DIAGNOSTIC/FEASIBILITY STUDY REPORT

RICHMOND LAKE

BROWN COUNTY, SOUTH DAKOTA

SOUTH DAKOTA CLEAN LAKES PROGRAM

DIVISION OF WATER RESOURCES MANAGEMENT

SOUTH DAKOTA DEPARTMENT OF WATER AND NATURAL RESOURCES

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Summary

In April 1987, the South Dakota Department of Water and Natural Resources began a Diagnostic/Feasibility Study on Richmond Lake under a contracted agreement with the Richmond Lake Association and the participation of the South Dakota Department of Game, Fish and Parks; Northern State College, Aberdeen, SD; and the water testing facility of the City of Aberdeen Sewage Treatment Plant.

Richmond Lake is a man-made lake that has experienced worsening nuisance algal blooms, several incidences of fecal coliform bacteria contamination, and an occurrence of algal toxicity in 1985. These events represent obvious impairments to the designated beneficial uses of the lake.

The purpose of this study was to provide a general assessment of the water quality status of Richmond Lake and to propose restoration alternatives which would enable the lake to meet its assigned beneficial uses and improve its recreation potential.

In order to identify problem sources in the watershed that may be impacting Richmond Lake and to focus restoration measures that may be required, a watershed survey was conducted that compiled land-use and feedlot information within the drainage.

The diagnostic study has shown that phosphorus is present in overabundance in Richmond Lake and its watershed tributaries. About twice the concentration of total phosphorus is entering the reservoir from its two largest tributaries as is found in Richmond Lake. Nitrogen loads are moderate by comparison. Richmond Lake is frequently nitrogen-limited while phosphorus is present at hypereutrophic levels. Moreover, lake water clarity appears to have decreased by more than 50% in the last ten years.

It is highly probable that a principal source of nutrients and occasional bacterial contamination to the lake is watershed runoff from surrounding feedlots and pastures. In the immediate future priority will be given to completing plans for establishment of animal waste management systems at two to four lakeside feeding operations that were determined to have the largest impact on Richmond Lake water quality if prior ground surveys confirm nutrient export problems at those sites. Procedures will also be established for stabilizing stretches of shoreline that are presently experiencing severe erosion from wind and wave action. Lakeside pastures that have been denuded of vegetative cover will be replanted and cattle excluded for a sufficient period of time to allow complete recovery. Thirdly, watershed acreages that have been identified by computer modeling (AGNPS) to be experiencing excessive soil losses will be inspected by ground survey to confirm the existence of erosion problems. If such are clearly evident upon inspection, arrangements will be made, if feasible, to establish BMP's appropriate to the acreage in question.

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The Richmond Lake Diagnostic/Feasibility Study

Introduction

In 1987, the South Dakota Department of Water and Natural Resources (DWNR) proposed to carry out a Diagnostic/Feasibility Study of Richmond Lake, Brown County, South Dakota to define the trophic state and use impairment of the lake and to propose restoration alternatives to improve its water quality. In the past, lake restoration measures implemented without a prior consideration of watershed management and treatment of point sources of pollution have proven fruitless after achieving some initial gains. Therefore, the decision was made to also undertake a comprehensive survey of the Richmond Lake watershed in order to identify problem sources within the drainage and develop means of reducing their impact on the lake. To aid in this effort, existing data and information from past studies of Richmond Lake and its watershed were compiled and evaluated for inclusion in this diagnostic study.

Responsibility for water quality sampling and analysis was divided among the Department of Game, Fish and Parks; Northern State College; the City of Aberdeen Sewage Treatment Plant; the State Health Laboratory; and the Richmond Lake Association which was also to collect watershed land use and feedlot data.

Description of the Study Area

Richmond Lake is a T-shaped man-made lake on lower Foot Creek located about eight miles northwest of Aberdeen, SD. The dam completed in 1938 was constructed about 1-1/4 mile east of the former confluence of Foot Creek and an unnamed tributary. Foot Creek acts as an outlet channel for the lake directing the occasional spillway overflows southeast to Moccasin Creek and thence into the James River.

Richmond Lake is fed by two other minor tributaries which, together with the Foot Creek drainage and that of the above mentioned tributary, comprise a total watershed area of approximately 92,000 acres. All four inflowing tributaries are intermittent in nature. Recent land use in the Richmond Lake watershed is estimated to be 70 to 80% pasture and grassland and 20 to 30% crop land. Approximately 137 residences and two recreational areas including a swimming beach are situated adjacent to the lake.

The lake covers 840 surface acres to an average depth of 11 feet and a maximum depth of 27 feet. The bottom varies from sand and gravel in the shallows to silt and muck in the deeper areas. There is no enduring thermal stratification in the summer months. Only about 5% of the shoreline is covered with cattail and bullrush and other aquatic plants are likewise uncommon. Crappie and bullhead represent the most abundant resident fish species.

The State of South Dakota has assigned the following beneficial uses to Richmond Lake:

- Warmwater permanent fish life propagation
- Immersion recreation
- Limited contact recreation
- Wildlife propagation and stock watering

Water Quality Standards established for Richmond Lake beneficial uses (ARSD 74:03:02:30) are the following:

Table 1

Parameter	Concentration*
Nitrate as N	<50
Total Cyanide	<0.02
Free Cyanide	<0.005
Hydrogen Sulfide	<0.002
Suspended Solids	<90
Total Dissolved Solids	<2500
Temperature (°F)	<80
Fecal Coliform	<200/100 ml
Total Alkalinity	<750
Conductivity	<2500 micromhos/cm @ 25°C
Dissolved Oxygen	>5.0
Total Chlorine Residual	<0.02
Unionized Ammonia	<0.04
pH	6.5 <---> 8.3 SU

*All values in mg/l unless otherwise indicated.

In recent decades, Richmond Lake has experienced water quality problems that are the result of accelerated eutrophication produced by many of the same cultural and natural influences that are presently impacting other lakes and reservoirs in eastern South Dakota.

This decline in Richmond Lake water quality has been evidenced by high in-lake nutrient levels, moderate to occasionally severe blue-green algal blooms, occasional low oxygen levels, poor water clarity, sporadic fecal coliform problems, and an incidence of algal toxicity in summer of 1985 brought on by the appearance of a toxic strain of the common planktonic blue-green alga Anabaena flos-aquae. Toxic blue-green algal blooms develop in open water areas of eutrophic lakes at infrequent and sporadic intervals in response to poorly understood environmental stimuli. There has been no further incidence of algal toxicity reported in Richmond Lake to date.

Existing Information

Several past studies have been completed on Richmond Lake which attempted to address, at least in part, some of the identified water quality problems:

A) Richmond Lake Environmental Health Survey (1973).

Public concern regarding the apparent deterioration of water quality in Richmond Lake, as was evidenced by an increase in the intensity of algal blooms, prompted the then South Dakota Committee on Water Pollution to conduct a field survey during June 14-16, 1973, to determine the major sources of pollution that may have been impacting Richmond Lake. A brief summary of results is presented below:

1) The lake has lost approximately 10% of its original capacity from 1938 to 1973 due primarily to sedimentation from its watershed. A SCS study estimated the rate of loss at 0.28% of capacity per year.

2) There were 121 dwellings situated around Richmond Lake in 1973. With an average of 2.9 persons per household there were approximately 351 persons occupying dwellings at one time or another during the year.

3) The local wastewater disposal facilities consisted of 71 septic tanks with tile fields, 4 septic tanks with seepage pits, 8 cesspools, and 38 outdoor privies.

4) A total of 42 wastewater disposal facilities (35%) including 25 septic tank systems were located less than 100 feet from the lakeshore.

5) No surface failures of septic systems or overflows from local wastewater facilities entering the lake were reported.

6) Of a total of 39 water wells reported, 10.3% were found to be improperly located within 25 feet of the shore.

7) Of 15 wells sampled for bacterial contamination,8 or 53.3% were found to be contaminated with fecal coliform bacteria.

B) EPA National Eutrophication Survey (1976).

1) Water quality of Richmond Lake was monitored at three widely spaced in-lake sampling sites during 26 April, 10 July and 18 September 1974.

2) Water sample analysis produced the following results: Nitrates - 0.05 ppm; Ammonia - 0.10 ppm; TP - 0.20 ppm; OP - 0.13 ppm; TKN - 1.77 ppm. These overall averages indicated low nitrate and ammonia levels but relatively high values for phosphorus (OP & TP) and organic nitrogen (~ TKN) during 1974.

3) Secchi disk transparency was good in April and July (mean: 2.8 meters) and poor in September 1974 (1.2 meter).

4) Chlorophyll a values ranged widely from 2.7 to 52.9 mg/m^3 dependent on sampling date and site. Chlorophyll levels for April and July (mean: 8.87 mg/m^3) were below the range indicative of eutrophic

waters. September chlorophyll levels (mean: 37.8 mg/m^3) ranged well within the eutrophic designation.

5) Nutrient loads from Richmond Lake tributaries were estimated using mean annual concentrations and mean annual flows. The amount of incoming phosphorus retained by Richmond Lake was excessive (.10 $grams/m^2/yr$) and indicative of eutrophic loading. Net nitrogen loads were more moderate by comparison (1.7 $g/m^2/yr$) and representative of meso-eutrophic loading for a water body with a mean depth of 5 meters (16.5 ft) or less.

6) Algal assay tests, using the green alga <u>Selenastrum capricornutum</u>, indicated that potential primary productivity of Richmond Lake was high but that the lake was nitrogen-limited at that time. Nitrogen limitation was also indicated by low available Nitrogen/Phosphorus ratios (~ 2/1) derived for all sampling dates and sites.

C) South Dakota Lakes Survey (Koth, 1981).

1) Results from three in-lake sites and two sampling dates in 1979 (June and August averages) indicated high nutrient levels in Richmond Lake except for Nitrates (0.10 ppm): TP-0.22 ppm; OP-0.18 ppm; and TKN-1.44 ppm.

2) Secchi disk transparency for June and August 1979 was only fair (mean: 1.6 meter).

3) No point sources of pollution were identified in the vicinity of Richmond Lake.

4) Shoreline erosion was estimated to be moderate to severe by field observers in 1979.

5) Mean chlorophyll <u>a</u> concentration was 15.3 mg/m^3 indicating moderately eutrophic conditions.

<u>DWNR Richmond Lake Diagnostic/Feasibility Study, 1987-1989</u>

<u>Methods and Materials</u>

<u>Tributary Sample Collection</u>

The purpose of the tributary monitoring program was to collect the water quality and flow data required to develop both nutrient and hydraulic budgets for the lake. These budgets were used to determine the total loadings from the various sources and will allow restoration efforts to be concentrated in the critical loading areas.

Five tributary sampling sites (Figure 1) have been selected for Richmond Lake. The reasons for selecting each site and their locations are as follows:

SITE #1. Outlet structure located at the spillway on the north side of the dam. Latitude 45° 32' 07" Longitude 98° 35' 24" T124N R64W Sec. 19. The data collected at this site will be evaluated to determine the total outflow from the lake.

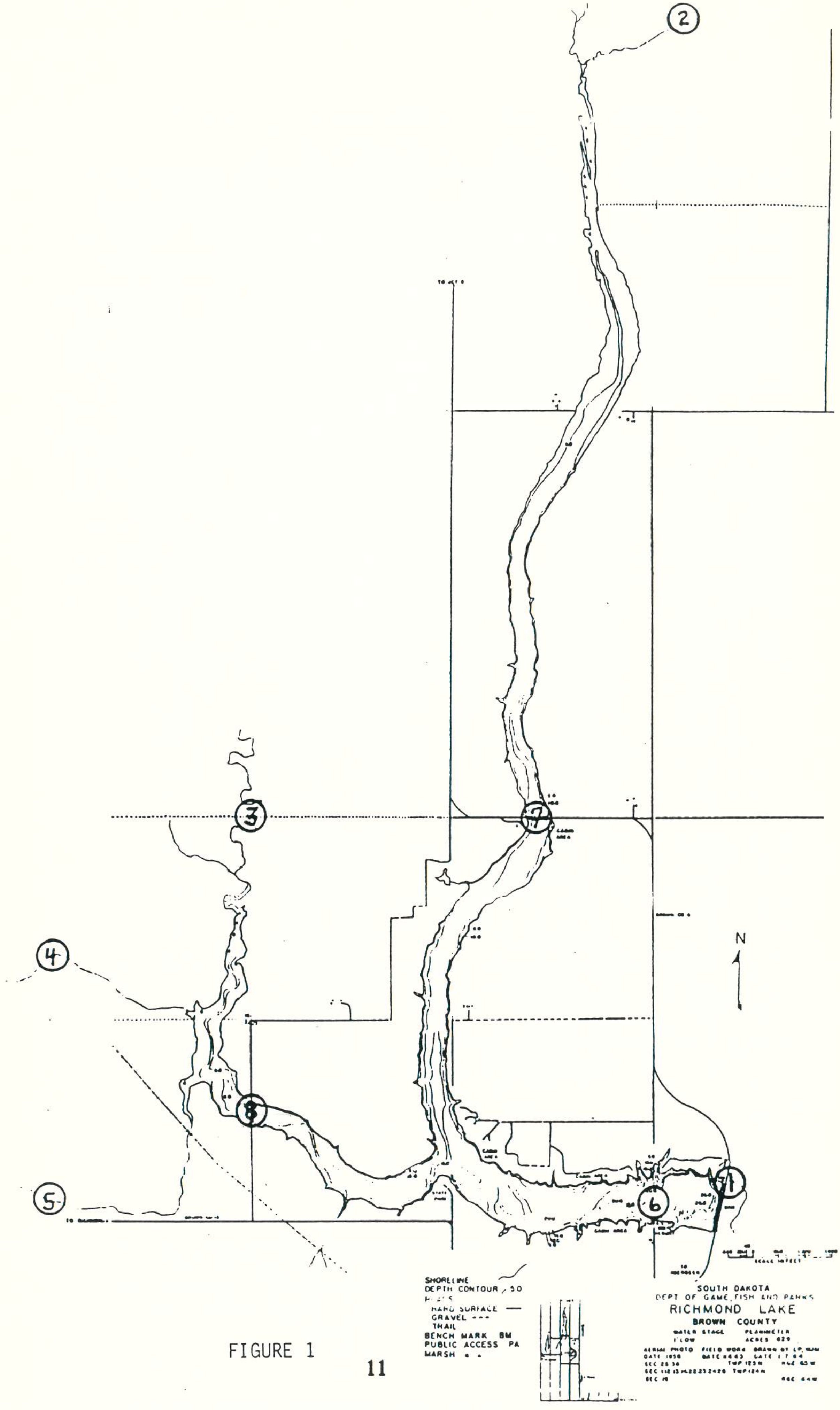
SITE #2. Located approximately 6 miles north of Richmond Lake on the section line forming the south boundary of Section 19 at the confluence of the north tributary and the section line. Latitude 45° 37' 11" Longitude 98° 34' 58" T125N R64W Sec. 19. This site will serve to provide loading data for approximately 15 percent of the watershed served by the north tributary.

SITE #3. Located approximately 3.5 miles northwest of Richmond Lake on the section line road forming the south boundary of Section 2 at the confluence of the stream and the section line road, Latitude 45° 34' 36" Longitude T124N R65W Sec. 2. This site was selected to collect data from the major tributary leading to Richmond Lake and represents approximately 76 percent of the watershed drainage. It will be the major data collection site in terms of total loadings.

SITE #4. Located approximately 1 mile west of the west arm of Richmond Lake on the section line road forming the east boundary of Section 16 at the confluence of the tributary and the section line road, Latitude 45° 33' 21" Longitude 98° 39' 35" T124N R65W Sec. 15. This site will provide loading data from a small subwatershed located west and north of the west arm of Richmond Lake.

SITE #5. Located approximately 3.5 miles west of the Richmond Lake Dam on the section line road forming the east boundary of Section 22 at the confluence of the tributary and the section line road, Latitude 45° 32' 07" Longitude 98° 39' 35" T111N R65W Sec. 22. This site will serve to provide loading data from a small subwatershed west and south of the west arm of Richmond Lake. Sites 4 and 5 combined represent nine percent of the total watershed area.

The above tributary sites and spillway site were sampled at three-day intervals over the entire period of snowmelt flow in 1987. No significant stormwater runoff events occurred during that year. Due to drought conditions no measurable runoff events took place for the entire year of 1988. Owing to time and labor constraints in 1989, snowmelt runoff samples were collected at one to seven-day intervals. As in 1987, no significant stormwater runoff events occurred during 1989.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SHORELINE
DEPTH CONTOUR 50
HARD SURFACE
GRAVEL
TRAIL
BENCH MARK BM
PUBLIC ACCESS PA
MARSH
SOUTH DAKOTA
DEPT OF GAME, FISH AND PARKS
RICHMOND LAKE
BROWN COUNTY
ACRES 829

FIGURE 1

Prior to or during sample collection each site was surveyed to determine cross-sectional area and stage recorders (automatic water depth measuring instruments) were installed at sites 1, 2, and 3. Reading and maintenance of recorders was the responsibility of the Richmond Lake Association. During each sampling session, current velocity measurements were to be taken by the Association at each site to develop a stage/discharge relationship. In this way total flows for the tributaries and the spillway were determined. Accurate determinations of flows are essential for developing a nutrient and sediment budget for the lake.

Laboratory parameters analyzed to characterize the inflow and outflow (spillway) and to develop a nutrient and sediment budget for the lake are listed in Table 2. The Department of Game, Fish and Parks was responsible for sampling and field data collection, including oxygen levels, pH, weather conditions, and Secchi disk depths. The Northern State College Department of Natural Sciences carried out chlorophyll analyses, performed coliform bacterial counts, and analyzed for Kjeldahl nitrogen levels. The City of Aberdeen Sewage Treatment Plant conducted chemical analyses to determine the remaining parameters (Table 2) for the years 1987 and 1988. The State Health Laboratory in Pierre, South Dakota performed all chemical analyses of water samples during 1989.

Field parameters to be collected and analyzed by sample collection personnel were:

Water Temperature	Stream Depth and Width
Air Temperature	pH

Visual observations included:

Precipitation	Dead Fish
Wind	Film
Odor	Turbidity
Septic Conditions	Color

In-Lake Sample Collection

Water quality samples were collected in the lake for the purpose of characterizing the existing chemical and biological quality of the lake, defining the trophic state and determining the use impairment. The baseline data collected during this diagnostic/feasibility study was to provide data to determine trends and implementation effectiveness.

Three in-lake sampling sites have been selected for Richmond Lake (Figure 1). Site 6, the mid-lake site, Latitude 45° 32' 01" Longitude 98° 36' 30" T124N R65W Sec. 24, located in the main body of the lake approximately 1250 feet directly south of the center of Section 24 on the half-section line, is representative of the lake after all tributaries have entered the lake and mixed. Site 7, Latitude 45° 33' 43" Longitude 98° 36' 34" T124N R65W Sec. 12, represents the north arm of Richmond Lake. Site 8, located at Latitude 45° 37'

27" Longitude 98^{o} 38' 19" T124N R65W Section 23 represents the west arm of Richmond Lake.

Each site was to be sampled monthly from October through March and bimonthly from April through September. Separate surface and bottom water samples were required for each inlake site. The Department of Game, Fish and Parks accepted the responsibility for providing field personnel to collect water samples and record field parameters from 1987 through 1988. The Richmond Lake Association performed this duty in 1989.

The laboratory parameters to be analyzed from in-lake samples are listed in Table 2.

Table 2. Methods and references for physical and chemical parameters.

Parameter	Method	Reference
Temperature	Thermometric	APHA (1975)
Secchi disc*	Shaded side of boat	Lind (1974)
Dissolved oxygen	Azide modification of Winkler	APHA (1975)
pH	pH probe	APHA (1975)
Total alkalinity	Potentiometric	EPA (1974)
Ammonia - N	Automated phenate	EPA (1974)
Nitrate - N + Nitrite - N	Automated cadmium reduction	EPA (1974)
Kjeldahl - N	Semi-automated block digester, colorimetric	APHA (1985)
Ortho-phosphorus	Ascorbic acid	EPA (1974)
Total phosphorus	Persulfate digestion, ascorbic acid reduction	EPA (1974)
Total solids	Gravimetric (103-105°C)	EPA (1974)
Total suspended solids	Gravimetric (103-105°C)	EPA (1974)
Total dissolved solids	Gravimetric (180°C)	EPA (1974)
Fecal coliforms	5-tube dilution (1987-1988), Membraned filter (1989)	APHA (1985) APHA (1985)
Conductivity	Conductivity probe, Wheatstone bridge	EPA (1974)
Chlorophyll _a_*	Spectrophotometric	APHA (1985)

* In-lake samples only

Field parameters to be collected and analyzed by sample collection personnel are:

Water Temperature	Air Temperature
Secchi Disk	Dissolved Oxygen
pH	Depth
Ice Cover	Color

Visual observations should include but not be limited to:

Precipitation	Wind
Odor	Septic Conditions
Dead Fish	Film
Turbidity	

As in the case of tributaries, any unusual circumstances should be noted in the field personnel's daily log.

<u>Sediment Sample Collection</u>

The collection of sediment and overburden water for analysis is a one time activity that was accomplished early in the diagnostic/feasibility study. The Corps of Engineers Elutriate Test of Richmond Lake sediments was completed in March 1987. Elutriate samples were analyzed from the bottom sediments at two in-lake sites for nutrients, metals, and toxic contaminants. Site A was located at the confluence of the reservoir arms, and site B was situated on the lower east arm of the reservoir about half way between the arm confluence and water quality site 7 (Figure 1).

The purpose of this exercise is to determine the contents of the lake sediments and what effect they would have on the water column if stirred by dredging in terms of nutrient release or the liberation of possible hazardous substances. These determinations will aid in the identification of the most effective method of dealing with accumulated lake sediment.

Results of the elutriate tests are presented in Table 3. Iron, manganese, and aluminum were by far the most important constituents of the tested sediments. These are typically among the most abundant naturally occurring metals in the alkaline soils and sediments of this general region. Other metals were present at minimal levels which were in many cases below detection limits. Pesticides and herbicides were also present below the level of detection. Due to the considerable buffering capacity of local alkaline water and trace concentrations of most heavy metals, there is little danger of developing conditions of metal toxicity in Richmond Lake should the sediments be disturbed.

The sediment contained elevated levels of ammonia which is to be expected in the organically enriched bottom constituents of productive lakes, and a somewhat higher concentration of phosphorus at site A (.23 ppm) than occurs on the average in the overlying water (.18 ppm for 1989).

Table 3. Standard Elutriate Test on Sediment and Water from Richmond Lake.

PARAMETER	RICHMOND LAKE SITE A			RICHMOND LAKE SITE B		
	SEDIMENT	RECEIVING WATER	ELUTRIATE WATER	SEDIMENT	RECEIVING WATER	ELUTRIATE WATER
AMMONIA, NH3, PPM		0.30	4.33		0.37	3.11
CHEMICAL OXYGEN DEMAND, PPM		31.2	47.0		33.1	45.0
CYANIDE, TOTAL (as CN)	0.17 mg/kg	<0.02 PPM	0.021 PPM	1.3 mg/kg	<0.02 PPM	0.15 PPM
NITRATE, TOTAL (as N)		<0.02 PPM	<0.02 PPM		<0.02 PPM	<0.02 PPM
PHOSPHORUS, TOTAL (as P)		0.01 PPM	0.231 PPM		<0.01 PPM	0.022 PPM
TOTAL KJELDAHL NITROGEN (as N)		1.14 PPM	3.14 PPM		1.25 PPM	3.45 PPM
OIL AND GREASE	0.23 mg/kg	<0.2 PPM	<0.2 PPM	0.27 mg/kg	<0.2 PPM	<0.2 PPM
ANTIMONY, TOTAL (as Sb)	0.6 mg/kg	<0.1 PPb	<0.1 PPb	0.7 mg/kg	<0.1 PPb	<0.1 PPb
ARSENIC, TOTAL (as As)	1.6 mg/kg	8.1 PPb	30.1 PPb	1.4 mg/kg	7.9 PPb	23.3 PPb
BARIUM, TOTAL (as Ba)	63.2 mg/kg	108 PPb	191 PPb	58.0 mg/kg	112 PPb	143 PPb
BERYLLIUM, TOTAL (as Be)	1.7 mg/kg	<5 PPb	<5 PPb	1.9 mg/kg	<5 PPb	<5 PPb
CADMIUM, TOTAL (as Cd)	0.3 mg/kg	<1 PPb	<1 PPb	0.3 mg/kg	<1 PPb	<1 PPb
CHROMIUM, TOTAL (as Cr)	3.4 mg/kg	<1 PPb	<1 PPb	3.6 mg/kg	<1 PPb	<1 PPb
COPPER, TOTAL (as Cu)	2.5 mg/kg	<5 PPb	<5 PPb	3.2 mg/kg	<5 PPb	10.5 PPb
IRON, TOTAL (as Fe)	5386 mg/kg	282 PPb	315 PPb	5909 mg/kg	683 PPb	619 PPb
LEAD, TOTAL (as Pb)	2.2 mg/kg	<2 PPb	<2 PPb	2.1 mg/kg	<2 PPb	<2 PPb
MAGNESIUM, TOTAL (as Mg)	2.4 mg/kg	24.5 PPb	27.7 PPb	2.5 mg/kg	24.5 PPb	26.3 PPM
MANGANESE, TOTAL (as MN)	854 mg/kg	803 PPb	3176 PPb	1523 mg/kg	800 PPb	3583 PPb
MERCURY, TOTAL (as HG)	<0.1 mg/kg	0.2 PPb	0.2 PPb	<0.1 mg/kg	0.2 PPb	0.2 PPb
SELENIUM, TOTAL (as Se)	<0.1 mg/kg	4.6 PPb	2.7 PPb	<0.1 mg/kg	1.3 PPb	3.6 PPb
ZINC, TOTAL (as Zn)	28.4 mg/kg	<5 PPb	<5 PPb	45.9 mg/kg	<5 PPb	<5 PPb
NICKEL, TOTAL (as Ni)	6.4 mg/kg	6.6 PPb	<5 PPb	10.9 mg/kg	10.9 PPb	<5 PPb
ALUMINUM, TOTAL (as Al)	6020 mg/kg	227 PPb	400 PPb	6376 mg/kg	633 PPb	943 PPb
CALCIUM, TOTAL (as Ca)	5.6 mg/kg	44.4 PPM	47.7 PPM	4.3 mg/kg	44.3 PPM	46.7 PPM
SODIUM, TOTAL (as Na)	0.3 mg/kg	102.4 PPM	103.2 PPM	0.3 mg/kg	103.3 PPM	102.7 PPM
POTASSIUM, TOTAL (as K)	1.3 mg/kg	20.0 PPM	24.8 PPM	1.5 mg/kg	19.6 PPM	21.1 PPM
SILVER, TOTAL (as Ag)	<0.1 mg/kg	<0.1 PPb	<0.1 PPb	<0.1 mg/kg	<0.1 PPb	<0.1 PPb
CHLORINATED PESTICIDES	<0.5 mg/kg	<0.5 PPb	<0.5 PPb	<0.5 mg/kg	<0.5 PPb	<0.5 PPb
PCB	<50 ug/kg	<50 PPb	<50 PPb	<50 ug/kg	<50 PPb	<50 PPb

Dredging the sediment would probably produce a temporary and localized increase in nitrogen levels in the form of ammonia but increases in phosphorus and heavy metal concentration in the overlying water are expected to be minor.

Land Use/Feedlot Data Collection

The purpose for collecting land use and feedlot data was to determine those feedlots that present the most severe problems in terms of water quality degradation and those tracts of land that exhibit critical erosion and nutrient loss. This allows efforts to be focussed on the worst problems first, thereby making best use of available funding.

The user manuals describing the information that is required to run the feedlot and land-use computer models have been provided to Richmond Lake Association personnel. To inventory the present condition of the watershed the size of the contributing drainage area was determined and sectioned into more than 2000, 40-acre square cells on a standard USGS topographic map. Twenty-one (21) cell parameters which describe the physical characteristics and land-use practices of each cell and ten (10) parameters describing each feedlot within the watershed were collected for the execution of the appropriate computer model (AGNPS) (Appendices C and D). The AGNPS computer program generates a sediment and nutrient output for each cell and feedlot and for the drainage as a whole. As of May 1990, land-use and feedlot data have been collected and processed for the remaining lower one-half of the Richmond Lake watershed.

Results and Discussion

All water quality data received by the Water Resources Management Office (WRM) have been processed and tabulated. This includes tributary and in-lake water quality lab results as well as hydrological records from tributary sampling for the years 1987, 1988, and 1989 (Appendix A). There were no usable tributary data for 1988 due to absence of significant runoff events during that year.

Owing to unforeseen scheduling conflicts and flood conditions in early spring of 1989 the first open water lake samples for that year were collected two months late on 15 June rather than in April as scheduled. Moreover, no winter in-lake samples (January to March) were collected in 1989.

Tributary hydrological data collection for 1989 was also limited by the unusually high water conditions which caused the loss of two stage recorders. Data collection was further hampered by the unavailability of a current velocity meter.

Careful examination of the 1987 and 1988 laboratory results indicated that these data will be of limited value for the purpose of this study owing to a number of deficiencies (Appendix B). In general, the conventions followed in recording parameters were inconsistent and unclear, many of the water quality parameter values were unrealistic, and there were many gaps in the data base. These limitations were particularly evident in the determination and recording of most nitrogen and phosphorus concentrations. While much of this data cannot be salvaged, some of it can probably be utilized to attempt a delineation of general water quality trends and to derive a broad interpretation of nutrient loading to Richmond Lake for 1987. Values for Kjeldahl Nitrogen (TKN), fecal coliforms, and chlorophyll a for 1987 and 1988 appear more reliable and can be used almost in their entirety. While there are gaps in the 1989 in-lake data as noted above, most of what is available is of usable quality (Appendix B).

Chlorophyll a

Large populations (standing crops) of algae, particularly when comprised of the nuisance bloom-forming blue-green varieties, constitute visual evidence of excessive lake nutrient enrichment and declining water quality. The amount of algal chlorophyll a extracted from a water sample is comparable to the number of chlorophyll-containing algal cells present. Measurement of chlorophyll levels is, therefore, a convenient means of assessing standing plant crops and thereby estimating the extent of lake eutrophication.

Chlorophyll a was sampled during 1987 and 1988. Time and labor constraints prevented chlorophyll determination in 1989.

In 1987 Richmond Lake displayed an annual pattern of chlorophyll abundance (Figure 2) that is not infrequent for eutrophic lakes: an early spring peak probably due to a bloom of diatoms; a period of low chlorophyll concentration in late spring which may be caused by depletion of utilized micronutrients and/or a rapid rise in herbivorous zooplankton populations; a summer chlorophyll peak caused by blooms of blue-green algae followed by another decrease, probably a partial result of declining light levels and water temperature; and a smaller chlorophyll peak in autumn whose constituents probably involve a mixture of different algal groups adapted to lower light intensities.

During 1988, monthly chlorophyll sampling was begun in January instead of April as in 1987. Sampling in February revealed high chlorophyll levels at sites 7 and 8 but not at site 6 (Figure 2). Those large peaks in chlorophyll a followed a very early ice-out and warm January thaw (Hodgson et al 1989). Late winter blooms of algae even under ice are not unusual in highly productive lakes provided there is sufficient light penetration. Secchi disk measurements conducted in Richmond Lake during ice cover indicated excellent water transparency at those sites with low algal concentrations.

There was no clearly defined early spring maximum in chlorophyll in 1988 which may have been related to a lack of significant spring runoff (ibid) but moderately high chlorophyll levels were present from April to early June (10.2 to 18.8 mg/m^3). By early July, however, there occurred a sharp drop in chlorophyll abundance at all sites and levels remained depressed to the end of the sampling period in October (mean: 1.10 mg/m^3). The concentrations recorded from July through October 1988 resembled those from lakes whose low chlorophyll levels may result from lack of nutrients or excessive water turbidity.

Richmond Lake had relatively moderate annual chlorophyll a values during this study despite several strong seasonal peaks, a sufficient nutrient supply, and an overabundance of phosphorus. Annual chlorophyll means for 1987 and 1988 were similar - 17.4 and 14.4 mg/m^3.

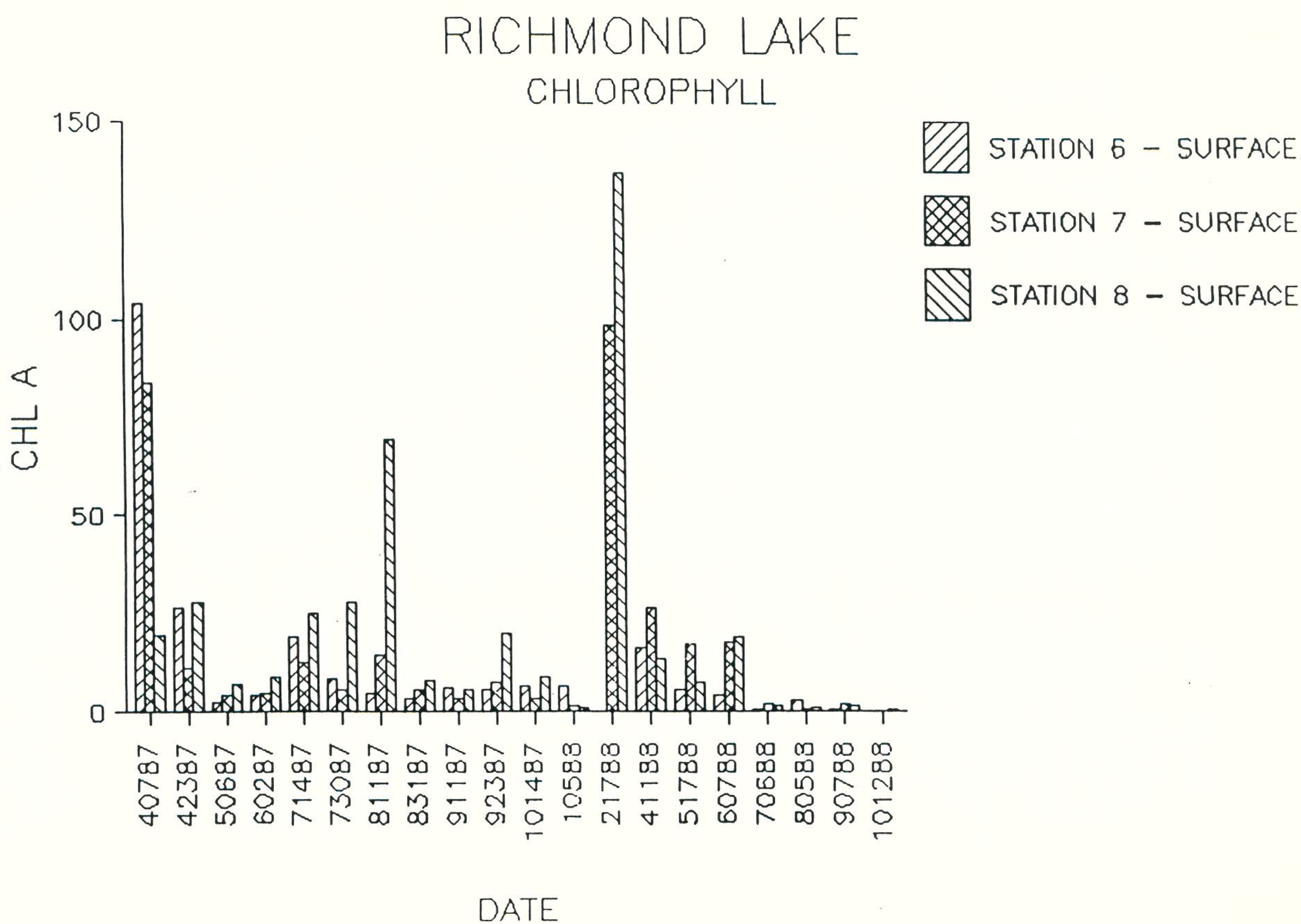

Figure 2: Chlorophyll a (mg/m^3), Richmond Lake(1987-1988).

Wide variation in chlorophyll values was also evident between in-lake sites on the same sampling dates (Figure 2) which may be ascribed to the irregular morphology of the lake and the effect of prevailing winds (Pukas, 1986). The sharp decline in chlorophyll levels during the second half of 1988 suggests the lake may be dependent on watershed runoff to supply some undetermined macro or micronutrients needed to maintain significant algal standing crops. Probably other factors limiting algal production in Richmond Lake are water turbidity due to suspended silt and clay particles during open water periods, and dissolved/colloidal organic matter which may impart a tea color to lake water further reducing light penetration. Annual mean Secchi disk visibility was 0.6 and 0.5 meter for 1987 and 1988, respectively. Since algal densities were often low during those years (as indicated by low chlorophyll), this poor water clarity cannot be wholly accounted for by the presence of algal cells in the water column.

Kjeldahl Nitrogen (TKN)

The Total Kjeldahl Nitrogen test is a combined measure of the inorganic ammonia plus the organic nitrogen components in a water sample. Subtraction of the result of a separate determination for ammonia from TKN yields the organic nitrogen concentration in the sample (i.e. TKN = ammonia N + organic N in mg/l). High levels of organic nitrogen can be an indication of pollution by human or animal wastes. Significant levels of ammonia are also evidence of organic pollution but unlike organic nitrogen, ammonia does not need to be broken down into simpler components before it can be utilized by algae and other plants for growth. High concentrations of ammonia can be toxic to fish particularly if it is abundant in its unionized form.

Ninety percent of in-lake TKN levels recorded over the study period from 1987 to 1989 ranged below 2.00 mg/l (Figure 3). About half of the remaining samples, particularly those registering above 3.00 mg/l TKN, probably represent sampling artifacts - a result of stirring up of bottom sediments.

Most in-lake samples had a somewhat elevated though not unusually high nitrogen content. Generally, for shallow prairie lakes, TKN values above 1.00 mg/l can be considered indicative of various degrees of cultural (man-made) nutrient enrichment.

It was expected that TKN levels would be conspicuously higher following significant rainfall and snowmelt events in 1987 and 1989 but this did not occur during the study (Figure 3). A possible difference noted in June and July 1989 samples was the high percentage (44%) of inorganic nitrogen, ammonia and nitrates, comprising total nitrogen concentrations (mean TN: 1.50 mg/l) at in-lake sites. Highest ammonia and nitrate/nitrite levels occurred at site 7 followed closely by site 6 (near dam). Relatively high ammonia levels in June 1989 were replaced by elevated nitrate/nitrite concentrations in July at all in-lake sites (Appendix A). Both species of nitrogen then declined to normal levels for the remainder of the sampling season. Inorganic nitrogen comprised about 30% of total nitrogen in tributary samples during spring runoff (mean TN: 1.42 mg/l).

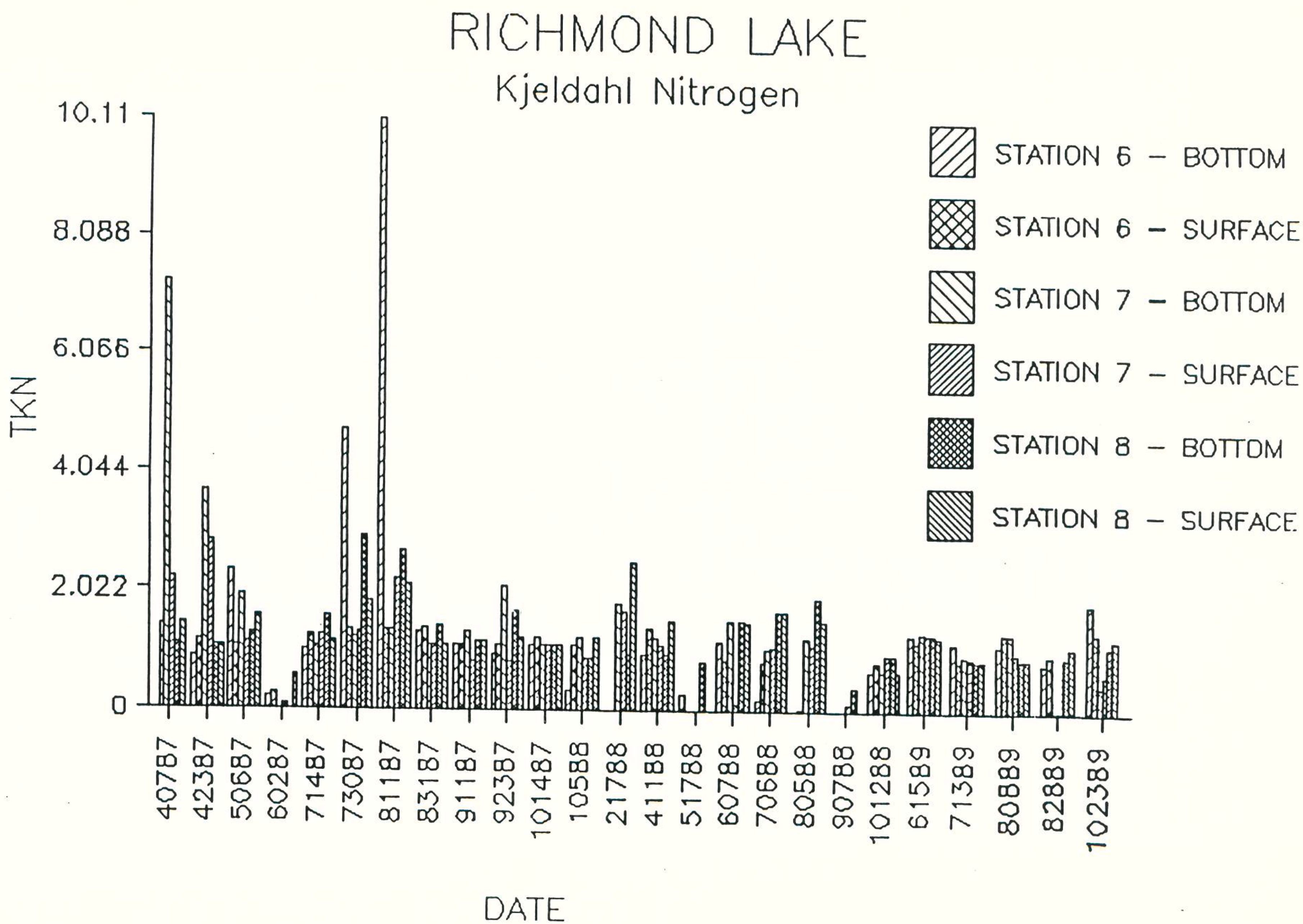

Figure 3: Kjeldahl Nitrogens (mg/l), Richmond Lake (1987-1989).

Tributary TKN levels in 1987 were similar to those of in-lake samples (4-tributary mean: 1.34 mg/l). Tributary site 3 (Foot Creek) which drains 76% of the watershed had an average TKN value of 1.30 mg/l. Slightly lower TKN averages of 1.20 and 1.23 mg/l, respectively, were obtained for the above sites during the 1989 runoff period from 27 March to 17 May. Except for a slightly higher mean concentration recorded for tributary site 2 (15% of watershed), TKN levels in 1989 roughly correlated with the area of tributary drainage ranging from 1.37 and 1.23 mg/l for sites 2 and 3, respectively, to 1.02 mg/l for tributary site 4. The same relationship seemed to apply for tributary total nitrogen and phosphorus concentrations.

Tributary Total Nitrogen and Total Phosphorus

According to a nationwide stream survey (Omerick, 1977), total nitrogen in streams with watersheds composed of 75% rangeland averaged 1.30 mg/l. Foot Creek draining three quarters of the Richmond Lake watershed comprised of predominantly range and pasture (at least 70%), yielded a slightly higher average reading of 1.47 mg/l whereas the 4-tributary mean was 1.42 mg/l during spring runoff in 1989.

These results suggest that nitrogen levels in Richmond Lake tributaries are not unusually high considering the land use patterns in the watershed drainage.

By contrast, average total phosphorus values at sites 2 and 3 are more than twice those encountered even in streams whose watersheds are composed of more than 90% cropland - 0.36 and 0.34 mg/l vs. 0.16 mg/l, respectively. Concomitant total nitrogen levels in the latter watersheds averaged 5.35 mg/l (Omerick, 1977). The reasons for the disproportionate abundance of phosphorus in the Richmond Lake watershed are unknown, possibly local climatic and edaphic influences are involved.

Fecal Coliforms

To comply with the State of South Dakota criteria for surface waters used for immersion recreation, fecal coliforms (FC) should not be greater than 200/100 ml in any one in-lake sample from 1 May to 30 September. Standards for designated state swim beaches are more stringent. The South Dakota Department of Game, Fish and Parks must close a beach if the fecal coliform concentration exceeds 100 coliforms per 100 ml of lake water on two consecutive samplings.

Such high concentrations occurred in the lake during 1986 and required the closing of the Richmond Lake State Beach for most of the beach season. There was one other incidence of beach closure in May 1987 but in general fecal coliform levels were lower in 1987, 1988, and 1989 (Figure 4).

From April to August 1987 counts of fecal streptococci (FS) were made from monthly lake samples for comparison with fecal coliform numbers present in the same samples. The usable ratios of fecal coliform to fecal streptococci densities that resulted were all less than 0.7 indicating that the bacteria were of animal rather than human origin. Similar results were obtained with tributary samples from 1987. Researchers from Northern State College also examined the Richmond Lake FC/FS ratios and concluded that the primary source

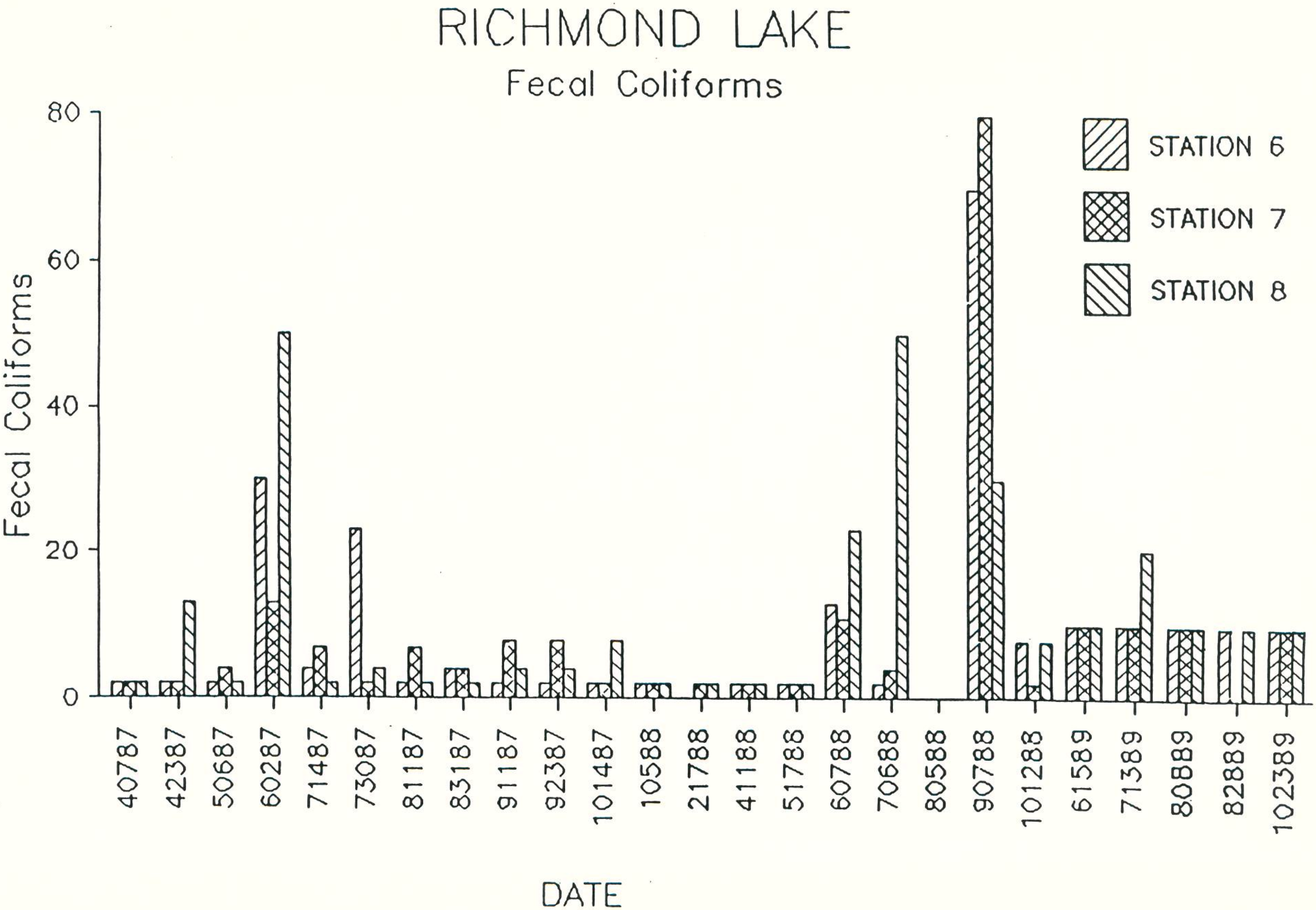

Figure 4: Fecal Coliform counts per 100 ml, Richmond Lake(1987-1989).

of in-lake bacteria was agricultural runoff from surrounding feedlots and pastures (Hodgson et al 1989). Therefore, the resulting health hazard is less than the hazard resulting from human sources.

Trends in Lake Water Quality

A limited amount of usable lake data from 1974 to 1989 was available for annual comparison. Caution must be exercised, therefore, in the interpretation of long term trends since there is often considerable seasonal and year-to-year variation in lake water quality parameters and earlier monitoring studies in Richmond Lake consisted of only two or three sampling dates in a year.

Secchi disk readings are probably one of the more reliable parameters listed in Table 4 for monitoring trends in lake eutrophication due to relative ease in their collection and interpretation.

Table 4. Richmond Lake selected water quality parameters from past monitoring studies and the present diagnostic/feasibility study (1987 - 1989).

Mean Parameters [1] for 3 in-lake sites	1974 (EPA) (Summer) [2]	1974 (EPA) (Annual) [3]	1979 (DWNR) (Summer)	1987 (DWNR) (Annual)	1987 (DWNR) (Summer)	1988 (DWNR) (Annual)	1988 (DWNR) (Summer)	1989 (DWNR) (Summer)
Secchi Disk (M)	1.8	2.3	1.6	0.6	0.6	0.6	0.4	0.5
Chlorophyll a (MG/M3)	24.2	18.4	15.3	17.3	15.0	7.2	1.3	-
Ortho-Phosphorus (OP)	0.16	0.13	0.18	0.10	0.10	0.04	0.03	0.04
Total Phosphorus (TP)	0.22	0.20	0.22	0.14	0.15	0.09	0.09	0.16
Nitrate and Nitrite-N	0.04	0.05	0.11	0.16	0.16	-	-	0.22
Kjeldahl-N (TKN)	2.06	1.78	1.44	1.46	1.28	1.08	1.02	1.22
Ammonia-N	0.12	0.10	-	0.14	0.17	0.06	0.08	0.28

[1] Concentrations in mg/l unless otherwise indicated
[2] Two sampling periods (June or July, August or September)
[3] Three sampling periods (summer and April)

Secchi disk visibilities recorded in 1974 and 1979 are considered good to satisfactory for shallow productive lakes. However, most Secchi transparency readings from 1987 to 1989 are classified in the poor category (Table 4).

As previously mentioned, this apparent decline in lake water clarity cannot be accounted for by increases in algal populations but could be due, in a large part, to fine suspended particles of silt and clay during open water periods. Supporting evidence for this conclusion is provided by data collected in 1988 which show small algal populations (low chlorophyll levels) combined with conditions of poor water transparency (Table 4).

The low algal densities in summer of 1988 were attributed to lack of runoff and drought conditions in the watershed which may have deprived the algae of one or more essential nutrients needed for growth other than phosphorus and nitrogen which are present in sufficient quantities. Water turbidity was thought not to be the primary limiting factor for some local algal populations since nuisance blue-green algae are known to be tolerant of the degree of water turbidity present in Richmond Lake.

Except for the decline in water clarity from 1974 to 1989 no other long term trends in Richmond Lake water quality are evident from an examination of the small amount of usable data available. Apparent trends in the other selected parameters (Table 4) probably reflect annual differences in snowmelt, rainfall and watershed runoff.

Watershed Studies

Watershed Nutrient Loading to Richmond Lake

Total phosphorus and nitrogen loading was estimated for Richmond Lake during the spring runoff period from 23 March to 27 April 1987. No other significant flows occurred during the rest of that year nor for the entire year of 1988 due to drought conditions. Attempts were made to calculate nutrient loads for 1989 but the hydrological (flow) data was insufficiently accurate to produce realistic loading results. The following is a table summary of net (accumulated) nutrient loads for Richmond Lake during 1987:

	Total Phosphorus (TP)		Total Nitrogen (TN)	
Richmond Lake	Total Inflow	Accumulated	Total Inflow	Accumulated
grams/m^2/yr.	0.70	0.25	1.18	0.62

Vollenweider (1968) phosphorus and nitrogen loadings based on Richmond Lake mean depth ($\leq$ 5 meters) and surface area (335.5 ha.):

'Dangerous' (eutrophic loading) for TP	0.13 g/m^2/yr.
'Permissible' (oligotrophic loading) for TP	0.07 g/m^2/yr.
'Dangerous' loading for TN	2.0 g/m^2/yr.
'Permissible' loading for TN	1.0 g/m^2/yr.

These results indicate nitrogen loading was not a problem in Richmond Lake whereas net phosphorus loads were well above the 'dangerous' level during 1987.

'Dangerous' loads are those which would cause the receiving lake to become eutrophic or remain eutrophic.

'Permissible' loads would cause the receiving lake to become less eutrophic, mesotrophic, or even oligotrophic if morphometry permitted.

To have attained 'Permissible' levels for total phosphorus loads under 1987 conditions, phosphorus input from Foot Creek and the north tributary (Site 2) would have had to be reduced by 90% or about 2.32 tons/yr.

<u>The Agricultural Non-Point Source Pollution Model (AGNPS)</u>

The Agricultural Non-Point Source Pollution Model (Young 1986) was executed to inventory recent conditions(1987-1988) on the Richmond Lake watershed and to simulate the effect on nutrient export of selected watershed areas after establishment of animal waste management by local feeding operations.

For the purpose of this computer simulation the watershed was divided into two parts as shown in Figure 5. The upper section of the watershed includes most of the Foot Creek drainage whereas the lower portion encompasses the drainages of three other major Richmond Lake tributaries. The limited capacity of the previously utilized AGNPS program (version 2.52 PC) required this division and the treatment of each section as a separate drainage. The water flow generated plus the nutrient/sediment output from the upper watershed were treated in the subsequent analysis as originating from a point source (Figure 5: point FC) impacting the lower watershed. In this way a reasonable approximation of the contribution of the entire drainage can be assessed for a simulated single rainstorm event.

Before an evaluation of results of this AGNPS exercise is attempted, a cautionary note must be injected here regarding the unconventional system of numbering watershed cells employed by the Richmond Lake Association. The AGNPS manual recommends that consecutive numbering of individual cells should begin at the northwest corner of a watershed and progress in single lines across the watershed west to east - north to south (Young et al 1986).

The Association followed a convention of numbering individual 40-acre cells by the quarter section as a convenient means of grouping land ownership. In this system the west-east, north-south convention is repeated at the level of cells (4) within each quarter section, the quarter sections within each section and finally the square mile sections comprising the watershed.

While the output of the AGNPS program using this numbering system did not contain obviously irregular or anomalous values, it is not certain at this point that the results obtained are correct in all respects.

Computer analysis indicated that agricultural runoff from the upper half of the watershed during a 5-year, 24-hour rainstorm event (total rainfall: 3.0 in.) can be expected to have little impact on Richmond Lake in terms of sediment and nutrients contributed. Sediment generated by computer simulation was 2981 tons total based on input storm characteristics that were chosen to reflect average annual erosion rates for the watershed as determined by SCS (Table 5).

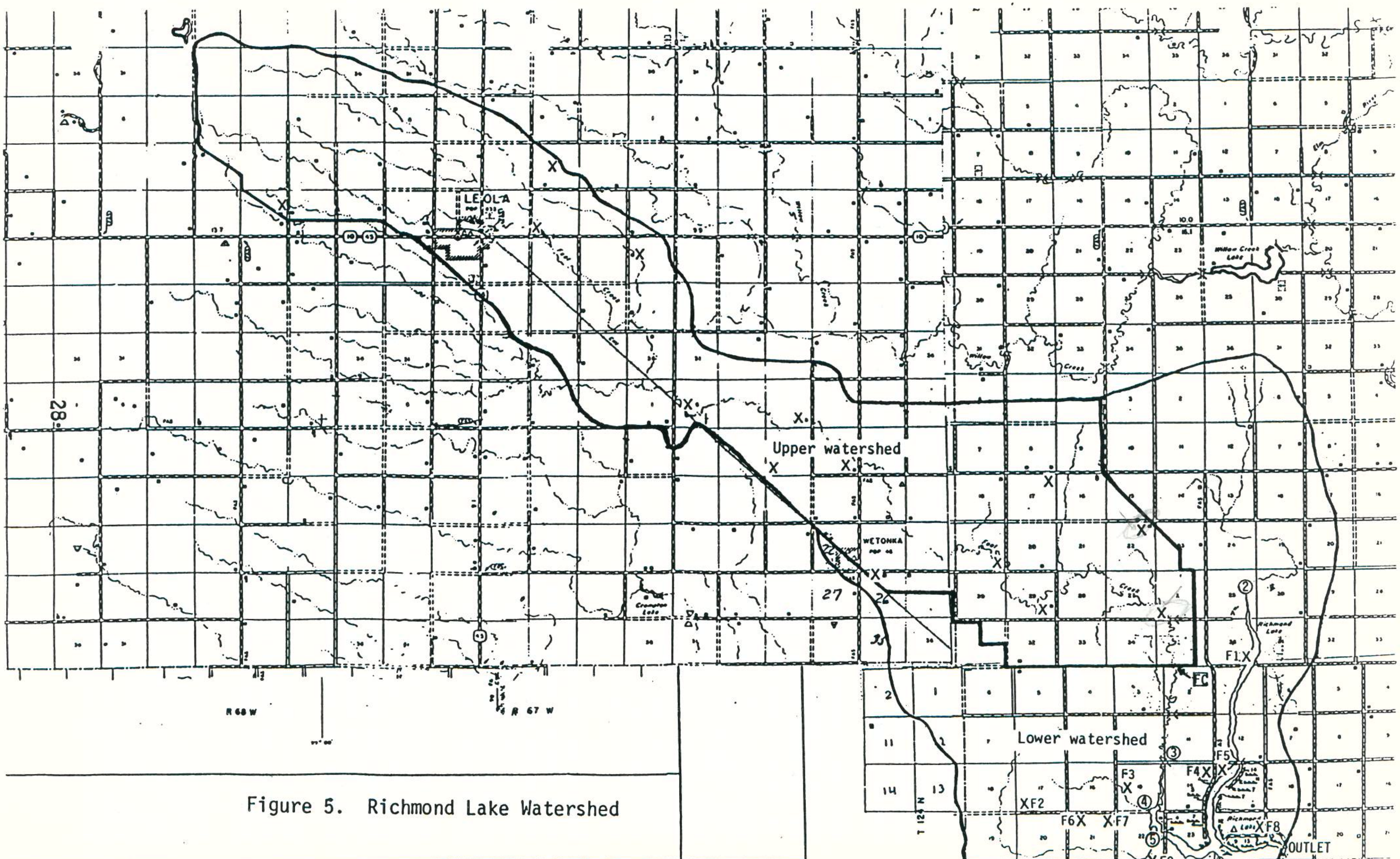

Figure 5. Richmond Lake Watershed

X = Feedlots
O = Tributary Inlets

Table 5. AGNPS output for the Richmond Lake Upper Watershed with feedlots deleted.

Watershed Summary

Watershed Studied	RICHMOND LAKE-UPPER WATERSHED
The area of the watershed is	49840 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	3.00 inches
The storm energy-intensity value is	75

Values at the Watershed Outlet

Cell number	1246 000
Runoff volume	0.9 inches
Peak runoff rate	4302 cfs
Total Nitrogen in sediment	0.38 lbs/acre
Total soluble Nitrogen in runoff	0.19 lbs/acre
Soluble Nitrogen concentration in runoff	0.99 ppm
Total Phosphorus in sediment	0.19 lbs/acre
Total soluble Phosphorus in runoff	0.01 lbs/acre
Soluble Phosphorus concentration in runoff	0.08 ppm
Total soluble chemical oxygen demand	13.51 lbs/acre
Soluble chemical oxygen demand concentration in runoff	69 ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.04	0.00	93	6	393.61	0.04	1921.8
SILT	0.02	0.00	29	2	73.44	0.01	358.5
SAGG	0.23	0.00	5	0	119.97	0.01	585.7
LAGG	0.10	0.02	1	0	17.62	0.00	86.0
SAND	0.01	0.01	4	0	5.93	0.00	28.9
TOTAL	0.41	0.01	14	1	610.56	0.06	2981.0

Probable reasons for this result are the relatively flat topography of this portion of the watershed, most of which appears to be reasonably well-managed grassland and pasture. In addition drainage over much of the watershed is poorly developed with many potholes, sloughs, and small farm ponds that trap runoff sediments (Monaghan 1970).

Nutrient output was correspondingly low due to the relatively small land area devoted to cropland in the upper watershed and the low frequency and level of fertilizer application. Nutrient yields were 1.0 ppm for soluble nitrogen and less than 0.1 ppm for soluble phosphorus in watershed runoff (Table 5).

The potential effect of local feedlots on subwatershed outflow was apparently negligible. When parameters for the 14 feedlots (Appendix D) in the area were added to the input data file the watershed output remained virtually the same as before (Table 6). Probably the primary reason for the absence of significant effect was the large buffer zones associated with most of the feedlots as determined by the distance from the edge of a particular feedlot to the nearest channelized waterway down gradient of the feeding area (DWNR 1988).

The same procedure carried out to detect any influence of the nine (9) feedlots on the lower watershed suggested that those feeding operations may be having an effect on Richmond Lake water quality. Tables 7 and 8 correspond to the output of the entire watershed (including Richmond Lake) at the lake spillway (Figure 5) prior to and after inclusion of 9 feedlots, respectively.

Because the model requires routing water flow through the length of the reservoir, sediment and nutrient values at the watershed outlet (spillway) are likely to be greatly diluted thus masking the full effect of the above feedlots on lake water quality. This accounts for the small differences observed between Tables 7 and 8.

The AGNPS model also contains a subroutine for analyzing feedlot runoff at the point of effluent channeling. The feedlot rating output permits a comparison of the potential impact of each feedlot on the watershed. Rating numbers range from 0 to 100 in order of severity.

Generally, feedlots with ratings of 40 or higher can be considered to have the most significant impact. Feedlots in the lower watershed produced ratings from 0 to 66 (Appendix D). By this criterion feedlots F1, F4, and F8 can be expected to have the most effect on lake water quality. Moreover, their close proximity to the lake shore enhances this impact. Lesser effects may be produced by feedlots F3, F5, and F9 due to smaller rating numbers and greater distance from the lake, except for F5 (Figure 5).

Nutrient inputs to Richmond Lake via its four major tributaries (Figure 5) are shown in Table 9. Relatively low dissolved nitrogen and zero phosphorus concentrations (ppm) are registered for all tributary inlets during a simulated 3.0 inch rainstorm. However, since nutrient values can be obtained only to the nearest unit (1 ppm) in this particular exercise, considerable phosphorus loads of 0.5 ppm or less would still appear in the output as 0 ppm. On the other hand, soluble nutrients reported as mass units (lb/acre) indicate that the Foot Creek basin (Inlet Number 003) which drains about 76 percent of the Richmond

Table 6. AGNPS output for the Richmond Lake Upper Watershed with feedlots included.

Watershed Summary

Watershed Studied	RICHMOND LAKE-UPPER WATERSHED
The area of the watershed is	49840 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	3.00 inches
The storm energy-intensity value is	75

Values at the Watershed Outlet

Cell number	1246 000
Runoff volume	0.9 inches
Peak runoff rate	4302 cfs
Total Nitrogen in sediment	0.38 lbs/acre
Total soluble Nitrogen in runoff	0.20 lbs/acre
Soluble Nitrogen concentration in runoff	1.03 ppm
Total Phosphorus in sediment	0.19 lbs/acre
Total soluble Phosphorus in runoff	0.02 lbs/acre
Soluble Phosphorus concentration in runoff	0.09 ppm
Total soluble chemical oxygen demand	13.58 lbs/acre
Soluble chemical oxygen demand concentration in runoff	69 ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.04	0.00	93	6	393.61	0.04	1921.8
SILT	0.02	0.00	29	2	73.44	0.01	358.5
SAGG	0.23	0.00	5	0	119.97	0.01	585.7
LAGG	0.10	0.02	1	0	17.62	0.00	86.0
SAND	0.01	0.01	4	0	5.93	0.00	28.9
TOTAL	0.41	0.01	14	1	610.56	0.06	2981.0

Table 7. AGNPS output for the entire Richmond Lake Watershed with lower watershed feedlots deleted.

Watershed Summary

Watershed Studied	RICHMOND LAKE-LOWER WATERSHED
The area of the watershed is	42000 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	3.00 inches
The storm energy-intensity value is	75

Values at the Watershed Outlet

Cell number	1004 000
Runoff volume	1.4 inches
Peak runoff rate	5104 cfs
Total Nitrogen in sediment	0.37 lbs/acre
Total soluble Nitrogen in runoff	0.32 lbs/acre
Soluble Nitrogen concentration in runoff	1.02 ppm
Total Phosphorus in sediment	0.19 lbs/acre
Total soluble Phosphorus in runoff	0.03 lbs/acre
Soluble Phosphorus concentration in runoff	0.08 ppm
Total soluble chemical oxygen demand	20.17 lbs/acre
Soluble chemical oxygen demand concentration in runoff	65 ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.10	0.01	54	10	370.56	0.06	2405.9
SILT	0.06	0.00	1	0	3.09	0.00	20.1
SAGG	0.56	0.04	0	0	0.62	0.00	4.0
LAGG	0.25	0.02	0	0	2.08	0.00	13.5
SAND	0.02	0.00	0	0	0.65	0.00	4.2
TOTAL	0.98	0.07	6	1	377.00	0.06	2447.7

Table 8. AGNPS ..tput for the entire Richmond Lake Watershed with all feedlots included.

Watershed Summary

Watershed Studied	RICHMOND LAKE-LOWER WATERSHED	
The area of the watershed is	42000	acres
The area of each cell is	40.00	acres
The characteristic storm precipitation is	3.00	inches
The storm energy-intensity value is	75	

Values at the Watershed Outlet

Cell number	1004	000
Runoff volume	1.4	inches
Peak runoff rate	5104	cfs
Total Nitrogen in sediment	0.38	lbs/acre
Total soluble Nitrogen in runoff	0.37	lbs/acre
Soluble Nitrogen concentration in runoff	1.20	ppm
Total Phosphorus in sediment	0.19	lbs/acre
Total soluble Phosphorus in runoff	0.04	lbs/acre
Soluble Phosphorus concentration in runoff	0.12	ppm
Total soluble chemical oxygen demand	20.80	lbs/acre
Soluble chemical oxygen demand concentration in runoff	67	ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.10	0.01	54	10	373.44	0.06	2424.6
SILT	0.06	0.00	1	0	3.09	0.00	20.1
SAGG	0.57	0.04	0	0	0.62	0.00	4.0
LAGG	0.25	0.02	0	0	2.08	0.00	13.5
SAND	0.02	0.00	0	0	0.65	0.00	4.2
TOTAL	1.00	0.07	6	1	379.88	0.06	2466.4

Lake watershed is the largest contributor of total nitrogen and phosphorus to the lake of the four tributaries considered. Table 9 also shows the substantial increases in soluble nutrient loads that result at each inlet when existing feedlots are added to their respective drainages in this computer simulation (F3 upstream of inlet 4 and F2, F6, F7, F9 upstream of inlet 5). It must be noted that increases in nutrients occurred only in the water soluble fractions. Moderately-sized feeding operations often contribute little sediment to runoff and therefore negligible levels of sediment-associated nutrients (Table 9).

Large increases in nutrient output resulted when this simulation exercise was repeated with lakeside feedlots F1, F4, F5, and F8 (Table 10). Due to the proximity of these feeding operations to the lakeshore most of the generated nutrients can be expected to enter Richmond Lake. Therefore, in any mitigation effort to reduce nutrient inputs to the lake, these particular feedlots should be given priority status for on-the-ground site evaluations by qualified SCS personnel.

Other possible major sources of nutrients recently investigated included an ongoing survey of on-site wastewater disposal facilities serving lakeshore residences, fertilizer use on lakeside lawns, and the general condition and present use of lake acreages. Field personnel noted heavy use of pastures bordering the upper east arm of Richmond Lake and cattle roaming freely in nearshore waters. It was concluded that nutrients and bacteria from lakeside pastures and cattle waste directly deposited into the lake could be significantly reduced in this area by restricting livestock access with a fencing of lakeshore land and providing alternative water sources.

Sediment analysis of the Richmond Lake watershed produced a total sediment load of 11,220 tons entering the lake from its four major tributaries during a 3-inch rainstorm event (Table 11). In so far as this simulation corresponds to annual erosion estimates in the watershed as previously noted, the generated loading of approximately 10 acre-feet of sediment would pose no immediate threat to present reservoir storage capacity which is estimated between 7,700 and 8,400 acre-feet. However, localized sedimentation problems could arise at three tributary inlets (Numbers 2, 3 and 5) in a relatively short time span. At these locations, shallow, marsh-like habitats would continue to develop and increase in area to the extent that the recreational potential of the upper reaches of Lake Richmond would be greatly diminished. This loss of volume may occur more than five times as rapidly in these upper reaches than loss of storage capacity in the main body of the lake below the confluence of the two reservoir arms (Monaghan 1970). The present cost of dredging 10 acre-feet of accumulated sediment at the tributary inlets is approximately $1.50/cu.yd. or at least $24,200.

Another detriment to lake water quality in the short-term would result from sediment-associated nutrients, particularly phosphorus, carried in with the soil particles (Table 9). Moreover, lake water clarity may be reduced by sediments derived from fine-textured, clay-based watershed soils which tend to remain suspended in the water column of the lake.

Table 9. Nutrient mass and concentration at Richmond Lake major tributary inlets.

Nutrient Analysis — NITROGEN

Cell Num	Inlet Num	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
306	002	10560	11.35	1.25	0.13	0.25	1
733	003	52360	15.51	4.63	0.13	0.63	1
844	004	1240	22.03	2.90	0.13	0.27	1
844	004 F3*	1240	22.03	2.90	0.13	0.53	2
962	005	17160	17.86	1.16	0.13	0.26	1
962	005 FT*	17160	17.86	1.16	0.13	0.31	1

*FT = feedlots F2,F6,F7,F9 (Figure 5)

*F3 = feedlot F3

Nutrient Analysis — PHOSPHORUS

Cell Num	Inlet Num	Drainage Area (acres)	Sediment Within Cell (lbs/a)	Sediment Cell Outlet (lbs/a)	Water Soluble Within Cell (lbs/a)	Water Soluble Cell Outlet (lbs/a)	Conc (ppm)
306	002	10560	5.68	0.63	0.01	0.02	0
733	003	52360	7.76	2.31	0.01	0.05	0
844	004	1240	11.02	1.45	0.01	0.02	0
844	004 F3	1240	11.02	1.45	0.01	0.06	0
962	005	17160	8.93	0.58	0.01	0.01	0
962	005 FT	17160	8.93	0.58	0.01	0.02	0

Table 10. Nutrient output of lakeside watershed cells with and without existing feedlots.

Nutrient Analysis — NITROGEN

Cell Num	Feedl Num	Drainage Area (acres)	Sediment: Within Cell (lbs/a)	Sediment: Cell Outlet (lbs/a)	Water Soluble: Within Cell (lbs/a)	Water Soluble: Cell Outlet (lbs/a)	Water Soluble: Conc (ppm)
430	000	160	16.00	4.20	0.13	0.24	1
430	000 F1*	160	16.00	4.20	17.47	4.58	17
853	000	80	16.12	6.94	0.13	0.18	1
853	000 F4	80	16.12	6.94	6.14	3.19	15
862	000	40	22.03	16.91	0.13	0.13	1
862	000 F5	40	22.03	16.91	1.54	1.54	10
995	000	80	1.83	2.06	0.13	0.52	3
995	000 F8	80	1.83	2.06	2.69	1.80	9

*F1-8 = feedlots(Figure 5)

Nutrient Analysis — PHOSPHORUS

Cell Num	Feedl Num	Drainage Area (acres)	Sediment: Within Cell (lbs/a)	Sediment: Cell Outlet (lbs/a)	Water Soluble: Within Cell (lbs/a)	Water Soluble: Cell Outlet (lbs/a)	Water Soluble: Conc (ppm)
430	000	160	8.00	2.10	0.01	0.01	0
430	000 F1	160	8.00	2.10	3.21	0.81	3
853	000	80	8.06	3.47	0.01	0.01	0
853	000 F4	80	8.06	3.47	1.64	0.83	4
862	000	40	11.02	8.45	0.01	0.01	0
862	000 F5	40	11.02	8.45	0.38	0.38	3
995	000	80	0.91	1.03	0.01	0.08	0
995	000 F8	80	0.91	1.03	0.59	0.38	2

Table 11. Sediment loads entering Richmond Lake from four major tributaries during a simulated 3-inch rainstorm event in the watershed.

Condensed Soil Loss

			RUNOFF				SEDIMENT			
Cell Num	Inlet Num	Drainage Area (acres)	Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	Generated Above (tons)	Generated Within (tons)	Yield (tons)	Depo (%)
306	002	10560	0.67	99.8	3807	4.15	2748.46	165.88	2782.57	5
733	003	52360	0.67	99.6	3127	6.13	3352.03	245.05	3403.15	5
844	004	1240	0.67	98.4	882	9.50	702.46	379.95	932.97	14
962	005	17160	0.67	99.9	4995	7.31	3978.26	292.27	4101.45	4

The AGNPS program identified 54 cells (2,160 acres) in the lower half of the watershed that may be experiencing higher than average soil losses of 5 to 22 tons per acre (Appendix D). Those cells with losses of 10 or more tons per acre should be given priority for a visual examination to confirm the existence of erosion problems. If these are clearly evident, arrangements should be made, if feasible, for the establishment of appropriate BMP's such as conservation tillage practices or planting of permanent vegetative cover.

Owing to the extensive shoreline of Richmond Lake relative to water surface area (Figure 1), substantial sedimentation may also accrue from runoff channeled by numerous smaller drainage pathways around the lake periphery, and shoreline erosion due to wave action produced by strong prevailing winds.

Visual inspection of the entire shoreline should be conducted to locate areas experiencing excessive erosion as a result of wind and wave action or runoff over lakeside land that has been denuded of vegetative cover by overgrazing and other causes. Efforts should be made to stabilize such areas with appropriate remedial measures such as rip-rapping, exclusion of livestock, and replanting with grass and trees.

Conclusions

1. Seasonal distribution of chlorophyll abundance (biomass) in 1987 was similar to that found in other eutrophic lakes in the region. Annual mean chlorophyll concentration (11 sampling dates) was 17.4 mg/m^3.

2. In 1988, summer and autumn chlorophyll concentrations fell to very low values (mean: 1.10 mg/m^3). This was ascribed to drought conditions and resultant lack of runoff and secondarily to in-lake water turbidity.

3. There was wide variation in chlorophyll values between in-lake sites as a probable result of the irregular lake morphology and the effect of prevailing winds.

4. Total Kjeldahl Nitrogen (TKN) for in-lake sites generally ranged below 2.00 mg/l during this study suggesting moderate nitrogen enrichment. Tributary TKN levels in 1987 and 1989 were similar to those from the lake sites. Very little tributary data was collected in 1988 due to absence of significant runoff events.

5. Mean total nitrogen concentration in Foot Creek (draining 76% of the watershed) during spring 1989 was only slightly higher than the average for streams whose watersheds are comprised of 75% rangeland.

6. Mean total phosphorus concentration in Foot Creek was more than twice as high as the average for streams with watersheds of 90% cropland.

7. Total phosphorus concentration at in-lake sites was often excessive. Total nitrogen was usually present at more moderate levels.

8. Richmond Lake is frequently nitrogen-limited while phosphorus is usually present in overabundance.

9. The lake is experiencing excessive phosphorus loading and relatively moderate nitrogen loading from its tributaries during periods of snowmelt runoff.

10. In-lake fecal coliform numbers were relatively low from 1987 to 1989 ($<$100/100 ml) and in compliance with state criteria for surface waters used for immersion recreation.

11. Fecal coliform/fecal streptococcus ratios calculated for tributary and lake samples indicated the bacteria were of animal rather than human origin (FC/FS = <0.7). (Human waste contamination is indicated by FC/FS = ≥ 4.0).

12. The primary source of in-lake fecal coliform bacteria at the time of sampling was probably agricultural runoff from surrounding feedlots and pastures.

13. There has apparently been a more than 50% decline in lake water clarity (Secchi disk transparency) from 1979 to 1987. Water turbidity was ascribed to a large extent to suspended fine particles of silt and clay.

14. There appears to have been a decrease in in-lake TKN concentration since 1987. It is not known if this represents a long-term trend.

15. Insufficient usable data was available to reliably chart trends in most other water quality parameters.

16. Results of AGNPS computer modeling indicated that four lakeside feeding operations and one feedlot on a west creek drainage (upstream of inlet 4) were potentially capable of having a significant impact on lake water quality and should be prioritized for mitigation measures.

17. The AGNPS program identified 54, 40-acre cells (2,160 acres), in the lower watershed that may be experiencing higher than average soil loss of 5 to 22 tons per acre. Soil loss for 18 watershed cells (720 acres) exceeded 10 tons per acre. The latter acreages should be prioritized for a ground survey to confirm any severe erosion problems and BMP's established if needed.

Recommendations

Based on the results of this study, the DWNR recommends the following alternatives for restoration. These recommendations should provide a basis for the development of a complete restoration work plan and subsequent implementation. The recommendations listed below are provided for review only. They are not to be considered as the only possible methods of restoration.

1. The AGNPS model indicated that four lakeside feeding operations and one feedlot (F3) on a west creek tributary (Figure 5) may be providing excessive nutrient loads to Richmond Lake.

Feetlot No.	Cell No.	Geographical Location	Owner(s)
F1	430	SE4,SE4,SEC 36,T125N,R65W	Calvin Nelson
F3	838	NW4,SW4,SEC 15,T124N,R65W	Merlyn Esker
F4	853	SE4,NE4,SEC 14,T124N,R65W	Steve Gaver Jr.
F5	862	NW4,NW4,SEC 13,T124N,R65W	William Kirchgesler
F8	995	NE4,SE4,SEC 24,T124N,R65W	Ingerson Inc.

As a next step toward reduction of nutrient inputs to Richmond Lake it is recommended that the above sites be given priority for on-the-ground evaluations. If nutrient export problems are confirmed, plans should be drawn up for the establishment of appropriate animal waste management systems.

2. Field investigations noted heavy use of lakeside pastures bordering the upper east arm of Richmond Lake and the presence of cattle in near shore waters. Recommendations include restriction of livestock access to the lake by fencing of overgrazed lakeshore land and providing alternative water sources.

3. An extensive shoreline and strong prevailing winds create conditions for significant lakeshore erosion by wind and wave action. Field surveys indicated several stretches of shoreline totalling about 700 to 1,000 feet of high banks on the south side of Richmond Lake may be subject to sloughing and extensive erosion particularly during high water levels. Shoreline stability can be improved by grading, rip-rapping and planting of grass and trees.

4. AGNPS sediment analysis has identified 54 cells in the lower Richmond Lake watershed that may be experiencing higher than average soil loss. Soil losses of 18 cells listed below (720 acres) exceeded 10 tons per acre. Those acreages should be prioritized for a SCS ground survey to confirm any severe erosion problems which may be responsible for contributing sediment and attached nutrients to Richmond Lake. Severe erosion can be corrected with conservation tillage practices or planting of permanent vegetative cover. The following potential problem cells lie adjacent to lower Foot Creek (Inlet No. 3); from 1/2 to 2 miles upstream of Inlet No. 5 (Figure 5); and near the south and east shorelines of Richmond Lake.

Cell No.	Cell Location	Cell Erosion(Tons/acre)
712	NE4,NE4,SEC 10,T124N,R65W	10.26
714	SE4,NE4,SEC 10,T124N,R65W	10.26
720	NE4,SE4,SEC 10,T124N,R65W	10.26
721	SW4,SE4,SEC 10,T124N,R65W	10.26
723	NW4,SE4,SEC 11,T124N,R65W	10.26
731	NW4,SW4,SEC 11,T124N,R65W	10.26
848	SW4,NW4,SEC 14,T124N,R65W	15.62
866	NW4,NE4,SEC 13,T124N,R65W	22.51
872	SW4,SW4,SEC 13,T124N,R65W	14.23
942	NW4,SW4,SEC 21,T124N,R65W	19.00
943	NE4,SW4,SEC 21,T124N,R65W	19.00
960	SW4,SW4,SEC 22,T124N,R65W	14.61
961	SE4,SW4,SEC 22,T124N,R65W	14.61
964	SW4,SE4,SEC 22,T124N,R65W	14.61
969	SE4,NW4,SEC 23,T124N,R65W	17.74
1038	NW4,NE4,SEC 26,T124N,R65W	10.07
1046	NW4,NE4,SEC 25,T124N,R65W	10.07
1047	NE4,NE4,SEC 25,T124N,R65W	10.07

5. Of secondary concern is the possibility that undetected septic system malfunctions around the lake periphery may be contributing nutrients and bacteria to the lake. An ongoing survey may be able to locate problem sources. Methods for rehabilitating improperly functioning on-site systems will then be recommended to the owners in question.

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APPENDIX A

RICHMOND LAKE WATER QUALITY DATA 1987
ALL CONCENTRATIONS IN MG/L, DEPTH IN INCHES, TEMP. IN C

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
1	23-Mar-87	1600	GRAB		3.0	4.0	1.25		19.21		2	8.24	122	4		4	0.30		0.50	1.300	0.460	
1	26-Mar-87	1000	GRAB	6.0	3.0	3.4	1.75		19.60	8.14		8.33	128	3		6	0.20		1.12	0.700	0.440	
1	30-Mar-87	1500	GRAB	3.0	2.5	4.0	1.25		17.70	8.69	2	8.35	134	8		7	0.80		1.00	0.140	0.100	
1	02-Apr-87	915	GRAB	6.0	2.5	5.5	2.00		20.00	8.72	2	8.10	138	2		2	1.00		1.12	0.180	0.060	
1	06-Apr-87	1430	GRAB	6.0	7.0	23.0			9.20	8.87	2	8.45	155	6		6	1.00		1.12	0.200	0.200	
1	09-Apr-87	930	GRAB	6.0	8.3	8.0	1.20		14.40	8.91	2	8.55	162	0		12	0.10		1.40	0.200	0.200	
1	13-Apr-87	1500	GRAB	6.0	8.0	10.0	1.00		12.20	8.79	2	8.33	178	18		18	0.30		1.12	0.300	0.300	
1	16-Apr-87	945	GRAB	4.0	12.0	20.0	0.70		13.20	9.05	2	8.55	174	12		10	0.00		1.43	0.200	0.200	
1	21-Apr-87	1500	GRAB	4.0	13.0	14.0	0.49		11.00	8.90	2	8.34	168	7		5	0.10		1.43	0.000	0.240	
1	23-Apr-87	1400	GRAB	4.0	14.0	19.0			9.60	8.88	2	8.40	174	6		5	0.10		2.02	0.200	0.160	
1	27-Apr-87	1430	GRAB	4.0	16.0	22.0			9.70	8.80	11	8.36	146	19		14	0.00	0.20	1.09	0.000	0.000	
2	19-Mar-87	1100	GRAB	6.0	1.2	5.0	1.50		14.50		70	6.65	56	7		5	3.00		0.00	1.500	0.600	
2	23-Mar-87	1500	GRAB	6.0	4.2	4.7			15.87		8	6.84	32	10		9	2.00		1.96	1.300	0.500	
2	26-Mar-87	1030	GRAB	0.0	2.5	3.4	0.55		17.15	7.72	17	7.13	62	7		5	1.50		1.68	0.880	0.520	
3	16-Mar-87	1430	GRAB	6.0	4.0	0.0			14.60		4	7.28	108	4		4	2.50		0.00	0.960	0.340	
3	19-Mar-87	1030	GRAB	6.0	0.9	5.0	1.07		14.70		500	7.21	96	10		4	2.00		0.00	0.840	0.300	
3	23-Mar-87	1500	GRAB	0.0	4.3	4.5	2.80		16.17		110	7.25	80	7		6	1.50		2.02	1.600	0.660	
3	26-Mar-87	1000	GRAB	6.0	2.0	3.4	1.35		16.86	7.68	4	7.31	66	8		6	1.00		1.42	1.100	0.600	
3	30-Mar-87	1500	GRAB	6.0	3.5	4.0	1.13		14.50	7.57	2	7.33	84	7		5	0.60	0.03	0.76	0.020	0.120	
3	02-Apr-87	930	GRAB	6.0	5.0	1.2	1.24		14.20	7.58	4	7.18	88	9		6	1.50		1.63	0.240	0.080	
3	06-Apr-87	1430	GRAB	0.0	7.0	23.0			7.90	7.94	2	7.54	119	9		8	0.10		1.43	0.000	0.300	
3	09-Apr-87	930	GRAB	4.0	7.2	10.0	2.00		4.70	7.42	23	7.28	136	0		10	0.10		1.46	0.400	0.300	
3	13-Apr-87	1500	GRAB	3.0	10.0	9.0	1.50		7.40	7.58	2	7.44	148	0		0	0.10		0.98	0.300	0.240	
3	16-Apr-87	945	GRAB	3.0	12.0	18.0	1.80		9.40	7.51	2	7.44	174	24		18	0.20		1.18	0.300	0.300	
3	21-Apr-87	1500	GRAB	3.0	13.0	14.0	1.00		7.30	7.75	8	7.52	126	9		9	0.10		1.04	0.000	0.180	
3	23-Apr-87	1400	GRAB	3.0	15.0	19.0			7.90	7.66	4	7.42	116	8		7	0.10		1.18	0.000	0.180	
3	27-Apr-87	1430	GRAB	1.0	19.0	21.0			6.20	7.57	2	7.42	244	6		5	0.20		1.23	0.000	0.000	
4	19-Mar-87	1200	GRAB	3.0	1.7	4.0	0.95		17.05		50	6.56	48	5		4	2.50		0.00	0.900	0.380	
5	19-Mar-87	1200	GRAB	4.0	1.0	4.0	1.56		16.07		300	6.84	66	7		7	2.50		0.00	0.700	0.280	
6	07-Apr-87	1400	TOP	6.0	6.5	17.0		37.0	14.40	8.72	2	7.75	126	8		7	0.20		1.40	0.000	0.000	103.86
6	23-Apr-87	1100	TOP	6.0	13.0	10.5		34.0	8.60	8.79	2	8.09	162	5		5	0.10		1.20	0.000	0.160	26.41
6	06-May-87	1000	TOP	6.0	16.0	17.2		47.0	7.50	8.28	2	7.78	164	22		16	0.10		1.09	0.300	0.280	2.31
6	02-Jun-87	1115	TOP	6.0	18.0	16.7		18.0	8.00	8.04	30	7.60	140	28		24	0.20		0.28	0.200	0.160	4.17
6	14-Jul-87	1130	TOP	6.0	22.5	18.7		22.0	11.20	8.97	4	9.03	178	11		10	0.30	0.20	1.29	0.200	0.140	18.92
6	30-Jul-87	1045	TOP	6.0	28.5	29.0		40.0	10.10	9.20	23	9.30	190	9		8	0.25	0.20	1.37	0.200	0.120	8.36
6	11-Aug-87	1130	TOP	6.0	24.5	26.0			12.00	8.78	2	8.81	170	27		24	0.65	0.20	1.37	0.200	0.120	4.93
6	31-Aug-87	1200	TOP	6.0	18.5	18.5		23.0	6.75	8.89	4	8.81	196	570		12	0.10	0.00	1.40	0.500	0.270	3.19

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
6	11-Sep-87	930	TOP	6.0	16.0	12.5		24.0	8.80	8.54	2	8.70	198	700		16	0.10	0.17	1.12	0.960	0.270	6.18
6	23-Sep-87	1145	TOP	6.0	17.0	21.0		38.0	8.00	8.57	2	8.70	192	640		8	0.26	0.40	1.12		0.160	5.80
6	14-Oct-87	1315	TOP	6.0	9.5	10.0		50.0	9.10	8.50	2	8.63	196	300		2	0.10		1.26	0.18	0.240	6.39
6	07-Apr-87	1400	BOTM	288.0	4.5	0.0		37.0	11.20	8.72		7.99	140	20		16	0.20		2.71	0.200	0.100	
6	23-Apr-87	1100	BOTM	276.0	12.0	10.5		34.0	9.40	8.79		8.08	162	12		11	0.10		0.90	0.200	0.200	
6	06-May-87	1000	BOTM	276.0	14.8	17.2		47.0	5.40	8.28				0		0	0.00		2.35	0.000	0.000	
6	02-Jun-87	1115	BOTM	282.0	18.0	16.7		18.0	7.60	8.04		7.76	142	24		22	0.20		0.22	0.300	0.200	
6	14-Jul-87	1130	BOTM	264.0	22.0	18.7		22.0	7.20	8.97		8.99	176	20		17	0.27	0.20	1.04	0.200	0.160	
6	30-Jul-87	1045	BOTM		23.5	29.0			0.90					492		418	0.28	0.20	4.76	0.200	0.160	
6	11-Aug-87	1130	BOTM	276.0	24.5	26.0			10.00			8.81	170	29		25	1.59	0.20	10.11	0.200	0.200	
6	31-Aug-87	1200	BOTM	279.0	18.5	18.5			5.20			8.74	204	825		155	0.10	0.00	1.34	0.660	0.280	
6	11-Sep-87	930	BOTM	270.0	17.5	12.5			6.30			8.70	190	640		28	0.10	0.33	1.12	0.700	0.430	
6	23-Sep-87	1145	BOTM	282.0	17.5	21.0			5.20			8.60	180	860		16	0.10	0.40	0.98		0.160	
6	14-Oct-87	1315	BOTM	246.0	9.5	10.0		50.0	7.80			8.52	200	900		43	0.10		1.12	0.140	0.240	
7	07-Apr-87	1315	TOP	6.0	7.5	17.0		28.0	14.80	8.89	2	8.08	145	10		10	0.00		2.24	0.200	0.200	83.79
7	23-Apr-87	1000	TOP	6.0	12.9	10.5		23.0	8.00	8.55	2	7.83	158	10		10	0.10		2.86	0.300	0.240	11.30
7	06-May-87	900	TOP	6.0	17.0	11.0		24.0	7.40	8.29	4	7.87	160	18		12	0.10		1.15	0.300	0.240	4.03
7	02-Jun-87	1030	TOP	6.0	19.0	16.7		16.0	8.00	8.12	13	7.74	142	18		15	0.20		0.10	0.200	0.140	4.94
7	14-Jul-87	1100	TOP	6.0	21.5	18.5		20.0	10.20	8.89	7	8.94	172	32		30	0.15	0.20	1.29	0.200	0.120	12.73
7	30-Jul-87	1015	TOP	6.0	28.2	31.5		40.0	7.80	9.05	2	9.11	178	22		20	0.11	0.20	1.35	0.200	0.080	5.45
7	11-Aug-87	1030	TOP	6.0	24.0	23.0		14.0	13.00	8.76	7	8.80	170	29		22	0.01	0.10	2.21	0.200	0.160	14.59
7	31-Aug-87	1130	TOP	6.0	18.5	18.5		13.0	6.80	8.72	4	8.73	196	590		17	0.10	0.00	1.12	0.620	0.270	5.56
7	11-Sep-87	900	TOP	6.0	16.5	11.0		18.0	7.40	8.67	8	8.50	210	720		10	0.10	0.13	0.84	0.960	0.430	3.44
7	23-Sep-87	1130	TOP	6.0	16.5	17.5		30.0	8.00	8.37	8	8.70	180	590		11	0.10	0.40	0.84		0.160	7.49
7	14-Oct-87	1245	TOP	6.0	9.0	10.0		38.0	9.30	8.52	2	8.67	208	340		3	0.10	0.17	1.12	0.140	0.120	3.28
7	07-Apr-87	1315	BOTM	152.0	6.0	17.0		28.0	15.40	8.89		8.18	154	14		13	0.20		7.28	0.400	0.400	
7	23-Apr-87	1000	BOTM	132.0	12.9	10.5		23.0	8.00	8.55		7.83	154	20		16	0.10		3.70	0.280	0.240	
7	06-May-87	900	BOTM	132.0	16.5	11.0		24.0	5.80	8.29		7.76	152	24		20	0.00		1.93	0.280	0.000	
7	02-Jun-87	1030	BOTM	137.0	19.0	16.7		16.0	8.00	8.12		7.74	144	26		22	0.20		0.00	0.200	0.100	
7	14-Jul-87	1100	BOTM	120.0	21.5	18.5		20.0	6.20	8.89		8.95	172	52		47	0.17	0.20	1.09	0.200	0.180	
7	30-Jul-87	1015	BOTM	135.0	26.5	31.5			1.20			9.12	178	111		95	0.11	0.20	1.26	0.200	0.200	
7	11-Aug-87	1030	BOTM	156.0	24.0			14.0	12.00					31		20	0.25	0.20	1.37	0.200	0.100	
7	31-Aug-87	1130	BOTM	144.0	18.5	18.5			5.90			8.55	138	675		70	0.10	0.00	1.12	0.280	0.270	
7	11-Sep-87	900	BOTM	78.0	17.5	11.0			7.50			8.50	174	710		12	0.10	0.12	1.34	0.640	0.200	
7	23-Sep-87	1130	BOTM	138.0	16.0	17.5		30.0	7.50			8.60	200	1110		343	0.10	0.40	2.10		0.160	
7	14-Oct-87	1245	BOTM	114.0	8.5	10.0		38.0	8.20			8.65	208	500		10	0.10	0.17	1.12	0.100	0.120	
8	07-Apr-87	1230	TOP		8.5	17.0		22.0	17.00	8.77	2	8.21	166	16		15	0.30		1.46	0.200	0.200	19.47
8	23-Apr-87	900	TOP	6.0	12.0	10.5		14.0	8.80	8.68	13	7.66	152	24		22	0.10		1.09	0.300	0.240	27.84
8	06-May-87	800	TOP	6.0	15.0	11.0		13.0	5.20	8.15	2	8.00	142	26		20	0.10		1.60	0.280	0.240	7.11
8	02-Jun-87	930	TOP	6.0	18.0	14.0		12.0	7.60	7.84	50	7.50	160	20		16	0.20		0.59	0.000	0.000	8.74
8	14-Jul-87	1015	TOP	6.0	22.0	18.9		15.0		9.02	2	9.11	182	20		16	0.19	0.20	1.19	0.200	0.140	25.07
8	30-Jul-87	945	TOP	6.0	28.0	29.0		23.0	7.30	9.19	4	9.30	180	23		22	0.02	0.20	1.84	0.300	0.160	27.74

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
8	11-Aug-87	945	TOP	6.0	24.0	27.5		13.0	15.50	9.05	2	9.12	178	23		21	0.01	0.10	2.13	0.200	0.100	69.34
8	31-Aug-87	1100	TOP	6.0	17.5	17.5		15.0	7.50	8.85	2	8.81	190	610		60	0.10	0.00	1.12	0.400	0.270	7.80
8	11-Sep-87	915	TOP	6.0	16.0	12.5		18.0	8.30	8.46	4	8.60	192	730		24	0.10	0.13	1.18	1.000	0.600	5.80
8	23-Sep-87	1100	TOP	6.0	16.0	17.5		24.0	8.00	8.60	4	8.90	200	680		25	0.10	0.40	1.26		0.160	20.13
8	14-Oct-87	1230	TOP	6.0	8.5	10.0		19.0	9.60	8.56	8	8.78	214	450		9	0.10	0.17	1.12	0.100	0.140	8.93
8	06-Apr-87	1330	BOTM	105.0	7.0	17.0		22.0	17.00	8.77		8.37	168	14		12	0.20		1.12	0.000	0.000	
8	23-Apr-87	900	BOTM	84.0	12.0	10.5		14.0	8.60	8.68		4.47	150	16		14	0.10		1.09	0.240	0.200	
8	06-May-87	800	BOTM	90.0	15.0	11.0		13.0	5.20	8.15		7.82	160	28		24	0.10		1.32	0.240	0.000	
8	02-Jun-87	930	BOTM	106.0	18.0	14.0		12.0	7.50	7.84		7.59	128	24		20	0.20		0.14	0.200	0.120	
8	14-Jul-87	1015	BOTM	78.0	21.0	18.9		15.0	7.80	9.02		9.11	180	31		25	0.18	0.20	1.59	0.200	0.120	
8	30-Jul-87	945	BOTM	84.0	27.0			23.0	6.20			9.25	180	227		204	0.91	0.20	2.94	0.200	0.160	
8	11-Aug-87	945	BOTM	78.0	24.0			13.0	12.00			9.14	178	29		24	0.01	0.20	2.69	0.200	0.160	
8	31-Aug-87	1100	BOTM	84.0	18.0	17.5			6.10	8.85		8.74	192	600		115	0.12	0.00	1.43	0.000	0.200	
8	11-Sep-87	915	BOTM	120.0	17.0	12.5			6.80			8.60	196	690		44	0.10	0.13	1.18	0.880	0.530	
8	23-Sep-87	1100	BOTM	66.0	16.0	17.5		24.0	8.00	8.60		8.90	200	840		51	0.10	0.40	1.68		0.160	
8	14-Oct-87	1230	BOTM	54.0	8.5	10.0		19.0	9.00			8.79	214	650		14	0.10	0.17	1.12	0.180	0.140	

RICHMOND LAKE WATER QUALITY DATA 1988
ALL CONCENTRATIONS IN MG/L, DEPTH IN INCHES, TEMP. IN C

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
3	11-Aug-88				17.5	30.0	1.24		4.70	6.80		6.70	28	468		82	0.32	13.20		0.680	0.600	
4	11-Aug-88				19.5	30.0	1.25		4.50	5.45		6.30	20	146		20	0.15	13.20		0.280	0.180	
5	11-Aug-88				22.0	30.0	2.24		4.20	6.98		6.80	60	484		98	0.06	19.60		0.34	0.260	
6	05-Jan-88	1330	TOP	6.0	1.0	6.4		132.0	8.2	7.95	2	8.20	196	250	248	2	0.10	4.40	1.12	0.160	0.120	6.46
6	17-Feb-88	1145	TOP	6.0	2.0	1.7		192.0		8.00	2	7.76	190	736	732	4	0.10	3.20	1.26	0.16	0.12	1.63
6	11-Apr-88	1300	TOP	6.0	12.0			42.0	9.00	8.00	2	8.38	114	708	697	11	0.01	4.40	1.40	1.000	0.020	16.38
6	17-May-88	1010	TOP	6.0	14.5	16.1		15.0	7.30	8.00	2	8.30		742	725	17	0.47	4.41		0.100	0.020	5.74
6	07-Jun-88	930	TOP	6.0	23.0	23.0		60.0	6.50	8.40	13	8.25	221	690	688	2	0.01	4.40	0.87	0.020	0.020	4.38
6	06-Jul-88	1000	TOP	6.0	24.0	32.2		26.0	6.25	8.45	2	8.30	216	680	669	11	0.25	4.40	0.84			0.75
6	05-Aug-88	1100	TOP	6.0	22.0	29.4		24.0	7.60	8.44	300	8.98	228	800	776	24	0.08	4.40	0.03			2.81
6	07-Sep-88	940	TOP	6.0	18.0			24.0	9.50	8.10	70	8.37	166	778	771	7	0.10			0.120	0.040	0.37
6	12-Oct-88	1030	TOP	6.0	9.5			20.0	7.75	8.55	8	8.26	192	836	831	5	0.49		0.84	0.047	0.027	0.16
6	05-Jan-88	1330	BOTT	246.0	1.0	6.4		132.0	10.00			8.31	207	850	810	40	0.10	4.40	0.34	0.060	0.140	
6	17-Feb-88	1145	BOTT	252.0	2.0	1.7		192.0	5.00	8.00		7.68	201	702	698	4	0.10		1.54	0.100	0.140	
6	11-Apr-88	1300	BOTT	222.0		12.0		42.0	3.50			8.20	112	815	675	140	0.01	8.80	0.98	3.000	0.100	
6	17-May-88	1010	BOTT	258.0	14.0	16.1		180.0	5.00			8.40	224	754	732	22	0.04	4.40	0.14	0.100	0.040	
6	07-Jun-88	930	BOTT		23.0	23.0			1.00			8.25	220	730	708	22	0.00	4.40	0.98	0.020	0.020	
6	06-Jul-88	1000	BOTT	186.0	23.0	32.2		26.0	1.50			8.30	216	686	679	7	0.01	4.40				
6	05-Aug-88	1100	BOTT	240.0	21.5	29.4		24.0	2.50			8.56	220	1,036	282	754	0.26	4.40	1.54	1.000	0.110	
6	07-Sep-88	940	BOTT							8.10		8.41	194	838	822	16	0.07	0.90	1.06	0.160	0.060	
6	12-Oct-88	1030	BOTT	186.0	9.0				7.00			8.37	202	796	790	6	0.45		1.26	0.030	0.020	

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
7	05-Jan-88	1230	TOP	6.0	2.3	-27.2		120.0	12.20	8.18	2	8.16	200	950	905	45	0.10	8.80	0.90	0.200	0.100	1.35
7	17-Feb-88	1100	TOP	6.0	1.5	1.7		16.0		8.70	2	8.68	200	734	714	20	0.10		1.68			98.29
7	11-Apr-88	1330	TOP	6.0	11.5	10.0		30.0	9.00	8.15	2	8.24	106	739	710	29	0.01	8.80	1.12	3.000	0.000	26.46
7	17-May-88	940	TOP	6.0	16.0			16.0	8.30	8.25	2	8.50	222	754	718	36	0.40	4.40		0.040	0.080	17.39
7	07-Jun-88	900	TOP	6.0	23.0	22.0		18.0	7.30	8.40	11	8.85	220	740	723	17	0.06	4.40	0.14	0.030	0.080	17.70
7	06-Jul-88	900	TOP	6.0	25.0	32.2		15.0	6.50	8.45	4	8.50	220	688	649	39	0.11	4.40	1.09			1.74
7	05-Aug-88	1015	TOP	6.0	20.5	25.0		15.0	5.50	8.19	500	8.42	202	872	853	19	0.45	8.80	1.12	1.000	0.080	0.59
7	07-Sep-88		TOP	6.0	18.0			13.0	10.00	8.20	80	8.45	202	860	821	39	0.05		0.14	0.360	0.180	1.93
7	12-Oct-88	950	TOP	6.0	9.0	7.8		25.0	9.00	8.40	2	8.45	206	862	855	7	0.34		0.98	0.039	0.023	0.16
7	05-Jan-88	1230	BOTTOM	114.0	2.5	3.1			12.50			8.19	200	450	441	9	0.10	0.00	1.26	0.160	0.120	
7	17-Feb-88	1100	BOTTOM	114.0	1.5	1.7		16.0		8.70		8.67	210	764	756	8	0.10		1.82	0.140		0.14
7	11-Apr-88	1330	BOTTOM	54.0	12.0	10.0		30.0	8.50	8.20		8.24	108	739	687	52	0.05	8.80	1.26	0.500	0.000	
7	17-May-88	940	BOTTOM	102.0	16.0			16.0	5.70			8.50	230	786	749	37	0.04	4.40		0.020	0.080	
7	07-Jun-88	900	BOTTOM		23.0	22.0			4.00	8.40		8.37	230	736	706	30	0.06	4.40	1.54	0.050	0.060	
7	06-Jul-88	900	BOTTOM	90.0	25.0	32.2		15.0	5.50	8.45		8.50	216	672	649	23	0.11	4.40	1.06			
7	05-Aug-88	1015	BOTTOM	96.0	20.5	25.0		15.0	5.20			8.40	202	1,630	750	880	0.50	7.50	1.26	1.000	0.160	
7	07-Sep-88		BOTTOM		17.0					8.20		8.33	196	728	689	39	0.06			0.460	0.060	
7	12-Oct-88	950	BOTTOM	108.0	9.0	7.8			8.30			8.43	206	820	815	5	0.38		0.70	0.083	0.023	
8	05-Jan-88	1300	TOP	6.0	1.0	-27.2		45.0	16.20	8.32	2	8.11	216	400	391	9	0.10	0.00	1.26	0.140	0.160	1.14
8	17-Feb-88	1115	TOP	6.0	1.5	1.7		20.00		8.75	2	8.75	215	740	736	4	0.10		2.52		0.200	136.80
8	11-Apr-88	1400	TOP	6.0	9.5	10.0		24.0	9.75	8.20	2	8.36	106	724	709	15	0.04	8.80	1.54	2.000	0.100	13.72
8	17-May-88	1000	TOP	6.0	16.0	16.1		14.0	8.20	8.23	2	8.60	228	866	797	69	0.72	4.40		0.100	0.060	7.54
8	07-Jun-88	915	TOP	6.0	22.0	22.0		18.0	6.90	8.40	23	8.30	220	730	692	38	0.04	4.40	1.52	0.100	0.060	18.97
8	06-Jul-88	930	TOP	6.0	26.0	32.2		12.0	6.75	8.70	50	8.60	220	728	672	56	0.04	4.40	1.68			1.68
8	05-Aug-88	1030	TOP	6.0	22.5	26.7		12.0	7.25	8.20	100	8.54	206	802	733	69	0.44	4.40	1.54	1.000	0.080	1.16
8	07-Sep-88		TOP	6.0	17.0	17.0		12.0	10.00	8.20	30	8.33	196	722	684	38	0.05			0.080	0.020	1.48
8	12-Oct-88	1015	TOP	6.0	8.0	8.3		14.0	9.20	8.13	8	8.45	204	746	727	19	0.47		7.00	0.037	0.010	0.72
8	05-Jan-88	1300	BOTTOM	78.0	1.0	-27.2		45.0	16.20			7.56	220	700	685	15	0.10	4.40	0.90	0.100	0.140	
8	17-Feb-88	1115	BOTTOM	72.0	1.5	1.7		20.0		8.65		8.76	230	822	746	76	0.10		0.98		0.120	
8	11-Apr-88	1400	BOTTOM	48.0	9.5	10.0		24.0	9.25			8.41	110	690	674	16	0.01	8.80	0.98	2.000	0.100	
8	17-May-88	1000	BOTTOM	66.0	16.0	16.1		14.0	6.60			8.60	226	746	674	72	0.44	8.80	0.84	0.120	0.060	
8	07-Jun-88	915	BOTTOM		22.0				5.70			8.30	230	760	723	37	0.08	4.40	1.54	0.100	0.040	
8	06-Jul-88	930	BOTTOM	42.0	26.0	32.2		12.0	6.75			8.60	218	758	699	59	0.04	4.40	1.68			
8	05-Aug-88	1030	BOTTOM	42.0	22.5	26.7		12.0	7.25			8.56	206	888	793	95	0.42	4.40	1.90	1.000	0.080	
8	07-Sep-88		BOTTOM							8.20		8.35	198	738	674	64	0.04		0.42	0.120	0.040	
8	12-Oct-88	1015	BOTTOM	54.0	8.0	8.3			9.20			8.46	206	720	703	17	0.01		0.98	0.033	0.010	

RICHMOND LAKE WATER QUALITY DATA 1989
ALL CONCENTRATIONS IN MG/L, DEPTH IN INCHES, TEMP. IN C

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
1	27-Mar-89	1440	GRAB								10	7.46	92	450	349	101	0.43	0.80	1.79	0.461	0.249	
1	28-Mar-89	915	GRAB		0.5	5.5			17.00	7.58	10	7.56	73	288	256	32	0.42	0.60	1.79	0.400	0.230	
1	29-Mar-89	1205	GRAB		1.6	5.9			8.40	6.96	10	7.55	66	235	225	10	0.44	0.60	2.14	0.403	0.231	
1	03-Apr-89	1150	GRAB		2.5	9.0			8.60	7.25	10	7.25	37	120	98	22	0.50	0.40	1.55	0.376	0.244	
1	05-Apr-89	1055	GRAB	6.0	3.2	8.5			8.00	7.22	10	7.52	37	152	136	16	0.50	0.50	1.46	0.366	0.248	
1	10-Apr-89	1010	GRAB		3.5	3.0			8.40	7.15	10	8.10	42	195	191	4	0.39	0.60	1.40	0.288	0.228	
1	24-Apr-89	1540	GRAB		12.0	28.0			11.40	7.98	10	8.06	116	436	432	4	0.04	0.40	0.95	0.231	0.114	
1	26-Apr-89	955	GRAB	6.0	10.0	10.5			10.90	7.99	10	8.09	118	442	418	24	13.50	0.02	0.40	0.950	0.119	
1	01-May-89	1120	GRAB	6.0	12.0	15.0			9.70	8.18	10	8.18	116	433	389	44	0.17	0.30	0.91	0.193	0.071	
1	03-May-89	1125	GRAB	6.0	14.0	20.0			13.20	8.66	10	8.74	116	446	434	12	0.02	0.20	1.19	0.251	0.052	
1	08-May-89	1145	GRAB	6.0	13.0	17.0			10.40	8.12	10	8.33	115	434	430	4	0.02	0.20	0.86	0.153	0.064	
1	10-May-89	1005	GRAB	6.0	15.0	17.0			12.50	8.69	10	8.49	116	431	409	22	0.02	0.30	1.27	0.166	0.005	
1	17-May-89	1135	GRAB	6.0	19.0	18.0			9.40	8.15	10	8.37	115	405	401	4	0.06	0.10	0.82	0.098	0.018	
2	27-Mar-89	1500	GRAB								10	7.60	17	85	47	38	0.51	0.30	1.60	0.275	0.150	
2	28-Mar-89	1020	GRAB		0.0	7.5			22.00	7.00	40	7.18	18	83	66	17	0.44	0.30	1.33	0.342	0.176	
2	29-Mar-89	1130	GRAB	6.0	0.5	8.5			11.70	6.62	10	7.37	16	38	26	12	0.37	0.20	1.65	0.325	0.182	
2	03-Apr-89	832	GRAB	6.0	4.0	5.5			6.60	6.60	10	7.11	27	52	36	16	0.30	0.20	1.29	0.390	0.284	
2	05-Apr-89	840	GRAB	6.0	2.5	2.5			10.00	6.96	10	7.30	25	98	82	16	0.20	0.20	0.97	0.397	0.303	
3	27-Mar-89	1405	GRAB								30	7.30	27	186	98	88	0.50	0.60	1.61	0.464	0.296	
3	28-Mar-89	1100	GRAB		0.0	8.0			23.00	7.40	10	6.88	20	143	105	38	0.48	0.50	1.99	0.498	0.271	
3	29-Mar-89	1045	GRAB		1.0	14.0			11.90	7.20	10	7.28	26	112	76	36	0.49	0.40	1.94	0.481	0.257	
3	03-Apr-89	930	GRAB	6.0	5.5	6.0			9.30	7.21	10	7.12	38	110	96	14	0.59	0.30	1.62	0.515	0.420	
3	05-Apr-89	920	GRAB	6.0	5.0	4.2			8.70	7.06	10	7.14	41.6	169	157	12	0.47	0.30	1.28	0.424	0.356	
3	10-Apr-89	850	GRAB		1.0	4.0			12.00	7.60	10	7.63	61.6	306	306		0.07	0.40	1.06	0.298	0.277	
3	24-Apr-89	1515	GRAB		24.0	29.0			7.90	7.50	10	7.84	110	518	514	4	0.02	0.10	1.11	0.281	0.233	
3	26-Apr-89	920	GRAB	6.0	12.0	12.0			4.80	7.20	20	7.47	121	567	563	4	0.02	0.02	0.10	1.020	0.236	
3	01-May-89	1000	GRAB	6.0	10.0	19.0			6.90	7.49	100	7.67	122	661	659	2	0.02	0.10	0.83	0.170	0.087	
3	03-May-89	1045	GRAB	6.0	13.0	19.0			5.80	7.42	70	7.88	145	777	773	4	0.02	0.10	0.73	0.197	0.075	
3	08-May-89	1040	GRAB	6.0	15.0	16.0			6.20	7.54	20	7.85	150	798	794	4	0.02	0.10	0.79	0.214	0.158	
3	10-May-89	925	GRAB	6.0	15.0	20.0			3.60	7.40	30	7.62	157	794	786	8	0.02	0.10	0.67	0.244	0.160	
3	17-May-89	1050	GRAB	6.0	18.0	18.0			3.50	7.40	310	7.80	198	854	852	2	0.02	0.10	1.20	0.400	0.301	
3	22-May-89	1155	GRAB	6.0	23.0	28.0			5.10	7.32	100	7.71	215	883	859	24	0.02	0.10	1.12	0.488	0.416	
4	27-Mar-89	1345	GRAB								20	7.33	15	87	48	39	0.26	0.30	1.01	0.176	0.076	
4	28-Mar-89	1134	GRAB	6.0	0.5	10.0			205.00	7.10	10	4.47	1	81	53	28	0.11	0.20	1.06	0.214	0.096	
4	29-Mar-89	1417	GRAB								10	7.25	18	82	30	52	0.15	0.20	1.25	0.258	0.089	
4	03-Apr-89	1100	GRAB	6.0	4.0	8.0			11.40	7.40	10	7.28	22	63	41	22	0.04	0.10	0.76	0.146	0.038	
4	05-Apr-89	1000	GRAB	6.0	1.7	3.0			12.00	7.33	10	7.31	24.6	95	87	8	0.04	0.10	0.95	0.122	0.025	
4	10-Apr-89	920	GRAB		1.5	2.0			13.50	7.45	10	7.68	32	213	169	44	0.02	0.10	0.98	0.115	0.032	
4	01-May-89	1025	GRAB	6.0	17.0	17.5			9.40	7.49	10	7.69	85.6	494	334	160	0.08	0.10	1.13	0.339	0.135	

SITE	DATE	TIME	SAMPLE	DEPTH	WTEMP	ATEMP	FLOW	SDISK	DISOX	FLD_PH	FCOLI	LAB_PH	TALKA	TSOLD	TDSOL	TSSOL	AMMON	NO32N	TKN_N	TPO4P	OPO4P	CHLOR.A
5	27-Mar-89	1245	GRAB								30	4.06	1	130	87	43	0.37	0.40	1.48	0.244	0.164	
5	28-Mar-89	1207	GRAB		0.5	10.5			28.00	7.28	10	6.28	14	81	53	28	0.27	0.40	1.20	0.268	0.130	
5	29-Mar-89	1355	GRAB		13.0	1.0			10.50	6.63	10	7.15	22	73	45	28	0.33	0.30	1.58	0.325	0.131	
5	03-Apr-89	1150	GRAB	6.0	2.5	9.0			8.60	7.25	10	7.18	28	81	67	14	0.14	0.20	1.08	0.264	0.165	
5	05-Apr-89	1030	TOP	6.0	3.0	6.0			11.70	7.45	10	7.27	31	125	117	8	0.10	0.10	0.83	0.237	0.113	
5	10-Apr-89	940	GRAB		0.5	0.0			12.20	7.20	10	7.53	34	147	143	4	0.02	0.10	0.72	0.119	0.057	
5	01-May-89	1050	GRAB	6.0	12.0	11.0			11.40	7.80	70	7.82	68.2	251	215	36	0.02	0.10	1.02	0.186	0.075	
5	08-May-89	1115	GRAB	6.0	16.0	15.0			9.35	7.54	20	7.89	128	397	393	4	0.02	0.10	1.67	0.332	0.268	
6B	15-Jun-89	1400	GRAB	276.0	20.9	28.0		33.6	9.90	7.47	10	7.93	127	442	422	20	0.43	0.30	1.28	0.142	0.048	
6B	13-Jul-89		GRAB	336.0	20.0	35.0		33.6	9.00	7.27	10	8.04	129	442	426	16	0.15	0.60	1.08	0.146	0.100	
6B	08-Aug-89		GRAB	264.0	24.0	22.0		15.6	12.40	8.77	10	8.20	131	430	414	16	0.05	0.10	1.14	0.163	0.011	
6B	28-Aug-89	1400	GRAB	288.0	24.0	27.1		27.6	10.70	8.28	10	8.32	137	434	398	36	0.15	0.20	0.77	0.159	0.029	
6B	23-Oct-89	1130	GRAB	324.0	9.0	15.0		36.0	13.80	8.17	10	8.53	147	486	488	8	0.17	0.10	1.89	0.115	0.035	
6S	15-Jun-89	1400	GRAB	6.0	26.0	28.0		18.0	10.00	7.49	10	8.12	127	438	420	18	0.41	0.30	1.19	0.129	0.056	
6S	13-Jul-89		GRAB	6.0	28.0	35.0		33.6	10.90	7.27	10	8.25	129	441	437	4	0.16	0.60	0.81	0.149	0.099	
6S	08-Aug-89		GRAB	6.0	24.0	23.0		27.6	12.40	8.77	10	8.37	129	424	404	20	0.06	0.10	1.34	0.197	0.015	
6S	28-Aug-89	1400	GRAB	6.0	24.5	27.1		27.6	12.60	8.28	10	8.32	134	452	412	40	0.14	0.20	1.05	0.159	0.038	
6S	23-Oct-89	1130	GRAB	6.0	9.5	15.0		36.0	15.00	8.17	10	8.55	146	493	489	3	0.18	0.20	0.88	0.112	0.042	
7B	15-Jun-89	1300	GRAB	84.0	25.0	33.0		18.0	5.40	7.42	10	7.82	256	450	422	28	0.43	0.30	1.38	0.163	0.050	
7B	13-Jul-89		GRAB	168.0	24.0	36.0		20.4	9.40	7.74	20	8.04	132	455	435	20	0.21	0.60	0.96	0.170	0.112	
7B	08-Aug-89	1530	GRAB	144.0	23.0	31.0		20.4	9.70	7.69	10	8.16	131	451	427	24	0.25	0.10	1.29	0.193	0.112	
7B	31-Aug-89	1400	GRAB	144.0	22.0	19.0		20.4	9.70	8.14												
7B	23-Oct-89	1400	GRAB	132.0	11.5	15.0		25.2	13.00	8.49	10	8.63	150	509	489	20	0.10	0.10	0.42	0.142	0.035	
7S	15-Jun-89	1300	GRAB	6.0	33.0	24.0		18.0	5.40	7.42	10	7.91	127	449	421	28	0.42	0.30	1.35	0.163	0.051	
7S	13-Jul-89		GRAB	6.0	28.0	36.0		20.4	9.70	7.74	10	8.09	131	444	432	12	0.20	0.60	0.94	0.190	0.114	
7S	08-Aug-89	1500	GRAB	6.0	25.0	31.0		20.4	8.80	7.69	10	8.03	131	448	432	16	0.23	0.30	1.00	0.180	0.114	
7S	31-Aug-89	1400	GRAB	6.0	21.0	19.0		20.4	10.40	8.14												
7S	23-Oct-89	1400	GRAB	6.0	12.0	15.0		25.2	14.30	8.49	10	8.65	149	501	497	4	0.10	0.10	0.64	0.119	0.031	
8B	15-Jun-89	1600	GRAB	168.0	18.0	28.8		15.6	14.70	7.28	20	7.89	130	581	445	136	0.34	0.20	1.29	0.163	0.019	
8B	13-Jul-89		GRAB	132.0	26.0	31.0		20.4	14.00	8.30	40	8.80	132	469	437	32	0.06	0.30	0.87	0.214	0.037	
8B	08-Aug-89		GRAB	144.0	24.0	38.0		24.0	11.00	7.86	10	8.32	130	458	422	36	0.01	0.10	0.90	0.258	0.010	
8B	28-Aug-89	1400	GRAB	84.0	23.0	31.0		20.4	9.80	8.37	2	8.63	135	462	410	52	0.18	0.10	1.00	0.173	0.029	
8B	23-Oct-89	1300	GRAB	120.0	13.0	15.5		24.0	14.20	8.38	10	8.61	147	515	503	12	0.22	0.10	1.11	0.156	0.012	
8S	15-Jun-89	1500	GRAB	6.0	24.0	28.8		15.6	14.55	7.28	10	8.00	131	456	432	24	0.37	0.20	1.33	0.136	0.027	
8S	13-Jul-89		GRAB	6.0	28.5	31.0		20.4	12.50	8.30	20	7.80	130	457	421	36	0.06	0.40	0.88	0.122	0.042	
8S	08-Aug-89		GRAB	6.0	25.0	38.0		20.4	9.80	8.61	10	8.41	129	456	420	36	0.07	0.10	0.91	0.170	0.012	
8S	28-Aug-89	1400	GRAB	6.0	28.0	31.0		20.4	12.40	8.37	10	8.63	138	471	413	58	0.16	0.10	1.20	0.163	0.024	
8S	23-Oct-89	1300	GRAB	6.0	12.0	15.5		24.0	14.90	8.38	10	8.63	147	500	488	12	0.17	0.10	1.21	0.142	0.018	
F.LOT	27-Apr-89	1320	GRAB	6.0	10.0	13.5			9.80	8.17	8000	7.55	223	1371	1135	236	3.12	1.20	5.17		1.880	

APPENDIX B

Deficiencies in the in-lake sampling frequency for Richmond Lake during 1987 and 1988.

Sample scheduling established by the Richmond Lake Diagnostic Study Plan called for the collection of two water samples (surface and bottom) at each of the three in-lake sites twice a month from April through September and monthly from October through March. The following table compares the scheduled with the actual sampling frequency for 1987 and 1988 for in-lake sites #6, 7, and 8:

1987	No. of samples scheduled	No. of samples collected
April	12	12
May	12	6
June	12	6
July	12	12
August	12	12
September	12	12
October	6	6
November	6	0
December	6	0
Total	90	66
1988		
January	6	6
February	6	6
March	6	0
April	12	6
May	12	6
June	12	6
July	12	6
August	12	6
September	12	6
October	6	6
Total	96	54

Evaluation of field and laboratory results of water quality monitoring at Richmond Lake for in-lake sites 6, 7, and 8 from 1987 to 1988.

Parameter	1987	1988
Field measurements:		
Water Temperature (^{o}C)	Adequate*	Adequate
Air Temperature (^{o}C)	Adequate	Adequate
Dissolved Oxygen (D.O.)	Marginal*	Marginal
Conductivity	No Data	No Data
pH	Adequate	Adequate
Secchi Disk	Adequate	Adequate
Lab measurements:		
Fecal Coliform	Adequate	Marginal
pH	Adequate	Adequate
Chlorophyll *a*	Adequate	Adequate
Alkalinity (T)	Adequate	Adequate
Total Solids	Deficient*	Adequate
Dissolved Solids	Deficient	Adequate
Suspended Solids	Marginal	Marginal
TKN-N	Adequate	Marginal
Ammonia-N	Deficient	Marginal
NO_3+NO_2-N	Deficient	Deficient
Total PO_4-P	Deficient	Marginal
Ortho PO_4-P	Marginal	Marginal

*For explanation of ratings see next page.

In-lake parameter evaluation:
Field measurements:

Water Temperature (^{o}C): O.K.

Air Temperature (^{o}C): O.K.

Dissolved Oxygen (D.O.): in general adequate to marginal; no D.O. readings for February 1988; several irregular values. Several other readings missing for 1987.

Conductivity: No conductivity readings were taken.

pH: O.K.

Secchi Disk: O.K.

Lab Measurements:

Fecal Coliform: In general adequate to marginal. Three questionable readings and three readings missing for August 1988.

pH: O.K.

Chlorophyll*a*: O.K.

Alkalinity (T): O.K.

Total Solids: All values from April 1987 through 11 August 1987 are clearly erroneous. These values generally ranged below 30 mg/l. Correct values should exceed 200 mg/l. Values for 31 August 1987 through October 1988 appear more reasonable.

Dissolved Solids: Cannot be determined from April 1987 through 11 August 1987 due to erroneous total solids data. Values from 31 August 1987 through October 1988 appear to be O.K.

Suspended Solids: Most values appear to be O.K. Some may be too low (e.g. when readings are less than 10).

TKN-N: Most values from April 1987 through April 1988 appear O.K.; values for June 1987 probably too low; TKN data for 1988 considered of marginal quality: a number of questionable zero readings and a few values that are probably too low.

Ammonia-N: Tests and measurements from April 1987 through April 1988 lack sensitivity. Almost all ammonia values listed as <.1 which does not allow adequate interpretation. Some values from May 1988 through October 1988 appear questionable because of the wide difference between surface and bottom values (e.g. .47 vs.

.04) at the same site with bottom samples showing a much smaller ammonia concentration.

NO_3+NO_2-N: No readings taken from April 1987 through June 1987. Most values of nitrogen for September 1987 through October 1988 reported as NO_3 and/or NO_2. Readings for NO_3 reported from May 1988 through August 1988 are all a constant value of 4.4 - questionable as this sort of uniformity is rare if at all possible in natural lakes.

Total PO_4-P: Reported as PO_4 and P or as PO_4 alone. Eleven readings missing in 1987 data out of a total of 48. Most values appear reasonable.

Ortho PO_4-P: Reported as PO_4 and P or as PO_4 alone. Four readings missing in 1987 data out of a total of 48. Most values appear reasonable. Four values of Ortho PO_4 greater than total PO_4 in the same sample.

APPENDIX C

Table A. AGNPS Input Parameters

1. Cell number - identification code given to each cell in the watershed.

2. Receiving cell number - number of adjacent cell receiving majority of surface runoff.

3. SCS curve number (CN) - characterizes surface conditions to estimate surface runoff.

4. Land slope - major or average slope in cell.

5. Slope shape factor - indicates dominant slope shape (uniform concave, or convex).

6. Field slope length - average or representative slope length.

7. Channel slope - average slope of channel.

8. Channel side slope - estimated side slope of channel.

9. Manning's roughness coefficient for the channel - used in Manning's channel flow equation.

10. Soil erodibility factor - relative soil erodibility factor used in universal soil loss equation.

11. Cropping factor - the "C" factor used in the universal soil loss equation.

12. Practice factor - the "P" factor used in the universal soil loss equation.

13. Surface condition constant - coefficient used to indicate time for overhead flow to channelize.

14. Aspect - Principal direction of flow.

15. Soil texture - major soil texture (sand, silt, clay, or peat).

16. Fertilization level - average amount of fertilizer applied.

17. Availability factor - percent of applied fertilizer available in top one-half inch of soil after planting.

18. Point source indicator - indicates presence or absence of feedlots within the cell.

19. Gully source level - gully erosion occurring in the cell.

20. Chemical oxygen demand (COD) factor - COD concentration from the cell, based on land use.

21. Impoundment factor - indicates the presence of an impoundment terrace system within the cell.

WATERSHED DATA FILE

SHEET NUMBER________

WATERSHED NAME________________________________

CELL NUMBER	RECEIVING CELL NUMBER	SCS CURVE NUMBER	LAND SLOPE %	SLOPE SHAPE FACTOR	FIELD SLOPE LENGTH FT.	CHANNEL SLOPE %	CHANNEL SIDE SLOPE %	MANNINGS ROUGHNESS COEFFICIENT FOR THE CHANNEL	SOIL ERODIBILITY FACTOR	CROPPING FACTOR	PRACTICE FACTOR	SURFACE CONDITION CONSTANT	ASPECT	SOIL TEXTURE NUMBER	FERTILIZATION LEVEL	AVAILABILITY FACTOR %	POINT SOURCE INDICATOR	GULLY SOURCE LEVEL TONS	CHEMICAL OXYGEN DEMAND FACTOR	IMPOUNDMENT FACTOR
XXX	XXX	XXX	XX.X	X	XXX	XX.X	XX.X	.XXX	.XX	.XX	X.XX	.XX	X	X	X	XXX	X	XXX	XXX	XX

Table B. AGNPS Cell Parameters

Table E. Soil Loss and Sediment Generated in Selected Cells of the Richmond Lake Lower Watershed.

Condensed Soil Loss

Cell Num	Div	Drainage Area (acres)	RUNOFF Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	SEDIMENT Generated Above (tons)	SEDIMENT Generated Within (tons)	Yield (tons)	Depo (%)
104	000	800	0.67	97.5	607	6.74	117.41	269.68	310.30	20
219	000	7200	0.67	99.7	3519	5.14	1097.33	205.55	1243.20	5
231	000	7880	0.67	99.7	3233	6.37	1317.09	254.75	1508.33	4
240	000	7720	0.67	99.7	3268	6.37	1153.71	254.75	1345.98	4
303	000	80	0.67	73.9	152	6.37	33.54	254.75	202.76	30
304	000	10320	0.67	99.8	3782	6.37	2542.68	254.75	2621.81	6
315	000	2320	0.67	98.7	1011	9.41	565.55	376.33	831.60	12
429	000	160	0.67	86.3	194	6.37	17.81	254.75	191.62	30
430	000	13200	0.67	99.8	4119	6.37	3433.03	254.75	3574.81	3
433	000	1000	0.67	97.0	548	6.13	269.96	245.05	447.40	13
566	000	80	0.67	64.0	118	8.77	12.38	350.62	248.27	32
572	000	360	0.67	93.1	361	6.74	290.22	269.71	462.84	17
574	000	440	0.67	93.9	379	6.74	474.55	269.71	627.07	16
576	000	360	0.67	93.4	334	6.74	1040.69	269.71	860.74	34
594	000	14160	0.67	99.8	4258	8.15	3986.03	325.91	4201.64	3
595	000	13400	0.67	99.8	4123	5.31	3766.42	212.22	3824.55	4
600	000	14360	0.67	99.8	4255	5.31	4308.08	212.22	4342.62	4
601	000	160	0.67	84.2	184	7.24	18.83	289.48	220.09	29
712	000	1200	0.67	98.3	906	10.26	156.28	410.45	465.95	18
714	000	120	0.67	78.0	160	10.26	15.69	410.45	313.74	26
720	000	680	0.67	97.1	550	10.26	362.52	410.45	616.40	20
721	000	120	0.67	81.9	190	10.26	11.57	410.45	313.96	26
723	000	1120	0.67	99.5	2937	10.26	2280.84	410.45	2553.81	5
725	000	2360	0.67	99.6	3419	7.89	3019.77	315.73	3110.97	7
731	000	2480	0.67	99.6	3360	10.26	3126.18	410.45	3352.03	5
733	000	2520	0.67	99.6	3127	6.13	3352.03	245.05	3403.15	5
741	000	200	0.67	89.5	227	6.37	20.43	254.75	199.23	28
834	000	240	0.67	91.0	314	9.50	336.90	379.95	576.82	20
837	000	3920	0.67	99.7	3625	9.50	4803.73	379.95	4992.39	4
841	000	1160	0.67	98.4	878	9.50	143.12	379.95	429.57	18
842	000	40	0.67	0.0	72	9.50	0.00	379.95	272.89	28
844	000	1240	0.67	98.4	882	9.50	702.46	379.95	932.97	14
846	000	2800	0.67	99.7	3269	6.43	3441.47	257.19	3530.06	5
848	000	2840	0.91	99.5	3223	15.62	3530.06	624.62	3903.37	6
853	000	80	0.67	64.0	114	6.43	9.87	257.19	179.23	33
856	000	120	0.67	80.5	185	6.43	35.06	257.19	201.21	31
860	000	40	0.67	0.0	72	6.43	0.00	257.19	184.80	28
862	000	40	0.67	0.0	72	9.50	0.00	379.95	272.89	28
866	000	80	1.13	50.0	135	22.51	88.62	900.50	672.90	32
872	000	160	1.13	75.0	166	14.23	92.27	569.14	459.24	31
929	000	14600	0.67	99.9	4599	5.68	1484.82	227.30	1642.08	4
942	000	15640	1.13	99.8	4853	19.00	1645.05	759.89	2246.61	7
943	000	15960	1.13	99.8	4912	19.00	2332.23	759.89	2844.81	8
946	000	16120	0.67	99.9	4916	7.31	2875.03	292.27	2980.67	6
956	000	17240	0.67	99.9	4982	7.31	4111.64	292.27	4280.56	3

Table E. (cont.)

Condensed Soil Loss

Cell Num	Div	Drainage Area (acres)	RUNOFF Volume (in.)	Generated Above (%)	Peak Rate (cfs)	Cell Erosion (t/a)	SEDIMENT Generated Above (tons)	Generated Within (tons)	Yield (tons)	Depo (%)
960	000	80	0.91	60.3	141	14.61	21.26	584.53	411.87	32
961	000	16760	0.91	99.8	4953	14.61	3253.98	584.53	3561.81	7
962	000	17160	0.67	99.9	4995	7.31	3978.26	292.27	4101.45	4
964	000	17120	0.91	99.8	5026	14.61	3604.61	584.53	3978.26	5
969	000	40	0.91	0.0	94	17.74	0.00	709.79	490.77	31
1038	000	80	0.91	50.0	112	10.07	36.73	402.85	274.39	38
1044	000	40	0.91	0.0	91	8.29	0.00	331.76	227.56	31
1046	000	80	0.91	50.0	112	10.07	17.83	402.85	262.87	38
1047	000	80	0.91	50.0	112	10.07	36.73	402.85	274.39	38

APPENDIX D

Table C. AGNPS Feedlot Parameters

FEEDLOT DATA COLLECTION SHEET

Feedlot Data:
Cell Number ________
Feedlot Number ________

	Area (Acres)	Curve Number
Area 1 Feedlot		
Area 2a		
Area 2b		
Area 2c		
Area 2d		
Area 2e		
Area 2f		
Area 2r Roof Area		
Area 3a		
Area 3b		
Area 3c		
Area 3d		
Area 3e		
Area 3f		

Buffer Areas

Section a	Slope	
	Surface Condition Constant	
	Travel Distance	
Section b	Slope	
	Surface Condition Constant	
	Travel Distance	
Section c	Slope	
	Surface Condition Constant	
	Travel Distance	

Animal Type Factors

Animal Type	Number	COD Factor	P Factor	N Factor

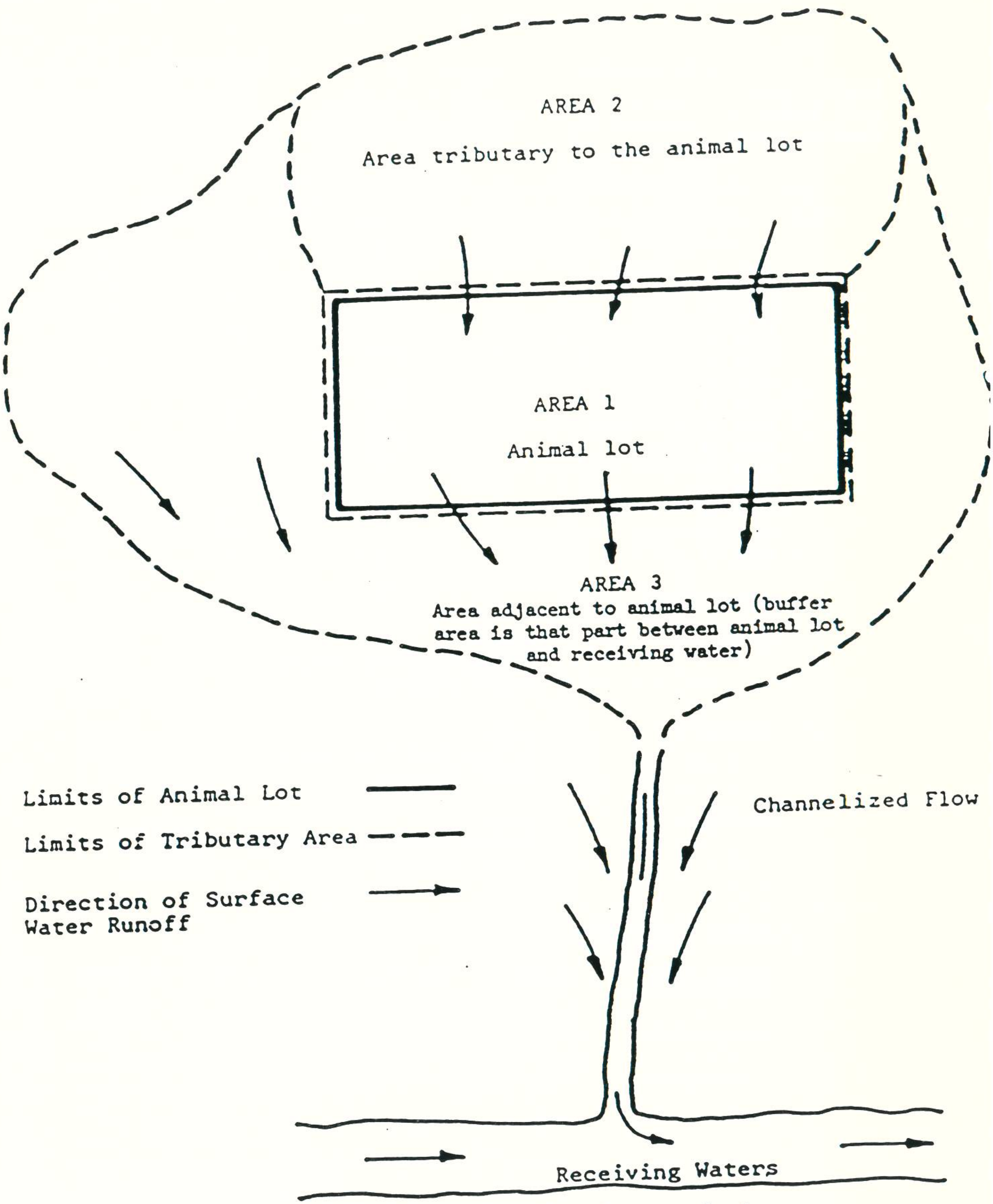

Figure 1.—Local watershed.

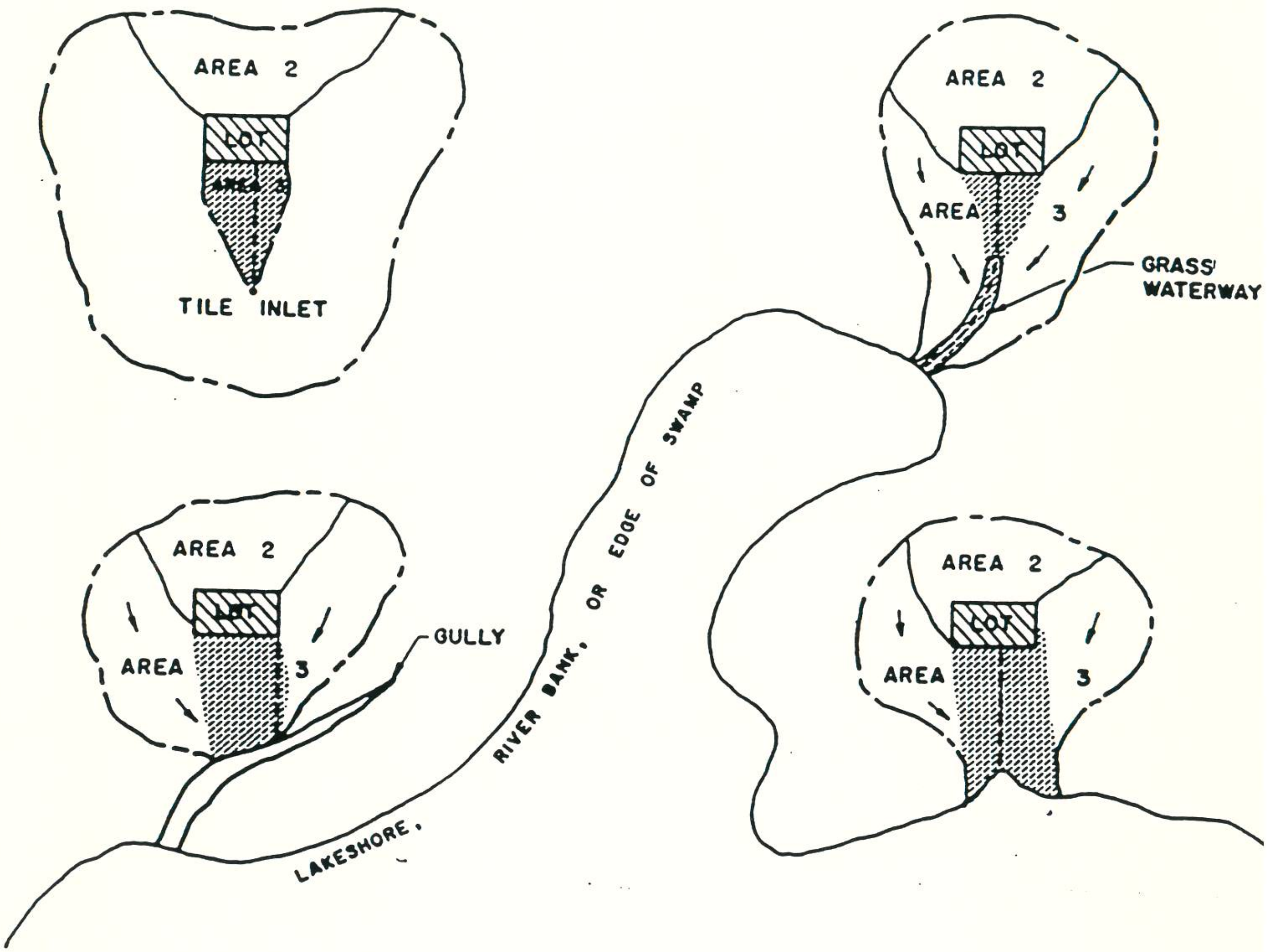

Figure 2. Examples of animal-lot watersheds (shaded area indicates buffer.)

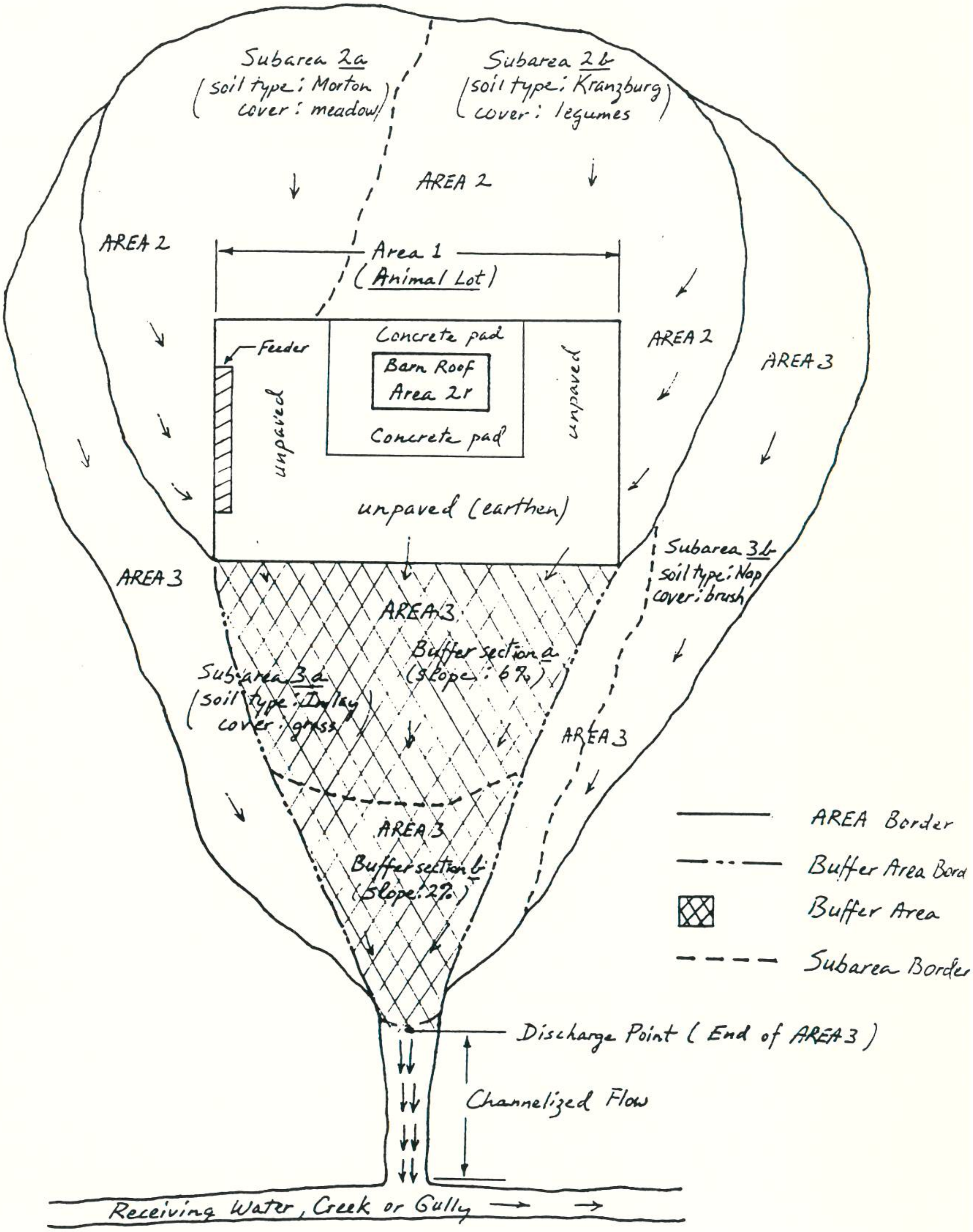

Figure 4. Example of animal lot with surrounding watershed (Top view)

Table D. AGNPS Feedlot Analysis of Lower Watershed Feedlots.

Feedlot Analysis

Cell # 430 000 (F1)

Nitrogen concentration (ppm)	70.068
Phosphorus concentration (ppm)	12.915
COD concentration (ppm)	1175.042
Nitrogen mass (lbs)	693.667
Phosphorus mass (lbs)	127.858
COD mass (lbs)	11632.870
Animal feedlot rating number	66

Feedlot Analysis

Cell # 808 000 (F2)

Nitrogen concentration (ppm)	11.259
Phosphorus concentration (ppm)	1.876
COD concentration (ppm)	56.293
Nitrogen mass (lbs)	659.440
Phosphorus mass (lbs)	109.907
COD mass (lbs)	3297.197
Animal feedlot rating number	0

Feedlot Analysis

Cell # 838 000 (F3)

Nitrogen concentration (ppm)	12.904
Phosphorus concentration (ppm)	2.444
COD concentration (ppm)	89.637
Nitrogen mass (lbs)	320.892
Phosphorus mass (lbs)	60.769
COD mass (lbs)	2229.034
Animal feedlot rating number	32

Feedlot Analysis

Cell # 853 000 (F4)

Nitrogen concentration (ppm)	21.830
Phosphorus concentration (ppm)	5.920
COD concentration (ppm)	337.500
Nitrogen mass (lbs)	240.348
Phosphorus mass (lbs)	65.174
COD mass (lbs)	3715.818
Animal feedlot rating number	50

Table D. (cont.)

Feedlot Analysis

Cell # 862 000 (F5)

Nitrogen concentration (ppm)	23.114
Phosphorus concentration (ppm)	6.143
COD concentration (ppm)	362.046
Nitrogen mass (lbs)	56.296
Phosphorus mass (lbs)	14.962
COD mass (lbs)	881.797
Animal feedlot rating number	28

Feedlot Analysis

Cell # 935 000 (F6)

Nitrogen concentration (ppm)	5.162
Phosphorus concentration (ppm)	1.264
COD concentration (ppm)	60.149
Nitrogen mass (lbs)	68.829
Phosphorus mass (lbs)	16.856
COD mass (lbs)	802.041
Animal feedlot rating number	21

Feedlot Analysis

Cell # 939 000 (F7)

Nitrogen concentration (ppm)	9.540
Phosphorus concentration (ppm)	2.047
COD concentration (ppm)	73.834
Nitrogen mass (lbs)	119.622
Phosphorus mass (lbs)	25.667
COD mass (lbs)	925.848
Animal feedlot rating number	21

Feedlot Analysis

Cell # 995 000 (F8)

Nitrogen concentration (ppm)	20.575
Phosphorus concentration (ppm)	4.691
COD concentration (ppm)	395.024
Nitrogen mass (lbs)	102.471
Phosphorus mass (lbs)	23.364
COD mass (lbs)	1967.380
Animal feedlot rating number	40

Table D. (cont.)

Feedlot Analysis

Cell # 1030 000 (F9)

Nitrogen concentration (ppm)	10.218
Phosphorus concentration (ppm)	3.968
COD concentration (ppm)	178.688
Nitrogen mass (lbs)	47.944
Phosphorus mass (lbs)	18.618
COD mass (lbs)	838.446
Animal feedlot rating number	27