	N/A	94	N/A	26**	N/A
16	<40*	48	<40*	37**	<40*
17	N/A	N/A	N/A	20**	35**
18	<40*	N/A	N/A	N/A	N/A
19	N/A	<40*	N/A	<40*	<40*
20	290	<40*	54	43	410
24	N/A	48	N/A	N/A	N/A
26	N/A	16**	N/A	500	N/A
27	N/A	<40*	N/A	<40*	N/A
41	<40*	N/A	N/A	N/A	N/A

TABLE 8. 1998-1999 nutrient and sediment influx and efflux from Clear Lake.

	Influx	Rain	Efflux	Net Retention	% Retention
Water (m^3)	19603696	18117733	12474557		
TP (kg)	8082	2388	2545	7925	76
TN (kg)	122640	38953	28691	132902	82
TSi (kg)	1535948	474141	623728	1386361	69
TSS (kg)	1117816	141318	349288	909846	72

TABLE 9. 1999-2000 nutrient and sediment influx and efflux from Clear Lake.

	Influx	Rain	Efflux	Net Retention	% Retention
Water (m^3)	5520325	10472743	853721		
TP (kg)	2963	2005	174	4794	96
TN (kg)	27321	19270	1964	44627	96
TSi (kg)	338451	268940	42686	564705	93
TSS (kg)	294896	144524	23904	415516	95

TABLE 10. 1998-1999 nutrient and sediment loading from different areas of the Clear Lake watershed.

Watershed Area	**TP flux**	**TN flux**	**TSi flux**	**TSS flux**	**Water Flux**
	kg	kg	kg	kg	m^3
Clear Lake	606	5,236	36,861	63,804	1,581,793
Ventura	188	1,062	34,011	31,422	368,056
South Shore Urban	219	1,052	34,375	9,939	379,393
South Shore Ag	499	6,214	87,375	60,236	1,439,119
North Shore Ag	1,448	43,365	290,773	170,100	4,030,369
Ventura Marsh Outflow	3,523	37,975	739,235	618,527	9,217,061
Ventura Marsh Inflows	2,381	78,640	513,762	472,010	7,018,543

TABLE 11. 1999-2000 nutrient and sediment loading from different areas of the Clear Lake watershed.

Watershed Area	**TP flux**	**TN flux**	**TSi flux**	**TSS flux**	**Water Flux**
	kg	kg	kg	kg	m^3
Clear Lake	204	503	11,752	19,504	335,109
Ventura	49	185	4,298	8,691	65,498
South Shore Urban	73	156	6,350	8,369	67,516
South Shore Agriculture	209	1,715	26,139	53,629	408,379
North Shore Agriculture	563	9,330	50,033	40,762	1,159,522
Ventura Marsh Outflow	936	7,934	95,432	101,767	2,649,884
Ventura Marsh Inflows	895	18,176	80,248	65,427	2,039,587

TABLE 12. Annual lake loading and watershed loss of selected nutrients for Clear Lake.

	1999 Lake Loading	**2000 Lake Loading**	**1999 Watershed Loss**	**2000 Watershed Loss**
Parameter Measured	g/m^2	g/m^2	kg/ha	kg/ha
Phosphorus	0.71	0.34	2.13	1.00
Nitrogen	11.0	3.2	33.1	9.5
Silica	137	41	411	124
Suspended Solids	86	30	258	90

TABLE 13. Comparison of phosphorus and nitrogen loadings among Iowa natural lakes.

	Years of Study	**Watershed Phosphorus Loss**	**Nitrogen Loading**
Lake		kg/ha/yr	$g/m^2/yr$
Black Hawk Lake	1981-1982	0.32	6.94
Clear Lake	**1998-1999**	**2.13**	**11.0**
Clear Lake	**1999-2000**	**1.00**	**3.2**
Crystal Lake	1998-1999	0.30	16.2
Okoboji chain (6 lakes)	1971-1973	0.35	N/A

TABLE 14. 1999 subbasin nutrient and sediment loss from different area in the Clear Lake watershed.

Site	TP loss		TN loss		TSi loss		TSS loss	
	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac
Clear Lake	2.3	2.0	20	18	138	124	240	214
Ventura	3.0	2.7	17	15	546	487	504	450
South Shore Urban	3.4	3.0	16	15	535	478	155	138
South Shore Agriculture	2.1	1.9	26	23	365	326	252	225
North Shore Agriculture	2.2	1.9	65	58	433	386	253	226
Ventura Marsh Outflow	2.2	2.0	24	21	460	411	385	344
Ventura Marsh Inflows	2.0	1.8	68	60	441	394	405	362

TABLE 15. 2000 subbasin nutrient and sediment loss from different area in the Clear Lake watershed.

Site	TP loss		TN loss		TSi loss		TSS loss	
	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac	kg/ha	lbs/ac
Clear Lake	0.8	0.7	2	2	44	39	73	65
Ventura	0.8	0.7	3	3	69	62	139	124
South Shore Urban	1.1	1.0	2	2	99	88	130	116
South Shore Agriculture	0.9	0.8	7	6	109	98	224	200
North Shore Agriculture	0.8	0.7	14	12	75	66	61	54
Ventura Marsh Outflow	0.6	0.5	5	4	59	53	63	57
Ventura Marsh Inflows	0.8	0.7	16	14	69	61	56	50

TABLE 16. Land use characteristics of Clear Lake watershed drainage basin.

Land Use	**Total Hectares**	**Total Acres**	**Percent of Watershed Area**
Row Crop	1969.9	4867.6	59%
Urban	335.4	828.9	10%
Marsh	294.1	726.6	9%
Grass	251.5	621.4	8%
Trees	182.5	451.0	5%
Road	152.1	375.8	5%
Farmstead	56.5	139.5	2%
Pasture	37.9	93.6	1%
State Park	26.8	66.1	1%
CRP	25.9	63.9	1%
Hay	9.2	22.7	<1%
Terraces	2.6	6.4	<1%

TABLE 17.

Parameter	**Present Conditions**
Soil # N/# soil	0.0025
Soil # P/# soil	0.00072
N in soil pores (ppm)	10.7
P in soil pores (PPM)	0.34
Organic Matter (%)	5
N fertilizer (#/ac)	100
P fertilizer (#/ac)	65

TABLE 18. Calculated sediment and nutrient inputs to Clear Lake from single storm event modeling present conditions.

Parameter	2-inch, 24-hour Storm Event	
	Metric	Imperial System
Phosphorus		
Sediment associated	1,598 kg	3,523 lb
Water soluble	444 kg	979 lb
Nitrogen		
Sediment associated	5,706 kg	12,580 lb
Water soluble	1,542 kg	3,399 lb
Sediment	261,274 kg	288 tons
Lake volume lost	181 m^3	0.09 ac-ft

FIGURE 1. Sampling sites and sub-basins used for modeling purposes in the Clear Lake watershed.

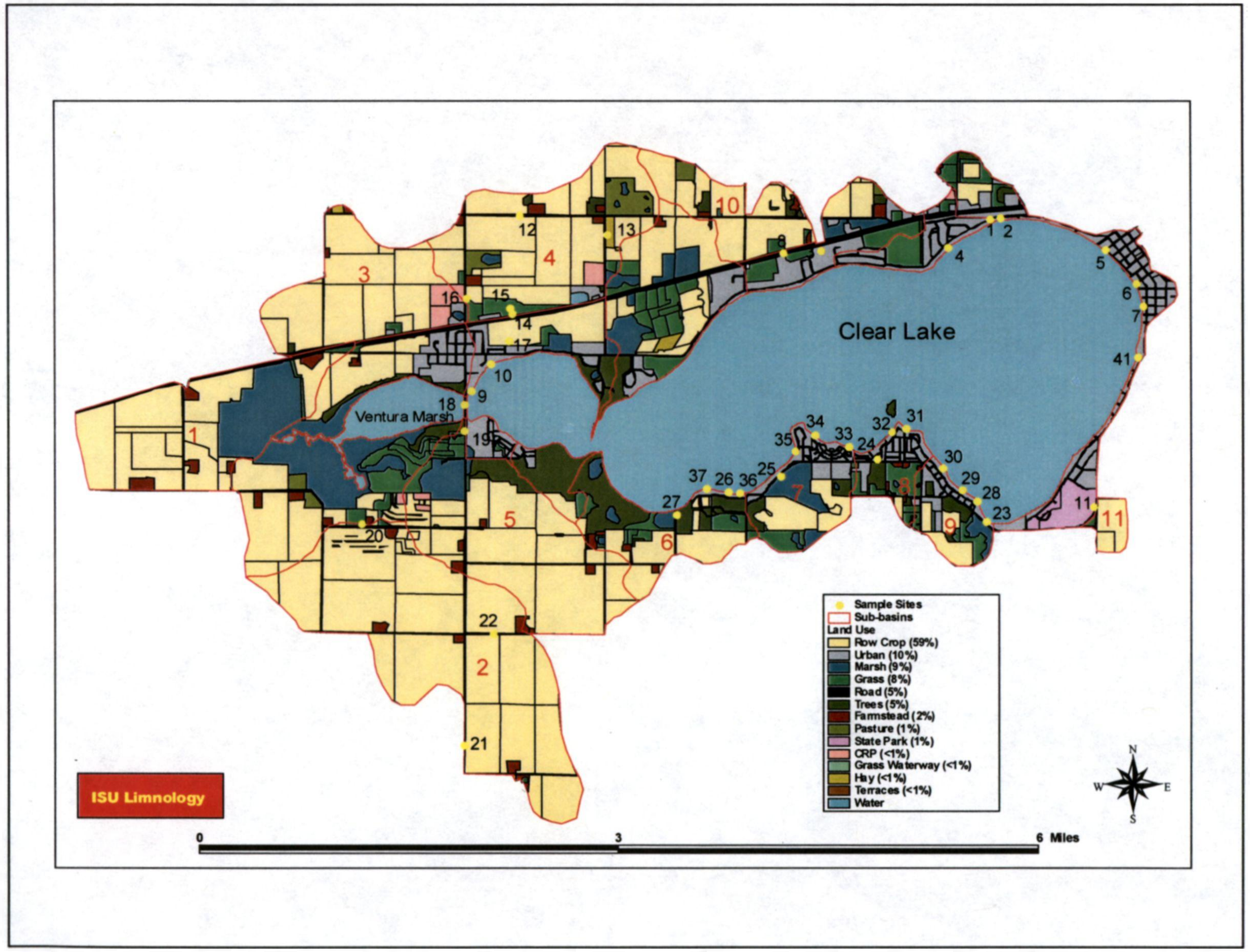
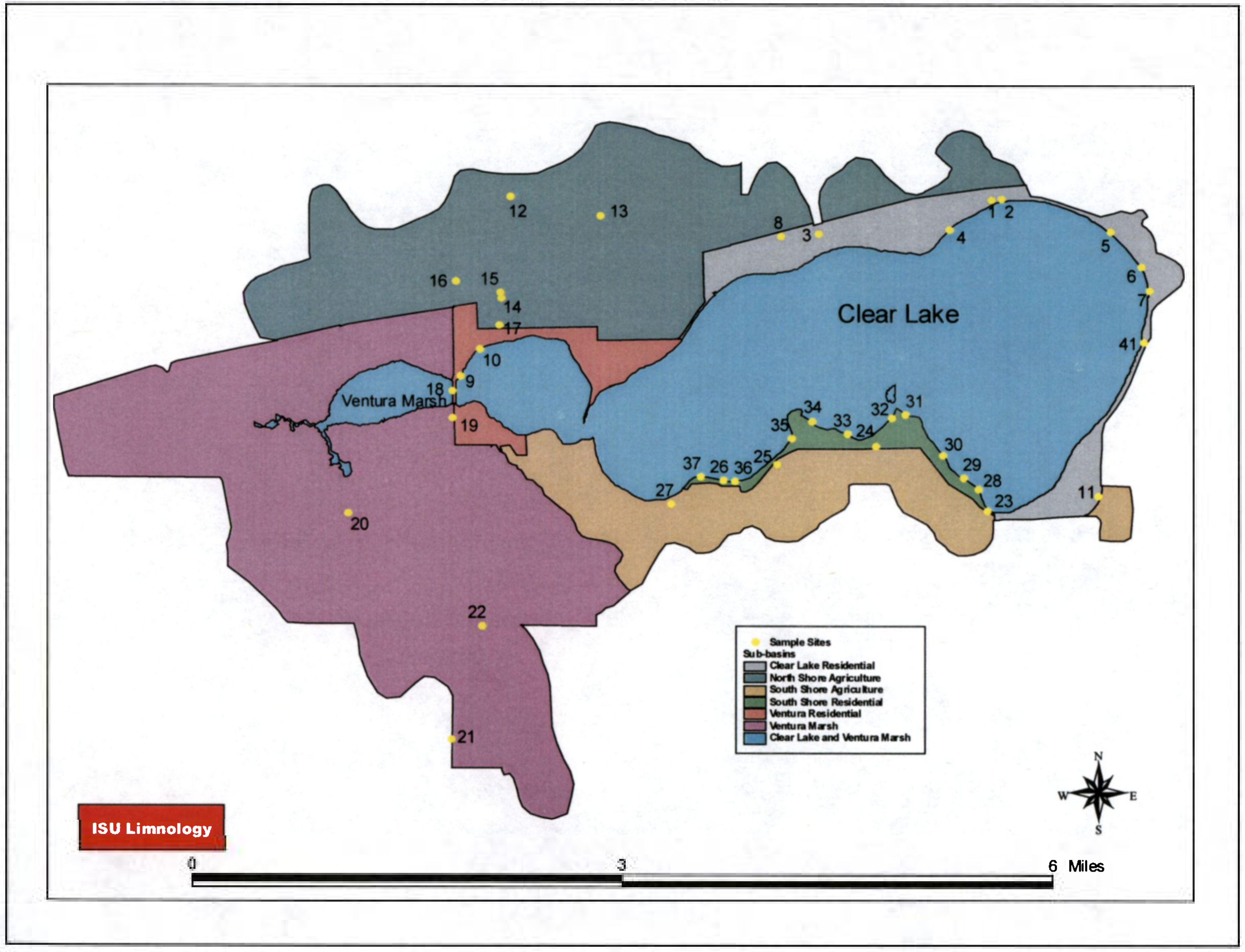


FIGURE 2. Watershed areas differentiated for nutrient flux calculations in the Clear Lake watershed.



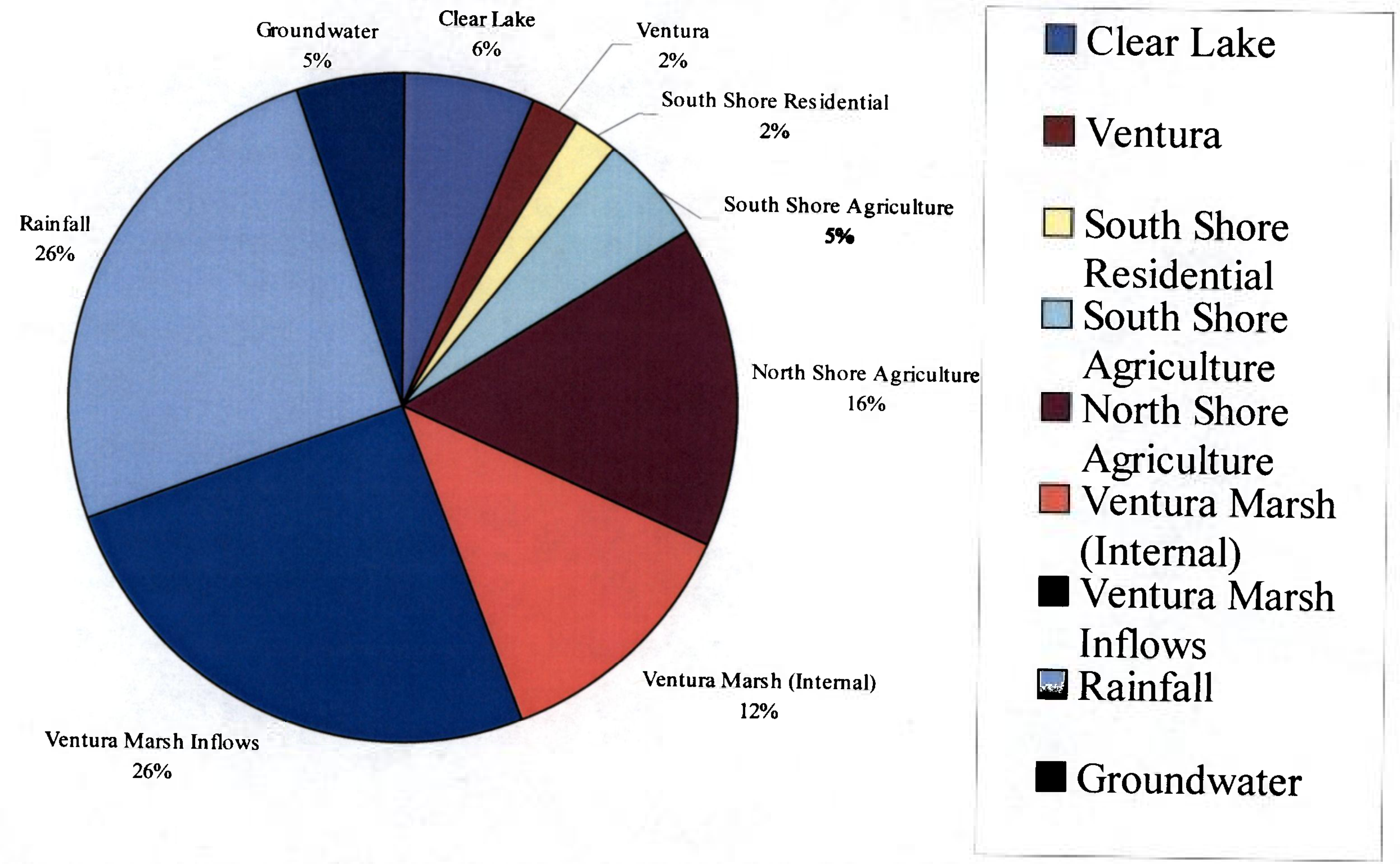


Figure 3. 1998-1999 Total Phosphorus load (kg)

Figure 4. 1999-2000 Total Phosphorus load (kg)

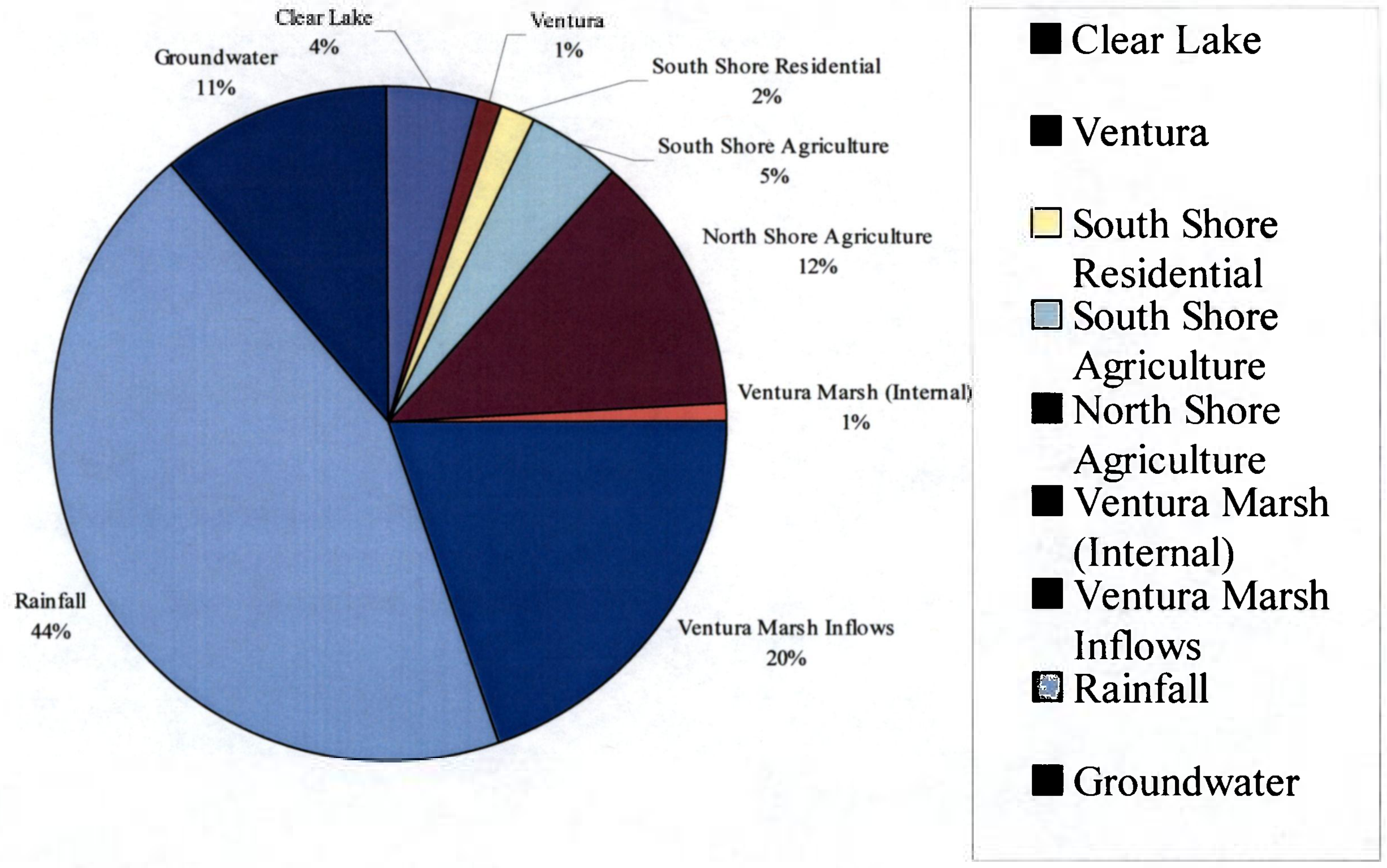


Figure 5. Average Total Phosphorus load (kg)

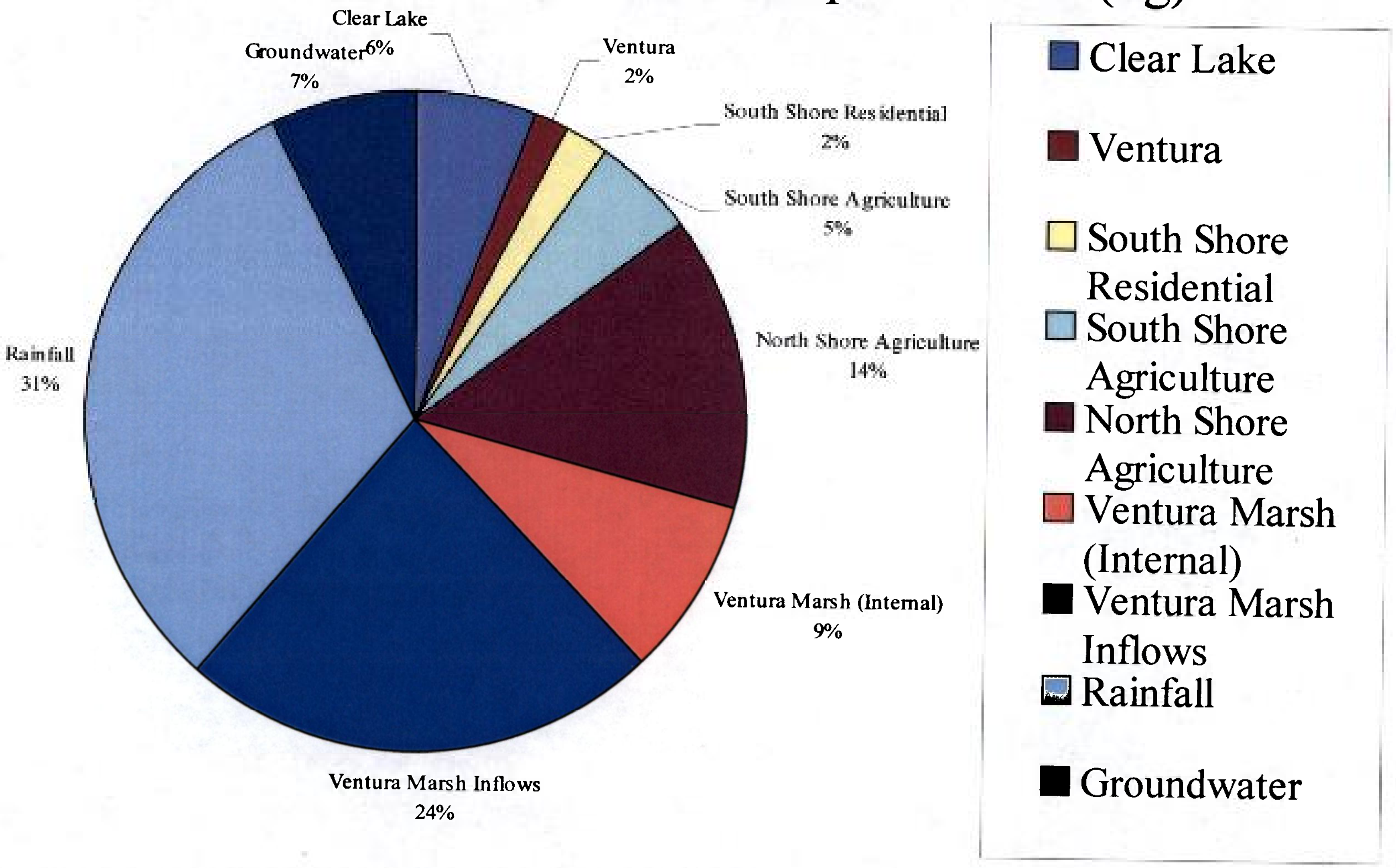


FIGURE 6. Land uses in the Clear Lake watershed.

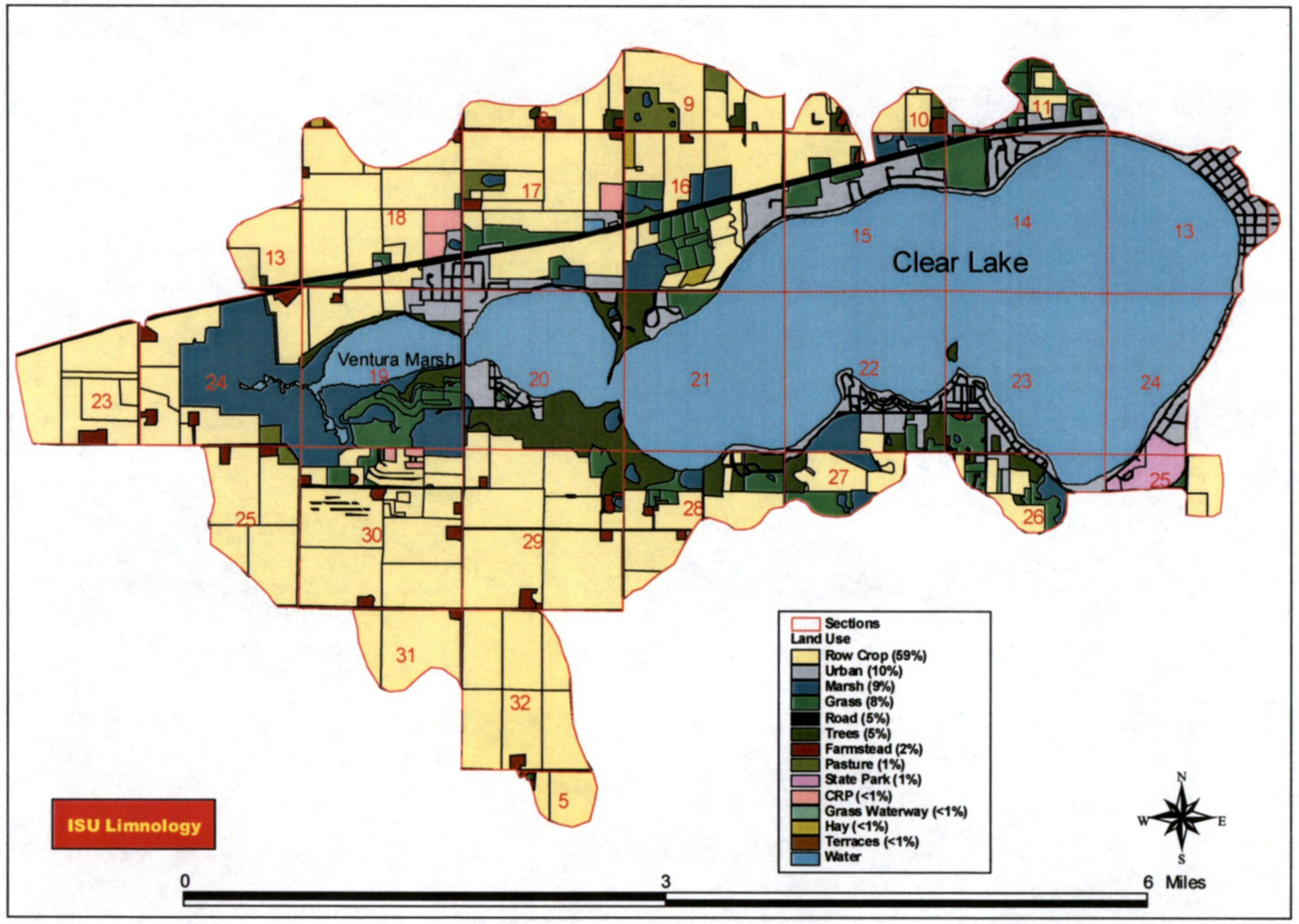
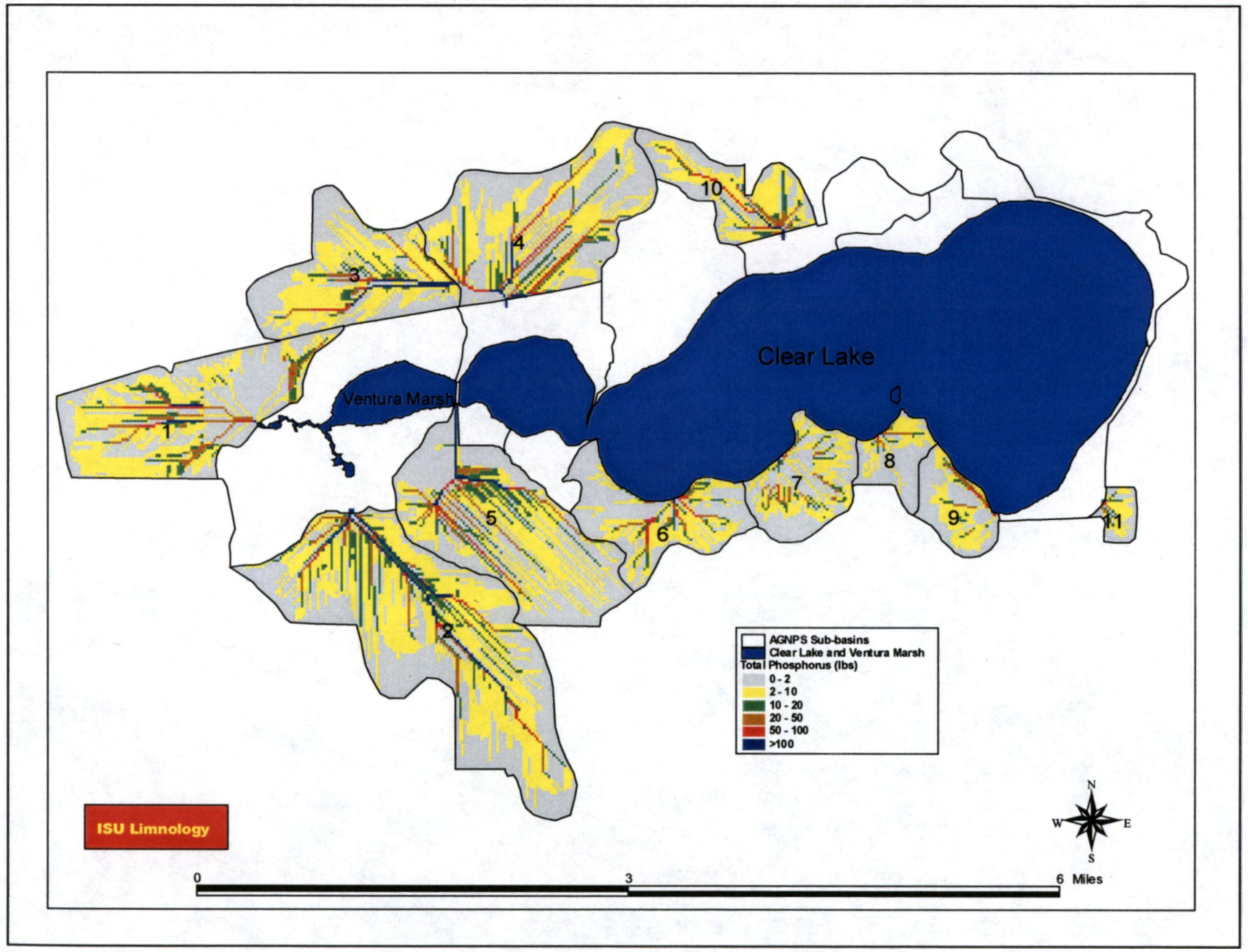


FIGURE 7. Present conditions modeling results from AGNPS model for the Clear Lake watershed.



CHAPTER 11

Soil Test and Agricultural Management Practices Survey of the Clear Lake Watershed

Soil Test and Agricultural Management Practices Survey of the Clear Lake Watershed

Antonio Mallarino and Jeremy Klatt

A. Introduction

This work was a component of the project Clear Lake Restoration Diagnostic and Feasibility Study lead by Dr. John Downing (Department of Animal Ecology), which included other components and co-investigators. Objectives and methods of the overall project, and how the component fits with the overall project objectives were described in the original project. The objective of this component was to survey surface soil test values, with emphasis on phosphorus (P), and nutrient management practices within the agricultural area of the watershed. This information is a key aspect that should help understand and assess the role of nutrient levels and management practices on the nutrient load to the lake and its water quality status. This knowledge will help determining alternatives for improving the water quality of the lake.

B. Methods

The work included a survey of nutrient levels in soils that involved extensive soil sampling and a survey of relevant soil and crop management practices. Plans for both surveys were developed during summer and early fall of 1999 in cooperation with personnel of the CLEAR Project, in particular with Mr. Ric Zarwell, who was CLEAR Project Coordinator until December 1999. Efforts until early September were directed toward developing the plan for the survey and to request permission from landowners to collect soil samples from their fields. This part proved to be more difficult than expected, and finally permission was denied for approximately 20% of the fields. Except for the small agricultural area at the extreme southeast corner of the watershed, however, the information collected provides a good representation of nutrient status and agricultural practices in the watershed.

1. Management Practices Survey. A two-page questionnaire was mailed or delivered in person to all landowners or operators from whose fields soil samples were collected in order to obtain information of agricultural practices that are occurring in the watershed. The questionnaire requested information about crop rotation, tillage system, and rates of application and type of P fertilizer, nitrogen (N) fertilizer and manure used during the last five years. Sixty-six percent of the surveyed farmers responded, which represents approximately 60% of the land in the watershed. This success rate is typical of these types of surveys (when no payment is included), and this high rate was achieved only after repeated telephone calls and some personal visits.

2. Soil Nutrients Survey. The soil sampling strategy was planned based on available information on field borders, soil types, current crop and planned fall fertilizer management. Consideration of the objectives, characteristics of the watershed, previous information of areas from where seemingly much of the P load to the lake could be derived from and the available budget were key aspects for deciding among several soil sampling alternatives. The sampling plan chosen was a systematic stratified sampling method, in which predominant soil map units of each field were sampled following a point mapping and sampling strategy. In a first step, approximately 500 small sampling areas (points) about 0.2-acre in size were identified within the predominant soil map units within each field on the basis of digitized and georeferenced soil survey maps, georeferenced maps of field borders, surface drainage, aerial photographs and visual observations of the watershed. Geographical Information Systems (GIS) techniques and ArcView computer software were used to produce several layers of information. A second step involved a field verification and modification (when necessary) of the location of the sampling points through use of hand-held Global Positioning Systems (GPS) receivers and field observations. The original number of 500 desirable sampling points had to be reduced to approximately 340 due to several reasons. These included lack of permission to sample several fields, that a small number of fields could not be sampled because contrary to our request the farmers applied P fertilizer immediately after harvest and before samples could be collected, and because of budget limitations. In a third step, one composite soil sample made up of 15 to 20 soil cores were collected from the top 6 inches of soil of each sampling area. This is the sampling depth recommended by ISU for agronomic soil tests. The GIS map in Figure 1 shows the sample points location.

All soil samples were dried, ground to pass a 2-mm screen, and analyzed in duplicates by several agronomic soil tests supported by Iowa State University. These included analyses for Bray-1 P (which will be referred to as the Bray test hereon), Olsen (or sodium bicarbonate) P, Mehlich-3 P (which will be referred to as M3 test hereon), ammonium acetate-extractable K, Ca, and Mg, soil pH and organic matter. The Bray test is the most commonly used P test by soil test laboratories and farmers in Iowa, and the Olsen P and M3 P tests provide a different assessment of soil P, mainly in high-pH soils. In addition, all soil samples were analyzed by the two environmental P tests most commonly used in ongoing research across the United States. These type of tests are the object of intensive research in Iowa and other states because they could provide a different assessment of the potential impact of soil P levels on P losses with water runoff or through the soil profile. Agronomic soil P tests were developed and calibrated to predict P sufficiency for crops, not necessarily to predict P losses to water resources. The tests chosen were the iron oxide-impregnated paper P test (which will be referred to as the Iron-oxide test hereon) and the deionized water extraction test (which will be referred to as the Water test hereon). The procedures used are not described here, but information can be found in published articles. Procedures followed for all agronomic tests were those described in the North Central Region Publication 221 (Brown, 1999), which includes agronomic soil test procedures recommended by the North Central Region Committee for Soil Testing and Plant Analysis (NCR-13). Procedures followed for the two environmental P tests were those described in the Southern Cooperative Series Bulletin 396 (Pierzynski, 2000), which includes procedures for a variety of P tests recommended by the national committee Minimizing Phosphorus Losses from Agriculture - Information Exchange Group (SERA-17/IEG).

When soil-test P values were summarized into GIS maps, values of agronomic soil P tests were grouped into the agronomic soil test interpretation classes used by Iowa State University. Two modifications were made, however, to better describe the results. One was that the Very

Low and Low classes were merged because very few fields tested Very Low and little distinction can be made between these two classes for the purpose of environmental conservation. The other modification was to split the Very High class into two classes to better describe the high-testing soils. The Optimum class (16 to 20 ppm for the Bray or M3 tests and 10 to 14 ppm for the Olsen test) defines soil test values for which only maintenance fertilization is recommended to account for P removal in harvested products. No P fertilizer is recommended for the High or very High classes by Iowa State University.

3. Data Management Procedures. The procedure used to summarize the soil P and field history survey information was to summarize the information for various sub-watersheds delineated according to surface drainage patterns. Regression and correlation techniques were used to study how the various soil test extractants assessed soil P.

C. Summary Results

1. Field Management Practices. Summaries of relevant field history are shown in Table 1 and several figures. The Clear Lake watershed is dominated by row-crop agriculture. Eighty-nine percent of the acreage surveyed was in a corn and soybean rotation (Fig. 2). Of the remaining 11% of the land, 7% was being cropped for corn continuously and the remaining land was either set aside as part of the Conservation Reserve Program (CRP) or under alfalfa or pasture.

The most common tillage practice in the watershed is a tillage system that includes chisel plowing in combination with disking and/or field cultivation. Forty-eight percent of the land was managed with this tillage system (Fig. 2). The remaining fields under row-crop production were split between no-till (21%), ridge-till (18%), moldboard plow (7%), and those that include V ripping (6%). From a soil conservation perspective, the moldboard plow system is the most prone to produce soil erosion and the no-till system usually produces the lowest soil erosion. The other tillage systems usually rank intermediate and their impact on soil erosion is highly dependant on the residue cover.

The most common P application method in the watershed is to incorporate the fertilizer into the soil in the fall by plowing, disking, or injecting. Forty-four percent of the land had P applied in this way. The next two most common methods were broadcast application in the fall without incorporation (13%) and injection or incorporation of the fertilizer into the soil in the spring (4%). Fall application with incorporation is the preferred method for P application from an environmental perspective as most runoff events occur in the spring. Injecting or incorporating is preferred over leaving it on the soil surface because this reduces the risk of P loss with surface runoff. When a no-till system is used, however, the advantage of incorporating P fertilizer or manure by injecting into the soil over a surface application with good conditions (other than application to frozen, water saturated, or snow-covered ground) is not clear, however. Commonly used injection equipment cause significant soil disturbance, which may increase soil erosion and total P loads to surface water resources. Soil loss (and loss of P attached to soil particles) is very small for no-till or pastureland that receives broadcast fertilizer or manure applications but loss of dissolved P can be high when soil conditions are adverse.

On average, during the last five years P fertilizer was applied 2.2 times. When P fertilizer is applied, it is typically applied at a rate of about 65 lb P_2O_5/acre. For comparison, Iowa State University recommends 70 lb P_2O_5/acre be applied once every two years to soils testing in the optimum range in a corn and soybean rotation. The Optimum range for the Bray or M3 soil P tests is 16-20 ppm. Consideration of the average M3 soil test P value of 40 ppm and the average application rate of 65 lb P_2O_5/acre may suggest that the watershed is being over fertilized, which is typical of most agricultural regions of Iowa. However, a close look at specific areas of the watershed shows that some fields testing much higher than the average are also being fertilized. These observations suggest that many farmers in the watershed are managing their land using recommended rates of application and that only a few are over-fertilizing their fields. This aspect will be visited further when results of the soil sampling are discussed.

Only 4% of the land received fall-applied N. In the last several years there has been a push to reduce fall application of N on agricultural lands. Nitrogen, unlike P, is very mobile in the soil and under the right conditions can be lost with surface runoff or leach through the soil profile into sub-surface drains or to groundwater supplies. The most common application method was broadcasting without incorporation in the spring (50%), followed by spring sidedressing (26%), and injection (11%). The remaining land had no N applied (8%). On average in the last five years, farmers have applied N 2.4 times to their fields. Farmers, for the most part only apply N before corn due to the ability of soybeans and forage legumes to fix atmospheric N. When applied, it is typically applied as anhydrous ammonia at a rate of about 130 lb N/acre.

Our survey showed that 18% of the farmland had received manure in the previous five years. The responses in most cases provided insufficient data concerning rates of manure application. Manure often can be overapplied to certain areas in order to dispose of it, which creates high nutrient levels in concentrated spots. The data actually shows, however, very similar average soil P tests for manured fields and nonmanured fields in this watershed. The average M3 soil test P value of manured soils was 34 ppm while nonmanured soils averaged 40 ppm. Manure is also thought to create more variability within a field but our data suggests very similar variation of P in manured and nonmanured soils. Our numbers showed higher organic matter percent and calcium in fields where manure was frequently applied.

2. Soils of the Watershed. The Clear Lake watershed is dominated by loam and silty-clay loam textured soils under a predominately agricultural setting. The soil survey map is shown in Figure 5. Background chemical analyses of the collected samples that are useful to describe the fields include organic matter, and extractable K, Ca, and Mg. Mineral soils predominate and have an average organic matter content of 5.7%. According to the digital soil survey maps, these soils typically have a cation-exchange capacity ranging from 0-65 (meq/100 gm) with an average of about 22 (meq/100 gm). The average pH in the watershed was 6.6. Calcium and Mg concentrations averaged 3357 ppm and 380 ppm respectively. The K values, which ranged from 49 ppm to 502 ppm and averaged 170 ppm, indicate that there is extensive but very uneven K fertilization occurring in the watershed. The optimum range for K for corn and soybeans as recommended by Iowa State University is 90-130 ppm. The landscape forms, soil types, and drainage patterns, which have strong influence on nutrient delivery to the lake were considered together with soil-test P data in others components of the project.

3. Soil Test Phosphorus.

a. Soil P assessment by five soil P tests. There were differences in amounts of P extracted by the five soil P tests used. Differences or similarities between tests and reasons for any difference should be discussed before interpreting distribution of soil-test P across the watershed. Average amounts of P extracted by the five methods are shown in Table 2. The M3 soil test extracted the highest amount of P followed very closely by the Bray test in most samples (except in those with high pH). Iowa research has shown that this test usually extracts similar to or only slightly higher amounts of P than the Bray test, except when soils have high pH and calcium carbonate content. This result was confirmed in this project because the Bray extracted much less soil P than the M3 in soils with pH 7.2 or higher. The Olsen and Iron-oxide test extracted very similar amounts of P that were less than the amount extracted by Bray or M3 tests. The Water P test extracted the lowest amount of P. All soil tests used with agronomic or environmental purposes extract only a small proportion of the total soil P, which includes the P fraction assumed to be better related to soil P sufficiency for crops (for the agronomic tests) or to potential loss of P dissolved in water (for the environmental tests). Current Iowa research is developing field calibrations for these tests and others in relation to potential loss of P to water resources. The ongoing research has not determined clear differences between the tests, and this is the main reason these five tests were chosen for this survey.

Three of the five soil P tests used were highly correlated across all samples collected (Table 3). The correlation coefficients between the M3, Olsen, and Iron-oxide P tests were very high and ranged from 0.96 to 0.97 across samples. Correlations involving the Bray and Water P tests were variable and usually lower. Correlations coefficients for the Bray test, the most commonly used agronomic P test in Iowa, were the lowest and ranged from 0.88 with the Water test to 0.92 with the M3 test. Correlations coefficients for the Water test (an environmental P test) were intermediate and variable, and ranged from 0.91 with the Bray test to 0.96 with the Iron-oxide test (which is another environmental P test). These differences in correlations between tests may suggest differences concerning estimates of P loss from the fields with surface runoff and tile drainage. While the Bray, M3 and Olsen tests are used for agronomic purposes, the environmental tests would predict better potential P delivery to surface water resources. The correlation between the Bray soil test and the other tests across all samples was poorer because this test extracted proportionally less P from soils with pH higher than 7.2, which likely were calcareous. This is a common occurrence observed in Iowa soils. Of the 332 samples analyzed from the watershed, 109 had pH higher than 7.2 and tended to have the highest exchangeable calcium concentrations. Correlation coefficients in Table 3 that included only soils with pH less than 7.2 showed much higher correlations for the Bray test. The intermediate and variable correlations for the Water test either across all soils or for noncalcareous soils suggest that this test extracts slightly different P fractions than other tests from different soils.

Overall, the only test that clearly departs from the others was the Bray test in high pH soils. This result may indicate that the Bray test should not be used across all fields in this watershed for agronomic assessment because it would underestimate sufficiency levels for crops. Conclusions concerning assessments of the potential P loss to the lake are not so clear cut, however. The Bray test would underestimate the amount of P tied-up to soil particles that could reach the lake in eroded soil. However, the presence of calcium carbonate could reduce P that could be released from the soil phase of the soils and that could be transported dissolved in water though surface runoff or subsurface drainage. If this were the case, the Bray test would provide a more accurate assessment of dissolved P loss. Theoretical considerations suggest that the two environmental tests would be less affected by soil properties and would provide better assessments of the potential P loss across all conditions. The soil test correlations suggest, however, that the Iron-oxide, M3, and Olsen tests provided similar environmental assessments which differed slightly with assessments obtained by using the Bray and Water tests.

b. Distribution of soil-test P throughout the watershed. There was a wide range of soil test P values throughout the watershed. Data for the individual soil samples collected from each field showed that values for the M3 P test (for example) ranged from 2 to 395 ppm across the watershed while values for the water P test ranged from 1 to 68 ppm (not shown). These wide ranges of values confirm that there has been extensive P fertilization occurring in the watershed. Available soil P of most Iowa soils was in the Very Low or Low interpretation classes until approximately the mid 1900s, and were increased to current levels by fertilization and/or manure management practices. The average M3 P test across the watershed was 40 ppm while the median value was 32 ppm. The median may be a better value to look at to prevent a few very high soil samples from skewing the data. The median value is higher but not very much higher than the value considered optimum for agronomic purposes (20 ppm). Also, although this median value is high, it is not far from the range that could be considered acceptable (16 to 25 ppm) if the usually very high variability in soil tests due to high and largely unavoidable sampling error is considered. Iowa research shows that a soil test value of about 30 ppm would drop into the Optimum level within two to three years of cropping without P fertilization.

The distribution of soil test values for sub-watersheds is shown in several GIS maps. On a field basis, using the M3 P test as an example, soil P ranged from 6 to 296 ppm across the fields of the watershed and averaged 41 ppm. Several fields tested very high in P. Approximately one third of the fields tested Very High by any of the three agronomic soil tests. The high-testing fields were spread without clear patterns across the watershed. In spite of lower correlations discussed above for the Bray and Water P tests, the five tests used tended to agree in identifying high-testing fields.

The other approach used for summarizing the soil test information was to calculate averages for sub-sections of the watershed delineated according to surface drainage patterns. The results of using this approach are shown in the GIS maps in Figures 4 to 9. This approach provides a slightly different perspective of the distribution of soil P and better idea of the potential impact of current management practices in different parts of the watershed on P loads to the lake and, also is useful to identify sub-watersheds where changes in P or soil conservation practices are most urgently needed. Continued use of the M3 P test as an example shows that soil P levels ranged from 18 to 65 ppm across all sub-sections of the watershed. In spite of minor differences between the five P test used, all tests identified high-testing subsections in the western side of the watershed, and also three smaller high-testing subsections bordering the south, southeast, and northeast sides of the lake. Although these maps must be interpreted with caution because each sub-section was highly heterogeneous, the results suggest the areas that potentially contribute a large proportion of the P loads to the lake.

D. Component Conclusions

The survey of soil P status and P management practices of the Clear Lake agricultural watershed was useful to identify areas that may be sources of large P loads to the lake and to identify priority areas where changes in P management practices would be desirable. Approximately one third of the area of the watershed had soil-test P values that were twice to five times higher than levels needed to maximize crop production. The highest soil-test P values were found in a very small number of fields that received either P fertilizer or manure, which likely are the source of a major proportion of the P being transported by surface runoff or subsurface drainage to the lake. There were minor differences between soil tests in describing the distribution of soil P across the watershed. All tests identified high-testing areas. The Bray test measured proportionally less P from high pH soils, and its use may mislead producers to apply more P fertilizer than needed to optimize crop production.

Phosphorus fertilizers or manure are not incorporated into the soil in approximately 30% of the area, a major proportion of which is under no-till or ridge-till management. Only approximately 40% of the area surveyed is under no-till or ridge-till tillage systems, which are the most effective in reducing soil erosion and surface water runoff. The finding that several fields had above-optimum soil P levels for crop production and were managed with conventional tillage do not necessarily mean that these fields are major sources of P loads to the lake. However, the results strongly suggest that further adoption of commonly recommended best management fertilization and soil conservation practices by some producers would have a major impact in reducing the risk of P delivery from the agricultural area of the watershed.

References

Brown, J. R. (ed.). 1998. Recommended soil test procedures for the north central region, North Central Regional Research Publication No. 221 (Revised).

Pierzynski, G.M. (ed.). 2000. Methods of phosphorus analysis for soils, sediments, residuals, and waters. Southern Cooperative Series Bulletin No. 396

TABLE 1. Summary of the field history information.

Item	Acres	% of land
Primary tillage		
Chisel/Disk	1983	48
Moldboard plow	291	7
No-Till	844	21
Ridge-Till	725	18
Other or unknown	229	6
Cropping System		
Alfalfa, pasture, or CRP	195	4
Continuous corn	266	7
Corn-soybean rotation	3649	89
Method of P Fertilization		
Fall injection/incorporation	1766	43
Spring injection/incorporation	687	17
Fall left on top	706	17
Spring left on top	532	13
No P applied	349	8
Unknown	70	2
Method of N fertilization		
Fall injected/incorporated	177	4
Spring injected/incorporated	447	11
Spring sidedress	1068	27
Spring left on top	2069	50
No N applied	349	8
Manure History		
No	3330	81
Yes	780	19

TABLE 2. Amount of P extracted by five soil P tests and soil pH for 332 soil samples collected throughout the Clear Lake Watershed.

Soil P test or pH	Mean	Median	Range	Minimum	Maximum
			Soil test P (ppm)		
Olsen	17	13	147	1	148
Bray-1	32	25	371	1	372
Mehlich-3	40	32	393	2	395
Iron oxide	24	20	168	4	172
Water	8	6	67	1	68
Soil pH	6.6	6.5	3.4	4.8	8.2

TABLE 3. Correlation coefficients between amounts of P extracted by five soil P tests from 332 soil samples collected throughout the Clear Lake Watershed.

Soil P test	Olsen	Bray-1	Mehlich-3	Iron oxide
		Correlation Coefficients		
		Entire pH range of 4.8 to 8.2		
Bray-1	0.89			
Mehlich-3	0.96	0.92		
Iron oxide	0.96	0.88	0.97	
Water	0.93	0.91	0.95	0.96
		Samples with pH less than 7.2		
Bray-1	0.97			
Mehlich-3	0.97	0.99		
Iron oxide	0.96	0.96	0.97	
Water	0.93	0.95	0.95	0.97

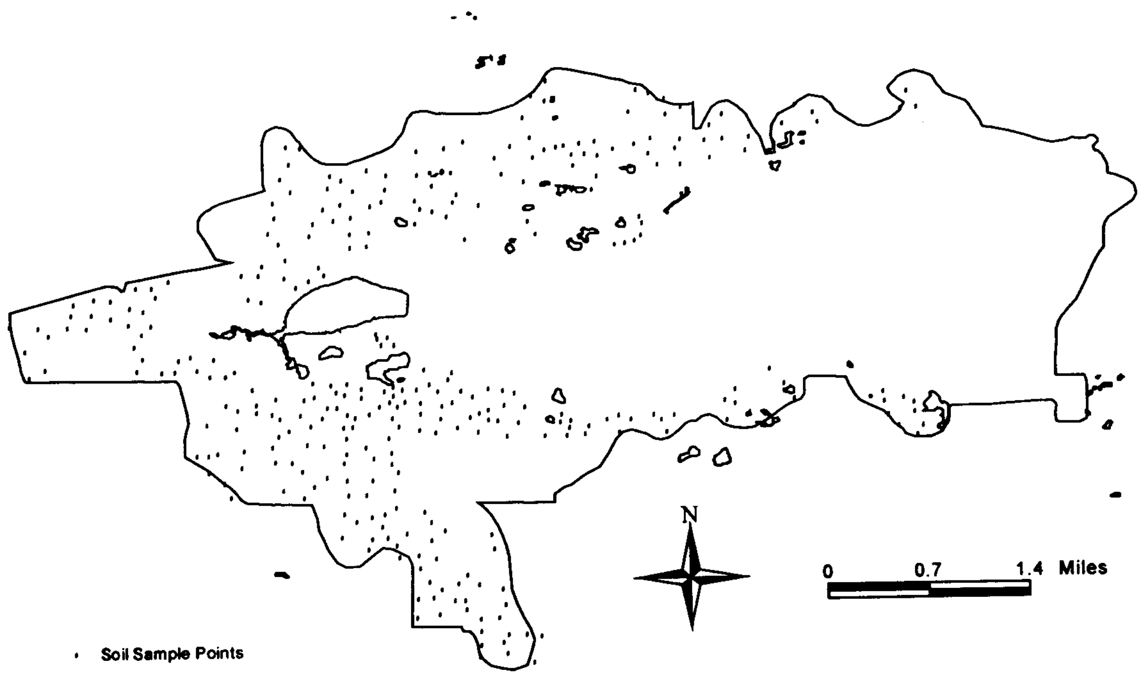


FIGURE 1. Soil samples taken in the Clear Lake watershed in the summer of 1999.

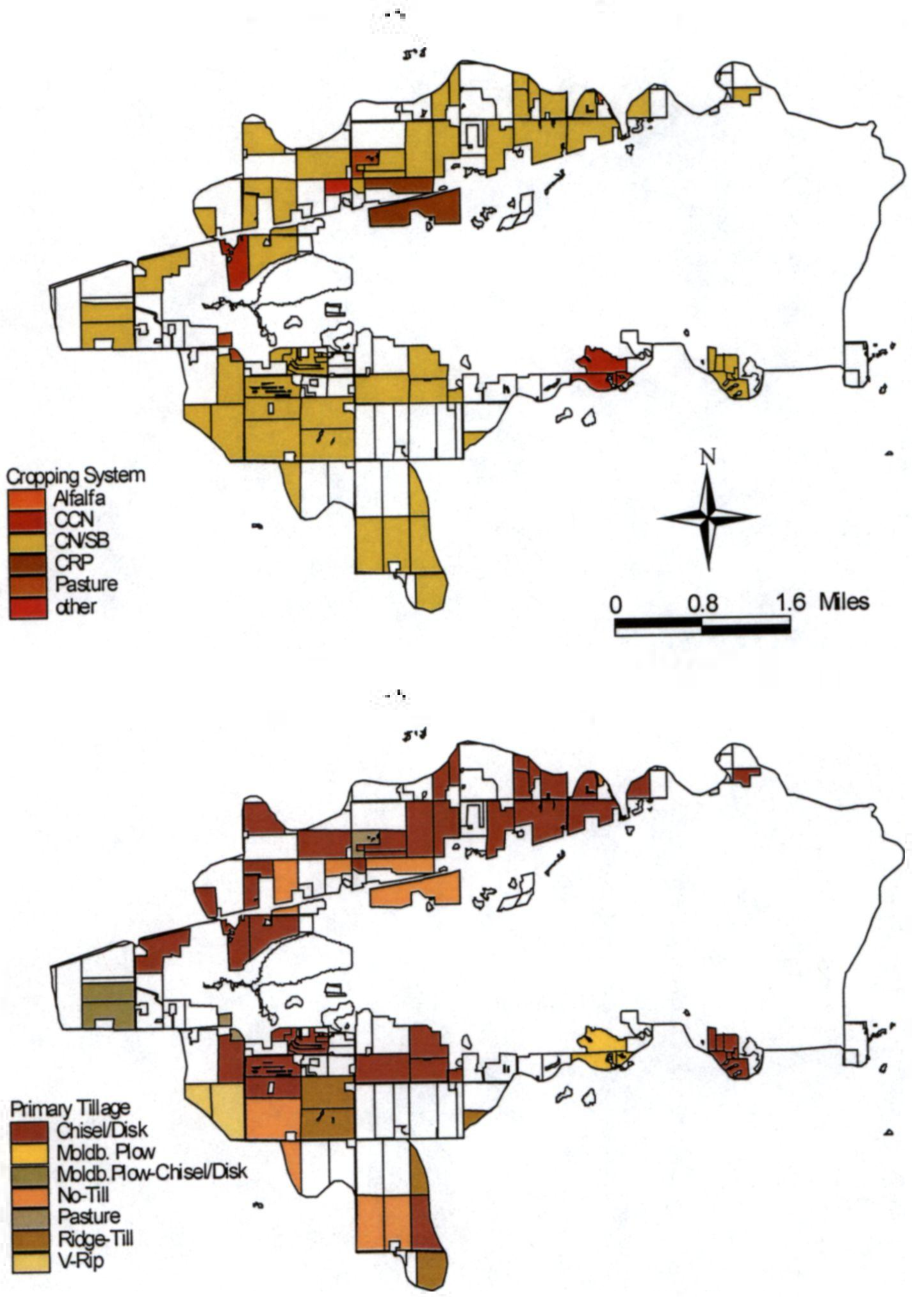


FIGURE 2. Cropping and tillage systems in the Clear Lake watershed.

FIGURE 3. Soil survey of the Clear Lake watershed.

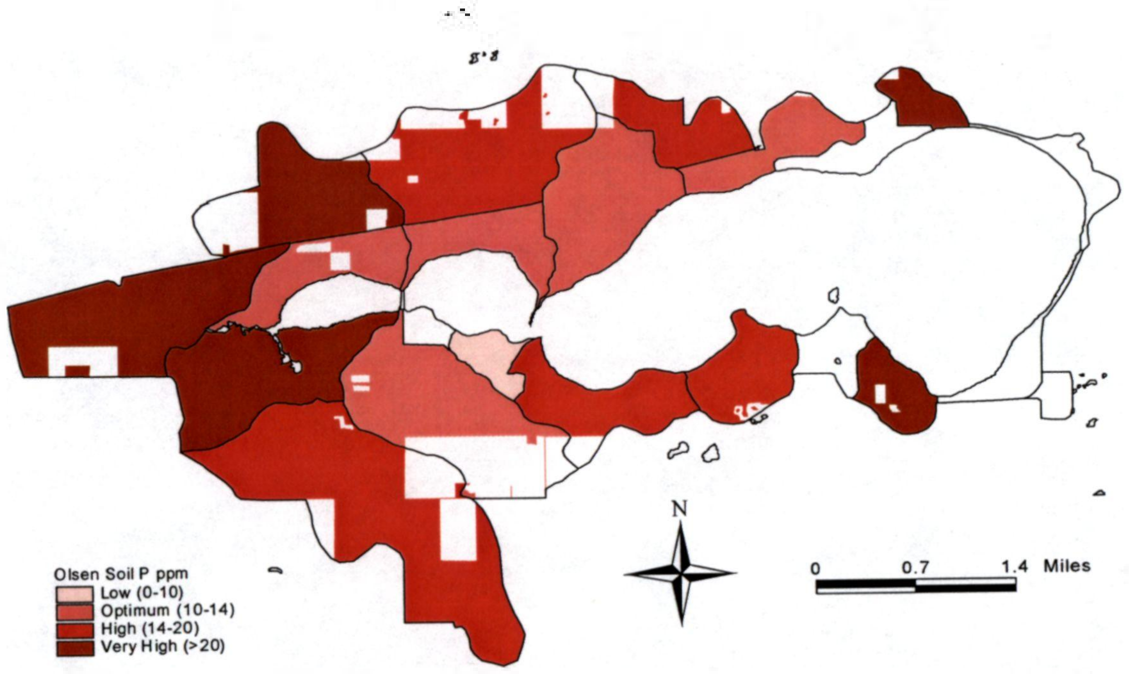


FIGURE 4. Olsen-P in Sub-sections of the Clear Lake Watershed.

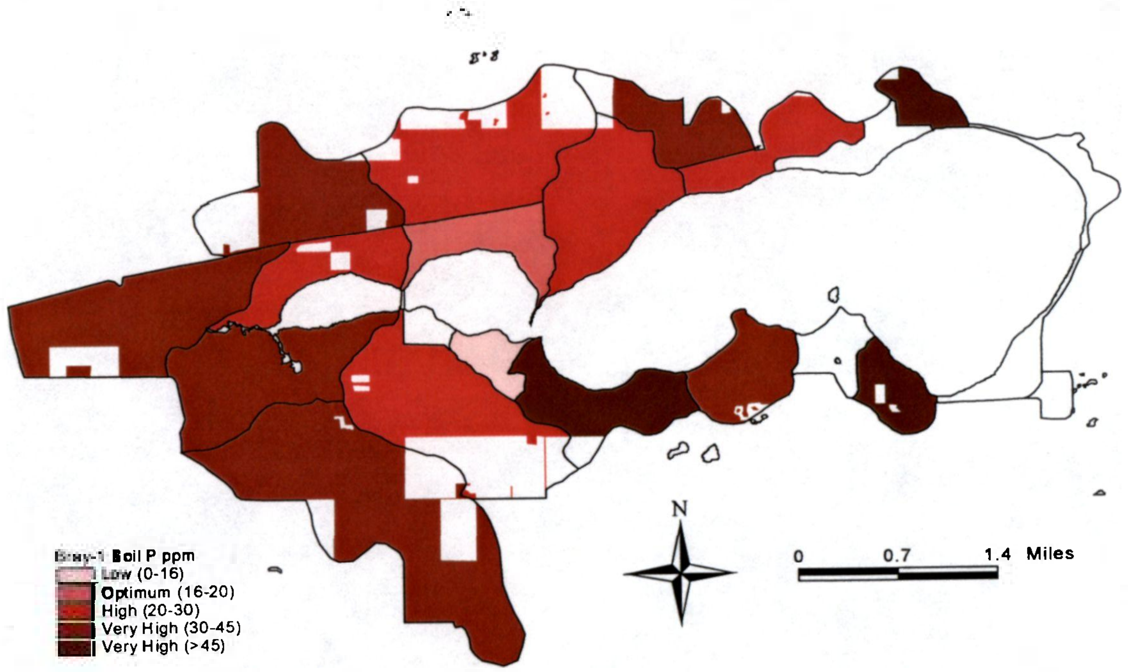


FIGURE 5. Bray-1 P in sub-sections of the Clear Lake watershed.

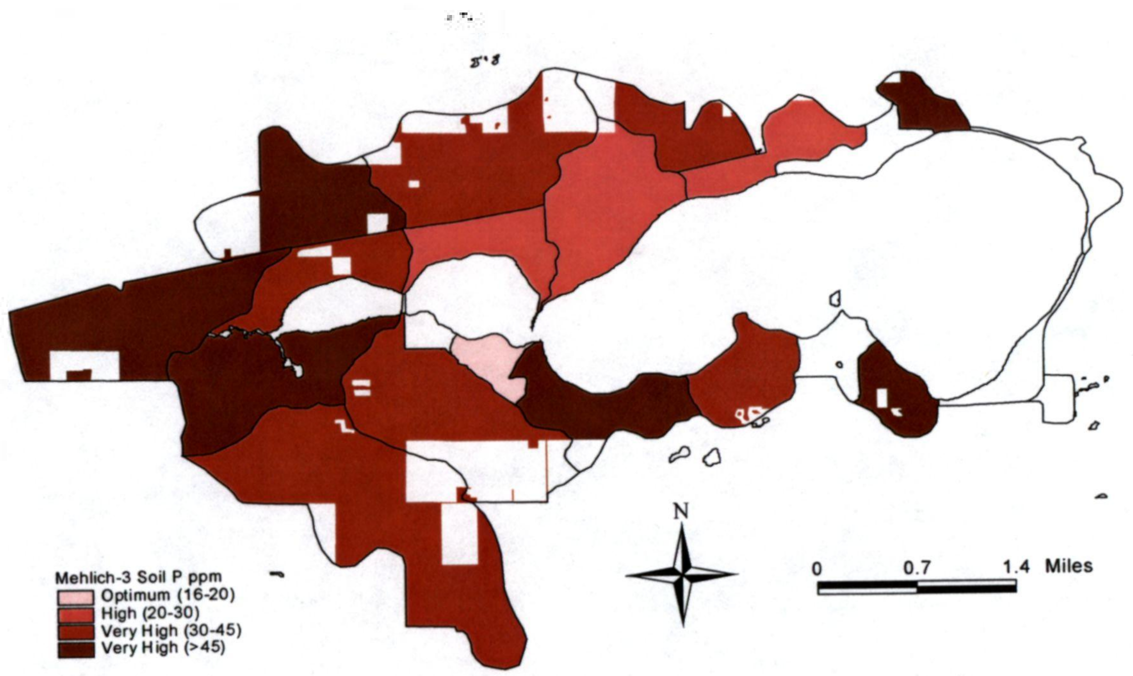


FIGURE 6. Mehlich-3 P in Sub-sections of the Clear Lake Watershed

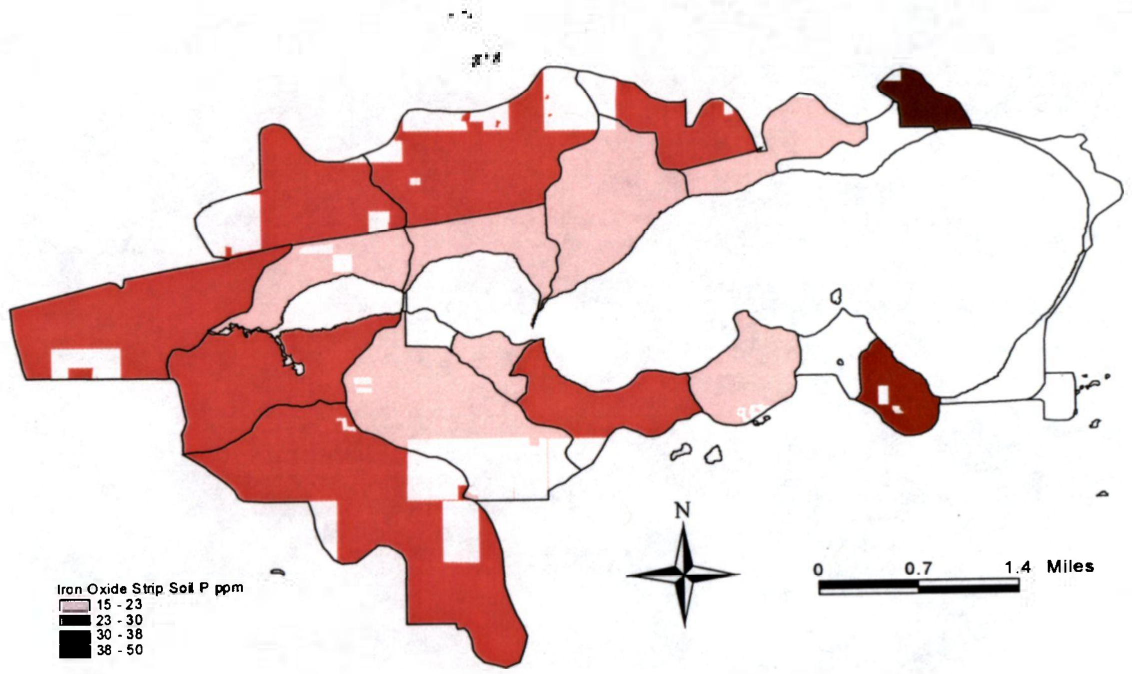


FIGURE 7. Iron-oxide strip P in sub-sections of the Clear Lake watershed.

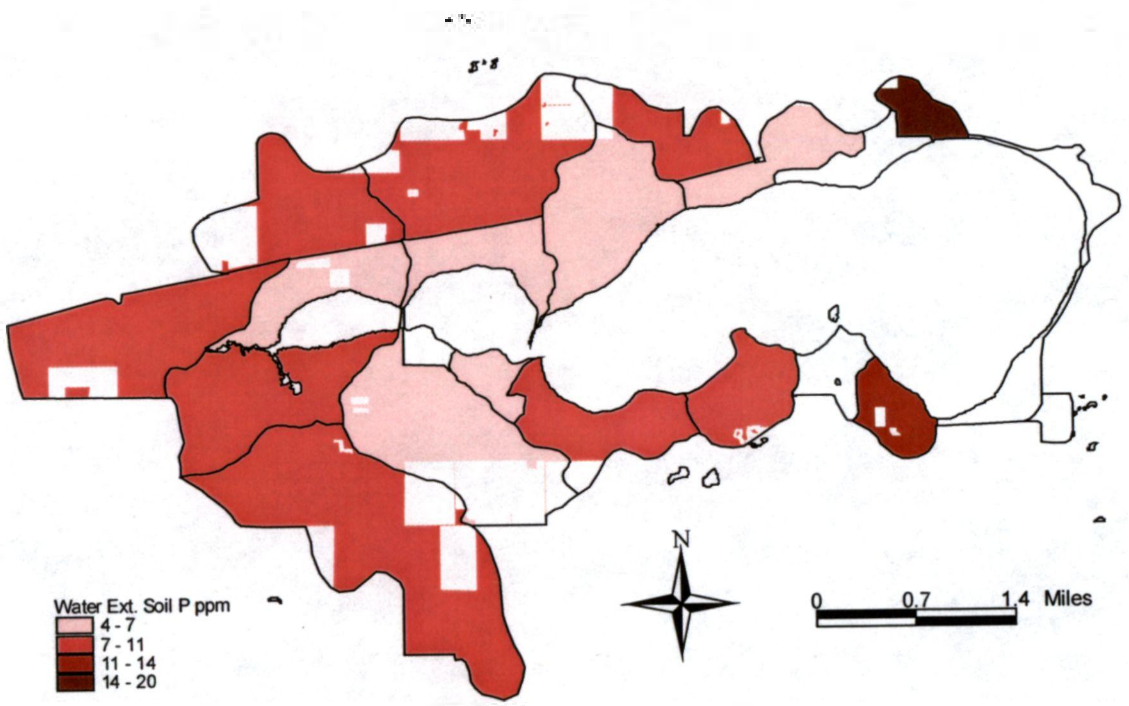


FIGURE 8. Water extractable P in sub-sections of the Clear Lake watershed.

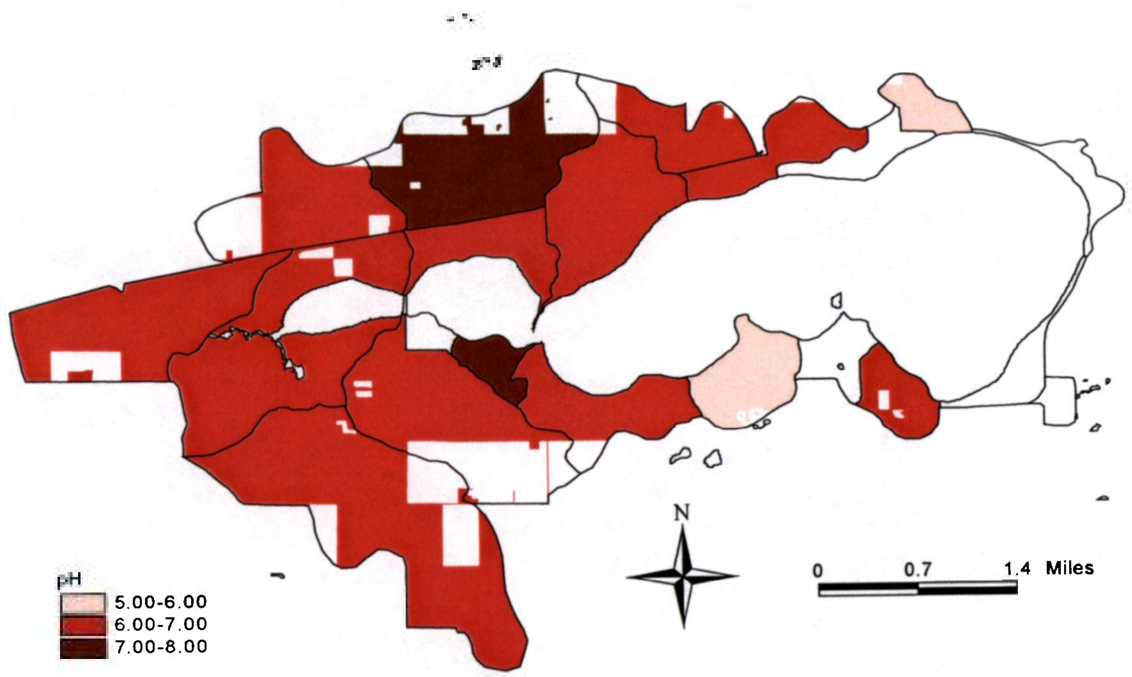


FIGURE 9. Soil pH in sub-sections of the Clear Lake watershed.

CHAPTER 12

An Analysis of the Fishery of Clear Lake, Iowa

An Analysis of the Fishery of Clear Lake, Iowa

James Wahl

A. History.

Bailey and Harrison (1945) described the fish community of Clear Lake based on collections made from 1941 through 1943. Although no density estimates were made, relative abundance was assigned to all species captured. Their work offers the most complete historical record of fishes found in Clear Lake.

When comparing the current fish community to that reported by Bailey and Harrison in the early 1940's there is one striking difference. Members of the Centrachid family were present in much greater numbers historically than what is currently found. Largemouth bass were listed as very common and were considered to be one of the dominant predators in the lake. Bluegill were ranked as very abundant and along with bullhead were considered to be the most abundant fish. Crappie were listed as abundant and cited as one of the four most abundant species in Clear Lake. All three of these species are currently found in Clear Lake, however their abundance would best be described as occasional.

The disappearance of these species may be directly related to the loss of aquatic vegetation in the lake. During and prior to the 1940's, Clear Lake supported extensive beds of both emergent and submergent vegetation. Bass, bluegill and crappie utilized these areas for spawning and nursery cover. As the vegetation declined, so did the populations of these species, which were dependant upon this critical habitat. Although emergent vegetation (bulrushes) remains in the lake today its coverage has been greatly reduced and submergent vegetation is virtually nonexistant.

Two species that were historically abundant and remain in high densities today are bullhead and carp. Bailey and Harrison (1945) listed bullhead as very abundant, and carp as common. Biomass estimates completed by DNR fisheries staff in 1999 and 2000 revealed bullhead density to be 150 to 300 lbs/acre, and carp at 100 to 200 lbs/acre. Although these species were abundant in the 1940's, it is unlikely that they dominated the total standing stock as they do today.

Despite the historical presence of bullhead and carp, aquatic vegetation flourished in Clear Lake. Apparently the density of these bottom-feeding fishes was not great enough to have a severe impact on vegetation. As water quality deteriorated in Clear Lake and water clarity became reduced the vegetation started to decline. As stated earlier, the loss of vegetation severely impacted populations of bass, bluegill and crappie. With a void created by their absence, it is likely that bullhead and carp increased in numbers taking advantage of the degraded environment, which they were better suited for.

B. Strategies for Improving Fish Community and Habitat.

It is obvious that there have been major changes in the Clear Lake fish community over the past 50 to 70 years. These changes have occurred because of a loss of habitat, which was impacted by deteriorating water quality. The challenge is to try and restore the Clear Lake fishery to resemble that found in the 1940's. To accomplish this two critical areas will need improvement. First, water quality needs improvement. This will help reestablish aquatic vegetation, which so many fishes are dependant upon. Second, populations of bottom-feeding fishes, primarily carp and bullhead, will need to be reduced. This will improve water clarity and also enhance aquatic vegetation. Doing one without the other may not bring the desired results, so combining the two appears to be the best plan.

C. Ventura Marsh.

A major goal for Ventura Marsh is to eliminate this area as a spawning and nursery area for carp and bullhead. The Iowa DNR (previously Iowa Conservation Commission) has attempted to keep carp out of the marsh with a rod barrier and fish trap over the past 50 years. The fish trap has not been functional for the past 30 years, however the barrier has been maintained and operated. Despite these efforts, carp and bullhead have periodically become established in the marsh. Once adults are established, they frequently produce large year classes of young carp and bullhead. These small fish often migrate back into Clear Lake, thus increasing Clear Lake's carp and bullhead population.

It is not realistic to think that we can keep carp and bullhead out of Ventura Marsh. The close proximity of the fishing jetty and the popularity of this area by anglers make it nearly impossible to prevent movement of angler caught fish from one side to the other. We can, however, manage the marsh to create an environment that even carp find difficult to live in. This can be accomplished by creating frequent winterkills and/or rotenone renovations.

Staff with the Iowa DNR tested this approach in 1999 and 2000. During the summer of 1999, Ventura Marsh was treated with rotenone, a fish toxicant, to reduce/eliminate bottom feeding fishes. Prior to the renovation, the marsh was lowered 0.8 feet. Rotenone was applied at a rate of 4 ppm. Although water levels were lowered in the marsh, water still remained in much of the cattail vegetation. This area was very difficult to treat, even with an aerial application. A follow-up netting survey revealed only a 33% reduction in the carp population.

Shortly after the 1999 waterfowl season, stop log boards were removed from Ventura Marsh lowering the water level 1.7 feet below crest. Under normal conditions the marsh can only be lowered one foot, however low water levels in Clear Lake allowed for an additional ¾ foot. The goal was to induce a natural winterkill. Unfortunately the winter was very mild and only a slight kill occurred reducing the carp population by 50%. This kill was also enhanced by the addition of rotenone under the ice while carp were congregated in front of the old fish trap.

During the summer of 2000 a second aerial rotenone application was planned. Two major changes were made on this attempt compared to the 1999 spraying. First, the DNR wildlife section pumped water out of the marsh utilizing a crissifoli pump to a level of 2 feet below crest. This was critical to the success of the project because it eliminated all the water within the cattails, thus removing escape areas that are extremely difficult to treat. The second was the rate of application was increased to 8 ppm. The result was a 99% reduction in carp. Unfortunately the renovation was conducted too early in the summer and the few adult carp that remained were still gravid. These fish successfully spawned and produced enough young to begin filling the void created by the renovation.

Future management of Ventura Marsh should incorporate late fall/early winter drawdown to induce winterkill and periodic aerial rotenone applications. To assist in this effort a new control structure should be considered that would improve water level manipulation and also fish barrier capabilities. An electric pump should be installed that would allow for significant water level reduction in the marsh. This would enable sufficient water level removal even when high water existed in Clear Lake. The need to remove water from the vegetation in the marsh is critical and pumping is the only technique that will work since there is only a one foot head difference between the marsh and the lake.

D. Mechanical Removal of Carp and Bullhead.

Clear Lake has a long history of rough fish removal. Eight hundred thirty-nine thousand pounds of carp were reported removed between 1929 and 1943. An additional 733,000 pounds were removed from 1949 through 1973. During these years, the State of Iowa had "rough fish crews" which conducted carp removal on Clear Lake as well as many other lakes. Beginning in 1980, contract commercial fishermen harvested carp and from that time until 1999 they removed 593,000 pounds from Clear Lake. A total of over 2.2 million pounds of carp have been removed from Clear Lake over the past 70 years.

Although past removal of carp from Clear Lake appears impressive, it has not been adequate to have a major impact on the fish community or water quality. Currently contract commercial fishermen have been taking the surplus and not making a substantial dent in the population. To increase the harvest a monetary incentive could be considered. The fishermen would continue to receive payment for the sale of fish, but they would also receive an additional payment (so many cents per pound) from the DNR.

Standing stock estimates conducted by the Iowa DNR showed that carp biomass ranged from 110 to 240 lbs/acre during 1999 and 2000. If standing stock estimates were continued in the future, the DNR could target a pre-determined poundage of carp to be removed and budget for that total. For example, if the standing stock was 100 lbs./acre, we could request a 50% removal or 50 lbs/acre. Fifty lbs/acre would equal about 180,000 pounds. If we paid 10 cents/lb, then $18,000 would need to be budgeted for carp removal.

Bullhead are not currently available to harvest under the present contract commercial fishing program. Some neighboring states do allow for the commercial harvest of bullheads. This could be considered for Clear Lake. Population estimates of bullhead during 1999 and 2000 estimated a population of 1.5 to 3 million bullheads in Clear Lake.

Despite this dense population, only 36,000 bullheads were harvested by sport anglers during those two years combined. These fish were considered to be angler acceptable size averaging 9 inches long and 0.4 pounds.

A review of creel surveys on Clear Lake shows a downward trend in bullhead harvest over the past 15 years. Two hundred thousand bullhead were taken by anglers in both 1986 and 1987, but have never approached these levels since. Angler attitudes have changed over the past two decades. Twenty to thirty percent of Clear Lake fishermen were specifically targeting bullheads during the mid-1980's, while in recent years less than 5% have targeted this species. It is unlikely that angler harvest will have any impact on reducing bullhead numbers in the future. It may also be socially acceptable to allow for a commercial harvest since so few anglers desire to catch these fish.

If a commercial harvest were allowed, several questions remain. Are Clear Lake bullheads large enough to have a market value? Are there commercial fishermen with the appropriate equipment to harvest fish of this size? Are there any fishermen in the area with an interest in catching bullhead?

E. Biological Control.

Flathead catfish appear to be the best predator for controlling undesirable species. Flatheads have been used successfully in Minnesota and Iowa on small lakes to reduce overabundant bullhead. A small number of flatheads were stocked in the fall of 2000 in Clear Lake. Additional fish are scheduled to be released this summer. A stocking strategy needs to be developed and refined as work continues with this species. Besides being a very effective predator, they will also provide a unique opportunity to catch a trophy-sized fish in the future.

Other predators that might be considered include largemouth bass and walleye. Although largemouth bass are an effective predator of bullhead, previous stockings have not done well in Clear Lake. Walleye will also readily consume bullhead, however large numbers of walleye are already stocked. Walleye density could be improved through the use of large fingerlings (>8 inches), in years when fry stockings produce a weak year class.

Any significant reduction in bullhead or carp populations, whether it be through mechanical removal or biological control, must be accompanied with a strategy to fill the void created with desirable sportfish. Sufficient predators must be available to control increased bullhead and carp reproduction. In addition, adequate panfish brood stock must be available to fill the void created.

F. Creating Habitat for Centrarchids.

Historically Ventura Marsh was open to free movement of fishes from Clear Lake. It was considered to be a prime spawning and nursery area for many sportfish. The placement of a rod fish barrier now prevents movement of adult fish into the marsh. It has been suggested that the barrier should be removed and once again allow free movement of all species. Although some desirable gamefish would use the marsh, we feel this management practice would do more harm than good. Carp and bullhead would likely utilize the area and dominate over bass, bluegill and crappie.

Two artificial canals are presently found on Clear Lake. These areas currently provide some of the best spawning habitat for Centrarchids. Crappies congregate heavily in the canals during the spring and bass and bluegill do as well, although to a lesser degree. Constructing additional canals might enhance the needed habitat to increase populations of these species. On the negative side, the natural shoreline must be broken to create a canal. This change may outweigh any benefits derived from increasing spawning habitat.

Another option would be to connect several small wetlands that currently exist to the lake. Although these areas would provide much needed nursery cover, the same problems that were discussed with opening up Ventura Marsh would occur in these small wetlands. Carp and bullhead would likely benefit the most and negate any value the area would have for desired sportfish.

The construction of breakwaters may have the greatest potential to improve fisheries habitat and improve water quality at the same time. Early findings by Iowa State University researchers has shown that wind resuspension is a major problem for Clear Lake water quality. Breakwaters placed parallel to existing bulrush beds would protect them from the pounding forces of the wind. These areas would then grow more vigorously and provide quiet water that would enhance the growth of submergent vegetation within the bulrush.

Potential sites for breakwaters include: State Dock, Baptist Camp, McIntosh Woods State Park, Farmers Beach, Lekwa Marsh. All of these sites are either publicly owned or undeveloped shorelines, which would improve the likelihood of public acceptance. Placing these structures in 5 to 6 feet of water would dampen the wind resuspension of nutrients, reduce wind disturbance to nearshore vegetation, reduce turbidity, and create excellent fish habitat. Constructing these structures from the shoreline out in a T or L configuration would allow shore anglers to access the main arm of the breakwater. The riprapped portion of the breakwater would attract small and large fishes and the quiet water on the backside would provide quality spawning and nursery habitat with the mixed growth of submergent and emergent vegetation.

CHAPTER 13

Specific Pollution Issues and Water Quality Standards Pertaining to Clear Lake

Specific Pollution Issues and Water Quality Standards Pertaining to Clear Lake

Jeff Kopaska and Nicole Eckles

A. Point-source pollution sources

Water quality planning representatives from the Department of Natural Resources report that there are presently no permitted livestock facilities in the watershed. Also, there were no point source dischargers in the Clear Lake watershed within the last 5 years. During the last five years, the Clear Lake Sanitary District had one occurrence of bypass pumping into the lake. This occurred on June 20, 1998, and 250,000 gallons of pretreatment sewage were discharged into Clear Lake (Kevin Moeller, Clear Lake Sanitary District, pers. comm.). This bypass pumping added approximately 1.5 kg of phosphorus to the lake, or 0.02% of the lake's annual average phosphorus budget. Additionally, during that same period, the City of Clear Lake had two occurrences of bypass pumping into the lake. The first one occurred in June 1995, and 126,000 gallons of pretreatment sewage were discharged into the lake. The second one occurred in June 1998, and 44,250 gallons of pretreatment sewage were discharged into the lake (Al Tompkins, IDNR-EPD, pers. comm.). These two events combined added around 1 kg of phosphorus to the lake, or about 0.01% of the lake's annual average phosphorus budget.

Residential areas in the watershed can provide point sources of nutrients to the lake. Most residences in the cities of Clear Lake and Ventura, as well as the unincorporated areas bordering Clear Lake are thought to be connected to the Clear Lake Sanitary District. Residences in other rural or unincorporated areas of the watershed generally have septic systems. The Cerro Gordo County Environmental Health representative indicates that issues concerning septic systems in Cerro Gordo County are handled on a case-by-case basis. If a septic system is determined to not be in compliance, there are county and federal low-interest loan programs to assist in updating or replacing septic systems.

B. Water quality standards from Chapter 61 of the Iowa Administrative Code:

1. Designated Uses. Under the state water quality classification system the lakes are classified as Class A (primary body-contact recreation) and Class B (LW) (lakes and wetlands - wildlife, fish, aquatic and semiaquatic life, and secondary contact water uses).

2. Applicable Criteria

GENERAL WATER QUALITY

Waters shall be free from substances attributable to point source wastewater discharges that will settle to form sludge deposits.

Waters shall be free from floating debris, oil, grease, scum, and other floating materials attributable to wastewater discharges or agricultural practices in amounts sufficient to create a nuisance.

Waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor or other aesthetically objectionable conditions.

Waters shall be free from substances attributable to wastewater discharges or agricultural practices in concentrations or combinations which are acutely toxic to human, animal, or plant life.

Waters shall be free from substances, attributable to wastewater discharges or agricultural practices, in quantities which would produce undesirable or nuisance aquatic life.

A point source discharge shall not increase turbidity of the receiving water by more than 25 Nephelometric units.

Total dissolved solids shall not exceed 750 mg/l in any lake or impoundment or in any stream with a flow rate three times the flow rate of upstream point source discharges.

CLASS A WATERS

Fecal coliform:	200 organisms/100 ml from April 1 to October 31.
pH:	6.5 to 9.0

CLASS B WATERS

pH:	6.5 to 9.0
Dissolved oxygen:	not to be lower than 5.0 mg/l during at least 16 hours per day, but not less than 4.0 mg/l at any time
Temperature:	32° C
Toxics Substances:	see Table 1, units in micrograms/liter unless otherwise noted
Ammonia:	see Table 2

C. Toxicity analyses

1. Benthic sediments. Dredging is a possible restoration technique for the western basin (Little Lake) of Clear Lake, so sediment samples were collected at four locations in that basin. One sample was taken near the inflow of Ventura Marsh; one was taken off the western shore of the Little Lake, near the Harbor Inn; one was taken off the northern shore of Little Lake; and the final one was taken just west of the channel between the Little Lake and main lake. Dredging or other activities may impact the sediments in Ventura Marsh, so one sample was also taken from sediments of Ventura Marsh. Water samples were taken at the same time and treated for elutriate analysis following procedures recommended to the University of Iowa Hygienic Laboratory by the U. S. Army Corps of Engineers (pers. comm., Sherri Marine). Heavy metals, pesticides and nutrients were analyzed by the University of Iowa Hygienic Laboratory in Iowa City. Results of these analyses, which indicate concerns, are listed in Table 3. Complete profiles and original data sheets are presented in Appendix 12.

Results shown in bold italics (Table 3) are chronic violations of Iowa Water Quality Standards. Cadmium and chromium do not occur naturally in Iowa, so the presence of these pollutants is probably the result of human activity in the watershed. Potential sources of these elements are nickel-cadmium batteries that were not properly disposed, leaching from chrome-plated metals, and trace sources in agricultural fertilizers. The presence of copper, lead and zinc may be the result of multiple sources, both natural- and human activity-derived. While a small percentage of the sources of these elements may be natural in origin, the majority is probably the result of human activity. Copper, lead and zinc are all micronutrients that may be found in small quantities in agricultural fertilizers. Copper has many other potential sources, due to its ubiquitous use in building materials. Other potential sources of lead included historic use of leaded gasolines, lead shot and lead fishing weights. Zinc is use extensively as a plating material for steel and other metals, and can be leached by acid rain, so trace amounts of this element are often present in storm water. (Ralph Turkle, IDNR-EPD, pers. comm.)

The presence of these pollutants indicates are issues that needs to be addressed, particularly if dredging is a restoration option. It is recommended that additional samples be taken in the future to determine the sources and the extent of these Water Quality Standard problems. If further testing show these pollutants to be persistent, it may impact the cost of lake dredging as a restoration option by requiring more stringent control over return water quality. Additionally, monitoring data (Appendix 5) showed very elevated concentrations of ammonia-nitrogen in water near the lake bottom. Hydraulic dredging would draw water from near the lake bottom, and this water would have elevated ammonia-nitrogen levels, thus elutriate water might pose another problem for return water quality.

After reviewing the data in Table 3, Ralph Turkle, IDNR-EPD summarized his recommendations by saying "... I think the report should not dismiss the metals as background levels. The pollutants should continue to be part of the total lake assessment with every attempt in the future to identify their likely source(s). In addition, any recommended lake restoration effort (hydraulic dredging) will be faced with addressing the return water quality and its impact on the lake."

2. Fish flesh. Common carp, channel catfish, walleye, black bullhead and yellow bass were collected from Clear Lake by IDNR personnel on August 2, 1999. Filets from the collected fish were analyzed for pesticides by the University of Iowa Hygienic Laboratory in Iowa City. They found only one detectable levels of pesticide in one species of fish analyzed (DDE in channel catfish), but this level of detection was far below the state's standard for a fish consumption advisory. This indicates that there is no reason for concern about contamination of fish from this lake with the listed chemicals. The list of chemicals analyzed and the results of these analyses on the original data sheets are presented in Appendix 13.

Literature cited

Iowa Administrative Code. 1990. Water quality standards, 61:1.

TABLE 1. Criteria for chemical constituents, for waters with Class B (LW) use designations. Units are in microgram/liter unless otherwise noted. Source: Iowa Administrative Code, Ch. 61, Water Quality Standards, November 1990.

Parameter	**Chronic Toxicity**	**Acute Toxicity**	**Human Health Criteria**
Aluminum	742	1073	-
Arsenic	200	360	50
Benzene	-	-	712.8
Cadmium	1	4	168
Carbon Tetrachloride	-	-	44.2
Chlordane	0.004	2.5	0.006
Chlorobenzene	-	-	20
Chlorpyrifos	0.041	0.083	-
Chromium	10	15	3365
Copper	10	20	1000
Cyanide	10	45	-
4,4-DDT++	0.001	0.55	0.00559
Para-Dichlorobenzene	-	-	2.6 mg/l
3,3-Dichlorobenzidine	-	-	0.2
1,2-Dichloroethane	-	-	986
1,1-Dichloroethylene	-	-	32
Dieldrin	0.0019	2.1	0.0014
Dioxin (2,3,7,8-TCDD)	-	-	0.00014 ng/l
Endosulfan	0.15	0.3	2400
Endrin	0.0023	0.18	8.1
Heptachlor	0.0038	0.38	0.002
y-Hexachlorocyclopentadiene (Lindane)	0.33	4.1	0.63
Lead	3	80	-
Mercury	0.05	2.5	0.15
Nickel	150	1400	4584
Parathion	0.013	0.065	-
Pentachlorophenol (PCP)	(a)	(a)	82
Polychlorinated Biphenyls (PCBs)	0.014	2	0.0004
Polynuclear Aromatic Hydrocarbons (PAHs)	0.03	30	0.3
Phenols	50	1000	300
Selenium	70	100	-
Silver	0.35	4	-
Toluene	50	2500	300 mg/l
Total Residual Chlorine (TRC)	10	20	-
Toxaphene	0.0002	0.73	0.0075
1,1,1-Trichloroethane	-	-	173 mg/l
Trichloroethylene (TCE)	80	4000	807
Vinyl Chloride	-	-	5250
Zinc	100	110	5000

(a) Numerical criteria are a function of pH using the equation: Criterion ($^{\mu}$g/l = $e^{[1.005(pH)-x]}$, where e = 2.71828 and x_{acute} = 3.34 and $x_{chronic}$ = 3.80

TABLE 2. Criteria for ammonia nitrogen, for warm water streams and lakes. Source: Iowa Administrative Code, Ch. 61, Water Quality Standards, November 1990.

Temp °C	**pH**	6.5	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
1.0	Acute	49.0	39.5	33.8	27.6	21.4	15.8	11.2	7.1	4.5	2.9	1.8	1.2
	Chronic	9.8	7.9	6.8	5.5	4.3	3.2	2.2	1.4	0.9	0.6	0.4	0.2
5.0	Acute	46.4	37.4	32.1	26.2	20.3	15.0	10.6	6.8	4.3	2.8	1.8	1.2
	Chronic	9.3	7.5	6.4	5.2	4.1	3.0	2.1	1.4	0.9	0.6	0.4	0.2
10.0	Acute	44.0	35.5	30.5	24.9	19.3	14.3	10.1	6.5	4.1	2.7	1.8	1.2
	Chronic	8.8	7.1	6.1	5.0	3.9	2.9	2.0	1.3	0.8	0.5	0.4	0.2
15.0	Acute	42.3	34.1	29.3	24.0	18.6	13.8	9.8	6.3	4.1	2.7	1.8	1.2
	Chronic	8.5	6.8	5.9	4.8	3.7	2.8	2.0	1.3	0.8	0.5	0.4	0.2
20.0	Acute	41.2	33.3	28.6	23.4	18.2	13.5	9.7	6.2	4.1	2.7	1.8	1.2
	Chronic	8.2	6.7	5.7	4.7	3.6	2.7	1.9	1.2	0.8	0.5	0.4	0.2
25.0	Acute	40.7	32.9	28.3	23.2	18.1	13.5	9.7	6.3	4.2	2.7	1.8	1.2
	Chronic	8.1	6.6	5.7	4.6	3.6	2.7	1.9	1.3	0.8	0.5	0.4	0.2
30.0	Acute	20.4	16.5	14.2	11.7	9.1	6.8	5.0	3.3	2.2	1.5	1.1	0.8
	Chronic	4.1	3.3	2.8	2.3	1.8	1.4	1.0	0.7	0.4	0.3	0.2	0.2

TABLE 3. Substances of concern in lake water and sediment elutriate water. Substances of concern are shown in bold italics.

	Southwest side of Little Lake at Ventura Marsh Outflow		**Northwest Side of Little Lake (near Harbor Inn)**		**North Side of Little Lake**		**Site 40 in Little Lake**		**Ventura Marsh**	
Pollutant	Water	Elutriate	Water	Elutriate	Water	Elutriate	Water	Elutriate	Water	Elutriate
Cadmium	<0.001 mg/L	<0.001 mg/L	***0.001 mg/L***	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L	<0.001 mg/L
Chromium	<0.02 mg/L	<0.02 mg/L	***0.03 mg/L***	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L	<0.02 mg/L
Copper	<0.01 mg/L	<0.01 mg/L	***0.03 mg/L***	<0.01 mg/L	<0.01 mg/L	***0.03 mg/L***	<0.01 mg/L	***0.01 mg/L***	<0.01 mg/L	<0.01 mg/L
Lead	***0.02 mg/L***	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L	***0.01 mg/L***	<0.01 mg/L	<0.01 mg/L	***0.01 mg/L***	<0.01 mg/L	<0.01 mg/L
Zinc	0.04 mg/L	***0.31 mg/L***	***0.22 mg/L***	***0.15 mg/L***	0.02 mg/L	***0.36 mg/L***	<0.02 mg/L	***0.39 mg/L***	<0.02 mg/L	0.02 mg/L

CHAPTER 14

Suggested Restoration Alternatives

Suggested Restoration Alternatives

John A. Downing and Jeff Kopaska

Introduction/Summary of Issues

The diagnostic portion of this study shows that Clear Lake has water quality problems, due to historic and present phosphorus and sediment loading, internal resuspension of sediment and nutrients and inputs of fecal-derived bacteria. These problems derive from the agricultural and urban watersheds and from the lake bottom. Deep lakes (i.e. >13 ft (4 m) average depth) generally have better water clarity, lower densities of algae, lower concentrations of suspended particles in the water, and are more likely to lack winter fishkills or other oxygen depletion problems. Shallow lakes like Clear Lake (mean depth=9.6 ft (2.9 m)) have less volume for the dilution of nutrient and sediment inputs. Accumulated sediments also decompose and resuspend and can exacerbate oxygen and nutrient problems. Further, even these nutrient-rich sediments derive from watershed impacts since sedimentation rates increase sharply when eutrophication and deposition of eroded material lead to increased plankton production and carbon-rich detritus. Anthropogenically eutrophied lakes like Clear Lake suffer many undesirable ecological characteristics (Table 9, Chapter 5, p. 96) most of which can be remediated through better watershed management.

Sediment from watershed runoff has had a major impact on this lake over its lifetime. Sediment flux has reduced the volume of Clear Lake to 38% of its original post-glacial volume, and nearly 25% of that sediment was deposited since 1935. The rate of sediment deposition in the lake may have been reduced in the last few decades due to improved erosion management. Sediment deposition still occurs, however, so Clear Lake is becoming shallower and smaller with the passing years.

Runoff from the watershed contributes bacteria, nutrients and turbidity to the water and leads to algal blooms, reduced transparency and great concentrations of suspended solids. In the long term, sediments accumulate in the lake basin and cause water quality problems that are common to shallow lakes. Eventually, lake basins can fill to the point that they are no longer useful for recreation. Nutrients in the excess quantities found in Clear Lake impair many aspects of water quality.

The following restoration alternative suggestions are designed to reverse the eutrophication and sedimentation processes by improving the nutrient retention of the watershed and by deepening parts of the lake. Preventative measures in the watershed are necessary to slow the input of new nutrients and sediments into the lake, so that the restored lake can have an enhanced lifetime and improved water quality.

Principle restoration needs would be aimed to:

- reduce phosphorus inputs to the lake,
- reduce bacteria inputs to the lake,
- improve management of bottom sediments, siltation, erosion and fish populations to reduce turbidity and nutrients due to sediment.

We project that phosphorus loading to the lake could be reduced by 50-60% by implementing practices designed to address these issues. This would lead to a substantial increase in water clarity and improved biological function.

Issue Identification and Potential Solutions

1. Reduction in phosphorus inputs to the lake

a. Phosphorus sources. Phosphorus is the most important limiting nutrient in Clear Lake. The Clear Lake diagnostic study attributed two-year average phosphorus loading to the lake as follows: rainfall, 31%; Ventura Marsh inflows, 24%; north shore agriculture, 14%; internal loading from Ventura Marsh, 9%; groundwater, 7%; City of Clear Lake urban, 6%; south shore agriculture, 5%; City of Ventura urban, 2%; and south shore (Cerro Gordo County) residential, 2%. Thus, rural areas provided 52% of the phosphorus, rainfall accounted for 31%, urban areas provided 10%, and groundwater provided 7%. Areas of the lake and watershed west of McIntosh Point provided 54% of the lake's phosphorus input or about 81% of all non-precipitation surface inputs. A total mass balance of Clear Lake (not including Ventura Marsh) suggests that internal loading, on average, amounts to about 800 kg annually or <10% of the overall phosphorus budget. Because of the predominance of agricultural sources to the phosphorus budget of the lake, and the difficulty of managing rainfall and groundwater, mitigation of agricultural phosphorus holds the best hope for substantial phosphorus reduction.

Because agricultural P in the western watershed is substantial, AGNPS (Young et al. 1994) modeling of watershed nutrient transport was applied to present land use practices in the watershed. Much of the phosphorus input in Iowa lakes derives from storm driven inputs (Downing et al. 2000). We therefore modeled one storm event to simulate the typical rain event-driven loading seen in Iowa watersheds. This event was a 2-inch, 24-hour storm, which climatic records show to occur at least once annually (National Climatic Data Center 2001). The results of the modeling of present conditions, which included some AGNPS default values, are shown in Table 1 and Figure 1. Default values and values appropriate for local conditions were acquired from Young et al. (1994) and the 1978 USDA Agricultural Handbook. Results of this modeling show sub-basins 2, 3, 4, 5, and 10 (Fig. 1) export the greatest masses of phosphorus and nitrogen to the lake. The model also predicts that sub-basin 11 loses the most nitrogen and phosphorus on a per unit area basis considering all agricultural basins. The results from modeling nutrient and sediment loss under current conditions therefore reflect the general trend of field observations. Field observations also show subbasins 2, 3, 4, 5, and 10 losing the largest masses of nutrients on an annual basis.

b. Phosphorus reductions. Decreasing the transport of phosphorus and eroded soil into the lake is critical to improving the health of the lake. Many conservation practices that address this issue are already in use in this watershed. Contour farming, terracing, and grass waterways are best management practices (BMPs) that are presently in use in the Clear Lake watershed, and many farmers are using field management methods that help to reduce phosphorus losses (see Chapter 11, p. 254).

The diagnostic study indicates a clear need to undertake a reasonable reduction in phosphorus delivery to Clear Lake, through a variety of in-lake, marsh, and watershed modifications. Little water quality improvement will be achievable without substantial reductions in phosphorus loading. The amount of reduction necessary to achieve a given degree of water quality improvement and thus determine target levels of phosphorus- and sediment loading to the lake can be assessed using a variety of models available in the published literature. We used a combinations of models (Table 2, see references below) published in the Wisconsin Lake Modeling Suite 3.1.1 (1999) to perform these analyses. These models calculate the likely total phosphorus concentration in a water body by making assumptions about the likely phosphorus retention of a lake. The diagnostic portion of the study determined that the annual average water column total P was 166 ppb while the volume-weighted spring-overturn total P was 186 ppb. Morphometric and hydrologic data were added to this and entered into the models along with known mass loading rates of P. Although several of these models fit quite well, the Canfield-Bachmann, Natural Lake model fits the data best, yielding a predicted P concentration at spring circulation of 189 ppb. Fit of this model was thus within 2% of the observed concentrations. Using this model, we were able to calculate the likely changes in total phosphorus that would be obtained given hypothetical changes in total phosphorus loading (see Fig. 40 in Chapter 5). Since substantial water quality improvement is sought, we judged that a useful criterion would be to bring the lake as close as possible to the 100 ppb range in order to decrease algae blooms and increase water clarity. Such a change would require a decrease of 50-70% in the overall total phosphorus input to Clear Lake. This should increase water clarity by 100-200%. The feasibility analysis therefore sought a combination of watershed modifications that could yield this level of phosphorus load reduction. Because the lake is shallow and mixed by wind, boats and benthic fish, water quality improvements will be contingent upon decreasing internal loading, as well. Since rainfall and groundwater are now P-enriched in this region, every effort to reduce P input from all sources will be of short-term and long-term benefit to the lake.

A principle objective of this feasibility study was to suggest activities that would improve and protect the lake at a reasonable cost. We therefore applied well-known watershed models and GIS (Geographic Information Systems) to indicate areas in the watershed that currently supply the highest rates of sediment and nutrient delivery. We used the AGNPS (Young et al. 1994) model to simulate sediment and nutrient transport following a rain event in the Clear Lake watershed. An introduction to the modeling process, and the results for present conditions modeling were presented in Chapter 10 and in the *Phosphorus Sources* section above. The methods used in the AGNPS modeling effort are also presented in Chapter 10. The AGNPS model was applied according to present land use practices, verified through observations of actual field uses in 2000 and was then modified to simulate future land use scenarios designed to reduce inputs to the lake from the watershed. We modeled one storm event to simulate typical rain event-driven loading seen in Iowa watersheds. This event was a 2-inch, 24-hour storm.

Different land use changes were applied using model simulation to the watershed. The first land use change was to look at model cells (0.22 acres) lying in row crop fields that exhibited the highest levels of phosphorus export. These cells tended to be in areas with the highest slopes. Cells with the highest phosphorus export under optimal nutrient conditions were "changed" from row crops to permanent grass for modeling purposes. These "changes" from row crops to permanent grass were modeled in stages, "changing" the top 1%, top 5%, and top 10% of phosphorus exporting cells in a step-wise fashion. The area removed from row crop production by these "changes" is 22.6 hectares (55.8 acres), 111.6 hectares (275.8 acres) and 220.1 hectares (543.7 acres) respectively (Fig. 2). The results of the model following these changes are shown in Table 1. These step-wise changes in land use produced an entire watershed average of a 2% reduction, a 10% reduction and an 18% reduction in phosphorus loading, respectively, from agricultural lands. This would represent a 1% reduction, a 4% reduction and an 8% reduction, respectively, in total phosphorus loading to Clear Lake. Thus, placing 10% of the agricultural land in permanent vegetation could yield an average reduction in phosphorus load to that lake of around 8%.

The next step in the watershed modeling effort was to identify areas in the watershed where water and nutrients could be retained in order to reduce nutrient flux to the lake. Wetlands and other small impoundments are well known to immobilize significant amounts of sediments and nutrients in agricultural watersheds and the abundance of hydric soils in the watershed (see Fig. 5, Chapter 1, p. 20) suggests that wetlands were quite abundant prior to human habitation. We used the PONDNET model (Walker 1987) to assess the impact of installing small nutrient retention ponds and restored wetlands in identified potential sites across the watershed. Four existing wetlands, six areas that were previously wetlands, and six areas for potential wetland construction were located, added hypothetically to the landscape, and nutrient retention was modeled. The area taken up by these 16 wetlands is estimated to be 135 hectares (335 acres). The placement of these hypothetical wetlands in the landscape is shown in Figure 3. The results of the model following these changes, and the ones listed earlier, are shown in Table 1. The estimated sizes, volumes, phosphorus reduction potential (from PONDNET), and flow paths are listed in Table 3. The cumulative changes in land use produced a 59% reduction in phosphorus loading, a 57% reduction in nitrogen loading, and a 24% reduction in sediment loading from the agricultural sections of the watershed to the lake, according to the models. When combined with idling 10% of the agricultural land, these changes represent an 18% reduction in the total phosphorus load to Clear Lake.

Ventura Marsh and the tributary streams that flow into it provide 33% of the total phosphorus budget to Clear Lake. Marshes are well known to serve as nutrient traps, but the diagnostic study showed that Ventura Marsh exports more phosphorus than it receives from its watershed except after the carp removal experiment apparently decreased internal loading (contrast "Ventura Marsh Internal in Chapter 10, Figs. 3 and 4). The next stage in identifying potential phosphorus reductions was to suggest restoration activities designed to enhance the nutrient retention capacity of the marsh. The PONDNET model was used to estimate nutrient reductions in water flowing through Ventura Marsh, if the marsh was functioning properly. Under that scenario, Ventura Marsh would remove 50% of the phosphorus load from the water flowing through it.

This alone would reduce Clear Lake's phosphorus load by 17%. When combined with the watershed modifications and wetland installations discussed above, results in a 26% reduction in the phosphorus load to Clear Lake. A schematic diagram of how all these wetlands will work in concert to filter water on its trek to the lake is shown in Figure 4.

The steps suggested to restore Ventura Marsh are as follows:

- Separating the eastern and western sections of the marsh by building a dike across it. This would permit independent level controls of the two marsh basins.
- Installing islands in the eastern basin of the marsh to limit wind-resuspension of marsh sediments and enhance aquatic vegetation growth.
- Installing improved fish barriers in both the present grade structure and the new dike.
- Installing a pumping system to serve as a primary means of water movement between Ventura Marsh and Clear Lake. The outfall could serve as a high-water overflow. Water level could thus be maintained both above and below the lake level.
- Enhanced fishery management to limit benthic fish populations in Ventura Marsh.

A visual representation of these structural changes is shown in Figures 5 and 6. There would be many additional benefits from these restoration activities. By dividing the marsh into an eastern and western basin, the ability to manage water levels would be greatly increased. This would result in improved nutrient retention in the marsh, and improved aquatic vegetation growth. An additional result would be improved waterfowl production and increased waterfowl hunting opportunities. Similarly, the islands planned for the eastern basin of Ventura Marsh would be constructed to limit wind, but also to provide waterfowl nesting habitat and waterfowl hunting opportunities. This plan also suggests widening the existing grade between Ventura Marsh and Clear Lake when the fish barrier is improved. The widened grade could be developed into a park, with trees, picnic tables, and educational information, as well as water pumps for marsh level control. The improved grade would provide safer public access for anglers; a safer access across the grade for bikers, walkers, and runners; give DNR staff safer access to the structures and pumps; and, allow the construction of a goose-proof fence on the west side of the grade without drastically reducing the visual amenities that the lake and marsh provide. This fence would be necessary because of the greatly increased waterfowl production that should occur in Ventura Marsh. The widened grade structure would also help to improve fishery management, because it would make it more difficult for anglers to carry or throw fish across the grade into the marsh, and educational signs could be installed that would explain the reasons for keeping fish out of the marsh. Improving water level management could also enhance fishery management by improving the ability to induce winterkills in the marsh, thus limiting benthic fish populations and allowing levels to fluctuate for optimum enhancement of wetland plants. Other enhancements to fishery management might include increased monitoring of the fish population in Ventura Marsh, stocking predator fish to reduce benthic fish populations, and occasional chemical applications to reduce fish populations in the marsh.

The urban areas surrounding Clear Lake provide 10% of the annual phosphorus budget to the lake. This phosphorus enters the lake through storm drains following rain events. The sources of this phosphorus include pet waste, sediment from construction sites, yard waste, materials washed off of the streets, and numerous other miscellaneous sources. Phosphorus concentrations in water flowing from storm drains was incredibly high, with an average of 520 µg/L from Ventura, 560 µg/L from Clear Lake and 900 µg/L from the south shore residential area. Suggestions in this report, if implemented, would reduce phosphorus loading from the agricultural areas of the watershed by 80-90%. Similar reductions should also be expected from the urban areas of the watershed. Activities such as improved construction practices, appropriate disposal of pet and yard wastes and regular street cleaning would all aid in reducing phosphorus transport to the lake. Additionally, structures such as detention basins, constructed wetlands, and other approaches suggested in the Vierbicher Associates (2000) report concerning storm water management should be investigated. Bonestroo, Rosene, Anderlik, and Associates are already implementing some efficient designs in this area. Examples of activities that can be undertaken by different groups, such as citizens, cities, regional governments and agricultural communities, are shown in Table 4.

All of the above mentioned practices would reduce sediment and phosphorus transport from non-point sources to Clear Lake, but would have no impact upon point sources. Potential point sources of phosphorus in the watershed may include overflows from the wastewater collection system of the City of Clear Lake, residences in the city of Clear Lake that are not connected to the wastewater collection system and rural residences in the Clear Lake watershed. We did not specifically observe these problems, but we did find numerous occurrences of caffeine, a known human sewage tracer, in water from field tiles in the Clear Lake watershed. Additionally, a 1998 study for the City of Clear Lake showed caffeine present in water flowing from 30 storm drains into Clear Lake. It is assumed that all residences in the cities of Clear Lake and Ventura are connected to the wastewater system. It is well known that the system is not adequate to prevent overflows during large precipitation events, but now overflows are pumped to areas that do not drain into Clear Lake. Additionally, little is known about the condition of the septic systems in rural areas of the watershed. We believe that there is no ongoing inspection program for septic systems in Cerro Gordo or Hancock County, although there are local regulations that regulate on-site wastewater treatment and disposal (e.g., Cerro Gordo County Ordinance 27). These are important issues with respect to limiting phosphorus transport to Clear Lake. It is suggested that local officials, both from the cities of Clear Lake and Ventura, as well as from Cerro Gordo and Hancock Counties, begin an assessment program to determine if there is a need to upgrade systems for the protection and preservation of Clear Lake. Further, minimum setback from surface waters (lakes, ponds, streams) of open and closed portions of systems should be made ample to reduce chances of input from these sources (at least 100 ft).

Two disturbing aspects of the nutrient budget of Clear Lake are (1) that rainfall is now so significantly phosphorus enriched that it represents a substantial fraction of the budget, and (2) that groundwater is now very phosphorus-enriched and represents a pool of nutrient that can be reduced only with great difficulty. Although rainfall is likely a widespread problem with elements of local and long-range transport and cannot be remediated within the scope of this restoration project, groundwater is likely local in origin (see Chapter 8), but will decline very slowly over time, even long after surface inputs have been alleviated. One new means of reducing concentrations of nutrients and other contaminants in groundwater is through phytoremediation. In this approach, trees are planted that extend roots into the groundwater, removing target substances. Research in Florida suggests that trees can remove up to 10 g of P per m^2 each year (Dierberg & Brezonik 1983, Dolan et al. 1981). Therefore, although not completely quantifiable at this time (and therefore not part of the cost analysis), establishing broad (e.g., 100 m or more), wooded buffer strips around Clear Lake, Ventura Marsh and their tributaries would engender a long-term benefit since groundwater is moving on the order of 50 feet linearly per year. Groundwater would be helped most if such buffers were established along shores where groundwater flux is substantial (see Fig. 7, Chapter 8). This would also provide an increased measure of shelter of the lake from wind.

2. Reduction in bacteria inputs to the lake

a. Bacteria sources. Shallow, warm-water systems such as Clear Lake, frequently receive coliform bacteria from the surrounding watershed during rain events, and the very rich nutrient and sediment environments found in eutrophic and hypereutrophic lakes allow these bacteria and probably the pathogenic microbes to survive for relatively long periods. Coliform bacteria reside in the intestines of warm-blooded creatures, which include humans, livestock, birds, raccoons, rabbits, deer, and many types of pets. All of these creatures are potential sources of the bacteria that have been found in Clear Lake. The locations around the watershed indicated as sources of bacteria in Clear Lake were discussed extensively in Chapter 6. Bacteria and caffeine were found in outflows from all storm drains in the City of Clear Lake. Additionally, lake-wide bacteria sampling indicated persistent sources of bacteria from Ventura. But, all shoreline areas around Clear Lake were shown to be a potential source of bacteria to the lake.

Samples from some of Clear Lake's sediments showed high populations of coliform bacteria. These sediments, and also the bacteria, are often resuspended into the water column by wind and boat action. The sediments do not produce coliform bacteria, but instead they are a place where these bacteria survive after being washed into the lake from its watershed. Thus, the lake's sediments can become an indirect source of bacteria at times.

b. Bacteria reductions. Steps that could lead to the reduction of bacterial populations in Clear Lake include the following: controlling animal wastes in the watershed; addressing storm drain, sanitary and water management systems; addressing septic systems; and reducing the resuspension of lake sediments. Controlling animal wastes is both an urban and rural issue. In the agricultural sector, minimizing livestock contact with waterways is one important way to keep bacteria out of the lake. Another would be to reduce or eliminate manure application near waterways or tile inlets. Urban sources of animal wastes include pets and wildlife. Wildlife-derived bacteria may be difficult to control, but this is likely an insignificant source. Proper disposal of pet waste by owners could eliminate that potential bacteria source. Citizens around the watershed can institute a number of measures to reduce bacterial inputs.

Issues involving storm drain, sanitary, septic and water management systems include overflows from the wastewater collection system of cities, urban residences not connected to the wastewater collection system and rural residences in the Clear Lake watershed. We did not specifically measure or observe these problems, but we did find numerous occurrences of caffeine, a known human sewage tracer, in water from field tiles and storm drains in the Clear Lake watershed (Appendix 10). It is assumed that all residences in the cities of Clear Lake and Ventura are connected to the wastewater system. It is well known that the system is not adequate to prevent overflows during large precipitation events, but now overflows are pumped to areas that do not drain into Clear Lake. In fact, raw sewage input to the wastewater treatment plant becomes very dilute during rainy periods (Kevin Moeller, pers. comm.), suggesting that there are connections between stormdrains and the sanitary sewage system that could be eliminated or investigated. Additionally, little is known about the condition of the septic systems in rural areas of the watershed. There is little systematic inspection of septic systems in Cerro Gordo or Hancock County. These are important issues with respect to limiting bacteria transport to Clear Lake. It is suggested that local officials, both from the cities of Clear Lake and Ventura, as well as from Cerro Gordo and Hancock Counties, begin an assessment program to determine if there is a need to upgrade systems for the protection and preservation of Clear Lake from bacterial inputs.

Places where intensive examination of systems is warranted are indicated on the bacteria distribution maps in Chapter 6 (Figs. 3-7). In addition, small, dredged harbors are often anaerobic near the bottom and are thus likely areas where fecal bacteria can persist. New dredging should be discouraged around this lake and all existing harbors should be aerated continuously and tested regularly for fecal bacteria. There are some innovative filtration systems that have been reported to be efficient means of removing bacteria from storm drainage (Richard Brasch, Bonestroo Rosene Anderlik Assoc., St. Paul, MN, pers. comm.). These systems should be installed where simpler means are found impractical.

Reducing bacteria sources from resuspended sediments will be addressed in the next section, concerning in-lake activities. Any actions, which would reduce sediment disturbance in the lake, would act to reduce bacteria resuspension.

3. In-lake activities

a. In-lake problems. Clear Lake is presently shallow and located in a relatively unprotected basin, thus it is very prone to wind-derived mixing of sediments. The diagnostic study showed that the current rate of sediment delivery to Clear Lake is 650 yd^3/yr (~ 1.6 million lbs/yr), but the rate of sediment deposition over the past 65 years has been over 71,200 yd^3/yr. The result of this sedimentation is that the lake has been reduced to 38% of its original (post-glaciation) volume, and its average depth has decreased by 6 feet. Analyses of wind direction, duration, and velocity records indicate that prevailing winds are generally out of the SSE and NW during the open-water season (Fig. 7). The physical impact of these winds on the lake was discussed in Chapter 7. Wind- and boat-derived resuspension of sediments contribute greatly to turbidity, or lack of water clarity, in Clear Lake. Additionally, these sediments are loaded with ammonia, phosphorus and bacteria, all of which contribute to water quality problems in Clear Lake.

High densities of benthic fish populations have also been implicated as causes of increased turbidity and water quality degradation in Clear Lake. Two species of benthic fish that were historically present and remain in very high densities today are bullhead and carp. Bailey and Harrison (1945) listed bullhead as very abundant, and carp as common. Biomass estimates completed by DNR fisheries staff in 1999 and 2000 revealed bullhead density to be 150 to 300 lbs/acre, and carp at 100 to 200 lbs/acre. Although these species were abundant in the 1940's, it is unlikely that they dominated the total standing stock as they do today. Despite the historical presence of bullhead and carp, aquatic vegetation flourished in Clear Lake. Apparently the density of these bottom-feeding fishes was not great enough to have a severe impact on vegetation, especially under higher water clarity, lower nutrient conditions. As water quality deteriorated in Clear Lake and water clarity became reduced the vegetation started to decline. The loss of vegetation severely impacted populations of bass, bluegill and crappie. With a void created by their absence, it is likely that bullhead and carp increased in numbers taking advantage of the degraded environment for which they were better suited. Thus, the problem became additive, with increased numbers of bullhead and carp further degrading the environment, creating an environment suitable for bullhead and carp to increase their numbers.

Another in-lake problem is that the Little Lake no longer retains nutrients, a function that it originally performed. During this analysis, 54% of the phosphorus load to Clear Lake passed through the Little Lake. Perusal of past and present bathymetric maps (Figs. 35-39, Chapter 5) shows that the Little Lake basin was originally much deeper than it is today. This deeper basin served as a nutrient and sediment retention site for the waters that flowed from west to east through the lake. Thus, cleaner, clearer water passed into the main lake. Through time, this basin filled with sediment and nutrients, and now it is full. This is illustrated by the fact that the entire bottom of the Little Lake now tilts downward toward the main lake. This results in increased nutrient flux to the main lake from the western watershed.

b. Potential in-lake solutions.

- **Dredging.** One potential step that could decrease P-delivery to the main lake is dredging. The diagnostic study showed that the current rate of sediment delivery to Clear Lake is 650 yd^3/yr (~ 1.6 million lbs/yr), but the rate of sediment delivery over the past 65 years has been over 71,200 yd^3/yr. The lake has already been reduced to 38% of its original (post-glaciation) volume, and if no action is taken, it could completely fill in approximately 700-800 years and could become a wetland in a much shorter period. This assumes that the trap efficiency of the lake will not change and current soil conservation measures in the watershed will continue. The removal of some of the accumulated lake sediments will add to the life of the lake and provide better environment for aquatic life.

Restoring Clear Lake to it's original volume would require the removal of 34.0 million yd^3 (26.0 million m^3) of sediment, and such a plan would be incredibly costly and difficult to execute especially because a huge spoil deposition area would be required. Dredging selectively chosen areas of the lake could provide vast water quality benefits. For instance, the PONDNET model was used to calculate potential phosphorus removal in the Little Lake. If the Little Lake were dredged to its original volume, it would remove 64% of the phosphorus that flowed into it via overland flow. When combined with watershed phosphorus reductions discussed earlier, this would result in a 50% reduction in Clear Lake's phosphorus loading. Also, by deepening the Little Lake, resuspension of sediments would be reduced in that portion of the lake. That would likely result in increased water clarity, which would in turn promote the growth of aquatic macrophytes. Increased growth of aquatic macrophytes would help to stabilize sediments, which again would help to increase water clarity and phosphorus retention. One remedial option would therefore be the removal of about 9% of the total accumulated sediments in Clear Lake, by removing sediments only from the Little Lake basin of Clear Lake.

A realistic goal for the lake is to restore the Little Lake basin to near its original depth and shape, while minimizing any disturbance of existing vegetation beds in the Little Lake. The proposed dredging areas are shown in Figure 8. The dredging proposal for Clear Lake would involve the removal of over 2.3 million yd^3 of sediment. This would result in 102 acres (41 ha) having depths of 7-13 feet (2-4 m), 71 acres (29 ha) with depths of 13-20 feet (4-6 m) and 41 acres (17 ha) with depths of 20-27 feet (6-8 m). This would be accomplished by dredging a polygon measuring 4400 feet (1340 m) by 3150 feet (960 m) at its widest dimensions (Fig. 8). Following this action, the maximum depth of the Little Lake would be increased from 8 ft (2.4 m) to 27 ft (8.1 m).

The diagnostic study indicated that some sediment in Clear Lake may contain contaminants, therefore, this is an additional consideration with respect to dredging at Clear Lake. Four sediment samples were collected from Clear Lake and analyzed at the University of Iowa Hygienic Laboratory for pesticides and heavy metals. These analyses showed that cadmium, chromium, copper, lead and zinc were present in lake water and/or in sediment elutriates in concentrations that constitute violations of Iowa Water Quality Standards. This indicates that these pollutants need to be addressed, particularly if the dredging option suggested here is exercised. Additional samples should therefore be taken before dredging to determine the sources and the extent of these Water Quality Standard problems. If further testing shows these pollutants to be widespread, it will likely impact lake dredging as a restoration option by requiring more stringent control over water quality and substantially increased costs. Additionally, monitoring data from the Little Lake sampling site showed very elevated concentrations of ammonia-nitrogen in water near the lake bottom. Hydraulic dredging would draw water from this area of elevated ammonia-nitrogen levels, and the elutriate water could pose another problem for water quality.

After reviewing the information concerning heavy metals in sediments, Ralph Turkle, IDNR-EPD summarized his recommendations by saying "... I think the report should not dismiss the metals as background levels. The pollutants should continue to be part of the total lake assessment with every attempt in the future to identify their likely source(s). In addition, any recommended lake restoration effort (hydraulic dredging) will be faced with addressing the return water quality and its impact on the lake."

There are two types of dredging, dry land and hydraulic dredging. Dry land dredging would require that the lake be drained and the sediment removed after drying. It is not frequently used because of the considerable length of time the lake is empty. It is very unlikely to be successful here since groundwater would tend to keep the lake wet.

Hydraulic dredging is more commonly used in this type of situation. Hydraulic dredging requires a floating cutterhead dredge, a large centrifugal pump, a slurry pipe system, and a water return system. The slurry that the hydraulic dredge creates is a mixture of lake water and lake sediment.

The disposal of dredged material is an important consideration associated with hydraulic lake dredging operations. A containment area is needed which would allow the solids to separate out of the slurry. The containment area needs to have a larger capacity than the amount of sediment to be removed because of a swell factor. This swell or bulking factor is the ratio of the volume that the dredge spoil will occupy in the containment area to the volume of sediment dredged. The bulking factor is based on the type of sediment being dredged. For this analysis a bulking factor of 1.5 was used (Ken Jackson, IDNR, personal communication). It is important to note that flocculent, organic sediments can actually shrink to a volume less than that occupied on the lake bottom when they are adequately de-watered. These sediments are abundant in Clear Lake, thus estimates of volume needed to hold dredge spoil may exceed the actual volume needed.

It is important to locate the containment area as near the dredging site as possible. This is because as the distance between the containment area and the dredging site increases the power requirements to pump the slurry increase dramatically. This in turn increases the cost of the dredging operation.

The suggested dredging plan indicates that over 2.3 million yd^3 (1.8 million m^3) of dredge spoil will be removed, and when a bulking factor of 1.5 is applied, this requires a containment site that could hold 3.5 million yd^3 (2.7 million m^3) of spoil. This volume of dredge spoil would need to be stored in a large area.

The location of one potential containment site for the dredge spoil is shown in Figure 9. The site would be located just to the northwest of the Ventura Marsh Wildlife Management Area. This area is approximately 2.5 miles (4.0 km) from the center of the proposed dredge area. A dam would be needed at both the east and west ends of this site, and small berms would be required along 2 property lines. The east dam would be 6 ft high and 330 yds long, and the west dam would be 11 ft high and 1310 yds long. The berm on the north side adjacent to the Davison property would be 3 ft high and 275 yds long, and the berm on the south side adjacent to the Woiwood property would be 3 ft high and 275 yds long. In this configuration, 4.6 million yd^3 (3.54 million m^3) could be disposed at this site. The area presently under consideration is located outside of the watershed, so water pumped out to this basin would not return to the lake. This site is located on private land. The cost of purchasing this land (a multiply divided 556 acre tract with separate parcels owned by Arthur Boehnke, Dolores Boehnke, Raymond Kassel etux, Ronald Knop etux, Robert Ollenburg, Marlys Pueggel Trust, and Kathleen Woiwood) could be $1,231,000, using a land value of $2,214 per acre (average value of agricultural land in Hancock county, November 1, 2000, from ISU Extension). The cost of building the east dam could be $12,000, and the cost of building the west dam could be $95,000 for the dam and water control structure. The cost of building the two berms would total $6,600. These estimates are based on a cost of $3/ yd^3 for dam construction (Dave Rohlf, NCRS, pers. comm.). Engineering and permitting costs for this site might be $201,700.

During the public meeting concerning the restoration of Clear Lake, there was substantial interest expressed in other potential containment sites for dredge spoil (see audio CD of hearing). Six additional sites have been identified within a 5 mile (8 km) radius of the center of the dredging site in the Little Lake (Fig. 10). No sites further away than 5 miles were considered, due to the expense incurred by pumping dredge spoil great distances. It should be noted that none of these additional sites are large enough to contain all of the dredge spoil. Also, the costs associated with installing pipes for pumping dredge spoil to more than one containment site would be extreme, and those costs are not estimated here.

The other potential spoil sites are numbered 1 through 6 in Figure 10, and are referred to as such in the following paragraph. The important information for each potential site is shown in Table 5. Each potential containment site would require at least one dike. The dikes used in these estimates have a 12 foot wide top, 3:1 side slopes and estimated costs of $3/ yd^3 for construction (Dave Rohlf, NRCS, pers. comm.). Sites 1, 2, 4 and 5 would require only one dike each. The dike for Site 1 would wrap from the north side all the way around to the east side, and would follow the curve of the land around the Lake Side Chapel. The dike for Site 2 would stretch parallel to the road and the north and east sides of this site. The dike for Site 4 would be parallel to the road along the north side of this site. The dike for Site 5 would be located on the east side of this site. Site 3 would require two dikes, one on the east and the other on the northwest corner. Site 6 would require three dikes, one to the west, one to the north and one on the east side of this site. A number of combinations of these sites could be used to contain the estimated 3.5 million yd^3 of dredged material that would be removed from Clear Lake. All of these areas are outside of the watershed, so water pumped to these basins would not return to the lake.

Another option for the containment of some dredge spoil is to construct fetch-foiling structures in Ventura Marsh. The locations of the proposed structures, as well as a visual representation of these structures, are shown in Figure 5. These are all areas where

Geotube™ material could be used for structure construction. These are flexible tubes into which sediment slurry is pumped and dewatering occurs through the pores in the membrane. This is efficient because dredged material is being re-used to form the structure. Further dredge spoil could then be pumped into the area behind the Geotube™. Using this material to construct the islands would allow the disposal of nearly 7,000 yd^3 of dredged material per island. Each structure is approximately 0.85 acres in size, and up to 13 of these structures could be constructed in the eastern cell of Ventura Marsh. These structures could then hold just over 83,000 yd^3 of dredged material. These islands would be important because they would provide vegetated windbreaks within the marsh, and vegetative plantings are necessary to help hold the dredged material in place. Additionally, these structures would provide excellent habitat for waterfowl breeding, as well as increased hunting opportunities within the marsh. The cost of the island structures would be as follows: Geotube™ materials, filling, and installation, $135,000 per island; construction mobilization and deployment, $20,000; obtaining the dredge material to fill the tubes is considered in the dredging cost.

The combination of these dredge material containment sites would contain all of the dredge spoil that is proposed to be removed. Using these locations would alter the present configuration of Ventura Marsh. Figure 11 provides a glimpse of what Clear Lake would look like bathymetrically following dredging. Implementation of this option would increase lake volume from its present 42,054,700 m^3 to 43,822,600 m^3 post-restoration.

- **No-wake zones.** Another step which would help with the problem of sediment resuspension would be to enforce existing no-wake zones in the lake, and perhaps expand the no-wake zones in some of the more vulnerable areas of the lake. Motorized vessels should proceed at speeds that minimize the depth of penetration of motor backwash in shallow waters. Lake monitoring, particularly the work summarized in Chapter 7 of the diagnostic study, showed that no-wake zones are often ignored by recreational boaters. No-wake zones presently extend 300 feet out from shore throughout Clear Lake. These near-shore areas are often shallow, and are vulnerable to sediment resuspension by all forms of motorized watercraft. Areas particularly vulnerable to sediment resuspension are shown in Figures 4-11 of Chapter 7 in the diagnostic study. These figures could be used as a guide to determine where no-wake zone expansion might be most beneficial, if that is employed as a restoration option. Limiting sediment resuspension is important because resuspension inhibits water clarity and macrophyte growth. Additionally, sediment disturbance in shallow areas inhibits the establishment of rooted aquatic macrophytes. These macrophytes consolidate sediments, limiting resuspension, and use nutrients, helping water clarity.

- **Aeration.** Aeration presently is an ongoing winter activity at Clear Lake. If the Little Lake is dredged, year around aeration of the Little Lake should be considered. The Little Lake will contain the deepest area of the lake, so aerating that basin would avoid anoxia and provide important wintering habitat for fish. Hypolimnetic aeration is a possible restoration activity that might be quite helpful in limiting phosphorus remobilization from lake sediments. Hypolimnetic aeration differs from the present method of aeration because it pumps water to the shore to be aerated, rather than pumping air to a deep spot in the lake. This allows the water to remain stratified, which could be important in the Little Lake following dredging. Maintaining stratification in the Little Lake will be important for limiting remobilization of phosphorus from the sediments. Additionally, hypolimnetic aeration could provide an opportunity for *in situ* alum treatment of the aerated basin to limit phosphorus remobilization and lengthen springtime clear-water periods throughout the lake.

- **Breakwater structures.** The construction of breakwater structures has great potential to improve fisheries habitat and improve water quality at the same time. The diagnostic study showed that wind resuspension is a major problem for Clear Lake water quality. Breakwaters placed parallel to existing bulrush beds would protect them from the pounding forces of the wind and waves. These areas would then grow more vigorously and provide quiet water that would enhance the growth of submergent vegetation within the bulrush.

Potential sites for breakwaters include: State Dock, Baptist Camp, McIntosh Woods State Park, Farmers Beach, Lekwa Marsh. All of these sites are either publicly owned or undeveloped shorelines, which would improve the likelihood of public acceptance. Placing these structures in 5 to 6 feet of water would dampen the wind resuspension of nutrients, reduce wind disturbance to nearshore vegetation, reduce turbidity, and create excellent fish habitat. The riprapped portion of the breakwater would attract small and large fishes and the quiet water on the backside would provide quality spawning and nursery habitat with the mixed growth of submergent and emergent vegetation. Constructing these structures from the shoreline out in a T or L configuration would allow shore anglers to access the main arm of the breakwater. The sociological and economic surveys reported on in Chapters 2 and 3 underlined the public's expressed need for more public access to the lake. These structures would address one aspect of the perceived public need.

Other potential locations for breakwater structure would be near storm drain outfalls along residential shorelines. Suggested locations for all of the breakwater structures are shown in Figure 12. The breakwater structures would provide the vegetation and fisheries benefits listed above, and would serve as additional filters for the water draining off of the watershed and entering the lake. By placing breakwaters near storm drains, the vegetation growth promoted by the quiet water area would serve to filter nutrients out of the water entering the lake. This would be an effective way to further cleanse storm drain water on its way to the lake proper.

- **Fish population management.** To address the problems with benthic fish populations in Clear Lake, it will be necessary to improve two critical areas. First, it would be necessary to improve water quality through the nutrient mitigation outlined above. This would help reestablish aquatic vegetation, which so many other fish species are dependant upon. Second, it would be necessary to reduce and control populations of bottom-feeding fishes, primarily carp and bullhead. This would improve water clarity and also enhance the recovery of aquatic vegetation. Doing one without the other may not bring the intended results, so combining the two appears to be the best plan.

Water quality improvements are the intended results of many of the watershed alterations discussed earlier. If the watershed and in-lake structures that are suggested achieve the desired results, increases in water quality and water clarity would result. This should then result increased aquatic vegetation, which would provide critical habitat for fish.

Effective management of benthic fish should be designed to hold carp populations below 50 lb/acre. Some removal of benthic fish from Clear Lake has occurred since the early 1900's. Although past removal of carp from Clear Lake may appear impressive, it has not been adequate to have had major impact on the fish community or water quality. Currently, contract commercial fishermen have been taking the surplus and not making a substantial dent in the population. To increase the harvest, a monetary incentive could be considered. The fisherman would continue to receive payment for the sale of fish, but they could also receive an additional payment (so many cents per pound) from the DNR.

Bullheads are not currently available to harvest under the present contract commercial fishing program. Some neighboring states do allow for the commercial harvest of bullheads. This could be considered for Clear Lake. Population estimates of bullhead during 1999 and 2000 indicate a population of 1.5 to 3 million bullheads in Clear Lake. Despite this dense population, only about 36,000 bullheads were harvested by sport anglers during those two years combined. These fish were considered to be angler acceptable size, averaging 9 inches long and 0.4 pounds. A review of creel surveys on Clear Lake shows a downward trend in bullhead harvest over the past 15 years. Two hundred thousand bullhead were taken by anglers in both 1986 and 1987, but have never approached these levels since. Angler attitudes have changed over the past two decades. Between 20% and 30% of Clear Lake fishermen were specifically targeting bullheads during the mid-1980's, while in recent years, less than 5% target bullheads. It is unlikely that sport angler harvest will have any impact on reducing bullhead numbers in the future. It may also be socially acceptable to allow for a commercial harvest since so few anglers desire to catch these fish.

Biological control of carp and bullhead could provide another opportunity for reducing the populations of these species in Clear Lake. Flathead catfish appear to be the best predator for controlling undesirable species. Flatheads have been used successfully in Minnesota and Iowa on small lakes to reduce overabundant bullhead. A small number of flatheads were stocked in the fall of 2000 in Clear Lake. Additional fish are scheduled to be released this summer. A stocking strategy needs to be developed, analyzed and refined as work continues with this species. Besides being a very effective predator, they could also provide a unique opportunity to catch a trophy-sized fish in the future. Care should be taken however to avoid replacing one problem species with another.

Other predators that might be considered include largemouth bass and walleye. Although largemouth bass are an effective predator of bullhead, previous stockings have not done well in Clear Lake probably due to lack of abundant suitable habitat. This is likely to self-correct as water quality improves. Walleye will also readily consume bullhead, however large numbers of walleye are already stocked. Walleye density could be improved through the use of large fingerlings (>8 inches), in years when fry stockings produce a weak year class.

Any significant reduction in bullhead or carp populations, whether it be through mechanical removal or biological control, must be accompanied with a strategy to fill the void created with desirable sportfish. Sufficient predators must be available to control increased bullhead and carp reproduction. In addition, adequate panfish brood stock must be available to fill the void created.

4. Role identification

There are many activities suggested in the sections above which all can help to improve the water quality of Clear Lake. No one agency, person or institution can work independently and achieve the goal of cleaning up Clear Lake. Rather, collectively people, agencies and institutions will need to work together to achieve this goal. To aid in this endeavor, many tasks and roles are identified below.

a. The role of citizens, residents and visitors. Every person can help to maintain and improve water quality at Clear Lake. The community at Clear Lake has been involved with the alteration and degradation of the lake over the last 100 years. Now the community has identified remediation as a major goal and is profoundly engaged in this pursuit (see Chapters 2 and 3). Personal citizen action can be very beneficial. Taking responsibility for reducing nutrient loads to the lake is one important step. This can include supporting riparian and watershed regulations and guidelines, reducing nutrient input through "good housekeeping" and awareness that everything that hits the ground goes to the lake, supporting watershed cleanliness, inspecting plumbing and real estate for potential sources of nutrients, being aware of and using low P products (washing products, fertilizers, chemicals) and using good old-fashioned common sense Citizens should be encouraged to ask themselves "would this help the lake if it got into it?" Additionally, it is important to keep the watershed free of bacteria-laden materials. This can be done by picking up after pets, controlling all types of human and animal wastes, and supporting structures that filter urban runoff.

b. The role of cities. The cities of Clear Lake and Ventura are provided many amenities by their proximity to Clear Lake. This close proximity also allows them to impact the lake in many ways, and some of them are clearly detrimental to the lake. Other cities have involved themselves in many activities to protect their lakes. One potential activity is to adopt comprehensive riparian management and development plans. Aspects of these plans could include increasing set-backs and buffers, decreasing shore impacts and erosion, maintaining high levels of cleanliness of pavement and land, minimizing impervious structures, decreasing construction-related impacts and routing effluents and nutrients out of the watershed and treating them to reduce harm elsewhere. If the plans outlined in this report were to go into place, it would also be important to promote and enforce riparian and nutrient management regulations. Inspecting, repairing and/or upgrading storm drains, sanitary systems and other water management systems, with the objective of lake restoration and minimizing impacts on the lake, is another important suggestion. Installing and maintaining bacteria- and sediment-trapping storm drain filters can be effective in removing these pollutants before they enter lakes. There also may be abandoned septic systems or other waste disposal systems that are still leaking into the lake. Addressing these issues within communities can be important in promoting a healthy lake.

c. The role of counties. Cerro Gordo and Hancock Counties both contain areas of the Clear Lake watershed. The lake's watershed provides most of the nutrients which enter Clear Lake. In particular, the unincorporated residential and agricultural areas which are under the respective counties' jurisdictions provide the majority of these nutrients. These counties receive many benefits from the lake, and they could also be involved in numerous activities that would, in turn, benefit the lake. One potential activity is to adopt comprehensive riparian management and development plans. Aspects of these plans could include increasing set-backs and buffers; decreasing shore impacts and erosion to tributaries, wetlands, shorelands and the lake; maintaining high levels of cleanliness; decreasing construction-related impacts; and, routing effluents and nutrients out of the watershed and treating them to reduce harm elsewhere. In relation to these plans, it is also important to promote responsible riparian and nutrient management. Rural waste management systems may also be contributing to the degradation of the lake. Activities that would reduce these impacts might include inspecting and repairing tile-line, storm-drain, sanitary and other water management systems; addressing old, abandoned septic and waste disposal systems; inspecting septic systems; upgrading septic systems to efficient designs that immobilize nutrients; and, enforcing regulations that prohibit disposal of "black" water to tile-lines and surface drainages. Adopting regulations that limits unplanned proliferation of casual drainage to the lake and its tributaries, and instead favors water-retention in wetlands, is a potential county activity. Counties could also promote moderate nutrient use in agricultural lands and seek ways to help producers keep nutrients within fields. Along the lines of general cleanliness and good housekeeping, counties could employ frequent street and road cleaning, as well as strive to control dust from construction sites and unpaved roads.

d. The role of the agricultural community. Agricultural areas surrounding Clear Lake provide 43% of the phosphorus that enters the lake (or perhaps more if one considers phosphorus moving as dust and groundwater). In order to restore Clear Lake, this phosphorus needs to be kept on the fields, where it is vitally important, and out of the lake. Thus, it is important that the agricultural community be receptive to initiatives that would decrease agricultural nutrient inputs to the lake. One such initiative would be voluntary agreement to changing 5-10% of the row-cropped land in the watershed from crops to permanent vegetation. This would result in a 10-20% reduction of the phosphorus export from all agricultural lands. Use of assessment tools, such as the NRCS Iowa P-Index, help farmers to determine their risk of phosphorus loss from the cropland. Expanded use of best management practices could decrease erosion and increase nutrient efficiency. Related to nutrient efficiency, the diagnostic study showed that over 50% of the crop fields in the Clear Lake watershed had levels of soil phosphorus much higher than levels optimal for crop production (see Chapter 11). Reductions in phosphorus applications and improved timing and methods of application could decrease field losses and decrease levels of phosphorus in groundwater. Consideration of Conservation Reserve Program (CRP), Wetlands Reserve Program (WRP) or other conservation easements of sensitive lands could ease nutrient delivery to streams and the lake. Similarly, construction and restoration of wetlands as retention and detention structures could decrease soil and nutrient delivery to the lake.

e. The role of government agencies. IDNR has indicated that government agencies will likely play a leadership role in the restoration of Clear Lake. There are many restoration alternatives which will help these agencies work with the community, the lake, and the watershed to lower phosphorus, sediment and bacteria inputs and decrease remobilization of these substances within the lake. One set of alternatives is simply the application of basic watershed restoration techniques, such as:

- promoting permanent vegetation on 5-10% of the most erosion-prone land to reduce P flux from the western watershed,
- installing and restoring wetland systems to retain nutrients,
- installing P retention and detention ponds in urban and agricultural areas,
- "Daylighting" some sections of tile lines and restoring streams and wetlands.

Working with the agricultural community to increase phosphorus retention on agricultural lands is an important restoration alternative. Ventura Marsh can and should act as a nutrient filter for waters that enter Clear Lake. An important restoration activity might be to restore and maintain Ventura Marsh, so that it acts as a nutrient retention basin. This might involve the structural changes listed earlier, as well as fish population management. Nutrient retention is a common theme in this restoration process, and another alternative which addresses nutrient retention is dredging the Little Lake. If the Little Lake were dredged to its original depth, it would act as a nutrient retention basin, holding back 64% of the phosphorus that enters it from passing on to the main body of the lake. Benthic fish population management and maintenance is another restoration option that has great potential for improving water quality in Clear Lake. Expanding and enforcing no-wake zones could have a similar positive impact. Finally, expanding and maintaining hypolimnetic aeration could address phosphorus resuspension issues.

Analysis of alternatives

The management approaches discussed above compliment each other; in-lake activities help to restore the basin by increasing water depths and stabilizing sediments, while watershed restoration helps improve water quality and decelerate the rate at which the lake will degrade in the future. We suggest that both approaches would be most effective if adopted together; for it will do little good to remove the sediments from the lake if soil erosion and nutrient loads rapidly return sediment and phosphorus to the lake, while watershed restoration would only restore the water quality of the supply to a lake of short life and dubious aquatic potential.

Benefits of restoration project

Clear Lake is an important recreational resource. Survey results and data analyses conducted by Azevedo, Herriges and Kling (Chapter 2) estimate that 178,650 households visit Clear Lake every year. It is a well-used lake in this region due to its location near Clear Lake and Mason City, and it's proximity to Interstate 35. Interviews conducted by Wagner (Chapter 3) indicate the major social role that the lake plays in the region. Additionally, few other public lakes are available for recreation in close proximity to Clear Lake. Over the years, multiple public entities have made investments in facilities in the parks around Clear Lake. It is important to note that water quality is likely to degrade substantially if no restoration is attempted. The major benefit of this project is to improve this recreational resource, by reversing degradation due to eutrophication and sedimentation, thus improving water quality within the lake for the benefit of water-based recreation.

Respondents to the Clear Lake survey indicated a willingness to pay of $19.5 million to avoid the deterioration of Clear Lake. Alternatively, respondents expressed a willingness to pay of about $40 million for quality improvements at the lake. These numbers represent the value to visitors and residents of water quality maintenance and improvement. In considering whether investments to clean up the lake are worth the costs, these value estimates provide the appropriate baseline for comparison. These large values associated with water quality improvements at the lake are consistent with the lack of good substitute resources and the potential quality of this unique resource.

Local residents and others may also be interested in the amount of economic activity generated locally as a result of water quality improvements. Households that responded to the survey on average made 6.6 visits to Clear Lake per year, so an estimate of annual total visits to Clear Lake would be 178,650 X 6.6 = 1,179,100 visits per year. Survey respondents reported spending an average of $51 in or near the City of Clear Lake on a typical visit, for a present expenditure level of just over $60 million annually. Following restoration, survey visitors indicated they would increase the number of trips they took to Clear Lake from 6.6 to 10.32 trips per year. If no additional households visited Clear Lake and these estimates accurately reflect future behavior, the number of visits would increase to 178,650 X 10.32 = 1,843,700. If spending remained the same, the level of visitors' expenditures in Clear Lake would then increase to over $94 million annually. The number of households that visit Clear Lake should increase following restoration, so these numbers may underestimate results following restoration. It should be noted that the numbers used above are estimates, and do not account for residents' expenditures, but yield an indication of the great economic value of Clear Lake.

It is important to note that from a societal perspective, this economic activity could occur elsewhere if Clear Lake's water quality is not improved and acceptable alternatives are available. Thus, it does not necessarily reflect a net increase in economic activity to the region. Therefore, although of significant importance to city and regional managers, measures of economic activity do not necessarily measure the inherent value of a resource such as water quality in Clear Lake. Rather, the willingness to pay represents this value.

If none of the restoration options are employed, the lake will become more and more eutrophic, and thus become a less attractive recreation resource. Additionally, in time, the lake will fill to the point that its value as a recreational lake will likely decline dramatically. Long before that time, however, severe water quality problems will be encountered. The combination of watershed improvements, management approaches and in-lake activities would enhance the recreational value of the lake and greatly prolong its useful life. Watershed restoration and lake deepening would act to reduce nutrient inputs and dilute their effect in the lake, however, the lake would still be likely to have some water quality problems due to algae blooms and low transparency. This is due to the limits on restoration imposed by phosphorus-rich precipitation and groundwater.

How long will it take? It should be noted that the time-course of response to nutrient abatement is likely to be quite long. Cooke et al. (1993) have analyzed a number of cases in which external nutrient loads were reduced substantially. They found that short-term (<5 years) improvements were only noted in about half the lakes and that most lakes take more than 5 years for changes to begin to be detected. In shallow lakes, the problem is exacerbated by internal loading, so changes may be very slow. Lakes may improve over a decade or two before the equilibrium level is approached. The time-course of restoration should therefore be expected to be 5-30 years depending upon the speed and degree to which restoration activities are undertaken.

Post-restoration monitoring plan

Once the dredging and watershed improvement work has been undertaken, a monitoring program should be established to determine the rate of recovery of the lake. Such a plan is outlined here. Three sampling stations should be established at the points in the lake shown in Figure 13. For at least a five-year period, samples should be taken monthly during the months of September through April and biweekly during May through August at the water surface, 0.5 meters deep and at 1 meter depth intervals to the lake bottom (maximum depth, 8 m). Samples would be collected between 0800 and 1600 hours. All samples should be analyzed for total and soluble reactive phosphorus; nitrite plus nitrate nitrogen, ammonium, unionized ammonia (the toxic form) and total nitrogen; total suspended solids; silicate; pH; temperature; and dissolved oxygen. Representative alkalinities should also be determined. Samples collected from the upper mixing zone should be analyzed for chlorophyll *a*. Algal biomass in the upper mixing zone should be determined through algal genera identification, cell counts and cell volumes, and reported in terms of biomass of each genus identified. Secchi disk transparency should also be determined at each sampling period. The surface area of the lake covered by macrophytes at mid-summer should be determined, and the predominant species should be identified and their distribution shown on a map. Water samples should also be taken from the main tributaries (9 sampling sites, Fig. 13) on the same days that the lake is sampled (when they are flowing) for analyses of total phosphorus, total nitrogen, total suspended solids and inorganic suspended solids.

Cost analysis

The preliminary cost analysis (Table 6) contains several assumptions and is for planning purposes only. More detailed cost estimates should be included as part of the engineering design of the project. The following items are addressed in this cost estimate: land conservation by planting permanent vegetation, pond and wetland installation, Ventura Marsh renovations, water control structure renovations, dredging, fish barrier construction and post-restoration lake monitoring. Several items that should be implemented but that are not addressed in this cost estimate are (1) costs for encouraging the adoption of Integrated Crop Management (ICM) strategies and other BMP practices throughout the watershed, (2) costs for improvements upon septic systems, sanitary sewers and storm drain systems in the watershed, (3) costs associated with planting of woodlands along lake shores, streams and wetlands to mitigate groundwater P, (4) other costs incurred by citizens, cities, counties and agricultural producers to mitigate P, sediment and bacteria fluxes from individual properties and (5) costs associated with various policy changes outlined in Table 4. These are also useful remedial measures the cost of which would vary greatly with the scope of application.

The costs of converting cropland to WRP permanent easements, assuming there are willing landowners and the land is accepted by NRCS, might be assumed by NRCS. This includes legal costs, survey costs, tile breakage and wetland construction and wetland and upland seedings (Dan Selky, Hancock Co. NRCS District Conservationist, pers. comm.). The landowner is also paid 100% of the appraised agricultural land value in return for the permanent conservation easement. The average value of agricultural land in Hancock County as of November 1, 2000, was $2,214, and the average value of agricultural land in Cerro Gordo County at the same time was $2,189 (ISU Extension 2000). For the purpose of this estimate, all land was valued at $2,200. There are two types of land conversions proposed. The first is converting cropland to permanent vegetation in areas with a high potential for phosphorus losses. If the top 5% of phosphorus exporting lands were idled by the purchase of permanent conservation easements that would idle 276 acres of cropland, and an estimate of the cost of the permanent easements would then be $607,200. If the top 10% of phosphorus exporting lands were idled by the purchase of permanent conservation easements that would idle 544 acres of cropland, and an estimate of the cost of the permanent easements would then be $1,196,200. The cost of converting cropland to permanent vegetation was based upon a study performed by Colleti (1996), Department of Forestry, ISU. The cost of site preparation, and purchasing and planting the seed to convert cropland to switchgrass, was a total of $77/acre. The modeling effort suggested that 276 or 544 acres be placed into permanent vegetation, which would translate to a cost of $21,250 or $41,900, respectively.

The second type of land conversion proposed is to restore and create wetlands for nutrient retention in the landscape. The locations and types of wetlands (restored or newly constructed) are shown in Figure 3. The costs associated with each particular wetland are shown in Table 7. The total cost for constructing or restoring these wetlands is estimated to be $971,050. These costs include purchasing the land or a conservation easement for the land in the wetland and a 100 foot upland buffer surrounding each wetland, building any required dikes, building or upgrading water control structures and planting upland buffers to native vegetation. All dikes estimated in this exercise had a 12 foot wide top, 3:1 slopes on the sides and cost \$3/ yd^3 for construction (Dave Rohlf, NCRS, pers. comm.). Legal costs, survey costs and the cost of tile breakage are not included in this cost estimate. If federal funds are not available or are not sufficient, the total cost of permanently idling the cropland, creating or restoring the wetlands, establishing plantings and placing them under permanent easement could be $2,209,150. It should be noted that USDA programs are short-term allocations and should not be considered a permanent fix.

Restoring Ventura Marsh is a many-faceted endeavor. One aspect of the restoration is building a dike across the upper end of the marsh, to facilitate differing water level management scenarios in the eastern and western basins of the marsh. To build a dike that would tie into existing slopes and curve with the existing marsh, the dike would be approximately 1260 yards long. For this estimate, a dike height of 21 feet was used. This allows for significant excavation to get down to a solid substrate to tie the dike into, and allows the dike to be high enough to pool significant amounts of water in the western basin, if future land purchases allow expansion of the western basin. The dike would be 12 feet wide across the top, have 3:1 slopes on the sides, and cost \$3/ yd^3 construction (Dave Rohlf, NCRS, pers. comm.). This structure would cost approximately $226,800. One of two types of water control structures could be used in this dike. One would be a three bay concrete stop-log structure, and the other would be a set of 10 Wisconsin tubes. Both would cost in the neighborhood of $30,000. Thus, the total cost of the Ventura Marsh dike would be around $256,800.

In addition to building a dike between the eastern and western basins of Ventura Marsh, it is suggested that wind- and wave-breaking islands be installed in the eastern basin of the Marsh. These islands would enhance waterfowl production, expand hunting opportunities, limit wind-resuspension of sediments and encourage the growth of aquatic macrophytes. Islands formed out of Geotubes placed side-by-side would be around 40 feet wide and 500 feet long. Each tube, and the interior of each island (if they were deployed such that there was an interior area) could be filled with material dredged from the Little Lake. The tubes for each island would hold 3,300 yd^3 of dredged material. The storage capacity of the interior would vary for each island, so it is not estimated here. The cost of island construction was based on dredge spoil island construction at Grass Lake, Illinois. Each island would cost approximately $85,000 for the Geotube materials and filling. There would be an additional charge of approximately $20,000 for mobilization and deployment by the construction firm. Vegetating the island with a common wetland species such as Reed canarygrass would cost approximately $100/island. If thirteen such islands were constructed in Ventura Marsh (Fig. 5), the total cost of this restoration activity would be $1,126,300.

Improving the fish barrier and water control structure between Ventura Marsh and Clear Lake, as well as widening the grade, is another facet of Ventura Marsh restoration. Expanding the width of the grade to 2 or 3 times its present width would be beneficial in many respects, as discussed earlier (Fig. 6). Expanding the grade width by 25 yards, and having a face with 3:1 slopes would require around 26,550 yd^3 of rock fill. At a cost of \$3/ yd^3 for construction (Dave Rohlf, NCRS, pers. comm.), this structure would cost approximately \$79,650. It is possible that material dredged from the Little Lake could be used for some of this fill. The cost of planting trees and grasses on this structure is estimated at \$1,000 (Coletti 1996). The cost of constructing a goose-proof fence on the west side of the expanded grade is not included in this cost estimate.

To control water levels in the marsh, a pumping station could be installed that would move water from the marsh to the Little Lake. IDNR personnel estimate a pump capable of removing 1/10th foot of water from the marsh in 24 hours would be adequate. This pump would the need to be able to pump 5,660 gallons per minute. For this exercise, the cost of a pump and pumphouse is estimated at \$50,000 (Guy Zenner and Doug Jahnke, IDNR, pers. comm.). In addition to the pump, an overflow structure is necessary. The overflow structure could be a three-tiered, two "pond" fish trap that would replace the existing structure in the grade. For this estimate, three, 4-bay stop-log structures would be placed in series between the marsh and the lake. The areas between the structures could be used as fish traps if so desired. The cost of one 4-bay stop-log structure was estimated to be \$75,000, so the cost for this structure is estimated to be \$250,000. The total cost for the new and expanded grade could be \$380,850. The total cost for all structural work on Ventura Marsh then would be \$1,763,950.

The cost of further sampling and analysis of sediments for heavy metals and pesticides was estimated on current per-sample and field rates of the ISU Limnology Laboratory and the University of Iowa Hygienic Laboratory (Table 6). We recommend that thirty core-type sediment samples be taken from the proposed dredge area, and that they be located throughout to represent the entire dredge area.

The cost of dredging was based upon the cost for a recently completed dredging project, that of Upper and Lower Pine Lakes in Hardin County. The cost of dredging at Pine Lakes was \$1.53/yd^3. Lake Ahquabi was also recently dredged, with a dredging cost of \$2.05/yd^3. The table below indicates the estimate of cost for dredging for each of the projected dredge options at Clear Lake. It should be noted that these costs are based upon smaller, easier dredging projects. In particular, at Clear Lake, the main spoil containment site is located 2.5 miles from the center of the dredging site. This will probably require the installation of a booster pump, which may significantly increase the cost of the dredging operation.

Dredge Volume (yd^3)	Cost 1 (\$/ yd^3)	Cost 2 (\$/ yd^3)	Total Cost 1 (\$)	Total Cost 2 (\$)
2,312,450	1.53	2.05	3,538,050	4,740,500

The costs of spoil site preparation, land purchase, engineering costs and site preparations for the spoil site originally identified were outlined in a previous section. The cost for the land purchase and site preparation would be $1,344,600, while permitting and engineering costs might be $201,700, for a total cost of $1,546,300. If it is determined that spoil containment should occur at a combination of the additional sites, the combination of Sites 3 and 5 seems to be the most economical and would allow enough freeboard above the stored dredge spoil for an adequate margin of safety. The total cost for the combination of these two sites would be $2,093,600. This combination is nearly $550,000 more expensive than the originally identified containment site. Additional expenses would be incurred by having to run pipe to two containment sites instead of one. This would add over $1,000,000 to the total cost of the project. The total cost for dredging, assuming the $2.05/ yd^3 cost, would be $4,740,500. The total cost for dredging and spoil containment, if the originally identified spoil site is used, would be $6,286,800.

The cost of adding an aerator similar to those presently installed was assumed to be similar to the cost of a recent installation of an aerator at Rice Lake (Jim Wahl, IDNR, pers. comm.). That cost was $50,000. The annual cost of operation for the aerators presently at Clear Lake is approximately $700 per year (Jim Wahl, IDNR, pers. comm.). The cost of a hypolimnetic for the Little Lake would be on the order of $125,000 and would have several important benefits.

The cost of benthic fish population management can involve many different aspects. One aspect that is not estimated here would be the cost of stocking flathead catfish in the lake. Flathead catfish are not presently cultured by IDNR, so the cost of stocking them depends upon purchase price from commercial fishermen, personnel costs for capturing and transporting them from other locations, or starting a culturing operation. Another aspect would be the cost of benthic fish removal. The number of fish removed from the lake could be based on many things, but the most scientifically valid is probably standing stock. Standing stock estimates conducted by the IDNR showed that carp biomass ranged from 110 to 240 lbs/acre during 1999 and 2000. If standing stock estimates were continued in the future, the IDNR could target a pre-determined poundage of carp to be removed and budget for that total. For example, if the standing stock was 100 lbs/acre, a 50% or 50 lbs/acre removal could be requested. Fifty lbs/acre would equal about 180,000 pounds. If IDNR paid 10 cents/lb, then $18,000 would need to be budgeted for carp removal.

The cost of building breakwater structures is based upon the average bid price for a similar project conducted on the Okoboji lakes in 1996 (Ken Jackson, IDNR, pers. comm.). The structures estimated here would be built in a T or L shape out from shore, have a 10 ft wide top and be situated parallel to shore approximately 300 feet out and in 6 feet of water. The length of the breakwater parallel to the shore will vary by structure, but for this estimate, a standard 300 ft length was used. These structures would rise 2 ft above water level at normal pool, which is assumed to be spillway elevation. Each structure described above would require 4,500 tons of rock. If the cost of acquiring and placing the rock were $45/ton, each structure would cost $202,500. Sixteen such structures are suggested, with 10 located near the City of Clear Lake, two at McIntosh Woods, and one each at the City of Ventura, the Baptist Camp, Farmer's Beach and Lekwa Marsh. Additional structures could be placed near storm drains from the residential area on the south side of the lake. The cost of installing these breakwater structures could be $3,240,000.

The cost of the post restoration monitoring study was estimated on current per-sample and field rates of the ISU Limnology Laboratory and the University of Iowa Hygienic Laboratory.

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TABLE 1. Calculated sediment and nutrient inputs to Clear Lake following a two-inch rain event. The table shows the results for all model iterations and the percent reductions from present conditions for each iteration.

	Total Phosphorus		Total Nitrogen		Sediment	
	Metric (kg)	Imperial (lbs)	Metric (kg)	Imperial (lbs)	Metric (kg)	Imperial (tons)
Present Conditions	2042	4502	7248	15979	261274	288
1% Land Idling	2008	4426	3702	8162	246758	272
% change	-2%	-2%	-49%	-49%	-6%	-6%
5% Land Idling	1829	4033	3407	7512	219542	242
% change	-10%	-10%	-53%	-53%	-16%	-16%
10% Land Idling	1667	3675	3121	6880	199584	220
% change	-18%	-18%	-57%	-57%	-24%	-24%
5% Land Idling and Wetlands	873	1925	N/A	N/A	N/A	N/A
% change	-57%	-57%	N/A	N/A	N/A	N/A
10% Land Idling and Wetlands	834	1839	N/A	N/A	N/A	N/A
% change	-59%	-59%	N/A	N/A	N/A	N/A

TABLE 2. Results from the Wisconsin Lake Modeling Suite 3.1.1.

Phosphorus Prediction and Uncertainty Analysis Module
Wisconsin Lake Modeling Suite 3.1.1 (1999)
Panuska, J. and J. Kreider. Wisconsin Department of Natural Resources. Madison, Wisc.

Observed spring overturn total phosphorus (SPO): 185.0 mg/m^3
Observed growing season mean phosphorus (GSM): 166.0 mg/m^3
% Confidence Range: 70%

Lake Phosphorus Model	**Low Total P (mg/m^3)**	**Most Likely Total P (mg/m^3)**	**High Total P (mg/m^3)**	**Predicted -Observed (mg/m^3)**	**% Dif.**
Walker, 1987 Reservoir	106	166	199	-19	-10
Canfield-Bachmann, 1981 Natural Lake	140	189	213	4	2
Canfield-Bachmann, 1981 Artificial Lake	82	100	108	-85	-46
Reckhow, 1979 General	48	75	90	-91	-55
Reckhow, 1977 Anoxic	421	658	789	492	296
Reckhow, 1977 water load<50m/year	121	189	227	23	14
Walker, 1977 General	296	463	555	278	150
Vollenweider, 1982 Combined OECD	145	209	243	34	19
Dillon-Rigler-Kirchner	173	271	325	86	46
Vollenweider, 1982 Shallow Lake/Res.	133	197	231	22	13
Larsen-Mercier, 1976	253	395	474	210	114
Nurnberg, 1984 Oxic	149	233	279	67	40

Lake Phosphorus Model	**Confidence Lower Bound**	**Confidence Upper Bound**	**Parameter Fit?**	**Back Calculation (kg/year)**	**Model Type**
Walker, 1987 Reservoir	107	229	Tw Pin	0	GSM
Canfield-Bachmann, 1981 Natural Lake	59	544	FIT	1	SPO
Canfield-Bachmann, 1981 Artificial Lake	31	288	FIT	1	SPO
Reckhow, 1979 General	46	108	FIT	0	GSM
Reckhow, 1977 Anoxic	434	891	P Pin	0	GSM
Reckhow, 1977 water load<50m/year	119	268	P Pin	0	GSM
Walker, 1977 General	253	741	Pin	0	SPO
Vollenweider, 1982 Combined OECD	110	352	FIT	0	ANN
Dillon-Rigler-Kirchner	177	370	P qs	0	SPO
Vollenweider, 1982 Shallow Lake/Res.	105	326	FIT	0	ANN
Larsen-Mercier, 1976	268	521	P Pin	0	SPO
Nurnberg, 1984 Oxic	134	358	P	0	ANN

TABLE 3: Estimated sizes and phosphorus reduction capacity (from PONDNET) for nutrient retention wetlands in the Clear Lake watershed.

Wetland (number from Fig. 3)	Wetland/water body area (ac)	Volume (ac/ft)	Potential P Reduction	Flows to …
1	65.5	48.6	33	2
2	12.3	13.7	30	Ventura Marsh
3	67.5	342	62	4
4	17.2	32.7	49	14
5	24.3	78.9	50	4
6	3.4	5	39	Clear Lake
7	7.6	29.2	29	Clear Lake
8	18.6	55.3	29	Clear Lake
9	4	7.3	43	Clear Lake
10	11.7	22.2	44	Clear Lake
11	50.6	354.7	73	Clear Lake
12	22.8	41.8	56	Clear Lake
13	5.6	3.6	41	Ventura Marsh
14	12.3	16.4	54	15
15	10.8	15.5	37	Little Lake
Ventura Marsh	187.4	614.6	50	Little Lake
Little Lake	319.8	3381	64	Clear Lake

TABLE 4. Suggested activities for lake restoration.

Citizens, Residents & Visitors	Cities and Municipalities	Regional Governments (i.e., Counties)	Agricultural Communities
• Support riparian and watershed regulations and guidelines • Reduce nutrient input through "good housekeeping" and awareness that everything that hits the ground goes to the lake • Support watershed cleanliness • Inspect <u>your</u> plumbing and real estate for potential sources of nutrients • Be aware of and use low P products (washing products, fertilizers, chemicals) • Use old fashioned good sense: ask yourself "would this help the lake if it got into it?"	• Comprehensive riparian management and development plans keep sediments and nutrients in their place o Increase set-backs and buffers o Decrease shore impacts and erosion o Maintain high levels of cleanliness of pavement and lands o Minimize impermeable structures o Decrease construction-related impacts o Route effluents and nutrients out of the watershed and treat them to reduce harm elsewhere • Inspection, repair and/or upgrades of storm-drain, sanitary and water management systems can be of great help • Installation of bacteria-trapping storm drain filters reduces bacterial tracers • "Abandoning" septic and waste disposal systems reduces unwanted leakage • Promotion of riparian and nutrient management regulations improves nutrient, sediment and bacteria fluxes	• Adopt comprehensive riparian management and development plans o Increased set-backs and buffers o Decreased shore impacts and erosion (tributaries, wetlands & shorelands) o Maintenance of high levels of watershed cleanliness o Decreased construction-related impacts (erosion and dust control) o Routing effluents and nutrients out of the watershed and / or treating them to reduce harm • Inspection and repair of tile-line, storm-drain, sanitary and water management systems helps reduce unnecessary losses • Employment of frequent street and road cleaning reduces sediments and nutrients • Adoption of policies concerning storm- and land- drainage (favoring water-retention) • "Abandoning" <u>old</u> septic and waste disposal systems • Inspection and promotion of the upgrading of septic systems to efficient designs that immobilize nutrients • Reduction or elimination of tile-line or surface disposal of black water • Promotion of responsible riparian and nutrient management • Promotion of moderate nutrient use in agricultural lands and seeking ways of helping producers keep nutrients out of waterways • Control dust from construction and unpaved roads as it is part of the airshed	• Use approaches to decrease agricultural nutrient losses to waters • Use BMPs to decrease erosion and increase nutrient efficiency • Reduce P application to decrease field-losses and help groundwater • Minimize livestock contact with waterways to help decrease P delivery • Adopt voluntary land management practices to ease nutrient delivery to streams and lakes

TABLE 5. Additional spoil containment site options.

Site	1	2	3	4	5	6
Distance from dredging area	4.2 mi	3.5 mi	3.4 mi	2.6 mi	2.5 mi	1.9 mi
Volume (yd^3)	1,312,800	2,525,600	2,706,200	1,447,400	1,383,100	788,500
Dike Length (yd)	1260	1640	950	1310	650	700
Mean Dike Height (ft)	10	10	11	8	12	10
Max. Dike Height (ft)	20	15	15	10	15	25
Dike Cost	$92,400	$120,270	$80,120	$69,870	$62,400	$53,340
Water Control Structure Cost	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Land Area (ac)	320	640	440	320	160	320
Land Cost	$704,000	$1,408,000	$968,000	$704,000	$704,000	$352,000
Permitting and Engineering Costs	$119,990	$229,690	$157,670	$116,530	$115,410	$61,250
Total Cost	$919,390	$1,760,960	$1,208,790	$893,400	$884,810	$469,590

TABLE 6. Preliminary estimate of the total cost of lake restoration.

Restoration Alternative	Cost (with land under permanent easements)
Land idling (if no NRCS funding)	$1,238,100
Wetland restoration and construction	$971,050
Ventura Marsh restoration	$1,763,950
Sediment sampling and analyses	$26,000
Lake dredging	$6,286,800
Hypolimnetic aerator installation	$125,000
Breakwater structure construction	$3,240,000
Contracted fish removal (annual cost)	$18,000
Post restoration monitoring	$472,275
Subtotal	$14,141,175
10% increase for unknown costs	$1,414,118
TOTAL COST	$15,555,293

TABLE 7. Estimated costs of land purchased, site preparation, vegetative plantings, and water control structure for nutrient retention wetlands in the Clear Lake watershed.

Wetland (number from Fig. 3)	Land Cost	Dike Cost	Planting Costs (upland buffer strips)	Water Control Structure Cost	Total Cost
1	$176,526	$9,186	$1,446	$3,000	$190,158
2	$47,683	$4,724	$928	$2,400	$55,736
3	$61,300	$0	$1,064	$600	$62,964
4	$58,354	$4,593	$223	$1,200	$64,370
5	$14,932	$2,362	$329	$1,200	$18,823
6	$16,900	$615	$201	$1,800	$19,516
7	$38,845	$4,265	$530	$2,400	$46,040
8	$38,015	$6,603	$622	$1,800	$47,039
9	$0	$0	$0	$10,000	$10,000
10	$124,075	$0	$556	$10,000	$134,631
11	$16,655	$3,150	$351	$600	$20,756
12	$25,727	$0	$0	$600	$26,327
13	$171,583	$4,183	$1,045	$600	$177,411
14	$28,717	$3,875	$544	$1,200	$34,337
15	$45,369	$14,348	$199	$3,000	$62,916

FIGURE 1. Present conditions modeling results from AGNPS model for the Clear Lake watershed.

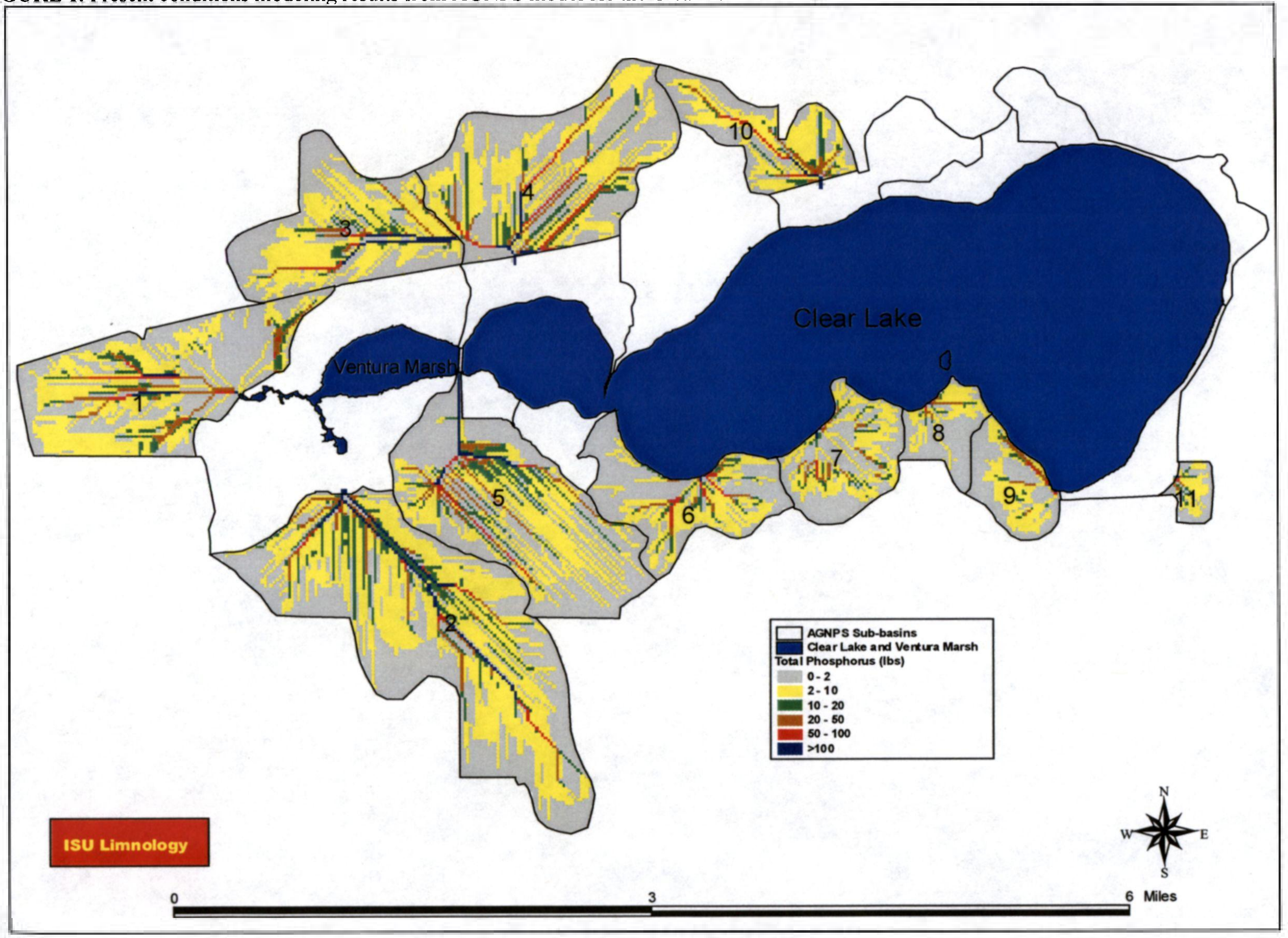


FIGURE 2. Top 1%, 5%, and 10% of phosphorus exporting cropland cells determined by AGNPS model.

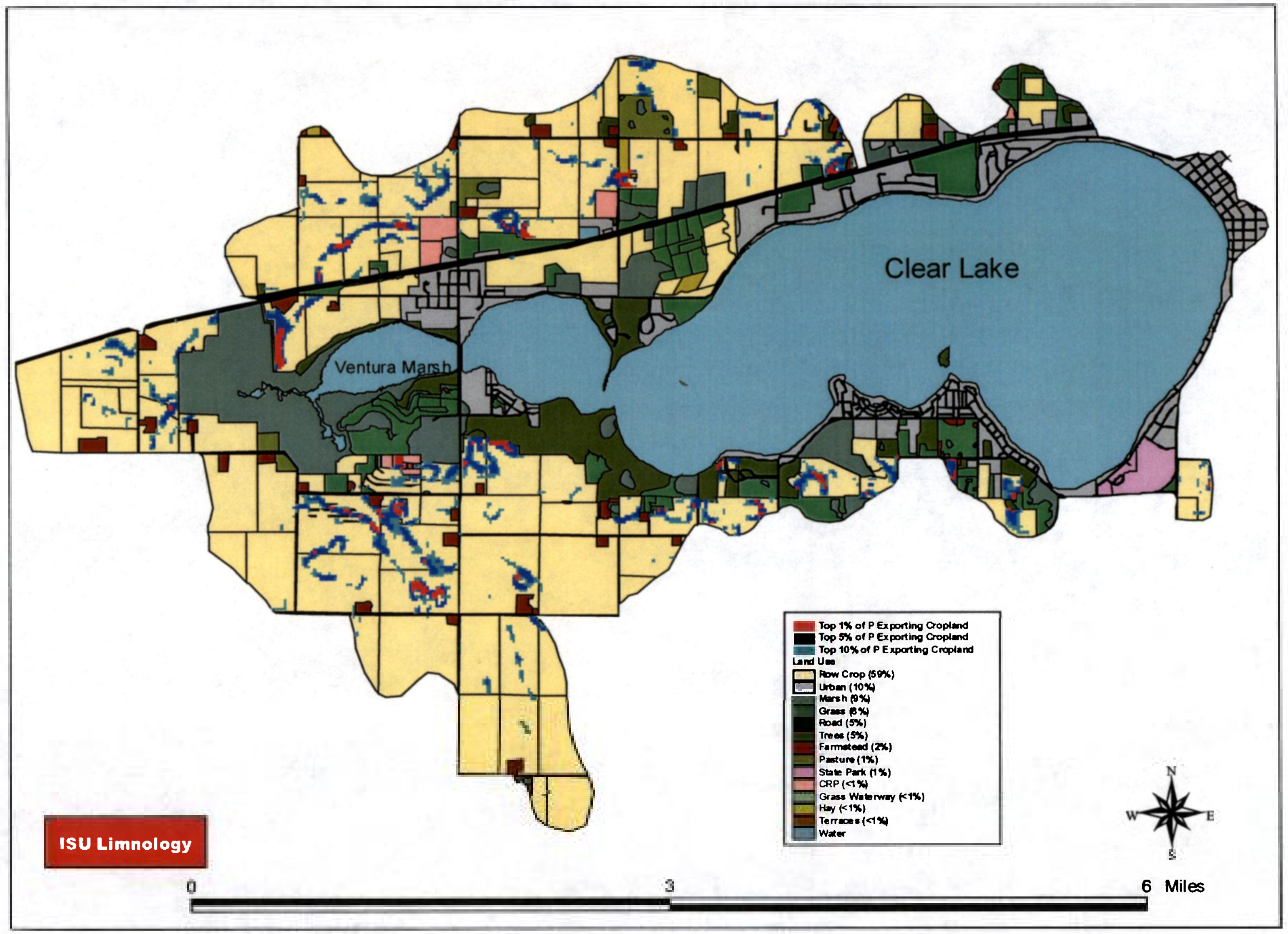


FIGURE 3. Proposed wetland restoration and construction in the Clear Lake watershed.

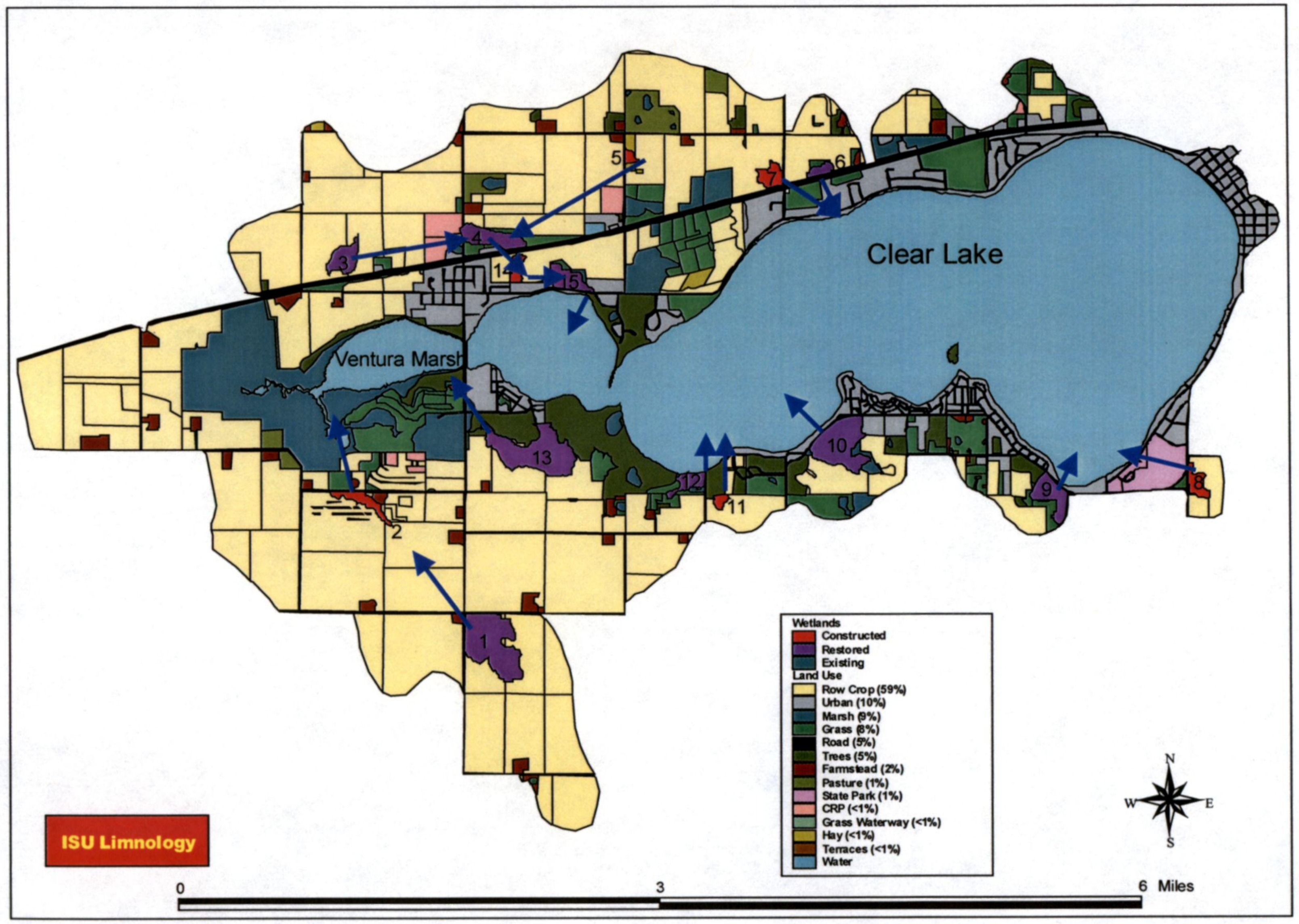


FIGURE 4. Schematic diagram of nutrient retention wetlands and their nutrient retention rates.

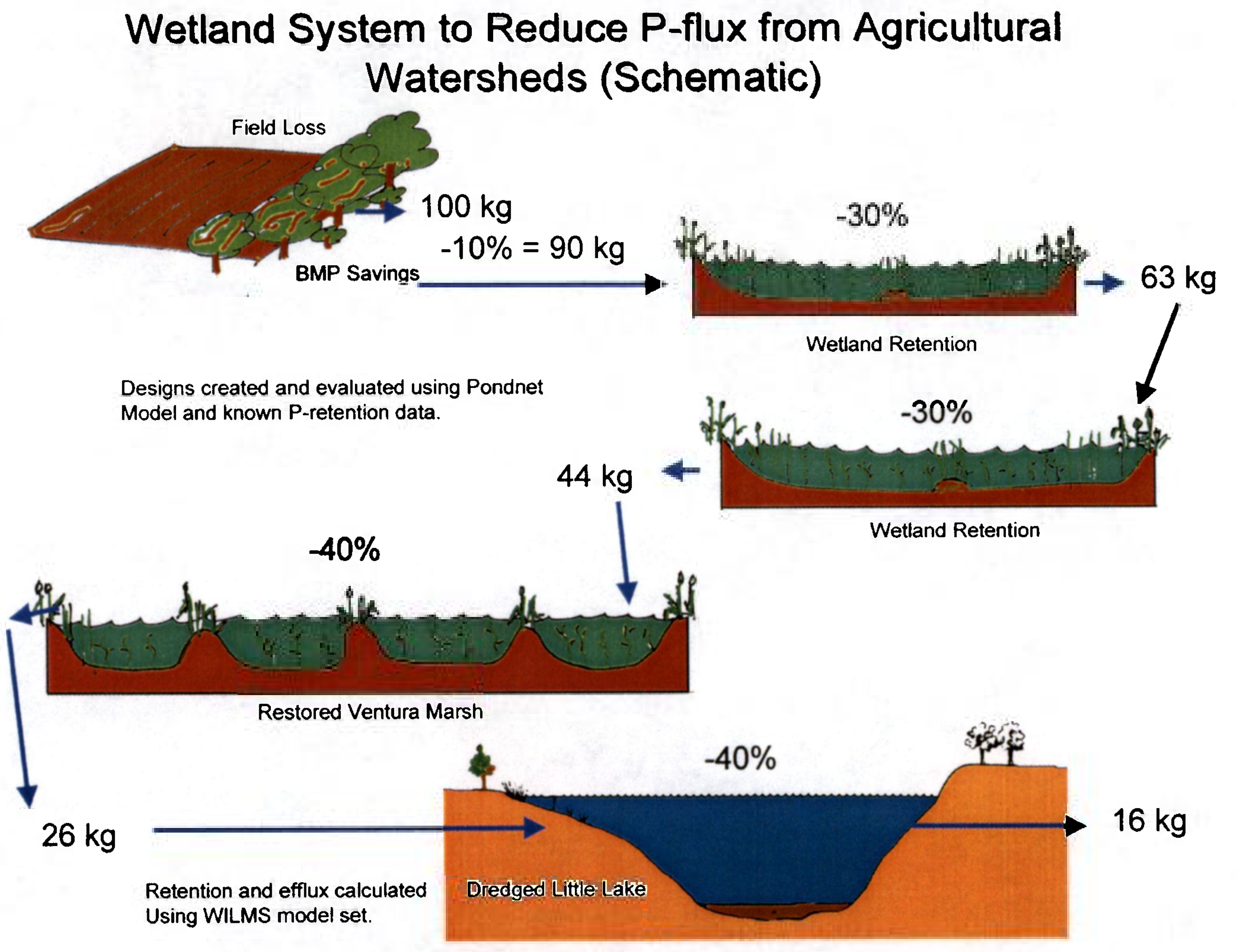


FIGURE 5. Aerial view of Ventura Marsh at the present time, and a visual representation of it in the future.

FIGURE 6. Aerial view of Ventura Grade at the present time, and a visual representation of it in the future.

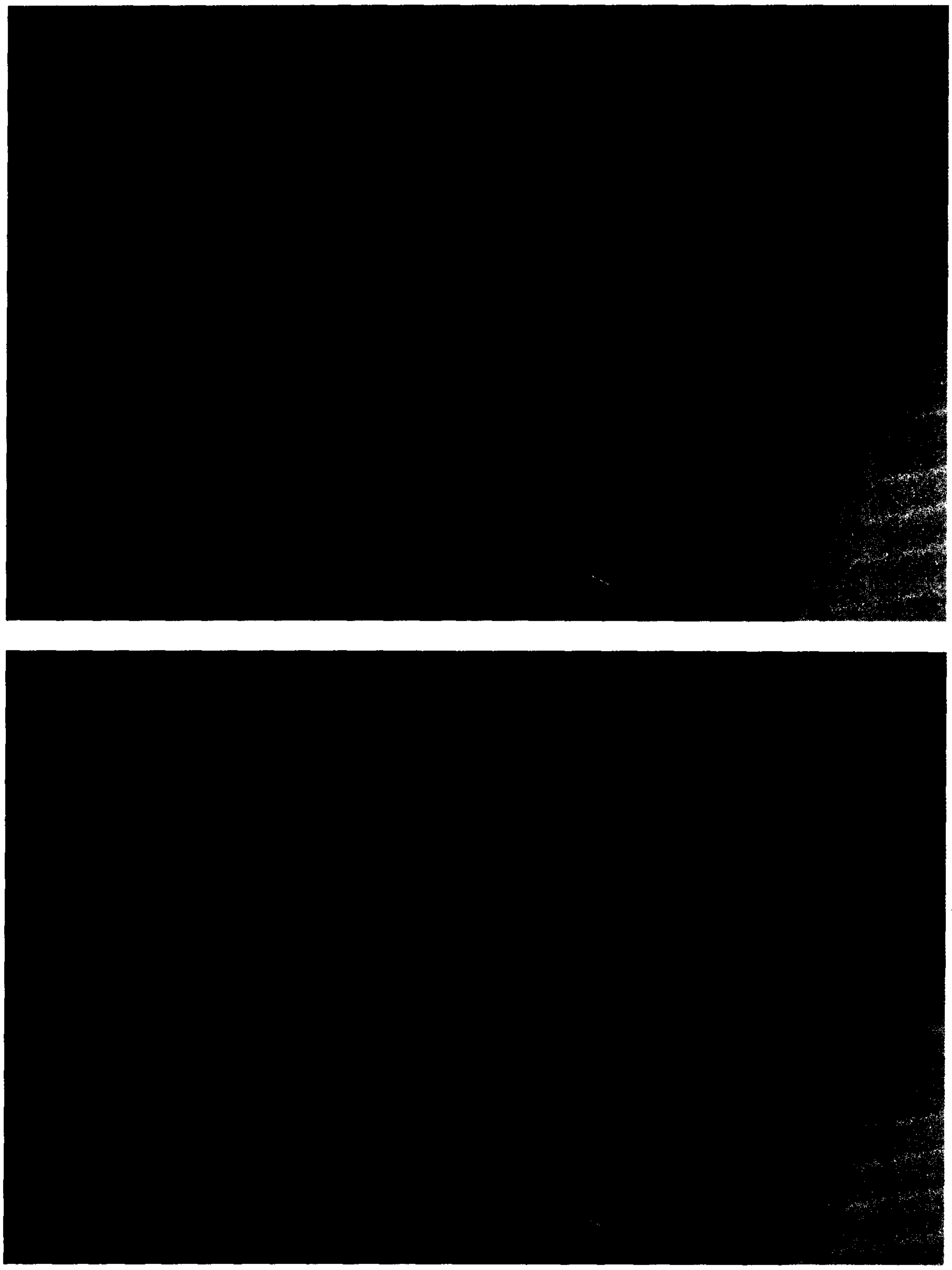


FIGURE 7. Wind rose for Clear Lake. Wind data from April 1998 – August 1999, Mason City Airport, source National Climatic Data Center, (http://www.ncdc.noaa.gov/ol/climate/climatedata.html).

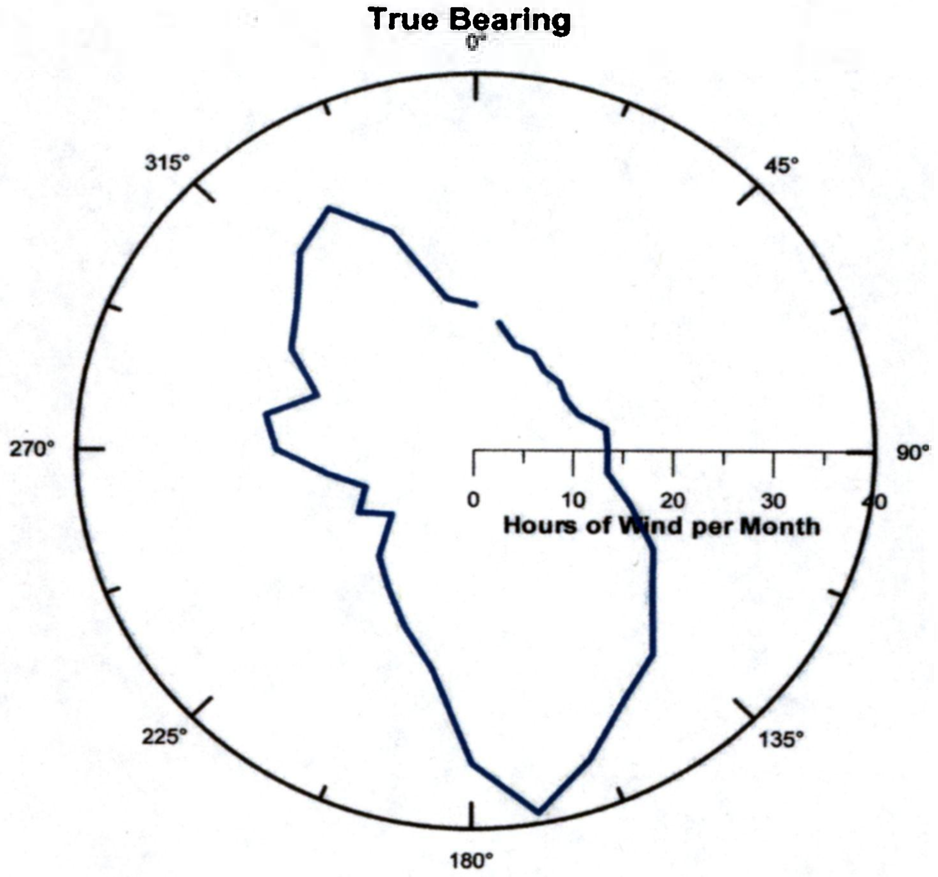


FIGURE 8. Proposed area of dredging and dredging depths in the Little Lake.

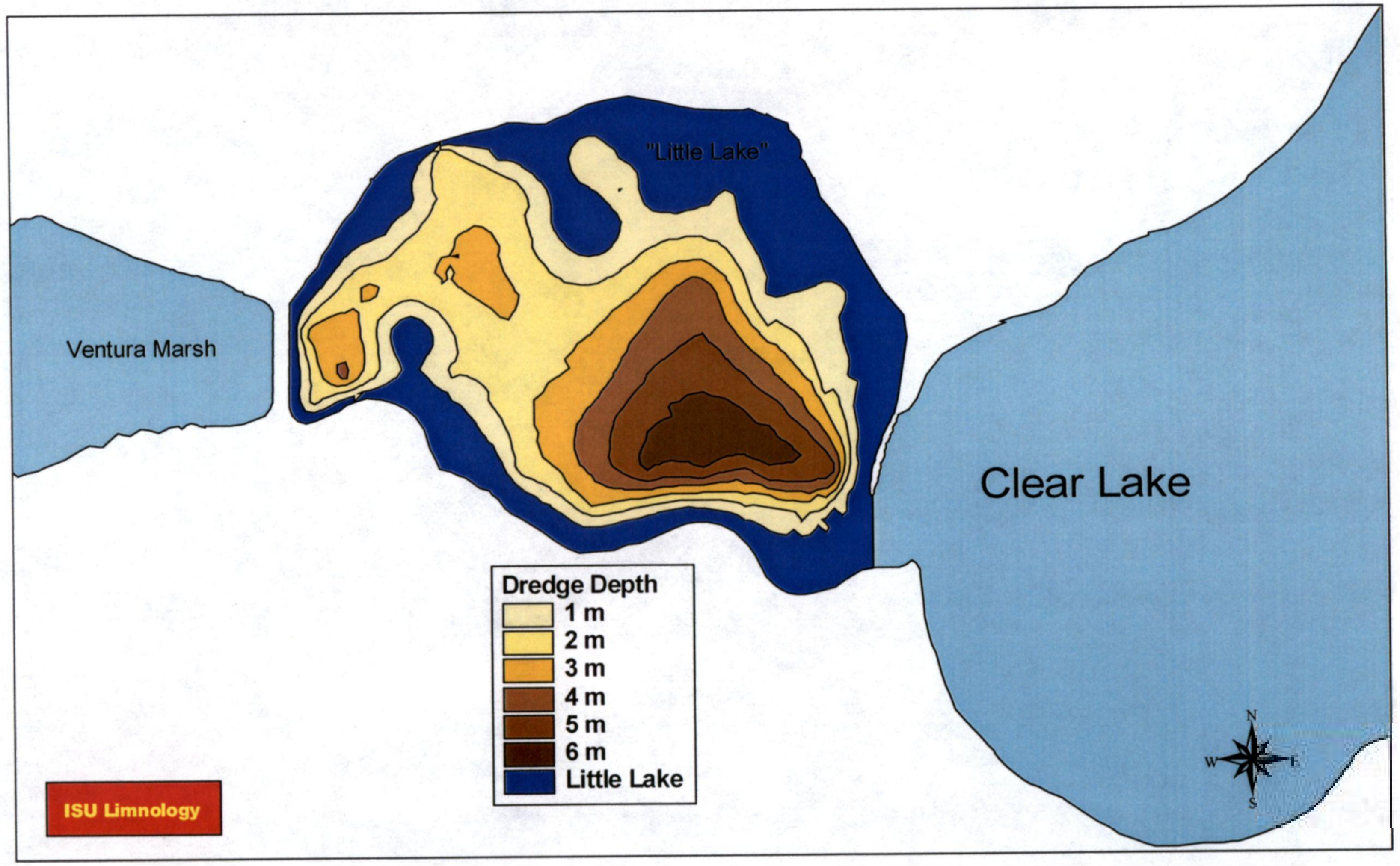


FIGURE 9. Containment site for dredge spoil.

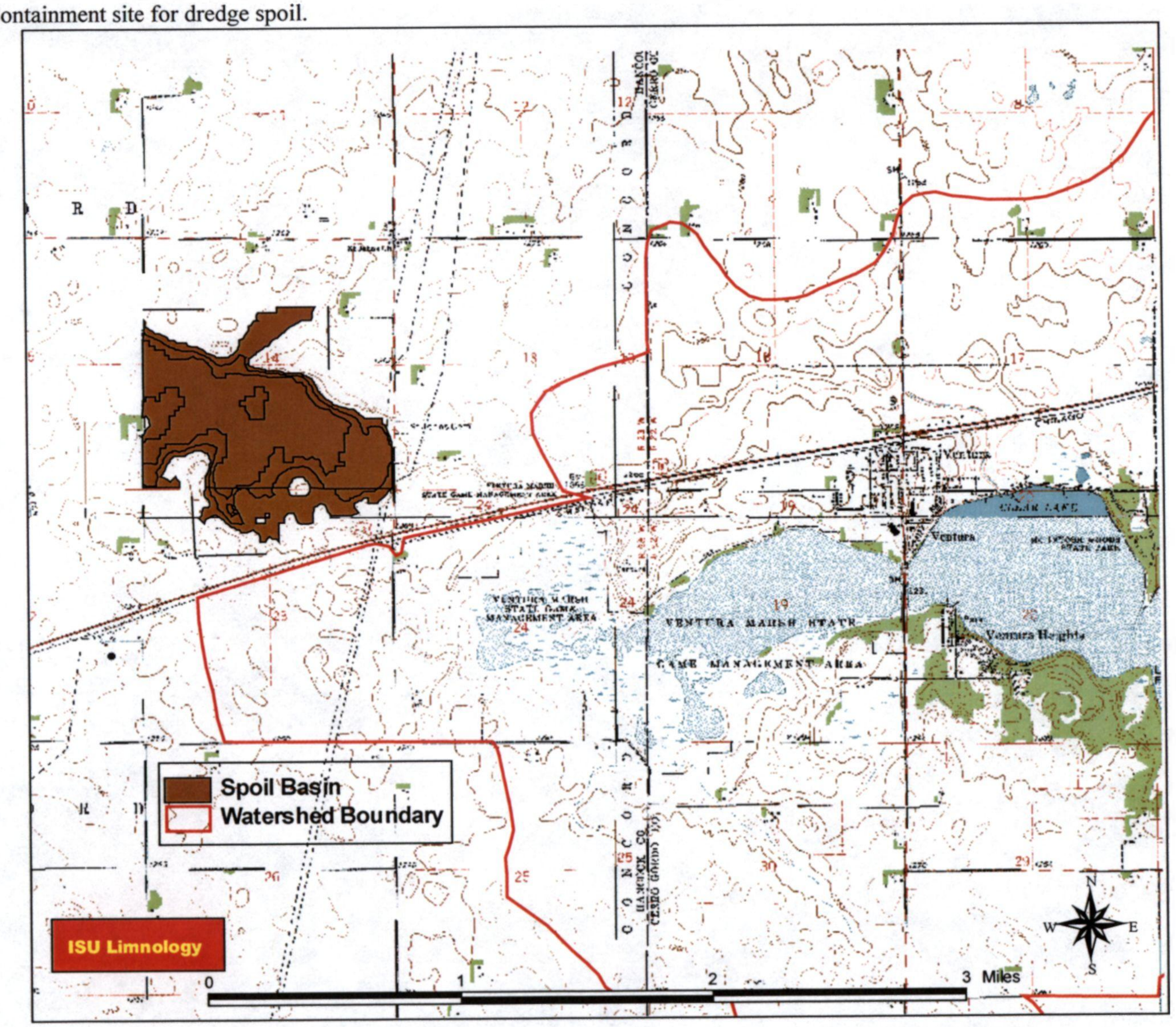
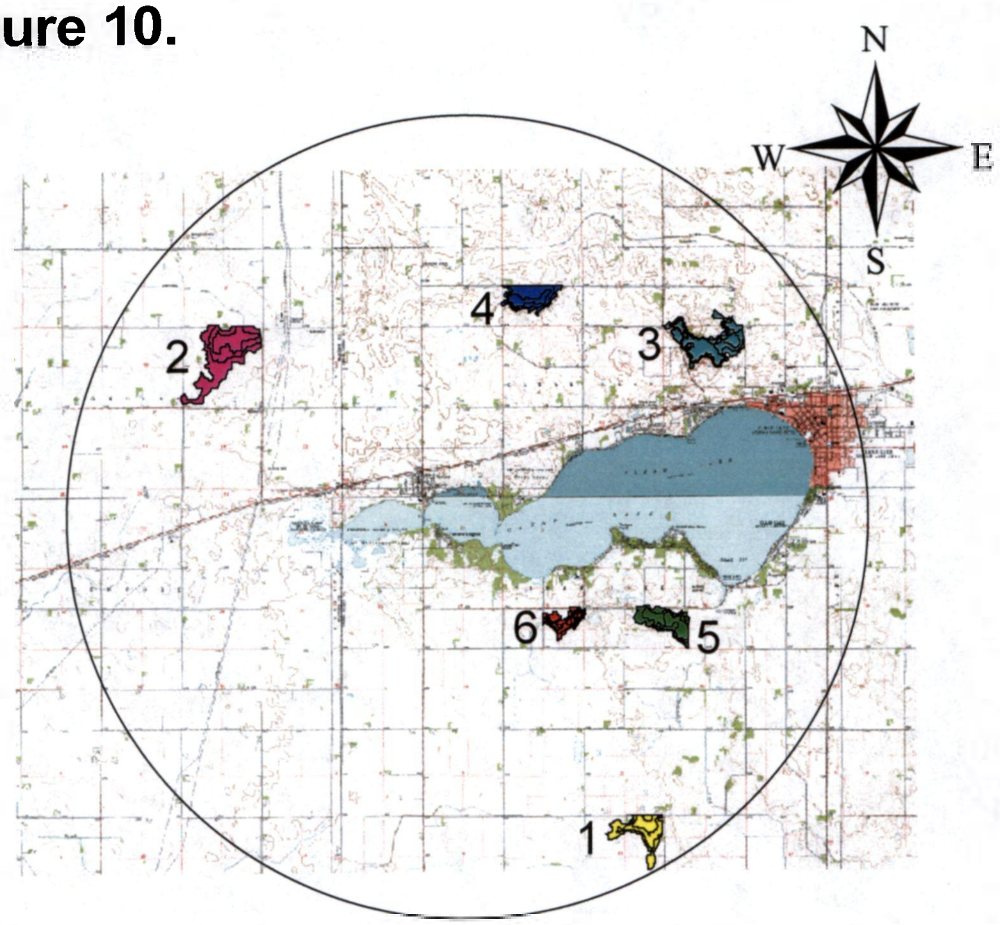


FIGURE 10. Additional potential dredge spoil containment sites.

Figure 10.



Circle indicates a 5 mile radius away from the center of the dredging site in the Little Lake.

- 🟨 **Dredge Site 1**
- 🟪 **Dredge Site 2**
- 🟦 **Dredge Site 3**
- 🟦 **Dredge Site 4**
- 🟩 **Dredge Site 5**
- 🟥 **Dredge Site 6**

FIGURE 11. Bathymetric map of the Clear Lake after dredging.

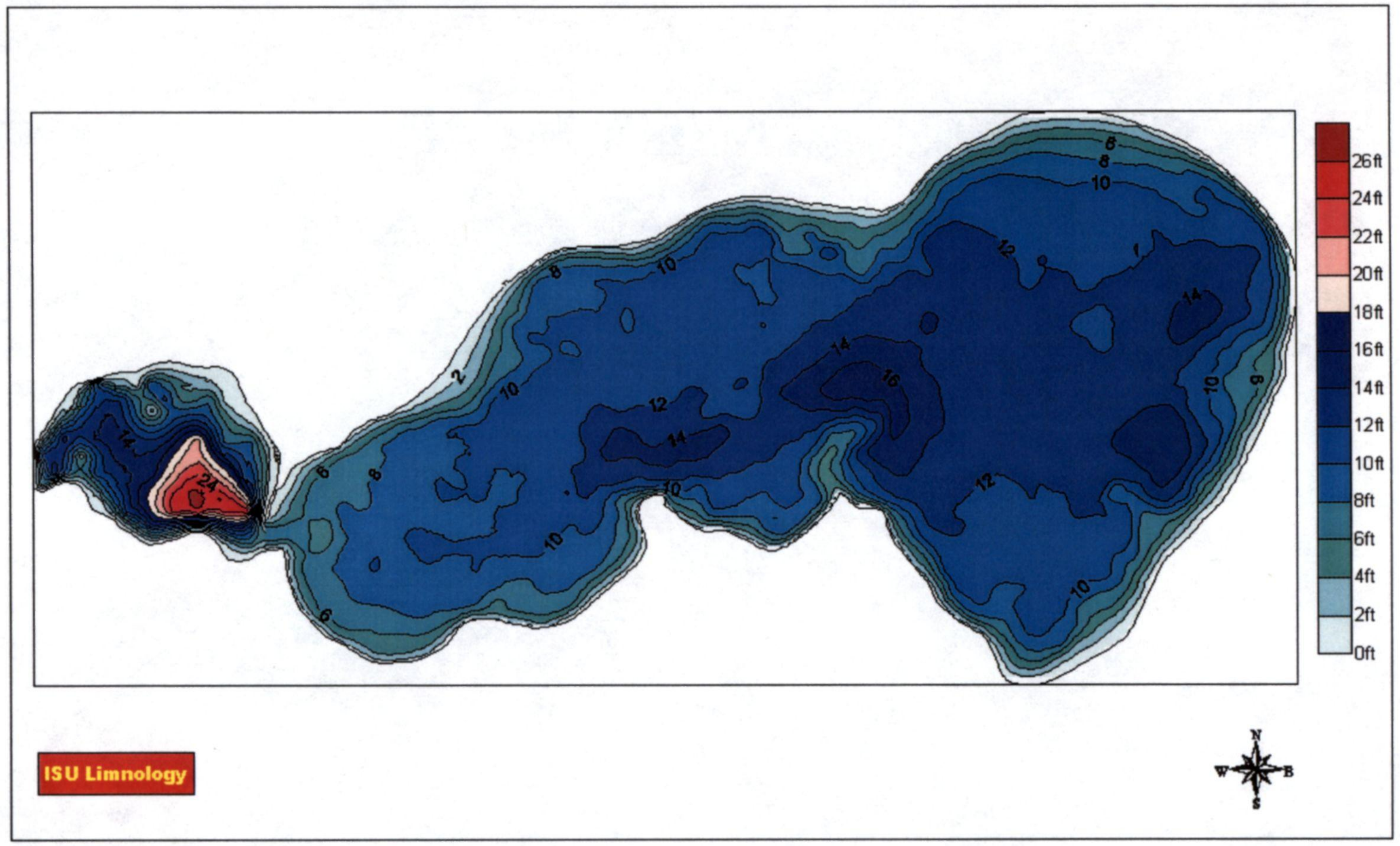


FIGURE 12. Potential locations of breakwater structures in Clear Lake.

Figure 12.

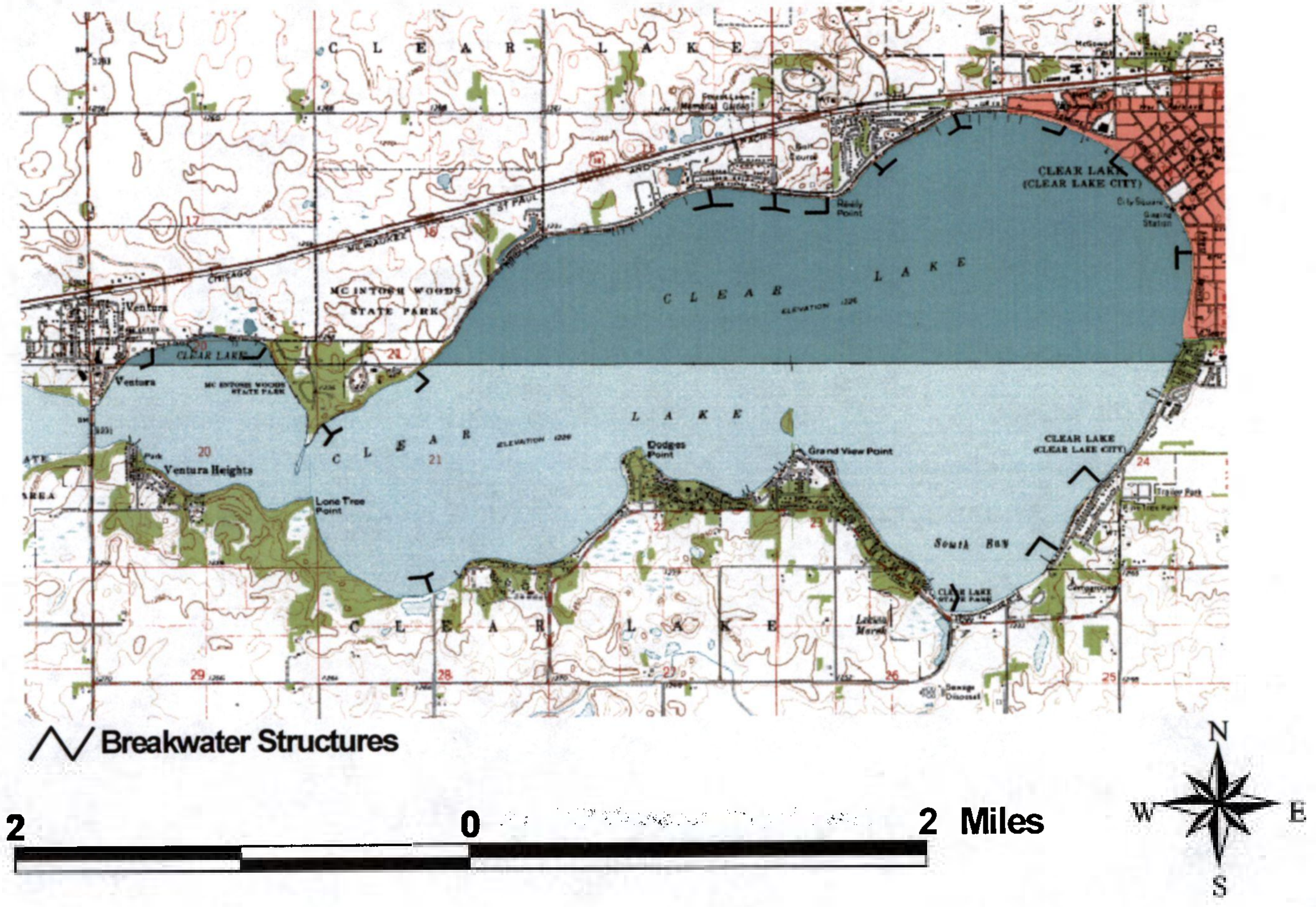


FIGURE 13. Post restoration water quality monitoring sites.