Total Maximum Daily Load
For Nutrients and Algae
Clear Lake
Cerro Gordo County, Iowa

2005

Iowa Department of Natural Resources
TMDL & Water Quality Assessment Section

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1. Executive Summary

Table 1. Clear Lake Summary

Waterbody Name:	Clear Lake
County:	Cerro Gordo
Use Designations:	A1 (primary contact recreation) B(LW) (aquatic life) C (potable water source) HQR (high quality resource)
Major River Basin:	Iowa-Skunk-Wapsipinicon Basin
Pollutant:	Phosphorus
Pollutant Sources:	Nonpoint, atmospheric and groundwater (background)
Impaired Use(s):	A1 (primary contact recreation)
2002 303d Priority:	High
Watershed Area:	8,667 acres
Lake Area:	3,625 acres
Detention Time (design):	4.7 years (IDNR hydrology)
Trophic State Index Targets:	Total phosphorus < 70 Chlorophyll < 65 Secchi depth < 65
Existing Total Phosphorus Load:	18,600 pounds per year
Allowable Total Phosphorus Load:	9,500 pounds per year
TP Load Reduction to Achieve Target:	9,100 pounds per year
TP Wasteload allocation:	Zero (no permitted point sources)
TP Load allocation:	9,100 pounds per year
Background TP Load allocation:	Precipitation = 4,500 pounds per year Groundwater = 900 pounds per year
Watershed / Internal TP Load allocation	3,700 pounds per year
Margin of Safety	400 pounds per year

The Federal Clean Water Act requires the Iowa Department of Natural Resources (IDNR) to develop a total maximum daily load (TMDL) for waters that have been identified on the state's 303(d) list as impaired by a pollutant. Clear Lake has been identified as impaired by algal blooms in response to high nutrient loading. The TMDL for Clear Lake calculates the maximum allowable phosphorus loading that will meet narrative standards for nuisance algal blooms and provide water quality fully supporting the lake's designated uses. The relationship of total phosphorus to chlorophyll (algae indicator) and Secchi depth is made by using Carlson's Trophic State Index (TSI). The TMDL water quality targets are expressed as TSI values based on historic and existing conditions and the characteristics and uses of the lake and its watershed.

A two-year diagnostic and feasibility study for Clear Lake and its watershed was completed in November 2001. Most of the comprehensive work was done by Iowa State University for the Iowa Department of Natural Resources and most of the information in this TMDL is taken from this study (1).

This TMDL has two phases. Phase 1 consists of setting specific and quantifiable targets for total phosphorus, chlorophyll, and Secchi depth expressed as Carlson's Trophic State Index. The waterbody load capacity, existing pollutant load in excess of this capacity, and the source load allocations are estimated based on currently available information. Phase 2 will consist of implementing the load reduction and monitoring plans, evaluating collected data, and readjusting target values if needed.

Phasing TMDLs is an iterative approach to managing water quality employed when the origin, nature and sources of water quality impairments are not well understood. The monitoring plan provides data that determines if load reductions result in attainment of water quality standards. Monitoring activities may include routine sampling and analysis, biological assessment, fisheries studies, and watershed and/or waterbody modeling. Section 5.0 of this TMDL includes a monitoring plan description. Monitoring:

- Assesses the future beneficial use status,
- Detects water quality trends, and
- Evaluates effectiveness of implemented best management practices.

This TMDL has been prepared in compliance with the current regulations for TMDL development that were promulgated in 1992 as 40 CFR Part 130.7. These regulations and consequent TMDL development are summarized below:

1. **Name and geographic location of the impaired or threatened waterbody for which the TMDL is being established:** Clear Lake, S13, T96N, R22W, on the southwest edge of the City of Clear Lake, Cerro Gordo County.

2. **Identification of the pollutant and applicable water quality standards:** The pollutants causing the water quality impairments are algae and nutrients. Designated uses for Clear Lake are Primary Contact Recreation (Class A1), Aquatic Life (Class B(LW)), Potable Water Source (Class C), and High Quality Resource (Class HQR). Excess nutrient loading has impaired aesthetic and aquatic life water quality narrative criteria (567 IAC 61.3(2)) and hindered the Class A designated use.

3. **Quantification of the pollutant load that may be present in the waterbody and still allow attainment and maintenance of water quality standards:** The Phase 1 target of this TMDL is a Carlson's Trophic State Index (TSI) of less than 70 for total phosphorus, 65 for chlorophyll a, and 65 for Secchi depth. These TSI are equivalent to a total phosphorus concentration of 96 ug/L, a chlorophyll concentration of 33 ug/L, and a Secchi depth of 0.7 meters.

4. **Quantification of the amount or degree by which the current pollutant load in the waterbody, including the pollutant from upstream sources that is being accounted for as background loading, deviates from the pollutant load needed to attain and maintain water quality standards**: The existing mean values for Secchi depth, chlorophyll a, and total phosphorus based on results from the Clear Lake Diagnostic and Feasibility Study are 0.41 meters, 42 ug/L and 166 ug/L (annual average), respectively. The target values to attain water quality standards are 0.7 meters Secchi depth, chlorophyll of 33 ug/l, and total phosphorus of 96 ug/l. The allowable total phosphorus load based on lake response modeling is 9,500 pounds per year; the existing load is 18,600 pounds per year. An average annual load reduction of 9,100 pounds per year is needed.

5. **Identification of pollution source categories:** Atmospheric deposition and groundwater are background sources that provide phosphorus to Clear Lake. Other nonpoint sources consisting of watershed and internal recycling of phosphorus from the lake bottom sediments contribute the remainder of the load to Clear Lake.

6. **Wasteload allocations for pollutants from point sources:** No significant point sources have been identified in the Clear Lake watershed. Therefore, the wasteload allocation will be set at zero.

7. **Load allocations for pollutants from nonpoint sources**: The total phosphorus load allocation for the nonpoint sources and internal recycling is 3,700 pounds per year not including 4,500 pounds per year attributable to atmospheric deposition and 900 pounds per year attributable to groundwater inputs.

Table 2. Summary of the load allocation for Clear Lake

Load	Source	Allocation
Background Load	Precipitation	4,500 pounds per year
	Groundwater	900 pounds per year
Non-Background Load	Internal Recycling and Watershed	3,700 pounds per year
Total Load Allocation		**9,100 pounds per year**

8. **A margin of safety:** An explicit MOS of 400 pounds per year total phosphorus has been included to ensure that the required load reduction will result in attainment of water quality targets.

9. **Consideration of seasonal variation:** This TMDL was developed based on the annual phosphorus loading that will result in attainment of TSI targets for the growing season (May through September).

10. **Allowance for reasonably foreseeable increases in pollutant loads:** An allowance for increased phosphorus loading was not included in this TMDL. Significant changes in the Clear Lake watershed landuse are unlikely. Any new residential development around the lakeshore will be sewered. The addition or deletion of animal feeding operations within the watershed could increase or decrease nutrient loading. Increases in the rough fish population or intensification of activities that add to lake turbulence could increase re-suspension of settled solids and internal phosphorus loading. Such events cannot be predicted and at this time conditions are not expected to change, therefore, an allowance for their potential occurrence was not included.

11. **Implementation plan:** Although not required by the current regulations, an implementation plan is outlined in the body of the report.

2. Clear Lake, Description and History

2.1 The Lake

Clear Lake is located in Cerro Gordo County in north central Iowa. It is one of Iowa's 34 natural, glacial lakes and was formed by the scouring actions of glaciers and filled when the great ice sheets melted. The lake is managed for water-based recreation and fishing and was also used historically as a source of potable water for the City of Clear Lake.

Clear Lake is an important recreational resource in Iowa. There are two state parks on the lake, Clear Lake State Park and McIntosh Woods State Park. Use of the two parks is estimated to be 660,000 person days per year and is growing substantially. Recreational use is:

- 44% camping, picnicking and other passive uses,
- 28% pleasure boating,
- 19% swimming,
- 7% fishing,
- 2% winter activities, and
- 0.2% hunting.

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.

Table 3. Clear Lake Characteristics

Waterbody Name:	Clear Lake
Hydrologic Unit Code:	HUC10 0708020303
IDNR Waterbody ID:	IA 02-WIN-00450-L
Location:	Section 13 T96N R22W
Latitude:	43° 08′ 01"N (gauging station)
Longitude:	93° 22′ 57" W (gauging station)
Water Quality Standards Designated Uses:	1. Primary Contact Recreation (A1) 2. Aquatic Life Support (B(LW)) 3. Potable Water Source (C) 4. High Quality Resource (HQR)
Tributaries:	Ventura Marsh
Receiving Waterbody:	Clear Creek
Lake Surface Area:	3,625 acres
Maximum Depth:	19 feet
Mean Depth:	9.5 feet
Volume:	34,800 acre-feet
Length of Shoreline:	72,000 feet
Watershed Area:	8,667 acres
Watershed/Lake Area Ratio:	2.4:1
Estimated Detention Time:	4.7 years

Morphometry

Clear Lake is shallow, with a maximum depth of 19 feet and an average depth of 9.5 feet. It is Iowa's third largest natural lake, and the lake measures 5 miles long and has a maximum width of 2 miles in the eastern portion. The long east-west fetch allows the prevailing winds to mix the lake preventing thermal stratification during the ice-free periods. The watershed to lake ratio of 2.4:1 is very small compared to most Iowa lakes.

Hydrology

Many small tributaries drain the watershed. The greatest portion (47%) of surface flow passes through Ventura Marsh on its way to the lake. At one time, Ventura Marsh was connected to the west end of the lake by a narrow inlet, but now is separated from the lake by a road. A control structure allows water to flow from the marsh into the lake during wet periods.

Annual estimates for lake inflow and discharge were made in the Diagnostic and Feasibility Study based on data collected over the two-year study. Estimates for inflow and discharge were also made by the IDNR for this TMDL. For modeling purposes, the detention time based on discharge is used. The IDNR methodology and calculations used to determine the detention time can be found in Appendix A. The average annual detention time estimates are found in Table 4.

Table 4. Clear Lake estimated average annual detention times

	Diagnostic and Feasibility Study	IDNR hydrologic method
Inflow	1.6 years	1.9 years
Discharge	6.3 years	4.7 years (modeling value)

The modeling for this TMDL used the IDNR detention time estimate of 4.7 years to maintain consistency among Iowa lake nutrient TMDLs. The IDNR estimate is based on average annual precipitation and flow as discussed in Appendix A. The Diagnostic Feasibility Study water budget is based on only 2 years of data and is relatively close to the IDNR estimate.

Because of Clear Lake's origin and relatively small drainage area, watershed precipitation is the major factor governing lake levels. A comparison of lake level and precipitation data by UHL (16) indicates a direct relationship exists between the two. The water levels in Clear Lake and in nearby shallow wells show similar fluctuations, indicating that the lake and its surficial aquifer are hydraulically connected. Clear Lake is sustained in part by groundwater inflow from the north, west and south. However, during prolonged periods of below-normal precipitation, the inflow diminishes and the lake level subsequently declines.

Fisheries Analysis

There are approximately 30 species of fish that inhabit Clear Lake. Many of these are small forage fishes, however substantial populations of predators exist through either natural reproduction or annual stockings. Species that are maintained or supplemented through stocking include: walleye, channel catfish, northern pike, muskellunge, and most recently flathead catfish. These fish are reared in state fish hatcheries and stocked as fry or fingerling size.

Dominant species harvested by sport anglers over the past twenty years are yellow bass, bullhead, walleye, channel catfish, crappie, white bass, and yellow perch. Incidental harvest would include: largemouth bass, northern pike, bluegill, and muskellunge. Open water fishing pressure ranges between 15,000 and 90,000 anglers with a mean of 40,000. Annual harvest varies between 10,000 and 250,000 with an average of 100,000 fish.

Substantial numbers of carp and buffalo exist that are commercially valuable. Commercial fishermen under contract with the state of Iowa harvest these species each year. Harvest during most years runs at about 100,000 pounds.

A winter aeration system was installed in Clear Lake and operated since 1986. There are two sites with 16 helixor-type aerators at each site. Clear Lake suffered a severe winterkill during the winter of 1978-79. No winterkill has occurred since the operation of the current system.

Ventura Marsh located on the west end of Clear Lake serves as a prime spawning and nursery area for many species of fish. Unfortunately bottom-feeding fishes such as carp and bullhead tend to dominate, so a barrier is maintained to exclude them. Extensive beds of bulrush and cattails located on the northwest shoreline of Clear Lake provide the best in-lake fishery habitat. Very little submergent vegetation is available to Clear Lake fishes. A thorough history and description of the Clear Lake fishery is presented in Appendix E.

2.2 The Watershed

Water is drained from 8,667 acres to Clear Lake. Based on 2002 statewide land coverages, the major landuses in the watershed consist primarily of cropland (55%), grass (13%), and urban areas and roads (13%). A map of the landuses in the Clear Lake watershed may be found in Appendix D.

Table 5. Landuse in Clear Lake watershed

Landuse	Area in Acres	Percent of Total Area
Row Crop	4,685	54
Grass	1099	13
Urban	725	8.4
Timber	578	6.7
Marsh	558	6.4
Roads	319	3.6
Pasture	315	3.5
CRP	175	2
Other	213	2.4

The topography of the Clear Lake watershed includes slopes of 0 to 9%. Nearly half of the soils in the watershed are of the Clarion, Webster, Canisteo, Nicollet grouping while another 43% of the soils are of the Clarion, Nicollet, Storden, Webster association. Other, less common soils found in the watershed include Okoboji, Harps, Wadena, Talcot, Flagler, and Saude.

3. TMDL for Nutrients and Algae

3.1 Problem Identification

Impaired Beneficial Uses and Applicable Water Quality Standards

The *Iowa Water Quality Standards* (2) list the designated uses for Clear Lake as Primary Contact Recreation (Class A), Aquatic Life (Class B(LW)), Potable Water Source (Class C), and High Quality Resource (HQR). Clear Lake also has general uses of secondary contact recreation, domestic uses, and wildlife uses.

Clear Lake was put on the 2002 impaired waters list due to partial support of primary contact recreation use caused by aesthetically objectionable blooms of algae and the presence of nuisance aquatic species, blue green algae. The applicable water quality standard is:

> 61.3(2)c: *Such waters shall be free from materials attributable to wastewater discharges or agricultural practices producing objectionable color, odor, or other aesthetically objectionable conditions.*

The algal blooms and the nuisance blue green algae are caused by excess nutrients in the water column. The limiting nutrient for the Clear Lake algal blooms is phosphorus; therefore, this TMDL is for total phosphorus. Based on mean values from ISU sampling during 2000 - 2003, the ratio of total nitrogen to total phosphorus for this lake is 18:1 indicating that nitrogen is not the limiting nutrient.

Data Sources

The data used to develop this TMDL came primarily from the ISU *Diagnostic and Feasibility Study for Clear Lake* (1) one of the most comprehensive lake studies done in Iowa. A second source of information was the ISU Iowa Lakes Survey (3,4,5,6). The data for the Diagnostic and Feasibility Study were collected from three in-lake sites running east-west from July 1998 to September 2000. Lake tributaries were also monitored at several locations in the watershed. A summary of the data relevant to this TMDL (total phosphorus, chlorophyll a, and transparency) is in Appendix B. The entire data set is available in the Diagnostic and Feasibility Study.

Water quality surveys have been conducted on Clear Lake in 1979, 1990, and 2000-03 (3,4,5,6,7,8). Data from these surveys is available in Appendix B. The Iowa State University Lake Study data from 2000 to 2003 were evaluated for this TMDL. This study is scheduled to run through 2004 and approximates a sampling scheme used by Roger Bachman in earlier Iowa lake studies. Samples are collected three times during the early, middle and late summer. A number of water quality parameters are measured including Secchi disk depth, phosphorus series, nitrogen series, TSS, and VSS.

Interpreting Clear Lake Water Quality Data

The water quality studies conducted over the last 30 years show that water quality seems to be degrading. The results of these studies are summarized below:

- 1974: Clear Lake was one of fifteen Iowa lakes and reservoirs studied in the National Eutrophication Survey by the U.S. EPA in 1974-75 (15). This survey indicated that Clear Lake was eutrophic, based on a combination of parameters, including total phosphorus, dissolved ortho-phosphorus, inorganic nitrogen, Secchi disk depth, chlorophyll-*a* and dissolved oxygen. Water samples were collected on April 18, July 3, and September 23, 1974 from Clear Lake. From these samples, mean total phosphorus was 59 ug/L (n=13), mean inorganic nitrogen was 0.19 mg/L (n=13) and mean Secchi disk depth was 0.89 m (n=8).

- 1978: A one-year limnology study was conducted on Clear Lake from November 1978 to August 1979 by the University Hygienic Laboratory (16) for the Iowa Department of Environmental Quality. Water, sediment and fish samples were collected for a variety of analyses. Results indicate that during low lake level periods, water quality declines as concentrations of chemicals increase and phytoplankton blooms occur. Inflow water to the lake from Ventura Marsh was of poor quality, especially during the winter.

- 1979: Data collected in 1979 as part of Iowa's lake classification survey (7) showed that Clear Lake was eutrophic. The mean total phosphorus concentration was 110.5 ug/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). A water quality index was calculated for the 106 lakes involved in the 1979 survey based upon Secchi disk depth, total phosphorus, algal chlorophyll concentration, total suspended solids, and winter fishkill frequency. The index ranked Clear Lake as having the 28th poorest water quality of survey lakes and showed the major problems to be water level fluctuation and nonpoint source pollution from soil erosion and agricultural activities. At the time of the survey, 77% of the watershed was in row crop production.

- 1990: From the Classification of Iowa's Lakes for Restoration in 1994 (8), data collected in 1990 indicated that Clear Lake continued to be eutrophic. The mean total phosphorus concentration was 155 ug/L (n=9), mean total nitrogen was 4.1 mg/L (n=9) and mean Secchi disk depth was 0.4 m (n=3).

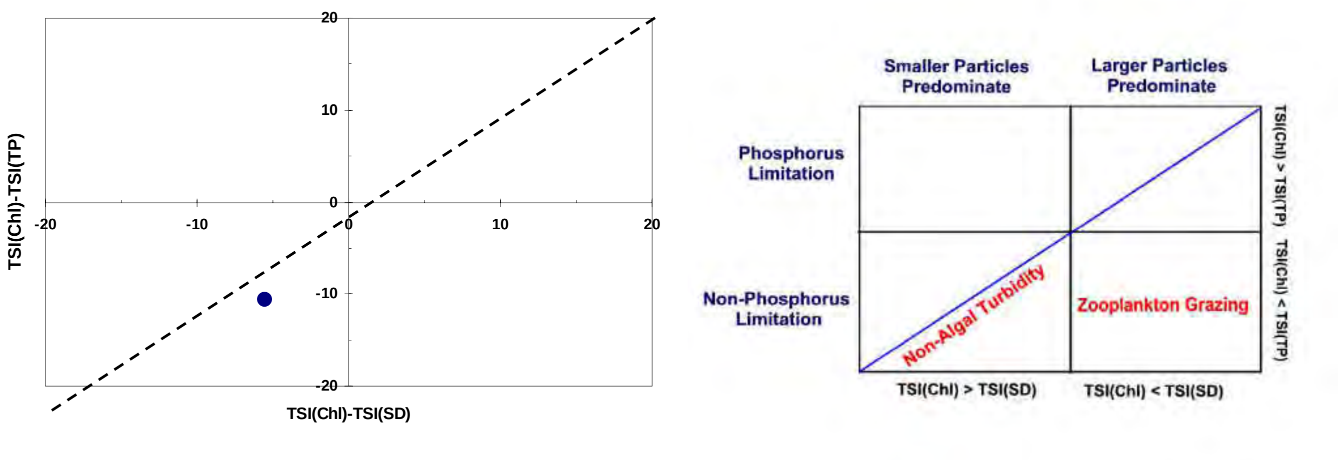
- 1998: Clear Lake was monitored from July 1998 to September 2000 as part of the Diagnostic and Feasibility Study for Clear Lake (1). Clear Lake was analyzed by sampling at three points distributed from west to east across the lake. Tributary monitoring was conducted at a number of stations throughout the watershed. A summary of this data is provided in Table 1 of the Clear Lake Diagnostic and Feasibility study (1).

- 2000: Clear Lake was sampled in 2000-04 as part of the Iowa Lakes Survey (3,4,5,6). This survey samples the lake three times each summer for five years at the deepest part of the lake. The data collected in 2000-02 is shown in Appendix B.

Carlson's Trophic State Index (TSI) is used in this TMDL to relate total phosphorus to chlorophyll and Secchi depth. Appendix C includes an explanation of the TSI and its application to TMDL development.

The TSI comparison plot in Figure 1 shows (point in lower left hand quadrant) that there is a small phosphorus surplus, i.e., not all TP is expressed as algae. This also indicates that non-algal turbidity is a factor. Inorganic suspended solids data from 2000-03 show that the lake is subject to episodes of high non-algal turbidity. Comparisons of the TSI values for chlorophyll, Secchi depth, and total phosphorus from Iowa Lake Survey data indicate possible limitation of algal growth from light attenuation by elevated levels of inorganic suspended solids (Table B-6 of Appendix B).

Figure 1. Mean TSI Multivariate Comparison Plot of the Clear Lake Diagnostic Feasibility Study data used in this TMDL



The median level of inorganic suspended solids in the 130 lakes sampled for the ISU lake survey in 2000 and 2001 was 5.27 mg/L. The median level of inorganic suspended solids at Clear Lake in 2000 and 2001 was 12.2 mg/l, the 28th highest of 130 survey lakes.

Data from ISU phytoplankton sampling indicate that bluegreen algae dominate the summertime phytoplankton community. The percentage of the phytoplankton community that is bluegreen algae for the years 2000 to 2003 is:

- 2000 – 70%
- 2001 – 79%
- 2002 – 94%
- 2003 – 86%

Potential Pollution Sources

Phosphorus loading to Clear Lake is influenced only by watershed nonpoint sources, internal recycling of pollutants from bottom sediments, and precipitation. There are no permitted point source discharges in the watershed.

Natural Background Sources

Contributions of phosphorus attributable to dry atmospheric deposition were not separated from the direct precipitation load. Potential phosphorus contributions from groundwater influx were separated from the total nonpoint source load. The direct precipitation load has been incorporated into the lake response model.

3.2 TMDL Target

The Phase 1 targets for this TMDL are a mean TSI value of less than 70 for total phosphorus, and mean TSI values of less than 65 for both chlorophyll and Secchi depth. These values are equivalent to total phosphorus and chlorophyll concentrations of 96 and 33 ug/L, respectively, and a Secchi depth of 0.7 meters. The total phosphorous target is in line with the Clear Lake Diagnostic and Feasibility Study (CLDFS) determination that the total phosphorous concentration in the water column should be near 100 ppb in order to decrease algae blooms and increase water clarity.

Table 6. Clear Lake Existing vs. Target TSI Values

Parameter	Mean TSI	Mean Value	Target TSI	Target Value
Chlorophyll	68	42 ug/L*	<65	<33 ug/L
Secchi Depth	73	0.41 meters*	<65	>0.7 meters
Total Phosphorus	78	166 ug/L (annual average)*	<70	<96 ug/L

* The target values for chlorophyll and Secchi depth are based on the growing season mean and are from Table 6 in the CLDFS. Total phosphorus is based on the CLDFS estimate for average annual water column total phosphorus (p. 284) because the selected lake model (Vollenweider combined OECD) for this TMDL is based on the average annual concentration rather than the growing season mean. The growing season average was 188 ug/l.

Criteria for Assessing Water Quality Standards Attainment

The State of Iowa does not have numeric water quality criteria for algae or turbidity. The cause of the algae and turbidity impairments is algal blooms caused by excessive nutrient loading to the lake. The nutrient-loading objective is defined by mean total phosphorus TSI of less than 70 and is linked through the Trophic State Index to chlorophyll a and Secchi depth. The TSI is not a standard, but is used as a guideline to relate phosphorus loading to the algal impairment for TMDL development purposes and to describe water quality that will meet Iowa's narrative water quality standards.

Selection of Environmental Conditions

The critical condition for which the TMDL TSI target values apply is the growing season (May through September). It is during this period that nuisance algal blooms are prevalent. The existing and target total phosphorus loadings to the lake are expressed as annual averages. The model selected for estimating phosphorus loading to the lake utilizes the annual average total phosphorous concentration lake total phosphorus concentrations to calculate an annual average total phosphorus loading.

Modeling Approach

A number of different empirical models that predict annual phosphorus load based on measured in-lake phosphorus concentrations were evaluated. In addition, watershed phosphorus delivery using both export coefficients and an annual loading function model as outlined in Reckhow's EUTROMOD User's Manual (11) was calculated. The results from both approaches were compared to select the best-fit empirical model.

Of the empirical models evaluated, the Vollenweider, Walker General and Reckhow Anoxic models (10) resulted in values closest to the Loading Function and export estimates while remaining within the parameter ranges used to derive them. Application of the Reckhow Anoxic Model to Clear Lake, which is an oxic lake, is of questionable value. The Walker General Lake Model result is slightly below the range of loadings predicted by the Loading Function and export estimates. The Vollenweider 1982 Combined OECD Model result is above the range predicted by the watershed estimates but close to the estimated average phosphorus flux determined in the ISU Diagnostic Feasibility Study. Therefore, the Vollenweider 1982 Combined OECD relationship was selected as best-fit empirical model.

Table 7. Model Results

Model	Predicted Existing Annual TP Load (lbs/yr) for in-lake GSM TP = 166 ug/L, SPO TP = 186 ug/L	Comments
Loading Function	10,920	Reckhow (11)
EPA Export	11,980	EPA/5-80-011 (21)
WILMS Export	9,780	“most likely” export coefficients
Reckhow 1991 EUTROMOD Equation	13,233,230	GSM model
Canfield-Bachmann 1981 Natural Lake	46,080	GSM model
Canfield-Bachmann 1981 Artificial Lake	126,420	GSM model
Reckhow 1977 Anoxic Lake	6,300	GSM model
Reckhow 1979 Natural Lake	66,180	GSM model
Reckhow 1977 Oxic Lake (z/Tw < 50 m/yr)	24,970	GSM model. P out of range
Nurnberg 1984 Oxic Lake	16,800 (internal load = 0)	Annual model. P out of range
Walker 1977 General Lake	9,730	SPO model.
Vollenweider 1982 Combined OECD	18,600	Annual model.
Vollenweider 1982 Shallow Lake	20,290	Annual model.

The equation for the Vollenweider 1982 Combined OECD Lake Model is:

$$P = 1.55\left[\frac{\left(LT_w / z\right)}{1+\sqrt{T_w}}\right]^{0.82}$$

where:

P = predicted in-lake total phosphorus concentration (ug/L)
L = areal total phosphorus load (mg/m^2 of lake area per year)
T_w = lake hydraulic detention time (years)
z = lake mean depth (meters)

The calculations for the existing total phosphorus load to Clear Lake are as follows:

$$P = 166(ug/L) = 1.55\left[\frac{\left(575(mg/m^2)4.73(yr) / 2.87(m)\right)}{1+\sqrt{4.73(yr)}}\right]^{0.82}$$

The calculations for the total phosphorus load capacity are:

$$P = 96(ug/L) = 1.55\left[\frac{\left(295(mg/m^2)4.73(yr)\big/2.87(m)\right)}{1+\sqrt{4.73(yr)}}\right]^{0.82}$$

The annual total phosphorus load is obtained by multiplying the areal load (L) by the lake area in square meters and converting the resulting value from milligrams to pounds.

With a low watershed to lake ratio at Clear Lake, the Loading Function estimate is weighted heavily towards the dissolved phosphorus component (90% of the estimated NPS loading is dissolved). Since this part of the Loading Function relies on assumed runoff coefficients and dissolved phosphorus concentrations derived from literature, confidence in the estimate is less than for lakes with large sediment attached TP loading. The Vollenweider 1982 Combined OECD equation is selected because it gives an existing loading value that is close to the average of the observed TP loadings from the Diagnostic Feasibility Study. The annual loading estimate from the Vollenweider Model is 18,600 pounds per year and that estimated from the two-year Clear Lake study is 17,000 pounds per year (1). For further comparison of the Diagnostic Feasibility study with this TMDL, see Appendix E.

Due to the low watershed/lake ratio, direct precipitation inputs are large relative to other loading sources. The ISU-observed precipitation concentration of 169 ug/L versus an assumed concentration of 50 ug/L makes a large difference in nonpoint source load reduction required to achieve the total phosphorus TSI target of 70. The ISU value of 169 ug/L is used for the TMDL load allocation.

Waterbody Pollutant Loading Capacity

The waterbody loading capacity for the total phosphorus TSI target of 70 (96 ug/L) is 9,500 pounds annually as estimated using the Vollenweider 1982 Combined OECD Model.

3.3 Pollution Source Assessment

Existing Total Phosphorus Load and Departure from Loading Capacity

The existing annual total phosphorus load to Clear Lake estimated by the Vollenweider 1982 Combined OECD model is 18,600 pounds per year based on an average annual lake water column concentration of 166 ug/l. This concentration is the estimated annual average for total phosphorus in the CLDFS. The difference between the loading capacity and the load target is:

18,600 pounds per year – 9,500 pounds per year = 9,100 pounds per year.

Identification of Pollutant Sources

The two-year Diagnostic and Feasibility Study estimated the phosphorus load to the lake is distributed as follows:

- 31%, rainfall,
- 24%, Ventura Marsh inflows,
- 14%, north shore agriculture,
- 10%, urban and residential areas,
- 9%, internal loading from Ventura Marsh,
- 7%, groundwater, and
- 5% south shore agriculture.

A mass balance completed as part of the study estimates that the internal load from Clear Lake itself amounts to 1,760 pounds annually.

While 59% of the Clear Lake watershed is in row crop agriculture, only 19% of the total phosphorus load comes from these portions of the watershed. Direct precipitation, groundwater, and internal loading from resuspension of sediment in Ventura Marsh and Clear Lake are major sources of phosphorus to the lake.

While there are no point source discharges in the watershed, there is stormwater runoff that flows from the urban and residential areas to the lake. The City of Clear Lake and Cerro Gordo County have installed storm water filtration systems, which intercept stormwater and allow solids to settle out prior to the water being discharged to the lake.

The last occurrence of a wastewater bypass by the Clear Lake Sanitary District was on June 20, 1998, when 250,000 gallons of pretreatment sewage were discharged into Clear Lake (Kevin Moeller, Clear Lake Sanitary District, (1)). This bypass pumping added approximately 3 pounds 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, when 126,000 gallons of pretreatment sewage were discharged into the lake. The second one occurred in June 1998, when 44,250 gallons of pretreatment sewage were discharged into the lake. These two events combined added around 2 pounds of phosphorus to the lake, or about 0.01% of the lake's annual average phosphorus budget.

Residential areas in the watershed can provide nonpoint 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. There are no permitted livestock facilities in the watershed.

Linkage of Sources to Target

Excluding background sources, the average annual phosphorus load to Clear Lake originates entirely from nonpoint sources and internal recycling. To meet the TMDL endpoint, the annual nonpoint source and internal recycling contribution to Clear Lake needs to be reduced by 9,100 pounds per year.

3.4 Pollutant Allocations

Wasteload Allocation

There are no permitted point source dischargers in the Clear Lake watershed. Therefore the wasteload allocation is zero.

Load Allocation

Because of Clear Lake's small watershed to lake ratio, the estimated nonpoint source load reduction is rather sensitive to the precipitation phosphorus concentration. The usual assumption for lake modeling is that this concentration is 50 ug/l (12,17,18,19). Direct monitoring and analysis of rainfall during the Clear Lake Diagnostic and Feasibility Study measured an average concentration of 169 ug/l.

Selection of a precipitation phosphorus concentration has quite an effect on the nonpoint source load (Table 8). For this TMDL, it is assumed that the direct precipitation load cannot be changed and that all reductions will need to come from non-background sources including internal recycling and watershed loads. Lake response modeling estimates the total annual load to Clear Lake to be 18,600 pounds. For this TMDL, the measured precipitation concentration of 169 ug/l is used, constituting a load of 4,500 pounds per year.

The Diagnostic & Feasibility Study for Clear Lake (1) estimates total phosphorus inputs from groundwater to be approximately 7% of the total load, or 900 pounds per year. A mass balance completed as part of the study estimates that the internal load from Clear Lake itself amounts to 1,760 pounds annually. The remaining load is attributed to watershed sources. The load allocation for non-background sources is 3,700 pounds per year and the total load allocation is 9,500 pounds per year less the MOS of 400 pounds per year or 9,100 pounds per year.

Table 8. Phosphorus load contributed by precipitation and its effects on the NPS load

Precipitation TP concentration (ug/l)	Precipitation load (lbs/yr)	Existing nonpoint source load (lbs/yr)	Total existing load (lbs/yr)
50	1,300	17,300	18,600
169	4,500	14,100	18,600

Table 9. Summary of the load allocation for Clear Lake

Load	Source	Allocation
Background Load	Precipitation	4,500 pounds per year
	Groundwater	900 pounds per year
Non-Background Load	Internal Recycling and Watershed	3,700 pounds per year
Total Load Allocation		**9,100 pounds per year**

Margin of Safety

The margin of safety for this TMDL is explicit and consists of a 10% reduction in the non-background portion of the load allocation. This margin of safety is calculated as 400 pounds per year.

TMDL Equation

TMDL = LA + WLA + MOS
= 9,100 pounds per year + 0 pounds per year + 400 pounds per year
= 9,500 pounds of total phosphorus per year

4. Implementation Plan

The following implementation plan is not a required component of a Total Maximum Daily Load but can provide department staff, partners, and watershed stakeholders with a strategy for improving Clear Lake water quality. The Clear Lake Enhancement and Restoration (CLEAR) Project is a watershed project working with local landowners, the City of Clear Lake, NRCS field office, and the IDNR to develop a priority-based watershed plan. The implementation of the CLEAR Project is based on the Clear Lake Diagnostic & Feasibility Study completed in 2001 (1).

The study evaluated the feasibility and implementation of various best management practices that would reduce sediment and nutrient delivery to the lake. The CLEAR project has focused on information and education within the Clear Lake watershed and is working with the NRCS and IDNR to implement many of the recommendations made in the Diagnostic & Feasibility Study. The CLEAR Project is implementing best management practices with the goal of improving the water quality of Clear Lake and Ventura Marsh and meeting the targets of the TMDL.

The CLEAR Project is funded by a CWA Section 319 grant from the IDNR and by a Watershed Protection Fund Grant from the Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation.

The City of Clear Lake and Cerro Gordo County have already installed storm water filtration systems, which intercept urban stormwater prior to its discharge to the lake. These storm water filtration systems allow time for suspended sediments, debris, bacteria, and nutrients to settle out of the water rather than enter the lake. To help pay for these storm water filtration systems, the City of Clear Lake has established a stormwater fee of $1.50 per month along with water utility bills. In addition, stenciling has been done on storm drains that drain to the lake, and one rain garden has been installed.

In addition to the storm water filtration systems, the City of Clear Lake is active in educating residents and encouraging them to use low or no-phosphorous lawn fertilizers.

In the agricultural areas of the watershed, the project has helped enroll 300 acres in the wetland reserve program, 25 acres in the farmed wetland program, and established nutrient and pest management programs on 1,400 acres in the watershed.

The U.S. Army Corps of Engineers (ACOE), Rock Island District, has recently completed a reconnaissance study on Clear Lake and its watershed to determine if there is a Federal interest in providing environmental restoration in the watershed. The study was completed from February through November 2004, and found that there was a Federal interest in continuing the planning process into a more detailed feasibility study. The goals of a Clear Lake Feasibility study would be to improve water quality related to habitat levels compared to 50-70 years ago and restore aquatic ecosystem balance to favor native macrophytes growth and fish diversity.

The ACOE has identified potential project features that would be considered in the feasibility phase. These include the following: wetlands at drain tile outlets or pocket wetlands, buffer strips, stormwater filtration systems, rain gardens, ground water treatment options (for high phosphorous), rough fish control (including rotenone applications and a carp barrier), new outflow weir for Clear Lake, a berm across Ventura marsh and pumping station, sediment removal, alum treatment, water level control, and construction of in-lake structures.

This ACOE Feasibility study would cost approximately $2 million, of which $1 million would be ACOE, and $1 million would be from state and/or local sources as either cash or in-kind. This study would be completed within 36 months. By continuing with the feasibility study, it is possible to leverage further Federal funds for the implementation of the suggested alternatives. This is currently under review by the IDNR.

5. Monitoring

Further monitoring is needed at Clear Lake to follow-up on the implementation of the TMDL. This monitoring will, at a minimum, meet the minimum data requirements established by Iowa's 305(b) guidelines for a complete water quality assessment (3 lake samples per year over 3 years, 10 lake samples over 2 years, etc.). This data will be collected by 2010. Clear Lake has been included in the five-year lake study conducted by Iowa State University under contract with the IDNR. Although this lake monitoring program concluded in 2004, it may be extended under a new lake monitoring strategy. The TMDL program is committed to monitoring waters where TMDLs have been completed, and in the absence of a statewide lake monitoring program, follow-up monitoring will be conducted through the TMDL program.

In addition to the DNR lake monitoring, the CLEAR Project has been collecting water quality samples at the same locations as the ISU Diagnostic and Feasibility Study. These samples are collected according to an EPA approved QAPP and are submitted to a state certified laboratory for analysis. Continuation of this sampling will provide pre- and post-project data to be analyzed for water quality improvements.

In addition to water quality monitoring in Clear Lake, ISU is currently working on a project to better estimate the phosphorous contribution from direct precipitation. As this data becomes available, it will be reviewed and incorporated into Phase II of this TMDL.

6. Public Participation

A presentation on the TMDL process was made to the Clear Lake City Council on June 21, 2004. The draft TMDL was presented at a public meeting in Clear Lake on January 19, 2005. Comments received were reviewed and given consideration and, where appropriate, incorporated into the TMDL.

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8. Appendix A - Lake Hydrology

General Methodology

Purpose

There are approximately 127 public lakes in Iowa. The contributing watersheds for these lakes range in area from 0.028 mi^2 to 195 mi^2 with mean and median values of 10 mi^2 and 3.5 mi^2, respectively. Few, if any, of these lakes have gauging data available to determine flow statistics for the tributaries that feed into them. A select few have some type of stage information that may be useful in determining historical discharge from the lake itself.

With the large number of lakes on the State's 303(d) list and the requirement for rapid development of TMDLs for these lakes, it was realized that a method to quickly estimate flow statistics for required lake response model inputs would be desirable. In an attempt to achieve this goal, flow data and watershed characteristics for a number of USGS gauging stations with small contributing watershed areas were compiled and evaluated via both simple and multiple linear regressions. The primary focus of this evaluation was estimation of the average annual flow statistic for input to empirical lake response models. However, regression equations for monthly average and calendar year flow statistics were also developed that may be of additional use.

It should be noted that attempts were made to develop regression equations for low-flow streamflow statistics (1Q10, 7Q10, 30Q10, 30Q5 and harmonic mean) but the relationships derived were for the most part considered too weak (R^2 adj.< 70%) to be of practical use. One exception to this is the 30Q5 statistic, which gave an R^2 adj. of 85%. In addition, regression equations were developed for monthly flow prediction models for two months (January and May). Once again, the relationships did not exhibit a high level of correlation and due to the large amount of data required to develop these models, development of equations for additional months was not attempted.

Data

Flow data and watershed characteristics from 26 USGS gauging stations were used to derive the regression equations. The ranges of basin characteristics used to develop the regression equations are shown in Table A-1.

Drainage areas were taken directly from USGS gauge information available at http://water.usgs.gov/waterwatch/ . Precipitation values were obtained through the Iowa Environmental Mesonet IEM Climodat Interface at http://mesonet.agron.iastate.edu/climodat/index.phtml . Where weather and gauging stations were not located in the same town, precipitation information was obtained from the weather station located in the town with the shortest straight-line distance from the gauging station.

Average basin slope and land cover percentages were determined using Arc View and statewide coverages clipped within HUC-12 sub-watersheds. It should be noted that the smallest basin coverages used in determining land cover percentages and average basin slopes were single HUC-12 units (i.e. no attempt was made to subdivide HUC-12 basins into smaller units where the drainage area was less than the area of the HUC-12 basin). Therefore, the regression models assume that for very small watersheds the land cover percentages of the HUC-12 basin are representative of the watershed located within the basin.

The Hydrologic Region for each station was determined from Figure 1 of USGS Water-Resources Investigation Report 87-4132, Method for Estimating the Magnitude and Frequency of Floods at Ungaged Sites on Unregulated Rural Streams in Iowa. None of the stations included in the analyses were located in Regions 1 or 5. This is reflected in the regression equations developed that utilize the hydrologic region as a variable.

Table A-1. Ranges of Basin Characteristics Used to Develop the Regression Equations

Basin Characteristic	Name in equations	Minimum	Mean	Maximum
Drainage Area (mi^2)	DA	2.94	80.7	204
Mean Annual Precip (inches)	$\overline{P}_A$	26.0	34.0	36.2
Average Basin Slope (%)	S	1.53	4.89	10.9
Landcover - % Water	W	0.020	0.336	2.80
Landcover - % Forest	F	2.45	10.3	29.9
Landcover - % Grass/Hay	G	9.91	31.3	58.7
Landcover - % Corn	C	6.71	31.9	52.3
Landcover - % Beans	B	6.01	23.1	37.0
Landcover - % Urban/Artificial	U	0	2.29	7.26
Landcover - % Barren/Sparse	B'	0	0.322	2.67
Hydrologic Region	H	Regions 1 - 5 used for delineation but data for USGS stations in Regions 2, 3 & 4 only.		

Methods

Simple regression models were developed for annual average and monthly average statistics with drainage area as the sole explanatory variable. Multiple linear regression models considering all explanatory variables were developed utilizing stepwise regression in Minitab. All data with the exception of the Hydrologic Region were log transformed. Explanatory variables with regression coefficients that were not statistically different from zero (p-value greater than 0.05) were not utilized.

Equation Variables

Table A-2. Regression Equation Variables

Annual Average Flow (cfs)	$\overline{Q}_A$
Monthly Average Flow (cfs)	$\overline{Q}_{MONTH}$
Annual Flow – calendar year (cfs)	Q_{YEAR}
Drainage Area (mi^2)	DA
Mean Annual Precip (inches)	$\overline{P}_A$
Mean Monthly Precip (inches)	$\overline{P}_{MONTH}$
Antecedent Mean Monthly Precip (inches)	$\overline{A}_{MONTH}$
Annual Precip – calendar year (inches)	P_{YEAR}
Antecedent Precip – calendar year (inches)	A_{YEAR}
Average Basin Slope (%)	S
Landcover - % Water	W
Landcover - % Forest	F
Landcover - % Grass/Hay	G
Landcover - % Corn	C
Landcover - % Beans	B
Landcover - % Urban/Artificial	U
Landcover - % Barren/Sparse	B′
Hydrologic Region	H

Equations

Table A-3. Drainage Area Only Equations

Equation	R^2 adjusted (%)	PRESS (log transform)
$\overline{Q}_A = 0.832DA^{0.955}$	96.1	0.207290
$\overline{Q}_{JAN} = 0.312DA^{0.950}$	85.0	0.968253
$\overline{Q}_{FEB} = 1.32DA^{0.838}$	90.7	0.419138
$\overline{Q}_{MAR} = 0.907DA^{1.03}$	96.6	0.220384
$\overline{Q}_{APR} = 0.983DA^{1.02}$	93.1	0.463554
$\overline{Q}_{MAY} = 1.97DA^{0.906}$	89.0	0.603766
$\overline{Q}_{JUN} = 2.01DA^{0.878}$	88.9	0.572863
$\overline{Q}_{JUL} = 0.822DA^{0.977}$	87.2	0.803808
$\overline{Q}_{AUG} = 0.537DA^{0.914}$	74.0	1.69929
$\overline{Q}_{SEP} = 0.123DA^{1.21}$	78.7	2.64993
$\overline{Q}_{OCT} = 0.284DA^{1.04}$	90.2	0.713257
$\overline{Q}_{NOV} = 0.340DA^{0.999}$	89.8	0.697353
$\overline{Q}_{DEC} = 0.271DA^{1.00}$	86.3	1.02455

Table A-4. Multiple Regression Equations

Equation	**R^2 adjusted (%)**	**PRESS (log transform)**
$\overline{Q}_A = 1.17 \times 10^{-3} DA^{0.998} \overline{P}_A^{1.54} S^{-0.261} (1+F)^{0.249} C^{0.230}$	98.7	0.177268 (n=26)
$\overline{Q}_{JAN} = 0.213 DA^{0.997} \overline{A}_{JAN}^{0.949}$	89.0	0.729610 (n=26;same for all $\overline{Q}_{MONTH}$)
$\overline{Q}_{FEB} = 2.98 DA^{0.955} \overline{A}_{FEB}^{0.648} G^{-0.594} (1+F)^{0.324}$	97.0	0.07089
$\overline{Q}_{MAR} = 6.19 DA^{1.10} B^{-0.386} G^{-0.296}$	97.8	0.07276
$\overline{Q}_{APR} = 1.24 DA^{1.09} \overline{A}_{APR}^{1.64} S^{-0.311} B^{-0.443}$	97.1	0.257064
$\overline{Q}_{MAY} = 10^{(-3.03+0.114H)} DA^{0.846} \overline{P}_A^{2.05}$ Hydrologic Regions 2, 3 & 4 Only	92.1	0.958859
$\overline{Q}_{MAY} = 1.86 \times 10^{-3} DA^{0.903} \overline{P}_A^{1.98}$	90.5	1.07231
$\overline{Q}_{JUN} = 10^{(-1.47+0.0729H)} DA^{0.891} C^{0.404} \overline{P}_{JUN}^{1.84} (1+F)^{0.326} G^{-0.387}$ Hydrologic Regions 2, 3 & 4 Only	97.0	0.193715
$\overline{Q}_{JUN} = 8.13 \times 10^{-3} DA^{0.828} C^{0.478} \overline{P}_{JUN}^{2.70}$	95.9	0.256941
$\overline{Q}_{JUL} = 1.78 \times 10^{-3} DA^{0.923} \overline{A}_{JUL}^{4.19}$	91.7	0.542940
$\overline{Q}_{AUG} = 4.17 \times 10^{7} DA^{0.981} (1+B')^{-1.64} (1+U)^{0.692} \overline{P}_A^{-7.2} \overline{A}_{AUG}^{4.59}$	90.4	1.11413
$\overline{Q}_{SEP} = 1.63 DA^{1.39} B^{-1.08}$	86.9	1.53072
$\overline{Q}_{OCT} = 5.98 DA^{1.14} B^{-0.755} S^{-0.688} (1+B')^{-0.481}$	95.7	0.375296
$\overline{Q}_{NOV} = 5.79 DA^{1.17} B^{-0.701} G^{-0.463} (1+U)^{0.267} (1+B')^{-0.397}$	95.1	0.492686
$\overline{Q}_{DEC} = 0.785 DA^{1.18} B^{-0.654} (1+U)^{0.331} (1+B')^{-0.490}$	92.4	0.590576
$Q_{YEAR} = 3.164 \times 10^{-4} DA^{0.942} P_{YEAR}^{2.39} A_{YEAR}^{1.02} S^{-0.206} \overline{P}_A^{1.27} C^{0.121} (1+U)^{0.0966}$	83.9	32.6357 (n=716)

General Application

In general, the regression equations developed using multiple watershed characteristics will be better predictors than those using drainage area as the sole explanatory variable. The single exception to this appears to be for the May Average Flow worksheet where the PRESS statistic values indicate that use of drainage area alone results in the least error in the prediction of future observations.

Although 2002 land cover grids for the state are now available with 19 different classifications, the older 2000 land cover grids with 9 different classifications were used in developing the regression equations. The 2000 land cover grids should be used in development of flow estimates using the equations.

The equations were developed from stream gauge data for watersheds with relatively minor open water surface percentages relative to other types of land cover (see Table A-1). For application to lake watersheds, particularly those with small watershed/lake area ratios, the basin slope and land cover percentages taken from HUC-12 basins may need to be adjusted so that the hydraulic budget components of surface inflow and direct precipitation on the lake itself can be treated separately. One method of accomplishing this is by subtraction of lake water surface acreage from the total land cover and slope (lakes will have 0% slope) acreages and recalculation of the % coverages. The watershed (drainage) area used in the equations should not include the area of the lake surface.

Table A-5. Application to Clear Lake - Calculations

Lake	Clear Lake	
Type	Natural	
Inlet(s)	Ventura Marsh	
Outlet(s)	Clear Creek	
Volume	34094	(acre-ft)
Lake Area	3625	(acres)
Mean Depth	9.41	(ft)
Drainage Area	8667	(acres)
Mean Annual Precip	32.36	(inches)
Average Basin Slope	1.85	(%)
%Water	3.17	
%Forest	8.28	
%Grass/Hay	30.90	
%Corn	29.59	
%Beans	24.99	
%Urban/Artificial	3.03	
%Barren/Sparse	0.00	
Hydrologic Region	4	
Mean Annual Class A Pan Evap	47.00	(inches)
Mean Annual Lake Evap	34.78	(inches)
Est. Annual Average Inflow	7942.84	(acre-ft)
Direct Lake Precip	9775.42	(acre-ft/yr)
Est. Annual Average Det. Time (inflow + precip)	1.9242	(yr)
Est. Annual Average Det. Time (outflow)	4.7275	(yr)

9. Appendix B - Monitoring Data

Table B-1. Data collected in 1979 by Iowa State University (7)

Date Collected	7/26/79			8/23/79			9/25/79		
Depth (feet)	0	3	9	0	3	6	0	3	6
Secchi (meters)	0.6			0.70			0.9		
Suspended Solids (mg/L)	37.8	39	17.1	19.1	18.8	20.1	10.7	11.1	10.7
Dissolved Oxygen (mg/L)	19.3	19.1	7.2	9.6	9.5	2.4	9.6	9.6	9.6
Ammonia N (mg/L)							0.08		
Nitrate-Nitrite N (mg/L)							0.08		
Total Phosphate(mg/L)	0.180	0.200	0.107	0.091	0.089	0.083	0.051	0.054	0.50

Table B-2. Data collected in 1990 by Iowa State University (8)

Date Collected	5/27/1990			6/28/1990			7/26/1990		
Sample Number	1	2	3	1	2	3	1	2	3
Secchi (m)	0.4			0.3			0.4		
Suspended Solids (mg/L)	22.6	28.4	24	62.8	58.8	69.8	76.7	72.3	77.6
Total Nitrogen (mg/L)	3.7	3.5	3.6	3.7	3.3	8.8	3.5	3.2	3.2
Total Phosphorus (ug/L)	198	189	208	135	164	126	125	118	135
Chlorophyll a (ug/L) Corrected	20	101	62	52	68	71	38	36	33

Each sample was a composite water sample from all depths of the lake.

Table B-3. Data collected in 2000 by Iowa State University (3)

Parameter	**7/10/00**	**7/31/00**	**9/6/00**
Secchi Depth (m)	0.5	0.5	0.3
Chlorophyll (ug/L)	66	20	6
NH_3+NH_4^+ -N (ug/L)	1166	855	1354
NH_3 –N (un-ionized) (ug/L)	1	87	55
NO_3+NO_2-N (mg/L)	0.18	0.22	0.11
Total Nitrogen (mg/L as N)	2.09	1.94	1.87
Total Phosphorus (ug/l as P)	163	74	150
Silica (mg/L as SiO_2)	25	29	51
pH	6	8.3	8
Alkalinity (mg/L)	164	137	147
Total Suspended Solids (mg/L)	45.0	35.7	61.6
Inorganic Suspended Solids (mg/L)	15.8	10.7	30.4
Volatile Suspended Solids (mg/L)	29.2	25.0	31.2

Table B-4. Data collected in 2001 by Iowa State University (4)

Parameter	6/4/01	7/9/01	8/6/01
Secchi Depth (m)	0.9	0.6	0.5
Chlorophyll (ug/L)	14	70	128
NH_3+NH_4^+ -N (ug/L)	417	664	522
NH_3 –N (un-ionized) (ug/L)	38	127	65
NO_3+NO_2-N (mg/L)	0.41	0.05	0.27
Total Nitrogen (mg/L as N)	1.60	2.12	1.77
Total Phosphorus (ug/l as P)	73	131	104
Silica (mg/L as SiO_2)	19	56	119
pH	10	13	15
Alkalinity (mg/L)	8.5	8.6	8.3
Total Suspended Solids (mg/L)	21.4	30.4	32.4
Inorganic Suspended Solids (mg/L)	8.6	9.6	13.6
Volatile Suspended Solids (mg/L)	12.8	20.7	18.8

Table B-5. Data collected in 2002 by Iowa State University (5)

Parameter	6/10/02	7/15/02	8/12/02
Secchi Depth (m)	0.8	1.0	0.5
Chlorophyll (ug/L)	25	28	38
NH_3+NH_4^+ -N (ug/L)	164	152	202
NH_3 –N (un-ionized) (ug/L)	22	22	31
NO_3+NO_2-N (mg/L)	0.22	0.21	0.17
Total Nitrogen (mg/L as N)	1.21	1.19	1.25
Total Phosphorus (ug/l as P)	57	39	90
Silica (mg/L as SiO_2)	<1	6	11
pH	8.5	8.4	8.5
Alkalinity (mg/L)	158	158	156
Total Suspended Solids (mg/L)	17.7	13.3	22.2
Inorganic Suspended Solids (mg/L)	7.3	4.3	9.0
Volatile Suspended Solids (mg/L)	10.3	9.0	13.2
Dissolved Organic Carbon (mg/L)	--	--	12.4

Additional lake sampling results and information can be viewed at:
http://limnology.eeob.iastate.edu/

Table B-6. TSI values calculated from the Iowa Lake Survey data through 2003 and the mean and median values for the Secchi depth, chlorophyll, and total phosphorus. Note the variability from month to month and year to year. (3,4,5,6)

	Sample Data			TSI Values		
	Secchi Depth (meters)	Chlorophyll (ug/l)	Total Phosphorus (ug/l)	Secchi Depth	Chlorophyll	Total Phosphorus
7/10/2000	0.5	66.5	163	70	72	78
7/31/2000	0.5	19.9	74	70	60	66
9/6/2000	0.3	5.9	150	77	48	76
6/4/2001	0.9	14.1	71	62	57	66
7/9/2001	0.6	70.1	133	67	72	75
8/6/2001	0.5	128	105	70	78	71
6/10/2002	0.8	25	57	63	62	62
7/15/2002	1	27.8	39	60	63	57
8/12/2002	0.5	37.9	90	70	66	69
6/9/2003	2.9	4	58	45	44	63
7/15/2003	0.8	27.2	72	63	63	66
8/11/2003	0.6	30.8	71	67	64	66
average	0.83	38.1	90.3	63	66	69
median	0.6	27.8	74	67	63	66
targets	>0.7	<33	<96	<65	<65	<70

Table B7 is from the Clear Lake Diagnostic and Feasibility Study (November 2001, Table 2, page 94) and summarizes the data collected during the study at three sampling locations in the lake. These values represent the growing season mean used to determine targets for chlorophyll and secchi depth. The value used for total phosphorous in the development of the TMDL is the average annual TP 166 ug/l that is found on page 284 of the CLDFS. The average annual value was used rather that the growing season mean because the lake response model (Vollenweider) used for the TMDL has its basis on the average annual TP.

TABLE B7. Summary table of measurements made on all Clear Lake sampling stations 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

10. Appendix C - Trophic State Index

Carlson's Trophic State Index
Carlson's Trophic State Index is a numeric indicator of the continuum of the biomass of suspended algae in lakes and thus reflects a lake's nutrient condition and water transparency. The level of plant biomass is estimated by calculating the TSI value for chlorophyll-a. TSI values for total phosphorus and Secchi depth serve as surrogate measures of the TSI value for chlorophyll.

The TSI equations for total phosphorus, chlorophyll and Secchi depth are:

$$TSI\ (TP) = 14.42\ \ln(TP) + 4.15$$

$$TSI\ (CHL) = 9.81\ \ln(CHL) + 30.6$$

$$TSI\ (SD) = 60 - 14.41\ \ln(SD)$$

TP = in-lake total phosphorus concentration, ug/L

CHL = in-lake chlorophyll-a concentration, ug/L

SD = lake Secchi depth, meters

The three index variables are related by linear regression models and *should* produce the same index value for a given combination of variable values. Therefore, any of the three variables can theoretically be used to classify a waterbody.

Table C-1. Changes in temperate lake attributes according to trophic state (modified from 22,23,24)

TSI Value	Attributes	Primary Contact Recreation	Aquatic Life (Fisheries)
50-60	eutrophy: anoxic hypolimnia; macrophyte problems possible	[none]	warm water fisheries only; percid fishery; bass may be dominant
60-70	blue green algae dominate; algal scums and macrophyte problems occur	weeds, algal scums, and low transparency discourage swimming and boating	Centrarchid fishery
70-80	hyper-eutrophy (light limited). Dense algae and macrophytes	weeds, algal scums, and low transparency discourage swimming and boating	Cyprinid fishery (e.g., common carp and other rough fish)
>80	algal scums; few macrophytes	algal scums, and low transparency discourage swimming and boating	rough fish dominate; summer fish kills possible

The relationship between TSI variables can be used to identify potential causal relationships. For example, TSI values for chlorophyll that are consistently well below those for total phosphorus suggest that something other than phosphorus limits algal growth. The TSI values can be plotted to show potential relationships as shown in Figure C-1.

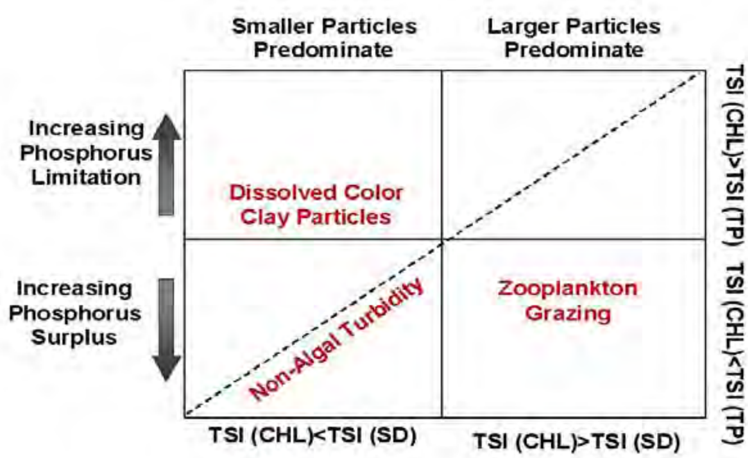
Table C-2. Summary of ranges of TSI values and measurements for chlorophyll-a and Secchi depth used to define Section 305(b) use support categories for the 2004 reporting cycle

Level of Support	TSI value	Chlorophyll-a (ug/l)	Secchi Depth (m)
fully supported	<=55	*<=12*	*>1.4*
fully supported / threatened	55 ➔ 65	*12 ➔ 33*	*1.4 ➔ 0.7*
partially supported (evaluated: in need of further investigation)	65 ➔ 70	*33 ➔ 55*	*0.7 ➔ 0.5*
partially supported (monitored: candidates for Section 303(d) listing)	65-70	*33 ➔ 55*	*0.7➔ 0. 5*
not supported (monitored or evaluated: candidates for Section 303(d) listing)	>70	*>55*	*<0.5*

Table C-3. Descriptions of TSI ranges for Secchi depth, phosphorus, and chlorophyll-a for Iowa lakes

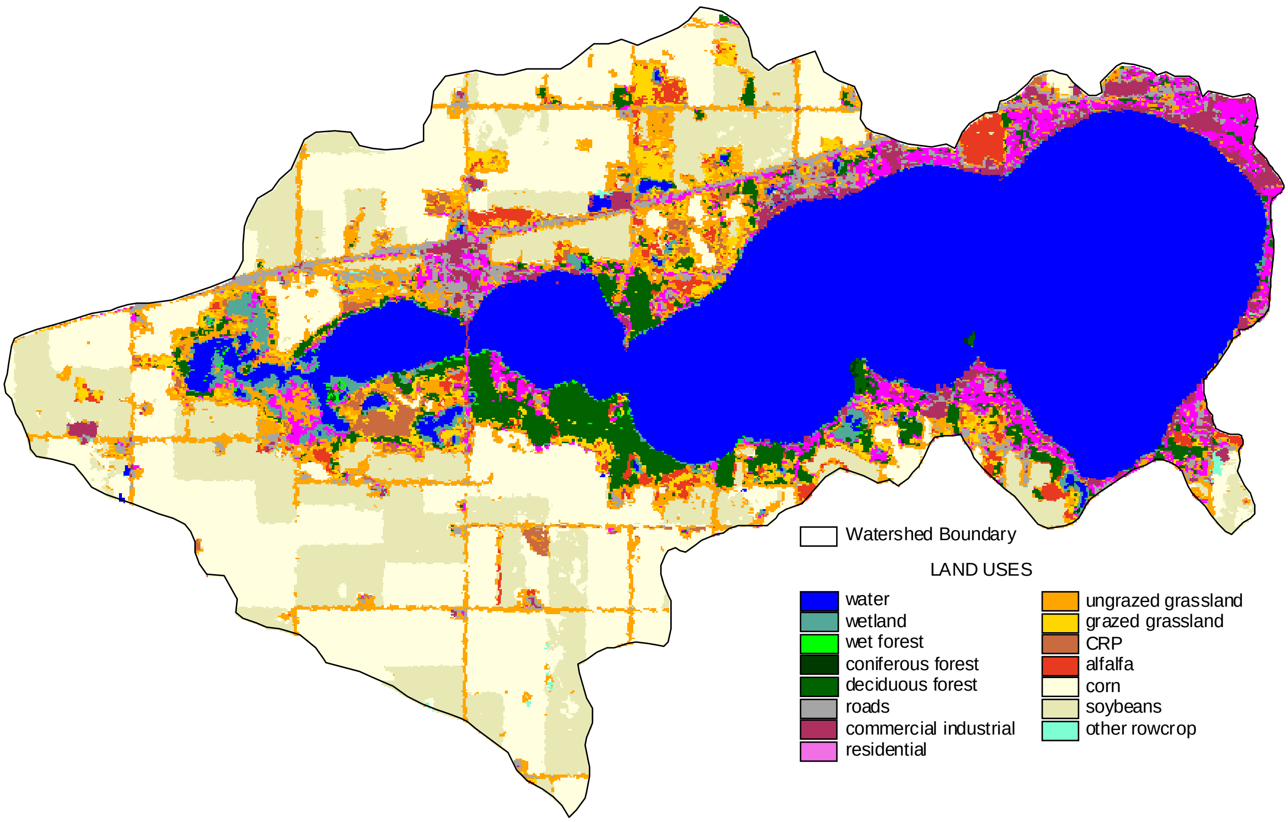
TSI value	Secchi description	Secchi depth (m)	Phosphorus & Chlorophyll-a description	Phosphorus levels (ug/l)	Chlorophyll-a levels (ug/l)
> 75	extremely poor	< 0.35	extremely high	> 136	> 92
70-75	very poor	0.5 – 0.35	very high	96 - 136	55 – 92
65-70	poor	0.71 – 0.5	high	68 – 96	33 – 55
60-65	moderately poor	1.0 – 0.71	moderately high	48 – 68	20 – 33
55-60	relatively good	1.41 – 1.0	relatively low	34 – 48	12 – 20
50-55	very good	2.0 – 1.41	low	24 – 34	7 – 12
< 50	exceptional	> 2.0	extremely low	< 24	< 7

Figure C-1. Multivariate TSI Comparison Chart (Carlson)



11. Appendix D - Land Use Map

Figure D-1. Land uses in the Clear Lake watershed based on 2002 land use coverages



12. Appendix E - The Fish Community

An Analysis of the Fishery of Clear Lake, Iowa
As prepared for the Clear Lake Diagnostic And Feasibility Study (1)
By James Wahl, IDNR Fisheries Management Biologist

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. Our challenge is to try and restore the Clear Lake fishery to resemble that found in the 1940's. To accomplish this we will need to improve two critical areas. First we need to improve water quality. This will help reestablish aquatic vegetation which so many fishes are dependant upon. Second we need to reduce bottom-feeding fishes, primarily carp and bullhead, which will improve water clarity and also enhance aquatic vegetation. Doing one without the other may not bring us the results we hope for, 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 makes 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 fisherman 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 30% of Clear Lake fishermen were specifically targeting bullheads during the mid-1980's, while in recent years less than 5%. 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.